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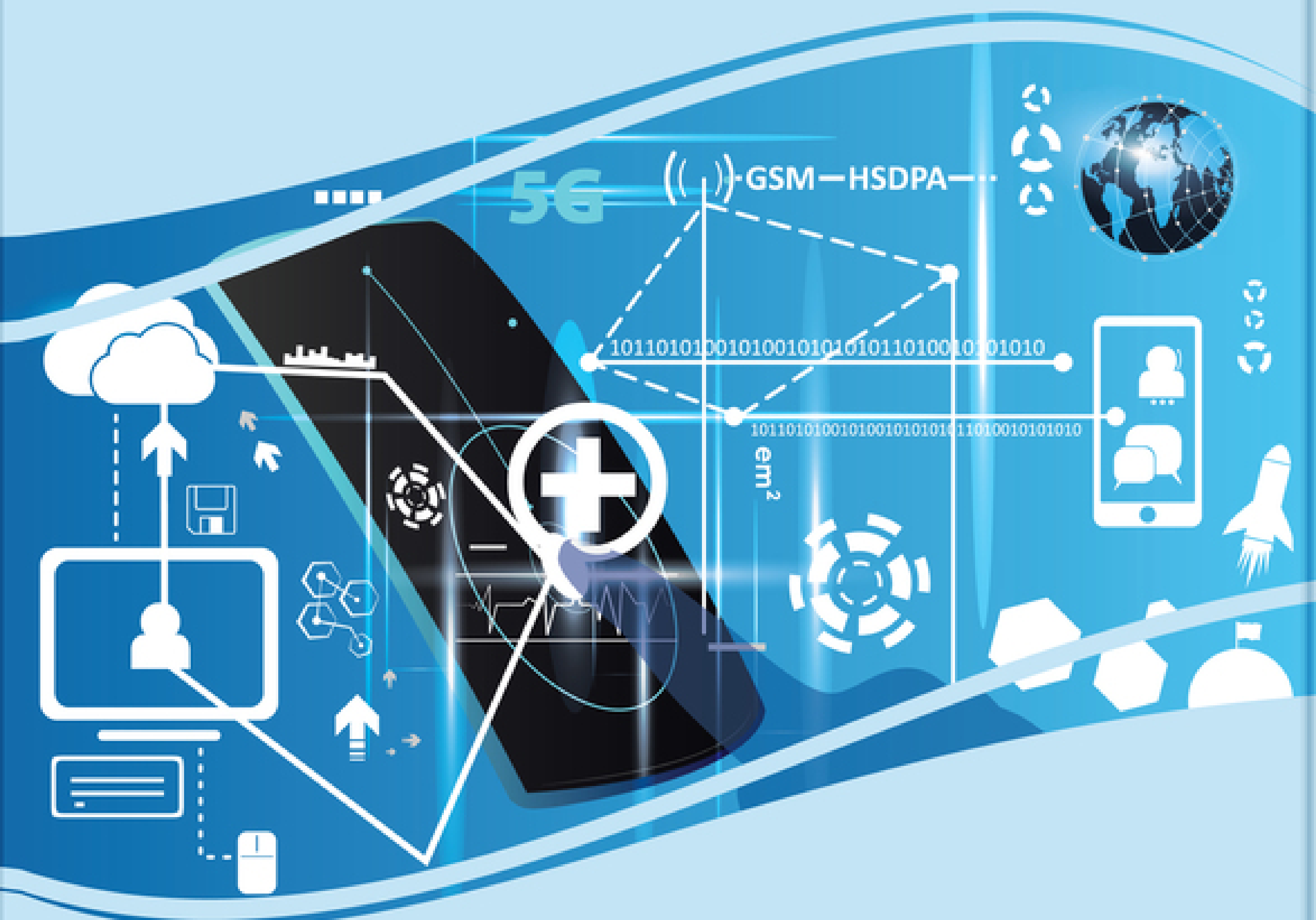
Fundamental and Supportive Technologies for 5G Mobile Networks



Sherine Mohamed Abd El-Kader and Hanan Hussein

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Fundamental and Supportive Technologies for 5G Mobile Networks

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A volume in the Advances in Systems Analysis, Software Engineering, and High Performance Computing (ASASEHPC) Book Series

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Published in the United States of America by
IGI Global
Information Science Reference (an imprint of IGI Global)
701 E. Chocolate Avenue
Hershey PA, USA 17033
Tel: 717-533-8845
Fax: 717-533-8661
E-mail: cust@igi-global.com
Web site: http://www.igi-global.com

Library of Congress Cataloging-in-Publication Data

Names: El-Kader, Sherine Mohamed Abd, 1972- editor. | Hussein, Hanan, 1986- editor.
Title: Fundamental and supportive technologies for 5G mobile networks / Sherine Mohamed Abd El-Kader and Hanan Hussein, editors.
Description: Hershey, PA : Information Science Reference, [2020] | Includes bibliographical references and index. | Summary: “This book examines 5G cellular networks and recent proposed technologies and applications in this field”-- Provided by publisher.
Identifiers: LCCN 2019025552 (print) | LCCN 2019025553 (ebook) | ISBN 9781799811527 (hardcover) | ISBN 9781799811534 (paperback) | ISBN 9781799811541 (ebook)
Subjects: LCSH: 5G mobile communication systems.
Classification: LCC TK5103.25 .F86 2020 (print) | LCC TK5103.25 (ebook) | DDC 621.3845/6--dc23
LC record available at https://lccn.loc.gov/2019025552
LC ebook record available at https://lccn.loc.gov/2019025553

This book is published in the IGI Global book series Advances in Systems Analysis, Software Engineering, and High Performance Computing (ASASEHPC) (ISSN: 2327-3453; eISSN: 2327-3461)

British Cataloguing in Publication Data
A Cataloguing in Publication record for this book is available from the British Library.

For electronic access to this publication, please contact: eresources@igi-global.com.

Advances in Systems Analysis, Software Engineering, and High Performance Computing (ASASEHPC) Book Series

Vijayan Sugumaran
Oakland University, USA

ISSN:2327-3453
EISSN:2327-3461

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at a low level of abstraction in a wireless telecommunication system. The results show improvements of 89.08% in memory utilization, related to information compression, in the context of the research. Therefore, the presented results of the proposed methodology show an enormous potential for the non-orthogonal multiple access (NOMA) contexts, credited as the future 5G, and can compensate for the additional complexity brought by the techniques to the telecommunications channel.

Millimeter-wave antennas are the trend nowadays because of the necessity of higher data rates. Designing a supplementary efficient antenna capable of dealing with dual bands has several challenges. This chapter reports the problematic approaches introduced in the field of a millimeter wave design. Prevailing investigations in millimeter-waves and MIMO antennas have a tendency to emphasize discovering how to increase the data rate without the need of increasing the bandwidth and what type of antenna preferred in the 5G band. However, there is a little indication that researchers have come close to the issue of antenna integration in the mobile handset with the intent of adding multiple antennas with multi-band capability in a small space. Accordingly, the target of this chapter is to offer a summary of how the small-dimensional MIMO antennas with band duality for 5G mobile communications can be intended, designed, sustained and fabricated.

This chapter focuses on the design of dual band flexible wearable antennas for modern 5G applications to integrate on a smartwatch. The first is a rectangular antenna which the patch and the ground etched on new flexible material is called ULTRALAM® 3850HT. This antenna is designed to operate at 38 GHz and 60 GHz. The second is a planar inverted-2F wearable antenna pasted on a jeans textile material. Two methods for measuring the dielectric properties of the jeans will be presented. This antenna is designed to operate at 28 GHz and 38 GHz. The SAR (specific absorption ratio) is also introduced and SAR results will be shown. Moreover, the proposed smartwatch under the bent condition will be also studied. These antennas are simulated using HFSS and CST 2018.

Orthogonal frequency division multiplexing (OFDM) is an efficient method of data transmission for high speed communication systems over multipath fading channels. However, the peak-to-average power ratio (PAPR) is a major drawback of multicarrier transmission systems such as OFDM is the high sensitivity of frequency offset. The bit error rate analysis (BER) of discrete wavelet transform (DWT)-OFDM system is compared with conventional fast Fourier transform (FFT)-OFDMA system in order to ensure

5G is the next step in the evolution of mobile communication. The evolving 5G cellular wireless networks are envisioned to provide higher data rates, enhanced end-user quality-of-experience (QoE), reduced end-to-end latency, and lower energy consumption. Device to device (D2D) is one of the key technologies provided to enhance 5G performance. Direct communication between two devices without involvement of any central point (i.e., base station) is defined as device to device (D2D) communication. It is a recommended technique to enhance the network performance of 5G in terms of energy efficiency, throughput, latency, and spectrum utilization. In this chapter, the authors provide a detailed survey on the integration of D2D communication into cellular network especially 5G network. The survey highlights the potential advantages; classifications and application for D2D technology have been indicated. Main D2D standards have been presented. Finally, the chapter addresses main topics that could be related to D2D and indicates all major possible challenges that face most researchers.

This chapter addresses cognitive radio systems (CRSs) in the 5G network and presents the existing, emerging, and potential applications employing CRS capabilities and the related enabling technologies, including the impacts of CRS technology on the use of spectrum from a technical perspective. The description of such technologies, operational elements, and their challenges are also presented. Furthermore, this chapter provides high level characteristics, operational and technical requirements related to CRS technology, their performances, and potential benefits. Finally, factors related to the introduction of CRS technologies and corresponding migration issues are discussed.

The fifth generation of wireless networks (5G) will kick off with evolved mobile broadband services as promised by several mobile-related associations, researchers, and operators. Compared to 4G, 5G aims to provide greater data rates with lower latency and higher coverage to numerous users who stream

Foreword

The exponential growth of wireless data services driven by mobile Internet and smart devices has triggered the investigation of the 5G cellular network. Around 2020, the new 5G mobile networks are expected to be deployed. 5G networks will have to support multimedia applications with a wide variety of requirements, including higher peak and user data rates, reduced latency, enhanced indoor coverage, improved energy efficiency and so on. 5G network should achieve 1000 times the system capacity, 10 times the spectral efficiency, energy efficiency and data rate (i.e., peak data rate of 10 Gb/s for low mobility and peak data rate of 1 Gb/s for high mobility), and 25 times the average cell throughput.

The main target of 5G heterogeneous networks is to connect the entire world, and achieve seamless and ubiquitous communications between anybody (people to people), anything (people to machine, machine to machine), wherever they are (anywhere), whenever they need (anytime), by whatever electronic devices/services/networks they wish (anyhow). This means that 5G networks should be able to support communications for some special scenarios not supported by 4G networks. In order to achieve these requirements, a lot of promising technologies have suggested.

This book provides a valuable window on 5G heterogeneous networks' concept. It discusses the main promising technologies that support 5G networks in order to elevate network efficiency and next future 5G applications. It investigated several technologies related to physical layer such as Multiple Input Multiple Output (MIMO), dual-band flexible wearable antenna, improving channels with multipath fading, and Bit Error Rate (BER) improvement in OFDM systems. Furthermore, the book studied some technologies related to upper layers as cloud computing, Device to Device (D2D) connectivity, Cognitive Radio (CR), and cache management of Cloud Radio Access Networks (CRAN). Finally, some of future applications are introduced like Internet of Things (IoT), Vehicle to everything (V2X), and Machine to Machine (M2M).

Authors were worked on that book with enthusiasm, tenacity, and dedication to cover all main topics, develop new methods of analysis and provide new solutions to keep up with the ever-changing threats. At last, this book is considered as a good step in that direction.

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Esmat A. F. Abdallah *received the degree from the Faculty of Engineering and the M.Sc. and Ph.D. degrees from Cairo University, Giza, Egypt, in 1968, 1972, and 1975, respectively. She was nominated as an Assistant Professor, an Associate Professor, and a Professor, in 1975, 1980, and 1985, respectively. In 1989, she was appointed as a President of the Electronics Research Institute (ERI), Cairo, Egypt, a position she held for about ten years. She became the Head of the Microstrip Department, ERI, from 1999 to 2006. She is currently with the Microstrip Department, ERI. She has focused her research on microwave circuit designs, planar antenna systems, and nonreciprocal ferrite devices, and recently on EBG structures, UWB components and antenna and RFID systems. She acts as a single author and as a co-author on more than 260 research papers in highly cited international journals and in proceedings of international conferences in her field.*

Preface

The innovative and effective use of Information and Communication Technologies (ICT) is becoming increasingly important to improve the economy of the world. Wireless communication networks are perhaps the most critical element in the global ICT strategy, underpinning many other industries. It is one of the fastest growing and most dynamic sectors in the world.

The development of wireless technologies has greatly improved people's ability to communicate and live in both business operations and social functions. The phenomenal success of wireless mobile communications is mirrored by a rapid pace of technology innovation. From the second generation (2G) mobile communication system debuted in 1991 to the 3G system first launched in 2001, the wireless mobile network has transformed from a pure telephony system to a network that can transport rich multimedia contents. The 4G wireless systems were designed to fulfill the requirements of International Mobile Telecommunications-Advanced (IMT-A) using IP for all services. In 4G systems, an advanced radio interface is used with Orthogonal Frequency-Division Multiplexing (OFDM), Multiple-Input Multiple-Output (MIMO), and link adaptation technologies. 4G wireless networks can support data rates of up to 1 Gb/s for low mobility, such as nomadic/local wireless access, and up to 100 Mb/s for high mobility, such as mobile access.

Long-Term Evolution (LTE) and its extension, LTE-Advanced systems, as practical 4G systems, have recently been deployed or soon will be deployed around the globe. However, there is still a dramatic increase in the number of users who subscribe to mobile broadband systems every year. More and more people crave faster Internet access on the move, trendier mobiles, and in general instant communication with others or access to information.

More powerful smartphones and laptops are becoming more popular nowadays, demanding advanced multimedia capabilities. This has resulted in an explosion of wireless mobile devices and services. As more and more devices go wireless, many research challenges need to be addressed. One of the most crucial challenges is the physical scarcity of Radio Frequency (RF) spectra allocated for cellular communications. Cellular frequencies use ultra-high-frequency bands for cellular phones, normally ranging from several hundred megahertz to several gigahertz. These frequency spectra have been used heavily, making it difficult for operators to acquire more.

Another challenge is that the deployment of advanced wireless technologies comes at the cost of high energy consumption. The increase of energy consumption in wireless communication systems causes an increase of (CO_2) emission indirectly, which currently is considered as a major threat for the environment. Other challenges are, for example, average spectral efficiency, high data rate and high mobility, seamless coverage, diverse Quality of Service (QoS) requirements, and fragmented user experience (incompatibility of different wireless devices/interfaces and heterogeneous networks), to mention only a few.

All the above issues are putting more pressure on cellular service providers, who are facing continuously increasing demand for higher data rates, larger network capacity, higher spectral efficiency, higher energy efficiency, and higher mobility required by new wireless applications. On the other hand, 4G networks have just about reached the theoretical limit on the data rate with current technologies and therefore are not sufficient to accommodate the above challenges.

As a result, 5G is the next step in the evolution of mobile communication. It will be a key component of the Networked Society and will help realize the vision of essentially unlimited access to information and sharing of data anywhere and anytime for anyone and anything. 5G will therefore not only be about mobile connectivity for people. Rather, the aim of 5G is to provide ubiquitous connectivity for any kind of device and any kind of application that may benefit from being connected.

Mobile broadband will continue to be important and will drive the need for higher system capacity and higher data rates. But 5G will also provide wireless connectivity for a wide range of new applications and use cases, including wearable, smart homes, traffic safety/control, and critical infrastructure and industry applications, as well as for very-high-speed media delivery.

In contrast to earlier generations, 5G wireless access should not be seen as a specific radio access technology. Rather, it is an overall wireless-access solution addressing the demands and requirements of mobile communications.

LTE will continue to develop in a backwards-compatible way and will be an important part of the 5G wireless-access solution for frequency bands below 6GHz. There will be massive deployments of LTE providing services to an enormous number of devices in these bands. For operators with limited spectrum resources, the possibility to introduce 5G capabilities in a backwards-compatible way, thereby allowing legacy devices to continue to be served on the same carrier, is highly beneficial and, in some cases, even vital.

In parallel, new Radio Access Technology (RAT) without backwards-compatibility requirements will emerge, at least initially targeting new spectrum for which backwards compatibility is not relevant. In the longer-term perspective, the new non-backwards-compatible technology may also migrate into existing spectrum.

THE CHALLENGES

In 5G cellular networks, the challenges are to enable connectivity for a very wide range of applications with vastly different characteristics and requirements. The capabilities of 5G wireless access must extend far beyond those of previous generations of mobile communication.

Massive System Capacity

Traffic demands for mobile-communication systems are predicted to increase dramatically. To support such traffic in an affordable way, 5G networks must be able to deliver data with much lower cost per bit compared with the networks of today. Furthermore, in order to be able to operate with the same or preferably even lower overall energy consumption compared with today, 5G must enable radically lower energy consumption per delivered bit.

Another aspect of 5G system capacity is the capability to support a much larger number of devices compared with today. The new use cases envisioned for 5G include, for example, the deployment of billions of wirelessly connected sensors, actuators and similar devices. Each device will typically be associated with very little traffic, implying that, even jointly, they will have a limited impact on the overall traffic volume. However, the sheer number of devices to be connected provides a challenge, for example, in terms of efficient signaling protocols.

High Data Rates

Every generation of mobile communication has been associated with higher data rates compared with the previous generation. In the past, much focus has been on the peak data rate that can be supported by a wireless-access technology under ideal conditions. However, a much more important capability is the data rate that can actually be provided under real-life conditions in different scenarios.

5G should be able to provide data rates exceeding 10Gbps in specific scenarios such as indoor and dense outdoor environments. Data rates of several 100Mbps should be generally achievable in urban and suburban environments. Data rates of at least 10Mbps should be achievable essentially everywhere, including sparsely-populated rural areas in both developed and developing countries.

Low Latency

Lower latency has been a key target for both 4G and the evolution of 3G, driven mainly by the continuous quest for higher achievable data rates. Due to properties of the internet protocols, lower latency over the wireless interface is critical to realize the higher data rates. 5G targets even higher data rates, and this in itself will drive a need for even lower latency.

However, lower latency will also be driven by the support for new applications. Some of the envisioned 5G applications, such as traffic safety and control of critical infrastructure and industry processes, may require much lower latency compared with what is possible with the mobile-communication systems of today. To support such latency-critical applications, 5G should allow for an application end-to-end latency of 1ms or less.

Ultra-High Reliability and Availability

In addition to very low latency, 5G should also enable connectivity with ultra-high reliability and ultra-high availability. For critical services, such as control of critical infrastructure and traffic safety, connectivity with certain characteristics, such as a specific maximum latency, should not only be 'typically available.' Rather, connectivity with the required characteristics has to be always available with essentially no deviation.

Low Energy Consumption

The possibility for low cost and low energy consumption for mobile devices has been a key requirement since the early days of mobile communication. However, in order to enable the vision of billions of wirelessly connected sensors, actuators and similar devices, a further step has to be taken in terms of device cost and energy consumption. It should be possible for such 5G devices to be available at very low cost and with a battery life of several years without recharging.

High Network Energy Performance

While device energy consumption has always been prioritized, high energy performance on the network side has more recently emerged as a Key Performance Indicator (KPI).

- High network energy performance is an important component in reducing operational cost, as well as a driver for better dimensioned nodes, leading to lower total cost of ownership.
- High network energy performance allows for off-grid network deployments relying on decently sized solar panels as power supply, thereby enabling wireless connectivity to even the most remote areas.
- High network energy performance is part of a general operator aim of providing wireless access in a sustainable and more resource-efficient way.

The importance of these factors will increase further in the 5G era, and the possibility of very high network energy performance will therefore be an important requirement in the design of 5G wireless access.

SEARCHING FOR A SOLUTION

Such requirements need special technologies to be deployed. The detailed 5G standards are still work in progress and uncertain yet. Carrier Aggregation, massive Multiple Input – Multiple Output (MIMO), beam forming, cloud computing, millimeter Waves (mmW), Cognitive Radio (CR), Full Duplex (FD), Non-Orthogonal Multiple Access (NOMA), green communication, energy harvesting, Device-to-Device (D2D), wearable antenna, new security techniques and Cloud Radio Access Networks are potential technologies under research to meet 5G needs and be applied on it. In this book, we tend to overview some of these supportive technologies for 5G heterogeneous networks.

ORGANIZATION OF THE BOOK

The book is organized into 12 chapters. A brief description of each of the chapters follows:

Chapter 1 covers the major developments in cellular Communication networks namely Fixed Internet, Mobile internet, Things Internet and the upcoming Tactile Internet. The authors of this chapter present new trends and challenges in adopting 5th Generation of Cellular Communication (5G) for Internet of Things (IoT). Further, they provide an insight about the transformation from infrastructure based internet to opportunities or service based internet design.

Chapter 2 present a study aims to develop a model of information transmission based on discrete event concepts. This methodology aims to increase efficiency in sending and receiving data by reducing the consumption of time during this process. Next, chapter discusses the technological concepts that involve the mobile transmission and that motivated the development of the CBEDE methodology (Coding of Bits for Entities by means of Discrete Events) presented in this chapter.

Chapter 3 introduces an overview of microstrip antenna and MIMO systems for the next 5G band. Also, in this chapter, a novel design of MIMO antenna for the coming generation 5G bands as a solution for the next generation of smartphone antennas is investigated. Moreover, the effect of mutual coupling on closely coupled microstrip antennas in closely MIMO antenna systems is discussed. The anticipated wireless system is size-compact, relatively easy to fabricate and implement in practical mobile applications.

Chapter 4 shows two different types of dual-band flexible wearable antennas design. The first one is a rectangular antenna with six U-slots on the patch. This wearable antenna combines the hardness and flexibility in that, it is printed on a material called "ULTRALAM® 3850HT". The second antenna is a planar inverted-2F wearable antenna pasted on Jeans textile material as a substrate. The two proposed 5G-antennas are applied for founded of a smart watch.

Chapter 5 compares between Bit Error Rate analysis (BER) of Discrete Wavelet Transform (DWT)-OFDM system and conventional Fast Fourier Transform (FFT)-OFDMA system in order to ensure that wavelet transform based OFDMA transmission gives better improvement to combat Inter Carrier Interference (ICI) than FFT based OFDMA transmission and hence improvement in BER. In this chapter, author uses a kalman filter in order to improve BER by minimizing the effect of ICI and noise.

Chapter 6 focuses on adaptive cache management schemes for Cloud Radio Access Networks (CRAN) and Multi-Access Edge Computing (MEC) of 5G mobile technologies. Moreover, this chapter proposes a new cache management algorithm using Zipf distribution to address dynamic input for CRAN and MEC models. This work contributes in the support of 5G for IoT by enhancing CRAN and MEC performance; it also contributes to how novel caching algorithms can resolve the unbalanced input load caused by changing distributions of the input traffic.

Chapter 7 designs new efficient cache management schemes for the BaseBand Unit (BBU) pool in CRAN. It adopts the Exponential-Decay (EXD) scheme to keep recently frequently requested records in cache and enhances it with Analytical Hierarchy Process (AHP) to support multiple levels of mobility and QoS. The other new algorithms include a probability-based scoring scheme, a hierarchical, or tiered, approach, and enhancements to previously existing approaches.

Chapter 8 obtains an overview about Device-to-Device (D2D) communication technology in the existence with cellular network. Some standards have been summarized such as recent 3GPP and D2D WRAN based IEEE 802.22 evaluation. Moreover, current D2D's prototypes have been showed. Also, the importance of attaching D2D technology with different features has been illustrated. Besides that, D2D technology faces a lot of vital challenges; that have been highlighted.

Chapter 9 addresses Cognitive Radio Systems (CRSs) in the 5G network and presents the existing, emerging and potential applications employing CRS capabilities and the related enabling technologies, including the impacts of CRS technology on the use of spectrum from a technical perspective. The description of such technologies, operational elements and their challenges are also presented. Furthermore this chapter provides high level characteristics, operational and technical requirements related to CRS technology, their performances and potential benefits.

Chapter 10 is discussing the role of Cloud Computing centers in 5G networks, and how such integration could be implemented as found in the literature. The benefits of Cloud/5G integration will be explained as well. In addition, some challenges related to the integration is demonstrated.

Chapter 11 proposes a 5G tutorial consisting of the previous Vehicles to anything (V2X) technologies, the improvements over the 4G and IEEE802.11P, the 5G vital requirements, challenges, technologies, security enhancements, and the 5G system structure. In this chapter, authors cover the previous Dedicated Short Range Communication (DSRC)/wave standards, the LTE-V, the cellular V2X, the structure of C-V2X, the evolution of LTE towards 5G, the enhancement of the proposed 5G technologies, and finally the security aspects of the proposed 5G within V2X communications.

Chapter 12 presents a summary and state of art of Machine-to-Machine (M2M) communications characteristics, taxonomy, applications. The authors also show different technologies for deploying of M2M communications, and future challenges.

The purpose of this book is to take a step toward clarifying what '5G' really means in the technological sense, by: introducing 5G fundamental supportive technologies; expanding on some of the use case scenarios and applications that 5G might enable; and discussing conceivable implications for operators in terms of network infrastructure and commercial opportunities. Finally, researchers, academicians, students, faculties, scientists and Information Technology sector industry professionals will find this handbook beneficial for research exposure and new ideas in the field of 5G cellular communication and wireless heterogeneous networks technologies.

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Acknowledgment

The editors would like to acknowledge the help of all the people involved in this book and, more specifically, to the authors and reviewers that took part in the review process. Without their support, this book would not have become a reality.

First, the editors would like to thank each one of the authors for their contributions. Our sincere gratitude goes to the chapter's authors who contributed their time and expertise to this book.

Second, the editors wish to acknowledge the valuable contributions of the reviewers regarding the improvement of quality, coherence, and content presentation of chapters. Most of the authors also served as referees; we highly appreciate their double task.

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Section 1

Fifth Generation Fundamentals

Chapter 1
5G for IoT:
Between Reality and Friction

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ABSTRACT

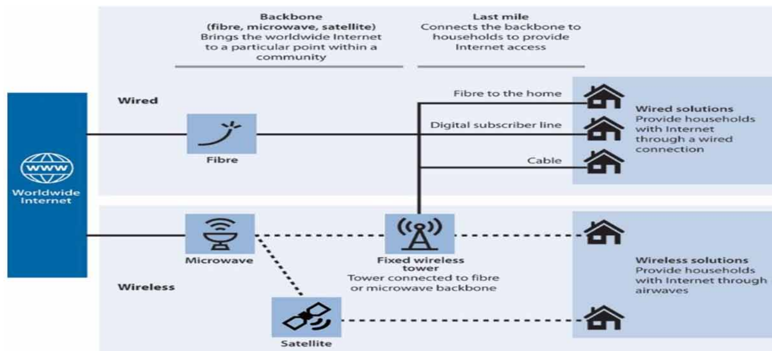
The 5th Generation of wireless network technology (5G) is a rising set of cellular technologies, specifications and projected standards that promise to dramatically improve the speed and responsiveness of wireless networks. The arrival of 5G guarantees new architectures for connecting billions of IoT (Internet of Things) devices and introduces a bunch of development challenges for sensible applications. Enterprises measure are trying to find out the solutions for omnipresent property and near-real-time remote solutions and management capabilities for mission-critical IoT systems and 5G is here to answer that decision.

INTRODUCTION

Cellular mobile communications play a significant role in technological developments by creating the platform for mobile Internet, connecting billions of smart phones and laptop, the focus of mobile communication is now shifting towards pervasive computing for machines and devices and hence achieving Internet of Things (IoT). It is envisioned that cellular networks take at least ten years to get from one generation to another. 5G is not an exception to that, as, for global standardization, the whole cellular ecosystem needs to be agreed on all technological aspects which include antenna, modulation, security, mobility, authentication and so on. The 5th Generation of cellular communication (5G) guarantees sufficient latency and speed for connecting billions of IoT devices and introduce several recent development challenges for sensible applications. Just because the technology is there does not imply it fits your strategy. It is advisable to learn the execs and cons of cellular Internet of Things properly before recommending it as a research area for enterprise development.

DOI: 10.4018/978-1-7998-1152-7.ch001

Figure 1. Fixed internet architectural design setup



The chapter covers the major developments in cellular communication networks namely fixed internet, mobile internet, things internet and the upcoming tactile internet. In this chapter, we present new trends and challenges in adopting 5th Generation of Cellular Communication (5G) for Internet of Things (IoT). We further provide an insight about the transformation from infrastructure-based internet to opportunities or service-based internet design.

FIXED INTERNET

Fixed wireless internet is not quite the same as progressively regular associations like DSL and fiber. Rather than utilizing a link, it brings the internet. When you decide on a fixed wireless internet, your supplier will introduce a collector to your home. It will speak with the closest remote base station and offer you access to the internet through a link conveying the broadband sign from the collector to the switch in your house (Brake, 2016). Signal to your home through radio waves transmitted by a base station.

Fixed wireless internet is primarily utilized in country territories were setting up the foundation for broadband administrations like DSL is restrictively costly. Transporting and covering links in the ground and getting the vital licenses can be costly. So, it doesn't bode well for specialist co-ops to go down this street in less populated territories, where they can't get enough endorsers on board to legitimize the all-out expenses.

UPSIDES AND DOWNSIDES OF FIXED WIRELESS INTERNET

As with everything throughout everyday life, fixed wireless internet has a lot of favorable circumstances and disservices. We should discuss the focal points first.

It's simpler to set up the hardware required for fixed wireless internet than it is for other broadband administrations since it doesn't require physical links or the issue they involve. The fixed internet is circulated to parts of India through laser beams.

Suppliers likewise don't normally set information tops, which is regular with cell internet providers. Furthermore, the innovation offers high download speeds that are similarly as quick if not quicker than those you get from other broadband administrations.

The issue with fixed wireless internet is that the association isn't constantly steady. Downpour, mist, and other climate conditions can influence its quality.

There additionally must be a viewable pathway between the beneficiary on your home and the remote base station. Obstacles, for example, trees and slopes can influence the nature of the administration and can even keep it from being set up (Miao, Zander, Sung, & Slimane, 2016). At that point there's additionally the cost: fixed wireless internet is normally more costly than different types of broadband.

FIXED REMOTE VERSUS SATELLITE INTERNET

Satellite internet is another choice for those living in regions where fixed broadband administrations are not accessible. Although it additionally requires a dish and furnishes you with rapid internet access without utilizing a telephone or link line, the satellite is unique to fixed wireless from multiple points of view.

Climate conditions influence satellite internet more than they do fix wireless. The signal needs to go through the whole environment and back. That implies a tempest in the following state can cause issues. A base station utilized for fixed wireless internet is about as tall as a normal phone tower. It's generally situated inside 10 miles of your home, so the mists above it and the tempest that is miles away won't meddle with the sign it's transmitting.

What's more, we should not disregard slack. Since the satellite is situated a lot more remote from the beneficiary on your home than the remote base station, satellite internet experiences high dormancy. This can make even a fast association languid and bigly affects things like internet gaming and gushing video.

Satellite internet services likewise set information tops, constraining the measure of information you can use on a month to month premise. In case you're online frequently and watch a lot of recordings, this is a major issue (Kafiloglu, Gur, & Alagoz, 2016).

A standout amongst the most significant contrasts between the two administrations is the cost. In spite of its impediments, satellite internet is still more costly than fixed remote. So when you consider every one of these things, plainly the last is the better decision.

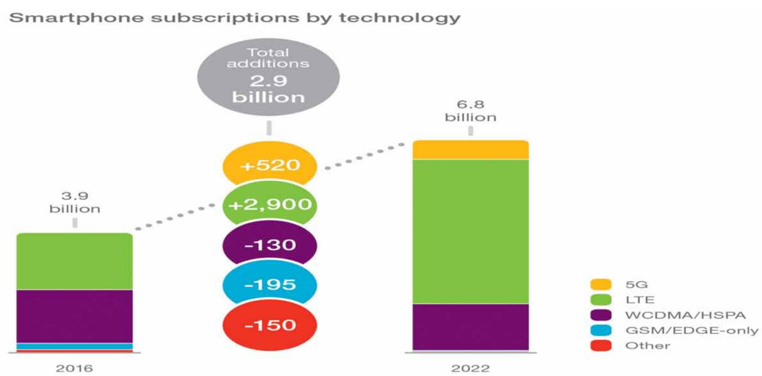
Mobile Internet in 5G Era

All sides of the business are going to be compact by 5G, particularly production, transportation, health care, and retail. Developers are going to be ready to access different types of network capabilities provided through unified IoT and 5G networks. Use cases like increased mobile broadband can target a lot of economical broadband access to connected homes and mobile devices, whereas large machine property use cases can support the property of billions of tiny, non-real-time IoT sensors for a variety of connected applications. Another category of uses cases can cowl ultra-reliable low-latency property and target high-value, Industrial IoT and Vehicle-to-X property that needs a mixture of low latency and high responsibleness (Rana, Swarnkar, & Jain, 2014).

Within the long-standing time, Enterprises ought to concentrate on a distinctive, manageable, scalable, secure network that uses the correct technique for the correct system. It's beneficial that enterprises wanting to deploy IoT networks begin with applying the new 5G Innovations or work backward to the choice of existing wireless technology.

Till today, it looks that IPv6 is used for carrying traffic. However, it additionally sounds like 5G offers opportunities for rethinking the styles of networking architectures used at the physical layer. To

Figure 2. Need of mobile internet in 5G era



take an example, an issue in IoT would usually have a bunch of IPv6 addresses that will have different networking technologies beneath them (5G, Wi-Fi, Ethernet, Btle, Zigbee, etc.). The s/w challenge, that IPv6 helps with, is to prevent engineers from taking advantage of' networking technology specific capabilities as these simply get within the method of issue ability.

By 2025, billions of devices are internet-connected, providing organizations a bevy of insights to optimize operations cut prices and improve decision-making. However, it isn't magic. One cannot simply add a sensing element to a machine and make a brand-new revenue model. The right sensors must be used to gather the right knowledge, and therefore the correct analytics to Garner's insights. The proper property is vital to the current method (Bhalla & Bhalla, 2010).

Once it involves property for IoT, one size does not work all. Whereas the square measure wired choices and satellites, most IoT systems can use short- or long-range wireless, betting on the utilization case. However, the selections do not stop there. An array of choices exists for short-range property for IoT, from Bluetooth to near-field communications to Wi-Fi and additional. For long-range, their square measure even additional decisions to form, together with authorized (such as LTE Cat M1, Narrowband IoT or 5G) or unauthorized (LoRaWAN, Sigfox or Random part multiple Access). Each IoT property possibility has its edges and tradeoffs around knowledge transmission (e.g., the quantity of information and frequency), latency, power consumption, value, and security, to call some. High-volume, quick knowledge transfers usually use additional power (Arunkumar & Kalaiselvi, 2014).

In an industrial setting that has to connect billions of tiny, non-real-time sensors or needs ultra-reliable, low-latency connectivity, 5G is also best. For agriculture businesses that need to maximize IoT, cellular is not associate in nursing the possibility of low-power, long-range WAN. This is a crucial call to form currently that the IoT market has reached a turning point. Organizations square measure finding out the simplest ways that to increase their investment as their scales comes, driving payment for the hardware, software, services and property needed to alter IoT solutions. Cellular may be a decades-old possibility. This chapter is beneficial in choosing the simplest cellular IoT options.

This chapter demonstrates the current problems to be tackled before prognostic maintenance build digital twins or alter machine learning. To opt for the right property for IoT to urge the knowledge wherever it's going expeditiously, cost-effectively and safely are the decisions that may be tackled after reading this chapter the square measure has a myriad IoT applications and diverse choices once it involves connecting them, however, there is no one-size-fits-all.

Overview of Cellular Communication System

A cell correspondence framework is where the last association is remote. The framework is dispersed over land zones known as cells; every cell is served by at any rate one fixed-zone base handset stations. These base stations give the cell the required framework incorporation which may be used for transmission of sound, video and various types of information. In a cellular network, all things considered uses a specific plan of frequencies from neighboring cells, to keep up a key separation from the deterrent and supply fundamental organization quality at fixed breaks to each cell. (Simonite, 2013) when joined along, these cells give radio consideration over a fixed land district. this permits an extent of transportable handsets (e.g., mobile phones, tablets, and workstations outfitted with versatile broadband modems, pagers, etc.) to converse with one another and with joined handsets and telephones at any place inside the framework, by methods for base stations, anyway a portion of the handsets domain unit moving from one cell to other cell all through the transmission.

Cellular systems give assortment of entrancing highlights (Simonite, 2013):

a) More capacity than one gigantic transmitter, since indistinguishable recurrence, might be utilized for different connections insofar as they are in various cells.
b) Mobile gadgets utilize less power than with one transmitter or satellite since the cell towers region units are closer.
c) Larger inclusion space than one earthly transmitter, since further cell towers aren't limited by the skyline

A cellular communication system is a network where the last connection is wireless. The system is disseminated over land zones known as cells; each cell is served by at least one fixed-area base handset stations. These base stations give the cell the required system inclusion which might be utilized for transmission of sound, video and different kinds of data. A phone by and large uses a particular arrangement of frequencies from neighboring cells, to maintain a strategic distance from the obstruction and supply essential administration quality at fixed interims to each phone. (Simonite, 2013) When joined along, these cells give radio inclusion over a fixed topographical region. This allows a scope of transportable handsets (e.g., cell phones, tablets, and workstations furnished with portable broadband modems, pagers, and so forth.) to talk with each other and with attached handsets and phones at wherever inside the system, by means of base stations, however some of the handsets territory unit moving from one cell to other cell all through the transmission.

Cellular Networks Provide Variety of Fascinating Features

1. More capability than one massive transmitter, since identical frequency, may be used for multiple links as long as they are in numerous cells.
2. Mobile devices use less power than with one transmitter or satellite since the cell towers area units are nearer.
3. Larger coverage space than one terrestrial transmitter, since further cell towers aren't restricted by the horizon (Simonite, 2013)

Real media communications providers have sent voice and learning cell organizes over the greater part of the crowded grounds of earth. This empowers cell phones and portable figuring gadgets to be associated with the overall population exchanged phone system and open web. Non-open cell systems might be utilized for research (Guowang, 2016) or for monster associations. In a phone radio framework, a real estate's to be prepared radio administration is part into cells, in an exceedingly design that relies upon package of land and gathering qualities anyway which may join generally polygon, square, roundabout or other customary shapes.

Each cell is dispensed with various frequencies (f1 – f6) that have their individual radio base stations. The group of frequencies might be reused in various cells; giving indistinguishable frequencies aren't reused in adjoining neighboring cells as that may cause co-channel impedance.

The brought capacity up in an exceedingly cell arrange, contrasted and a system with one transmitter, originates from the versatile correspondence change framework created by "Amos Joel" of Bell labs (Flood, 1997). This framework permits numerous guests inside a similar space to utilize indistinguishable recurrence by evolving calls. The very reality that indistinguishable recurrence might be reused in an exceedingly totally extraordinary space for an alternate transmission. On the off chance that there's one plain transmitter, only one transmission might be utilized on some random recurrence. Unavoidably, there's some degree of obstruction from the sign from the contrary cells that utilization indistinguishable recurrence. This recommends, in ordinary recurrence division different access (FDMA) framework, there ought to be at least a 1 cell hole between cells that use indistinguishable recurrence. For instance, in taxi organization, each radio had a worked by hand channel selector handle to tune to totally various frequencies as the drivers enchanted around, had revision from channel to channel. The drivers realized that recurrence covered generally what space. On the off chance that they didn't get a proof from the transmitter, they'd endeavor various channels till they discovered one that worked. The cab drivers would exclusively talk each one in turn, once welcomed by the base station administrator. This is, it could be said, time-division different access (TDMA).

The main mechanical cell arrangement, the 1st Generation (1G), was propelled in Japan by Nippon transmit and Telephone (NTT) in 1979, at first inside the metropolitan space of national capital. Following 5 years, the NTT system had been stretched to shroud the full populace of Japan and have turned into the essential across the country 1G arrangements.

CELL SIGNAL ENCODING

To separate sign from numerous totally various transmitters, time-division different access (TDMA), frequency division different access (FDMA), code-division different access (CDMA), and orthogonal frequency division different access (OFDMA) were created (Miao, Zander, Sung, & Slimane, 2016). With TDMA, the transmitted and getting availabilities used by clients in each cell zone unit has unique relation to each other. With FDMA, the transmitted and accepting frequencies used by clients in each cell unit is not same to each other. For example, in a taxi framework, the cab driver physically tuned to a frequency of a chosen cell to get a vigorous sign and to maintain a strategic distance from obstruction from various cells. The guideline of CDMA is the progression that accomplishes steady outcome; the conveyed handsets will pick one cell and hear it.

Other realistic techniques of multiplexing like polarization-division multiple access (PDMA) cannot separate sign from one cell to resulting cell, since the outcomes of each shift with position and this may make signal detachment absurd. TDMA is utilized together with either FDMA or CDMA during a scope of frameworks to give up various channels at interims (the inclusion space of one cell).

Frequency utilizes the key normal for a cell to organize. The capacity to re-use frequencies is utilized to expand inclusion and ability of cell arrange. Henceforth neighboring cells should utilize totally different frequencies. Two cells which are adequately so much separated may work on consistent recurrence, gave the cell organize clients' instruments don't transmit with an over the top measure of intensity (Miao, Zander, Sung, & Slimane, 2016). The components that affirm the recurrence, utilize zone unit, the utilize remove and subsequently the utilize issue.

The reuse distance, d is determined as any place r is that the cell sweep and n is that the scope of cells per bunch. Cells may change in range from one to thirty kilometers (0.62 to 18.64 mi). The limits of the cells additionally can cover between contiguous cells and colossal cells are regularly separated into littler cells. (Flood, 1997)

The frequency reuse issue is that the rate at that steady recurrence is frequently utilized in the system. Its 1/k where is that the scope of cells that can't utilize consistent frequencies for transmission. Normal qualities for the recurrence utilize issue region unit 1/3, 1/4, 1/7, 1/9 and 1/12 (Pauli, Naranjo, & Seidel, 2010).

On account of n area radio wires on steady base station site, each with totally unique bearing, the base station site will serve n totally various segments (n is frequently three). An utilize example of n/k signifies an extra division in recurrence among n segment receiving wires per site. Some present and recorded utilize designs territory unit 3/7 (North Yank AMPS), 6/4 (Motorola NAMPS), and 3/4 (GSM). If the generally speaking realistic data measure is b, each cell will exclusively utilize assortment of recurrence channels like a data proportion of b/k, and each division will utilize a data proportion of b/n*k.

Code-division multiple access-based frameworks utilize a more extensive waveband to accomplish steady rate of transmission as FDMA, be that as it may, this can be salaried for by the ability to utilize a recurrence utilize issue of one, for example utilizing an utilize example of 1/1. In various words, nearby base station locales utilize steady frequencies, and accordingly the totally extraordinary base stations and client's territory unit isolated by codes rather than frequencies. While n is appeared as one during this model, doesn't mean the CDMA cell has just 1 part, anyway rather that the total cell data measure is also possible to each segment individually. Contingent upon the components of town, a taxi framework probably won't have any recurrence reuse in its town. However entirely unique close urban communities, steady frequencies are often utilized.

During a monster town, on the contrary hand, and frequency reuse may be being used. As of late moreover orthogonal frequency division multiple access principally based frameworks like LTE region unit being sent with a frequency reuse of one. Since such frameworks don't unfurl the sign over the waveband, between cell radio asset the board is imperative to arrange asset portion between totally extraordinary cell destinations and to restrict the between cell obstruction. Their territory unit various recommends that of inter-cell interference coordination (ICIC) effectively lay out inside the ordinary (Pauli, Naranjo, & Seidel, 2010). Coordinated programming, multi-site MIMO or multi-site bar framing territory unit various models for between cell radio assets the executives which might be institutionalized inside what's to come.

USE OF DIRECTIONAL ANTENNA IN CELLULAR NETWORKS

Cell towers frequently utilize a directional sign to improve gathering in higher-traffic territories. Inside the U. S., the Federal Communications Commission (FCC) limits spatial connection cell tower sign to a hundred watts of intensity. On the off chance that the pinnacle has directional radio wires, the FCC allows the cell administrator to communicate up to five hundred watts of effective radiated power (ERP) (Drucker, Elliott, 2016).

Despite the fact that the primary cell towers made a magnificent, spatial connection signal, were at the focuses of the phones and were spatial connection, a phone guide are frequently redrawn with the remote phone towers put at the sides of the hexagons any place 3 cells meet(Farley, T., and Vander Hoek, M. 2002). Each pinnacle has 3 sets of directional receiving wires pointed in 3completely various ways with a hundred and twenty degrees for each cell (totaling 360 degrees) and accepting/transmitting into 3 unique cells at various frequencies. This gives at least 3 channels and 3 towers for each phone and significantly will expand the potential outcomes of accepting a usable sign from at least one heading.

The numbers inside the representation square measure channel numbers that recurrent each three cells.

Gigantic cells are frequently separated into littler cells for top volume regions (Richard H. Frenkiel). Cell telephone enterprises furthermore utilize this directional sign to improve gathering on roadways and inside structures like arenas and fields. (Drucker, Elliott, 2016).

BROADCAST MESSAGES AND PAGING

For all intents and purposes each cell framework has some sensibly communicated instrument. This will be utilized legitimately for conveying data to different mobiles. Ordinarily, for example, in versatile media transmission frameworks, the premier indispensable utilization of communicate information is to arrange channels for coordinated correspondence between the portable handset and in this manner the base station. This is frequently alluded to as paging. The 3 diverse paging systems ordinarily received square measure progressive, parallel and selective paging.

The subtleties of the technique for paging shift to some degree from system to organize, anyway generally we as a whole know a confined scope of cells any place the telephone is discovered (this group of cells is named a Location space inside the GSM or UMTS framework, or Routing space if an information bundle session is included; in LTE, cells square measure arranged into pursue Areas). Paging happens by making the printed message any or these cells. Paging messages are regularly utilized for information move. This occurs in pagers, in CDMA frameworks for causing SMS messages, and inside the UMTS framework any place it grants for low downlink inertness in parcel based associations.

CELL TO CELL MOVEMENT AND RETURNING

In a crude taxi framework, when the taxi moved far from an essential pinnacle and closer to a subsequent pinnacle, the cab driver physically changed from one frequency to an alternate as required. On the off chance that correspondence was intruded on due to lost a side effect, the cabbie asked the base station administrator to rehash the message on a particular frequency.

In a phone framework, on the grounds that the disseminated portable handsets move from cell to cell all through partner in nursing current persistent correspondence, the move from one cell frequency to an unmistakable cell frequency is done electronically while not intrusion and keeping in mind that not a base station administrator or manual move. This is frequently alluded to as the surrender or football play. Regularly, a fresh out of the box new channel is precisely choose for the versatile unit on the new base station which can serve it. The versatile unit at that point precisely changes from this channel to the new channel and correspondence proceeds. The accurate subtleties of the portable framework's move from one base station to the inverse shift essentially from framework to framework.

MOBILE PHONE NETWORK

The most widely recognized case of a cell system could be a transportable (mobile phone) Network. A transportable could be a transportable telephone that gets or makes calls through a phone site (base station), or transmittal tower. Radio waves square measure need to move sign to and from the mobile phone. Current transportable systems use cells because of radio frequencies square measure a confined, shared asset.

MODIFICATION OF CELL SITES AND HANDSETS

Recurrence underneath PC the board and utilize low power transmitters so the occasionally confined assortment of radio frequencies is in the meantime utilized by a few guests with less obstruction.

A cell system is utilized by the transportable administrator to understand every inclusion and capacity for his or her endorsers. Mammoth geographic square measures are part into littler cells to dodge view-able pathway signal misfortune and to help a larger than usual assortment of dynamic telephones in that space. The majority of the cell destinations square measure associated with phone trades (or switches), that progressively connect with the overall population phone organize. In urban communities, each cell site could have an assortment of up to some 1⁄2 mile (0.80 km), though, in country zones, they differ might be the most extreme sum as five miles (8.0 km).

It's potential that in clear open zones, a client could get signals from a phone site twenty-five miles (40 km) away. Since most cell phones utilize cell innovation, together with GSM, CDMA, and AMPS (simple), the expression "wireless" is in certain locales, prominently the North American nation, utilized conversely with "cell phone".

Nonetheless, satellite telephones square measure cell phones that don't discuss legitimately with a ground-based cell tower, in any case, they could do in this manner in a roundabout way by the strategy for a satellite.

There square measure assortment of different advanced cell advances, including worldwide System for Mobile Communications (GSM), General Packet Radio Service (GPRS), CDMAOne, CDMA2000, Evolution-Data Optimized (EV-DO), expanded information Rates for GSM Evolution (EDGE), Universal Mobile Telecommunications System (UMTS), Digital expanded conductor Telecommunications (DECT), Digital AMPS (IS-Brake D (2016). 6/TDMA), and Integrated Digital expanded Network (iDEN).

The change from existing simple to the computerized standard pursued a totally extraordinary way in Europe and accordingly the North American nation (Paetsch, Michael, 1993). As a result, numerous advanced principles surfaced inside the North American nation, while Europe and a lot of nations combined towards the GSM standard.

STRUCTURE OF THE PORTABLE CELLULAR NETWORK

A easy examine of the cell mobile-radio network consists of the following:

- A network of radio base stations forming the backside station system.
- The core circuit switched community for dealing with voice calls and text
- A packet switched community for coping with mobile information
- The public switched phone community to connect subscribers to the broader smartphone network

This community is the foundation of the GSM gadget network.

There square measure various features that rectangular measure carried out through this network to create fine customers get the required service collectively with great management, registration, decision set-up, and relinquishing. Any telephone connects to the community with the aid of companion degree RBS (Radio Base Station) at a nook of the corresponding mobile phone that successively connects to the Mobile shift core (MSC). The MSC offers affiliation to the generic Public Switched Telephone Network(PSTN). The link from a phone to the RBS is termed companion degree transmission whereas the contrary strategy is termed downlink.

Radio channels efficiently use the transmission medium via the employment of the subsequent multiplexing and get entry to schemes: Frequency division more than one get entry to (FDMA), Time division more than one get right of entry to (TDMA), Code division a couple of get admission to (CDMA), and Area division more than one access (SDMA).

This system is the establishment of the GSM framework . There square measure a few capacities that square measure performed by this system to make positive clients get the required administration together with quality administration, enrollment, choice set-up, and giving up.

Any telephone interfaces with the system by means of partner degree RBS (Radio Base Station) at a side of the comparing cell that progressively associates with the Mobile shift centre (MSC). The MSC gives association to the public switched telephone network (PSTN). The connection from a telephone to the RBS is named partner degree transmission though the contrary methodology is named downlink.

Radio channels adequately utilize the transmission medium through the work of the consequent multiplexing and access plans:

Frequency division various access (FDMA), Time division multiple access (TDMA), Code division multiple access (CDMA), and space division multiple access (SDMA).

SMALL CELLS

Small cells, that have a smaller coverage space than base stations, square measure categorized as follows:

- Microcell, but a pair of kilometers
- Pico cell, but two hundred meters
- Femto cell, around ten meters

CELLULAR RELINQUISHING IN PORTABLE NETWORKS

As the telephone client moves from one cell space to an alternate cell while a choice is progressing, the versatile station can investigate for a fresh out of the box new station to interface with out dropping the choice. When a pristine channel is discovered, the system can direct the versatile unit to change to the new channel and at the indistinguishable time switch the choice onto the new channel.

With CDMA, multiple CDMA handsets share a chosen radio channel. The sign square measure isolated by utilizing a pseudo noise code (PN code) that is explicit to each telephone. Since the client moves from one cell to an alternate, the French phone sets up radio connections with different cell locales (or areas of the indistinguishable site) in the meantime. This is frequently alluded to as "soft handoff" because of, as opposed to antiquated cell innovation, there's no one laid out reason any place the telephone changes to the new cell.

In IS-95 between cell frequency handovers and more established simple frameworks like NMT, it'll for the most part be impractical to check the objective channel straightforwardly though human activity. For this situation, elective strategies must be constrained to be utilized like pilot reference points in IS-95. This recommends there's almost consistently a brief break inside the correspondence while looking at the new channel pursued by the opportunity of partner degree unexpected return to the past channel.

On the off chance that there's no in-advance correspondence or the correspondence will be interfered with, it's feasible for the portable unit to not indispensable move from one cell to an alternate so educate the base station with the most grounded sign.

CELLULAR FREQUENCY SELECTION IN PORTABLE NETWORKS

The effect of frequency on cell inclusion infers that various frequencies serve higher for different employments. Low frequencies, as 450 megacycles for every second NMT, serve o.k. for provincial territory inclusion. GSM (900 MHz) could be a fitting goals for light-weight urban inclusion. GSM 1800 (1.8 GHz) begins to be limited by auxiliary dividers. UMTS, at 2.1 Giga cycle every second is kind of comparable in inclusion to GSMone800. Higher frequencies square measure a hindrance once it includes inclusion; be that as it may, it's a set preferred position once it includes capacity. Pico cells, covering for example one story of a structure, become feasible, and furthermore a similar frequency will be utilized for cells that square measure numerous neighbors.

Cell spot can likewise shift in view of obstruction from transmittal frameworks, each at interims and around that cell. This is regularly valid, especially in CDMA essentially based frameworks. The beneficiary needs an exact sign/commotion proportion, and furthermore the transmitter mustn't send with

Table 1. Coverage comparison of different frequencies

Frequency (MHz)	Cell radius (km)	Cell area (km^2)	Relative Cell Count
450	48.9	7521	1
950	26.9	2269	3.3
1800	14.0	618	12.2
2100	12.0	449	16.2

excessively high transmission control unmistakable to not cause impedance with elective transmitters. Since the recipient moves detached from the transmitter, the capacity got diminishes, thusly the power the executives algorithmic principle of the transmitter will expand the capacity it transmits to restore the degree of got control. Since the obstruction (commotion) rises higher than the got power from the transmitter, and furthermore the intensity of the transmitter can't be upgraded any further, the sign winds up debased and in the long run unusable.

In CDMA-based frameworks, the effect of obstruction from elective portable transmitters inside a similar cell on inclusion space is amazingly checked and incorporates an extraordinary name, cell breath. One will see tests of cell inclusion by learning some of the inclusion maps given by genuine administrators on their sites or by review severally publicly supported maps like Open Signal. In sure cases they will stamp the situating of the transmitter, in others it will be determined by understanding the reason for the most grounded inclusion.

A cell repeater is utilized to expand cell inclusion into bigger zones. They change from expansive band repeaters for customer use in homes and workplaces to great or advanced repeaters for modern wants.

FREQUENCIES COVERAGE COMPARISION

The following table shows the dependency of the coverage area of one cell on the frequency of a CDMA2000 network: [Colin Chandler (3 December 2003).]

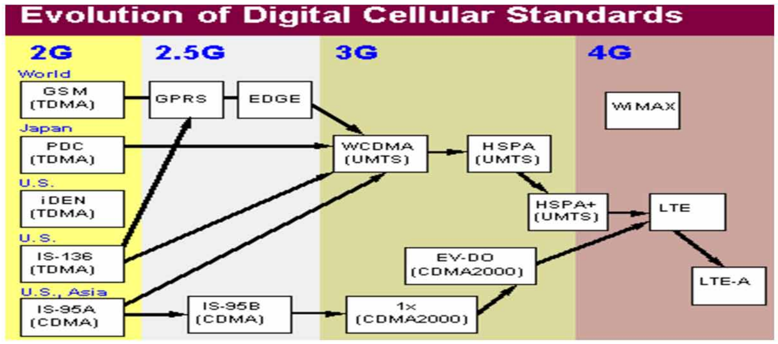
CELLULAR GENERATIONS

The evolution of cellular communications networks popularized by 1G, 2G, 3G and 4G designations.

We are currently in the fourth generation (4G).4G - LTE begins in 2011. GSM and CDMA carriers embraced LTE, that offers higher speeds than 3G networks. LTE embodies the design goals of the IP Multimedia Subsystem (IMS), which integrates all communications using the IP protocol (voice, video, e-mail, Web, messaging, etc.).4G - WiMAX was the primary carrier to supply a 4G cellular network .Using the WiMAX technology, 4G service was rolled out to major cities in 2009, providing faster downloads than 3G service. In late 2010, the ITU officially designated HSPA+ as a 4G technology, having previously defined it as 3G.

3G, WCDMA/HSDPA and CDMA2000 Launched at the flip of the century, the third generation features faster access to the Internet with downstream speeds up to 1 Mbps and more depending on the 3G

Figure 3. Mobile generations overview



version. The predominant 3G technologies on the GSM side are WCDMA and HSDPA with CDMA2000 on the CDMA side. 3G also embraces worldwide roaming for global travelers.

2G/2.5G - GSM/CDMA, GPRS/EDGE/IS95-B, and The second generation refers to the digital voice systems of the 1990s, replacing analog phones and based on the TDMA and CDMA air interfaces. First deployed in Europe, GSM became the predominant TDMA-based cellular system worldwide. Data networks (GPRS, EDGE, IS-95B) were added and commonly called 2.5G technologies, enabling Internet access and e-mail with slow downstream speeds up to approximately 200 Kbps.

1G - Analog Voice Introduced within the late Nineteen Seventies, the first cellular systems were analog voice. Years later, some 1G cellphones occasionally provided wireless data service to a laptop by connecting them to the laptop's dial-up modem, but hookups were precarious, and when it worked,

The data transfer rate was minuscule.

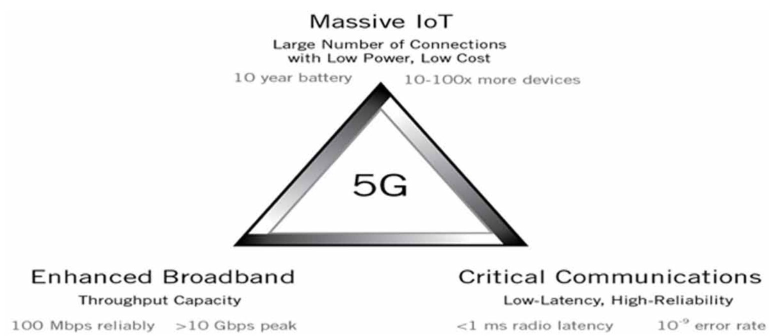
TRANSFORMATION FROM INFRASTRUCTURE BASED INTERNET TO OPPORTUNITIES OR SERVICE BASED INTERNET DESIGN

20 years ago the internet is Ethernet cables. Ethernet cables are connected to domes. The whole internet is infrastructure based. And 20 years from now the internet is all about Facebook, eBay, twitter, etc. that is we forgot all about the underlying architecture. We imagine the internet to be wireless and we forgot the cables. The Internet is now mobile. We are moving towards the service-based architecture of the internet.

The mobile internet is now a fabric of interest now. We are using mobile internet on our phones, laptops, etc. This mobile internet becomes visible when we move from 3G cellular architecture to 4G cellular infrastructure. There is a massive difference in speed of 4G from 3G. When we talk about 5G architecture then there is a massive difference of 2-3 times in data rates offered by 5G.

The 4G capabilities are not fully functional now. The 4G is in the process of development. By using carrier aggregation techniques we are experiencing the speed of 1gigabits/second. 5G speed is around 100 gigabits/ seconds. Applications like putting cameras on the shirts of football players. So that we can experience the fields from players. All these moving cameras provide us with a large amount of raw data that needs to be processed with an ultra-high speed of 5G. All the raw stuff is uploaded to uplink and after processing, the camera clips are played. This will happen within the delay of 4-6 seconds (Akyildiz IF, Nie S, Lin SC, Chandrasekaran M 2016). People who are seeing this football play in real

Figure 4. Three corners of triangle stressing towards the goals of 5G



time can see the picture after a gap of 5-6 milliseconds. And this is enough time to process all the data that can be present on the planet earth. Ericson started designing 3G when the mobile internet concept is now they're and 4G when i-phones are not even launched. And 5G designing is now started when the capabilities of 4G are under progress.

WHAT IS 5G?

There is not yet an agreed definition of 5G. This upcoming generation of wireless cellular networks is envisioned to offer everything to everybody with an expected speed of 25 Gbps and latency up to 1ms to enable Tactile Internet .5G is used to refer as combination several new technologies. The development of these driving technologies is governed by the fundamental challenges faced by current network standards.

The prime protocol for 4G-LTE was designed based on the concept of mobile broadband. While 5G designs are guided by increased user networking demands in the field of industrial automation, precision agriculture and augmented reality. Hence researchers are forced to consider the union of new technologies instead of incremental additions to the LTE specifications (Galiotto C, Pratas NK, Doyle L, Marchetti N, 2017).

5G is a new and very capable radio, with governing technologies like beam-forming, MIMO antenna, and frequency bands reaching to millimeter waves. 5G provides transmission speeds in the Gigabit range, up to 15 Gbps or even beyond. This new radio is essential to serve mass deployment of networked sensors and to enable various mission-critical services of Tactile internet that may require 1ms latency and improved reliability characteristics.

THE GOALS OF 5G

The three use cases that govern the development of 5G are Massive Internet of Things support; Enhanced mobile broadband requirements; and need of infrastructure to enable critical communication for public safety and tactile internet (Ying Wang, Jing Xu, and Lisi Jiang, 2014).

Day by day increasing use of social networking by human users overburden the communication network with video traffic, which is managed through enhanced mobile broadband as it can handle the increased capacity requirements of existing network infrastructure.

Machine/device connectivity in IoT architecture relies on scalability, signal simplification, low cost and long term sensors for energy efficiency and improved battery lifetime (Pauli, Naranjo, & Seidel, 2010). 5G networks will have to be adaptable to several types of IoT devices and provide mobile functionality when needed otherwise conserve recourses to improve power efficiency.

Critical communication demands for future networks are fulfilled by improving latency up to 1ms. Latency is the time delay as the information travels across the network. The latency of 5G networks becomes more important as real-time interactions between machines and humans are increasing at an alarming rate. Reliable and Low latency connections enable the previously impossible applications of the Tactile Internet (Arunkumar & Kalaiselvi, 2014).

WILL 5G AND THE INTERNET OF THINGS PLAY TOGETHER?

5G upgrades are in advancement and implications of range and information exchange limit usage is always progressing to acclimate to the forthcoming time of versatile frameworks. The mobile phones measure is getting as little and utilitarian as they could ever be. IoT might be recognized when data and information are free gushing's between different systems, geographies, dealers and organizations, achieving exceedingly planned start to finish game plans.

The 5G and IoT helpful energies are self-evident. The versatility from 5G frameworks will be required to manage all the varying assortment of data made by the Internet of Things. Along these lines, the Internet of Things will manage the structure of a 5G framework to pass on the perfect and capable setup to serve end customers' needs at whatever point and wherever they develop.

THE INTERNET OF THINGS AS AN ENABLER OF TACTILE INTERNET

By utilizing Mobile Internet and interfacing billions of cutting-edge cell phones and workstation reevaluate entire parts of the economy in the primary decade of the 21st century.

Today, we witness the ascent of the Internet of Things (IoT), in mere seconds to interface trillions of articles and started reexamining economies of this decade.

Since the Tactile Internet will profit amazingly fundamental pieces of society, it ought to be ultra-trustworthy, probably producing a second of power outage for every year, reinforce low torpidity and short start to finish delays in the solicitation of milliseconds – and have satisfactory capacity to empower colossal amounts of contraptions to talk with each other at the same time, independently (Agyapong, Iwamura, Staehle, Kiess, & Benjebbour, 2014) .It will have the ability to interconnect with customary wired web, the versatile web and the Internet of things – this way surrounding web of totally new measurements and capacities.

Substance and scope of capacities data will be transmitted on a very basic level increasingly exceptional 5G focal framework and also the front line Internet. The constrained speed of light, regardless, will require a significant proportion of the cloud knowledge to be engaged close at the edge, close to the material experience.

Noteworthy research tries are relied upon to plan and interface the tactile internet with the ordinary wired internet, the mobile internet and the Internet of Things – along these lines forming an Internet of totally new measurements and capacities. Instead of the prior Internets which exchange substance, the Tactile Internet, in any case, will be an engaging impact for the scope of the range of abilities movement.

The term Tactile Internet created as of late. Early completely robotized headways named related structures "haptic figuring", anyway it didn't have the thought of the bleeding edge sorting out limits.

ISSUES AND CONTROVERSIES FORTHE REALIZATION OF THINGS INTERNET

In 2000 it is realized that there are billions of sensors and actuators are being attached to the network shortly. This network of computers with actuators and sensors is named as thing internet or internet of thing (IoT). To achieve this some proposals are:

1. Wireless design is required.
2. Low power solutions are needed.
3. Need to work on the physical layer (media access control)
4. The devices attached to the network must speak the language of the Internet (IPV6).
5. Since IPV6 has larger packets than small chips of sensors and actuators attached to the devices. So ITEF standards are designed to chop the large IPV6 packet to smaller packets and reassemble them together when needed.
6. To utilize the benefit of things internet on the application layer, it is recommended that the devices attached to the physical layer must comply with the standards of the web (www).

The internet community is working on all the above proposals for the last 15- 20 years, but things do not work well to the expectations. That means some assumptions are wrong. So to achieve the 5G speed for the proper working of things internet some mistakes are realized. These are:

1. The pitch of low power is believed to be more accurate. But power does not drain your battery. Power gives us the range. It is the energy that drains your battery. So low energy solutions are needed to increase the time for network coverage.
    a. Power * Energy = Time
2. The wrong spectrum is used. Since ISM bands are used abruptly and these bands are highly congested. Interference is not the only problem with ISM. These ISM bands do not provide us with the license service agreement. Therefore, for real-time mission-critical solutions, using ISM bands is a bad choice.
3. The low cost design the low-cost chips are preferred. And to babysit the network for 24*7 by assigning this work to human resources. Hence the total cost of ownership is large then the chip cost.

RECOMMENDATIONS AND SOLUTIONS FOR THINGS INTERNET

The Wi-Fi community realized these mistakes and in 2008 (OSMO devices) come with the concept of Duty cycle. We can duty cycle the Wi-Fi devices. That means we can switch off the Wi-Fi connected device when not in used and on it when required. And 802.11ah standard of IEEE came into existence.

In 2012, BOSH did an interesting study. They compare the energy consumption of low power Zigbee chip to the low power Wi-Fi chip and the Wi-Fi chip are more energy efficient as compare to Zigbee. And slowly and steadily the Zigbee is gone out of the market now.

Low power wide area network also revolutionaries the internet word by using licensed band.

Internet of things (IoT), alludes to the billions of physical gadgets around the universe that are linked with the internet, gathering and sharing information. This vision is conceivable because of minimal effort of processors and wide zone inclusion in remote systems.

A new dimension of computerized knowledge is given to the gadgets. This advanced knowledge empowers them to convey themselves with no human intervention. In this way, IoT will blend with the advanced and physical worlds (Aijaz, Dohler, Aghvami, Friderikos, & Frodigh, 2017).

The Internet is a large segment of the Internet of Things communicating with each other and the internet.

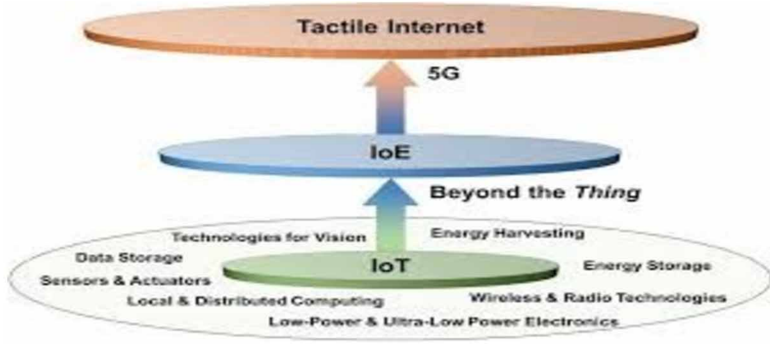
Global Positioning system of Satellites (GPS) is currently a reality. GPS is established by the Department of Defense in 1993. GPS provides a stable and exceptionally useful arrangement of 24 satellites. This stable and exceptionally useful arrangement of 24 satellites was trailed by private and business satellites. Satellites give essential interchanges framework to the IoT.

One extra and significant part in building up useful IoT frameworks was expanding the address space of IPV6's. Now a day, Internet of Things had advanced into to a framework utilizing numerous innovations, extending from the Internet to remote correspondence and from small scale electro-mechanical framework to installed frameworks. The conventional fields of robotization, remote sensor systems, GPS, control frameworks, and others, all helps the IoT to cope up with the coming advancements.

Today Internet of things comprises of any gadget associated with the internet. This incorporates nearly everything, running from mobile phones to building support to the stream motor of a plane. Medicinal gadgets, for example, a heart screen embed or a biochip transponder in a homestead creature, can exchange information over a network (Dohler, Mahmoodi, Lema, Condoluci, Sardis, Antonakoglou, & Aghvami, 2017).

Adding sensors and knowledge to fundamental articles was talked about all through the 1990s. The advancement was moderate because the innovation wasn't prepared. The processors attached to the sensors are modest but control hungry. So, it isn't savvy to interface up billions of gadgets. Hence the utilization of RIFD tags (low control chips) that can convey remotely is by all accounts a decent option (Steinbach, Hirche, Ernst, Brandi, Chaudhari, Kammerl, & Vittorias, 2012). But there will be requests expanding accessibility of broadband web and remote systems administration support with low inertness. Such continuous emotionally supportive network is just conceivable by employing 5G.

Figure 5. Technological drivers (IoT, IoE pushing 5G towards Tactile Internet)



FUTURE RESEARCH DIRECTIONS (TACTILE INTERNET)

Till today the computer networks can transmit text, audio, and video data. Professor Gerhard Fettweis of Germany coined the term tactile internet to transmit something else via computer networks that is touch (feelings). Skill and labor can also be democratize by transmitting the touch. The factor that will be taken into account is the network delay.1ms delay is required for the action –reaction time to become negligible. The speed of light in the fiber is 200km/s. This speed is not enough to give us the delay of 1ms. We need the speed more than that to achieve the latency of 1ms. This can be done while breaking the laws of physics.

Human beings are checking and detecting a wide range of things, constantly. The response time of visual human framework to contact and move an article before eye with the goal that it appears to be genuine is less than 1ms.Furthermore, if this is done remotely the lag time which relies on human visual abilities is 1 millisecond. The gamers realize that 1ms counts. As the speed of light (300km/s) is moderate for gamers' perspective and speed of fiber optic link (200km/s) are much slower. To make this communication human, the idleness of a couple of milliseconds should be maintained. With 1ms inertness, our characteristic method for associating with the correspondence organize came into the picture (B. Bhattacharyya and S. Bhattacharya (2013). This organization is useful in exchanging the ranges of abilities, controlling a robot remotely and accurately. This will be cultivated when the arch is constrained by a versatile edge cloud, vehicle companies by furnishing a 10,000 wheel with the assistance of web cameras appended to each vehicle in the unit. And the camera is associated with GPS demonstrating worldwide picture of the street traffic to each article (autos) in the company, and there are quantities of uses for online administration checking. The above clarification depicts the vision of the material web. The material web utilizes human haptic sense to transmit contact continuously anytime on the planet earth and even in space.

This vision of tactile internet can be realized only through the 5G mobile network communication system. Using 5G cellular technological assumptions, billions of sensors can be made to work with very little energy. The idea of power and energy must be clear for these upcoming technologies. Energy is that which drains your battery and power gives the density of base station or its range. For systems connected with millions of sensors, the number of base stations needs to be increased, so we have to go for multi-hop networks which are practically not feasible. Hence star topology network like 5G cellular is required. Using 5G cellular technology, it is possible to design a system that can transmit at a very high power range and consumes very little energy. According to physics laws, this can be achieved by transmitting data packets very quickly at a very high rate (Fettweis, 2014). The upcoming 5G technology is ready to give us more than 25Gbps in the coming 10 years with a clear vision to use higher frequency bands, small cell sizes, improvement in the physical layer and designing the key modulation schemes. Moving into the high frequency with widening the spectrum and building more access points is the right strategy to go.

CONCLUSION

In this era, remote versatile correspondence assumes a fundamental job in data trade which requests rapid information exchanges, quick access to information, secure and solid system conventions that too at low expenses. Additionally, the capacity to associate in a flash and anyplace made them increasingly prevalent and fruitful. Nonetheless, the remote is not an ongoing innovation. Technological evolutions guided us that probably cellular technology comes out to be the right answer for 5G, IoT and tactile internet to take off. While working with other technologies there is a struggle for coverage, reliability, scalability, and liability. By using cellular it is possible to design a telecommunication system which can transmit at a very high power range and consumes very little energy. By 2020, 5G plans to give information rates up to 25Gbps, opens up the ways for large numbers of associated gadgets (Internet of things) conveying basic administrations (tactile internet) through haptic sensors. Haptic correspondence alludes to the manners by which individuals and creatures associate through the feeling of touch. In this manner, another codex is required to transmit muscle movement. Enormous volumes of information with haptic criticisms is gone through the single packet.

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KEY TERMS AND DEFINITIONS

Access Delay: The time between two consecutive allocations of resources to the same user.

Access Reliability: A reliable service is one that notifies the user if delivery fails.

End to End System: An application program or system will provide all the hardware and software components and resources to meet the customer's requirement no matter who is the supplier or vendor.

Fixed Internet: The Internet which is totally infrastructure based.

Haptic: The use of technology that stimulates the senses of touch and motion, especially to reproduce in remote operation or computer simulation the sensations that would be felt by a user interacting directly with physical objects.

Mobile Internet: The Internet is realized wirelessly anywhere, anytime.

Tactile Internet: The Internet through which instead of text, audio, and video data something else is transferred i.e. touch.

Things Internet: The Internet which transfers the data collected by sensors and actuators attached to the ends of the computer network.

Section 2

Fifth Generation Physical Layer

Chapter 2
Improvement for Channels With Multipath Fading (MF) Through the Methodology CBEDE

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ABSTRACT

The present study aims to implement a discrete event simulation (DES)-based model. This model is called coding of bits for entities by means of discrete events (CBEDE) and aims to improve the transmission of content in wireless telecommunication systems. This is done by applying advanced modulation format DQPSK in a simulation environment, the Simulink of the MATLAB software, through a pre-coding process of bits applying discrete events in the signal before of the modulation process, occurring in the discrete domain with the implementation of discrete entities in the process of bit generation applied at a low level of abstraction in a wireless telecommunication system. The results show improvements of 89.08% in memory utilization, related to information compression, in the context of the research. Therefore, the presented results of the proposed methodology show an enormous potential for the non-orthogonal multiple access (NOMA) contexts, credited as the future 5G, and can compensate for the additional complexity brought by the techniques to the telecommunications channel.

DOI: 10.4018/978-1-7998-1152-7.ch002

INTRODUCTION

Fading degrades the communication system performance due to a loss of signal power without decreasing the noise power over some or all the signal bandwidth. The probability of experiencing fading with the concomitant bit errors as the signal-to-noise ratio (SNR) drops on the channel limits the link performance. The adequate simulation of multipath fading channels is a fundamental issue in the development and evaluation of wireless systems. Since the received signal is contingent on several mutable factors, statistical models typically help to simulate fading (Curwen & Whalley, 2016).

Multipath fading (MF) affects most forms of radio communications links in one way or another. MF occurs in an environment where there is multipath propagation, and the paths change for some reason, resulting in propagating multiple versions of signals transmitted across different paths before they reach the receiver. The Rayleigh fading model is ideally suitable to typical scenarios include cellular telecommunications where there is a large number of reflections from buildings and the like and HF ionospheric communications where the uneven nature of the ionosphere means that the overall signal can arrive having taken many different paths (Yadav & Singh, 2018).

The discrete event mainly relates to the model representing the system as a sequence of operations performed on entities (transactions) of certain types such as data packets, bits, among others. These entities are discrete in a discrete event simulation. This technique is usually used to model concepts having a high level of abstraction, such as clients in a queue, emails on a server, flow of vehicles, transmission of data packets, and so forth (Campante et al., 2016).-

The modulation formats quadrature phase shift keying (QPSK) and DPSK are widely used in satellite broadcasting, in various cellular wireless standards such as GSM, CDMA, LTE, 802.16 fixed and mobile WiMAX, satellite as also cable tv applications, the DQPSK modulation is a particular form of QPSK modulation, in which instead of being sent a symbol corresponding to a pure phase parameter, this symbol represents a phase change.

Based on this, the present study aims to develop a model of information transmission based on discrete event concepts. This methodology aims to increase efficiency in sending and receiving data by reducing the consumption of time during this process. Next, we will discuss the technological concepts that involve the mobile transmission and that motivated the development of the Coding of Bits for Entities by means of Discrete Events (CBEDE) methodology presented in this chapter.

MOBILE TECHNOLOGY

The second generation of telephone technologies is called 2G (Second Generation) and this methodology was based on GSM technology. It is coming into operation around the 90s and allowed, mainly, the exchange of text messages and photos via SMS. Their focus was on voice connection, talk and be heard on the phone without the need to exist an internet connection. Subsequently, around the year 2006, the term 3G was created; and was responsible by the first cell phone technology that was born to bring fast internet to mobile phones. In its first wide-band code-division multiple access (WCDMA) standards, the maximum theoretical speed was 384 Kbits per second. In recent years, very little, but its first network appeared in 2002, where fixed broadband barely reached megabits. Another great bet of the 3G was the video calls through the cellular network, however, the service was not popularized due to the technology of the time (Curwen & Whalley, 2016; Yadav & Singh, 2018).

Technically, 3G works with the transmission of voice data (audios exchanged for mobile apps, for example) and internet services (website navigation, downloads, use of online applications, among others). This methodology was (and still is) very important to democratize Internet access in Brazil. If it is a mobile network, a 3G modem was the salvation for people who lived where there is no fixed broadband presence. It is responsible for popularizing mobile internet access in Brazil. With their development, companies began to commercialize modems that made fixed broadband access feasible for many Brazilians (Campante et al., 2016; Yadav & Singh, 2018).

The 4G network is already known by more than half of Brazilian cell phones, through LTE technology, it allows data traffic at speeds higher than 2G and 3G networks, as well as greater spectrum efficiency (more connected devices without damaging the network) and significantly lower latency than in previous generations. Its differential is that, in addition to being faster, there is the possibility that more people connect to it without losing quality in the signal. Another difference is that it prioritizes data traffic (audio, text, video, photo) on the internet, not just voice traffic. Data transmission operates in one frequency range at a time. It is important to note that in Brazil, 4G is synonymous of LTE (Long Term Evolution). In the United States, the operators chose to use the name 4G to designate high-speed packet access plus (HSPA+) networks, which in Brazil are known as 3G+ or 3G Plus. Where in the USA, the 4G is called 4G LTE (Campante et al., 2016, Yadav & Singh, 2018).

When LTE was created, there was no voice over the network. In order for the network to support connections, operators needed to adapt. There are two possibilities: one of them is to receive the connection, to demote the mobile device to the Groupe Special Mobile (GSM)/WCDMA network; the other possibility came a little later, with the creation of VoLTE (Voice over LTE), in which the phone normally works on the 4G network. It is the standard technology for the evolution of GSM / WCDMA networks and adopted by almost every country in the world. The main differential of LTE is the data network. In tests conducted, an experimental LTE network with 20 MHz spectrum reaches approximately 300 Mbps downstream and upstream 75 Mbps. However, the actual browsing speed is 100 Mb/s download and 50 Mb/s upload in a good scenario. The response time of the LTE is noticeably lower than what we know of 3G networks: under normal conditions, the latency of the network reaches a maximum of 30 ms (Paradisi et al., 2015).

Another difference is the number of users connected in the network: 5 MHz of the spectrum allows up to 200 simultaneous accesses. The LTE also allows maintaining the speed and latency when used in motion, at a speed of up to 350 km/h. Depending on the operating frequency of the network, this value rises to 500 km/h. The 4G+ is basically the 4G technology that we already know but with extra detail, the cell phone connects simultaneously to more than one frequency or range of the spectrum. The technology behind the 4G+ is called the LTE Advanced. In Brazil, the main frequencies used with 4G are 2,600 MHz (band 7) and 1,800 MHz (band 3), in addition to the recent 700 MHz (band 28) that are being gradually released with the analog TV signal disconnection. To use the 4G+, you must have a device compatible with LTE-Advanced and be in a coverage area with the technology (Paradisi et al., 2015; Ezhilarasan & Dinakaran, 2017).

5G

The 5G (Fifth generation mobile internet or Fifth generation wireless system) represents the future generation of mobile telecommunication. The 5G is the evolution of the current fourth-generation mobile network. It is a more powerful and fast network that, besides being "intelligent". It is about using the radio spectrum better and allowing more devices to access the mobile internet at the same time (Ezhilarasan & Dinakaran, 2017).

5G has already been studied to replace the 4G and have the next generation launched within the next 10 years, following the same pattern of evolution of previous generations. Where it has been developed to handle the growing volume of information exchanged daily by billions of devices connected and scattered around the world. That is, the idea is that a huge amount of different devices connect to these networks (Internet of Things), so more than speed, the 5G should offer low latency and stability, that is, more reliable connections. In theory, the speed of connections can reach 10 to 20 Gbps, but in practice, it should be considerably below that (Ribeiro, 2019, Agiwal et al., 2016).

The interest around the 5G by many technology companies has a reason that goes beyond faster downloads (where there are already tested networks reaching 20 Gb/s), but rather to account for a future in which trillions of devices will be permanently connected to the network, between drones, autonomous cars, lamps, coffee maker, refrigerator, among so many and anything else, the famous Internet of Things (IoT) As existing and pre-built networks are not designed and are not designed for such fully-connected environments, we have 2G that is designed for voice, 3G for data, and 4G for large data stream applications such as streaming music and video. So the 5G needs to be more efficient to handle not necessarily a huge amount of data, but a huge number of connected devices. The Internet has passed through the age of computers and people, and is currently being and will be even more "used" by objects, where they are designed and developed to understand our behavior, communicating with each other through the network, thereby facilitating our daily routine, automating even more our tasks and sometimes, in a safe and guaranteed way by making decisions (Ezhilarasan & Dinakaran, 2017; Li et al., 2018).

The 5G networks operate via radio waves, just like the mobile networks of previous generations, the spectrum covered by the fifth generation of mobile broadband is significantly larger than the previous ones. Expectations about 5G technology are about a data rate with power in the home of Gbps, being 10 to 100 times better than the 4G and 4.5G networks, a lower latency, in the case of 1 milliseconds, faster broadband per unit as well as a greater number of devices connected per unit area (compared to 4G LTE networks currently in operation), increased availability and coverage, as well as a reduction in network power consumption. The world is becoming mobile more and more and we consume more data each year, especially as the popularity of streaming video and music increases. Existing frequency bands are getting congested, leading to service failures, especially when many people in the same region try to access services online at the same time. The 5G is much more efficient at dealing simultaneously with thousands of devices ranging from smartphones to equipment sensors, video cameras and intelligent urban lighting (Ezhilarasan & Dinakaran, 2017; Medbo et al., 2016).

NOMA

Non-orthogonal multiple access (NOMA) schemes in recent years have received significant attention for the fifth generation (5G) cellular networks. One of the main reasons for adopting NOMA in 5G technology is its ability to serve multiple users using the same time and frequency resources. Its principle emerges as a solution to improve the spectral efficiency while also allows some scale of multiple access interference at receivers. In NOMA, each user operates in the same band and at the same time where all other users are, in that way they are distinguished by their power levels (Kassir et al., 2018).

There are two main NOMA techniques, they are (1) power-domain and (2) code-domain. Power-domain in NOMA attains multiplexing in the power domain, while code-domain in NOMA achieves multiplexing in the code domain. NOMA uses superposition coding at the transmitter such that the successive interference cancellation (SIC) receiver can separate the users both in the uplink and in the downlink channels (Islam et al., 2017).

NOMA dominates conventional orthogonal multiple access (OMA) in several aspects, as: (1) achieves superior spectral efficiency by serving multiple users at the same time and with the same frequency resource, and attended the existing interference; (2) increases the number of simultaneously served users, and thus, it can support massive connectivity within the system; (3) with respect to the simultaneous transmission nature, the user does not need to go through the scheduled slot to transmit its information, and because of this, it experiences lower latency; (4) NOMA can maintain user-fairness and diverse quality of service by flexible power control between the strong and weak users; in this way, offers higher cell-edge throughput and thus enhances the cell-edge user experience (Shirvanimoghaddam et al., 2017).

This methodology uses the power domain to separate signals from each other, thus giving a new dimension in which signals can be separated and given access to a base station. This technique has been used within 2G, 3G or 4G technologies before. As a promising 5G technique, NOMA has been shown to be compatible with other enabling techniques for 5G communications. For example, the heterogeneous network architecture will play an important role in 5G networks, where macro-base stations and small-cell base stations cooperate for spectrum sharing, an essential aspect today. The NOMA is beneficial for heterogeneous networks, the other users connected, can be served in a small cell by exploiting the fundamental principle of NOMA. Finally, these are the reasons that NOMA has recently been recognized as a promising multiple access technique to significantly improve even more the spectral efficiency of mobile communication networks (Shirvanimoghaddam et al., 2017; Kassir et al., 2018).

DISCRETE EVENTS AND ENTITIES

Discrete events (DES) is a tool capable of addressing a wide variety of communication problems and is mainly used to relate a model that represents a system as a sequence of operations performed on entities (transactions) of certain types, such as data packets, bits, among others. The discrete events are derived from the results of the actions taken in a system and can be classified as an occurrence responsible for the change in the state of the system in which they act, and can be of all types, where they are generally able to act producing state changes at random intervals of time, generating data and consequently the information. They can be seen as the solution to various problems related to the areas of communications.

This technique is often related to a system composed of sequential operations of entities (transactions) of several types of data, such as the bits. The DES is the result of actions taken in a system being its occurrence directly related to the state of the system that it acts, thus causing the generation of data and consequences of the information (Rubinstein & Melamed, 1998).

On the other hand, it is considered that an event exists at the instant in which a system changes state. The appearance of an event then triggers a certain sequence of actions in the system, which may or may not give rise to new events in the future. The temporal evolution of the state of any real system can be considered as the sum of partial behaviors of certain elements of that system, elements that are usually denominated by entities. Entities will be, for example, workers and devices in a factory, customers and patients in a clinic, and in general all elements that are likely to change state. These entities are discrete in a discrete event simulation. This technique has been used to model concepts with a high-level of abstraction, as patients, nurses, doctors, ranging from the exchange of emails on a server to transmission of data packets between devices connected in a network, also uses the queuing concept and can be used to manage people data and so forth, i.e., the entire extent of a communication system. The diversity of applications that the discrete events technique provides, showing its importance in several areas of knowledge, as well as in engineering (area of the proposal of this research), was remarkable, being able to apply it in a telecommunication system, more specifically in the transmission of data in a channel (Bouanan et al., 2018, Lee, 2011).

The meaning of the term entities is directly dependent on what is being modeled and the type of System employed. Thus, entities can be defined as discrete intensities in a simulation system. However, the terms entity and discrete events are distinct from each other, since discrete events are considered instantaneous discrete incidents that have the ability to change a variable from the state of another System. The entity terminology is related to what is being modeled (Cassandras & Lafortune, 2009, Dammasch & Horton, 2008).

Based on this, objects in a discrete event system are called entities. One of the objectives of a model with discrete events is to reproduce the activities of the entities that compose the system and, from there, to know the behavior and performance of the system. Thus, entities are the transactions or tasks that move along the system, generating a flow, which are the paths that the entity will go through the system. An event is a conceptual notation that denotes a state change in a system, i.e., the main characteristic of discrete events is to indicate that something has occurred (Cassandras & Lafortune, 2009, Dammasch & Horton, 2008).

Based on these concepts some authors have developed their work using discrete events and entities in 2011, electronic collaboration over the internet was studied among business partners. This study was performed through the exchange of messages that involve defined standards and through user-defined infrastructure patterns. At the same time, the notion of the event was increasingly promoted for asynchronous communication and coordination in SOA (Service Oriented Architecture) systems. This communication between partners or between components was carried out through the exchange of discrete units of data (messages or events) (Cassandras & Lafortune, 2009, Dammasch & Horton, 2008).

Also, in 2013, was studied real-time cloud information flow processing. At that time this concept was gaining significant attention because of its ability to extract large amounts of data for a variety of applications. In cloud-based real-time streaming applications, dynamic resource management mechanisms are required to support your operations. Thus, a performance-oriented approach to discrete event modeling with SimEvents was presented. This study aimed to identify the controllable properties of this communication structure (An & Gokhale, 2013).

In 2014, interference in LTE-Advanced systems was investigated. This system can be attenuated using coordinate multipoint techniques (CoMP) with the joint transmission of user data. Thus, the discrete event simulation was used to evaluate the latency requirements investigating the consequences of a backhaul contained. The results demonstrated a gain in system throughput compared to the case without CoMP for low latency backhaul (Artuso & Christiansen, 2014).

Yet in 2014, it has been seen that many researchers use discrete event simulation for call centers as a tool to improve resource planning and optimize services. The study investigated the use of discrete event simulation in a more complex system consisting of a multi-stage information technology service center (ITC). Customer orders went through several processes involving different types and levels of services (Deb et al., 2014). In 2016, a simulation model was presented to discrete events to analyze the processing of an e-mail server. The sending and receiving of messages were analyzed, taking into account the lead time of the messages (Rangel et al., 2016).

AWGN CHANNEL

A communications channel is characterized as being a means of connecting between a transmitter and a receiver. This communication may be wired or related to a logical connection in a multiplexed medium. An everyday example of a multiplexed medium is a radio channel and computers. A telecommunications system basically needs three components: (1) a transmitter responsible for sending information and subsequent conversion into a signal, (2) a transmission medium to carry this signal, and (3) a receiver receiving the same signal, and then convert it into useful information. Data transport typically uses two types of media: physical (twisted pair and fiber optic cable) and electromagnetic (microwave, satellite, radio, and infrared) (Bossert, 1999; Lakshmanan & Nikookar, 2006).

A widely used model applicable to a large set of physical channels is the Additive White Gaussian Noise (AWGN) channel model. This model has the characteristic of introducing a statistically modeled noise, such as a white Gaussian additive process, into the transmitted signals. The existence of disturbances/noise in the channel (free space/atmosphere) has multiple causes. One of them is the thermal noise by the virtue of the movement of the electrons in the electronic circuit used for transmission and reception of the signal. The AWGN channel models such as existing imperfections, naturally, in a communication channel (Barnela & Kumar, 2014).

MOBILE COMMUNICATION CHANNEL

The wireless mobile channel refers to wireless communication and devices that are based on radio frequencies, and where the communication path is mobile at both ends. The channel is modeled by a random attenuation (known as fading) of the transmitted signal, followed by additive noise. This type of channel is susceptible to several types of impediments such as: multipath, fading, shadowing, noise, among other interferences. In this way, these deficiencies can cause a huge degradation in system performance. The mobile communication channel may also be referred to as the Mobile Radio Communication Channel (MRCC) and is characterized according to its relationship to the variations suffered by the signal. These variations are classified into two types: large-scale variations and small-scale variations (Dalal, 2010; Ghassemlooy et al., 2017).

Variations in the received signal are only noticed when observed on a large scale, that is, when the signals travel long distances or long periods of time, so this type of variation is called large scale. In this way, the increment or decrement of the distance between the base unit and the mobile unit is called the long term. In turn, the variation is determined by loss in the course, is directly related to the distance and the frequency of its propagation, presenting linear variation, expressed in dB (decibels). The main effects of large-scale fading are signal power losses in free space and obstruction signal shadowing. The latter affects the signal, mainly due to the presence of irregularities in land, buildings, vehicles and the presence of trees during the course. Small-scale variations are also called short-term and fast-fading. These variations can be observed at distances of few wavelengths (Dalal, 2010; Ghassemlooy et al., 2017).

In cases where there is no line of sight, the behavior of fast fading is best represented by the Rayleigh distribution. The Rayleigh fading is an ideal model for large urban centers, as these areas have a large extension of buildings. The number of buildings is a quantity that is indirectly proportional to the quality of the signal transmission, because the larger the number of buildings, the greater the number of physical barriers to signal propagation, which leads to a decrease in the quality of information transmission. The distributions described above are used to better describe the level of the received signal. This signal, in turn, can be affected mainly by three factors: (1) a fading channel, (2) depending on its temporal variation, (3) and/or the amplitude of its individual multipath components. The wireless networks have their differential related to their physical layer, where during the transmission of data are used electromagnetic waves. These waves are propagated through space, where they suffer interferences such as reflection, dispersion, attenuation, etc. Thus, for this type of transmission, efficient modulation of carrier frequency data is required (Farjow et al., 2015, Shankar, 2017).

DPSK and PSK

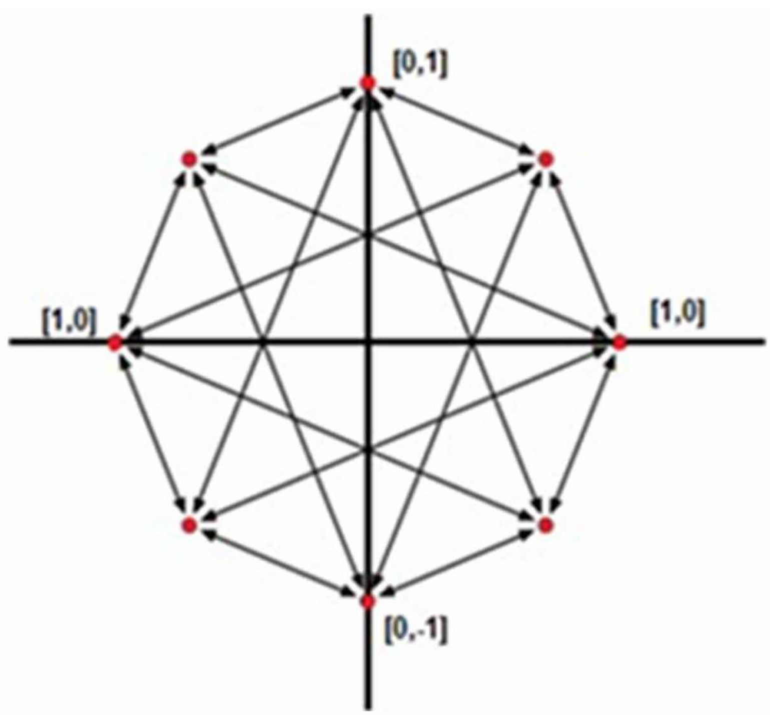
Differential Phase Shift Keying (DPSK) is a modulation scheme responsible for facilitating non-coherent demodulation. However, PSK (Phase Shift Keying) modulation generally requires only coherent demodulation. This coherent demodulation is related to the carrier, which is modulated to obtain the signal in the passband. In turn, this signal is reproduced at the receiver and subsequently used for demodulation in the passband to obtain the message. When the same carrier frequency as the transmitted signal is used, a noisy demodulated signal is generated, which results in a laborious process for the receiver to generate the received carrier. In the DPSK modulation, in turn, there is the modification of the transmissions so that each transmitted signal also depends on the previous one. Thus, the demodulation of the current signal is dependent on the signal received in the previous time period; and can be used as the local carrier. This equality leads to the cancellation of the signals, allowing their demodulation. Accordingly, the phase of that modulated signal is shifted relative to the phase element of the previous signal (Ling et al., 2017).

Differential Quadrature Phase Shift Keying (DQPSK) is a particular form of QPSK (Quadrature Phase Shift Keying) modulation. In this modulation, instead of being sent a symbol corresponding to a pure phase parameter, this symbol represents a phase variation. Already, in the QPSK modulation, the information is transmitted by the absolute phase of each symbol. In turn, in DQPSK modulations, each set of bits represented by a symbol causes a determined phase variation in the carrier signal. In the carrier, the respective bits for these data/symbols are determined based on the phase change of the previous symbol. The constellation has a function to analyze both signals transmitted by the models. In the case of the DQPSK constellation, there are 4 possible states 0, π, + π/2, -π/2, where each symbol represents two bits of information. The division of the binary pattern is equal to QPSK, except when a bit string is shifted to about π/4 or π/2. This means that there is a total of 8 status positions (compared to the 4 states for QPSK). This modulation is widely used in several airborne systems in association with other modulation techniques (Koike-Akino et al., 2008). Figure 1 shows the DQPSK constellation diagram for the displaced version π/4, as well as its constellation rotated by 45 ° from the previous point, as explained above. This modulation is widely used in several airborne systems in combination with other modulation techniques.

Methodology

The development of this methodology was performed in a computer with hardware configuration being an Intel Core i3 processor, containing two processing cores, Intel Hyper-Threading technology, and 4GB RAM. To provide enhancements in cloud environments, the present study implements a model CBEDE applied to a communication system, and advanced modulation format Differential Quadrature Phase Shift Keying (DQPSK) and with fading Rayleigh in a simulation environment, the Simulink simulation environment of the Matlab software, improving the transmission of data, through a pre-coding process of bits applying discrete events in the signal before of the modulation process.

Figure 1. Theoretical DQPSK constellation



The experiments were conducted through the Simulink tool, from Matlab (2014a). This simulation environment was chosen because it is already consolidated in the scientific medium, having a development and simulation environment already tested and validated. DQPSK modulation was chosen in this study, because are considered the most robust of modulation schemes in terms of noise immunity, is less immune to the interference, allowing the highest level of distortion in the signal being still successfully demodulated.

Four libraries were used: (1) Communications System ™, which is designed to design, simulate and analyze systems, being able to model dynamic communication systems; (2) the DSP System ™ that is capable of designing and simulating systems with signal processing; (3) Simulink®, which is a block diagram environment for multi-domain simulation, capable of supporting system-level projects for the modeling and simulation of telecommunication systems, and (4) the library SimEvents®, which is classified as a discrete event simulation mechanism and components to develop systems models oriented to specific events (Matlab, 2014). In this way, the proposed methodology is based on the development of an AWGN hybrid channel, characterized by the introduction of the discrete event technique in the bit generation process, focusing on bits 0 and 1.

In the proposed model, Figure 2, the signals corresponding to bits 0 and 1 will be generated and modulated with the advanced modulation format DQPSK, which will use the phase shift, coming from the modulation format itself. It will then proceed to an AWGN channel according to the parameters shown in Table 1. Also developed was a simulation model aimed at a wireless application, which will use a channel with Rayleigh fading. For this, the treatment of the bits will follow the logic presented in Figure 3 explaining the CBEDE methodology.

The proposed bit precoding was implemented through the discrete event methodology. Bit processing is understood as the discrete event methodology in the step of generating signal bits (information) to make it more appropriate for a specific application. The event-based signal is a signal susceptible to treatment by the SimEvents® library, and posteriorly passed by conversion to the specific format required for manipulation by the Simulink® library. Both time-based signals and event-based signals were in the time domain. This treatment had an emphasis on bits 1 and 0, which were generated as a discrete entity and followed the parameters as presented in Table 1. Then, Entity Sink® represents the end of the modeling of discrete events by SimEvents library. This tool is responsible for marking the specific point in which Entity Sink will be located, where later the event-based signal conversion will be performed for a time-based signal. This time-based signal was converted to a specific type that followed the desired output data parameter, an integer, the bit. By means of the Real-World Value (RWV) function, the actual

Figure 2. Traditional model of a telecommunication system

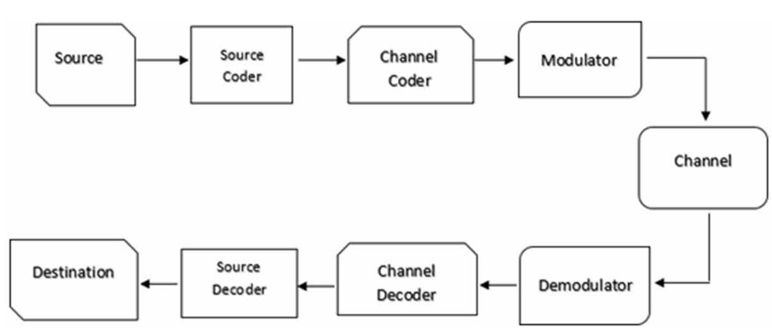


Figure 3. Proposed bit precoding

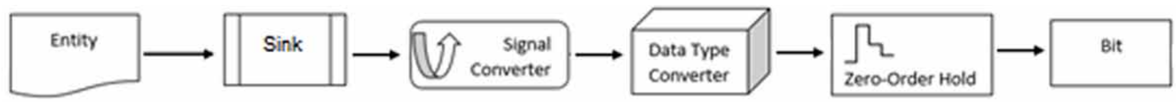


Table 1. Parameters channel models DQPSK Rayleigh

AWGN DQPSK Rayleigh	
Sample Time	1 sec
Simulation time	10000 sec
Eb/N0	0 a 25 dB
Symbol period	1 sec
Input signal power	1 watt
Initial seed in the generator	37
Initial seed on the channel	67

value of the input signal was preserved. Then a rounding was performed with the floor function. This function is responsible for rounding the values to the nearest smallest integer.

Also used to a Zero-Order Hold (ZOH) which is responsible for defining sampling in a practical sense, being used for discrete samples at regular intervals. The ZOH describe the effect of converting a signal to the time domain, causing its reconstruction and maintaining each sample value for a specific time interval. The treatment logic on bits 1 and 0 is shown in Figure 3.

Subsequently, the signal is modulated with the advanced modulation format DQPSK and passing through a Rayleigh fading channel, having multipath, with Jakes model having Doppler shift set at 0.01. It will also be employed a mathematical function 1/u, having importance for the modeling of mobile channels with fading and multipath. This function will be employed to track the channel time variability, where the receiver implementation usually incorporates an automatic gain control (AGC). It will then follow an AWGN channel, according to the same parameters specified in Table 1. The signal will be demodulated to evaluate the bit error rate (BER) of the channel.

The relative values of the BER are sent to the Matlab workspace in the name variable “yout1” to verify equality and generate the BER graph of the signal, as shown in Figure 4.

In the proposed model, Figure 2 and 4, the signals corresponding to bits 0 and 1 will be generated, respecting the rule and mathematical logic shown in Figure 5 below.

This rule and mathematical logic with respect to PSK M-ary numbers generate randomly distributed integers in the interval [0, M-1], where M is the definition for bit representation, following the nomenclature of the MATLAB software. Figure 6 shows the respective generation of the bits by means of this logic.

The models are shown in Figures 2 and 4 run with 10000 seconds of simulation and will respect the configuration defined according to Table 1.

The verification of equality of the signals is performed through the “size” and “isequal” functions of the Matlab software, as well as through the bit error rate (BER). These functions are responsible for the mathematical comparison proving that the signals have the same size and the same size. Together with the BER check, it will state that the same amount of information will be transmitted (bits) in both

Figure 4. Model of a Rayleigh telecommunication system with the proposal

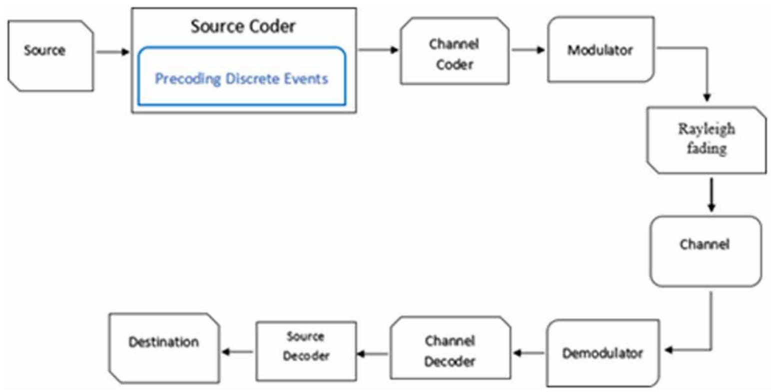


Figure 5. Generation M-ary numbers for bits 0 and 1

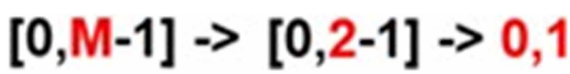
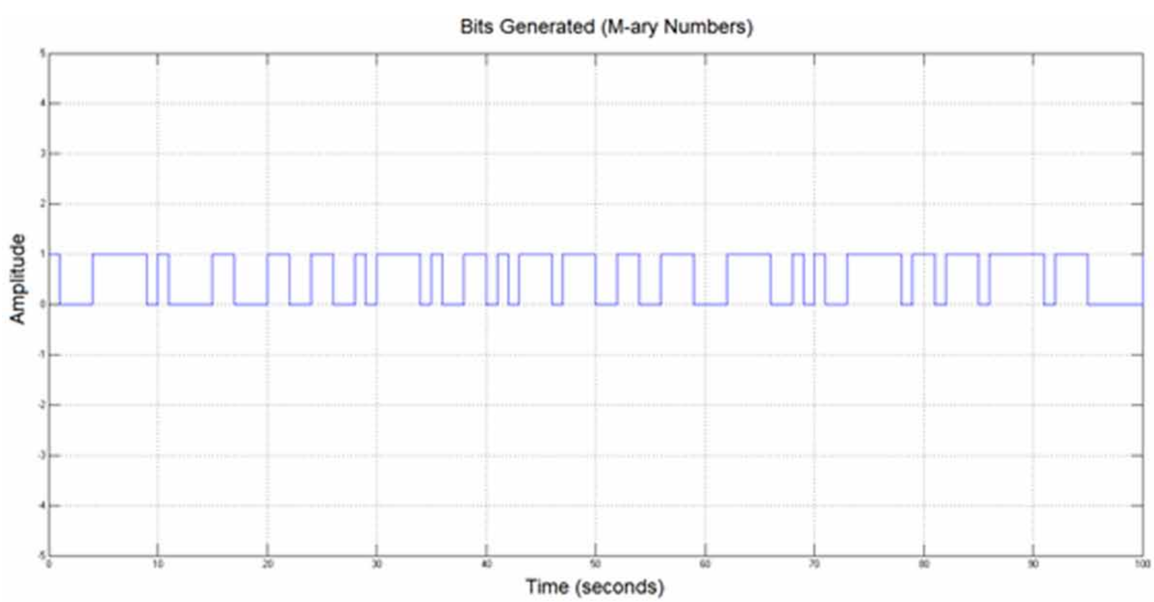


Figure 6. Traditional Model of a Telecommunication System



the proposed methodology (hybrid AWGN channel) and the conventional methodology (AWGN channel). Thus, if the signals are of the same size and size, the logical value 1 (true) is returned and the same volume of data is transmitted, indicating that the equality of the signals is true. Otherwise, the value will be 0 (false). This check will show that the submitted proposal does not add or remove information to the originally transmitted signal.

Results and Discussion

As discussed earlier an AWGN transmission channel was mutated into DQPSK. Thus, Figure 7 presents simultaneously two methodologies: The traditional and the methodology proposed in this study. It is possible to note that the flow and transmission of the signal (0 and 1) is generated and modulated in the DQPSK, later being passed through the AWGN channel. Figure 8 presents the constellations of 15 dB for both methodologies.

Both models were submitted to evaluations of memory consumption, being analyzed only the first simulation of each one of them. This is because it is in the first simulation in which all variables are allocated.

In this context, the memory calculation will come from the sldiagnostics function, where the variable "TotalMemory" is responsible for receiving the sum of all processes related to the memory consumption of the models from ProcessMemUsage. This parameter, along the simulation, measures the memory used in each process, showing the total in MB (megabyte). This parameter counting the amount of memory used in each process, throughout the simulation, returning the total in MB (megabyte) For this was used a

Figure 7. Transmission Flow for DQPSK Rayleigh

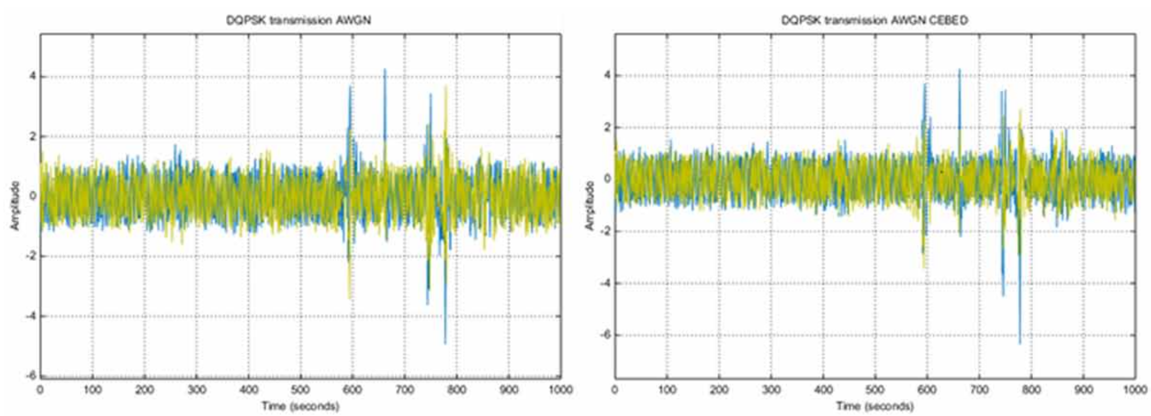
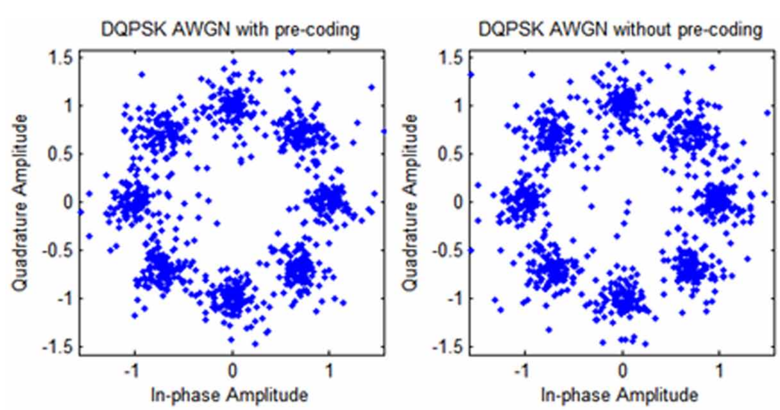


Figure 8. Simulated DQPSK Rayleigh Constellations



computer with hardware configuration being an Intel Core i3 processor, containing two processing cores, Intel Hyper-Threading Technology, and 4GB RAM. This machine relates the proposal to the dynamics of the real world and will affirm its efficiency and applicability.

For this, physical machines with hardware configuration were used, consisting of an Intel Core i3 processor and 4GB RAM, as previously discussed. The experiments were carried out through 7 simulations of each model developed in order to develop the analysis of this chapter, as shown in Figure 9.

The results obtained by the “size” and “isequal” functions, the DQPSK modulation were analyzed through its constellation, by means of the “compass” function, which will display a compass graph with n arrows, and how the constellations will be PSKs, their representations of points will be radial. This feature, the graph format has a compass shape, where n is the number of elements in Z. The location of the base of each arrow will be its origin. In turn, the location of the tip of each arrow will be determined by the real and imaginary components of Z, relative to the constellation of the signal. In the same way and with the same intention will be used the diagram of the constellation. In the Figure 10 is shown the comparative between a traditional methodology and the CBEDE methodology. In this context, the traditional methodology corresponds to a channel without discrete events. But improving signal transmission is as important a task as developing a new methodology, so respective amounts of memory consumption shown in Figure 9 are found previously are in Table 2.

To analyze the relationship between the simulation methodology (proposed x traditional method), and the impact on the physical layer of the channel, scripts were made in the MATLAB for processing of the graph BER. Figure 11 display the performance of the models during transmission with noise ranging from 0 to 25 dB.

This proposal brings a new approach to signal transmission. In this case, the transmission is performed in the discrete domain with the implementation of discrete entities in the bit generation process. Thus, information compression is a byproduct, since the proposal acts on the bits, having a substantial impact on the compression methods performed in higher layers (for example, format types such as HEVC, MPEG-4 AVC / H.264, JPG, PNG, among others) in a communication system, for example, affecting all the media information (data of examinations of the most varied types) that can be transmitted, resulting in a higher quality of both sending and receiving

Through this, it is possible to increase the capacity of the transmission of information through several types of telecommunications systems. By means of the methodologies used it is possible to notice that the technique of discrete events has great potential for treatment of bits in the generation phase, as

Table 2. Amounts of Memory Consumption

simulation	TRADITIONAL	PROPOSAL
1	55,5078	53,8242
2	54,6367	52,8320
3	54,0430	50,5117
4	58,1367	49,5078
5	57,0742	47,9258
6	67,9727	48,6133
7	85,3438	45,1367

Figure 9. First simulations (memory) model DQPSK Rayleigh

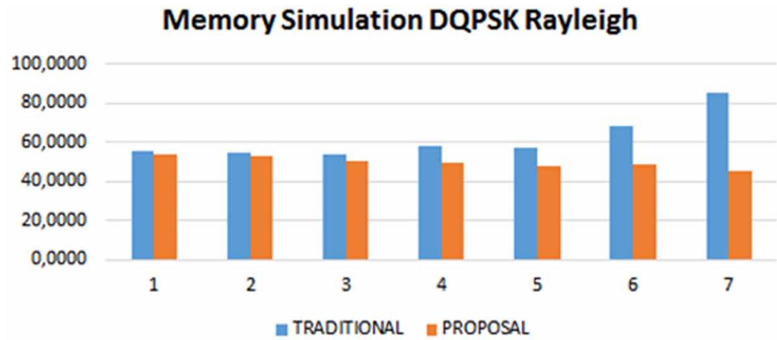


Figure 10. Vectors DQPSK Rayleigh

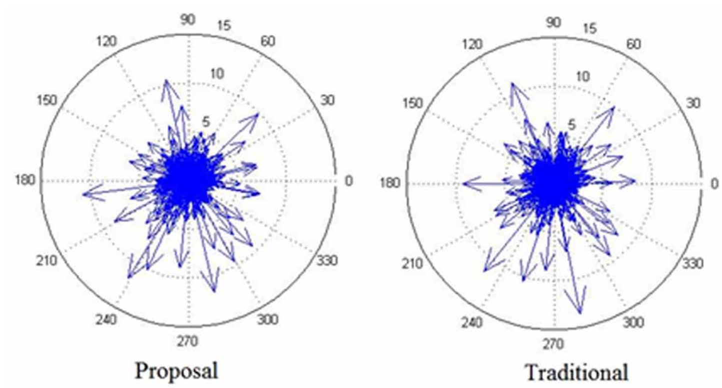
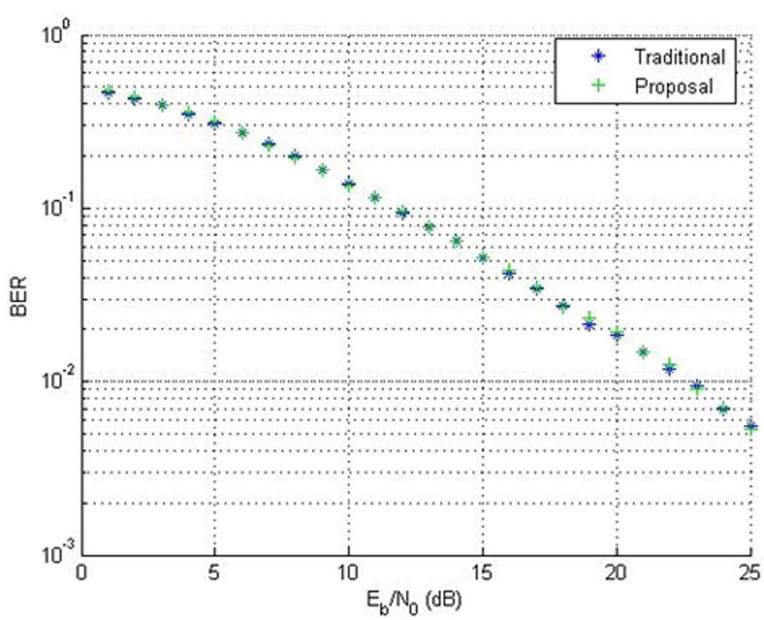


Figure11. BER between the models DQPSK Rayleigh



well as for their conversion into discrete entities. Generally, this process has a high level of abstraction. However, the CBEDE methodology acts on the physical layer and consequently presents a low level of abstraction, being also able to reduce the need for large computational resources, such as memory.

Considering that speed is a key issue when choosing a methodology, whether it is used by a user, companies or universities, the CBEDE methodology can be seen as a great allied. Today, memory is an issue of extreme importance both from the point of view of product/service developers and consumers/users, that consume less memory of the devices, in order to please the users as well as reduce costs by parts of the service providers. With the result reaching up to 89,08% in the improvement of memory consumption of the CBEDE methodology can be employed in this process, since the amount of data of the user greater is the concern with the speed of the transmission.

The slowness related to the speed of communication and the cloud technology implemented in the system structure used by these users, can often generate device crashes, inconvenience to the user and sometimes even loss of data, if these are in real time. When this happens, often the reliability of the services can be put to the test by the user. Thus, in order to break this bad impression and generate greater reliability, the CBEDE methodology can also be seen as a great ally. This is because the experiments demonstrate a lower reaching up to 89,08% memory consumption in data transmission, being better than the traditional methodologies, which do not require the use of discrete events.

FUTURE RESEARCH DIRECTIONS

Future work on the CBEDE methodology includes simulations on a wider variety of hardware, including Intel Dual Core Processor, Intel i5 Processor, Intel i7 Processor, as well as other. These physical platforms will be targeted for research as they are the most common on the market today.

In the same way that the proposal will be modeled and implemented in other communication systems in order to analyze its performance. In addition, testing of data transmission in systems optimized via mobile devices is expected due to its greater popularization in recent years.

CONCLUSION

The 5G is more than just a wireless upgrade. Its purpose is to unify the best in previous technologies. The expectation is that 5G satisfies the accelerated growth of devices on the network, especially all IoT (Internet of Things) devices, the expected increase in 5G performance compared to 4G LTE is very aggressive and really surprising, we are approaching the ambitious goals for its use of the real world.

The more wireless we become, the greater our fixed-line independence, and even considering that as data requirements in these mobile networks increase, it will be necessary to have a more and more dense as well as efficient and technological radio base station network. Nowadays, basically, everything that is being done is to build a solid-structure and solid-line network with wireless antennas hung at the far end of it for implementations of future technological innovations.

With this focus, this chapter shows a proposal for improvement with the differential of this research, the use of discrete events applied in the physical layer of a transmission medium, the bit itself, being this a low-level of abstraction, the results show better computational performance related to memory utilization related to the compression of the information, showing an improvement of 89,08%.

This demonstrates that the CBEDE has great potential in the improvement of the communication services for wireless environments and systems as well as a potential bet in 5G, being able to improve already existing processes to increase the performance of communication response between all the devices in the system, because the flow of data will consume fewer resources and, therefore, can improve the interactions between the users.

The objective of this research is in the use of discrete events being applied at the lowest level of abstraction possible within a communication system, as is done in bit generation, and as a result make the cloud environment more productive, faster and with better performance.

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Chapter 3
Review on 5G Millimeter-Wave Antennas:
MIMO Antennas

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ABSTRACT

Millimeter-wave antennas are the trend nowadays because of the necessity of higher data rates. Designing a supplementary efficient antenna capable of dealing with dual bands has several challenges. This chapter reports the problematic approaches introduced in the field of a millimeter wave design. Prevailing investigations in millimeter-waves and MIMO antennas have a tendency to emphasize discovering how to increase the data rate without the need of increasing the bandwidth and what type of antenna preferred in the 5G band. However, there is a little indication that researchers have come close to the issue of antenna integration in the mobile handset with the intent of adding multiple antennas with multi-band capability in a small space. Accordingly, the target of this chapter is to offer a summary of how the small-dimensional MIMO antennas with band duality for 5G mobile communications can be intended, designed, sustained and fabricated.

INTRODUCTION

5G antennas are still a new conception in the mobile applications industry and prevailing expectations about 5G antennas and MIMOs are associated generally with electronic devices with the limited space and with a minimized isolation. Weightless antennas to be synthesized with compact handheld devices are

DOI: 10.4018/978-1-7998-1152-7.ch003

used for modernistic mobile applications. Latest considerations and research in 5G antenna design field display the improved demands of emerging and designing antennas able to deal with the millimeter-wave frequencies with reduced size, graceful weight and inexpensive fabrication cost whereas keeping respectable efficiency, performance, and simplicity of installation. Traditional antenna elements comprising dipoles, monopoles, patches, and PIFAs are normally exploited in 5G and MIMO systems. Conversely, standing exploration gives narrow insight into when and why to use these or other applicant antenna forms (Landon, 2008). While market data was indicated that there is an intense variation in antennas demography and topologies.

This Chapter introduces almost of research activities in 5G mobile communication designs. First, a historical background about phased and AFSL constructions is reviewed. Second, the historical background of microstrip antennas is discussed. Finally, the fifth generation and MIMO systems for mobile communications are reviewed. To report the coupling and impedance concerns so fundamental to closely-spaced antennas on compacted platforms, both (Waldschmidt, Schulteis, & Wiesbeck, 2004) and (Wallace & Jensen, 2004) individually put forward system channel prototypes in S-parameter form (Pozar, 2009). Handheld schemes do not take the luxury of substantial inter-element spacing. Succeeding the diversity literature, one might use a consistent array with a more restrain spacing of 0.25 λ of 0.13 λ. Still, there is no convincing motivation to use a regular array particularly when handhelds are commonly not square and when antennas participate for space with different electronic components together with liquid crystal display LCD and a battery. Such restrictions may force a designer to use microstrip or ineffective, reduced antennas (Landon, 2008). Customary antennas achieve very poorly when subjected to arbitrary handset positioning.

BACKGROUND OF AIR-FILLED-SLOTTED-LOOP MIMO ANTENNAS

Allowing for the significance and role of cellular phones in the mobile network industry and production, mm-wave handsets antennas are considered as the movement shifting scheme for 5G networks. The use of a millimeter-wave transceivers with mobile phones offers great challenges which need to be awarded. Surrounded by the vital factors considered in the mm-wave networks establishing, the antenna designs necessitate broadly adjustments (Naqvi & Lim, 2018). Arrays thru multiple beams can be recognized at mm-wave frequencies utilizing analog or digital system architectures. This section review introduces the state of the art of phased and AFSL arrays in millimeter-wave mobile terminals (MSs). The phased and air-filled-slotted-loop AFSL arrays procedures have been very corporate in the design in warships and military jet aircraft and the defense area emphasis on phased array radars. These systems are recognized to remunerate for the path differences happened in free space. The path loss is condensed by using directional high gain antennas. The antennas with high directional gain are used at the transmitter as well as at the receiver, leading to greater SINR, and better data security, and maybe adopted in long-range millimeter-wave point to point (P2P) communications with LOS links.

Uniform spacing is reserved between consecutive elements of the antenna. The AFSL design involves different radiating elements with numerous types of array feeding constructions. To enhance the wireless communicating systems performance, advanced antenna arrays are adapted, with names of phased arrays (AFSL arrays), beamforming arrays, and multi-input-multi-output (MIMO) transceivers.

Certain designs recognize just two antennas on a small handheld or three on a larger handheld. In contrast, the design in (Browne, Manteghi, Fitz, & Rahmat-Samii, 2006) concludes four multi-band

PIFAs as close to the end of a small handheld as probable, with two antennas on the front and two antennas on the back of the mobile device. Though the design may lose power into the user's head and body, it is unexpectedly well-matched and uncoupled for its compact size. For an extremely millimeter-wave antenna practical design, we need to exploit inexpensive materials and mechanically and electrically robust that can be definitely adapted in printed circuit boards (PCB) technologies that allow a moderate spacing between antenna array elements. (Ojaroudiparchin, Shen, & Pedersen, 2015) designed and manufactured an air-filled-slotted-loop phased array antenna pointing for 5G mobile communications. The antenna was configured on an inexpensive FR-4 substrate to be functioned at 28 GHz. Ten elements of the slotted-loop antenna had been arranged to form a uniform linear array on the top region of the cellular handset PCB. The elements are parted by an amount of $\lambda/2$. So as to enlarge the antenna performance and minimize the effect of high losses in FR-4 material, the customary slot configuration of the resonators had been transformed to the air-filled-slotted-loop configuration. (Naqvi & Lim, 2018) introduced a review to indicate the newly introduced phased arrays for 5G access terminals. The effects of contact by the operator's body and human to electromagnetic-waves by these phased arrays with 3D coverage designed on a single-layer substrate and multilayer substrates were illustrated. Other concern often leads away from designs targeting the 28 GHz and 38 GHz bands. (Yashchyshyn et al., 2018) presented a switched 28 GHz five beams antenna built on rectangular waveguides and reconfigurable semiconductor circuits (RSC) with slots. The user's hand utilizes as a tough absorber which is expected to own damaging effects on the gain, radiation pattern and reflection coefficients of the antenna. Further than 9.5 dB decrease in gain is assessed using mathematical simulations when the user's hand completely involves the region of the 28 GHz antenna array (Hong, Baek, Lee, & Kim, 2014). Implementation of plural elements of antenna arrays in the 5G cellular device is used to relieve the possible performance danger initiated by the user's hand. An antenna conformation which assembles radiation characteristics similar to a fan beam was introduced in (Hong et al., 2014). The principal radiator configuration was made of electrically small pitches in an array of vias in the PCB. This allows an establishment of a mesh-grid surface that is in vertical coordination (along with the z-axis) by positioning the vias in a small-spaced periodic way. The intended patch antenna was applied with a ten layer of FR-4 substrate. The mesh grid patch involves a series of stacked vias applied through seven layers in the z-axis direction with a total height of h = 0.512 mm. The resonance frequency is attained by creating the grid length alongside the x-axis with L = 2.65 mm. A microstrip line positioned on the 5th layer beginning from the top directly feeds the patch, closely approximating an inductive probe feeding mechanism. The feed was located on the x-axis of $d_F = 1.1$ mm. The patch and the ground were spaced by $d_P = 0.35$ mm. The antenna and the RF circuitry were insulated by laying a metallic sheet on the 8^{th} layer of the PCB layer. To support beam steering in the azimuth direction, 16 elements were ultimately organized nearby alongside the edge areas.

MICROSTRIP ANTENNA THEORY

Microstrip patch antenna conception was initiated by G.A. Descamps in the year of 1953 but came into incidence in the 1970s when Robert E. Munson and more of researchers industrialized it using inexpensive substrates. These antennas are primarily adopted at microwave and millimeter-wave frequencies (above 1 GHz) (Mehta, 2015). In the preceding decades, printed antennas have been basically studied outstanding to their advantages over other radiating systems such as lightweight, reduced size, low cost, conformability and the easiness of combination with active devices.

Microstrip patch antennas have been broadly involved in a multitude of areas such as radio-frequency (RF) identification, mobile communication systems, local multipoint distribution systems, remote sensing, a global positioning system (GPS), a device to device communications, multiple-input-multiple-output (MIMO) systems, etc. (Bairavasubramanian, 2007). Microstrip antennas work as a transducer which can transmit or receive EM waves. On a top of a dielectric substance, the microstrip antenna is composed of the radiating strip with a ground plane on the opposite surface with a microstrip line feed as revealed in Figure 1 and Figure 2. The patch and ground plane are made of a conducting material such as copper, PEC or gold.

The substrates are dielectric materials and there are numerous categories of substrates that could be adopted in designing of microstrip antennas. The radiation from a patch is fundamentally created from the two edges along the resonating dimension which are corresponding to the two radiating apertures as explained in Figure 3. The two radiating apertures have a width of w and a height of h. A transmission line of length $\lambda_g / 2$ is used to separate the two apertures so as to the fields at the two slots aperture to

Figure 1. Arbitrary Patch Microstrip Antenna geometry

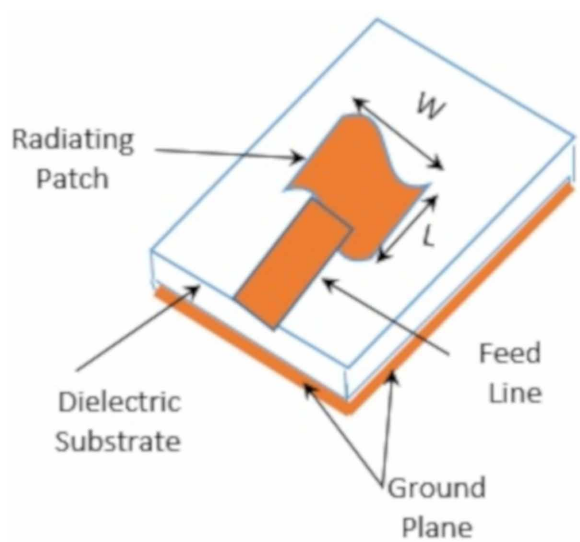
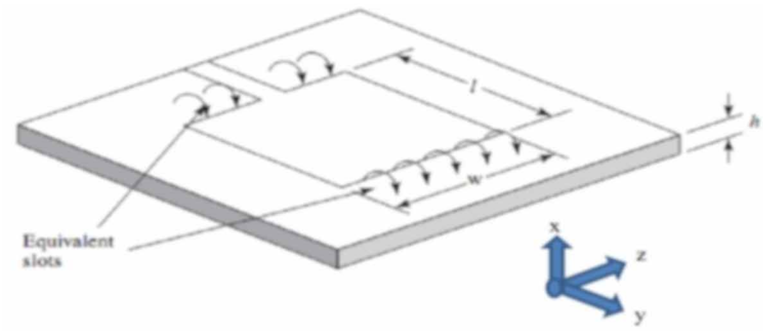


Figure 2. Arbitrary Patch Microstrip Antenna different Patch Shapes

Figure 3. Two equivalent slots generating rectangular patch radiation



have conflicting polarization. This will be equal to a two-element array with a spatial arrangement of λ_g / 2 between the elements. The fields created from these two apertures will be the same in a direction normal to the patch and be out of phase at a direction longitudinally positioned with the patch. Therefore, maximum radiation will be normal to the patch. Therefore, it is a broadside antenna (Balanis, 2005).

The substrate features comprise the dielectric constant and loss tangent tan δ. It is necessity be strong and has the endurance of the high temperature through the soldering procedure and impervious to chemicals that used in the fabrication process. A substance with small dielectric constant values is helpful in increasing the fringing field at the patch. This accounts for superior radiation power. The antenna efficiency is reduced in the high loss tangent tan δ material by intensifying the dielectric loss (Garg, Bhartia, Bahl, & Ittipiboon, 2001).

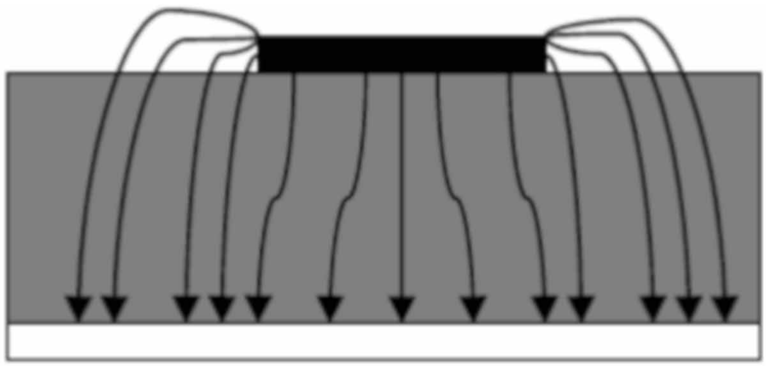
MICROSTRIP ANTENNA DESIGN

Thickness (h) and permittivity (ε_r) of the substance are the parameters to define the electrical characteristic of an antenna. Their dielectric constants are typically $2.2 \leq \varepsilon_r \leq 12$ in range. The variety of thickness is typically $0.003\ \lambda_0 \leq h \leq 0.05\ \lambda_0$. Usually, thicker substrates with a lower dielectric constant will raise efficiency and bandwidth but it will be the source of the surface waves to spread and spurious coupling will come to pass. While the thinner substrate is perfect for microwave application since they necessitate strongly bound fields to reduce undesired radiation and coupling. Consequently, in most designs, the material with minimized dielectric constant and very low loss tangent is the best.

The radiating patch of the microstrip antenna is a highly delicate patch of $t << \lambda_0$. The patch width and length are predetermined as the two critical parameters in designing a microstrip antenna. The patch length ($0.3333\ \lambda_0 \leq L \leq 0.5\ \lambda_0$) acts as a significant part in deciding the resonating frequency f_0 of it. When the microstrip antenna is operating at its fundamental mode, patch length is smaller than one half guided wavelength (λ_g) as the fringing field revealed in Figure 4 adds additional electrical length to the patch. The patch width and length are calculated from the next equations (2.1) to (2.5).

The radiating patch width W (Balanis, 2005; Carver & Mink, 1981) is given as:

Figure 4. Fringing field lines



$$W = \frac{c\sqrt{\frac{2}{\varepsilon r + 1}}}{2f} \tag{1}$$

The patch length L is given as:

$$L = \text{Leff - } 2\Delta L \tag{2}$$

where the effective length L_{eff} is given as:

$$\text{Leff} = \frac{c}{2f\sqrt{\varepsilon \text{eff}}} \tag{3}$$

and ε_{eff} is the substrate effective permittivity and is given as:

$$\varepsilon\text{eff} = \frac{\varepsilon r + 1}{2} + \frac{\varepsilon r - 1}{2\sqrt{\left(1 + \frac{12h}{W}\right)}} \tag{4}$$

The microstrip antenna radiates by the fringing field. Where the fields are not restricted to the patch, but a small fraction of the fields is radiated outside the patch dynamic lengths. This fringing field accounts for the effective length and dielectric constant. This leads the patch length to be greater than its dynamic length.

The value of this normalized length extension ΔL is given as:

$$\Delta L = 0.412h \frac{(\varepsilon \text{eff} + 0.3)\left(\frac{\text{W}}{h} + 0.264\right)}{(\varepsilon \text{eff} - 0.258)\left(\frac{\text{W}}{h} + 0.8\right)} \tag{5}$$

It is perceived from these given equations that for a specified frequency, the patch length is reliant on the dielectric substrate permittivity and height.

Hence, the three crucial considerations to design a microstrip patch antenna are:

1. The resonating frequency f_0.
2. The substrate dielectric material ε_r.
3. The effective length L_{eff}.

FEEDING TECHNIQUES

- Microstrip patch antennas are fed by different methods:
    - Contacting methods.
    - Non-contacting methods.
        - In the contacting methods, the patch is fed straight with RF power using a relating element which is a microstrip line.
        - In the non-contacting method, between both the patch and the microstrip line, the power is transmitted through EM coupling.
- There are four feeding techniques used:
    - Microstrip line.
    - Coaxial probe.
    - Aperture coupling.
    - Proximity coupling.

In our design, we use Inset Line Feeding as exposed in Figure 5. Previously in the microstrip feed line, the patch was fed at its end and has high input impedance. Because the current is low at the half-wave ends and increases in magnitude near the center, the input impedance is minimized provided that the patch was fed adjacent to the center. But it has a disadvantage: if the substrate thickness (h) rise, surface waves and pretended feed radiations increase which confines the bandwidth.

ADVANTAGES AND DISADVANTAGES OF MICROSTRIP ANTENNAS

The reputation of microstrip antennas is increased for the use in wireless applications outstanding to their moderate configurations and their advantages. Consequently, they are enormously compatible to be implanted antennas in handheld devices similarly cellular phones.

Some of their Dominant Advantages Are

Figure 5. Inset feed microstrip line

- Inexpensive fabrication
- Weightless and low volume
- Moderate conformation
- Can be modestly incorporated with other integrated circuits
- Talented to afford dual and triple-band frequency operations
- Robust when attached on rigid surfaces

But they suffer from a number of disadvantages:

- Narrow bandwidth.
- Low gain and efficiency.
- Surface wave excitation.

These disadvantages can be enhanced such as:

- Narrow bandwidths can be condensed by increasing the substance thickness.
- Low gains and efficiencies can be increased by using an array of elements.
- Surface waves can be diminished by the use of photonic bandgap structures.

ANTENNA MEASUREMENT

It is required to define an antenna characterization to decide if it is appropriate to an application or not. The antennas are measured for their parameters and radiation patterns. Such parameters are the measurement of S- parameters (Scattering parameters) like impedance matching and insulation within two antenna ports. For a multiport antenna array, at a time two ports are measured by Anritsu ZVA 67 with the remaining ports matching are terminated. Radiation pattern consists of measurement of gain, directivity, efficiency, and axial ratio. The far-field radiation pattern determination is through measuring absolute antenna gain established on the Friis transmission prescription (Balanis, 2005).

APPLICATIONS OF MICROSTRIP ANTENNAS

The microstrip antennas are popular outstanding to their performance. Microstrip antennas have many applications in many fields (Barrett, 1984; Howe, 1984) such as:

- Biomedical fields
- Rockets
- Satellite
- Military system
- Aircrafts missiles
- Radar applications
- Mobile communications
- Radiofrequency identification (RFID)
- Global positioning system applications (GPS)

5G TECHNOLOGY

The technology raises from the first generation, recognized as 1G, 2G, 3G, 4G, and momentarily to be comprehended to 5G. The first-generation (1G) communications introduced analog mobile signal as a phone call. The second-generation (2G) communications bought to send or receive the text messages. The third-generation (3G) communications introduced the internet. The fourth-generation (4G) focused on the internet of data, making all those services of a web (GPS, videos, and audios) come alive. Millimeter waves are investigated as the solution of current 4G shortage in data rates, by utilizing the underutilized frequency range from 3 to 300 GHz (Henderson, 2017).

WHY 5G?

The movement nowadays is to transfer to the fifth-generation (5G). There are predictable developments in many applications, for instance, health care, Internet of Things (IoT), telecommunication field, and military. The attention in 5G is on the internet of data comparable to 4G. The importance of 5G is its collaboration with other technologies like MIMO, digital beamforming, and beam steering to offer lower latency and faster data rates. Wireless communications have witnessed violent progress over the preceding years and are now heading in the track of implementing 5G for its features promised. Efforts by researchers are dedicated to studying the 5G spectrum and developing new antennas. Commercialization of 5G is widespread when it is made more economical. Figure 6 demonstrates an indication of things that 5G can accomplish.

Federal Communications Commission (FCC) released 5G frequency bands (Lerude, 2016) as follows:

1. 27.5 GHz to 28.35 GHz
2. 37 GHz to 38.6 GHz
3. 38.6 GHz to 40 GHz
4. 71 GHz to 76 GHz and 81 GHz to 86 GHz (E-band)

Figure 6. 5G communications system overview (TV, 2016)

Also, FCC is working to provide access to frequency spectrums up to 95 GHz.

The area rate will be 1000 folded times larger than that of the existing 4G network. The edge rate will be at minimum 100 Mbps to as much as 1 Gbps in relative estimation to the 4G standard of 1 Mbps. Recent capacity marks explain that the impending mm-Wave cellular networks may use 1 or 2 GHz channels, as an alternative of LTE 40 MHz channel bandwidth. The 5G technology will complete the 4G and delivers clarifications to the lack delivered from 4G for instance restricted bandwidth and speed (Rappaport, Heath, Daniels, & Murdock, 2014). This is because of the enormous growth in the number of mobile devices.

BANDWIDTH AND CHANNEL CAPACITY

Bandwidth is the band of frequencies in which an antenna can transmit and receive electromagnetic signal correctly. Impedance bandwidth is determined by reflection coefficient (Γ) to be fewer than -10 dB, denotes to the antenna impedance to be matched, which consequences in the electromagnetic radiation of 90% of the transferred power to the antenna. Impedance bandwidth is slightly smaller than radiation bandwidth. Antenna bandwidth is indexed in denominations of fractional bandwidth, which is the ratio of the difference between highest and lowest frequencies to the center frequency (Zucchelli, 2016). 5G provides large bandwidth in denominations of GHz depending on the spectrum of interest. Shannon's channel capacity expresses the amount of data that can be transferred through a wireless channel and is conveyed in denominations of bits per Hertz (b/Hz) (Shannon, 1948).

$$C = B * n * \log_2\left(1 + \frac{S}{N}\right) \tag{6}$$

where C is the channel capacity in b/Hz, B is the frequency bandwidth in Hz, n is the number of antennas used in a MIMO system, and S/N is the signal strength relative to the noise strength named as Signal to Noise Ratio (SNR).

FRIIS TRANSMISSION EQUATION

With respect to far-field communications, Friis Transmission Equation links the received power with the transmitted power between two antennas disjointed by a distance d and is specified in dB (Balanis, 2005)

$$Gt\left|d_B + G_r\right| \mathrm{d}2 = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right) + 10\log_{10}\left(\frac{P_r}{Pt}\right) \tag{7}$$

where G_t and G_r are the values of absolute gain of transmitting and receiving antennas, respectively, P_t is the transmitting antenna input power and P_r is the power delivered to the receiver load, d is the extreme dimension between the transmitting and receiving antennas and λ is the operating wavelength.

Propagation of the radiofrequency waves through free space faces attenuation of the wave which is inevitable. According to the path loss equation (Balanis, 2005), attenuation at millimeter-waves is high and at microwave frequencies used in 4G communications is low. While occupied with that, obstructions, for example, high outbuildings and trees in civil locations attenuate millimeter waves. Therefore, 5G communications have to implement a number of base station units called small cell (Nordrum, 2017). Appropriate massive MIMO array antennas are needed to be deployed in tiny cells so as to realize adequate gains to ensure the fidelity of the link between a small cell and a user.

COMMUNICATION SYSTEMS CLASSIFICATION

The communication system is categorized derived from the total number of transmitting and receiving antennas. If T is the antennas number at the transmitter and R is the antennas number at the receiver, the communication schemes are labeled as follows:

1. Single-Input-Single-Output (SISO), where T = R = 1.
2. Single-Input-Multiple-Output (SIMO), where T = 1 and R >1.
3. Multiple-Input-Single-Output (MISO), where T >1 and R = 1.
4. Multiple-Input-Multiple-Output (MIMO), where T > 1 and R > 1.

MULTIPLE-INPUT-MULTIPLE-OUTPUT (MIMO) SYSTEMS

MIMO systems are adapted to expand the coverage and the wireless communication range through the array gain. Interference must be reduced which improves the Signal to Noise Ratio (SNR), also to enhance the capacity through the spatial multiplexing and enlarge the quality and reliability of the reception through the spatial diversity. One of the significant characteristics that decide SNR is the channel between the transmitter and the receiver. Figure 7 reveals the MIMO system involving a transmitter (T_x) prepared with M antennas and a receiver (R_x) with N antennas (Almelah, 2017).

Applying MIMO and massive MIMO technologies is one of the crucial approaches to maximize the data rates and enhance the performance for succeeding generation. MIMO technology provides multiple replicas of data to be transmitted simultaneously through multiple antennas. This technology provides a remarkable potential in maximizing network capacity and saving energy to satisfy the accumulative command for wireless facilities compared with SISO systems without the need for increasing the bandwidth of transmitted power. However, as a consequence of distinct propagation paths by a user from separate spread antennas, each path is exposed to an independent and various degree of fading effects (i.e., path loss). The important features specifically in MIMO systems is the spatial diversity or transmitting diversity that ensures link fidelity by transmitting the identical quantity of data through numerous independent and diverse channels (Mathuranathan, 2014). The number of independent channels is dependent on the number of antennas at the transmitter and receiver.

Multiple-Input-Multiple-Output (MIMO) antenna systems, are deliberated for instance one of the operative ways for accumulating the channel capacity, improving reliability and a concurrent increase in the range all without overwhelming extra radio frequency (Najam, Duroc, & Tedjini, 2012). Multiple Input Multiple Output MIMO technologies with a higher volume of data rates and respectable radiated efficiencies is the significant challenge in present 4G and approaching 5G wireless mobile communication systems. By increasing the number of radiators (antenna elements) at the transmitter and the receiver margins, there is an unlimited enhancement in data rate and capacity (Babu & Anuradha, 2018). For the previous few years, millimeter-wave frequency bands have been dealt with and under concentrating by the research communities around the whole world that make it be promising strong candidates for the subsequent generation mobile communication (Ashraf, Haraz, Ali, Ashraf, & Alshebili, 2016).

One of the principal challenges that in front of MIMO antenna designs is the difficulty to incorporate multi-antennas closely in a small space and compact mobile handset while keeping good isolation within the antenna elements since the antennas couple intensely to one another and the ground plane by sharing the surface currents on them (Yang, Li, & Yan, 2015) as visible in Figure 8. The term "Mutual Coupling" is denoted to the coupling occurred within antenna elements. Mutual coupling is produced

Figure 7. MIMO system architecture

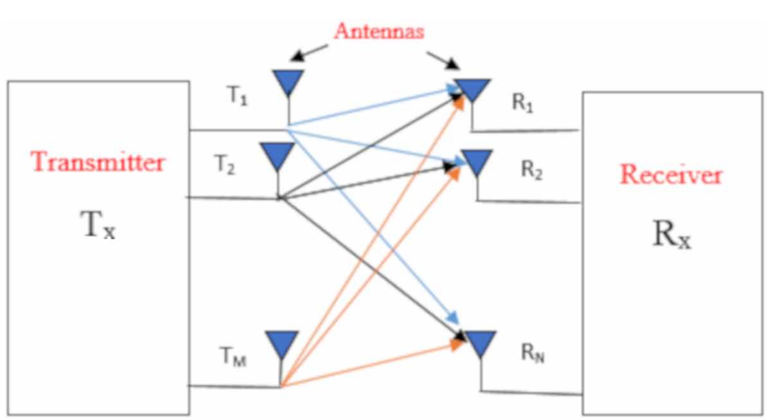
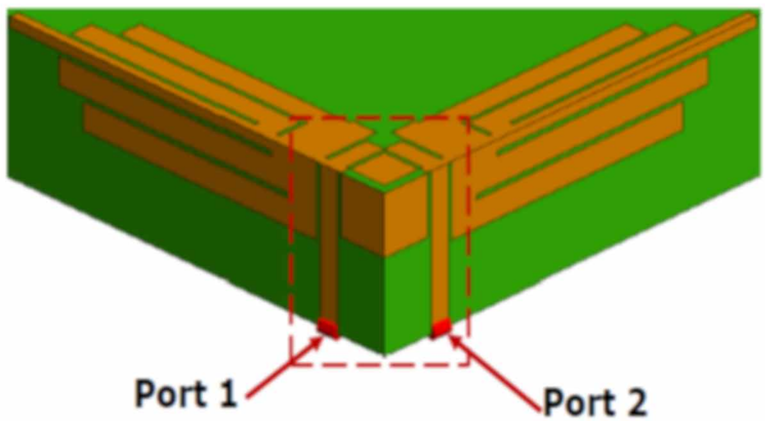


Figure 8. Example of mobile handset antenna in close proximity



from the interaction between antenna elements. Its effect is considered grand and grave provided that the element spacing distance is small. When coupling occurred within the antenna elements, there would be a detrimental effect on radiation patterns, impedance matching and isolation between ports (Fletcher, Dean, & Nix, 2003).

The coupling between the signals is contingent not only on the propagation situation (e.g. multipath effect owed to the reflection and diffraction of outdoor buildings or indoor partitions) but also on the coupling between antennas elements (Djordjevic, 2018). An unusual degree of antenna coupling would introduce signal correlation within the channels. It will also diminish the antenna radiation efficiency outstanding to the loss of the power consumed in the coupled antenna ports (Chen, Wang, & Chun, 2008). One common solution to resolve the coupling issue is by expanding the antenna spacing. However, this spacing is generally limited, particularly for a mobile termination which has very constrained volume for the antennas. The further approach to diminish the correlation is by using numerous antennas with dissimilar radiation patterns. It is better to have the patterns corresponding to each other in space, so as to receive a multipath signal from various directions (Derneryd, Fridén, Persson, & Stjernman, 2009).

The millimeter waves at higher frequencies undergo the atmospheric absorption and path loss. Designing exceedingly gain antennas with compact size are a challenge and a promising technique (Sulyman et al., 2014). Generally, for new RF designs, the antenna elements must have the properties of a moderate profile, inexpensive, dual or multi-band procedures, simple planar designs, and squeezed size. The antennas are an imperative portion of any wireless system. Rendering to the IEEE regularity explanation of antenna terminology, the antenna is distinguished as “a method for transmitting and receiving radio waves” (Yazdandoost & Kohno, 2004). In the advanced wireless systems, an antenna is frequently obligatory for the radiation energy to be accentuated and optimized in approximate directions and destroyed in others at certain frequencies. The decent design of the antenna can comfort system supplies and progress inclusive system performance. There are numerous regularly used parameters, embracing impedance bandwidth, radiation pattern, directivity, gain, efficiency, and polarization to designate the antenna performance (Balanis, 2005).

In SISO systems, individual contributions are summarized in scalar factors of the Friis equation, which accurately summarizes their relationship. In contrast, there is no simple and accurate "MIMO Friis equation" to compute tradeoffs in a scalar MIMO capacity budget. Simulations and measurements generally approach the coupled MIMO arrays formulations by 'converting each knob' one at a time to explore efficiency, correlation or matching in isolation (Landon, 2008).

ENVELOPE CORRELATION COEFFICIENT (ECC)

Envelope Correlation Coefficient (ECC) is a measure of the isolation within various MIMO antenna channels and the correlation between received signals at the same side of a wireless link (Sharawi, 2014). For a moral spatial diversity or spatial multiplexing feature for any MIMO system, there should be a least or no correlation (maybe named as uncorrelated) within radiation patterns of several antennas in array design and no cross-interference occurs. ECC is adopted to estimate the diversity capability in a multi-antenna system, in which minimum ECC rate signifies greater isolation and larger diversity gain.

ECC can be premeditated in two ways:

1. Created from the far-field three dimensional (3D) radiation patterns
2. Using S-parameters of the array.

For ECC (ρ) based on far-field (Sharawi, 2014):

$$\mathrm{ECC}\left(\rho\right)=\frac{\int\int_{4}\pi E_{1}\left(\theta,D\right).E_{2}^{*}\left(\theta,D\right)d\Omega}{\sqrt{\left(\int\int_{4}\pi E_{1}\left(\theta,D\right).E_{1}^{*}\left(\theta,D\right)d\Omega.\int\int_{4}\pi E_{2}\left(\theta,D\right).E_{2}^{*}\left(\theta,D\right)d\Omega\right)}} \tag{8}$$

where, $E1\,(\theta, \varnothing)$ and $E2\,(_{\theta}, \varnothing)$: the far-field radiation patterns of antennas 1 and 2, Ω is the solid angle of the radiation sphere.

For ECC (ρ) established on S-parameters (Sharawi, 2014):

$$ECC\left(\rho\right)=\frac{\left|S_{11}*S_{12}+S_{21}*S_{22}\right|^{2}}{\left(1-\left|S_{11}\right|^{2}-\left|S_{21}\right|^{2}\right)\left(1-\left|S_{22}\right|^{2}-\left|S_{12}\right|^{2}\right)} \tag{9}$$

where $S11$ $_{a}$nd $S22$ $_{ar}$e the reflection coefficients of an antenna at ports 1 and 2, respectively. $S12$ a$_{nd}$ $S21$ ar$_{e}$ the mutual coupling coefficients through antennas 1 and 2 in forward and backward directions, respectively. S-parameters based ECC provides a simplified estimation, yet powerful. They can be used only when the antenna in the examination is being highly efficient. As this computation involves circuit parameters, the ECC value obtained will be too small. ρ should be less than 0.5 for good MIMO operations. Besides, this advances to an increase in isolation.

MIMO increases the data rate of the communication systems by means of diversity and spatial multiplexing. This is done by transmitting a set of data independently through different channels (from different antennas) between the transmitter and the receiver (Mathuranathan, 2014) as displayed in Figure

7. This confirms increasing the communication system bit rate which is comparable to the Orthogonal Frequency Division Multiplexing (OFDM) technique, in which different frequency is separated to sub-channels that convey various parts of data. The transmitter and receiver have a number of antennas that decides the number of independent channels which decides the system diversity. Diversity is specified by (Mathuranathan, 2014) as:

$$\text{Div}ersity = T \times \text{R} \tag{10}$$

where T *i*s the transmitting antennas number, and R *i*s the receiving antennas number. For 2 × 2 MIMO system, diversity is 4 and multiplexing gain is 2. Diversity and spatial multiplexing create multipath propagation (multiple copies of the same data with various altitudes of fading). Thus ensure, at the minimum, one of the copied data is reduced the amount of fading to ensure fidelity in the communication link. Hence, diversity is achieved with no additional expense.

LITERATURE REVIEW FOR MICROSTRIP ANTENNAS AND MIMO APPLICATIONS

Multiple-input-multiple-output (MIMO) systems continue to have considerable attention in the literature because they promise significantly higher channel capacity than single-input-single-output (SISO) architectures. (Yang et al., 2018) projected a millimeter-wave massive MIMO with digital beamforming (DBF) structural design functioned at 28 GHz. The transceiver had a (16 × 4) 64 element antenna configurations. A printed Yagi-Uda antenna element with microstrip balun assemblies was chosen to be the radiating element in the transceiver design. (Jiang, Chen, Zhang, Hong, & Xuan, 2017) introduced a new architecture for beamforming and multi-beam massive MIMO systems using a metamaterial constructed slight planar lens antenna. A seven-element array of SIW fed stacked patch antenna at 28 GHz was placed at the focal region behind the electromagnetic lens. Compact antenna volumes can appear to be the natural domain for electrically small antennas, offering an antenna with minimum size volume to target. However, although certain fundamental limits have been determined for electrically small antennas. (Imran, 2018) designed a microstrip patch antenna and an array of 4 elements. The microstrip antenna offered dual bands of 38 GHz and 54 GHz frequencies and the array offered three bands 38.6 GHz, 47.7 GHz, and 54 GHz frequencies. The array was made of Rogers RT 5880 substrate with dielectric constant 2.2 and loss tangent of 0.0013 and standard thickness 0.508 mm with PEC patch and ground plane. The substrate dimensions were 6 mm × 6.25 mm and the patch with dimensions 2 mm × 2 mm. Microstrip feeding line technique was used. An array having 4 elements with 4 mm spacing had been used.

Other common compact antennas include (I. F. da Costa, 2017) that developed a dual-band (24.7 - 32.2 GHz and 35.5 - 39.1 GHz) slotted waveguide antenna array for 5G networks. The antenna configuration was constructed with two collections of radiating slots that were milled into the conflicting surfaces of the waveguide to enable antenna operation in two frequency bands. Microstrip antennas are the greatest widespread designs for their small total volume and low profile. The work in (Jandi, Gharnati, & Said, 2017) existed the proposal of a patch antenna at 10.15 GHz and 28 GHz. Its configuration was of 19 × 19 × 0.787 mm^3 including the ground plane. A lot of patch antenna designs are available but are not equally suited to accommodate the desires of a handheld device in (Dellaoui, 2017) that introduced a patch array antenna operating at three bands of 25 GHz, 28 GHz, and 38 GHz for the next 5G cellular communications. The introduced array composed of two patches fed by a 1-to-2 Wilkinson power divider. An Electromagnetic Band Gap (EBG) superstrate dielectric layer was employed over the array antenna for auxiliary gain improvement. (Ur-Rehman, Adekanye, & Chattha, 2018) presented the design of tri-band slotted patch antenna functions at 28 GHz, 38 GHz, and 61 GHz for coming Body Centric applications. The introduced antenna had an overall size of 5.1 mm × 5 mm × 0.254 mm in a single layer, slotted patch structure with L- and F- shaped slots. It was excited by a single fed microstrip line. Numerous basic antenna forms are used in handsets today. (Alreshaid, Hammi, Sharawi, & Sarabandi, 2015) existed the proposal of a two-dimensional slot antenna array at 28 GHz only which consists of 8 elements in a 2 × 4 configuration. The work by (Ashraf et al., 2016) introduced a dual-band 28/38 GHz printed slot antennas consists of a circular radiating patch that was situated acentric inside a circular slot engraved from the ground plane. Another research by (Sunthari & Veeramani, 2017) developed four-element antenna linear array operating at 28 GHz, 37GHz, 41 GHz, and 74 GHz bands. The antenna was designed established with the resonant cavity model. The MIMO antenna was fed by a microstrip transmission line. The patch and the feed line were matched through inset feed techniques. The four antennas were placed established on the spatial diversity in the spacing of $\lambda/2$. (Ali & Sebak, 2016) developed a massive MIMO series fed antenna array for 28/38 GHz. Its size is size 13×20 mm^2. It was a six sector base stations with six subsectors or antenna array each covering a range of 40° at 28 and 30° at 38 GHz in the azimuth-plane (θ). Research reported by (Babu & Anuradha, 2018) is a compact Minkowski patch antenna used to raise the return loss as well as reducing mutual coupling for MIMO systems. The intended MIMO resonated at four dissimilar resonance frequencies of 2.5 GHz, 3.5 GHz, 5.2 GHz, and finally resonated at 7.0 GHz with an improvement in bandwidth mutual coupling levels. (Hong et al., 2014) introduced an antenna element arrangement which featured a fan-beam like radiation characteristics. The main radiator structure was composed of an array of vias within the PCB with electrically small pitches. By arranging the vias in a compactly spread out periodic manner. The design was realized within a 10 layers FR-4 substrate.

SOLUTIONS AND RECOMMENDATIONS

In this chapter, the authors present an integrative background that draws on earlier studies, categorizes and synthesizes the design of 5G antennas in mobile applications. Because the primary analysis was incapable of finding evidence signifying with dealing with 5G applications with the corporate set of terminology. We hypothesize that a set of the introduced MIMO antennas in the succeeding chapters for 5G mobile applications could explicitly form the groundwork for merging the topic (MIMO antennas) into one reference argument (user's handset). In contrast, with the antenna parameters established to denote to, a designer can definitely decide which antenna to be included and designed for a particular purpose.

Our emphasis will be on designing a millimeter-wave antenna as a tool that can be adopted in mobile terminals with the identified dimensions and is integrated with other circuit components and studying its parameters. We start from the outline of the advantages of an air-filled-slotted-loop and microstrip antenna approach, with a concentration on the contribution of each approach to our understanding of 5G communications. Then, we introduce a brief summary of the MIMO antenna systems and discuss its parameters containing mutual coupling, envelope correlation coefficient, channel capacity and the effect of propagation in air. The designs designate the dimensions in terms that can be evaluated, fabricated, and measured in empirical studies. Hence, the proper combination of antennas and other components is considered. Further importantly, the introduced MIMO antennas can be adopted for their development in data rates, providing an improvement in all antenna parameters.

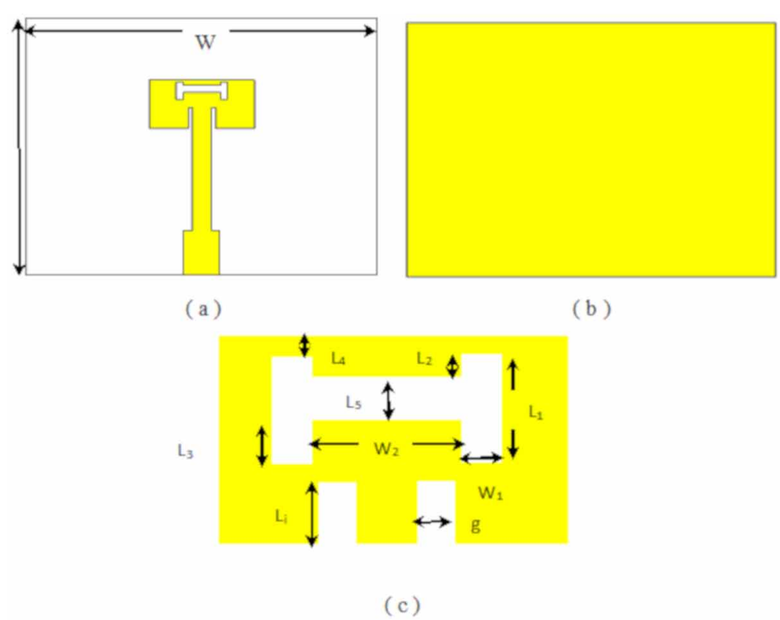
MAIN CONTRIBUTIONS AND SOLUTIONS

As 5G is used at the higher frequencies, the configuration of antennas differs than that used earlier. The higher frequency introduces lower antenna size. As 5G is developed and implemented, there will be a major requirement especially on the user equipment and base station infrastructures. So, the need for designing new antennas that deal with the upcoming millimeter frequency bands is challengeable and promising techniques for achieving the purpose of moving to these bands. The objective of this chapter is to design, analyze, fabricate, and measure mm-wave MIMO antenna at 28 GHz and 38 GHz to compensate the wastage of energy from propagation losses and fading.

Single Element Antenna Design

The arrangement of the essential design of dual-band slotted microstrip 5G antenna is shown in Figure 9. The patch is constructed on Rogers RT5880 substrate of 0.508 mm thickness, dielectric constant $\varepsilon_r = 2.2$ and loss tangent tan $\delta = 0.0009$ with dimensions of w x L = 15 x 15 mm^2. The antenna is a rectangular microstrip patch with inverted I-shaped slot at the higher portion of the patch.

Figure 9. (a) Introduced antenna, (b) Ground plane, and (c) Detailed dimensions



The slot at the higher portion of the rectangular patch varies with various sizes cutting lengths. This variation leads to an extraordinary matching at the required frequencies. The slot dimensions are exposed in Figure 9. The single antenna procures a patch size of W_P x L_P = 4.5 x 2.82 mm^2 with inset feed of g x L_i = 0.2 x 1.2 mm^2 in accordance to (Balanis, 2005). The slot is situated in a horizontal arrangement within the patch. In the instance of a horizontal slot, it is accurately situated in the central point of W_P. Then, it is moved vertically alongside L_P to the endpoint of the patch for the superlative location point is got and adjusted. The results reveal that as the slot get closer to the higher portion of the patch, a superior response can be predictable.

A microstrip transmission line is used to feed the patch to animate the applicable set with dimensions W_F x L_F = 1.55 x 2.61 mm^2. The input impedance of 50 Ω is realized because it provides high matched impedance between the patch and feed line ends. A multiple quarter wavelength transformer of 75 Ω is introduced to between the patch and feed line. This means that the feeding is not recognized on the patch edges directly. The transformer dimension is $W_T \times L_T$ = 0.8 x (3 × 1.98) mm^2 at 28 GHz. The resonant frequencies and return loss levels are affected by the width and length of the inset feed so the highest adequate results should be gained. The adjusted parameters, nominated in Table 1, are initiated built on optimization and several parametric studies.

ANTENNA RESULTS AND DISCUSSIONS

CST numerical simulator is used to simulate the introduced slotted microstrip antenna. The antenna dimensions are optimized to give the estimated 28 GHz and 38 GHz resonance frequencies.

Parametric Study

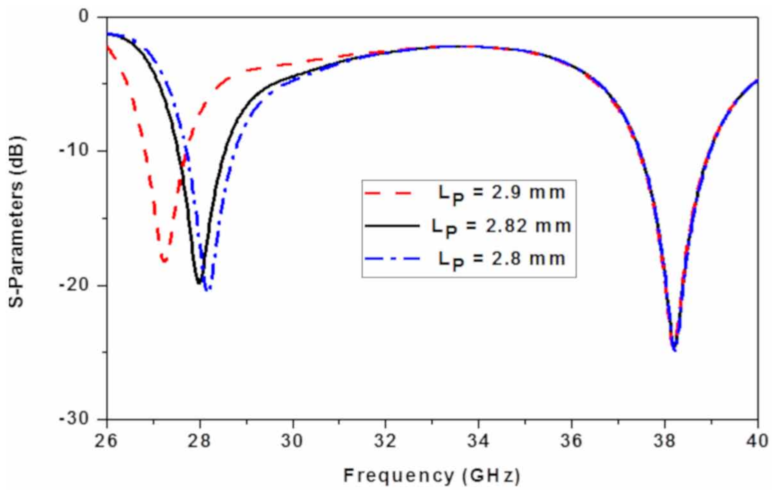
Effect of Patch Length L_P on S-Parameters

In our work, the authors studied the significance of patch length L_P on antenna parameters. It affects the lower frequency as verified in Figure 10. As can be appreciated, when varying the patch length, the

Table 1. Total dimensions of the introduced antenna

Parameter	Dimension (mm)	Parameter	Dimension (mm)
W	15	W_T	0.8
L	15	L_T	5.94
W_P	4.5	h	0.508
L_P	2.82	g	0.2
W_F	1.55	L_i	1.2
L_F	2.61	L_4	0.12
L_1	1	L_5	0.4
L_2	0.2	W_1	0.3
L_3	0.4	W_2	1.6

Figure 10. Effect of Patch Length L_P

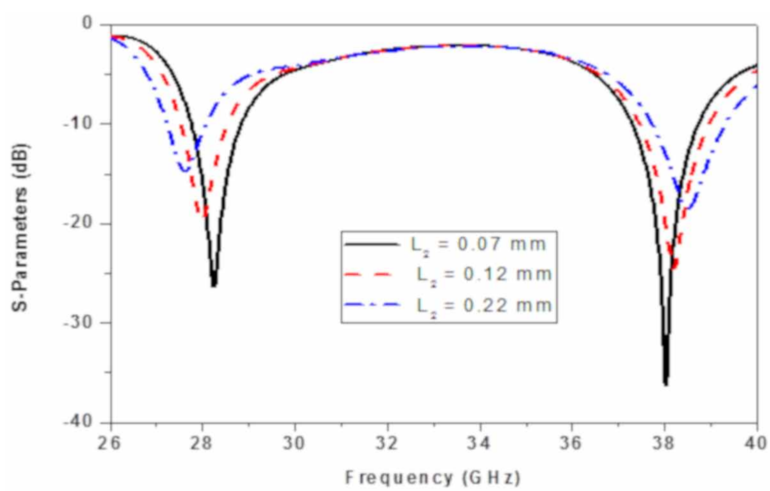


lower frequency varies progressively but the bandwidth and impedance matching are varying tangibly. The best value giving exactly 28 GHz is $L_P = 2.82$ mm.

Effect of Length L_2

This dimension is very critical. The results display that the resonance frequencies and return losses are to some extent depending on the length of L_2 as perceived in Figure 11. The value of $L_2 = 0.12$ mm is preferred for upright result and ease of fabrication.

Figure 11. Effect of Length L_2 on S-Parameters



Effect of Width W_2

Figure 12 indicates the significance of dimension W_2 on S-Parameters. It has an excessive effect on both resonance frequencies, return loss and impedance matching. The taken value in our design is 1.6 mm for its accepted values of return loss and frequency.

Impedance bandwidths of the two ports lie in between (27.53 - 28.57) GHz with impedance bandwidth 3.71% and BW of 1.04 GHz at 28 GHz and (37.36 - 38.99) GHz with impedance bandwidth 4.04% and BW of 1.54 GHz at 38 GHz. The final simulated reflection coefficient S_{11} of the single antenna is -20.82 dB at 28 GHz and -27.21 dB at 38 GHz for the succeeding 5G mobile communications as displayed in Figure 13.

Figure 12. Effect of Width W_2 on S-Parameters

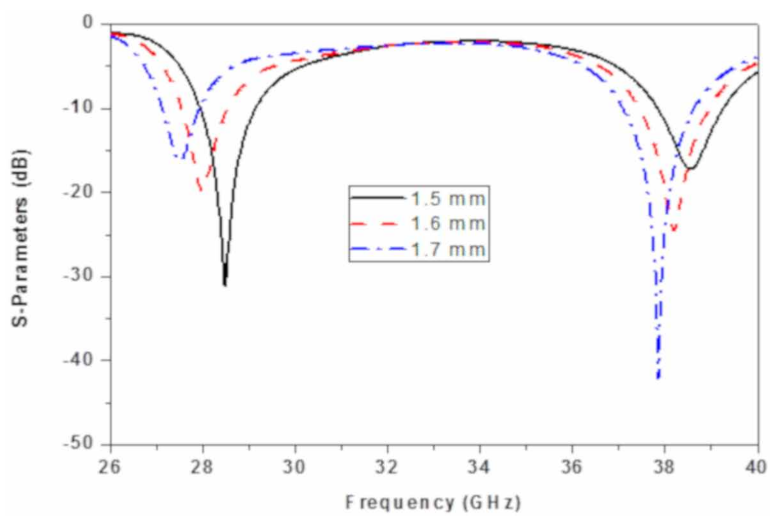
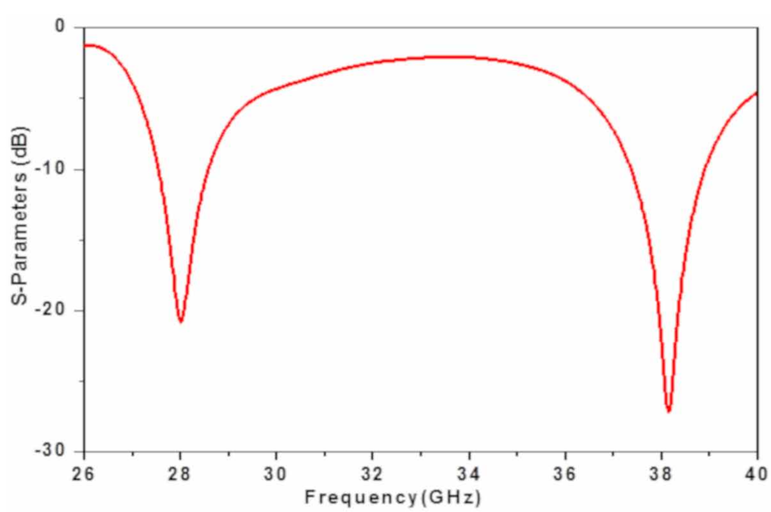


Figure 13. simulated s-parameters of the introduced antenna



Radiation Patterns and Gain

The radiated far-field patterns are demonstrated in Figure 14 and Figure 15. In the simulated directivity, gain and efficiency of the single mm-wave antenna are 8.59 dBi, 7.85 dBi and 84.2% at 28 GHz and 6.22 dBi, 5.69 dBi and 88.59% at 38 GHz, respectively. The antenna accomplished very well in the expected frequency bands.

Figure 14. Polar radiated far-field patterns at (a) 28 GHz and (b) 38 GHz

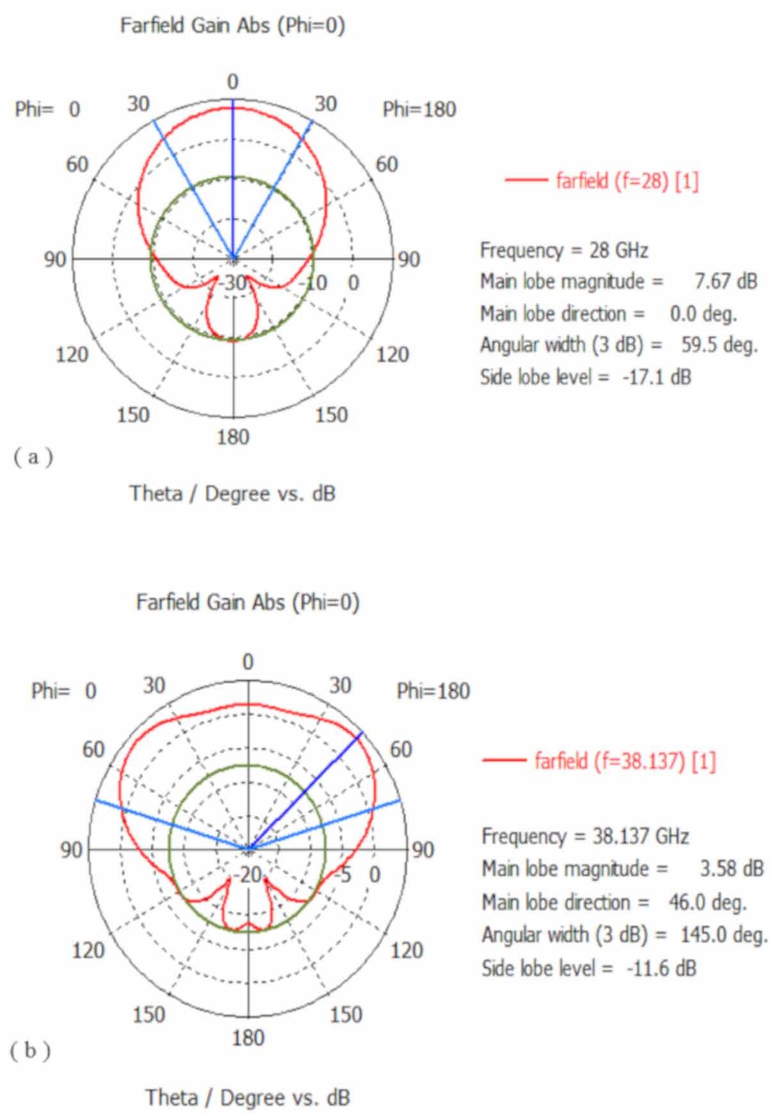
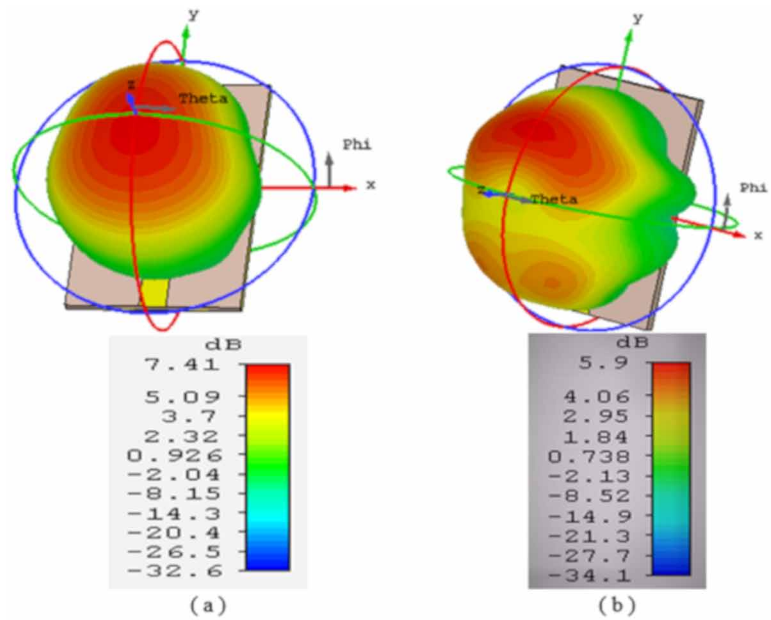


Figure 15. 3-D Radiated Far-Field Patterns at (a) 28 GHz and (b) 38 GHz



TWO-ELEMENT MIMO ANTENNA

In this section, two slotted microstrip antennas with inverted I- shapes are positioned on the same substrate of 55 × 110 × 0.58 mm^3, designed and fabricated for broadband wireless access services at two dissimilar operating frequencies which are 28 GHz and 38 GHz for the 5G mobile applications.

Two-Element MIMO Antenna Geometry

The configuration of the specified antenna is explained in Figure 16.

It is fabricated on a W × L = 55 X 110 mm^2 Rogers RT5880 substrate of 0.508 mm thickness, dielectric constant $\varepsilon_r = 2.2$ and tan δ = 0.0009. The two radiating constructions which are positioned on the uppermost and lowermost of the substrate are prepared from copper material. The back view publicized in Figure 16 is the ground plane of dimensions W x L_g = 55 × 22 mm^2. A rectangular slot is implanted in the partially rectangular defective ground structure DGS. The slot dimension is $W_S \times L_S = 1 \times 15.07$ mm^2. The slot is adopted to augment the antenna radiation characteristics and minimize the surface waves within the two-elements of MIMO antenna.

The focal concern for this design is the mutual coupling, which principally increases outstanding to the slight distance amongst the two antennas, by intensifying the space between the two elements, the mutual coupling can be declined. The distance from the two patch edges is 9.41 mm (which about 0.87 λ_0) at 28 GHz to evade mutual coupling and grating lobes. The antennas in the array have the dimensions as stated in Section.2, in addition to dimensions in Table 2.

Figure 16. Introduced two-element MIMO antenna

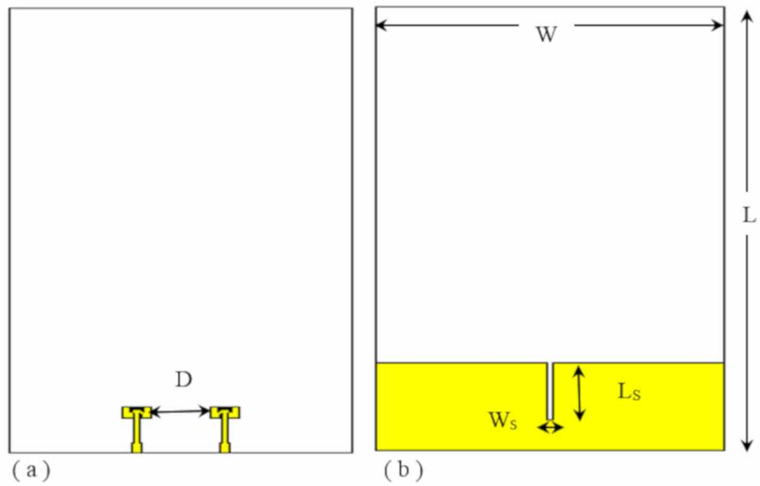


Table 2. Total dimensions of the introduced 2-element MIMO antenna

Parameter	Dimension (mm)	Parameter	Dimension (mm)
W	55	Lg	22
L	115	Ls	15.07
Ws	1	D	9.41

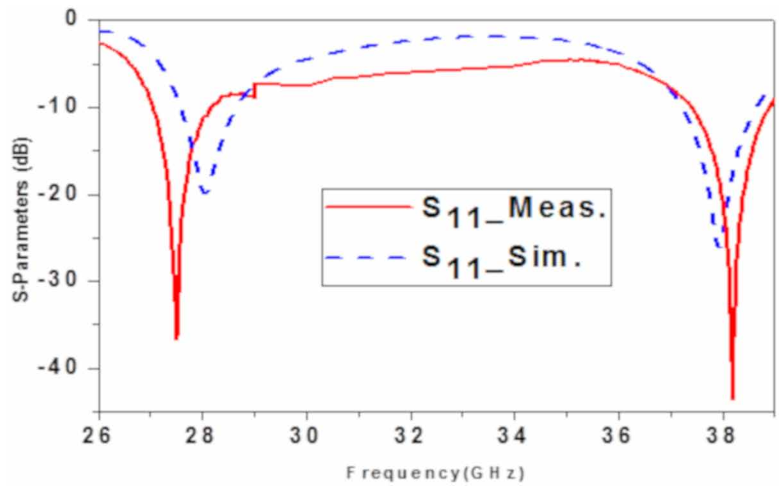
Element MIMO Antenna Experimental Results

MIMO performance has been explained to depend on a wide-ranging of parameters comprising return loss, mutual coupling, radiation efficiency, and correlation. These parameters are particularly significant to the handheld MIMO antenna designs. The MIMO antenna system with two ports is simulated in CST Microwave Studio simulation software and measured using Vector Network Analyzer ZVA 67 (measures up to 67 GHz frequency) with a port impedance of 50 Ω. The array is supplementary analyzed and fabricated for the following parameters.

Reflection Coefficient and Mutual Coupling

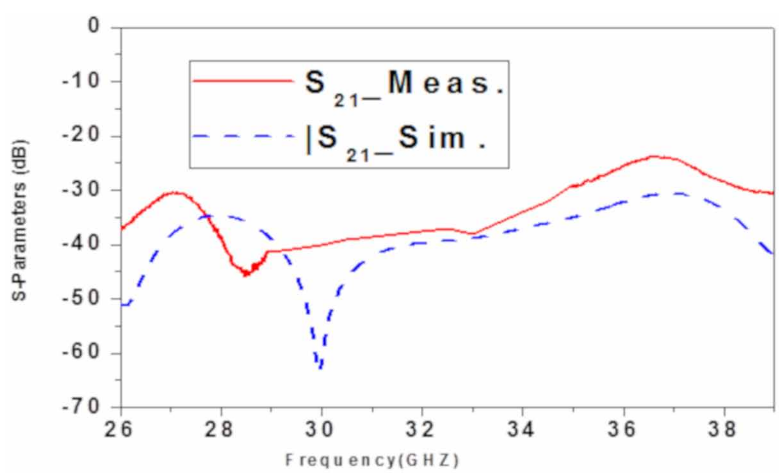
The authors can perceive that, for the two-elements MIMO antenna, the -10 dB BW achieved are 1.0683 (27.58–28.649) GHz at 28 GHz and 1.4306 (37.213-38.643) GHz at 38 GHz. The reflection coefficients obtained from simulation and measurement are - 19.91 dB and - 36.8 dB at 28 GHz and - 26.12 dB and - 42.3 at 38 GHz of the 5G bands lately established by FCC (Psychoudakis, Zhou, Biglarbegian, Henige, & Aryanfar, 2016) as shown in Figure 17. There is a good assurance between the measured and simulated data with tolerable frequency discrepancies. It is distinguished that the measured values are better than the simulated ones.

Figure 17. S-Parameters of the introduced Two-Element MIMO antenna reflection coefficients



Due to the symmetry of the two elements, only the S_{11} and S_{21} are announced. It was prominent that inter-elements mutual coupling is condensed by separating the elements. Figure 18 indicates the isolation between the dual-ports and is below - 25 dB and higher, over the two anticipated bands, which are in favor of a MIMO system. The simulated and measured isolation was better than - 29.4 dB for the lower frequency and - 27.3 dB for the upper one. This is one of the significant features that would ensure no correlation of radiation patterns of the two adjacent antennas desirable for the MIMO system. This was achievable owed to the inter-linear MIMO spacing of 0.87 λ_0.

Figure 18. S-Parameters of the introduced two-element MIMO antenna transmission coefficients



The Reason for Using Transformer

The upper part of the patch is less than 12 mm from the bottom side because, at 28 GHz and 38 GHz, the patch size and the feeding length are very small and the connector used in simulation and measurement will affect the performance of the antenna. So, the quarter wavelength transformer is used to get the patch away from the connector as exemplified in Figure 19.

Radiation Patterns

The obtained gain in this study is the optimal gain of a single slotted antenna. Simulated polar and 3-D radiation patterns at 28 GHz and 38 GHz of the individual antenna at $\phi = 0°$ and $\phi = 90°$ cuts for observation are recorded, respectively in Figure 20 to Figure 22.

The MIMO antenna system offers maximum directivity, gain and radiation efficiency of 8.63 dB_i, 7.88 dB_i and 89.74% at 28 GHz and 10.02 dBi, 9.49 dBi and 88.59% at 38GHz, respectively. Provisional to the application's essential for extraordinary MIMO gain, this antenna is introduced. The conquered side-lobe levels are -17.8 dB at 28 GHz and -4.4 at 38 GHz.

In the higher frequency band, the antenna gain is bigger. On the other hand, the radiation efficiency is reduced at the higher band. This may well be outstanding to the point that the directivity increases at the higher frequencies. The radiation efficiency η is the relation between gain g and directivity D and while the directivity increases, the radiation efficiency decreases rendering to (5.1). The loss tangent tan δ (happened due to the resistance in the dielectric) increases with frequency. This diminishes the radiation efficiency at higher frequencies but by the way of the directivity (which the radiation efficiency does be not taken into account) increases for that specific frequency, consequently the antenna gain at that frequency increases (Salamin, Das, & Zugari, 2018).

Figure 19. Photograph of the introduced MIMO antenna (a) without multiple wavelength transformer and (b) with multiple wavelength transformer

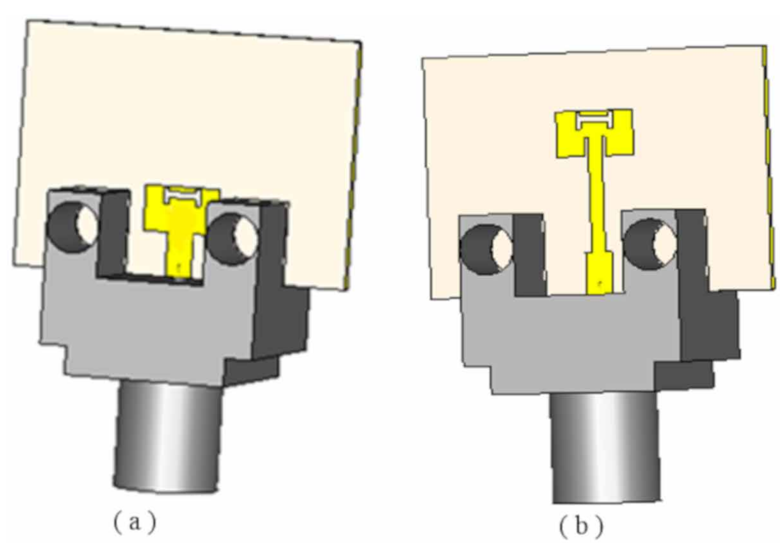
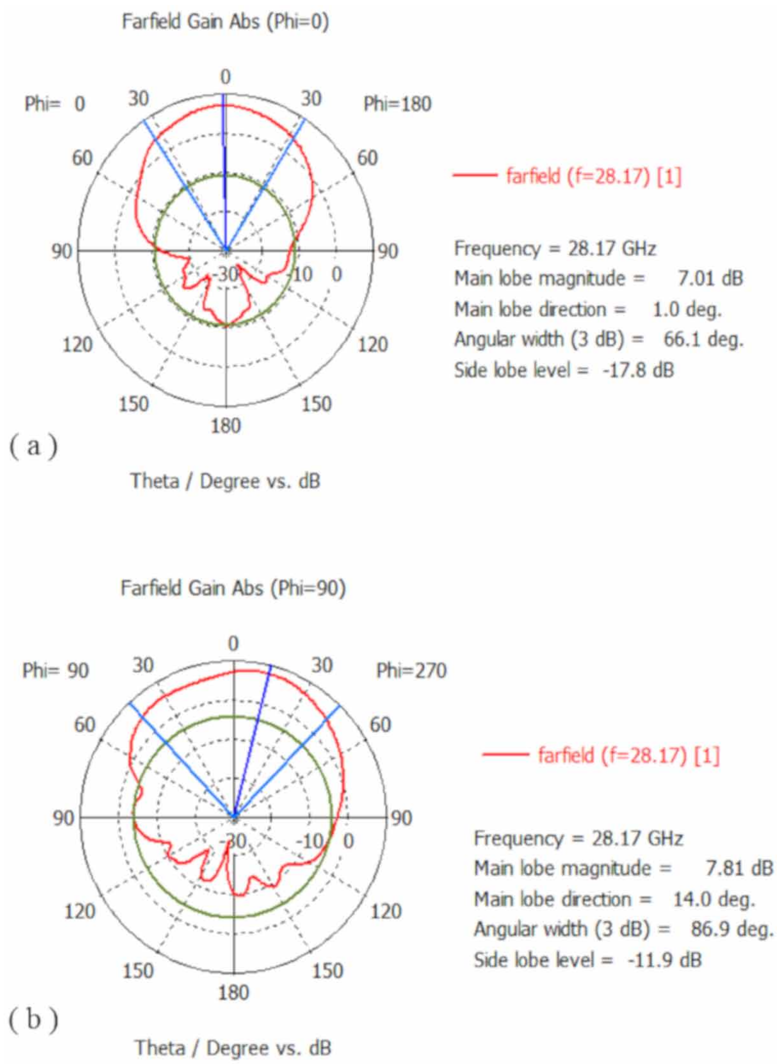


Figure 20. Radiated far-field patterns for 28 GHz at (a) phi= 0 deg. and (b) phi= 90 deg



$$\mathcal{G} = \eta \times D \tag{11}$$

Envelope Correlation Coefficient

For the offered MIMO antenna system, ρ was premeditated at the two frequencies 28 and 38 GHz, and the corresponding obtained value is 1.36×10^{-5} and 3.86×10^{-5}, respectively as exposed in Figure 23. It is noticeable that the considered MIMO antenna system satisfies the requirement for good MIMO operation for 5G mobile applications.

Figure 21. Radiated Far-field patterns for 38 GHz at (a) phi= 0 deg. and (b) phi= 90 deg

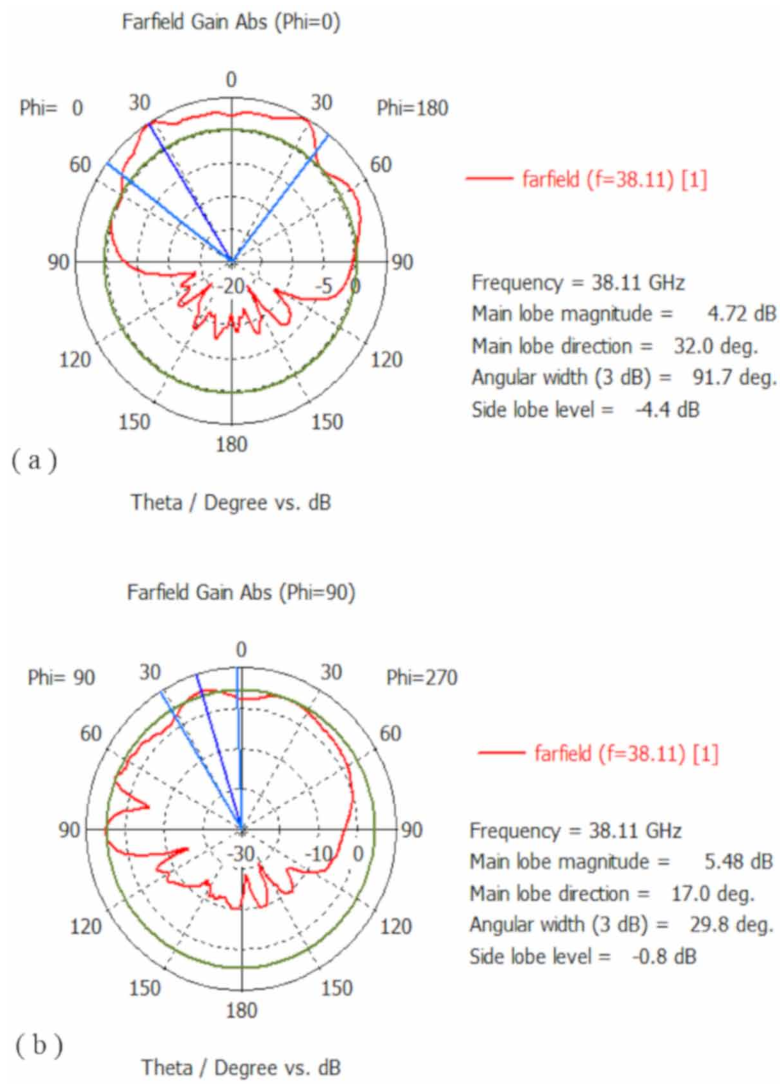


Figure 22. 3-D radiated far-field patterns at (a) 28 GHz and (b) 38 GHz

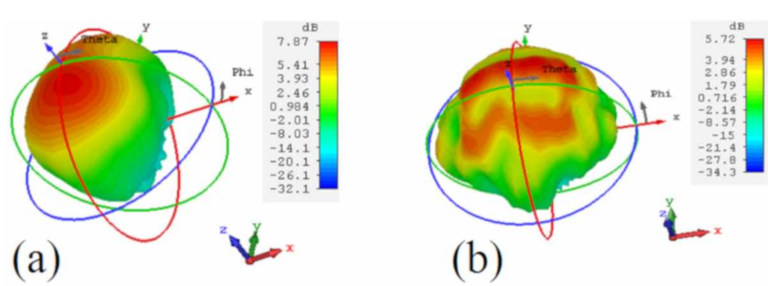
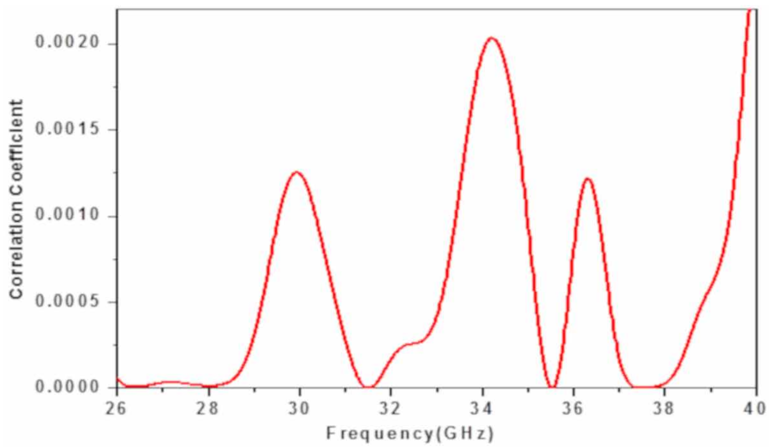


Figure 23. Envelope correlation coefficient of MIMO antenna



Results accomplished from two-element MIMO antenna design are better improved than that accomplished from single elements and there is an amplification in all antenna factors. Figure 24 specifies the fabricated dual-band two-elements MIMO 5G antenna. Table 3 introduces a comparison between the different substrate and ground lengths with S-Parameters and gain. It is realized that the best results in the meaning of reflection coefficients and gain are improved at the values of $L_g = 22$ mm and $L_S = 110$ mm.

FUTURE RESEARCH DIRECTIONS

MIMO antenna configurations are growing very rapidly. The current MIMO configuration is a 2-element slotted microstrip MIMO antenna in which both the transmitter and receiver will have the same number of antenna elements. This chapter introduces a solution for multiple configuration and therefore it is very beneficial to consider this technique on extra configurations as a next step. Also, the design of passive components such as filters and power dividers for the 5G and millimeter wave band is a main issue in the future work.

CONCLUSION

An overview of microstrip antenna and MIMO systems for the next 5G band is introduced. This chapter discusses the literature review for microstrip antennas and MIMO applications. Also, in this chapter, a novel design of MIMO antenna for the coming generation 5G bands as a solution for the next generation of smartphone antennas is introduced. Also, the effect of mutual coupling on closely coupled microstrip antennas in closely MIMO (Multiple-Input-Multiple-Output) antenna systems is discussed. The anticipated wireless system is size-compact, relatively easy to fabricate and implement in practical mobile applications.

Figure 24. Photograph of the introduced two-element MIMO 5G antenna

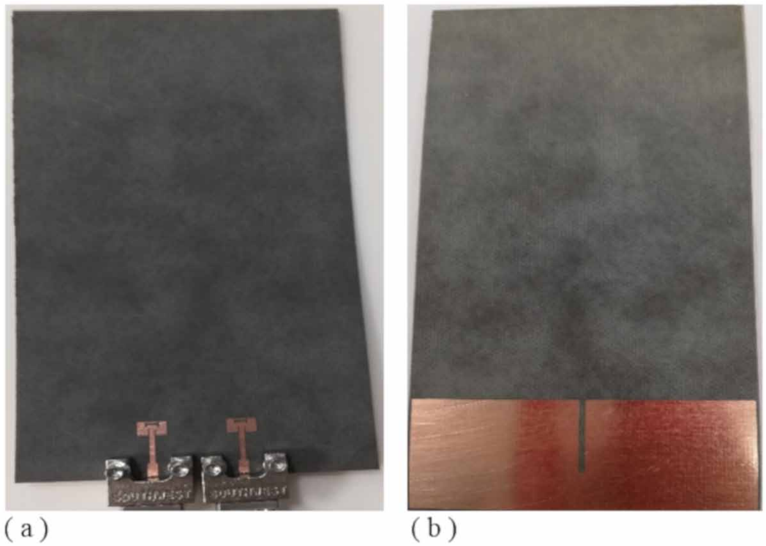


Table 3. Comparison between different substrate and ground lengths with S-parameters and gain

Different lengths Vs. Results		L_g=22 mm & L_s=22 mm	L_g=22 mm & L_s=110 mm	L_g=110 mm & L_s=110 mm
S_{11} (dB)	28 GHz	-21.96	- 19.91	-21.182
	38 GHz	-22.267	- 26.12	-20.873
Gain(dB_i)	28 GHz	7.372	7.88	6.97
	38 GHz	5.661	9.49	8.02

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Chapter 4
A Dual-Band Flexible Wearable Antenna Integrated on a Smart Watch for 5G Applications

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ABSTRACT

This chapter focuses on the design of dual band flexible wearable antennas for modern 5G applications to integrate on a smartwatch. The first is a rectangular antenna which the patch and the ground etched on new flexible material is called ULTRALAM® 3850HT. This antenna is designed to operate at 38 GHz and 60 GHz. The second is a planar inverted-2F wearable antenna pasted on a jeans textile material. Two methods for measuring the dielectric properties of the jeans will be presented. This antenna is designed to operate at 28 GHz and 38 GHz. The SAR (specific absorption ratio) is also introduced and SAR results will be shown. Moreover, the proposed smartwatch under the bent condition will be also studied. These antennas are simulated using HFSS and CST 2018.

INTRODUCTION

Millimeter-wave technology brings a new model of wireless communication in various fields including mobile devices, automobiles, military, medical, IoT (Internet objects) and many more (Jajere, 2017). There are many problems faced in wireless communications in 4G such as the frequency resources for their customers are not enough (Huang, 2018). So, the millimeter wave frequencies are the most suitable solutions for the broadband requirement in communication systems which have the availability of millimeter frequency range (20 – 300 GHz) (Jun, Miao & Hui, 2017). From this ranges chosen four frequencies are 26, 28, 38 and 60 GHz where the operation of the antenna in these frequencies is requested to use the currently 5G spectrums in single systems (Imran, Farooqi, Khattak, Ullah, Khan, Khattak,

DOI: 10.4018/978-1-7998-1152-7.ch004

& Dar, 2018). The main feature of the millimeter wave technology is reducing the size of the hardware devices as they have very high resonant frequencies, therefore, the smaller size of the antenna, in addition, high speed and high capacity (Hong, Baek, & Seungtae, 2017). Also, there are two bands for 5G technology other than the millimeter-wave frequency band, they are “Low-band 5G” and “Mid-band 5G” using frequencies from 600 MHz to 6 GHz, especially 3.5 - 4.2 GHz (Parchin, 2016). This chapter focuses only on the frequency band of millimeter-wave technology for 5G applications.

Generally, when an antenna attached or closed to the human body is called wearable antenna. A wearable antenna or body-worn antenna radiates the electromagnetic waves (EMWs) which are absorbed by tissues of the human body. The absorption of these waves will cause damage and burn human tissues (Sunohara, Laakso, Hirata & Onishi, 2014). So, it is necessary to decrease the electromagnetic energy interaction towards the human body tissues from the wearable antennas when in use. The absorption of the electromagnetic waves (EMWs) from the human tissue is measured by the specific absorption rate (SAR) (Hirata, Fujiwara, Nagaoka & Watanabe, 2010). Further, the SAR safety limit is based on the standardization committee and is various in different regions over the world. In the US is regulated by the Federal Communications Commission (FCC) where the acceptable maximum SAR value 1.6 W/kg, averaged over 1 gram of tissue. But in Europe, the acceptable maximum SAR value is 2.0 W/kg averaged over 10 grams of tissue which is regulated by the International Commission on Non–Ionizing Radiation Protection (ICNIRP) (Zhao, Zhang, Chiu, Ying, & He, 2014).

In this chapter, dual-band flexible wearable 5G (Fifth-Generation) millimeter-wave antennas are designed and simulated for integration on smartwatch applications. There are two different designs are included in this chapter: the first design is a rectangular antenna including six U-slots on the patch. The patch and the ground plane are etched on new flexible material as a substrate which is called “ULTRALAM® 3850HT”. This material is characterized by thin flexible cores with low and stable dielectric constant, which is a key requirement for high frequency and wearable designs. This flexible material has a dielectric constant ε_r is equal to 3.14, and loss tangent tanδ is equal to 0.005. This antenna is designed to operate at two resonant frequencies 38 GHz and 60 GHz. The second antenna is a planar inverted-2F wearable antenna pasted on jeans textile material as a substrate. Two methods for measuring the dielectric constant (ε_r) and loss tangent (tanδ) of the Jeans material will be presented in this chapter: a microstrip ring resonator method and DAK equipment. This antenna is designed and simulated to operate at two resonant frequencies 28 GHz and 38 GHz.

The presented antennas are body-worn antennas where they are integrated into the smartwatch. Therefore, the specific absorption ratio (SAR) plays a vital role in the design of any body-worn antenna. So, the SAR value should be calculated for all the presented designs in this chapter. Also, in general, it’s not possible to keep the smartwatch position in a flat at all the time. Therefore, the performance characteristic of the presented smartwatch with the two millimeter-wave antennas under the bent condition is also investigated. Furthermore, these antennas are simulated using two basically different techniques. These are HFSSTM from Ansoft which used FEM and CST STUDIO SUITETM 2018 which used FIT. The two software packages are basically different; therefore, the second has been used to confirm the results determined using the first.

Background

In our time, wireless communication is considered one of the most effective regions of the development of modern technology. This development is primarily due to the transformation of what was largely an intermediary to support voice communication to the center to support other services, such as video, image, text and data transmission (Rappaport, 2002). Thus, along with developments in the wired line technology in the 1990s, the demand for new wireless energy began to grow rapidly (Stallings, 2005). Although there are still many technical problems to be solved in the area of telecommunication lines, the additional capacity of the wireline can be achieved to a large extent with the addition of new private infrastructures, such as additional fiber optics, routers, and switches (Stallings, 2005). In recent years, there are many research efforts aimed to develop a new wireless capability by increasing intelligence in wireless networks. But, the key to this development is increasing the wireless capacity without having to increase the bandwidth or power requirements (Stallings, 2016). There are evolutions of wireless technology, namely from 1G to 5G (Berezdivin, Breinig, & Topp, 2002). Current research in wireless technology concentrates on the advanced implementation of 4G technology and 5G technology. Firstly, 1G refers to the first generation of wireless telephone technology for analog GSM systems. Its Speed was very low and up to 2.4 kbps (Abdullah, Xichun, Yang, Zakaria, & Anuar, 2009). The 2nd generation (2G) is implemented for digital GSM systems. Its data speed was up to 64kbps. It enables services such as text messages, picture messages and MMS (multimedia message) (Pereira, 2000). Also, there are the 2.5G is a technology between the second (2G) and third (3G) generation of mobile telephony. The 2.5G is sometimes described as 2G Cellular Technology combined with general packet radio service (GPRS). Its data speed was up to 144 kbps. It enables services such as phone calls, e-mail messages, web browsing, and camera phones (Bria, 2010). Then to the 3G technology refer to the third generation in which data transmission speed increased from 144kbps- 2Mbps. its increased bandwidth and data transfer rates to accommodate web-based applications and audio and video files (Honkasalo, 2002). And then go to the 4G technology which high-speed data access and high-quality streaming. It's capable of providing 100Mbps – 1Gbps speed (Bande, Marepalli & Gudur, 2011). Still cannot accommodate some challenges like spectrum crisis, high energy consumption, poor coverage, bad interconnectivity, poor Quality of service and flexibility (Janevski, 2009). To address all these demands 5G wireless system is expected to be deployed in the future by 2020. Future fifth-generation (5G) framework of cellular system use millimeter-wave frequencies and is expected to offer an extremely wide spectrum and multi-Gigabit-per-second (Gbps) data rates to mobile communications. The data rate is expected to be 40-100 times faster than today's wireless LAN. The frequency range is from 20 GHz to 300GHz and the wavelength is between 10mm to 1mm (Zehai, Biqun, Zhenhua, & Zhang, 2018). So, the 5G technology is more effective and more attractive where it supports interactive multimedia, voice, streaming video, Internet and other. Some researchers are usually dedicating for the development of 5G technology. In (Ermolov, Heino, Kärkkäinen, Lehtiniemi, Nefedov, Pasanen, Radivojevic, Rouvala, Ryhänen, Seppälä, & Uusitalo, 2007) Ermolov et al. this paper reviews the expected wide and profound impact of nanotechnology for future wireless devices and communication technologies. In (Ahmad, Kumar & Shekhar, 2012) Ahmad et al. This paper, presented a novel model to solve the network congestion problem through an iterative server. In (Sood & Garg, 2014) Sood et al. this paper covers the difference from 1G to 5G and challenges to be faced for deploying 5G networks. Also, in (Charu & Gupta, 2015) Charu et al. this paper, examined the performance of the earlier wireless communication systems. Finally, in (Eze, Sadiku & Musa, 2018) Eze et al. provided a brief introduction to 5G wireless technology.

Rectangular Flexible Wearable Millimeter-wave Antenna for 5G Applications Antenna Design

Figure 1 illustrates the geometry of the proposed dual-band rectangular millimeter-wave antenna. This proposed antenna includes six U-slots loaded on the top of the patch specially designed to achieve the dual-band concept with good impedance matching. The patch and the ground plane are rectangular as shown in Figure 2. It is etched on the opposite sides of new flexible material is called "ULTRALAM® 3850HT" as a substrate with very thin thickness h = 0.05 mm to achieve the flexibility for the wearable antenna, relative permittivity $\varepsilon_r = 3.14$ and tan (δ) = 0.005. Also, this material is characterized by low and stable dielectric constant, which is a key requirement for high frequency and wearable designs. The optimized dimensions are tabulated in Table 1.

Figure 1. The geometry of proposed rectangular wearable antenna top view

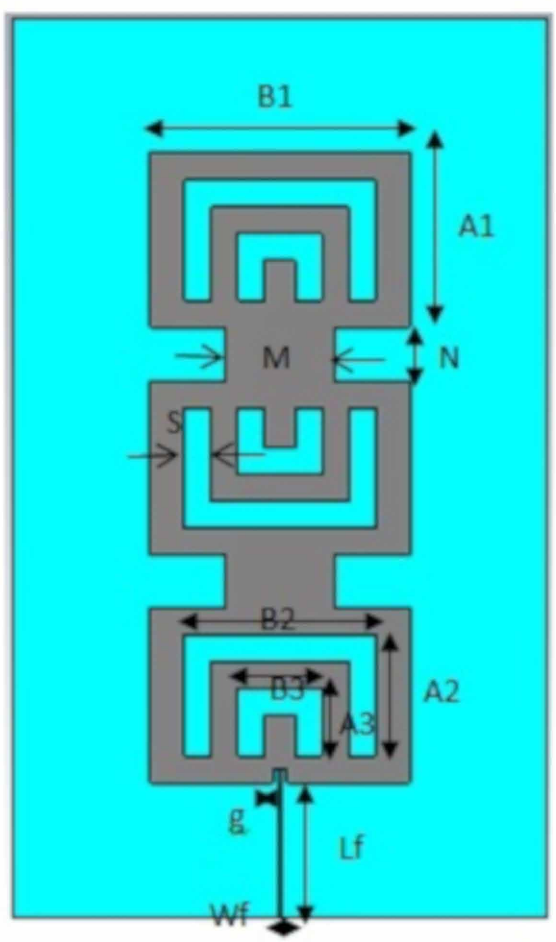


Figure 2. The geometry of proposed rectangular wearable antenna back view

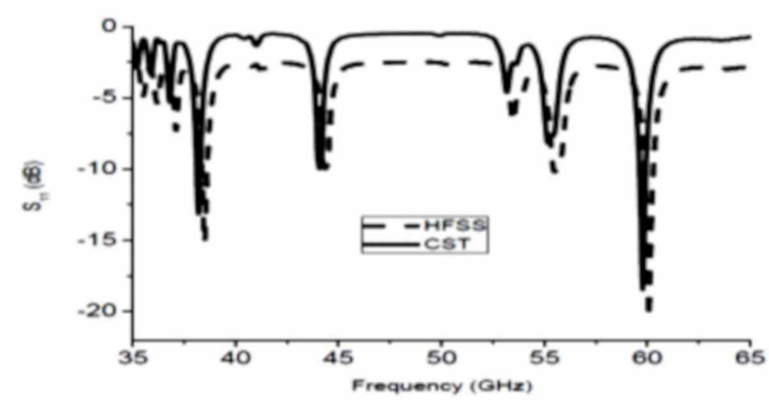
Table 1. The optimized dimensions of the proposed antenna

Wg	Lg	A1	B1	A2	B2	A3	B3	M	N	S	g	Wf	Lf
20	33.5	6.5	9.7	4.5	7.12	2.5	3.12	4.1	2	1	0.2	0.1	10

RESULTS AND DISCUSSION

The simulation analysis of the presented antenna is carried out by applying two different commercial software packages are called HFSS from Ansoft and CST 2018 to confirm the results. The simulation of the return loss S11 for the proposed rectangular wearable antenna is shown in Figure 3. From the results obtained, this presented antenna is operated at two resonant frequencies 38GHz and 60 GHz as

Figure 3. The return loss against frequency for the proposed antenna



required for 5G Applications. Also, there is a small shift between two results that is because they are basically different where the HFSSTM from Ansoft uses FEM and CST STUDIO SUITETM 2018 uses FIT. The simulation results are summarized in Table 2. For each resonant frequency, the current distributions are simulated as shown in Figure 4 and Figure 5. In addition, the radiation patterns of the proposed antenna in E-plane (ϕ = 0°) and H-plane (ϕ = 90°) are also simulated and plotted in Figure 6

Figure 4. Current distribution for the proposed rectangular wearable antenna at 38 GHz

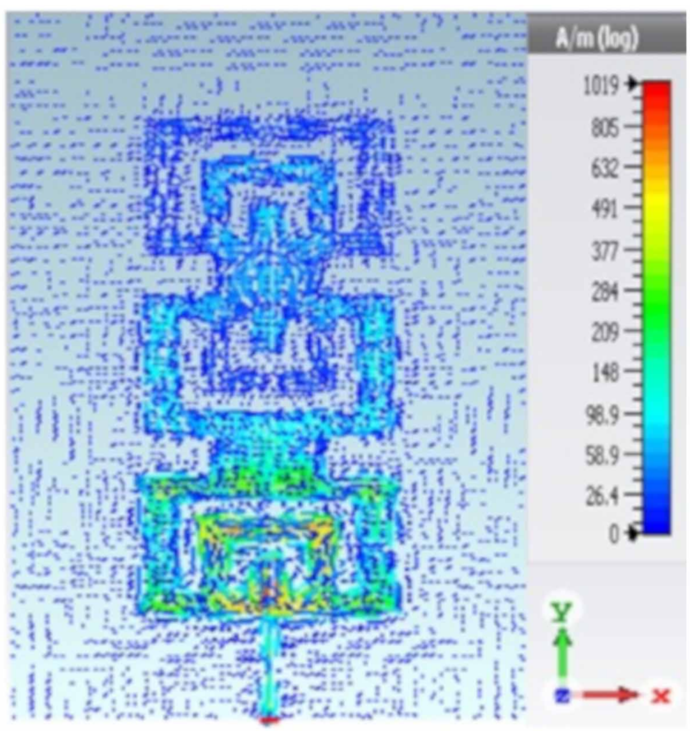
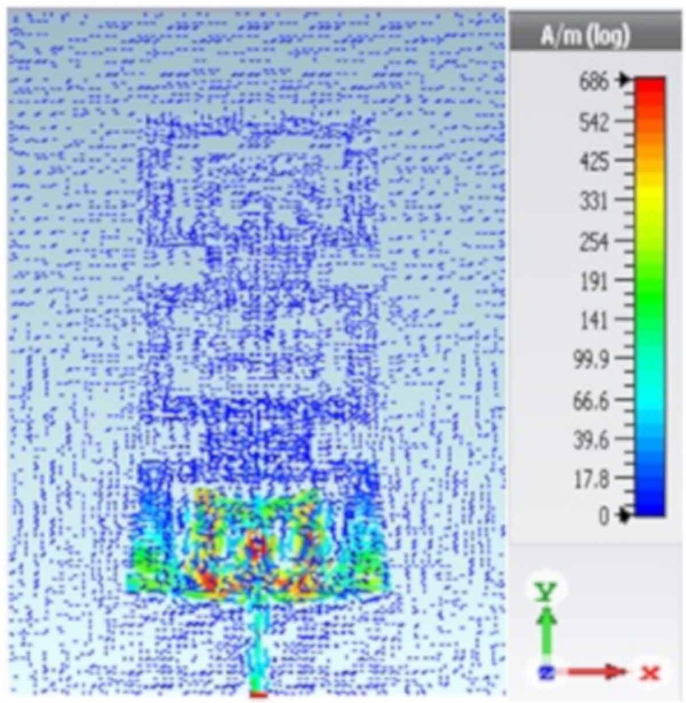


Table 2. The Simulation results of a proposed rectangular wearable antenna for 5G applications

Resonant Frequency Bands (GHz)	Return Loss S11 (dB)	Gain (dB)	Total Efficiency (%)
38	13.996	2.19	62.2
60	19.268	4.73	71.7

Figure 5. Current distribution for the proposed rectangular wearable antenna at 60 GHz



and Figure 7. From these results, it was found that a good distribution of the current and further, notes that a low side and back radiation lobes resulted in improved antenna gain and efficiency as shown in Figure 8 and Figure 9, simultaneously.

Planar 2F-inverted Flexible Wearable Millimeter-wave Antenna for 5G Applications Antenna Design

The geometry of the proposed dual-band planar 2F-inverted millimeter-wave wearable antenna is illustrated in Figure 10 and Figure 11. The patch of this antenna is a planar 2F-inverted specially designed to achieve the dual-band concept with a good performance. The feed-line is divided into two parts for 50Ω impedance matching. The optimized dimensions are tabulated in Table 3. The patch and the ground plane are pasted on the opposite sides of a Jeans textile material as a substrate with thickness h = 0.6 mm, relative permittivity $\varepsilon_r = 1.78$ and tan (δ) = 0.085.

Figure 6. The radiation pattern for the proposed rectangular wearable antenna in E-plane ($\phi = 0°$) at (a) 38 GHz, (b) 60 GHz

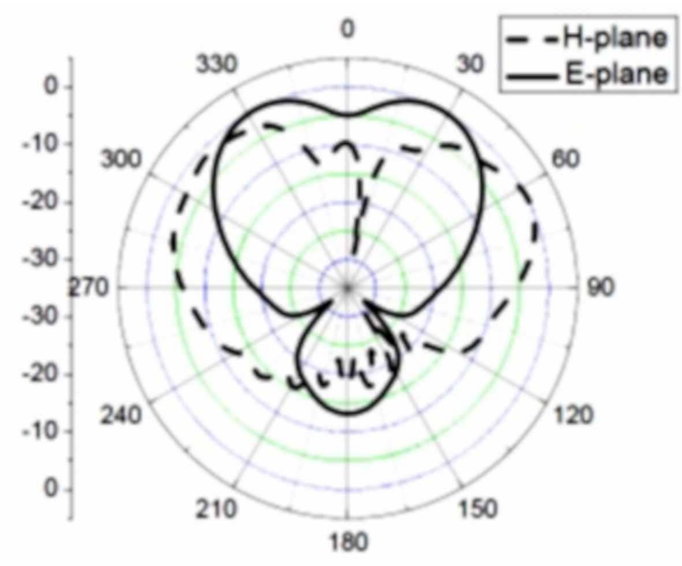


Figure 7. The radiation pattern for the proposed rectangular wearable antenna in H-plane ($\phi = 90°$) at (a) 38 GHz, (b) 60 GHz

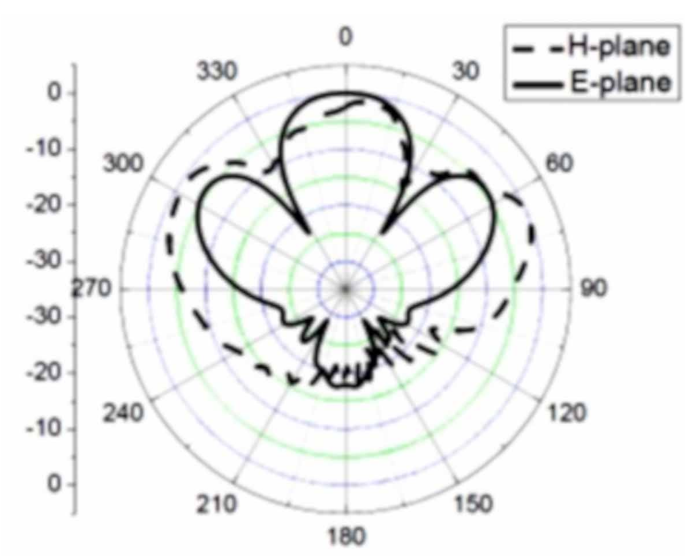


Table 3. The optimized dimensions of the proposed antenna

Wg	Lg	W1	L1	S1	W2	L2	S2	WL	WR	Wf	Lf	Wt	Lt	g
4.6	3	1.7	0.5	0.1	0.55	0.25	0.2	0.65	1.75	0.2	0.5	1.4	0.5	0.2

Figure 8. The performance results of a 1st proposed wearable antenna gain

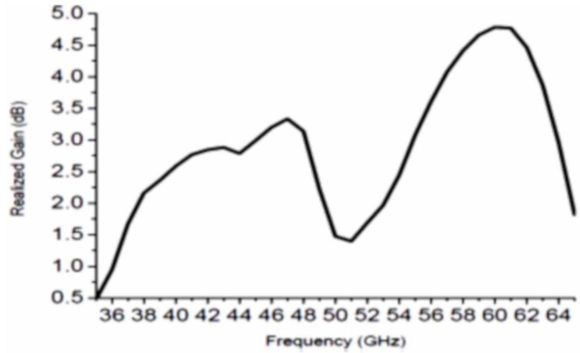


Figure 9. The performance results of a 1st proposed wearable antenna efficiency

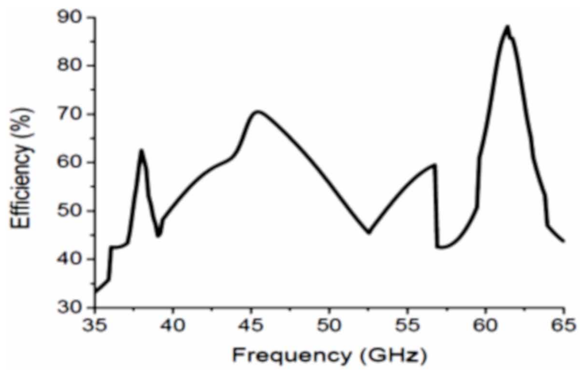


Figure 10. The geometry of the proposed planar 2F-inverted wearable millimeter-wave antenna top view

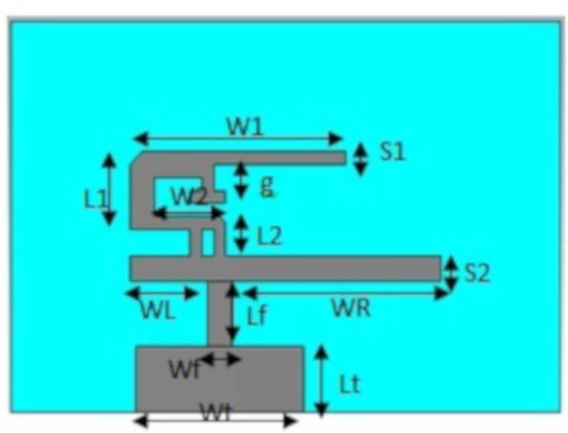
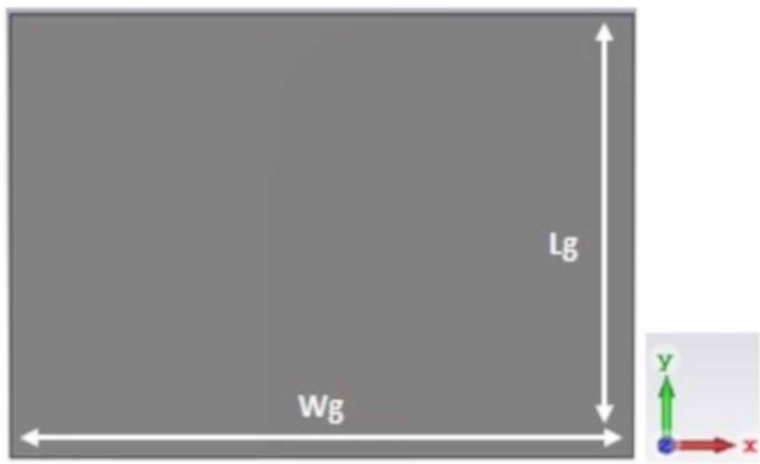


Figure 11. The Geometry of the proposed planar 2f-inverted wearable millimeter-wave antenna back view



The dielectric properties of the jeans material are characterized by two different methods to confirm the results. The first method is DAK equipment (Dielectric Assessment Kit) which used for dielectric measurements such as permittivity, loss tangent (Ahmed, Ahmed & Shaalan, 2017). It is the solution for all applications where the dielectric measurements are required as shown in Figure 12. The results of this equipment are tabulated in table 4.

Now, the second method is called a microstrip ring resonator method. This ring is simulated and fabricated to obtain another result to confirm the results obtained by the first method. In this method, a ring resonator model is designed and fabricated on jeans textile material which consists of the ring and two feed lines on one side and the ground plane on the opposite side of jeans material, also a small gap Δ is included between the ring and each feed line (Ahmed, Ahmed & Shaalan, 2017). Figure 13 illustrates the fabricated geometry of the proposed ring model and the dimensions of this ring model are tabulated in Table 5.

By measuring S_{21} for this model which is shown in Figure 14, the peak of S_{21} is recorded at each resonant in Table 6. From these results, the dielectric properties of Jeans textile material can be determined through some specific steps as,

1. **Determine The Dielectric Constant:** from the value of each resonant frequency by,

$$f_n = \frac{nc}{2\pi r\sqrt{\varepsilon_r}} \tag{1}$$

where r is the mean radius; c is the speed of light in a vacuum; and ε_r is the required dielectric constant.

2. Determine The Loss Tangent: from the dielectric quality factor (Q) by:

$$\tan\delta = 1/Q_d \tag{2}$$

Figure 12. The DAK equipment system

Table 4. DAK Equipment experimental results for jeans textile

Substrate Material	Dielectric constant (ε_r)	Loss tangent (tanδ)
Dry Jeans	1.78	0.085

Table 5. The optimize dimensions of the ring model

Length	Inner Radius	Outer Radius	Mean Radius (R_m)	Width of Fed-line	Length of Fed-line	Gap (Δ)
Value(mm)	8.5	10	9.25	3	14	1

Table 6. The experimental results of the ring resonator method

	The Microstrip Ring Resonator Method				
Textile Material	Mode	Resonant Frequency (GHz)	S_{21}(dB)	dielectric constant (ε_r)	loss tangent (tanδ)
Dry Jeans	n=1	4.26	-35.5	1.73	0.077
	n=2	8.89	-36.9	1.69	0.073

Figure 13. The fabricated geometry of the ring resonator model

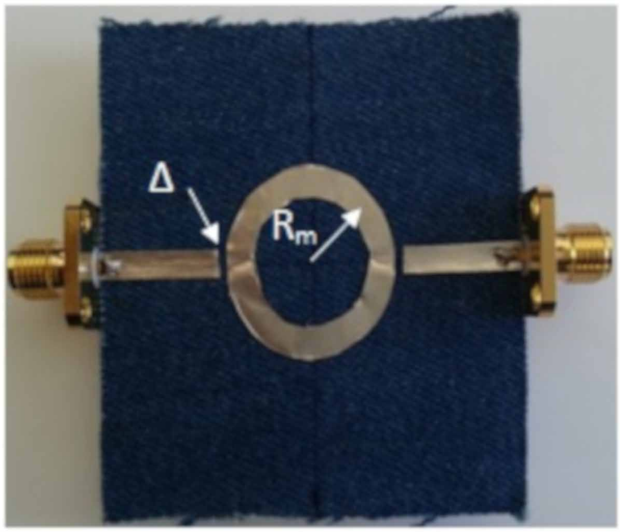
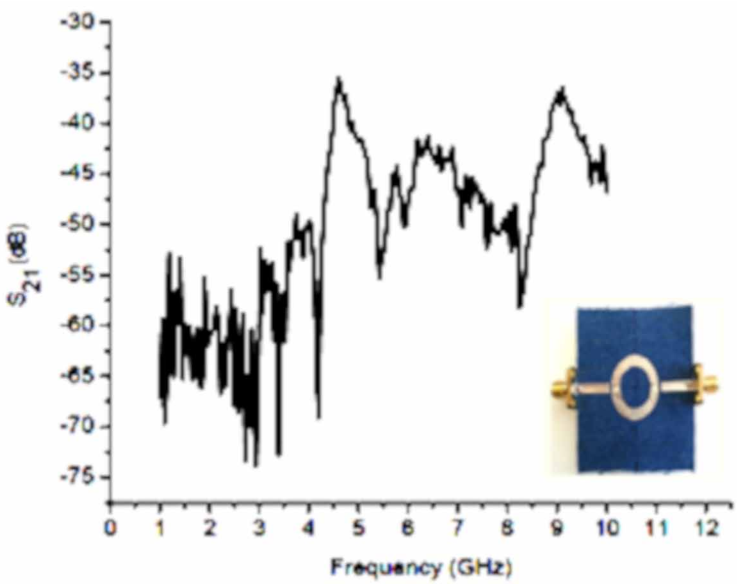


Figure 14. The measured S_{21} with the frequency for the ring resonator model



3. The Dielectric Quality Factor can be obtained: from the unloaded quality factor (Qu) as:

$$\frac{1}{Q_u} = \frac{1}{Q_c} + \frac{1}{Q_d} \tag{3}$$

where Q_d due to dielectric loss and related to loss tangent by ($\tan\delta = 1/Q_d$) and Q_c is due to conducting walls loss and can be calculated by ($h\sqrt{f_o \mu_o \Pi \sigma_c}$).

4. Now, The Unloaded Quality Factor (Q_u) can be calculated: from the loaded quality factor (Q_l) and the insertion loss (IL) as:

$$\mathrm{IL} = S_{21}(\mathrm{dB})) = 20\log\left(1 - \frac{Q_l}{Q_u}\right) \tag{4}$$

where Q_L is measured by ($fo/\Delta f$) at the 3 dB around the resonance in S_{12} curve and Q_u is the desired parameter for any passive design. (Hint: if Q_L and Q_U are similar, this means that this material is very lossy so, it must be $Q_u \gg Q_l$ to avoid excessive losses).

From the steps above, the dielectric properties of the jeans textile material can be obtained. The results for this method are tabulated in Table 6. Furthermore, the digital screw gauge is used to measure the thickness of the Jeans textile which is 0.6 mm.

RESULTS AND DISCUSSION

The simulation of the return loss S_{11} for the proposed planar 2F-inverted wearable antenna is shown in Figure 15. From the results obtained, this presented antenna operates at two resonant frequencies 28 GHz and 38 GHz at the same time for 5G Applications. The simulation results are mentioned in Table 7.

Furthermore, the current distributions at each resonant frequency are simulated as shown in Figure 16 and Figure 17. In addition, the radiation pattern of the proposed wearable antenna in E-plane ($\phi = 0°$) and H-plane ($\phi = 90°$) are also plotted in Figure 18 and Figure 19. From these results, it was found that a good distribution of the current and good antenna gain and efficiency as shown in Figure 20 and Figure 21.

Figure 15. The return loss against frequency of the proposed planar 2F-inverted antenna

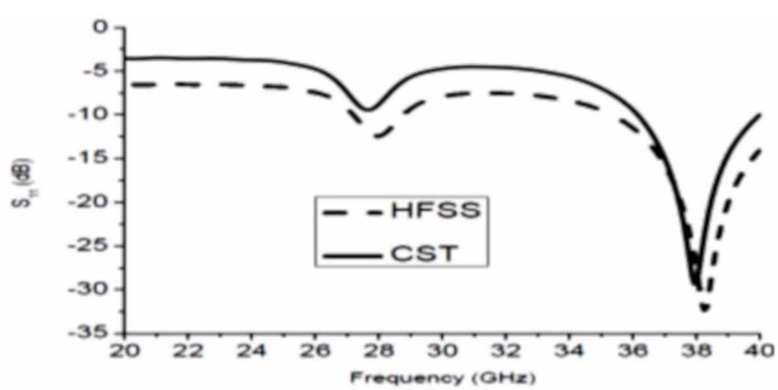


Table 7. The simulation results of a proposed rectangular wearable antenna for 5G applications

Resonant Frequency Bands (GHz)	Return Loss S11 (dB)	Gain (dB)	Total Efficiency (%)
28	13.425	1.45	55.9
38	36.276	5.85	62.3

Figure 16. Current distribution for the proposed 2F-inverted wearable antenna at 28 GHz

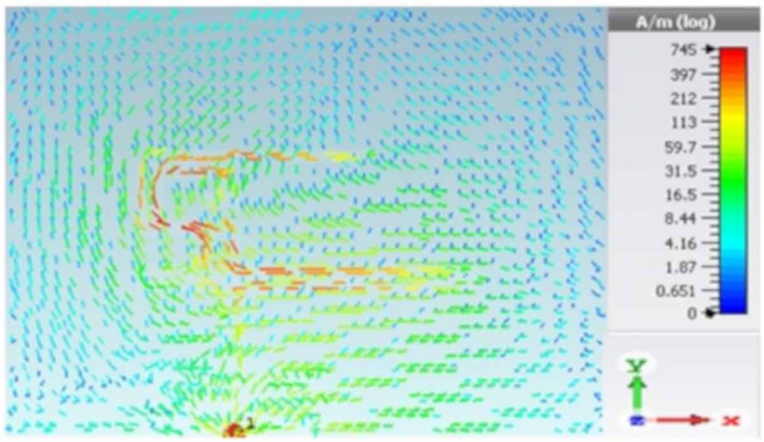
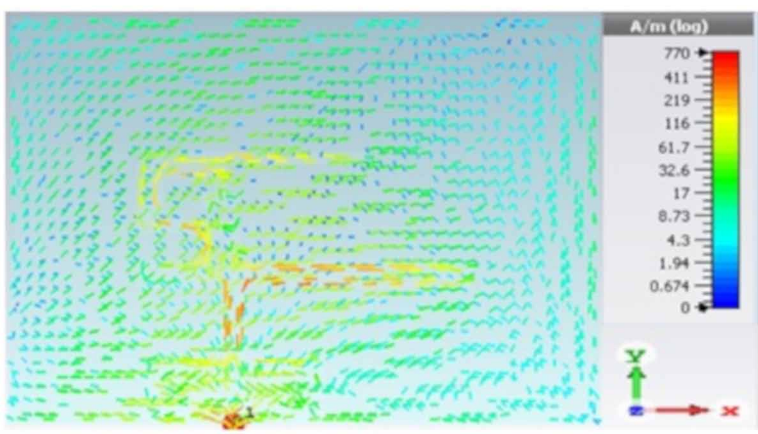


Figure 17. Current distribution for the proposed 2F-inverted wearable antenna at 38 GHz



SmartWatch Design

Nowadays, the field of smart wearable devices like smartwatches is growing rapidly and has attracted great attention from publications and industries (Wu, Wong, Lin & Su, 2007). Generally, smart wearable watches need access to wireless data networks, making antennas necessary part in the smartwatch. Furthermore, wearable smartwatch antennas represent many challenges for design engineers. It must

Figure 18. The radiation pattern for the proposed planar 2F-inverted wearable antenna in E-plane (ϕ = 0°) and H-plane (ϕ = 90°) at 28 GHz

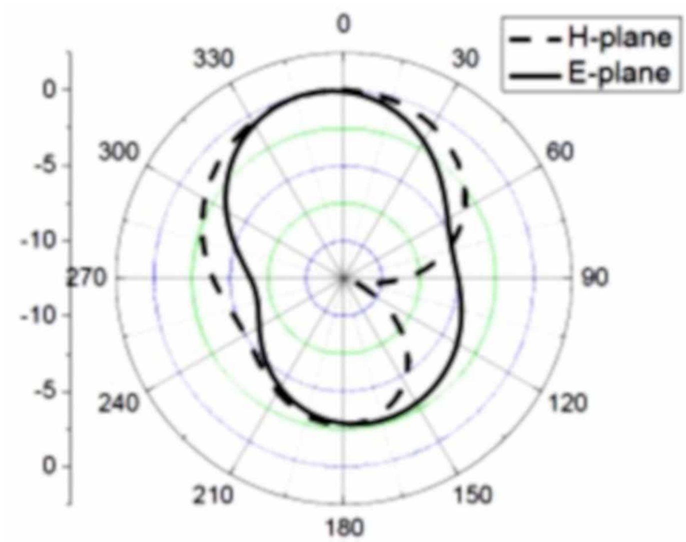
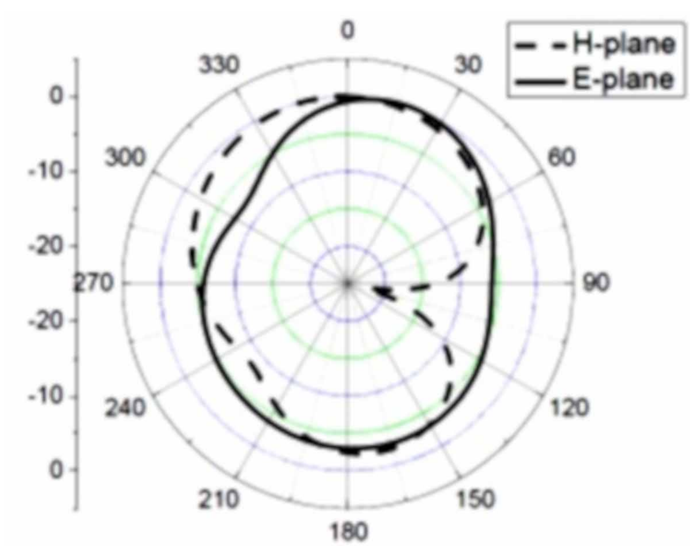


Figure 19. The radiation pattern for the proposed planar 2F-inverted wearable antenna in E-plane (ϕ = 0°) and H-plane (ϕ = 90°) at 38 GHz



be flexible, low profile, lightweight, small size, low cost and eases for integration to be worn or carried on human hand (Hamouda, Thuc, Staraj & Kossiavas, 2014). In this chapter, a smartwatch is designed, simulated and attached with a millimeter-wave antenna to operate on 5G wireless technologies. Figure 22 and Figure 23 illustrate the geometry of the watch with a practical size. This watch consists of two parts: the watch body and rubber straps. The dimensions and materials properties of the watch are tabulated in Table 8.

Figure 20. The performance results of a 2nd proposed wearable antenna gain

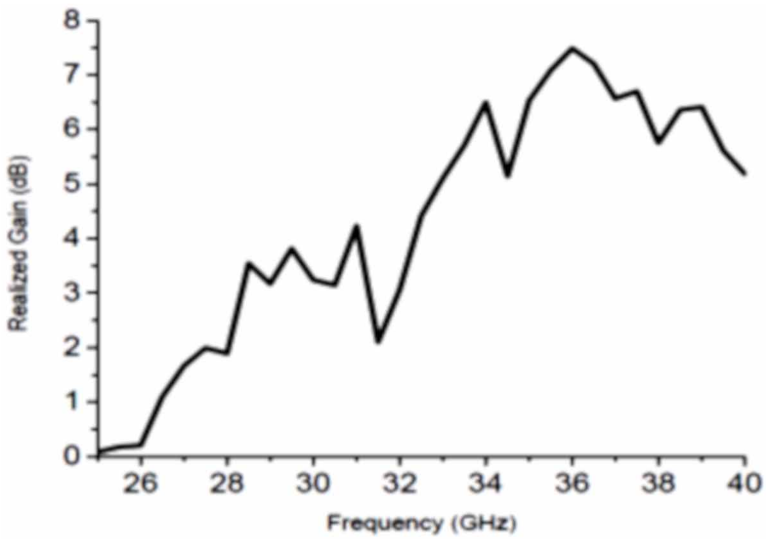


Figure 21. The performance results of a 2nd proposed wearable antenna efficiency

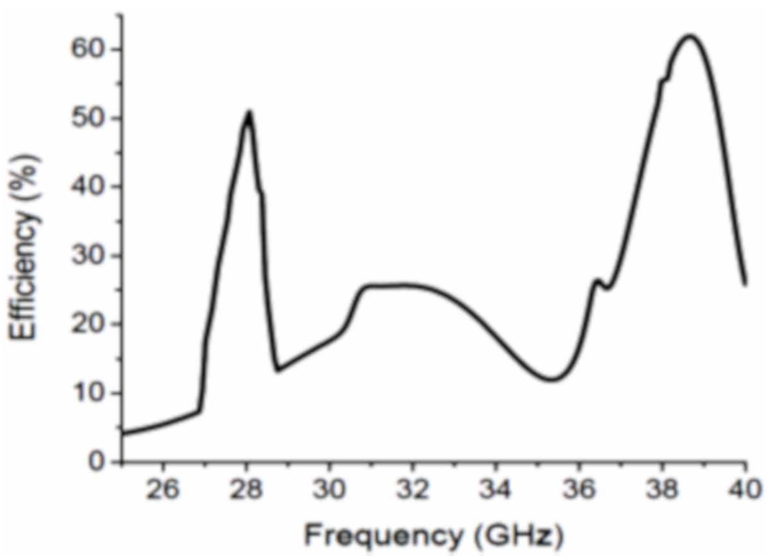


Figure 22. The geometry of smartwatch top view

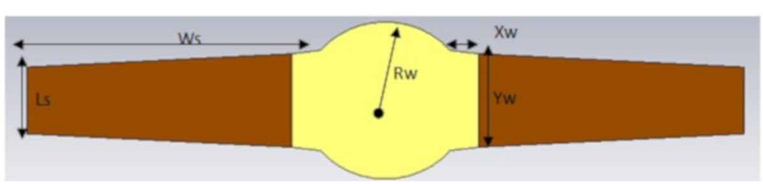


Figure 23. The geometry of smartwatch side view

Table 8. The Dimensions and the materials properties of the watch

Smart Watch										
Watch						Strap				
Material: Aluminum			Dimensions (mm)			Material: Rubber			Dimensions (mm)	
Thickness (mm)	Dielectric Constant (ε_r)	Loss Tangent (tan δ)	Rw	Xw	Yw	Thickness (mm)	Dielectric Constant (εr)	Loss Tangent (tan δ)	Ws	Ls
6	9.4	0.0004	23.5	7.96	28	1.9	3	0.0025	74	20

Next, the presented antenna above is integrated onto the designed watch to be smart. The antenna is placed near the main PCB board to obtain the required input power from the internal battery of the watch. The smartwatch with the first proposed rectangular millimeter-wave antenna is shown in Figure 24 and the simulated return loss for the first proposed rectangular antenna with and without a smartwatch is plotted in Figure 25. Further, the second proposed planar 2F-inverted millimeter-wave antenna is integrated on the smartwatch as shown in Figure 26. Also, the simulated return loss for the second proposed antenna with and without a smartwatch is plotted in Figure 27. From these results, there is a little shift in them; this is due to the presence of the smartwatch.

Now, the two presented millimeter-wave antennas above are integrated together onto the watch to be smart in three bands (28, 38, and 60 GHz) at the same times for 5G wireless communications. The geometry of the smartwatch with two proposed 5G antennas is shown in Figure 28. Also, the simulated return loss S_{11} and S_{22} for the two proposed antennas with a smartwatch is plotted in Figure 29. The presented smartwatch with two millimeter-wave antennas has good isolation with regard to s_{21} and s_{12} and s_{41} as it is seen from the *s*–parameter variations are given in Figure 30 where the isolation coefficient is lower than -70 dB.

Figure 24. The smartwatch with rectangular millimeter-wave antenna geometry

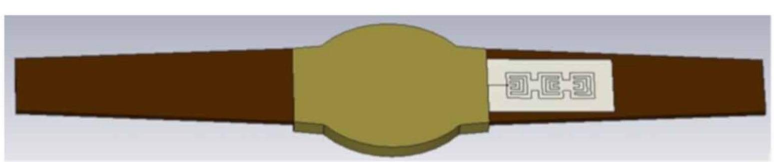


Figure 25. The smartwatch with rectangular millimeter-wave antenna S_{11} against frequency

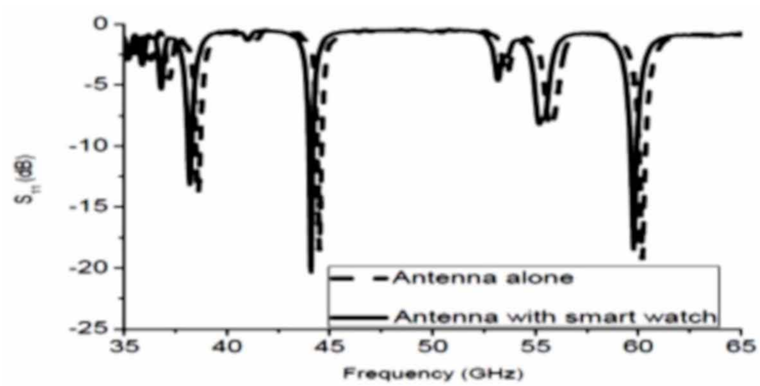


Figure 26. The smartwatch with planar 2F-inverted millimeter-wave antenna geometry

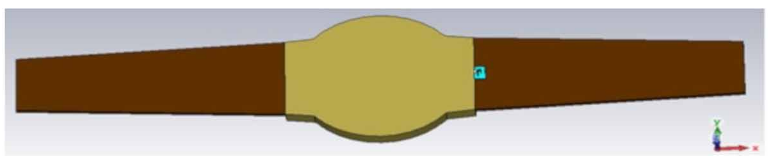


Figure 27. The smartwatch with planar 2F-inverted millimeter-wave antenna S_{11} against frequency

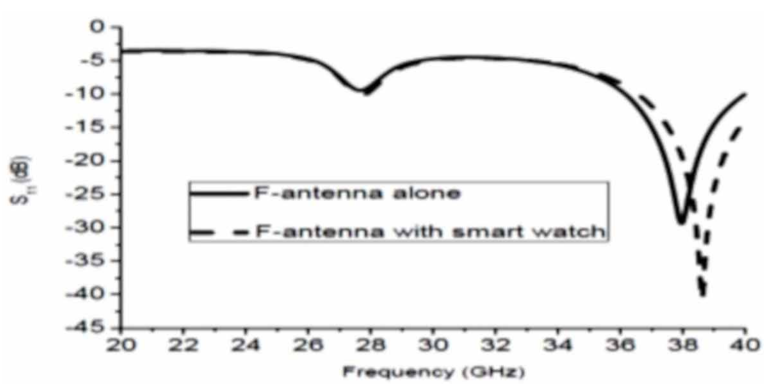


Figure 28. The smartwatch with two millimeter-wave antennas geometry

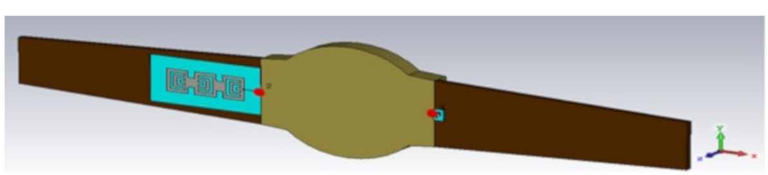
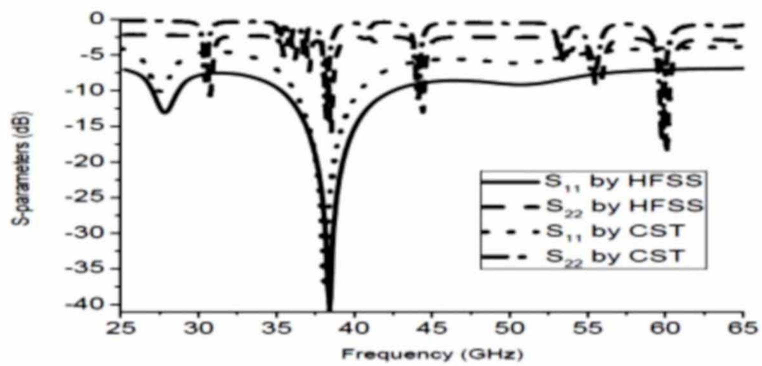


Figure 29. The smartwatch with two millimeter-wave antennas S_{11} and S_{22} against frequency



Smartwatch Under Bent Conditions

To investigate the effect of antenna bending on its impedance characteristics for the presented smartwatch with two millimeter-wave antennas, this study is carried out by bending it around a curved surface with a diameter of 150 mm. This dimension is typical of the human arm (Ferreira, Pire, Rodrigues & Caldeirinha, 2017). The results for a wearable smartwatch with two millimeter-wave antennas for flat and bending positions are shown in Figure 31, Figure 32, and Figure 33.

SAR Calculations

It is important to make sure that the humans are exposed to less electromagnetic waves and the presented smartwatch is safe. For these reasons, the specific absorption ratio (SAR) is studied, which must be satisfying the international safety standards, FCC (SAR < 1.6W/kg over 1g) and ICNIRP (SAR<2W/kg over 10g). Figure 34, Figure 35, and Figure 36 illustrate the simulated SAR distribution for the smartwatch with the two proposed millimeter-wave and attached to the human hand model at three resonant frequencies 28, 38, and 60 GHz, respectively. These results are mentioned in Table 9. From these results, the SAR values are safe enough. Finally, these proposed designs are compared with recently publishing work in the literature. These results are presented in Table 10.

FUTURE RESEARCH DIRECTIONS

In this chapter, the presented designs of the wearable antennas are fabricated using copper tape pasted on the substrate. But this copper tape is not very reliable in antenna fabrication, because of when the antenna bending, it flaked off or breaks. Nowadays, there is a new type of textile material is called electro-textile material which used as a conductive part in the wearable antenna. If we are using the electro-textile material as ground and radiating element and the textile material as the substrate, we can make a fully wearable antenna can be washable, it can be done as future work.

Figure 30. The smartwatch with two millimeter-wave antennas S_{12} and S_{21} against frequency

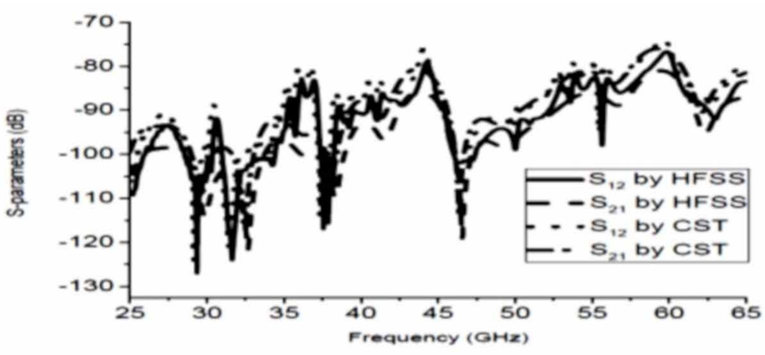


Figure 31. The proposed smartwatch bending watch geometry top view

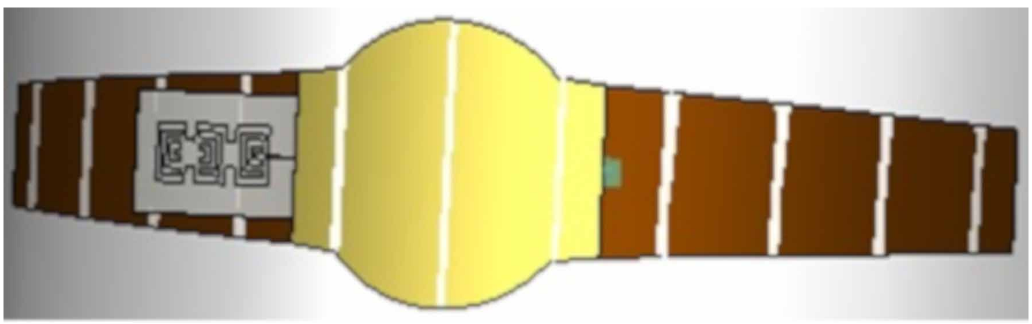


Figure 32. The proposed smartwatch bending watch geometry side view

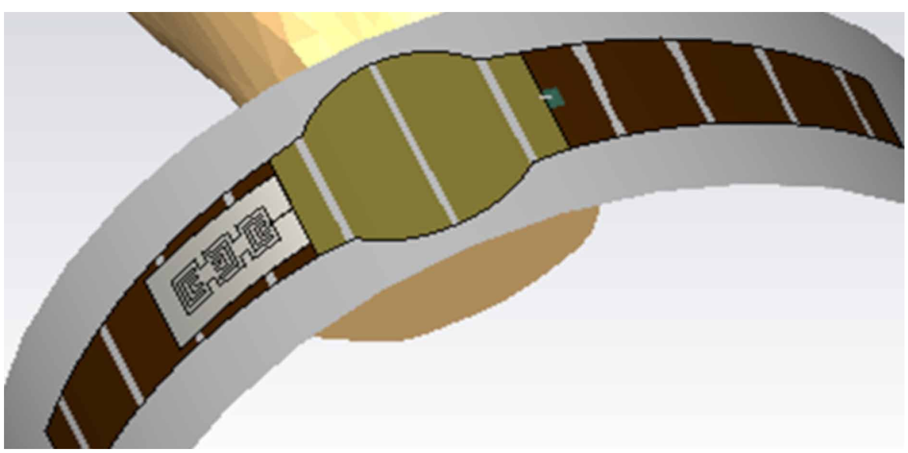


Figure 33. The proposed smartwatch bending S-parameter against frequency

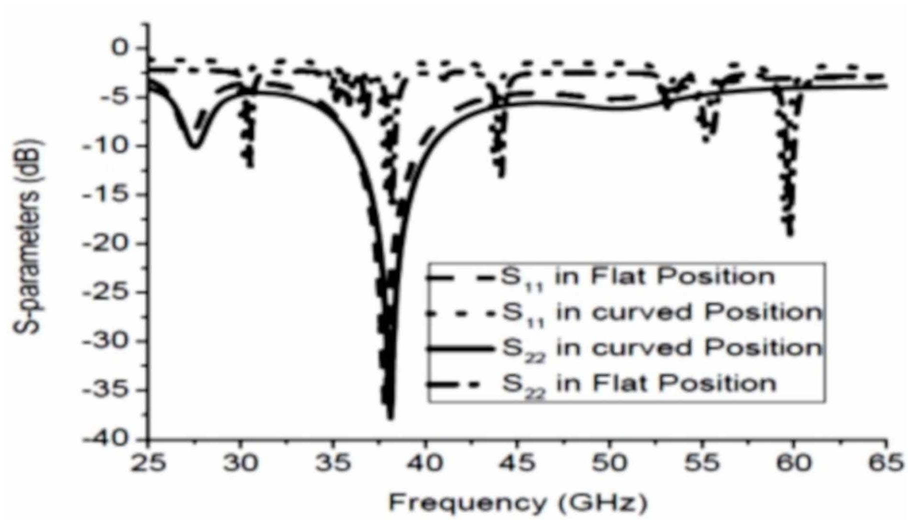
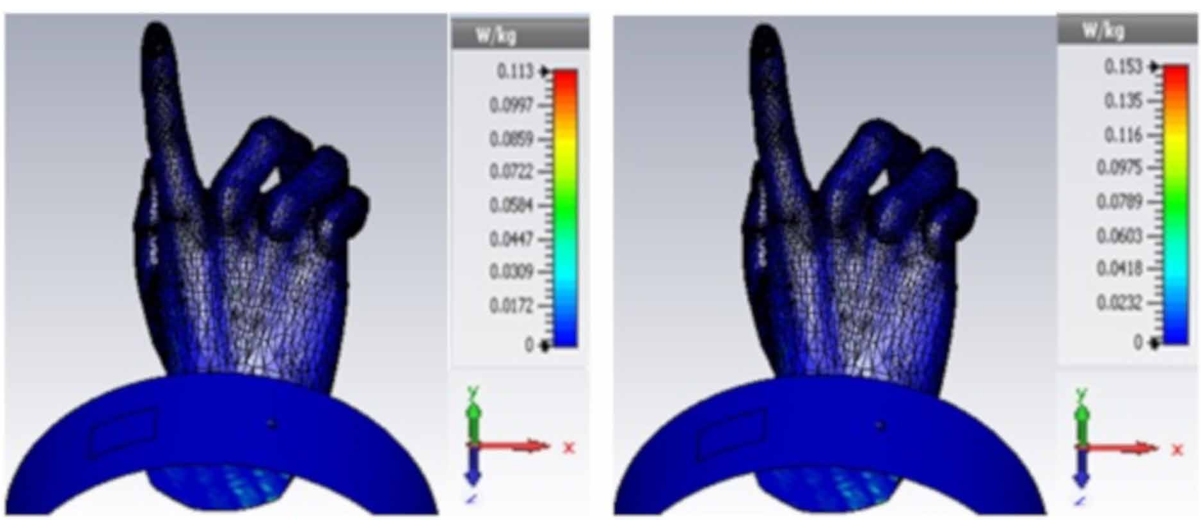


Figure 34. The SAR on human hand model (10g) in distance 10 mm from the smartwatch at 28 GHz



CONCLUSION

In this chapter, two different types of dual-band flexible wearable antennas are designed and simulated for integration onto a watch to make it smart for modern wireless 5G networks. The first one is a rectangular antenna with six U-slots on the patch. This wearable antenna combines the hardness and flexibility in that, it is printed on a material called “ULTRALAM® 3850HT”. This material is characterized by thin flexible cores with low and stable dielectric constant. This antenna is designed to operate at two resonant frequencies 38 GHz and 60 GHz. The second antenna is a planar inverted-2F wearable antenna pasted on jeans textile material as a substrate. For measuring the dielectric constant and loss tangent of

Figure 35. The SAR on human hand model (10g) in distance 10 mm from the smartwatch at 38 GHz

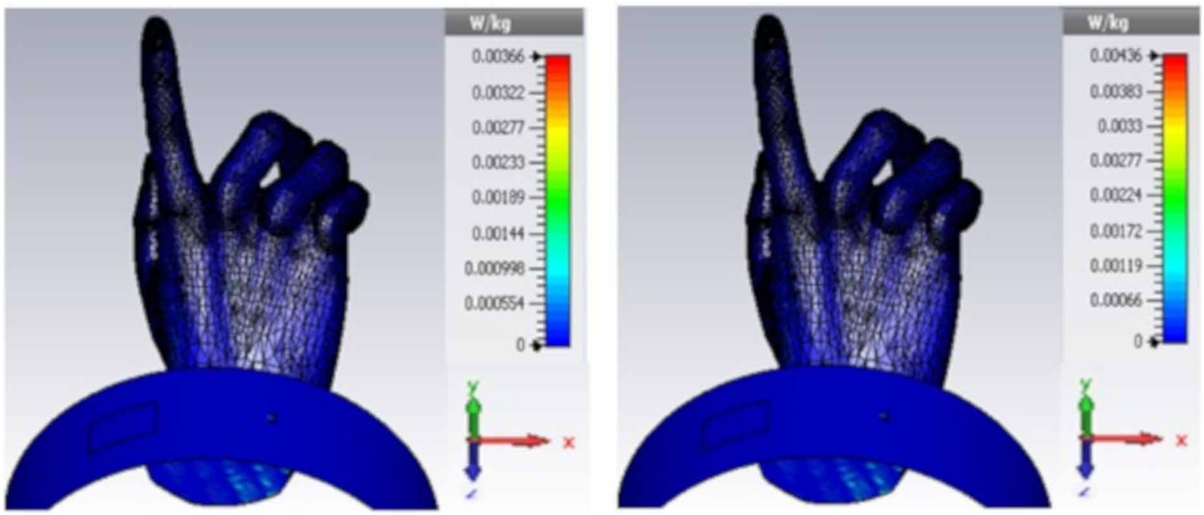


Figure 36. The SAR on human hand model (10g) in distance 10 mm from the smartwatch at 60 GHz

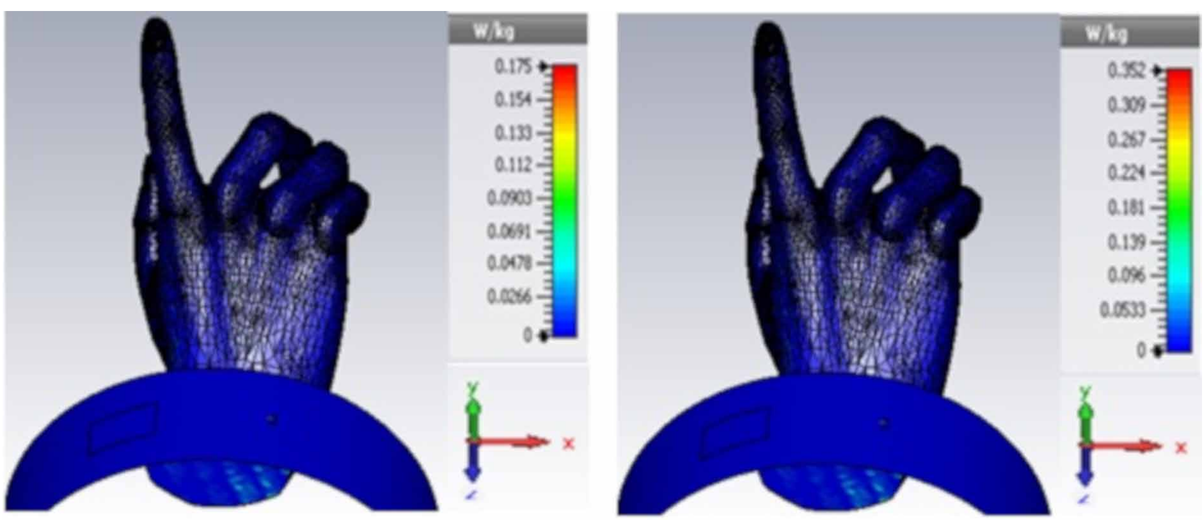


Table 9. The maximum SAR values for the presented smartwatch at a distance 10mm from the human hand by FCC (1g) & ICNIPR (10g) standards

Frequency (GHz)	**SAR value (w/kg)**			
	Due to the planar 2F-inverted antenna (1st antenna)		**Due to the rectangular antenna (2nd antenna)**	
	10g	**1g**	**10g**	**1g**
28	0.113	0.301	0.153	0.326
38	0.0366	0.104	0.0436	0.155
60	0.175	0.435	0.352	0.631

Table 10. Comparison between this work and other published works

Ref.	Resonant Frequencies	material	S_{11} (dB)	Gain (dB)	SAR Study	
					1g	10g
(Zhao, 2015)	0.75	Silicon Belt	-22	Not calculated	0.3	0.18
	1.8		-24		1	2.6
(Ying, 2014)	2	Rubber Belt	-24	Not calculated	1.3	1.1
(Lindsey, 2017)	2.36	Rubber Belt	-15.2	5	No study	
	2.61		-17	3.12		
This work	28	Rubber Belt with flexible textile antenna	-13.4	1.45	0.31	0.12
	38		-36.27	4.85	0.11	0.004
	60		-19.26	4.43	0.63	0.35

the jeans, two different methods are used: DAK equipment and ring resonator method. This antenna is designed and simulated to operate at two resonant frequencies 28 GHz and 38 GHz. The two proposed 5G-antennas are applied for founded of a smartwatch. So, the SAR values are considered important parameters and it is proved are very low, thus this smartwatch operates properly nears the human body. The effect of antennas bending on the performance characteristics is also studied.

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Chapter 5
BER Improvement in OFDM Systems Using Wavelet Transform Based on Kalman Filter

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ABSTRACT

Orthogonal frequency division multiplexing (OFDM) is an efficient method of data transmission for high speed communication systems over multipath fading channels. However, the peak-to-average power ratio (PAPR) is a major drawback of multicarrier transmission systems such as OFDM is the high sensitivity of frequency offset. The bit error rate analysis (BER) of discrete wavelet transform (DWT)-OFDM system is compared with conventional fast Fourier transform (FFT)-OFDMA system in order to ensure that wavelet transform based OFDMA transmission gives better improvement to combat ICI than FFT-based OFDMA transmission and hence improvement in BER. Wavelet transform is applied together with OFDM technology in order to improve performance enhancement. In the proposed system, a Kalman filter has been used in order to improve BER by minimizing the effect of ICI and noise. The obtained results from the proposed system simulation showed acceptable BER performance at standard SNR.

INTRODUCTION

The FFT based systems are replaced by one of the wavelet transforms called the discrete wavelet transform (DWT). Since DWT based OFDM does not use cyclic prefix, so a better spectral control of channels can be achieved. Discrete wavelet transform employs a low pass filter (LPF) and a high pass filter (HPF) which operates as a quadrature mirror filters fulfilling perfect reconstruction and orthogonal properties. In order to transmit the modulated signal zero padding and vector transposing is done in DWT OFDM systems. The use of wavelet promises to reduce the inter symbol interference (ISI) and inter carrier interference (ICI). The wavelet transform offers a higher suppression of side lobes. First,

DOI: 10.4018/978-1-7998-1152-7.ch005

gives the already existing self-cancellation scheme and adaptive modulation to decrease ICI in OFDM system have been explained. Kalman filter (KF) method, statistically estimate the frequency offset and correct the offset, using the estimated value at the receiver. It has been showed that using Kalman filter with DWT based OFDM systems; improvement in BER can be made Kalman filter has been discussed laterally. From discussion then observed that the proposed DWT-based OFDM system outperforms than other existing schemes.

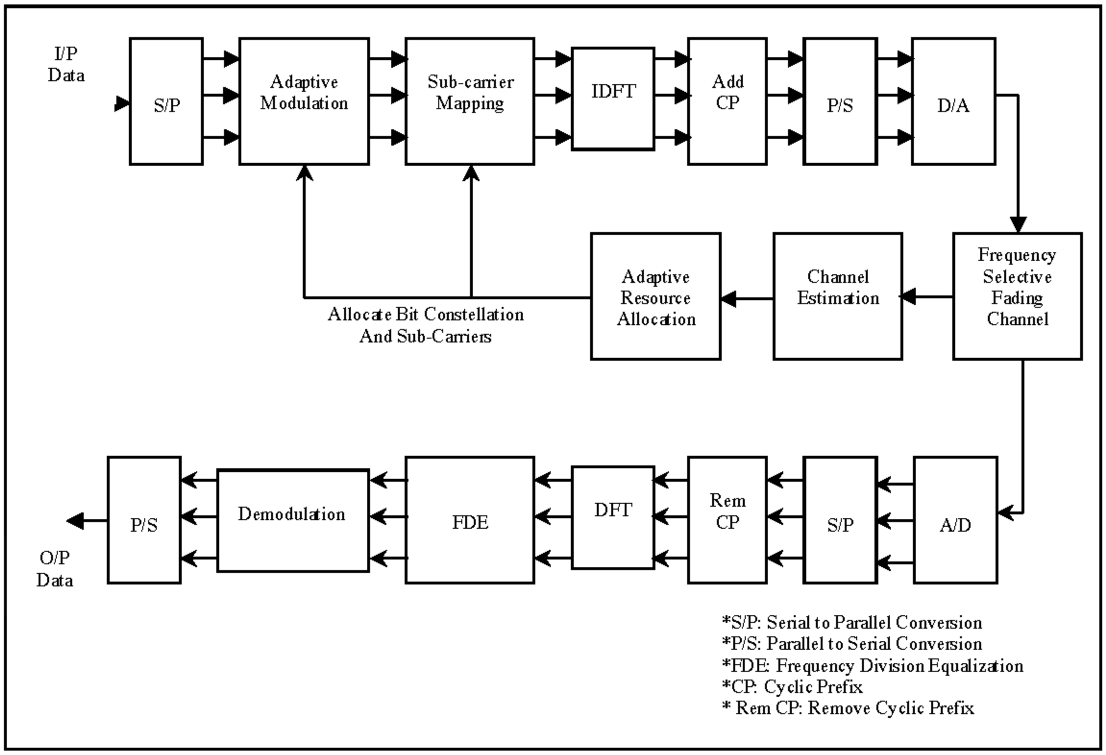
Expansion of OFDM and OFDMA

A major restriction in the transmission of high bit rates over a wireless medium is the large delay spread come from multipath propagation. The delay spread causes inter-symbol interference (ISI) which restricts the maximum achievable data rate. To overcome this limit and others, orthogonal frequency division multiplexing (OFDM) has been successfully employed in wireless systems. The basic idea underlying this technique is to partition the entire bandwidth into several narrowband subcarriers and the amnesty to multipath propagation acquires from the fact that an OFDM system transmits information on multiple orthogonal frequency carriers, each operating at a low bit rate. Moreover, OFDM has the following three main advantages: (1) Spectral efficiency is high (2) Easy to implement and (3) robustness against multipath delay spread. Since OFDM system subcarriers can be shared among multiple users, orthogonal frequency division multiple accesses (OFDMA) has been expected. The subcarriers are common among users, each having a mutually displace set of subcarriers, by setting up the subcarriers to the users with the best channel status for the specific subcarrier over others. The procedure, of course, is not simple since the best subcarrier of one user may be also the best subcarrier of another user who may not have any alternative one. Arranging the subcarriers and bit constellations in an excellent manner is called adaptive resource allocation which will be discussed below in this chapter.

An uplink OFDMA system block diagram is shown in Figure 1. The QAM input symbols are delivered into an inverse fast Fourier transform (IFFT) block (Krishna et al., 2018). Using channel estimation information feedback, adaptive resource allocation assigns a set of subcarriers to every user and adapts bit constellations for the data mapped in the assigned subcarriers. After IFFT, a cyclic prefix (CP) is added to the front of an OFDM symbol. As long as the CP length is larger than the wireless channel delay spread, only 1- tap frequency domain equalization per subcarrier is required to recover the transmission data. The function of rest of the receiver blocks essentially to invert the operations at the transmitter (Sreekanth et al., 2018).

On the other hand, the OFDMA waveform shows very clear-cut envelope variations resulting in a high peak-to-average power ratio (PAPR). Signals with a high PAPR desire highly linear power amplifiers toward off exaggerated inter-modulation distortion. In order to attain this linearity, the amplifiers have to run with a large back-off from their peak power capacity (Pareyani et al., 2012). This results in low power efficiency measured by the ratio of transmitted power to dc power dissipated, places a significant load on portable wireless terminals. Another problem with OFDMA in cellular uplink transmissions derives from the unavoidable offset in frequency references among the different terminals that transmit together. Frequency offset damages the orthogonality of the transmissions, thus introducing multiple access interference (Sreekanth et al., 2018).

Figure 1. Block diagram of uplink OFDMA system



Advantages of OFDM system:

- High spectral efficiency as compared to other double sideband modulation schemes, spread spectrum, etc.
- Can easily adapt to severe channel conditions without complex time-domain equalization.
- Robust against narrow-band co-channel interference.
- Robust against intersymbol interference (ISI) and fading caused by multipath propagation.
- Efficient implementation using Fast Fourier Transform (FFT).
- Low sensitivity to time synchronization errors.
- Tuned sub-channel receiver filters are not required (unlike conventional FDM).
- Facilitates single frequency networks (SFNs); i.e., transmitter macro_diversity.

Disadvantages of OFDM system:

- Sensitive to doppler shift.
- Sensitive to frequency synchronization problems.
- High peak-to-average-power ratio (PAPR), requiring linear transmitter circuitry, which suffers from poor power efficiency.
- Loss of efficiency caused by cyclic prefix/guard interval.

To overcome these disadvantages, 3GPP investigated a modified form of OFDMA for uplink.

SELF-CANCELLATION METHOD

Intercarrier Interference (ICI) is an impairment well known to degrade performance of Orthogonal Frequency Division Multiplexing (OFDM) transmissions. It arises from carrier frequency offsets (CFOs), from the Doppler spread due to channel time-variation and, to a lesser extent, from sampling frequency offsets (SFOs).

A number of carrier frequency offset (CFO) estimation algorithms have been presented in the literature. Some of them are quite simple, while some are more computationally demanding. The main disadvantage of OFDM, however, is its susceptibility to little differences in frequency at the transmitter and receiver, in general referred to as frequency offset. This frequency offset can be cause by doppler shift owing to relative motion between the transmitter and receiver or by differences linking the frequencies of the local oscillators at the transmitter and receiver. To eliminate the problem of inter symbol interference a guard time inserted between two symbols, duration of guard interval should be greater than maximum delay spread. Guard time consists of no signal at all. Among the all ICI cancellation schemes, the ICI-self cancellation scheme is a simple way for ICI reduction. The main idea is to modulate one data symbol onto the next sub-carrier with predefined inversed weighting coefficient "-1". In this part, the frequency offset is modeled as a multiplicative factor introduced in the channel, as exposed in Figure 2.

The received signal is given by,

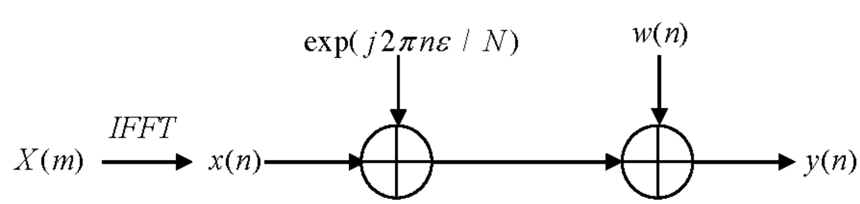
$$y(n) = x(n)\ e^{\frac{j2\pi n\varepsilon}{N}} + w(n) \tag{1}$$

where ε is the normalized frequency offset, and is given by ΔfNT_s. Δf is the frequency difference between the received and transmitted carrier frequencies and T_s is the subcarrier symbol period and $w(n)$ is the additive white Gaussian noise introduced in the channel.

The outcome of this frequency offset on the received symbol flow can be understood by taking into consideration the received symbol $Y(k)$ on the k^{th} sub-carrier.

$$Y(k) = X(k)S(0) + \sum_{l=0,l\neq k}^{N-1} X(l)S(l-k) + n_k \qquad k = 0,1..........N-1 \tag{2}$$

Figure 2. Frequency offset model



Somewhere N is the total number of subcarriers, $X(k)$ is the transmitted symbol (M-ary phase-shift keying, for example) for the k^{th} subcarrier, n_k is the FFT of $w(n)$, and $S(l\text{-}k)$ are then complex coefficients for the inter carrier interference components in the received signal. The inter carrier interference components are the interfere signals transmitted on sub carriers other than the k^{th} sub-carrier. The complex coefficients are given by:

$$S(l-k)=\frac{\sin(\Pi(l+\varepsilon-k))}{\mathrm{N}\sin(\Pi(l+\varepsilon-k)/\mathrm{N})}\exp\left(j\Pi(1-\frac{1}{N})(l+\varepsilon-k)\right) \tag{3}$$

Inter carrier interference self-cancellation is a scheme that was introduced by Yuping Zhao and Sven-Gustav Häggman in 2001 to battle and suppress Inter carrier interference in OFDM. Concisely, the major thought is to modulate the input data symbol onto a group of subcarriers with predefined coefficients such that the generated Inter carrier interference signals within that group cancel each other, hence the name self- cancellation.

ICI Canceling Modulation

The basic requirement of ICI self-cancellation scheme is that the transmitted signals be embarrassed such that $X(1) = -X(0)$, $X(3) = -X(2)$, $X(5) = -X(4)$, …, $X(N-1) = -X(N-2)$. Using (3), this task of transmitted symbols allows the acknowledged signal on subcarriers k and $k + 1$ to be written as:

$$Y'(k)=\sum_{\substack{l=0\\ l=even}}^{N-2} X(l)[S(l-k)-S(l+1-k)]+n_k \tag{4}$$

$$Y'(k+1)=\sum_{\substack{l=0\\ l=even}}^{N-2} X(l)[S(l-k-1)-S(l-k)]+n_{k+1} \tag{5}$$

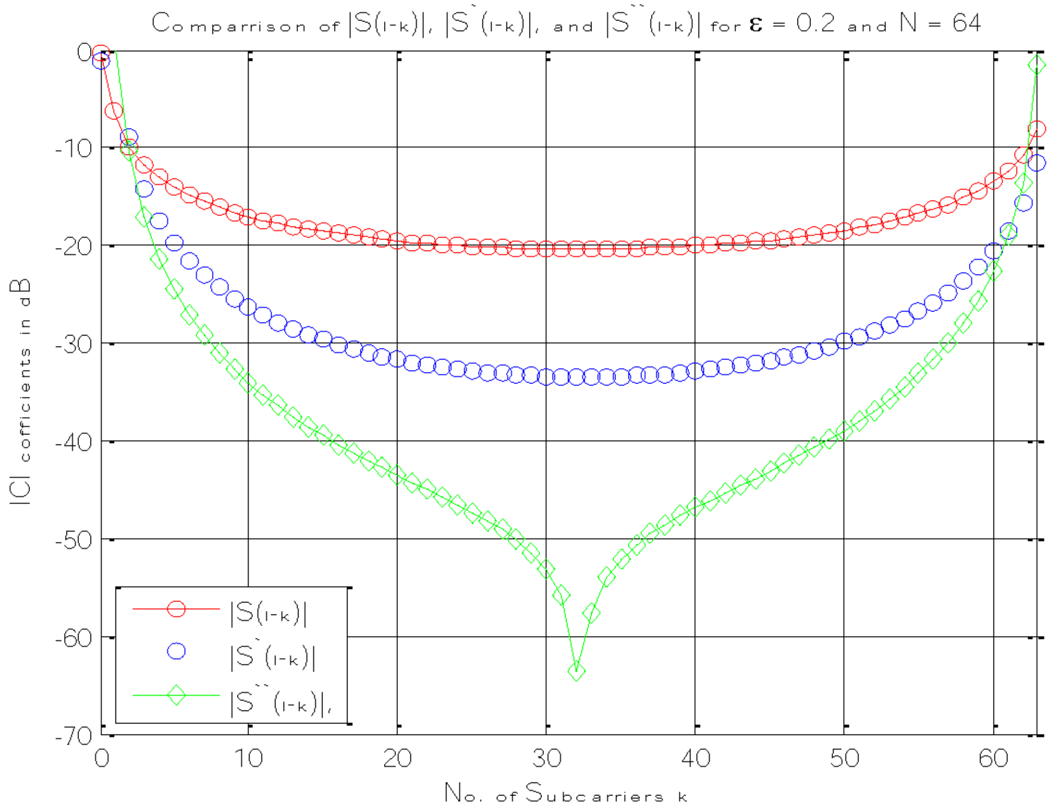
$$S''(l-k)=S(l-k)-S(l+1-k) \tag{6}$$

and the ICI coefficient $S'(l\text{-}k)$ is denoted as:

Figure 3 shows a comparison between $\left|S'\left(l-k\right)\right|$ and $|S(l\text{-}k)|$ on a logarithmic level. It is seen that $\left|S'\left(l-k\right)\right| << \left|S\left(l-k\right)\right|$ for most of the $l\text{-}k$ values. Hence, the Inter carrier interference mechanisms are much smaller in (6) than they are in (3). Also, the total number of interference signals is halved in (2) as opposed to (3) since only the even subcarriers are concerned in the summation.

It is seen that the difference of ICI coefficient between two consecutive subcarrier {(S ($l\text{-}k$) and S(l+1-k)} is very small. Therefore, if a data pair (a, -a) is modulated onto two adjacent subcarriers (l,

Figure 3. Comparison among various ICI components



l+1), where a is a complex data, then the ICI signals generated by the subcarrier l will be cancelled out significantly by the ICI generated by subcarrier l+1.

ICI Canceling Demodulation

Inter carrier interference modulation introduces idleness in the received signal since each couple of subcarriers transmit only one data symbol. This redundancy can be broken to improve the system power performance, while it definitely decreases the bandwidth efficiency. To obtain advantage of this redundancy, the received signal at the $(k+1)^{th}$ subcarrier, where k is even, is subtracted from the k^{th} subcarrier. This is expressed mathematically as:

$$Y''(k) = Y'(k) - Y'(k+1)$$

Subsequently, the ICI coefficients for this received signal becomes

$$= \sum_{\substack{l=0 \\ l=even}}^{N-2} X(l)[-S(l-k-1)+2S(l-k)-S(l-k+1)]+n_k-n_{k+1} \quad (7)$$

$$S''(l-k) = -S(l-k-1)+2S(l-k)-S(l-k+1) \quad (8)$$

When compared to the two earlier ICI coefficients $|S(l\text{-}k)|$ for the standard OFDM system and $|S'(l-k)|$ for the ICI canceling modulation, $|S''(l-k)|$ has the smallest inter carrier interference coefficients, for the best part of l-k values, followed by $|S'(l-k)|$ and $|S(l\text{-}k)|$. This is shown in Figure 4 for $N = 64$ and $\varepsilon = 0.4$. The collective modulation and demodulation process is called the inter carrier interference self-cancellation scheme. Thus, the ICI signals become smaller when applying ICI cancelling modulation. On the other hand, the ICI canceling demodulation can further reduce the residual ICI in the received signals.

The decrease of the inter carrier interference signal levels in the ICI self-cancellation method leads to a superior CIR. From (8), the theoretical CIR can be derived as:

$$CIR = \frac{|-S(-1)+2S(0)-S(1)|^2}{\sum_{L=2,4,6,...}^{N=1} |-S(l-1)+2S(l+1)|^2} \quad (9)$$

Figure 4. CIR versus normalized frequency offset ε

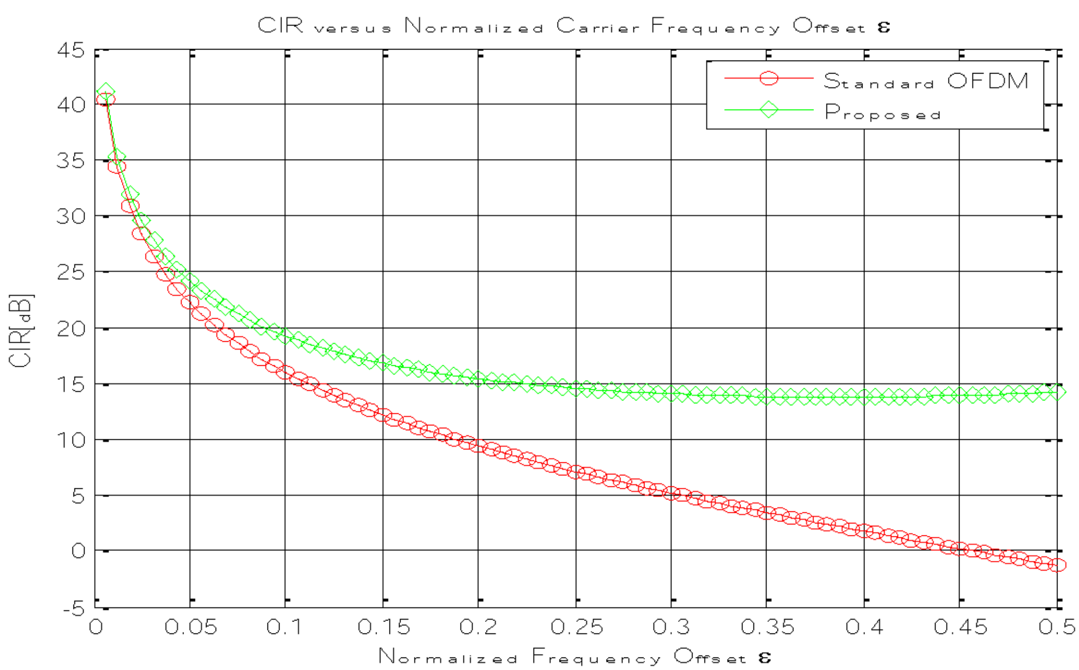


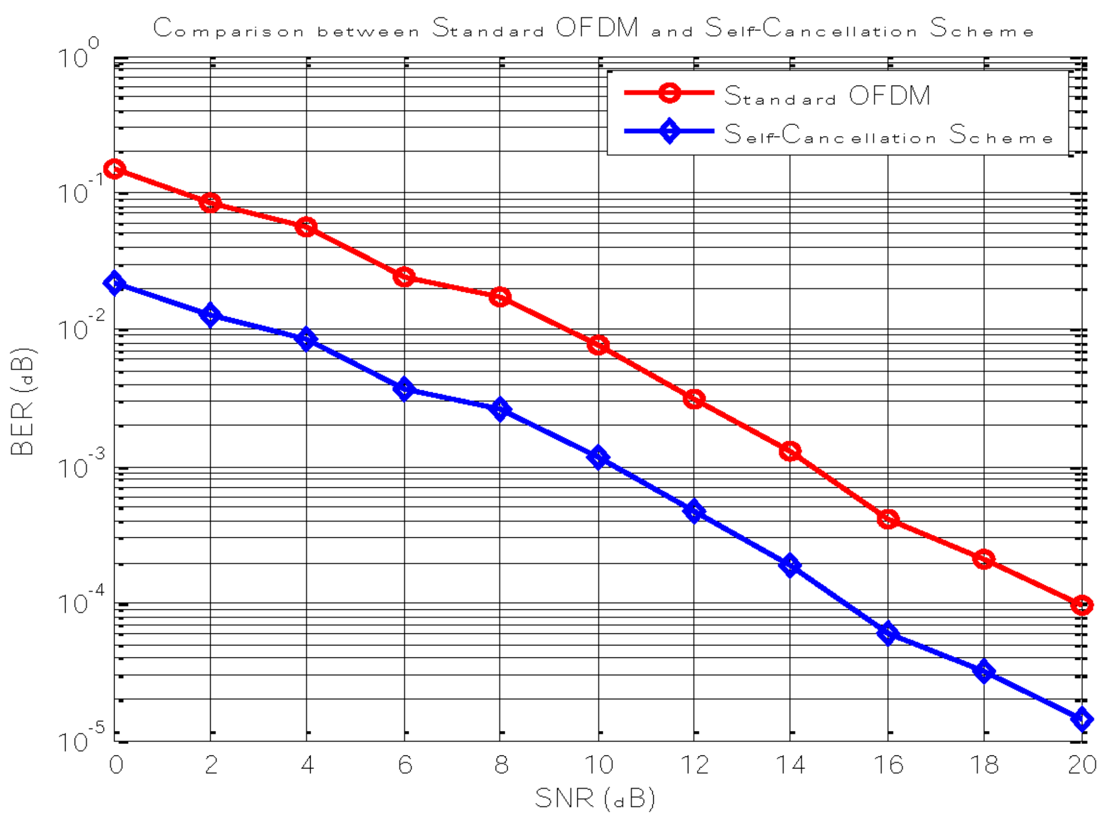
Figure 5 above shows the comparison of the theoretical CIR curve of the ICI self -cancellation scheme, calculated by (9), and the CIR of a standard OFDM system calculated by (3). As expected, the CIR is very much improved using the inter carrier interference self-cancellation scheme. The improvement can be greater than 15 dB for $0 < \varepsilon < 0.5$. Figure 5 shows comparison between standard OFDM system and self-cancellation based OFDM system. It shows that self-cancellation performs better than standard OFDM system.

As mentioned above, the idleness in this scheme reduces the bandwidth effectiveness by half. This could be rewarded by transmitting signals of larger alphabet size. Using the speculative results for the improvement of the CIR should increase the power efficiency in the system and gives better results for the BER. Hence, there is a tradeoff between bandwidth and power tradeoff in the inter carrier interference self-cancellation scheme.

ADAPTIVE MODULATION SCHEME IN OFDM SYSTEM

Orthogonal frequency division multiplexing (OFDM) is an attractive technique for combating the effects of delay spread in high-speed wireless data transmission. One way to improve the performance is to use adaptive modulation, where the modulation used on each sub channel is dependent on the multipath

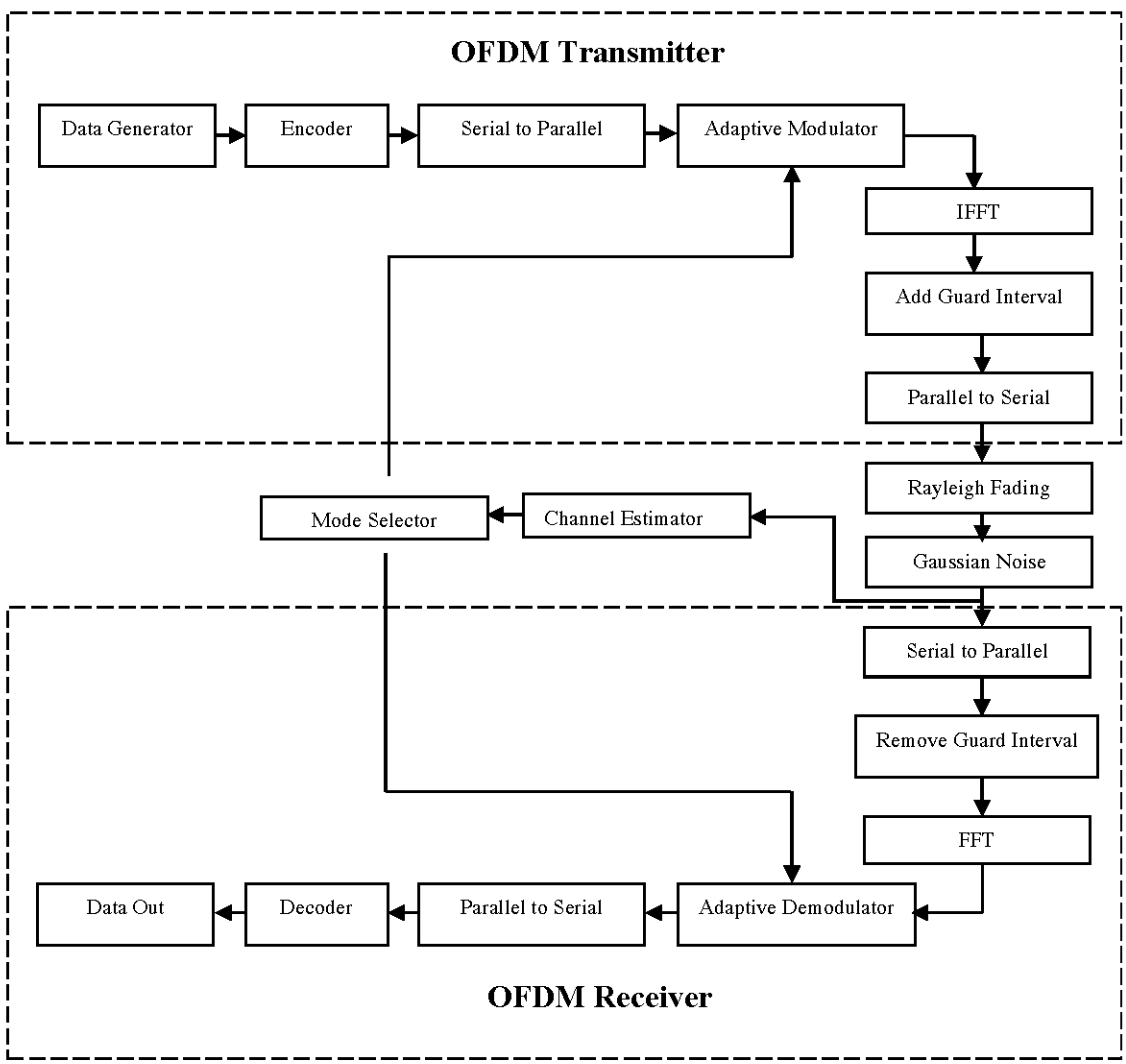
Figure 5. Standard OFDM BER vs. self-cancellation BER



channel response for that sub channel. In an OFDM transmission system, each subcarrier is attenuated individually under the frequency-selective and fast fading channel.

The channel performance may be highly fluctuating across the subcarriers and varies from symbol to symbol. If the same fixed transmission scheme is used for all OFDM subcarriers, the error probability is dominated by the OFDM subcarriers with highest attenuation resulting in a poor performance. Therefore, in case of frequency selective fading the error probability decreases very slowly with increasing average signal-to-noise ratio (SNR). To achieve the performance advantages of adaptive modulation, however, accurate receiver channel state information (CSI) is required at the transmitter. In wireless communications, because the channel is noisy and time-varying, the estimated channel response may be noisy and outdated. Figure 6 shows the block diagram of OFDM transmission and reception based on adaptive modulation scheme.

Figure 6. Block diagram of OFDM system using adaptive modulation scheme



OFDM using a small symbol rate and the use of a guard period minimize multipath. Potential for a high SNR means that high modulation scheme can be used in OFDM systems, allowing for improved system spectral efficiency. Furthermore, each subcarrier can be allocated a different modulation method based on the calculated channel conditions.

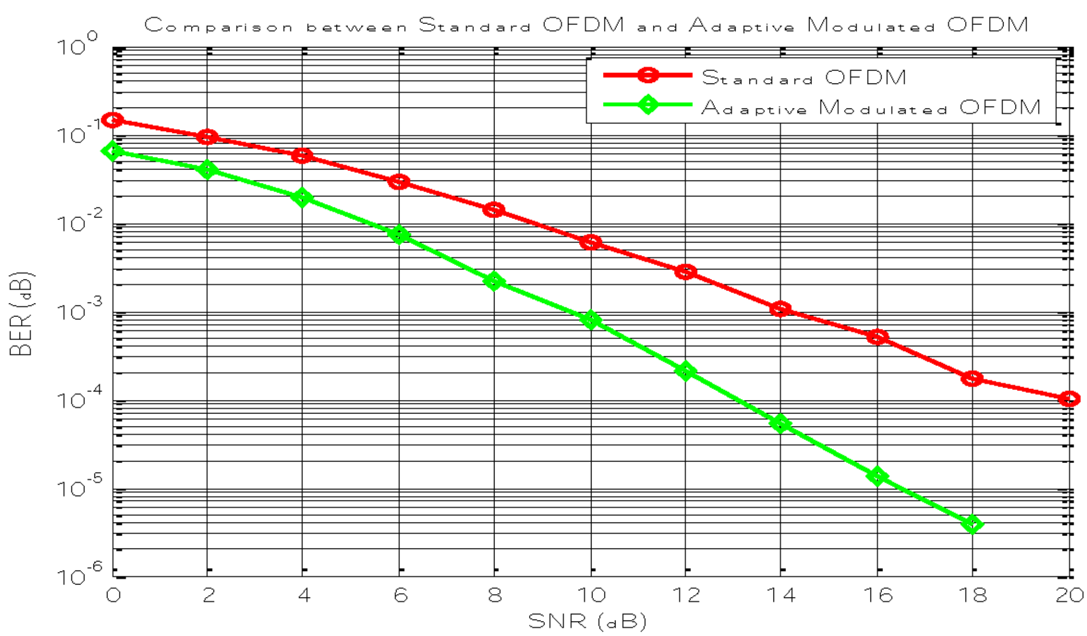
These measurements can be easily obtained as part of the channel equalization step, allowing subcarriers to be dynamically allocated modulation schemes based on the SNR of each subcarrier.

These variations in SNR arise due to interference, transmission distance, frequency selective fading, etc. This technique is known as adaptive modulation. Those subcarriers with a low SNR can be allocated to use BPSK (1 b/s/Hz) or to transmit no data at all. Subcarriers with a high SNR can transmit higher modulation schemes such as 256-QAM (8 b/s/Hz) allowing a higher system throughput. The modulation allocation is flexible in OFDM systems allowing them to be optimized to local current conditions, rather than having to always use a low modulation scheme just to ensure the system operates during worst-case conditions.

Once each subcarrier has been allocated bits for transmission, they are mapped using a modulation scheme to a subcarrier amplitude and phase, which is represented by a complex in-phase and quadrature-phase (IQ) vector. A large number of modulation schemes are available allowing the number of bits transmitted per carrier per symbol to be varied. For example, with a 16-QAM modulation scheme, it maps 4 bits for each symbol. Each combination of the 4 bits of data corresponds to a unique IQ vector.

Figure 7 shows the BER performance of OFDM system based on adaptive modulation with conventional OFDM system. Adaptive modulation based OFDM system outperforms than standard OFDM system.

Figure 7. BER performance of OFDM system using adaptive modulation



WAVELET TRANSFORM BASED OFDM SYSTEM TO IMPROVE BER WITH KALMAN FILTER (PROPOSED SCHEME)

We know that the Bandwidth is the most precious commodity in all communication systems such as 2G, 3G and 4G. Each service provider now searching, that how can we accommodate a large numbers of users with in a limited allocated bandwidth, In order to increase the data rate of wireless medium with superior performance, orthogonal frequency division multiplexing (OFDM) is chosen. The bit error rate analysis (BER) of discrete wavelet transform (DWT)-OFDM system is compared with conventional fast Fourier transform (FFT)-OFDM system in order to ensure that wavelet transform based OFDM transmission gives better improvement to combat ICI than FFT based OFDM transmission and hence improvement in BER. Wavelet transform is applied together with OFDM technology in order to improve more performance enhancement. In our proposed system we are using Kalman filter in order to improve BER by minimizing the effect of ICI and noise. Obtained results from proposed system simulation showed acceptable BER performance at low SNR. Wavelets are known to have compact hold (localization) both in time and frequency domain, and acquire better orthogonality (Chisab et al., 2013).

Since DWT based OFDM does not use cyclic prefix, so a better spectral containment of channels can be achieved. Discrete wavelet transform employs low pass filter (LPF) and high pass filter (HPF) which operate as quadrature mirror filters fulfilling perfect reconstruction and orthogonal properties.

Discrete Wavelet Transform Based OFDM System DWT-OFDM

Discrete wavelet transform is another way to implement OFDM system, such a system is called as wavelet based OFDM i.e. DWT-OFDM, in this transform the time-windowed composite exponentials are replaced by wavelet "carriers", at different scales *(j)* and positions on the time axis *(k).* These functions are generated by the translation and dilation of a unique function, called "mother wavelets" and denoted by ψ (t) as given by equation (3.10):

Wavelet carriers show improved time-frequency localization than complex exponentials. The orthogonality among wavelet carriers can be achieved by generating members of wavelet family, according to equation (11) and (12):

$$\Psi_{j,k}(t) = 2^{-j/2}\Psi(2^{-j/2} - k) \tag{10}$$

$$\langle \psi_{j,k}(t), \psi_{\mathrm{a,b}}(t) \rangle = 1, \text{ if } j = a,\ k = b \tag{11}$$

$$\langle \psi_{j,k}(t), \psi_{\mathrm{a,b}}(t) \rangle = 0, \text{ otherwise} \tag{12}$$

Fourier transform based OFDM system has been a popular choice for wireless transmission over a long time for its better transmission performances. But wastage of bandwidth brought by adding cyclic prefix in FFT, FFT based OFDM systems are now replaced Wavelet transform based OFDM systems which allows saving of bandwidth.

In fourier transform analysis the signal which is to be transmitted is broken into a set of an infinite sum of sines and cosines terms to promise the orthogonality relationship between them. While in case of wavelet transform the signal is decomposed by a pair of low-pass (LP) and high-pass (HP) filters. Each of the filters output contains half of the frequency components and hence it can be down-sampled. At the filters output we get approximation coefficients and detail coefficients from *g(n)* and *h(n)* filters respectively as shown in Figure 8 (a). Where *g(n)* and *h(n)* are the wavelet's half-band low pass filter and high pass filter impulse responses.

In wavelet transform these two coefficients are obtained by performing convolution between the input signals and filter coefficients.

Decomposition process is repeated by a series of high and low pass filters until we are left with a coefficient sequence of wavelets that are orthogonal in nature, the original signal is then reconstructed by performing the reverse operation of this decomposition. The equations obtained at the output of LPF and HPF is given by equations (14) and (15):

$$\psi_{lpf}(n) = \sum_{k=-\infty}^{k=+\infty} x(k)g(2n-k) \tag{14}$$

$$\psi_{hpf}(n) = \sum_{k=-\infty}^{k=+\infty} x(k)\,\mathrm{h}(2n-k) \tag{15}$$

One most important benefit of wavelet packet analysis that attracts communication system is "accurate reconstruction" using wavelet coefficients. In the trans-receiver model as shown in Figure 9, at the transmitter side, the input binary data mapped on the data to modulator (QAM), which converts binary data d_k into symbols X_{mi}, where i=0,1,2,3,…,n.

Each X_{mi} symbol is firstly converted into serial representation having a vector *XX* which will next be transposed into *CA*. Since, at the transmitter side we will perform inverse discrete wavelet transform (IDWT) but for IDWT operation we required two inputs, so we consider zero padding as second input of IDWT transmitter. After this the signal is up-sampled and filtered by the LPF coefficients or approximation coefficients. Since our goal is to have low frequency components of the signal, the modulated signals *XX* now accomplish circular convolution with LPF filter while the HPF filter performs the convolution

Figure 8. Wavelet transform based decomposition and reconstruction

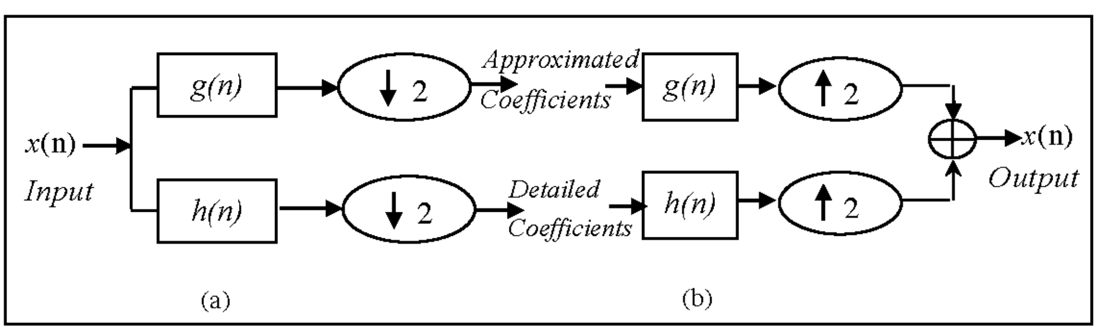
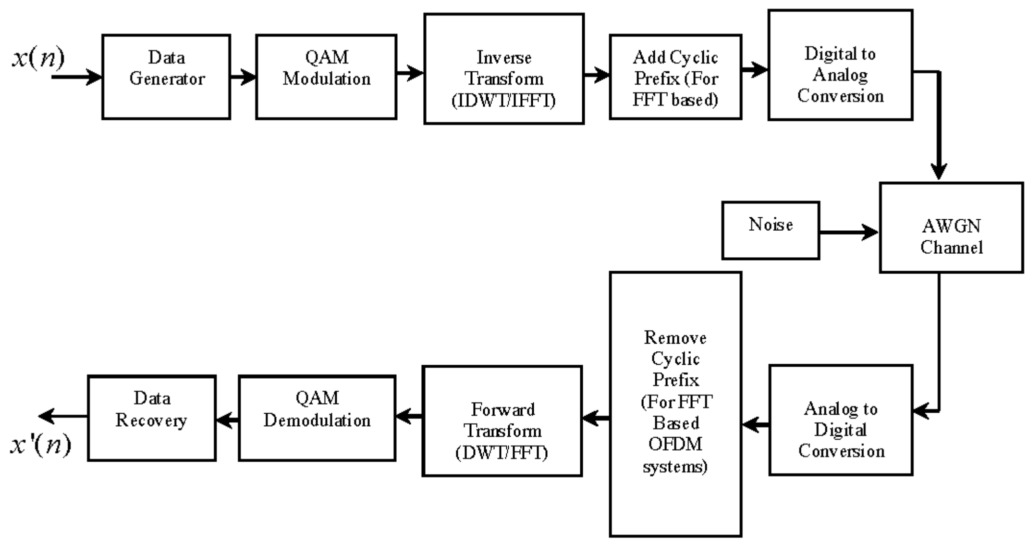


Figure 9. Wavelet transform based OFDM transceiver



with zeroes padding signals *CD* respectively. The HPF filter contains detailed coefficients and this data is given as an input IDWT block where a particular wavelet (haar or bior or db2 etc. it is discussed below) is chosen for simulation and it is observed that a better performance can be obtained as compared to FFT based OFDM. To modulate spread data symbol on the orthogonal carriers, an N-point Inverse wavelet Transform IDWT shall be used, as in conventional OFDM.

Zeros will be inserted in some bins of the IDWT in order to make the transmitted spectrum compact and reduce the adjacent carriers' interference.

At the receiver side DWT action is performed with QAM demodulator in order to recover back the original data which we had transmitted. Figure 10 and Figure 11 shows the DWT based transmitter and receiver.

KALMAN FILTER

The kalman filter is a mathematical tool which consists of a set of mathematical equations; these equations provide an efficient computational means in order to estimate the state of a process, in a way such that the mean of the squared error is minimized. The filter can be used to estimate past, present and even future states.

In order to estimate the state $x \in \Re^n$ of a discrete-time controlled process which is given by the linear stochastic difference equation (16) below:

$$x_k = Ax_{k-1} + Bu_{k-1} + w_{k-1} \tag{16}$$

With a measurement $z \in \Re^m$ that is given by Eqn. (17)

$$z_k = Hx_k + v_k \tag{17}$$

Figure 10. Typical DWT transmitter

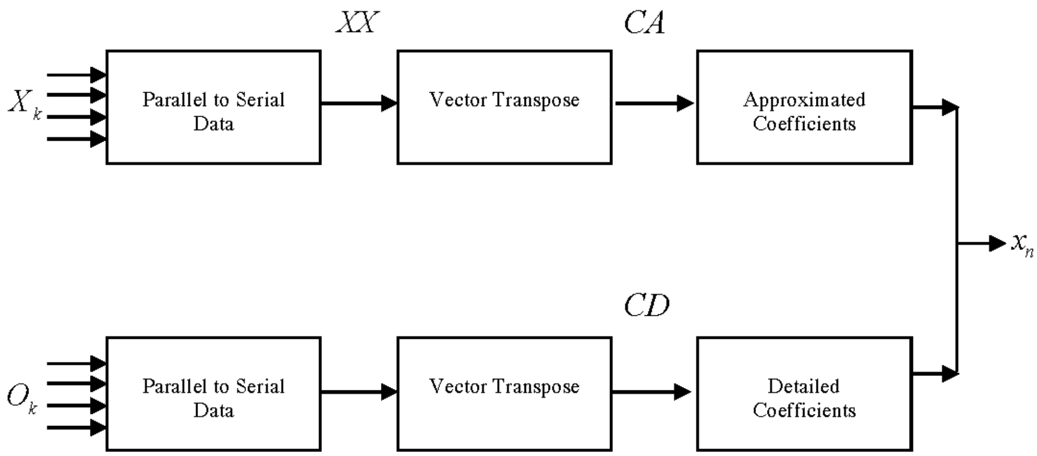
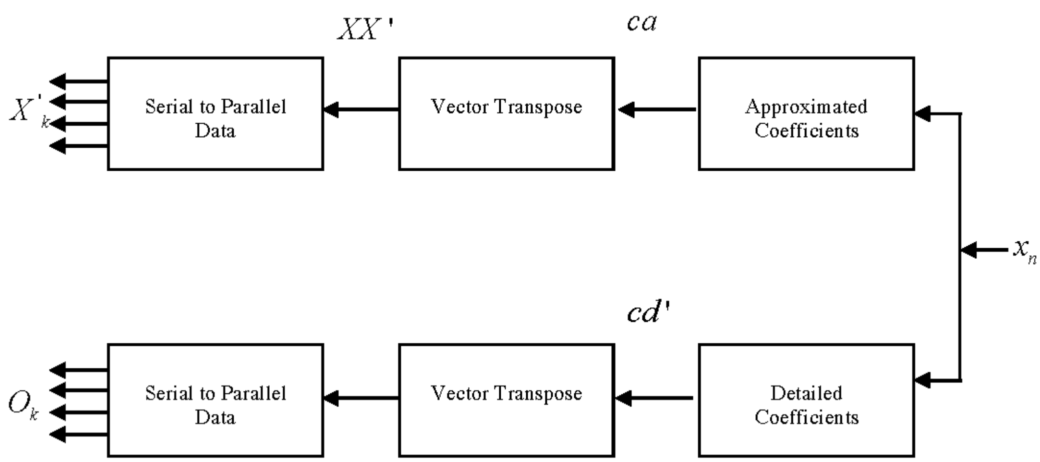


Figure 11. Typical DWT receiver

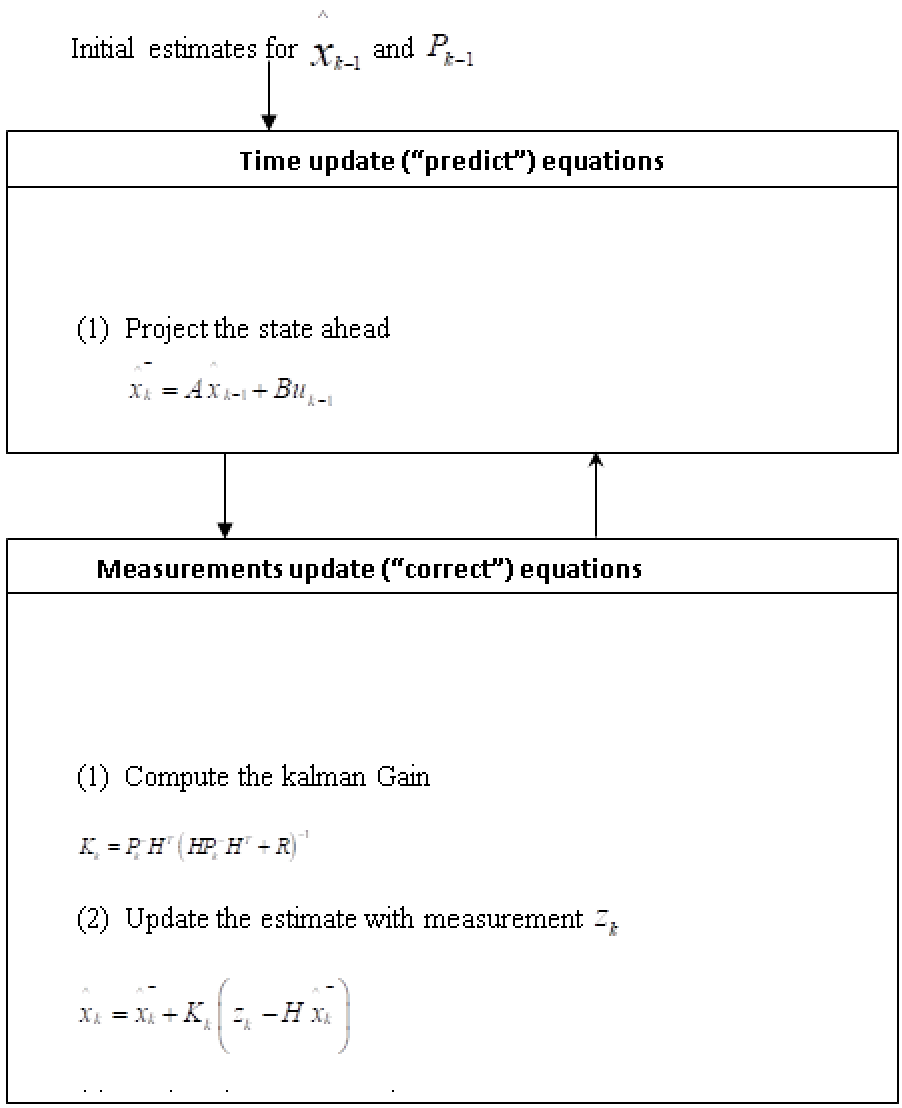


In practice *H* might change with each time step, but here we assume it is constant. The Kalman filter estimates a process with the help of feedback control: the filter estimates the process state at some time and then obtains feedback in the form of measurements.

The equations of Kalman filter are divided into two groups viz: (1) time update equations and (2) measurement update equations. The time update equations can also be thought of as predictor equations, while the measurement update equations can also be thought of as corrector equations. The equations for the time update and measurements update are shown in Figure 12.

The OFDM system shown in Figure 9 is simulated using MATLAB. The user data stream is firstly QAM modulated and then single level wavelet transform is performed, in this approach it is done by Haar wavelet function.

Figure 12. A Complete operation of the Kalman filter with time update and measurement update equations



For this function the low-pass and high-pass decomposition filter coefficients are [0.7071, 0.7071] and [0.7071, -0.7071], whereas reconstruction filter coefficients are [0.7071, 0.7071] and [-0.7071, -0.7071]. During the simulation some other wavelet functions such as *bior3.5, db2, db and bior5.5* were also used but Haar function shows better performance among others. The BER performance of two different systems (FFT based OFDM and DWT based OFDM system) are studied and compared. The discrete wavelet transform-based orthogonal frequency division multiplexing (OFDM) system using "Haar wavelet" function is implemented with Kalman filter in order to reduce the inter carrier interference (ICI) effect and to minimize noise effect introduced in the signal.

Extended Kalman Filter

The Kalman filter is basically beneficial for the optimization or the error reduction of linear equation-based systems but in case of non-linear system it does not provide effective results. Where the extended Kalman filter is been designed specially to provide the optimization and error reduction to the non-linear equations. The complete set of extended Kalman filter equations is given in this section. It also defines the process in two stages called time update stage and the measurement update stage. The respective equations of these two stages are given as under.

Time Update Operations (Extended Kalman Filter)

$$\hat{x}_k^- = f\left(\hat{x}_{k-1}, u_{k-1}, 0\right) \tag{18}$$

$$P_k^- = A_k P_{k-1} A_k^T + W_k Q_{k-1} W_k^T \tag{19}$$

Measurement Update Operations (Extended Kalman Filter)

$$K_k = P_k^- H_k^T \left(H_k P_k^- H_k^T + V_k R_k V_k^T\right)^{-1} \tag{20}$$

$$\hat{x}_k = \hat{x}_k^- + K_k \left(z_k - h\left(\hat{x}_k^-, 0\right)\right) \tag{21}$$

$$P_k = \left(I - K_k H_k\right) P_k^- \tag{22}$$

The important feature of the extended Kalman filter is that the Jacobian H_k in the equation for the Kalman gain K_k serves to correctly propagate only the relevant component of the measurement information.

BASE METHODOLOGY

Traditionally, orthogonal frequency division multiplexing (OFDM) is implemented using fast Fourier transform (FFT). This transform however has the limitation that uses a rectangular window, which creates rather high side lobes. Furthermore, the pulse shaping function worn to modulate each subcarrier extends to infinity in the frequency domain. This leads to high interference and lower performance levels. Inter carrier interference (ICI) and inter-symbol interference (ISI) can be avoided by adding a cyclic prefix (CP) to the head of OFDM symbol. Adding CP reduces the spectrum efficiency. The wavelet transform based system has a higher spectral efficiency while providing robustness with regard to inter-channel interference than the conventional OFDM system, because of low out-of-band energy (low side-lobes).

So, to improve BER the FFT based systems are replaced by discrete wavelet transform (DWT) based systems. DWT based system does not require CP, thereby enhancing the spectrum efficiency. According to the IEEE broadband wireless standard 802.16.3, avoiding CP gives wavelet OFDM an advantage of roughly 20% in bandwidth efficiency. Moreover as pilot tones are not necessary for wavelet based OFDM system, they perform better in comparison to existing OFDM systems like 802.11a or hiper LAN. Therefore, propose an OFDM system based on Discrete Wavelet Transform with Kalman filter. The steps carried out in proposed scheme are performed in Matlab environment is as follows:

- In first step input binary stream is generated parallely and QAM (quadrature modulation scheme) is performed on the input data stream.
- Towards the transmitter side inverse discrete wavelet transform (IDWT) is performed on the modulated data. Haar wavelet is the most basic wavelet transform used for data decomposition.
- After applying wavelet transformation, the parallel data is converted into serial and then digital to analog conversion is performed and data is transmitted.
- When the signal is transmitted through channel some random noise is also added in the signal which causes interference with signal transmitted.
- At the receiver side the serial data is converted into parallel after performing analog to digital conversion.
- In order to reduce the effect of noise Kalman filter is used, which predicts the state of original one and then apply some gain to the received signal to minimize noise effect.
- Discrete wavelet transform is performed on this parallel data by using Haar wavelet; it performs reconstruction on received data.
- After performing discrete wavelet transform the data is fed to demodulator where QAM demodulation process is carried out on data.

IMPLEMENTATION AND SIMULATION RESULTS

Design proposed Discrete Wavelet Transform based OFDM system (Through Simulink Tool)

A baseband OFDM scheme, as shown in Figure 13 and Figure 14 are implemented in Simulink environment. Both the FFT-based and wavelet-based Haar wavelet schemes are implemented in Simulink. Their relative performance study is carried out using AWGN channel scenario at different SNR ratio. The measure of performance used is bit error rate versus signal-to-noise ratio.

The implemented program simulates a 64, 128 subcarrier OFDM system. Constellation mapping is performed using quadrature amplitude modulation QPSK, BPSK, (16-QAM) and 64-QAM for FFT and DWT. The additive white gaussian noise (AWGN) channel model is used for this system.

A simulated of FFT-OFDM and DWT-OFDM system with 16-QAM and 64-QAM modulation. Figure 15 shows the results of the simulation. From the graph it is observed that the performance of DWT-OFDM is superior to FFT-OFDM.

In case of FFT-OFDM a BER of 0.0366 at 12 dB SNR, whereas DWT-OFDM gives BER of 0.0002 dB at 12 dB SNR. The 16 QAM DWT OFDM achieve 0.0364 low errors at 12 dB SNR. Thus, from Figures 13 and 14 we observed that the proposed DWT based system outperforms than FFT based OFDM system.

Figure 13. Design using Simulink of FFT-OFDM at SNR=10db

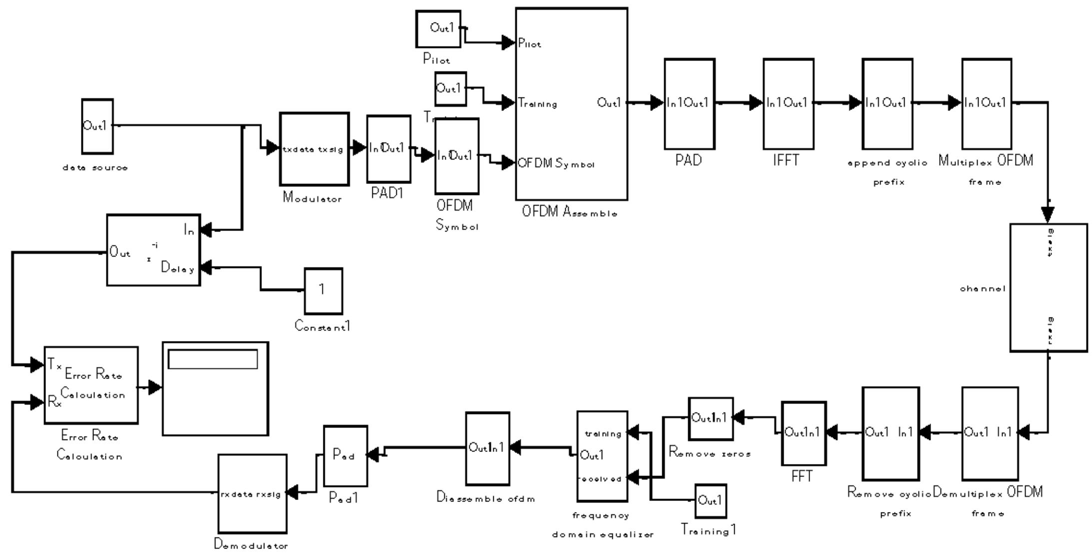
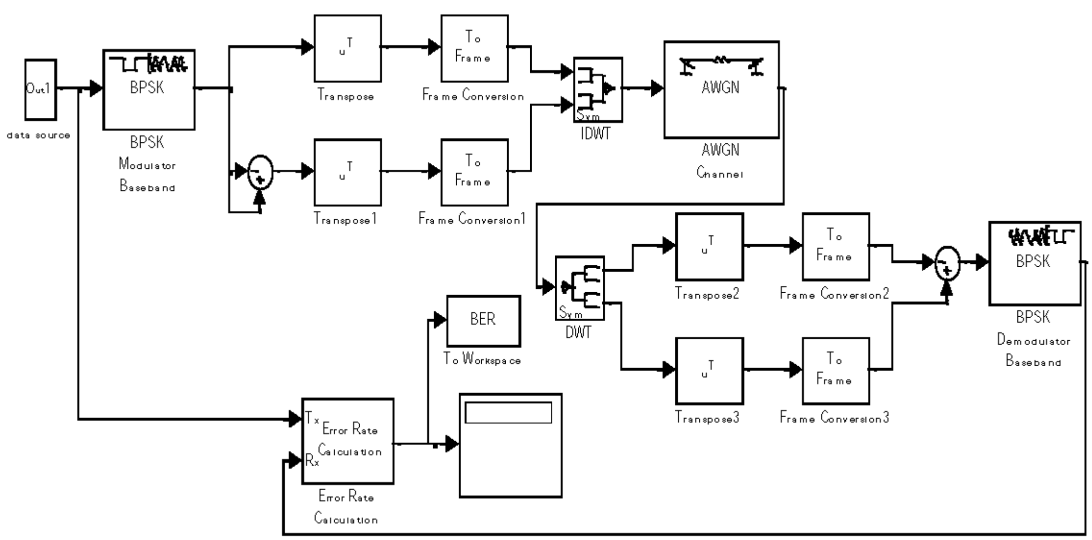


Figure 14. Design using Simulink of DWT-OFDM at SNR=10db



The other experiment is performed to show the performance of DWT OFDM for mother wavelets namely Haar which are recommended for DWT-OFDM. Figure 15 shows the simulation results in terms of BER. The graph shows the performance of BPSK DWT Haar wavelet better than 16 QAM DWT OFDM Haar wavelet transform. The Haar mother wavelet transform is recommended which has less complexity in implementation for simple system. The BPSK based system is suitable for less no. of user access. The throughput is more and improves the bit error rate efficiency of the system.

Thus, from table 1 observed that the proposed BER performance for BPSK DWT OFDM gives better results than conventional OFDM system

Figure 15. Comparison b/w FFT OFDMA & DWT OFDMA by using Haar Wavelet

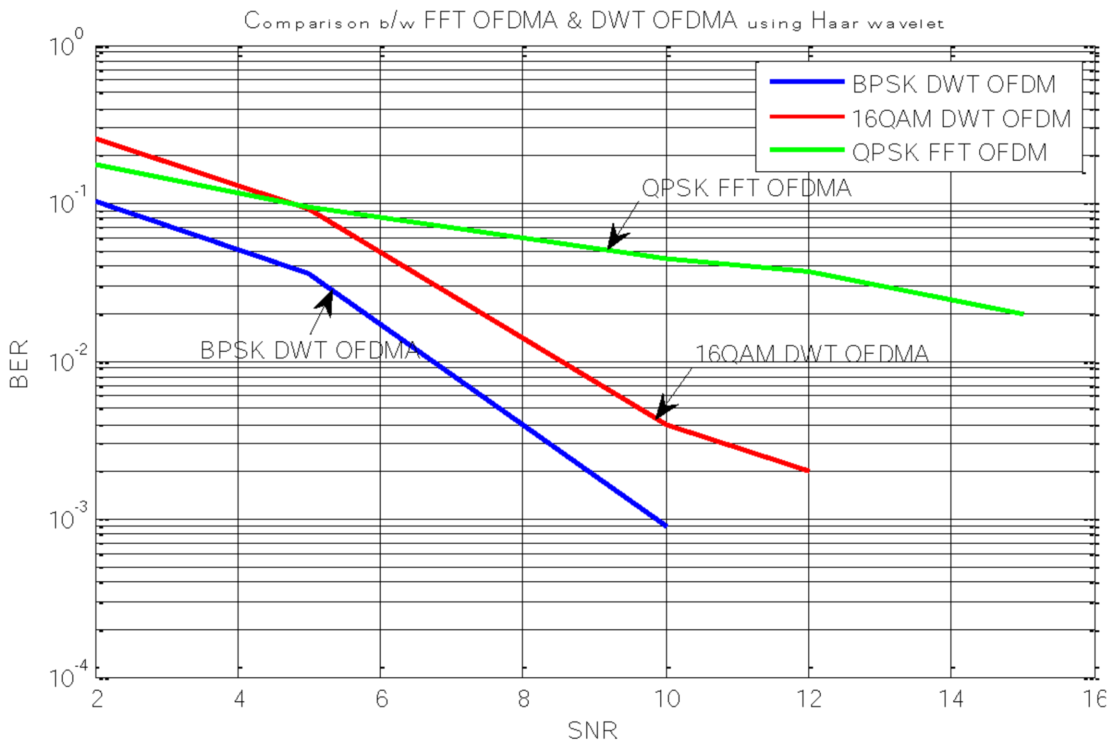


Table 1. Performance analysis of the BER 16-QAM FFT and DWT-OFDM system

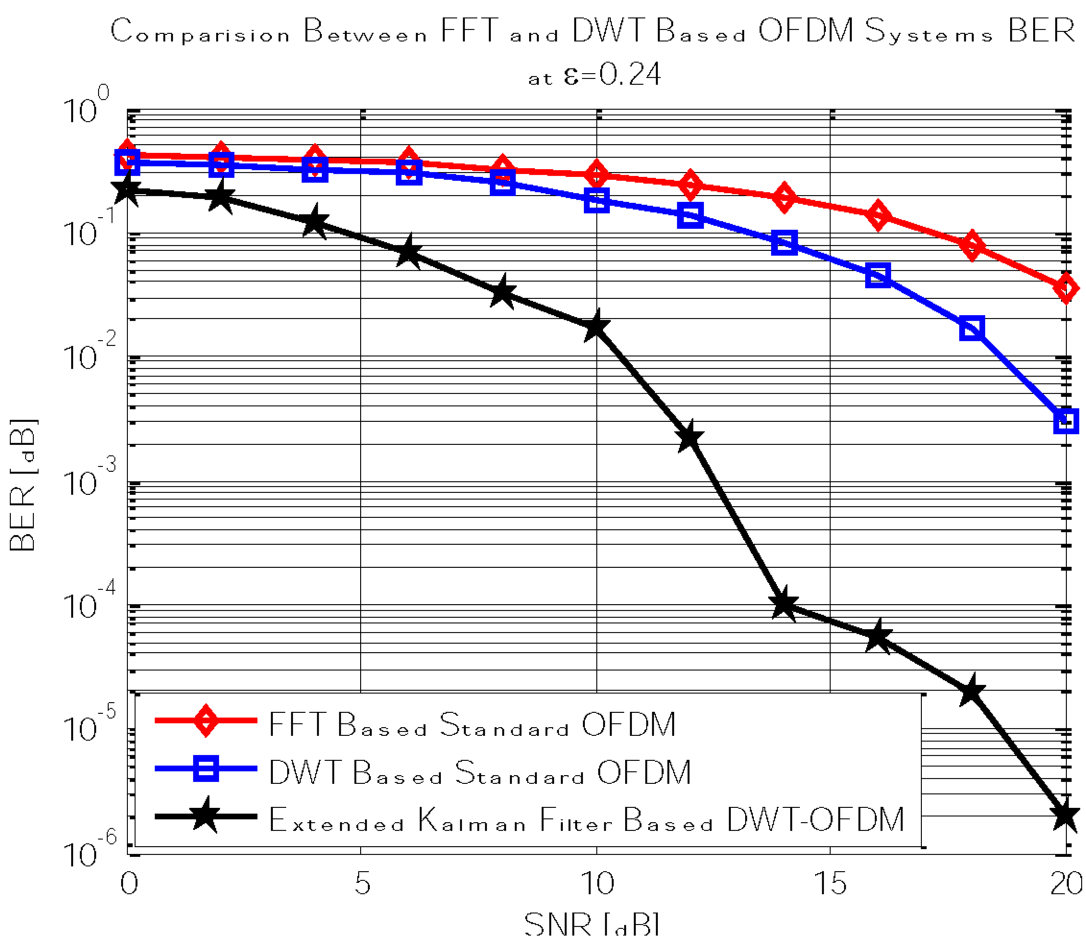
S.No.	SNR	BER for FFT OFDM	BER for 16 QAM DWT OFDM	BER for BPSK DWT OFDM
1	0	0.2694	0.3597	0.1511
2	2	0.1741	0.2567	0.1014
3	4	0.1114	0.1393	0.05339
4	6	0.08449	0.05829	0.0218
5	8	0.06479	0.0141	0.005
6	10	0.0449	0.00399	0.00089
7	12	0.0366	0.0002	0
8	14	0.0235	0	0
9	16	0.0156	0	0
10	18	0.0122	0	0
11	20	0.0101	0	0

BER PERFORMANCE IN OFDMA SYSTEM USING PROPOSED EXTENDED KALMAN FILTER

The kalman filter plays a very important role in estimating the state and corrects the observation by using time update and measurement update equations. The figure 16 shows a comparison between the BER of *SISO* (single input single output) FFT-OFDM and DWT-OFDM.

The extended Kalman filter is been designed specially to provide the optimization and error reduction to the non-linear equations. The extended firstly convert the non-linear system into linear system after that using predict equation use for predicting the value and measurement equation measure the error or reduce the error at the particular point. The extended Kalman filter is best filter for non-linear signal and filter the error rate in data transmission.

Figure 16. BER plot for QAM SISO FFT/DWT OFDM systems



The Table 2 shows the comparison in BER of FFT based OFDM and DWT based OFDM, from Table 2 we can see the difference between these two techniques. It is observed from table that without extended Kalman filter the BER of DWT based OFDM is better than FFT based OFDM, if use extended Kalman filter with DWT based OFDM the improvement can be obtained as displayed in Table 2. Thus, we see that extended Kalman filter gives best results in comparison to other existing schemes.

From BER plot of standard OFDM shown in Figure 16, it is seen that DWT based OFDM (haar) outperformed FFT based OFDM system. The black line from BER plot shows that the BER of standard DWT-OFDM can be improved with the help of extended Kalman filter shown in BER plot Figure 16. Thus, by using extended Kalman filter with proposed DWT-OFDM, BER can be improved.

Thus, from table 2 observed that the proposed BER performance for DWT OFDM with Kalman filter gives outperforms than simple DWT OFDM system at low level of SNR.

CONCLUSION

Wavelet transform based OFDM provides a very interesting and powerful alternative to FFT OFDM, the strength of the wavelets being the better time/frequency localization and distribution in this domain. The BER performance in DWT based system, improvement that can be obtained is about 0.1376 BER at 12 dB SNR which is suitable for OFDM system. A maximum improvement of BER using DWT with Kalman filter obtained is about 0.0012 BER at 12 dB SNR which is suitable for next generation OFDM system. However, this characteristic also raises the problem of synchronization, which is already an issue for classical Fourier OFDM, but has greater impact in wavelet domain. Inter carrier interference (ICI) is the main problem with OFDM system. ICI causes loss of orthogonality among subcarriers and hence, loss of information occurs and BER increases as ICI increases. The performance comparisons of BER

Table 2. BER of QAM modulation scheme for FFT based and DWT based OFDM system at SNR 0 to 20 (in dB)

S.No.	SNR	BER for FFT OFDM	BER for DWT OFDM	BER for DWT OFDM with Kalman Filter
1	0	0.4267	0.3893	0.2548
2	2	0.4022	0.3526	0.1907
3	4	0.3834	0.3239	0.1222
4	6	0.3711	0.2994	0.0697
5	8	0.3179	0.2512	0.0326
6	10	0.2849	0.1806	0.0168
7	12	0.2442	0.1376	0.0021
8	14	0.1916	0.0842	0
9	16	0.1390	0.0459	0
10	18	0.0771	0.0166	0
11	20	0.0353	0.0030	0

performance for the conventional OFDM based on FFT with self-cancellation scheme, OFDM based on FFT with adaptive modulation scheme, conventional DWT based OFDM and DWT based OFDM with Kalman filter under different values of carrier frequency offset (CFO) together with their comparison for best achievable BER have been presented. Simulation results have been provided to demonstrate that significant gains can be achieved by introducing such combination technique with very little decoding complexity. Therefore, the DWT based OFDM system is a feasible way to reach the next generation of wireless communication for large data rates and applications. These results are observed from the Matlab coding and Simulink model in the Matlab. Finally observed that in both of the above cases wavelet transform based OFDM system is outperforms than conventional FFT based OFDM system.

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Section 3

Fifth Generation Supportive Technologies

Chapter 6
Dynamic Cache Management of Cloud RAN and Multi-Access Edge Computing for 5G Networks

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ABSTRACT

Using a cache to improve efficiency and to save on the cost of a computer system has been a field that attracts many researchers, including those in the area of cellular network systems. The first part of this chapter focuses on adaptive cache management schemes for cloud radio access networks (CRAN) and multi-access edge computing (MEC) of 5G mobile technologies. Experimental results run through CloudSim show that the proposed adaptive algorithms are effective in increasing cache hit rate, guaranteeing QoS, and in reducing algorithm execution time. In second part of this chapter, a new cache management algorithm using Zipf distribution to address dynamic input is proposed for CRAN and MEC models. A performance test is also run using iFogSim to show the improvement made by the proposed algorithm over the original versions. This work contributes in the support of 5G for IoT by enhancing CRAN and MEC performance; it also contributes to how novel caching algorithms can resolve the unbalanced input load caused by changing distributions of the input traffic.

DOI: 10.4018/978-1-7998-1152-7.ch006

INTRODUCTION

The last decade has witnessed the rapid rise of intelligent mobile devices and Internet of Things (IoT) systems. According to a research done by the United Nation's panel on global sustainability, by 2050, 70% of the world population will live in urban areas, which only cover 2% of the entire Earth surface, yet are responsible for 75% of the greenhouse gas emissions (United Nations, 2012). Based on this understanding, the concept of Smart Communities therefore needs the solutions and practices to advance the development and to allow the sustainability of urban environments. In particular, the use of Information and Communication Technologies (ICT) will provide the necessary backbone, not only for maintaining existing services but for enabling new ones; the Internet of Things (IoT) is among the most useful, hopeful ICT technologies for this purpose (Casana & Redondi, 2017).

The rapid growth of IoT also raises new challenges in resource constrained wireless networks. Fifth Generation (5G) mobile networks have been proposed to provide timely connectivity for these IoT and mobile devices in order to support the mounting services they deliver (Su & Moh, 2018). 5G relies on many fast-growing technologies including Cloud Radio Access Networks (CRAN), Multi-Access Edge Computing (MEC), Millimeter Wave, Massive Multiple-Input Multiple-Output (MIMO), etc. Among them, CRAN and MEC utilizes cloud and virtualization models, making 5G systems flexible, scalable, and cost-effective.

Cloud Radio Access Networks (CRAN) utilizes cloud computing model to support rapid growth of IoT devices. CRAN, which is a centralized and virtualized architecture is proposed for 5G networks and has better utilization of hardware and software resources.

Edge computing has become a standard in delivering services more efficiently and centralizing resources in such a way that reduces costs for service providers and clients. Based on the research conducted by Grand View Search, the global edge computing market size is projected to reach USD 3.24 billion by 2025 (Edge Computing Market Worth $3.24 Billion By 2025 CAGR: 41.0%", n.d.). For a market with such huge potential, how to efficiently make use of it become a crucial question. Edge computing reduces latency because data does not have to traverse over the network to a data center or cloud for processing. However, this also means that data has to be processed or stored without the support from a centralized data center in some cases. This requires for the authors to figure out a way to use the resource smartly.

One of the ways to managing resource efficiently in the network is caching. Caching refers to a component that stores data so that future requests for that data can be served faster. It is a promising way to moderate the burden of traffic load (Ma et al., 2018). Hierarchical memory systems usually make use of cache to reduce access delay for time-critical applications. Cache has been introduced in both CRAN and MEC to increase the speed of cellular network services as well as to improve resource utilization (Hou, Feng, Qin, & Jiang, 2017).

The cost of these high-speed, carrier-grade cache resources is, however, extremely high, so their sizes are often limited. It is therefore necessary to efficiently manage these cache resources. In addition, as traffic load changes and the required Quality-of-Services (QoS) varies, it is critical to make the cache management adaptive. Edge Computing, unlike cloud computing, has limited computing and storage resource. As a result, which services are cached on the BS determines which application tasks can be offloaded to the edge server, thereby significantly affecting the edge computing performance (Chen & Xu, 2017).

This first part of this chapter focuses on adaptive cache management to effectively utilize the limited cache resources in CRAN and in MEC; a preliminary version has been presented (Pathinga Rajendiran & Moh, 2019). The major contributions may be summarized as follows:

- Proposed H-EXD-AHP (Hierarchical Exponential Decay and Analytical Hierarchy Process), a hierarchical enhancement for an existing highly-effective cache management algorithm EXD-AHP (Tsai & Moh, 2018).
- Proposed AH (Adaptive Hierarchical) and IAH (Improved Adaptive Hierarchical); AH is an adaptive version for hierarchical cache management, and IAH is its improvement; both provide guaranteed QoS.
- Proposed GGAH (Good Guess AH), a fast-convergence version for AH, which rapidly speeds up the execution time of the original AH.
- AH, IAH, and GGAH have been applied to, and successfully demonstrated by both the newly proposed H-EXD-AHP and an existing hierarchical cache management algorithm H-PBPS (Probability Based Popularity Scoring) (Kaur & Moh, 2018). They both provide guaranteed QoS; GGAH in addition also swiftly speeds up the run time.

In second part of this chapter, the improvement is made to the first part of the chapter. This work focuses on dynamic cache management, especially for unbalanced, dynamic input traffic, for CRAN and MEC. A preliminary result has been presented (Pathinga Rajendiran, Tang, & Moh, 2019). The major contributions may be summarized as follows:

- Proposed a way to classify users' content requests based on Zipf's distribution, which dynamically evaluates the popularity of the requested files.
- Applied Zipf distribution and transformed three existing non-dynamic algorithms to their dynamic versions: D-H-EXD-AHP (Dynamic Hierarchical Exponential Decay and Analytical Hierarchy Process), D-H-PBPS (Dynamic Hierarchical Probability Based Popularity Scoring) and D-RRM-PBPS (Dynamic Reverse Random Marking with PBPS).
- Applied Zipf distribution and transformed three existing non-dynamic adaptive algorithms to their dynamic versions: D-AH (Dynamic - Adaptive Hierarchical) and D-IAH (Dynamic - Improved Adaptive Hierarchical); both provided guaranteed QoS.
- Applied Zipf distribution and transformed GGAH (Good Guess AH), a fast-convergence version for both AH and IAH, to its dynamic version, D-GGAH (Dynamic - GGAH).
- D-AH, D-IAH, and D-GGAH have been applied to, and successfully demonstrated by cache management algorithms H-EXD-AHP (Pathinga Rajendiran, & Moh, 2019) and H-PBPS (Kaur & Moh, 2018). They both provide guaranteed QoS; D-GGAH in addition also swiftly speeds up the run time.

This chapter is organized as follows: Section 2 discusses the background of CRAN and MEC architectures; it also presents major related works. Section 3 describes the most relevant existing cache management algorithms. Section 4 illustrates the preliminary results of the existing algorithms, which have motivated the design of new algorithms. Section 5 and 6 describes the proposed adaptive cache algorithms, including H-EXD-AHP, AH, IAH, GGAH and their dynamic versions. Section 7 presents the performance evaluation of the proposed algorithms with comparison to existing ones. It is followed by the conclusion section that includes future directions. This chapter is an extension of two conference papers (Pathinga Rajendiran, & Moh, 2019; Tang, Pathinga Rajendiran, & Moh, 2019). This chapter is a continuation of the author's research on cloud computing (Huang, Wu, & Moh, 2014; Reguri, Kogatam, & Moh, 2016), CRAN (Karneyenka, Mohta, & Moh, 2017; Shahriari, Moh, & Moh, 2017), cache management of CRAN (Tsai & Moh, 2017a, 2017b, 2018; Kaur & Moh, 2018; Pathinga Rajendiran & Moh, 2019), edge and fog computing (Choudhari & Moh, 2018; Gao & Moh, 2018; Moh & Raju 2018; Tang, Pathinga Rajendiran, & Moh, 2019), and IOT, mobile and 5G networks (Shahriari & Moh, 2016; Sathyanarayana & Moh, 2016; Su & Moh, 2018).

BACKGROUND AND RELATED WORK

CRAN and MEC Architectures

Traditional radio access networks (RAN) is a distributed architecture which consists of long term evolution (LTE) macro base station (MBS) (evolved Node B or eNodeB) and user equipment (UE) (Checko et al., 2015). Each remote radio head (RRH) of eNodeB has its own base band unit (BBU). They are connected to the core network or evolved packet core (EPC) and the internet. CRAN is a centralized cloud architecture where BBUs are separated from their RRHs, virtualized and pooled together. The architecture of CRAN is shown in Figure 1. Each BBU can be represented as a virtual machine (VM) and each VM has its own cache memory. The size of this cache memory involved in the BBU pool is limited, so it is important to manage this resource efficiently (Tran, Hajisami, & Pompili, 2017).

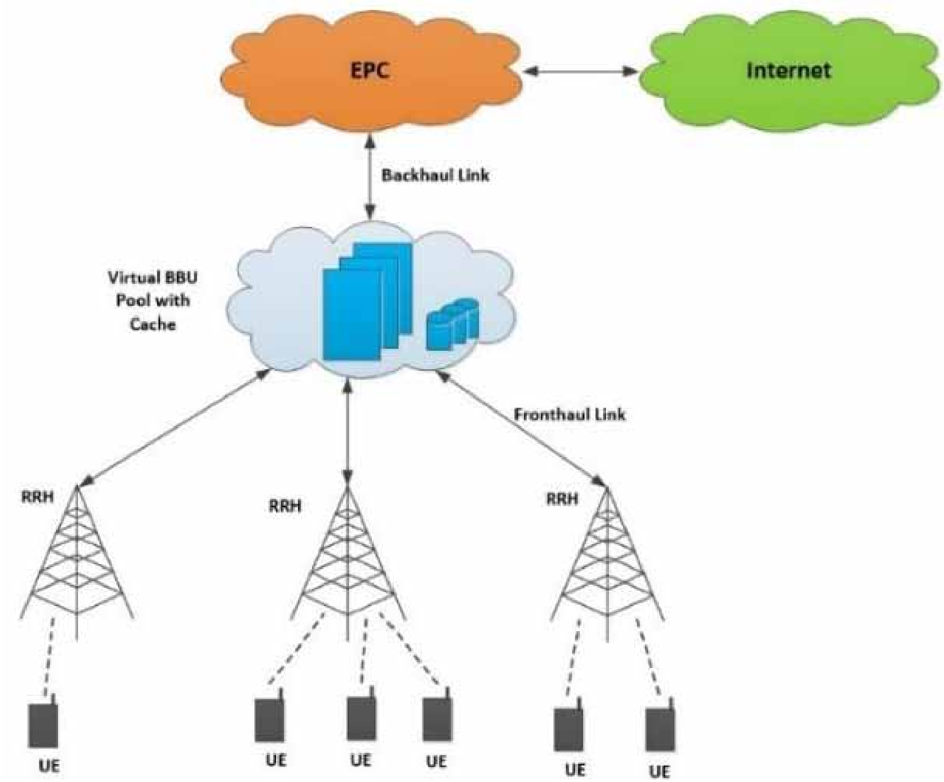
For each user, a User Equipment Context (UEC) record information is stored in the secondary cloud memory. This UEC information contains user's ID, state information of the current event or session, subscription details, etc. So, instead of retrieving this information from the secondary cloud, it will be easier to access if it is stored in the BBU pool cache. CRAN aims for better scalability, flexibility and better resource utilization (Tsai & Moh, 2018).

In MEC, cloud computing services are brought near the users to improve the user's experience (Wang et al., 2017). These services include but not limited to content caching, task offloading, storage, and computation. The architecture of MEC is shown in Figure 2. These servers can share its cached items with each other using the communications between MBS. To achieve communication between MBS, X2 interface can be used (Hou, Feng, Qin, & Jiang, 2017). MEC aims to reduce latency and backhaul traffic flow of the networks.

CRAN and MEC technologies can be combined and form a new hybrid architecture as shown in Figure 3. CRAN uses centralized BBU pool whereas MEC servers usually work with distributed MBS (Li et al., 2017; Lin, Hsu, & Wei, 2018). In this hybrid architecture, MEC's request can be sent and received via MBS (RRH and BBU pool) (Li et al., 2017). For 5G networks, it can be either CRAN architecture or MEC architecture or combination of both architectures.

However, an assumption for first part of this system is that the input of the whole system is static, which means that the amount of user request for each UE is fixed and will not change over time. In this second part of this chapter, the authors need to abandon this assumption. Therefore, a simulation that achieves the dynamic input is implemented via iFogSim (Gupta, Vahid Dastjerdi, Ghosh, & Buyya, 2017). The simulation supports unbalanced distribution of user devices and VMs, and the distribution of them may are continuously changing in this project. The connection between UE and VM/BBU may change

Figure 1. 5G CRAN architecture



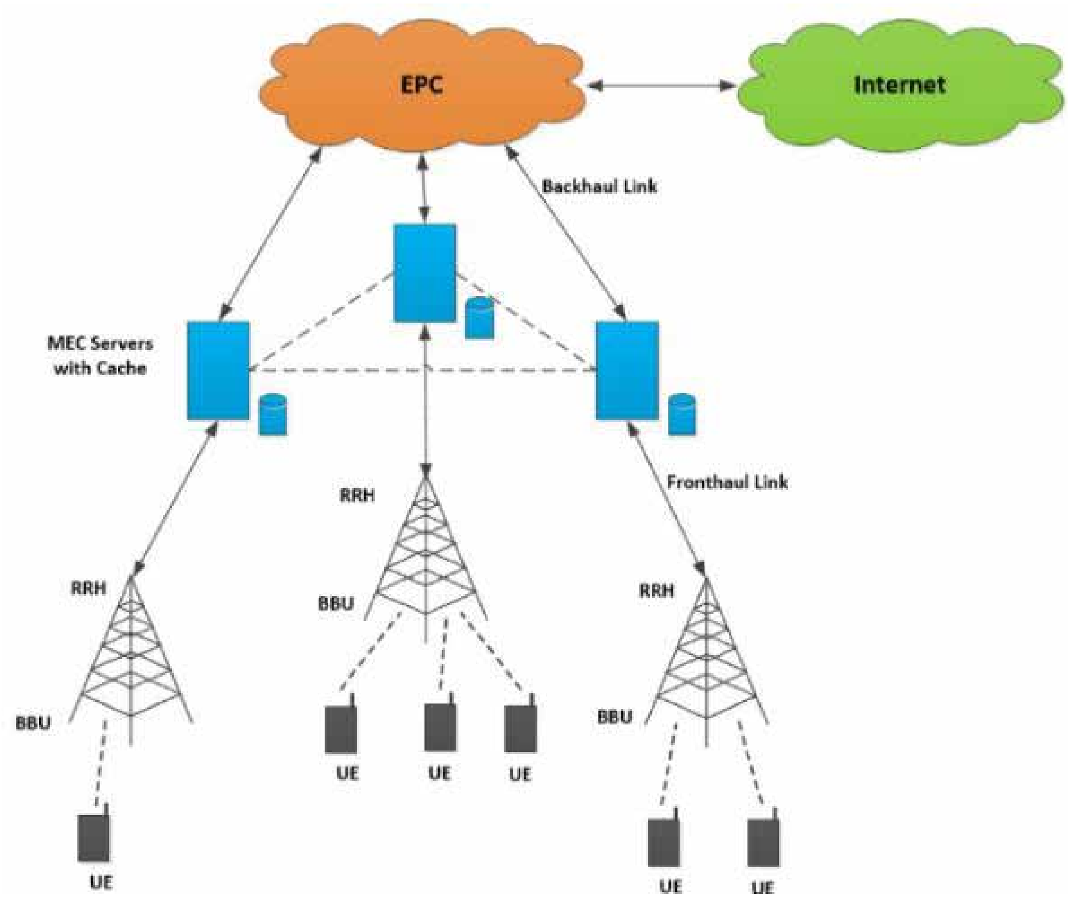
due to the change of UE in next second. In other words, the authors assume that the input to each of the BBU may change along with time, and one fundamental concept of the cache management strategy is to adjust this change by dynamically changing the binding between VMs in virtual BBU pool and user request file in UE list. A cache is implemented into the Fog node server, where the new algorithms will be achieved (Tang, Pathinga Rajendiran, & Moh, 2019).

Related Work

Floratou et al. (2016) proposed adaptive Exponential Decay (EXD) caching algorithm for Big SQL, in which they mentioned that parameter a value for adaptive EXD has significant impact on changing workload, so they changed the parameter value dynamically according to the workload which resulted in better performance than existing algorithms. For this research, the authors are using EXD for scoring the elements in the cache. If parameter a value is higher, more recent elements will be placed in the cache and if parameter a value is smaller, more frequent elements will be given importance in the cache (Tsai & Moh, 2018).

Huang, Zhao, and Zhang (2017) used cooperative multicast caching mechanism in MEC between base stations to utilize the resources efficiently. Cooperative means if the content is not in the small base station (SBS) instead of accessing it from MBS it can be accessed from another SBS if the data is present in any of the SBS. Multicast means instead of serving multiple requests separately and storing it

Figure 2. 5G MEC architecture



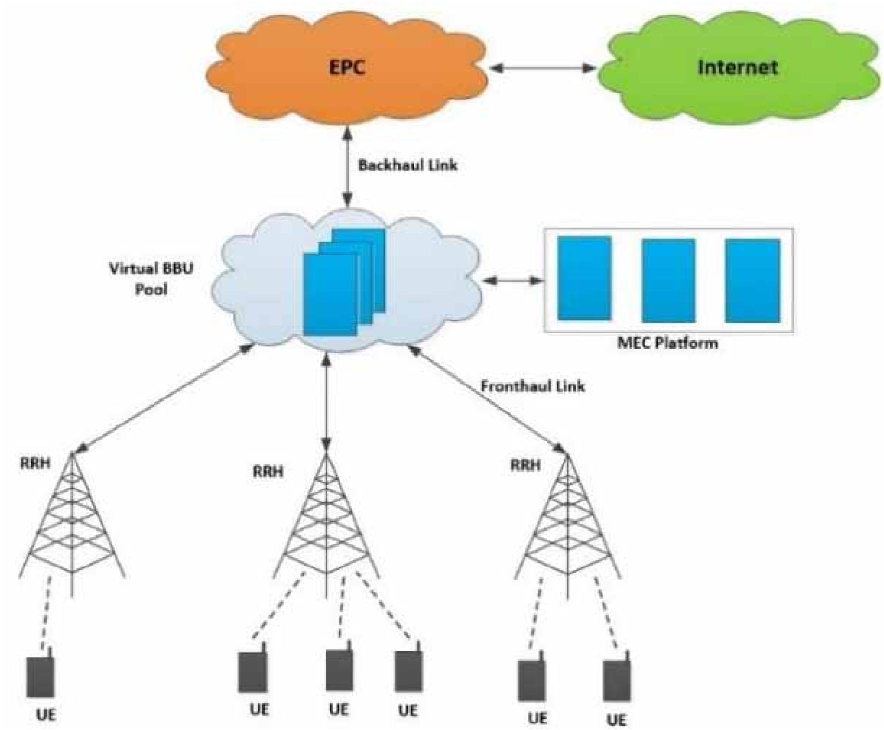
in each SBS, the popular videos can be multicasted to all. Thereby saving storage space and decreasing energy consumption. They demonstrated that by caching in the edge, network latency can be reduced, and CHR can be increased (Huang, Zhao, & Zhang, 2017).

Tran, Hajisami, and Pompili (2017) cached in a hierarchical manner. Their research experiment showed the authors that caching in the edge (RRH) is better than caching in the BBU pool (cloud cache) since RRH is nearer to the users. Their performance metrics were CHR, latency, and backhaul traffic load.

Tsai and Moh (2018) adopted Exponential Decay (Floratou et al., 2016) and Analytical Hierarchy Process (Gomes, Braun, & Monteiro, 2016; Saaty, 1987) came up with an algorithm called EXD-AHP scoring algorithm in which lowest score UEC is evicted to make space for highest score UEC. They have used four different levels of SLA users according to their mobility, basic and premium services. Using their algorithm, network traffic and cloud writes were reduced which increased their cache hit when compared to other existing algorithms. The authors have enhanced this algorithm; i.e., H-EXD-AHP.

Kaur and Moh (2018) proposed new algorithms for cache management in 5G. In this, for scoring the UEC records, they have used Probability Based Popularity Scoring (PBPS). One such algorithm is Reverse Random Marking (RRM) with PBPS (RRM+PBPS) in which a certain percentage of UECs are marked after it reaches a threshold. If there is a need to evict the records, then only evict from unmarked

Figure 3. Hybrid CRAN and MEC architecture in 5G



records. If all the records are marked, then increase the threshold and continue the same process. Another algorithm is that their PBPS scoring technique is combined with Hierarchy is called PBPS+Hierarchy (represented as H-PBPS in this chapter) in which the cache is partitioned and allocated to users according to their service levels. These algorithms which are simple in design were compared in terms of CHR, latency, and network traffic.

One proposal divided cache into several sub-sections and illustrated that the binding between these sub-sections and user requests does affect the performance of the model (Wang, Shen, Bose, & Shao, 2019). Therefore, an optimized placement strategy is necessary. The authors proposed a mixed integer linear programming model to solve this problem. It mainly used the popularity of files as the factor to decide if a file should be cached. They preferred to obtain the high arrival rate with the high cost of memory usage than a scheme with low arrival rate and low cost of memory. The analysis about the tradeoff between the performance of the cache and the cost of memory is helpful in the algorithm design.

A Mobility-Aware Coded Probabilistic Caching Scheme, proposed by Liu, J. Zhang, X. Zhang, & Wang (2017), is flexible and content-awareness. It analyzed and utilized the optimal caching strategy based on the user's request content in MEC. They also explained how the popularity of content affected the throughput of the scheme, and the tradeoffs made by a caching scheme focusing on user content. In particularly, when user content is changing dramatically, the popularity of user file becomes more "skewed" in the Zipf distribution. The desired status of a caching scheme is to make the popularity of user file less "skewed" because when it becomes constant, the cost of caching will most likely be decreased, even though it depends on how your scheme works.

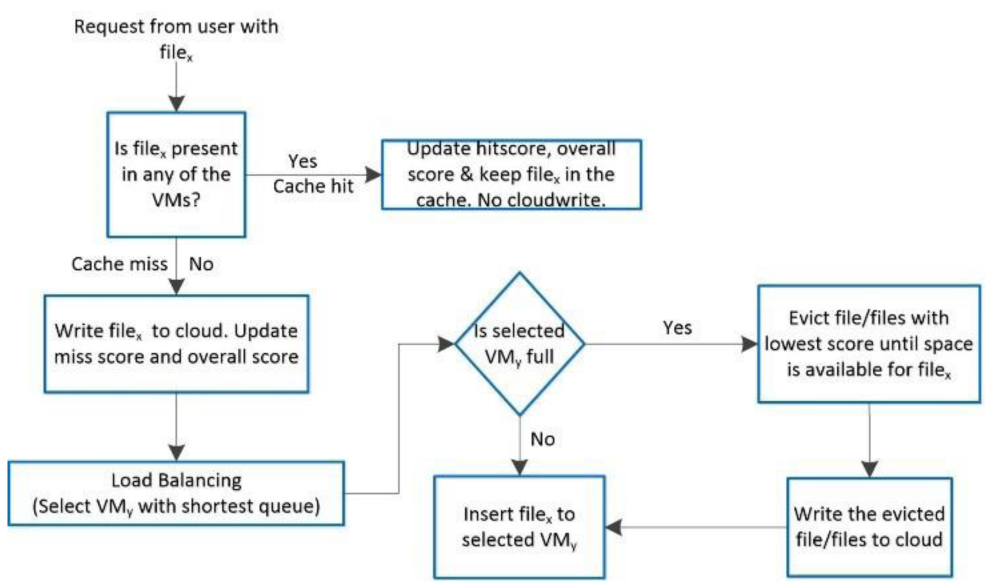
This method inspires the authors to optimize caching in CRAN and MEC by exploring the relationship between cache pool and the user's content, and it provides an example on combining two algorithms to solve a complex problem. In doing so, the algorithm adapts to the changes of incoming user requests and makes the binding between cache and user requests relatively stable without sacrificing the system throughput (Tang, Pathinga Rajendiran, & Moh, 2019).

EXISTING CACHE MANAGEMENT SOLUTIONS

In this section, the authors are going to discuss some of the existing cache management algorithms for 5G mobile networks. Before that, the following flowchart gives a general idea of the structure of the algorithms. This flowchart shown in Figure 4 is adapted from Tsai and Moh's (2018) work and this flowchart is also used in Kaur and Moh's (2018) work. A brief description of the flowchart follows.

In the existing papers, only UEC for CRAN is considered which is a small size record which is user's metadata. Pathinga Rajendiran and Moh (2019) have increased this record size and now it can be considered as user content files which can be used in MEC applications. Note that if the authors are using the algorithm or flowchart for BBU caching from CRAN then the "file" is a UEC record, and if they are using MEC server caching then it is file content. Each user with file or UEC request is incoming and if that file or UEC is already present in any of the Virtual Machine (VM) cache, then it is a cache hit and that file or UEC is updated in the cache. One must update the hit score and calculate the overall score according to the algorithm and there is no need to write in the cloud. On the other hand, if the requested file is not present in any of the VMs then it is a cache miss. One must write that file in the secondary cloud storage. After that, one must update the miss score and calculate the overall score according to the algorithm. While trying to add this file to any one of the VMs so that if it is requested in future again it will be present in the cache, the authors adopted S_{queue} LB algorithm (Tsai & Moh, 2017b). If

Figure 4. Cache management flowchart



the selected VM is full, evict files with the lowest score until space is available for this file. Write the evicted file or files to the cloud storage. After eviction when space is available, insert this file into VM (Tsai & Moh, 2018; Kaur & Moh, 2018).

Least Frequently Used (LFU) Algorithm

LFU algorithm is used as a baseline comparison algorithm in the preliminary results section. LFU is a classic algorithm which keeps track of the number of times files are being accessed. When it's time of eviction, the least number of accessed or least frequently used files are evicted (Podlipnig & Böszörmenyi, 2003).

EXD-AHP Algorithm

Tsai & Moh (2018) proposed EXD-AHP algorithm which uses a scoring method to decide which files need to be present in the cache and which files need to be evicted from the cache. To calculate the scoring both EXD and AHP weights calculations are considered (Floratou et al., 2016; Saaty, 1987). For EXD, there is a parameter *a* which can be tuned to keep the recently or frequently used files in the cache. Higher the parameter a value, the system keeps recently used files in the cache and smaller the parameter a value it leans towards the frequency of elements (Floratou et al., 2016). AHP weights are calculated by creating a matrix based on the SLA users (Saaty, 1987). If the file is accessed at time ui1+Δu for the first time after ui1, then scoring is calculated as follows (Tsai & Moh, 2018):

$$S_i(ui1+\Delta u) = S_i(ui1)*e^{-a\Delta u}+W_{AHP} \tag{1}$$

If the file didn't get requested at a time interval [ui1, (ui1+Δu)], then the score is calculated as follows (Tsai & Moh, 2018):

$$S_i(ui1+\Delta u) = S_i(ui1)*e^{-a\Delta u} \tag{2}$$

where $S_i(ui1)$ is the score (weight), $e^{-a\Delta u}$ is EXD calculation and W_{AHP} is AHP weight. From equation (1) and (2), it can be seen that the score of the file depends on both EXD and AHP weight calculations.

PBPS Cache Management Algorithms

Kaur and Moh proposed PBPS algorithms which also use a scoring technique to determine whether a file should be present in VM or not. This scoring is calculated using the equation (3).

$$\frac{hit\,score\,Li}{\#requests}\left(1-\left(\frac{hit\,score\,Li}{\#requests}\right)\right)^{\frac{miss\,score}{\#requests}} \tag{3}$$

As it can be seen from equation (3), the score is calculated based on both cache hits and cache misses. At a given point an overall score can be calculated for a file which tells how popular the file is based on hits and misses. The higher the score, the higher the popularity and less chance of eviction. This file will probably stay inside the cache because of its high PBPS score. The requests are constantly changing so the scores are calculated dynamically. The algorithm uses a rewarding system, in which the quantity of reward is varied according to the SLA users (Kaur & Moh, 2018).

RRM with PBPS (RRM+PBPS) Algorithm

This algorithm proposed by Kaur and Moh uses PBPS scoring method and in addition to that, it uses RRM. When files are being requested and it is in the cache then it is a cache hit. If the file score exceeds a certain threshold it is marked. Then if some files need to be evicted in order to make room for new files, eviction process happens from unmarked files. If all the files are marked, then the threshold value M_t is marginally increased to unmark a certain number of files (Kaur & Moh, 2018).

PBPS+Hierarchy (H-PBPS) Algorithm

This algorithm also uses the PBPS scoring method to calculate the addition and eviction of files in the cache. On top of this, the entire cache is divided, and each cache partition is dedicated to the users according to their SLA. This forms a hierarchy of users. The authors are giving preferential treatment, so the higher-SLA files will get the larger size of cache partition. The file addition or eviction happens in their allocated cache partition only (Kaur & Moh, 2018).

PRELIMINARY RESULTS

Experiment Setup

For the experiment setup, the authors have used the CloudSim simulator (Calheiros, Ranjan, Beloglazov, Rose, & Buyya, 2011). This simulator is very popular and effective to cloud based applications. The following Table 1 shows the simulation parameters and values (Tsai & Moh, 2018; Kaur & Moh, 2018); most have been provided by Nokia Lab researchers.

Preliminary Performance Evaluation

The preliminary performance evaluation section mainly serves the purpose of motivating the proposed new algorithms and the following performance evaluation on different file sizes, different cache distribution sizes are not evaluated in the existing papers. So, these new evaluation results from existing algorithms gave the authors a different perspective which inspired them to propose new algorithms.

Table 1. Simulation parameters and values

Parameter	Values
No. of host and of VM	1 and 4, respectively
VM cache sizes	0.75 GB & 2 GB
Arrival rate of files into the network	1400 files/sec
Total no. of users and of requests	25,000 and 420,000, respectively
File sizes	200 KB: fixed and distributed; 2000 KB: fixed and distributed; Distributed: uses the Normal (Gaussian) distribution.
Network bandwidth	1 Gbps
QoS level: mobility; subscription.	SLA 1: High Mobility; Premium. SLA 2: Low Mobility; Premium. SLA 3: High Mobility; Basic, SLA 4: Low Mobility; Basic.
EXD parameter *a* and LB algorithm	10^{-3} and S_{queue}
Analytical Hierarchical Process (AHP) weights	SLA1: 0.58; SLA2: 0.28; SLA3: 0.10; SLA4: 0.04.
QoS level: PBPS hit reward	SLA1: 1; SLA2: 0.75; SLA3: 0.5; SLA4: 0.25.

Cache Hit Rate (CHR)

CHR is an important performance evaluation metric for cache management problems. The following results use CHR for its performance measure. For different service levels L_i, CHR can be calculated using the following equation (4) (Tsai & Moh, 2018):

$$CHR \text{ of } L_i = \frac{\text{Total number of Li cache hits}}{Total\ number\ of\ file\ requests\ from\ Li} \tag{4}$$

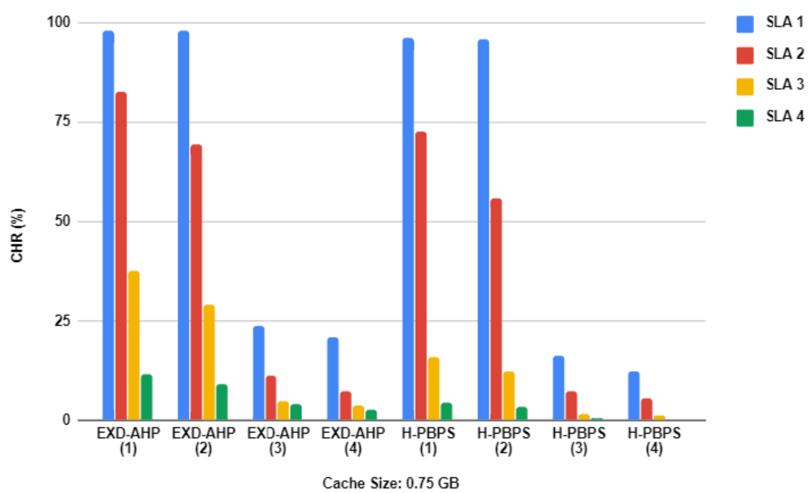
Different File Sizes

In this, the authors used different file sizes for EXD-AHP and H-PBPS algorithms (Tsai & Moh, 2018; Kaur & Moh, 2018). Distributed means the requested files sizes are varied, Gaussian distribution is used. In Table 2, different file sizes used for the simulations are displayed. Figure 5 comparing 200 KB and 2000 KB file sizes, the small file size gives the highest CHR; and comparing fixed and distributed file sizes, fixed file size gives the highest CHR. Note: EXD-AHP (1) means 200 KB fixed file size is used in EXD-AHP algorithm, H-PBPS (2) means 200 KB distributed file size is used in H-PBPS algorithm and so on. The EXD-AHP performs better than H-PBPS in all different settings (Pathinga Rajendiran & Moh, 2019).

Table 2. Different file sizes (Cache Size = 0.75 GB)

#	File Size	Values
1.	200 KB fixed	CRAN
2.	200 KB distributed	MEC
3.	2000 KB fixed	MEC
4.	2000 KB distributed	MEC

Figure 5. Cache Hit Rate (CHR) (%) for different file sizes



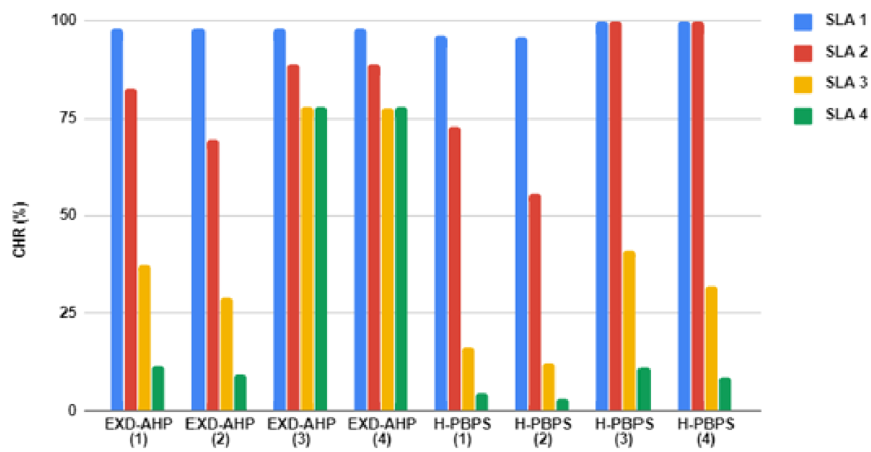
Different Cache Sizes

Table 3 displays the list of different cache sizes used for EXD-AHP and H-PBPS algorithms (Tsai & Moh, 2018; Kaur & Moh, 2018). CHR for different cache sizes is displayed in Figure 6. Of course, cache size 2 GB gives better CHR than cache size 0.75 GB. In 0.75 GB cache size, EXD-AHP algorithm gives better CHR than H-PBPS algorithm. After this experiment, it is apparent that EXD-AHP performs better than H-PBPS (Pathinga Rajendiran & Moh, 2019).

Table 3. Different cache sizes

#	File Size	Cache Size	Application
1.	200 KB fixed	0.75 GB	CRAN
2.	200 KB distributed	0.75 GB	MEC
3.	200 KB fixed	2 GB	CRAN
4.	200 KB distributed	2 GB	MEC

Figure 6. Cache Hit Rate (CHR) (%) for different cache sizes



Different Cache Management Algorithms

CHR for different existing cache management algorithms is evaluated in Figure 7. For RRM+PBPS the threshold increase is 10%. Different cache size partitions for SLA levels are summarized in Table 4. For example, H-PBPS (2) means CD for SLA1 is 55%, SLA2 is 28% and SLA3 is 11% distributed in H-PBPS algorithm. It can be seen that if the cache size partition is changed, CHR is also changed accordingly. This motivates the design of H-EXD-AHP and of various AH's.

Figure 7. Cache Hit Rate (CHR) (%) for different cache management algorithms

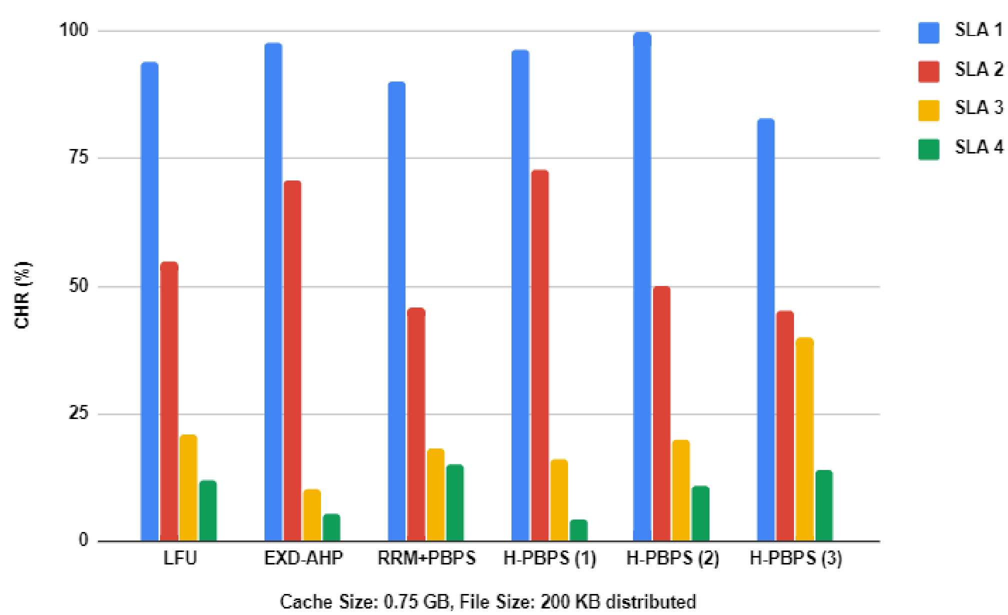


Table 4. Different Cache Distribution (CD) for H-PBPS

#	CD for SLA1	CD for SLA2	CD for SLA3
1.	70%	20%	8%
2.	55%	28%	11%
3.	47%	25%	20%

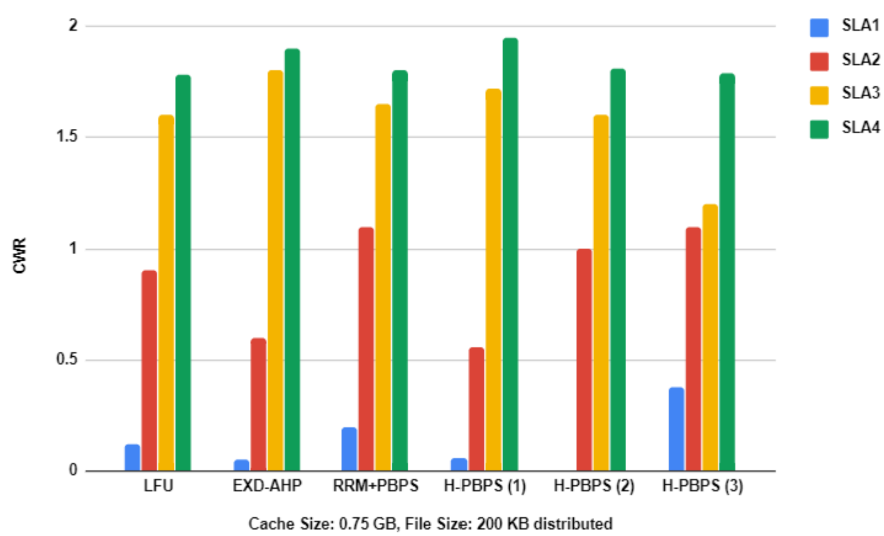
Cloud Write Rate (CWR)

CWR is another performance metric for these cache algorithms. CWR is defined as the number of cloud writes by the number of requests. CWR for service level L_i is calculated using equation (5) (Tsai & Moh, 2018):

$$\text{CWR of } L_i = \frac{\text{Total number cloud writes}}{\text{Total number of file arrivals in } L_i} \quad (5)$$

Cloud write is needed whenever there is a cache miss. Cloud Write Rate and Cache Hit Rate are inversely proportional to each other. H-PBPS uses different cache distribution from Table 4. Figure 8 displays the CWR for different SLA users. Note that CWR varies according to the different cache distributions. Cache size also has a huge impact on CWR. As the cache size grows the CWR will also be decreased (Pathinga Rajendiran & Moh, 2019).

Figure 8. Cloud write rate (CWR) for different cache management algorithms



Network Traffic

Network traffic is a performance metric calculated based on cloud writes. Because whenever there is a cache miss, there is a need for files to travel from cache to the cloud storage, which creates network traffic. Assuming each file size is 200 KB on average, it is calculated as follows in equation (6) (Tsai & Moh, 2018):

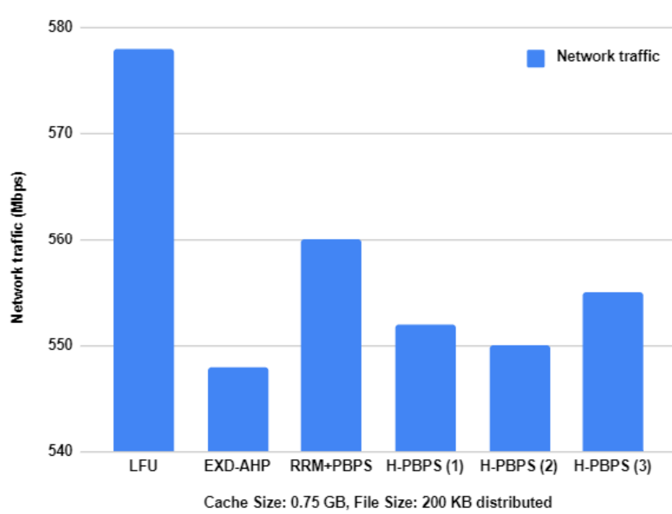
$$\text{Network Traffic of } L_i = \frac{\text{Number of Li cloudwrites} * 200 * 8 * 1000}{\text{Simulation Time}} \tag{6}$$

Network traffic is shown in Figure 9. This traffic result is not based on the different SLA, but the overall traffic result for different cache management algorithms. Note that CHR and network traffic are inversely proportional while CWR and network traffic are directly proportional. EXD-AHP algorithm has less network traffic overall. Different cache distribution of H-PBPS is used from Table 4. This shows that by changing the cache distribution the traffic can also be decreased. So, this also gave authors the idea of applying the hierarchy cache partition to EXD-AHP and try to decrease the traffic even more (Pathinga Rajendiran & Moh, 2019).

PROPOSED ADAPTIVE CACHE MANAGEMENT ALGORITHMS

The results presented in the previous section gave authors the motivation to design the following proposed algorithms. For the first part, inspired by the change in cache distribution of H-PBPS, the authors applied the hierarchical part to EXD-AHP, called H-EXD-AHP. For the second part, they designed 3 algorithms that adaptively change the cache distribution to guarantee the QoS; more specifically, to meet

Figure 9. Network traffic (Mbps) for different cache management algorithms



the Minimum Guarantee of CHR for differentiated users according to their SLA. The authors applied these 3 algorithms to H-EXD-AHP and H-PBPS (Pathinga Rajendiran, & Moh, 2019).

New: H-EXD-AHP Algorithm

Inspired by H-PBPS algorithm from the previous section, a hierarchical layer of cache allocation for differentiated SLA users according to their preferred treatment are applied in EXD-AHP. The total cache is divided according to the type of SLA users. The H-EXD-AHP algorithm is as follows (Pathinga Rajendiran, & Moh, 2019):

H-EXD-AHP Algorithm

```
1. For each file_x request with SLA L_i;
2.      Calculate new EXD-AHP score using equation (1);
3.      Update score of remaining files using
                                  equation (2);
4.      If  file_x is present in any one of the VMs;
        /* cache hit
5.          Update score of file_x;
6.          Return;
7.      Else; /* cache miss
8.           Write file_x L_i to the cloud;
9.           Select one of the VM using S_queue LB;
10.         If the selected VM has free space for file_i;
11.              Insert file_x with L_i;
12.              Return;
13.         Else if the VM is full;
14.              Find file_y which has the lowest score;
15.              Evict file_y from L_i;
16.              Write evicted file to the cloud;
17.          Else if file_x score is smaller than the
             lowest score;
18.              Evict lowest scored file from the cache;
19.              Write file_y to the cloud;
20.           Insert file_x L_i in the cache;
21.           Return;
```

New: Adaptive Hierarchy Cache Management Algorithms

AH Algorithm

This algorithm is an enhancement for both H-EXD-AHP and H-PBPS algorithms. In those algorithms, the cache size partitioned for SLA users is fixed and cannot be changed adaptively according to the runtime requirement. In the AH algorithm, the algorithm adaptively adjusts the Cache Distribution (CD) to improve CHR and to meet the Minimum Guarantee of CHR (Pathinga Rajendiran & Moh, 2019).

The first step is identical to either H-EXD-AHP scoring or H-PBPS scoring. For a given Traffic Distribution (TD), and with an initial Cache Distribution (CD), CHR is measured for each SLA. Minimum Guarantee of Cache Hit Rate is set for different SLA users. While any one of the SLA's CHR didn't meet the Minimum Guaranteed cache hit rate (MG) (CHR < MG), then, the surplus cache size is measured for each SLA whose CHR > MG. Next, the surpluses are arranged in increasing order. Then choose the highest surplus Li so that it can give some of its cache sizes to a deficit SLA. Choose the highest preferred SLA, whose CHR didn't meet the MG. Give X % (in this case 20%) of cache size from surplus CD to deficit CD. Remove X % (20%) of the surplus CD and update the new cache sizes. Do this until all SLA's MG is met (Pathinga Rajendiran & Moh, 2019). (The number of iterations to achieve the MG is also recorded and is used to compare the run time of all the AH's.)

AH Algorithm

```
1.  Use H-EXD-AHP or H-PBPS algorithm;
2.     Measure CHR_i of each SLA L_i for i = 1,2...n;
3.     While at least any one of the CHR_i  <  MG_i for L_i;
4.          Measure Surplus_i = CHR_i - MG_i for each L_i
            where CHR_i > MG_i;
5.          Arrange Surplus_i in increasing order;
6.               Choose L_i, which has the highest
                 Surplus_i;
7.               Choose L_j, which has the highest SLA
                 preference AND CHR_j < MG_j for j = 1,2...n
                 and i≠j;
8.                    Set CD_j = CD_j + [CD_i * (X/100)];
9.                         Set CD_i = CD_i - [CD_i * (X/100)];
10.     GoTo Step 1;
11.     END While; \* when CHR_i  >= MG_i for each L_i
12. Return;
```

Improved (I) AH Algorithm

This IAH algorithm is an improved version of AH algorithm, in this instead of borrowing from only one surplus SLA, borrow from top two highest surplus SLA and give it to deficit SLA users. From the first highest surplus borrow X % (in this case 20%) of its cache size and from second highest surplus borrow Y % (15%). Below is the IAH algorithm (Pathinga Rajendiran & Moh, 2019):

IAH Algorithm

```
1.  Use H-EXD-AHP or H-PBPS algorithm;
2.     Measure CHRi of each SLA Li for i = 1,2...n;
 3.     While at least any one of the CHRi  <  MGi for Li;
4.          Measure Surplusi = CHRi – MGi for each Li
            where CHRi > MGi;
5.          Arrange Surplusi in increasing order;
6.               Choose Li, which has the highest
                 Surplusi;
7.               Choose Lj, which has the second highest
                 Surplusj for j = 1,2...n and i≠j;
8.     Choose Lk, which has the highest SLA preference AND
       CHRk < MGk for k = 1,2...,n, k≠i and k≠j;
9.          Set CDk = CDk + [CDi * (X/100)] +
            [CDj * (Y/100)] where X > Y;
10.               Set CDi = CDi – [CDi * (X/100)];
11.               Set CDj = CDj – [CDj * (Y/100)];
12.     GoTo Step 1;
13.     END While; \* when CHRi  >= MGi for each Li
14. Return;
```

In this, choose the first and second highest surplus. Choose the highest preferred SLA Lj, whose CHR didn't meet the MG. Give X % (20%) of CDi AND Y % (15%) of CDj to CDk where X > Y. Remove X % (20%) of CDi from CDi. Remove Y % (15%) of CDj from CDj and update all cache sizes. End while all SLA's MG is met.

Good Guess AH (GGAH) Algorithm

The main purpose of GGAH is to speed up the convergence time in the above AH algorithms. In GGAH algorithm, instead of borrowing cache sizes from surplus SLAs, the authors try to meet the MG of CHR using the GG formula shown below. From previous algorithms, it is observed that for a given TD_i, CD_i is directly proportional to CHR_i for each L_i, that is, $CD_i = k_i * CHR_i$ (Pathinga Rajendiran & Moh, 2019). Thus,

$$k_i = CD_i / CHR_i \quad (7)$$

To find Good Cache Distribution GCD_i, it should also be directly proportional to MG_i. So,

$$GCD_i = k_i * MG_i \tag{8}$$

To get the GCD_i value for each L_i, first find the value of constant k_i for each L_i from equation (7) and substitute that k_i in equation (8). GGAH algorithm is as follows:

GGAH Algorithm

```
1. Use H-EXD-AHP or H-PBPS algorithm
2. Measure CHR_i of each SLA L_i for i = 1,2...n;
3.     While at least any one of the CHR_i  <  MG_i for L_i;
4.          Calculate k_i using equation (7);
5.          Substitute k_i from equation (7) and calculate
            GCD_i using equation (8);
6.      If GCD_i of each L_i sum is not equal to 100 then
        normalize;
7.      GoTo Step 1;
8.      END While; \* when CHR_i  >= MG_i for each L_i
9. Return;
```

New: Adaptive Hierarchy Cache Management Algorithms

The three versions of AH (namely, AH, IAH, and GGAH) are applied to H-EXD-AHP and H-PBPS. The algorithms are as follows in Table 5:

Table 5. Adaptive cache management algorithms

Adaptive H-EXD-AHP Algorithms	Adaptive H-PBPS Algorithms
AH-EXD-AHP Algorithm 1. Use H-EXD-AHP algorithm; 2. Use AH algorithm;	**AH-PBPS Algorithm** 1. Use H-PBPS algorithm; 2. Use AH algorithm;
IAH-EXD-AHP Algorithm 1. Use H-EXD-AHP algorithm; 2. Use IAH algorithm;	**IAH-PBPS Algorithm** 1. Use H-PBPS algorithm; 2. Use IAH algorithm;
GGAH-EXD-AHP Algorithm 1. Use H-EXD-AHP algorithm; 2. Use GGAH algorithm;	**GGAH-PBPS Algorithm** 1. Use H-PBPS algorithm; 2. Use GGAH algorithm;

PROPOSED DYNAMIC CACHE MANAGEMENT ALGORITHMS

Before introducing new solutions that can handle dynamic input, it is necessary to introduce a statistical distribution that is used to evaluate the popularity of user request called Zipf's distribution (Breslau, Cao, Fan, Phillips, & Shenker, 1999). Then, new hierarchical adaptive algorithms discussed in previous section, are transformed into their dynamic versions by introducing Zipf's distribution accordingly. Last but not least, the reason that why the authors decide the value of the threshold in the new algorithms is presented to help the audience better understanding the role threshold play (Tang, Pathinga Rajendiran, & Moh, 2019).

Zipf's Distribution

Assuming that the size of user request content has different size, the distribution of them would be unlikely in a normal distribution. In other words, the user request contents send to the MEC caching VM is unlikely to be equal, so the authors introduced Zipf's distribution to decrease that bias. As a matter of fact, the user's content requests follow a Zipf's distribution P_F (f), ∀f ∈ F given as (Bastug et al., 2015; Breslau, Cao, Fan, Phillips, &Shenker, 1999):

$$P_F\left(f\right) = \frac{\Omega}{f^{\alpha}} \tag{9}$$

where,

$$\Omega = \left(\sum_{i=1}^{F} \frac{1}{i^{\alpha}}\right)^{-1} \tag{10}$$

The parameter α in equation (9) and (10) describes the steepness of the distribution. Like the distribution of contents in the web proxies and the traffic dynamics of cellular devices, this kind of power law is used to characterize many real-world phenomena. The higher α value corresponds to a steeper distribution and indicates that a fraction of the content is more popular than the rest of the catalog. For another, lower values describe more consistent behavior almost as popular as the content.

In the dynamic algorithms, the parameter P_F is used to classify the user request file. Then, after a group of files is formatted or changed over 20%, the EXD-AHP or PBPS score of groups of files is calculated and updated, and the binding between VMs in cache and user request files is set or changed based on the score. By doing so, periodically updating is achieved in the dynamic algorithms (Tang, Pathinga Rajendiran, & Moh, 2019).

Dynamic Hierarchical and Adaptive Cache Management Algorithms

In H-EXD-AHP, H-PBPS algorithms assumed user content input is static. After introducing Zipf's distribution, new algorithms called D-H-EXD-AHP, D-H-PBPS and D-RRM-PBPS are proposed. These algorithms use Zipf's distribution to decide the correlation between the user request and VMs in the cache. D-H-EXD-AHP algorithm is as follows:

D-H-EXD-AHP Algorithm

```
1.        Use H-EXD-AHP algorithm
2.        For each file_x request;
3.            Calculate P_F(f)
4.            Decide which class/group of files f should go based on P_F;
5.            Update the Sum of P_F of the changed file group;
6.            If the sum of P_F changes over 20%;
7.               Update the classification of file groups
8.               Reset the CD of all of all file groups;
9.        Go back to Step 1.
10.        END For;
11.        Return;
```

For D-H-PBPS and D-RRM-PBPS, the only difference is the first step. The authors used H-PBPS and RRM-PBPS instead of H-EXD-AHP (Tang, Pathinga Rajendiran, & Moh, 2019).

D-AH Algorithm

```
1.        Use H-EXD-AHP or H-PBPS algorithm
2.        For each file_x request;
3.             Calculate P_F(f)
4.             Decide which class/group of files f should go based on P_F;
5.             Measure CHR for all file groups;
6.             If CHR of any file group below MG,
7.                Use AH algorithm; Measure Surplus; Reset CD;
8.             If the sum of P_F of all file groups changes over 20% after re-
setting CD;
9.                 Update the classification of file groups
10.                 If average MG of a group of files cannot be satisfied
11.                     Decrease 5% threshold;
12.                     Repeat until MG is satisfied for all groups of files;
13.        Go back to Step 1.
14.        END For;
15.        Return;
```

For D-IAH and D-GGAH, the significant difference is the step 7. For D-IAH use IAH in step 7. D-IAH reset the CD by borrowing the cache from first and second highest Surplus. For D-GGAH use GGAH in step 7. D-GGAH uses equation (7) and equation (8) to measure and reset CD.

Effects of Threshold Values

Ideally, Zipf's distribution should be updated as long as the distribution of user content changed. However, that would cost a large amount of computation resource without improving too much efficiency on it. The test results to decide the threshold of the improved algorithms is shown in the Figure 10. The authors assume that all the rest factors are same except the threshold and the size of the cache. It is evident that 20% threshold always achieve the best CHR no matter cache is 0.75 GB or 2 GB (Tang, Pathinga Rajendiran, & Moh, 2019).

Meanwhile, how many runs that the algorithm takes to update the binding is another way to evaluate the resource usage. The test results to decide the average number of runs to update is shown in the Figure 11. Less runs it takes means that it will check and re-assign the VMs more frequently, which means it will take more resource. Therefore, the authors expect to take more runs to update the binding as long as the cache hit rate stays at an acceptable level. Even though the number of runs that the algorithm takes to update the binding is larger when the threshold is 30%, 40% or 50%, the difference is large enough to convince the authors to change the threshold (Tang, Pathinga Rajendiran, & Moh, 2019).

Thus, for dynamic algorithms, the threshold is set as 20%, which means that the binding between VM and user request file stays unchanged until the change of distribution of user file is over 20%. This threshold helps the algorithm to avoid the wasting of computation resource and ensure that the pattern of this model can be dynamically and periodically updated.

Figure 10. CHR: Comparison between different threshold setting with two sizes of the cache

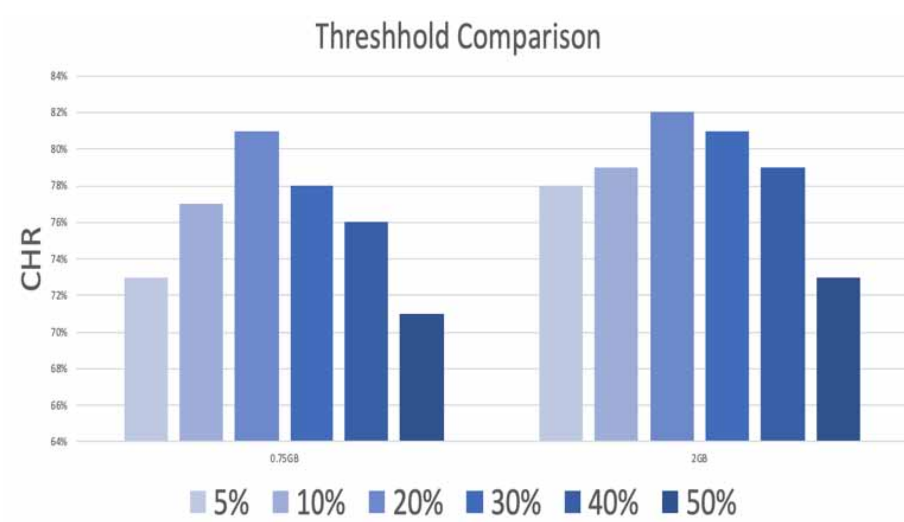
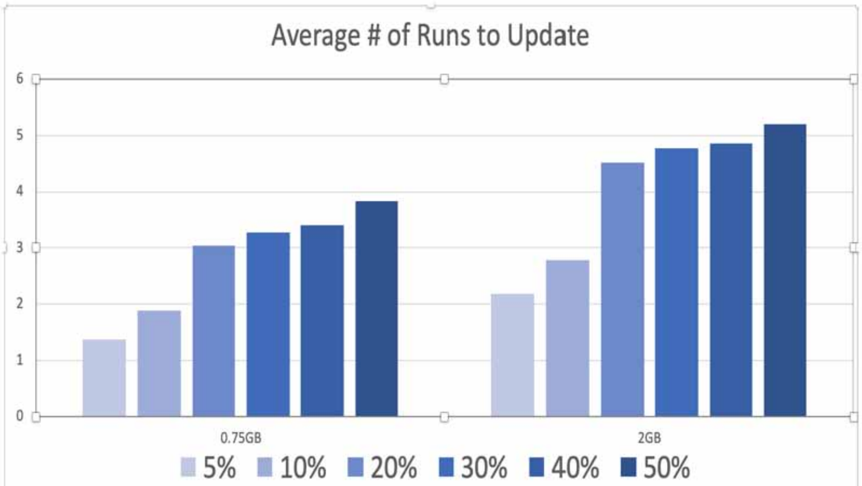


Figure 11. Average number of runs to update: Comparison between different threshold setting with two sizes of the cache



Algorithms Comparison

The three improved dynamic algorithms that the authors proposed have some similarity but also difference due to the introducing of Zipf's distribution. To tell these similarities and differences straightforward and helps readers to better understand the effect of Zipf's distribution in improved algorithms, Table 6 is shown below. This Table 6 summarizes six algorithms from three aspects, dynamic, hierarchical, and scoring based on what factors. Notice that if an algorithm is marked as "yes" in the dynamic section, it uses Zipf's distribution.

AH, IAH, GGAH, unlike algorithms in the above Table 6, split cache into different portions. Below Table 7 compares them and their dynamic versions to show the effect of Zipf's distribution and their characteristics:

Table 6. Comparison: Hierarchical cache management algorithms

Algorithm	Score based on	Hierarchical	Dynamic
H-EXD-AHP	SLA, no. of accesses per file	Yes	No
D-H-EXD-AHP	SLA, no. of accesses per file	Yes	Yes
H-PBPS	Cache Hit Rate (CHR)	Yes	No
D-H-PBPS	CHR	Yes	Yes
RRM-PBPS	CHR	No	No
D-RRM-PBPS	CHR	No	Yes

Table 7. Comparison: Guaranteed minimum cache management algorithms

Algorithm	Cache Redistribution	Dynamic
AH	Highest Surplus (20%)	No
D-AH	Highest Surplus (20%)	Yes
IAH	Highest (20%) and Second (15%) Highest surplus	No
D-IAH	Highest (20%) and Second (15%) Highest surplus	Yes
GGAH	Good Cache Distribution	No
D-GGAH	Good Cache Distribution	Yes

PERFORMANCE EVALUATION

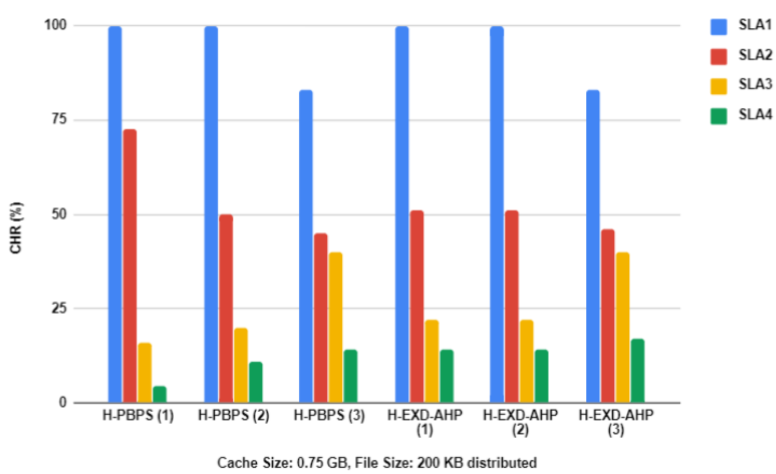
Cache Hit Rate for H-EXD-AHP Algorithm

CHR for H-EXD-AHP is displayed and compared with H-PBPS algorithm in Figure 12, using the cache partition shown in Table 4. Figure 12 uses 0.75 GB cache size and 200 KB distributed file size. Note that H-PBPS algorithms give good CHR for SLA 1 and SLA 2, but for SLA 3 and SLA 4 the CHR is less. Whereas H-EXD-AHP algorithm performs better because CHR is higher for all the SLA users when compared with H-PBPS algorithms. It is also clear that different cache partitions resulting in different performances (Pathinga Rajendiran & Moh, 2019).

Experimental Setup for Dynamic Input Algorithms

A comprehensive library called iFogSim is used to set up the simulation environment to run the dynamic algorithms. This library enhanced the CloudSim with a new package fog. It virtualized the environment that device close to edge nodes, which is not computationally powerful enough to host all operators of the application. In package fog, Edge Device Simulator, VM Simulator, variables that decide bandwidth,

Figure 12. Cache Hit Rate (CHR) (%) for H-EXD-AHP (Cache Size 0.75 GB, File Size 200 KB distributed)



memory, etc. has been provided. To complete the performance test, the authors also implemented a class that defines the cache management rule, a simulator that simulates the dynamic input which changes over time, and an override performance visualization class (Tang, Pathinga Rajendiran, & Moh, 2019).

Experiment Setup

In Pathinga Rajendiran & Moh's (2019) experiment, the arrival rate of files into the network is being set as 1400 files/sec. The authors tried to make it vary from 800 to 2000 files/sec since they assume a dynamic input is given. Meanwhile, a distance between the arriving file and VM is added to add an attribute that represents the geographical relationship between mobile devices and VMs/BBUs. Besides that, they selected two sizes of the cache to explore the potential impact to the performance of the caching algorithm. This setting aims to provide experiment support for the assumption that edge devices/servers are limited to hardware resources compared to cloud devices/servers (Tang, Pathinga Rajendiran, & Moh, 2019). The simulation parameters and values for dynamic algorithms is displayed below in Table 8.

The authors selected 20 seconds from the log and the performance of three improved algorithms and their dynamic version. Then three range is defined to separate number of arrival files into three classes:0-1000 files/sec, 1000-2000 files/sec, 2000-3000 files/sec. Then the authors run a test with two different cache size: 0.75 GB and 2GB. For each of the range of input, they calculate the average cache hit rate for each algorithm.

Cache Hit Rate

The reason the authors choose the CHR as the major evaluation factor is that it can display how important the role that cache plays in the network (Kaur & Moh, 2018). Higher cache hit rate means that the cache is efficiently used, but not occupies system resource without doing anything.

As shown in the Figure 13 and Figure 14, all three improved algorithm handles the dynamic input better compared with their original version, even though their performance is not stable at some points. Besides that, by observing the test result, several facts can be found. First, the impact of improvement is more obvious when RAM is 0.75 GB. This implies that the improvement works better when RAM is limited, which is a good sign because the edge server usually has limited RAM. Second, there is not a strong relationship between the range of input and the performance of algorithms. Both original and improved versions of all these algorithms perform stably with different ranges of input. H-EXD-AHP makes most improvement (Tang, Pathinga Rajendiran, & Moh, 2019).

Table 8. Simulation Parameters and Values for Dynamic Algorithms

Parameter	Values
No. of host and of VM	Min:1, Max:10
VM cache sizes	0.75GB, 2GB
Arrival rate of files into the network	0~3000 files/s
Total no. of users and of requests	20000, 400000
File sizes	200KB
Network bandwidth	1Gbps

Figure 13. CHR: RAM is 0.75GB

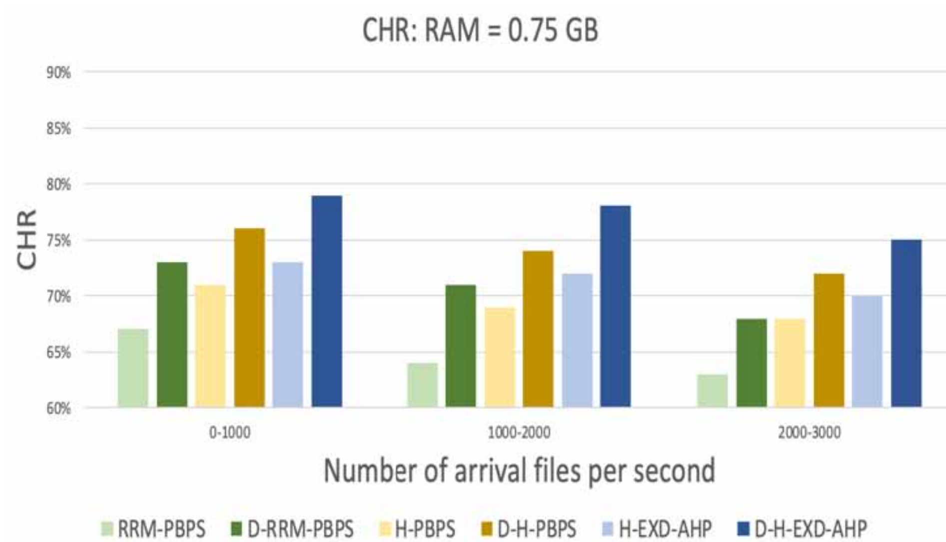
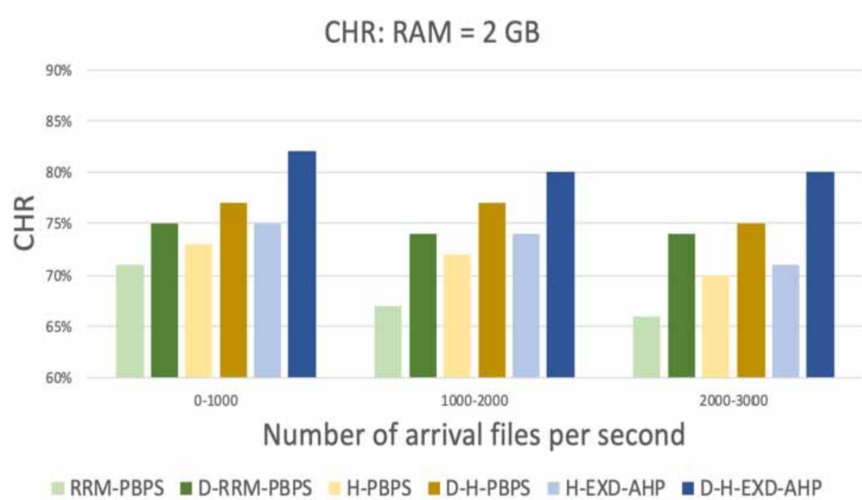


Figure 14. CHR: RAM is 2 GB



Average Access Time

Another evaluation that the authors run is based on the average access time of cache memory. The access time of a cache memory is calculated based on the equation (11) (Kaur & Moh, 2018):

$$\text{Average Access Time} = HT \times HR + MP \times MR \qquad (11)$$

where HR is the cache hit rate, HT is the hit time, MR is the cache miss rate, MT is the cache miss time. Since this algorithm takes additional time to check and update binding between VMs and user request files, the authors want to check if it affects the overall access time. If it does, it means that even though this solution improves the usage rate of cache, but it takes more time for a user request file to be placed.

Based on the test result from Figure 15 and Figure 16, the size of RAM does not make an obvious impact on the average access time. However, the range of input does, when the input ration gets smaller, this improvement makes an obvious effect, and when the input ratio gets larger, this effect is almost being eliminated. This reminds the relationship between cache miss penalty and input ratio since they are factors that change in the experiment. One statement can be made is that the miss penalty of this improved

Figure 15. Average access time: RAM is 0.75GB

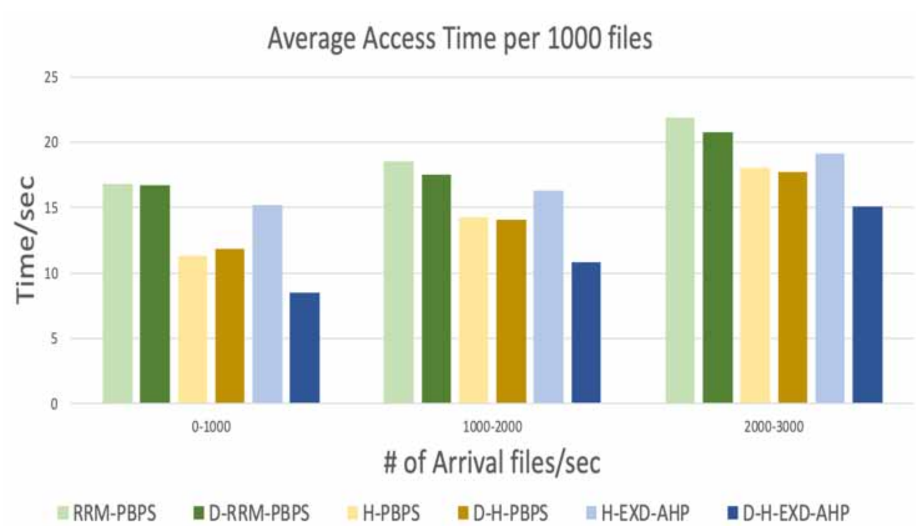
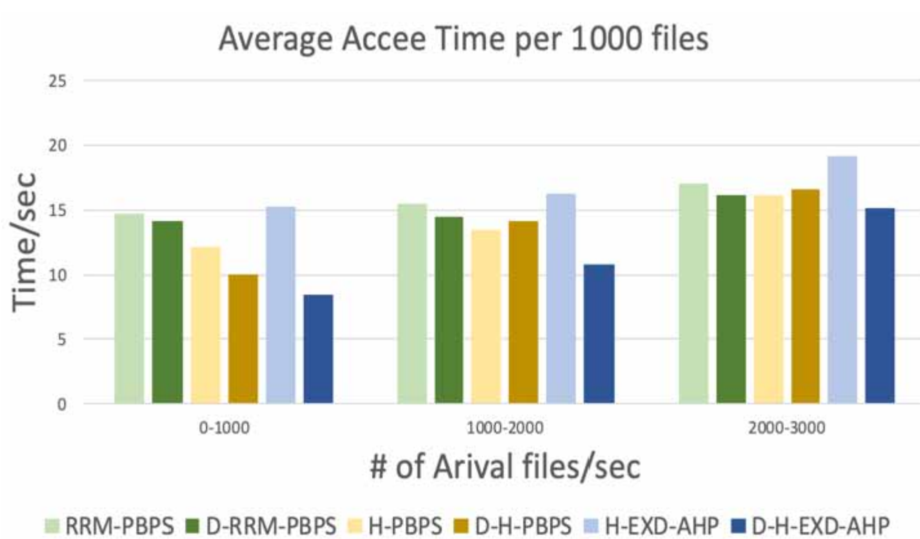


Figure 16. Average access time: RAM is 0.75GB



algorithm is getting larger when the input ratio is larger. Besides that, Zipf's distribution works best on H-EXD-AHP algorithm regarding the improvement of average access time.

Adaptive and Dynamic H-EXD-AHP Results

Below in Table 9 displays how many iterations do adaptive and dynamic H-EXD-AHP algorithms need to achieve Minimum Guarantee.

Based on the Table 9, it can be observed that Zipf's distribution successfully speed up the convergence time for D-H-EXD-AHP and D-IAH-EXD-AHP algorithms comparing with their non dynamic versions. However, for D-GGAH-EXD-AHP, since it only takes 2 iterations to meet the MG, Zipf's distribution cannot provides too much help.

Adaptive and Dynamic H-PBPS Results

Below in Table 10 displays how many iterations do adaptive and dynamic H-PBPS algorithms need to achieve Minimum Guarantee.

Even though Zipf's distribution speed up the convergence time of D-AH-PBPS and D-IAH-PBPS algorithms, the improvement is very limited. For the cache with more uniform MG of CHR such as {60%, 50%, 35%, 30%}, Zipf's distribution actually makes more benefits for D-H-PBPS than D-H-EXD-AHP than three dynamic adaptive algorithms.

Table 9. EXD-AHP: Number of Iterations for different MG

Minimum Guarantee of Cache Hit Rate (%)	**95, 50, 20, 10**	**80, 45, 35, 15**	**70, 40, 30, 20**	**60, 50, 35, 30**
AH-EXD-AHP	8	5	4	4
D-AH-EXD-AHP	6	5	4	3
IAH-EXD-AHP	6	4	4	3
D-IAH-EXD-AHP	5	3	3	3
GGAH-EXD-AHP	2	2	2	2
D-GGAH-EXD-AHP	2	2	2	2

Table 10. PBPS: Number of Iterations for different MG

Minimum Guarantee of Cache Hit Rate (%)	**95, 50, 20, 10**	**80, 45, 35, 15**	**70, 40, 30, 20**	**60, 50, 35, 30**
AH-PBPS	9	5	4	5
D-AH-PBPS	7	3	3	2
IAH-PBPS	7	4	3	3
D-IAH-PBPS	5	3	2	2
GGAH-PBPS	2	2	2	2
D-GGAH-PBPS	2	2	2	2

CONCLUSION

This work has addressed the challenge of providing fast access and guaranteed QoS in the 5G era of dynamically changing traffic input. While most existing cache management research has focused on improving cache hit rates, the proposed algorithms not only provide high cache hits, but also dynamically adjust to incoming workload and its changing traffic distribution and are therefore able to guarantee minimum QoS for different SLA levels. Performance evaluation based on iFogSim has shown that the proposed algorithms have successfully adjusted to the dynamic input, even in the midst of skewed, unbalanced changes, with improved efficiency. Future works would include further evaluation the impact of coefficients and threshold values would make to the dynamic algorithms, application of the proposed dynamic version to other cache management algorithms in other systems, and deployment of the proposed algorithms in real CRAN and MEC systems.

ACKNOWLEDGMENT

This research was supported in part by Nokia Foundation; and SJSU RSCA.

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KEY TERMS AND DEFINITIONS

Cache Distribution or Cache Hierarchy: Cache is distributed according to the service level of users. For example, highest service level users might enjoy maximum cache size.

Dynamic Input: For Dynamic Input, there is unbalanced distribution of user devices and virtual machines and distribution will continuously change over time.

Edge Computing: Instead of retrieving data from Internet, data can be accessed from nearby sources to improve users experience.

Minimum Guarantee: A guaranteed minimum percentage of service or cache hit is promised to the users.

Popularity Scoring: Since the cache size is small, files which has high score or "popular" are only stored in cache. Low score files are evicted if there is no space in cache.

Service: Level Agreement: Preferential treatment for users and quality of service is attained to the users according to their service level.

Static Input: For Static System, the amount of user request for each User Equipment is fixed and will not change over time.

Chapter 7
On Efficient Cache Management of Cloud Radio Access Networks for 5G Mobile Networks

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ABSTRACT

Cloud radio access networks (CRAN) have been proposed for 5G technologies to provide improved scalability, flexibility, and performance for supporting rapid increase of IoT devices. This chapter designs a new efficient cache management scheme for the baseband unit (BBU) pool in CRAN. First, it adopts the exponential-decay (EXD) scheme to keep recently frequently requested records in cache and enhances it with analytical hierarchy process (AHP) to support multiple levels of mobility and QoS. The other new algorithms include a probability-based scoring scheme, a hierarchical, or tiered, approach, and enhancements to previously existing approaches. Performance evaluation shows that the new schemes offer high cache hit ratios and a reduction in network traffic as compared with other existing and classic caching mechanisms. The authors believe that this work is important in advancing 5G technology for supporting IoT services and is also useful to other cache management systems.

DOI: 10.4018/978-1-7998-1152-7.ch007

INTRODUCTION

Cellular networking technology has been advancing at impressive rates since its emergence in the technological market. With the onset of new devices, cellular networks have had to keep up with a growing demand for connectivity. This explosion of activity is evident by the Internet of Things, or IoT. Technologies needing Internet connection have even been projected to reach a staggering fifty billion devices within the next few years. IoT applications can, and will be, seen in developing areas such as smart grids, health services, homes, and even cities (Kumar & Roa, 2015).

Internet of Things (IoT) devices are increasingly entering today's market. Similar to smart phones, many IoT devices rely upon a wireless connection to utilize data services. These IoT devices often have a characteristic of large volumes at unknown locations and thus using a wired connection would not be practical. Long Term Evolution Advanced (LTE-A) is the current 4th generation (4G) mobile communication standard. It is commonly used by smartphones as the data service medium to connect with the Internet. Though LTE-A was created to provide Internet access via wireless connection, it would not be able to handle the volume of IoT devices that is projected to need data services. 5^{th} generation (5G) mobile communication standard therefore has been proposed to handle IoT as well as rapidly growing number of smart wireless devices.

These developments have motivated the work around 5G Cloud Radio Access Network (CRAN) architecture. The CRAN is designed to utilize cloud computing technology for supporting the rapidly growing number of IoT devices. In particular, the consolidation of resources in cloud technology through virtualization and centralization, and consequently better utilization of hardware and software resources ("5G network architecture," 2016).

An important aspect of cellular networks is to achieve acceptable speeds of services in addition to supporting massive numbers of users and devices. One important way for speeding up compute and storage access is caching. Cache refers to a fast-accessible memory component that stores data so that future requests for that data can be served much more quickly. It is a vital for ensuring real-time services and for limiting network traffic due to memory or storage access.

Newer cellular architectures such as CRAN have included cache systems (Fan, Zhang & Yuan, 2016). Naturally, the cache must be efficiently maintained to make the best use of limited resources and offer users the quality of services (QoS) they were promised. This is another concept that has motivated work on finding useful and practical caching mechanisms (Tsai & Moh, 2018; Kaur & Moh, 2018).

This chapter proposes several efficient cache management algorithms and evaluates against existing schemes, aiming to provide fast access and effective resource management in 5G supporting IoT communication. This chapter is an extension of two conference papers (Tsai & Moh, 2018; Kaur & Moh, 2018). The chapter is organized as follows: The next section discusses background and related work. Section 3 dives into various cache management schemes and mechanisms. Section 4 evaluates the performance of those aforementioned schemes and is followed by the conclusion in Section 5. This is a continuation of the authors' work on 5G, CRAN, and cloud computing (Shahriari, Moh, & Moh, 2017; Su & Moh, 2018; Shahriari & Moh 2018), CRAN (Karneyenka, Mohta, & Moh, 2017; Shahriari, Moh, & Moh, 2017; Tsai & Moh, 2017a, 2017b, 2018; Kaur & Moh, 2018), and cloud and fog computing (Huang, Wu, & Moh, 2014; Reguri, Kogatam, & Moh, 2016; Choudhari & Moh, 2018; Gao & Moh, 2018).

BACKGROUND AND RELATED WORK

In this section, the authors first describe background information including the basic 5G/LTE-A architecture and CRAN model. This is followed by related works in cache management.

5G CRAN and User Equipment Context (UEC)

Before the proposal of CRAN, the radio access network (RAN) was distributed, as seen in Figure 1 (Checko et al., 2015; Tsai & Moh, 2018; Kaur & Moh, 2018). A RAN consists of eNodeB and UE. Traditional eNodeB consists of remote radio head (RRH) and baseband unit (BBU) with RRH on every eNodeBs, as seen in Figure 1. While RRH is mainly to transmit and receive wireless signal as well as to amplify signal for transmission, BBU is responsible for transforming IP packets into digital baseband signal, processing baseband signal from RRH, plus management of user mobility and Quality of Services (QoS) (Checko et al., 2015).

In order to address some of the challenges present in 5G cellular networks, a different type of architecture has been proposed, which is CRAN (Chow, 2015; Fan, Zhang, & Yuan, 2016). In CRAN, the BBUs of eNodeBs are pooled together, as seen in Figure 2 (Tsai & Moh, 2018; Kaur & Moh, 2018). The CRAN model therefore reduces power consumption, increases scalability, and lowers delay. It also offers other advantages such as high resource utilization, and better mobility and radio interference management (Checko et al., 2015).

Figure 1. Traditional distributed RAN

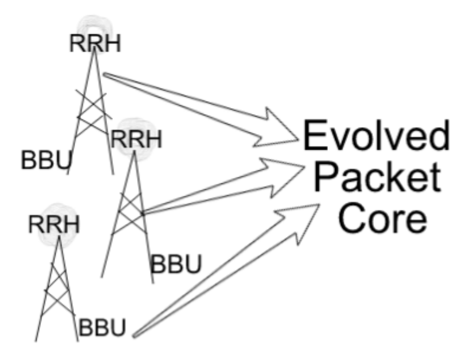
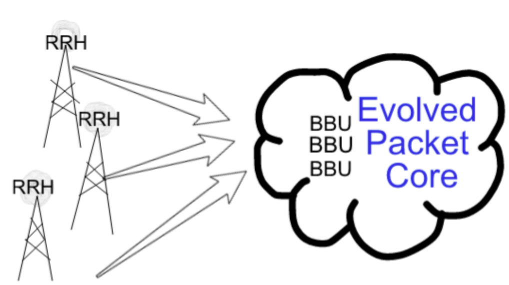


Figure 2. CRAN



Cellular networks use User Equipment Context (UEC) to represent the control information of a user's call/session, including the user's ID, subscription information, and state information of the current session or event. UEC records therefore are stored in the BBU, and need to be quickly accessed, read, and written. 5G aims at supporting a vast, exponentially growing volume of IoT devices, in additional to existing IP-based applications, it is important to design memory management for BBU pools that is scalable and supporting multiple QoS levels (Tsai & Moh, 2018).

Furthermore, since the memory size of a BBU pool is limited, CRAN often includes a secondary, cloud storage. The memory management architecture therefore includes cache in each Virtual Machine (VM) of the host operating the BBU pool. An ideal management scheme should also efficiently increase cache hit rate and thereby decrease accesses to the secondary cloud storage, thereby improve mobile users' experience (Tsai & Moh, 2018). This chapter improves cache management algorithms for BBU pools in CRAN.

An example of the benefits of CRAN would be handover (HO) support. HO occurs in cellular networks when a user moves from one eNodeB to another (Karneyenka, Mohta, & Moh, 2017). Its purpose is to transfer the UEC, which holds subscription and QoS information, to the current eNodeB the user is located. In the traditional Long Term Evolution (LTE) network, UECs are stored in a local BBU of an eNodeB; thus, it takes time to transfer UECs between the two eNodeB. In CRAN, because BBUs are pooled, many HO steps are now internal processes of BBU pool; this significantly reduces HO latency (Karneyenka, Mohta, & Moh, 2017).

Related Work

There are many works on dealing with cache performance. Floratou et al. (2016) introduced a cache algorithm for database applications in Big SQL using HDFS cache. In this algorithm, all files in a cache were sorted in descending order according to their scores, and first few lowest score files were evicted to make room for a newly arrived, more important file. The file score was determined by scoring functions such as exponential-decay (EXD) or least recently used method. The paper also introduced an adaptive algorithm which monitored the hit rate of the cache. The algorithm adjusted the parameters of scoring functions based on the observation to increase the hit performance. The EXD scoring function has been adopted in this work for UECs in BBU cache.

Gomes, Braun, and Monteiro (2016) discussed a content migration technique between edge caches located in eNodeBs. In their scheme, a specified controller predicted a mobile user movement and made the decision on whether to migrate contents to a new node. When the decision is positive, the Analytic Hierarchy Process (AHP) (Saaty, 1987) was used to determine the best edge node for content migration. The authors also pre-determined what content to migrate using content popularity. The authors successfully demonstrated that the technique could reduce download latency and increase hit rate at edge caches. The AHP scheme has been adopted in this work to compute the weight for different service and mobility levels, which in turn enhances the scoring function.

Podlipnig and Böszörmenyi (2003) compiled a list of common cache replacement strategies such as Least Frequently Used (LFU), Least Recently Used (LRU), and Greedy Dual (GD). LFU, which removes the least frequently requested file, has been used as a base line algorithm in the performance evaluation section.

Wang, Zhang, Yang, Wang, and Wang (2015) derived an LTE caching scheme to reduce communication cost by making a tradeoff between diversity and redundancy of cache contents at edge nodes. They successfully demonstrated that the algorithm can find the best content redundancy ratio to minimize transmission cost.

In an LTE cache management study, Stynes, Brown, and Sreenan (2014) attempted to reduce redundant communication during an LTE handover in Passive Optical Networks (PON). This was done by caching a destination node before a HO occurred. The study concluded that the proposed algorithm could increase a mobile device data rate by 50% during a HO.

Jing, Ali, She, and Zhong (2013) summarized a list of cache management works for reducing energy consumption of disks. One of those works included Partition-Based Least Recently Used (PB-LRU) algorithm by Zhu, Shankar, and Zhou (2004) which divided cache into multiple partitions. Each disk had its own partition and the size changed according to energy consumption of an individual disk. The same author also came up with Power-Aware Least Recently Used (PB-LRU) algorithm which evicted block with largest energy penalty at replacement (Zhu & Zhou, 2005). Both algorithms were shown to reduce energy consumption.

Ye, Chen, Fang, Li, and Feng (2015) aimed to ameliorate the performance of Solid State Drives, or SSDs, by using a caching algorithm that would analyze the popularity of entire disk blocks. Relatedly, another study by Baek, Cho, and Choi (2017) involved caching for SSDs using probability models, specifically a geometric probability model, to determine which elements to place in the cache and which ones to evict.

In a separate study about general caching, Zaidenberg, Gavish, and Meir (2015) discussed novel caching algorithms. The authors demonstrated partitioning and the use of a hierarchy. The concept of using a hierarchy has been used in one of the algorithms presented.

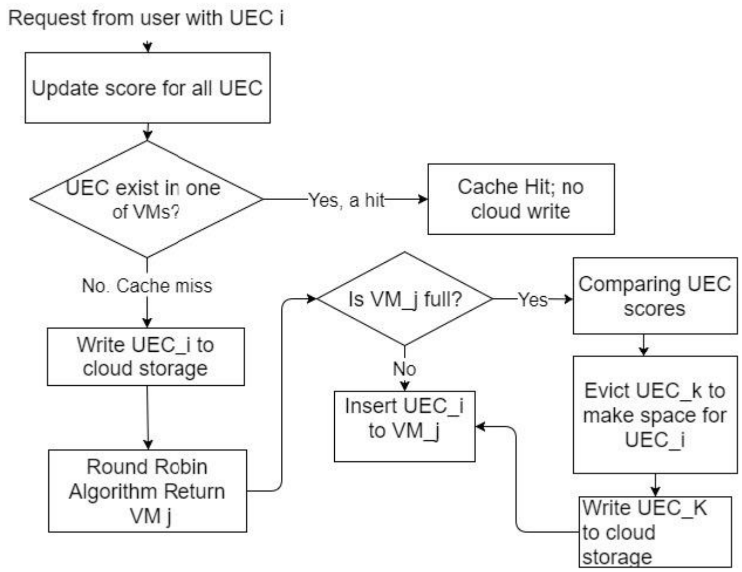
Huang, Zhao, and Zang (2016) studied the effects on latency of a caching scheme specific to the traditional distributed RAN. Anand and Barua (2015) discussed the use of locking mechanisms in instruction cache. This is especially useful when the most frequently and recently used items are locked and cannot be evicted, so hits are assured for those elements.

CACHE MANAGEMENT SCHEMES

The general structure of how UEC can be handled in 5G CRAN can be represented in Figure 3 (Tsai & Moh, 2018; Kaur & Moh, 2018). A detailed description of the flowchart follows.

Requests from users are incoming, and each user is associated with a unique UEC. Once the UEC is identified, the information regarding all other UECs currently in the system are updated using a scoring process. If the currently incoming UEC is present in one of the VM in the data center; i.e., a cache hit, the UEC is simply updated in the cache, and no cloud write is required. On the other hand, if the UEC is not present in one of the VM, meaning there is a cache miss, it must be written to the cloud, and a load balancing algorithm must be performed in order to determine in which VM the UEC is to be placed. Once the VM is determined, a check is performed to determine whether that VM has room to accommodate an additional UEC. If the VM has room, meaning the cache is not full, the UEC is simply

Figure 3. Cache management flowchart



inserted into the chosen VM. If the VM is full, then the cache management scheme will choose a UEC to evict, typically one with the lowest score. Once the eviction is performed, the evicted UEC must be written to the cloud and the previously incoming UEC can be inserted into the cache maintained by the VM (Tsai & Moh, 2018; Kaur & Moh, 2018).

In this general structure, there is much room for how exactly to handle the UECs, specifically how to handle insertion, eviction, and writes. This is where the various cache management schemes come into play. The succeeding schemes all present and discuss different ways of managing the UEC elements in the context of the cache.

Exponential-Decay (EXD) Cache Management Algorithm

EXD algorithm is adopted to keep the most requested UECs in the cache (Tsai & Moh, 2018). The Exponential-Decay algorithm was originally proposed to compute the score of partitions in HDFS cache for IBM Big SQL (Floratou et al., 2016). The EXD scoring function may be described below, adopting to the UEC cache management problem:

In EXD, each UEC score (weight) is determined by the time between requests. If a UEC_i currently in the cache is not requested during the time interval (u_{i1}, $u_{i1}+\triangle u$), its score S_i is updated (Floratou et al., 2016):

$$S_i\left(u_{i1}+\triangle u\right)=S_i\left(u_{i1}\right)*e^{-a\triangle u} \quad (1)$$

Otherwise, if UEC_i currently in the cache is accessed at time $u_{i1}+\triangle u$ for the first time after time u_{i1}, then its score S_i is updated (Floratou et al., 2016):

$$S_i\left(u_{i1} + \triangle u\right) = S_i\left(u_{i1}\right) * e^{-a \triangle u} + 1 \qquad (2)$$

Note that the score depends on the value of the parameter *a*. In fact, the value of the parameter *a* essentially determines how recency and frequency are combined into a single score. In fact, the larger the value of *a* is, the more emphasize is on recency.

To see this, observed from Equation (1), a UEC's weight is reduced to a fraction of $e^{-a\triangle u}$ if it is not requested for the time interval $\triangle$u. This fraction depends on the values of *a* and $\triangle$u. The larger the value of *a* is, the more reduction is; similarly, the longer the $\triangle$u, the higher the reduction. On the other hand, observed from Equation (2), when it is being accessed a UEC's weight is incremented by 1 after reduced to a fraction of $e^{-a\triangle u}$. Thus, the more requested UEC would have a higher score (Tsai & Moh, 2018).

Thus, the value of the parameter *a* essentially determines how recency (reducing to the fraction of $e^{-a\triangle u}$) and frequency (increasing by 1) are combined into a single score represented by Equations (1) and (2). The larger the value of *a*, the more emphasize is on recency (as opposed to frequency). Note also that its value may be chosen adaptively (Floratou et al., 2016).

Another strength of the EXD scoring function is that the score $S_i(u)$ can be calculated for any time $u_{i1} > u$ before the next UEC request. Also, the scores drop (decay) exponentially, and therefore may be approximated by zero after they drop below some threshold (Floratou et al., 2016). This would reduce the need to maintain the score record for UEC weights for a long time, and thus simplify implementation as well as improve the scalability.

Thus EXD (Exponential-Decay) algorithm calculates/updates the score of the newly UEC by Equation (2) while updates all other UEC scores by Equation (1). This is based on the algorithm proposed by Floratou et al. (2016) in managing the HDFS cache in Big SQL. The high-level description of the EXD algorithm is first presented below, followed by detailed explanation (Tsai & Moh, 2018).

EXD Algorithm

```
For each requested from user with UEC_i
Calculate new score of UEC_i using Equation (2)
Update the score of every entry in the cache using Equation (1)
If cache hit on one of the VMs then
Update both content and score of the in-cache UEC_i with those of this
newly arrived UEC_i
Return
Else /* cache miss
Write UEC_i to the cloud storage
Select a VM using Round-Robin algorithm
 If the VM has cache space then
 Insert UEC_i in VM's cache
 Return
 Else /* no cache space, compare UEC scores
 If score of UEC_i greater than the min. score
 Evict from the cache the first lowest E entries whose sum of scores
```

```
is just lower than score of UECi
16.        Write the evicted E UEC's to cloud storage
17.                Else /* UECi score lower than the min. score
18.                Evict minimum-scored UEC from cache
19.        Write the evicted UEC to cloud storage
20.                Insert UECi in VM's cache
21.        Return
```

The EXD algorithm may be explained in detail as follows (Tsai & Moh, 2018).

- **Steps 1-3:** when a new request (i.e., a new UEC event) arrives, then its score would be calculated based on Equation (2). All other UEC entries in the cache will update their scores according to Equation (1).
- **Steps 4-6:** for cache hit; i.e., the UEC_i is in one of the VMs, then update its content and score.
- **Steps 7-8:** for cache miss. First, write UEC in the cloud storage; every active UEC needs to have a copy stored in the central storage.
- **Step 9:** Choose VM. In this algorithm Round-Robin algorithm is used for choosing a VM for this newly arrived UEC. In later algorithms different load balance algorithms may be used.
- **Steps 10-12:** if the chosen VM has cache space, then simply insert the newly arrived UEC_i to its cache.
- **Steps 13-16:** No cache space in the chosen VM. Compare the score of the newly arrived UEC_i with the minimum score of all the UEC's in the cache. Evict the first lowest E entries whose scores summed up together is smaller than the score of UEC_i. Write the evicted E UEC's into cloud storage.
- **Steps 17-19:** In case that the newly arrived UEC_i has a score that is lower than the minimum of all the existing UEC scores in the same VM, then the UEC with the current minimum score will be evicted to make place for the new UEC. Write the evicted UEC into cloud storage.
- **Steps 20-21:** Insert the newly arrived UEC_i to the VM cache.

EXD-AHP+1 Cache Management Algorithm

While the EXD-based UEC scoring successfully keeps the most recently and frequently accessed UECs and in the cache, it does not address the support of different QoS levels. In this the authors mean to give different preferential treatment for users with different levels of subscriptions or Service Level Agreement (SLA), and therefore receive different QoS level guarantees (Tsai & Moh, 2018).

To achieve the second goal while still keeping the first goal, the authors essentially face a Multiple-Criteria Decision-Making (MCDM) problem. It is a problem, and thus an approach to make decisions to accomplish multiple, often conflicting, criteria. This approach supports multiple weighted criteria, and usually returns a finite number of solutions.

Score methods are commonly used for this kind of problems. Among them, the Analytical Hierarchy Process (AHP) (Saaty, 1987) is perhaps the most well-known. As its name implied, the method starts by deciding the hierarchical list of criteria and listing the alternatives to be ranked.

For this cache management problem, considering both recency and frequency of UEC requests, and the QoS level of a UEC, the following service levels are defined:

L1: UEC of high mobility and premium QoS
L2: UEC of low mobility and premium QoS
L3: UEC of high mobility and basic QoS
L4: UEC of low mobility and basic QoS

As each of the above levels may have a different significance for the decision, each of them should be given a different weight value. The authors then enhance the EXD-based scoring with the AHP-based weight value. The motive behind this modification is to increase the hit rate of UECs with higher QoS level while preventing UECs with low QoS from getting high score.

In order to rank among the 4 levels, a 4×4 matrix is created where each level is compared against the others using pair-wise comparisons; i.e., each is compared with all the others in terms of significance. For example, the authors may define L1 is 5 times more important than L2, so the matrix element that compares L1 with L2 will have a value of 5/1, while the opposite comparison the value of 1/5, an example is shown in Table 1 (the right-most column represents the weight value calculated following the steps described below) (Tsai & Moh, 2018).

Note that the AHP matrix cannot be used yet; an eigenvector with the final weights, W_{AHP}, as shown on the right-most column, need to be calculated with the following steps (Gomes et al., 2016):

1. Convert fractions to decimals
2. Square the result matrix
3. Sum up the rows of the matrix and get a vector
4. Normalize the result vector by dividing it with the sum of all elements in the matrix
5. Repeat steps 2 to 4 until the resulting vector no longer changed from the previous iteration

Each element of this resulting vector represents the weight of individual QoS level, W_{AHP}. These values are then used to modified to existing EXD scoring function. The modification is shown in Equation (3), adding W_{AHP} to the right side of Equation (2), where W_{AHP} corresponds to the weight corresponding to the QoS level of UECi. In this way, the score of the requested (accessed) UEC is increased by 1+ W_{AHP}; those with higher QoS level, therefore higher W_{AHP}, would be increased more.

$$S_i\left(u_{i1} + \triangle u\right) = S_i\left(u_{i1}\right) * e^{-a\triangle u} + 1 + W_{AHP} \tag{3}$$

Table 1. AHP matrix and weight

	L1	L2	L3	L4	Weight W_{AHP}
L1	1	5/1	5/1	5/1	0.579
L2	1/5	1	5/1	5/1	0.281
L3	1/5	1/5	1	5/1	0.102
L4	1/5	1/5	1/5	1	0.043

Note that while the EXD algorithm attempts to keep the recently and frequently arrived UECs in the cache by updating (increasing) their scores according to Equation (2), it does not consider service levels or priorities of individual UECs. The EXD-AHP+1 algorithm, integrating a weight W_{AHP} (Saaty, 1987) corresponding to service levels when updating scores for newly arrived UECs.

In this section, EXD-AHP+1 is presented, which uses Equation (3) for updating the score of a newly arrived UEC record (Tsai & Moh, 2018).

EXD-AHP+1 Algorithm

```
1. For each requested from user with UEC_i
2.        Calculate new score of UEC_i using Equation (3) /* simply adding the
weight to Eq (2) in EXD algorithm
3-21.        Identical to the EXD algorithm
```

EXD-AHP Cache Management Algorithm

Alternatively, replace Equation (2) by Equation (4) as shown below. In other words, the authors replaced the original 1 in Equation (2) by W_{AHP}, allowing QoS level, and thus W_{AHP} to be even more influential to the UEC score. In this case the authors let the service or priority level alone decides how much weight to add for newly arrive UEC (Tsai & Moh, 2018).

$$S_i\left(u_{i1} + \triangle u\right) = S_i\left(u_{i1}\right) * e^{-a\triangle u} + W_{AHP} \tag{4}$$

EXD-AHP Algorithm

```
1. For each requested from user with UEC_i
2.        Calculate new score of UEC_i using Equation (4) /* replacing "one" by
the weight W_AHP in Eq (2) in EXD algorithm
3-21.        Identical to the EXD algorithm
```

Probability-Based Popularity Scoring (PBPS)

As mentioned in Baek, Cho, & Choi's (2017) research, probability-based models and functions can be used to aid in effective cache management. Consider, for instance, the geometric probability model as follows:

$$y = p\,(1 - p)^k \tag{5}$$

This function will determine the probability of an event occurring based on success factor “p”. A function like this can potentially be very useful in cache management for a few reasons.

Firstly, success in the context of caching can be defined as getting a hit in the cache. Likewise, failure can be considered getting a cache miss. The above function can be altered and adjusted to take into consideration hit and miss ratios to determine the popularity of a particular element. The hit ratio, which is calculated as a score representing the hits a particular UEC has received in the cache based on its service level divided by the total number of requests so far, can take the place of “p.” Similarly, the miss ratio, which is the score representing the misses a particular UEC experiences divided by the total number of requests, can take the place of “k.” By changing the above function to adapt to a cache management scheme for 5G, a new function that is proposed and can be used for handling and scoring each UEC becomes the following (Kaur & Moh, 2018):

$$\frac{hit\, score\, L\_i}{\#\, requests}\left(1-\left(\frac{hit\, score\, L\_i}{\#\, requests}\right)\right)^{\frac{miss\, score}{\#\, requests}} \tag{6}$$

Note that this function takes into consideration both the hits and misses for each UEC at any given point in the cache management scheme and evaluates to an overall score. The overall score of a UEC represents how popular the UEC is based on its hits and misses. The greater the score, the greater the popularity is of the UEC. Because the number of requests is constantly changing, this function works by dynamically scoring UECs in the system. Furthermore, the hit and miss scores seen in the equation can be calculated depending on the QoS promised to a particular user. This system can use a reward system for hits, in which the quantity of the reward is dependent on service level (Kaur & Moh, 2018).

Probability-Based Popularity Scoring (PBPS) Algorithm

```
For each user request UEC_j with L_i
    If UEC_j is present in one of the VMs (cache hit)
        Update hit score of UEC_j based on service level and calculate new overall score using equation (6)
        Update content of UEC_j in the cache
        Return
    Else if UEC_j is not present in one of the VMs (miss)
        Update miss score of UEC_j and calculate new overall score using equation (6)
        Write UEC_j to the cloud
        Load balance: select VM with the shortest queue
         If the VM has space for the current UEC_j
             Insert UEC_j into the VM's cache
             Return
         Else if the VM is full
             Find UEC_k which has the lowest score
```

15. Evict UEC_k from the VM's cache
16. Write UEC_k to the cloud
17. Insert UEC_i into the VM's cache
18. Return
19. Update all other UECs in the cache using equation (6) with total number request parameter updated

This algorithm presents multiple advantages that are extremely useful in the 5G CRAN setting. As previously mentioned, the reward system for hits differentiates service levels. PBPS is also able to dynamically account for changes in user requests (Kaur & Moh, 2018).

Probability-Based Popularity Scoring with Hierarchy (PBPS + Hierarchy)

The entire cache can be separated into particular sections, in which case each service level would have a section of the cache. This would form a type of hierarchy, in which particular UEC can only be added to or evicted from the section of cache that is dedicated to the service level in which they belong (Zaidenberg, Gavish, & Meir, 2015). In order to maintain the preferential treatment of better service levels, a larger amount of the cache can be dedicated to better service levels. Cache management will be done in a section of the cache, instead of the entire cache, based on what service level the incoming UEC has (Kaur & Moh, 2018).

PBPS with Hierarchy Algorithm

1. For each user request UEC_j with Service Level L_i
2. If UEC_j is present in one of the VMs (cache hit)
3. Update hit score of UEC_j based on L_i and calculate new overall score using equation (6)
4. Update content of UEC_j *in the cache section for* L_i
5. Return
6. Else if UEC_j is not present in one of the VMs (miss)
7. Update miss score of UEC_j and calculate new overall score using equation (6)
8. Write UEC_j to the cloud
9. Load balance: select VM with the shortest queue
10. If the *VM section for* L_i has space for the current UEC_j
11. Insert UEC_j into the *VM's cache section for* L_i
12. Return
13. Else if the VM is full
14. Find UEC_k which has the lowest score from the cache section for L_i
15. Evict UEC_k from the *VM's cache section for* L_i
16. Write UEC_k to the cloud
17. Insert UEC_j into the *VM's cache section for* L_i

```
                 Return
           Update all other UECs in the cache using equation
   (6) with total number request parameter updated
```

Reverse Random Marking (RRM)

The Reverse Random Marking (RRM) (Zaidenberg, Gavish, & Meir, 2015) is a simple cache management algorithm. Elements are flagged as unmarked when they enter the cache and are marked (flagged) when they are accessed for the first time. This algorithm is included in this chapter, as it will be used to judge how well it can be improved with enhancements. Here is an example adaptation for 5G CRAN (Kaur & Moh, 2018).

Reverse Random Marking Algorithm

```
For each user request UEC_j with L_i
If UEC present in one of VMs (cache hit)
      If UEC is unmarked
         Mark UEC_j
      Else if UEC_j is already marked
            Return
     Else if UEC_j not present in one of VMs (cache miss)
        Write UEC_j to cloud storage
        Select VM_i using shortest queue load balancing algo.
             If VM has space for current UEC_j
                 Insert UEC_j into VM's cache
           Else if VM is full
              If there are unmarked elements
                 Evict random UEC_k from unmarked elements
              Else if all elements are marked
                  Evict random UEC_k
                    Write UEC_k to cloud storage
              Insert UEC_j into VM cache
        Return
```

Reverse Random Marking Algorithm (RRM) with PBPS

RRM alone seemed to present a few challenges (Zaidenberg, Gavish, & Meir, 2015). The authors mentioned continually expanding the size of the cache in order to run the algorithm. However, as cache is a limited resource, it cannot be expanded indefinitely. Furthermore, problems arise when, in the worst case, all elements in the cache are marked, and eviction becomes a question. In light of these challenges, RRM can actually be further enhanced with probability-based popularity scoring (PBPS) (Kaur & Moh, 2018).

With PBPS, each UEC is given a score based on the UEC's service level and the number of hits and misses it has received. Integrating into RRM, PBPS can be used in managing the cache elements. In terms of marking the elements, a threshold can be set to determine whether an element can be marked. This threshold is an arbitrary number and can be set high or low depending on the system needs. Furthermore, in the event that all elements in the cache become marked, the threshold can be marginally increased to unmark a number of elements. Given service level L_i and marking threshold M_t, the general algorithm for RRM with PBPS can be seen as follows (Kaur & Moh, 2018).

RRM with PBPS Algorithm

```
1. For each user request UEC_j with L_i
2.    If UEC_j is present in one of the VMs (cache hit)
3.       Update hit score of UEC_j based on service level
         and calculate new overall score using equation (6)
4.       Return
5.       If UEC_j's score exceeds M_t, mark UEC_j
6.       Else if UEC_j's score does not meet threshold,
   leave UEC_j unmarked
7.       If all UECs are marked, increase M_t and
8.       re-evaluate marked and unmarked elements
9.    Else if UEC_j is not present in one of the VMs (cache miss)
10.      Update miss score of UEC_j and calculate new
  overall score using equation (6)
11.      Write UEC_j to the cloud
12.      Load balance: select VM with the shortest queue
13.      If the VM has space for the current UEC_j
14.         Insert UEC_j into the VM's cache
15.         Return
16.      Else if the VM is full
17.         Pick random UEC_k from unmarked elements in
         the cache
18.         Evict UEC_k from the VM's cache
19.         Write UEC_k to the cloud
20.         Insert UEC_j into the VM's cache
21.         Return
22.   Update all other UECs in the cache using equation
   (6) with total number request parameter updated
```

This algorithm has brought forth an interesting revelation in regard to caching for 5G CRAN. Note that RRM alone was certainly something not intended to be used for the cellular network setting, at least not well. However, its combination with PBPS has now made it a reasonable algorithm that could be used to manage the cache in this particular architecture (Kaur & Moh, 2018).

Baseline Comparisons

In order to assess the benefit and performance of the various caching schemes, it is useful to compare them to a known classic scheme. Comparison will therefore be made with Least Frequently Used (LFU). LFU involves keeping track of the number of times a particular UEC element in the cache is accessed. In the event that eviction needs to be performed when the cache is full and space is needed for new elements, the element with the lowest number of accesses will be evicted (Podlipnig & Böszörmenyi, 2003).

PERFORMANCE EVALUATION

In order to assess and analyze the performance of these algorithms, they were implemented, tested, and compared through CloudSim (Calheiros, Ranjan, Beloglazov, Rose, & Buyya, 2011). The algorithms that were tested, and the settings in the simulation are summarized in the following Table 2 and Table 3 (Tsai & Moh, 2018; Kaur & Moh, 2018).

Cloud-Writes and Network Traffic

This section evaluates and compares the four algorithms from Tsai & Moh (2018) research paper in terms of the number of cloud writes and the corresponding network traffic produced. Recall that cloud-write occurs when (1) a newly arrival UEC is a cache-miss, thus this new UEC needs to be written into the cache as well as written to the cloud storage to ensure the cloud storage always has a copy of active UECs, and (2) evicted UECs.

The corresponding network traffic is measured as a result of cloud write. Since each UEC record is assumed to be 200 Kbytes, it can be calculated by the following Equation (7) below:

$$Network\,Traffic = \frac{Total\,Writes * 200 * 8 * 1000}{Simulation\,Time} \tag{7}$$

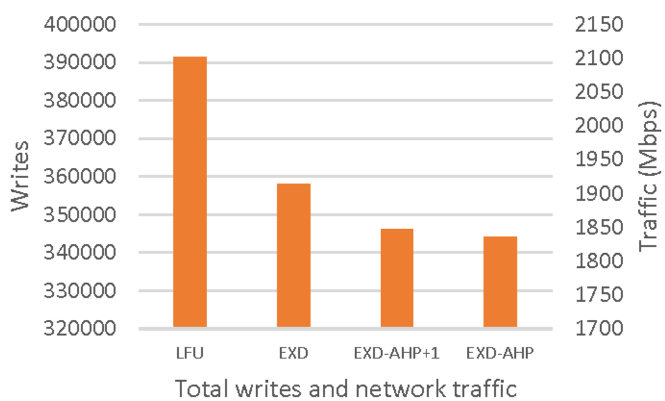
Table 2. Simulated algorithms

Acronym	Algorithm	Details
EXD	Exponential-Decay	Score using Equations (1) and (2)
EXD-AHP+1	Exponential-Decay with Analytical Hierarchical Process + 1	Score using Equations (1) and (3)
EXD-AHP	Exponential-Decay with Analytical Hierarchical Process	Score using Equations (1) and (4)
PBPS	Probability-Based Popularity Scoring	Score with Equation (6)
PBPS + Hierarchy	Probability-Based Popularity Scoring with Hierarchy	Score with Equation (6), with Hierarchical Cache
RRM	Reverse Random Marking	Marking and Unmarking
RRM + PBPS	Reverse Random Marking with Probability-Based Popularity Scoring	RRM with PBPS Equation (6)
LFU	Least Frequently Used	Uses Counter for # Accesses for UEC

Table 3. Simulation parameters and values

Parameter	Value
Number of Hosts	1
Number of VMs on Each Host	4
Virtual Machine Cache Sizes	1250 MB; 3750 MB
Network Bandwidth	1 Gbps
Arrival Rate of UECs into Simulation	1400 UEC/sec
UEC Size	200 KB
Number of Distinct Users in Cellular Network	25,000
QoS Levels	Description of QoS
SLA 1 (L1)	High mobility; Premium service
SLA 2 (L2)	Low mobility; Premium service
SLA 3 (L3)	High mobility; Basic service
SLA 4 (L4)	Low mobility; Basic service
Traffic Distribution	SLA1: 52%; SLA2: 26%; SLA3: 13%; SLA4: 9%
EXD Parameter "a"	10^{-3}
Analytical Hierarchical Process Weights	SLA1: 0.58; SLA2: 0.28; SLA3: 0.10; SLA4: 0.04
PBPS Hit Rewards	SLA1: 1; SLA2: 0.75; SLA3: 0.5; SLA4: 0.25
Cache Partitioning for Hierarchy	SLA1: 70%; SLA2: 20%; SLA3: 8%; SLA4: 2%
Threshold Increase for RRM+PBPS	10%
Simulation Run Time	300 Seconds (5 Minutes)

Figure 4. Total writes & network traffic, cache size 1250 MB



The result of this experiment suggests that when cache size is small, as shown in Figure 4 (Cache size = 1,250 MB). It is clear that both EXD-AHP and EXD-AHP+1 achieve very low writes and network traffic; lower than EXD, and much lower than LFU. Comparing with LFU, they incur less than 250

Mbps. Comparing with EXD, they are approximately 75 Mbps lower in Figure 4. Observed also that there is a trade-off between VM cache size and network traffic. The larger the cache size, more entries can be kept in the cache, resulting in less cache miss and therefore less cloud writes, less network traffic.

Figure 5 show cloud write and network traffic for larger cache size: 3,750 MB. It is clear EXD-AHP performs the best among four algorithms. Comparing with LFU, it results in 40 Mbps less. Comparing with EXD, it is 20 Mbps less. Note again that as cache size increases, there are less cache miss and less network traffic; the advantage of better cache management algorithm also reduces (Tsai & Moh, 2018).

Supporting Various Service Levels on Cache Hit Rates

Tsai & Moh (2018) show how well the four cache management algorithms provide different levels of support for different service levels (L1, L2, L3, and L4) in terms of cache hit rates, as defined below in the Equation (8):

$$L_i\ Cache\ Hit\ Rate = \frac{Total\ no.\ of\ L_i\ UEC\ cache\ hits}{Total\ no.\ of\ L_i\ UEC\ arrivals} \quad (8)$$

Figure 6 and Figure 7 show the percentage of cache hit rate for two cache sizes: 1,250 MB, and 3,750 MB, respectively. When the cache size is very small, (1,250 MB, shown in Figure 6), only L1 receives a good hit rate, all other service levels show negligible hit rate. When cache size increases (3,750 MB in Figure 7), the authors start to see the various support levels for various priority levels.

It is clear that all four algorithms are able to support differentiated services. When cache size is large (3,750 MB), EXD-AHP is able to achieve the highest hit rate L1, L2, and L3.

From Kaur & Moh (2018) research work, Figure 8 and Figure 9 illustrate how hit rates are supported for each of the four service levels in the simulation, and how the hit rates change and are affected by cache size. When the cache size is small, EXD-AHP tends to provide the best preferential treatment to the best service level, SLA1. However, it also provides close to no hits on the rest of the service levels. The tradeoff is seen with PBPS + Hierarchy. The latter algorithm offers a better distribution of the cache

Figure 5. Total writes & network traffic, cache size 3750 MB

Figure 6. Hit rates with cache size of 1250 MB

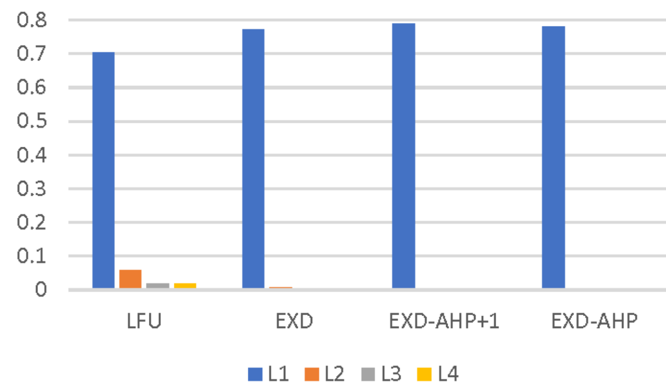
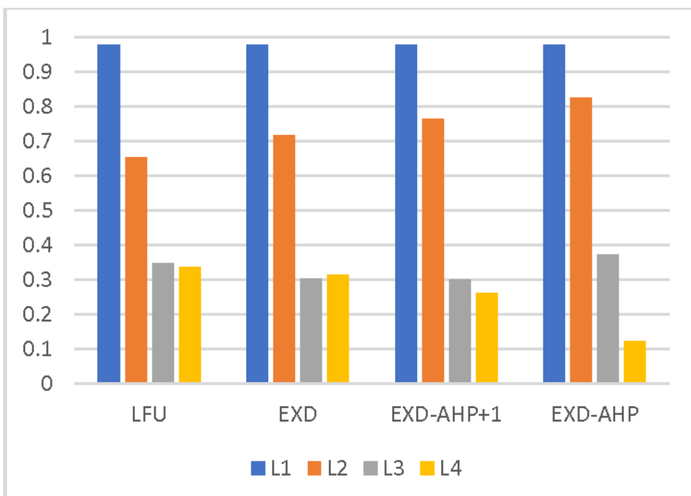


Figure 7. Hit rates with cache size of 3750 MB



hits, so each level has a reasonable number of hits while still being differentiated based on service quality. However, the hit rate on the best service level is much lower with PBPS + Hierarchy compared to EXD-AHP.

With larger cache sizes, as shown in Figure 9, more UECs can be accommodated and therefore hit rates in general rise. Larger cache sizes allow for PBPS + Hierarchy to potentially offer a 100% hit rate on the best service level, as more of the cache can be dedicated to storing SLA1 UECs, if not all. Note that EXD-AHP tends to offer some of the best performance in terms of hits rates, with hits on SLA1 and SLA2 now surpassing the hierarchical approach. Noted that PBPS on its own is certainly an acceptable algorithm but performs better and gives better distribution with the hierarchy in place. RRM all around tends to be the least impressive in terms of performance but can be greatly improved with incorporating PBPS at any cache size. RRM+PBPS then becomes an algorithm that is better suited for this type of architecture.

Figure 8. Cache hit rates with cache size of 1250 MB

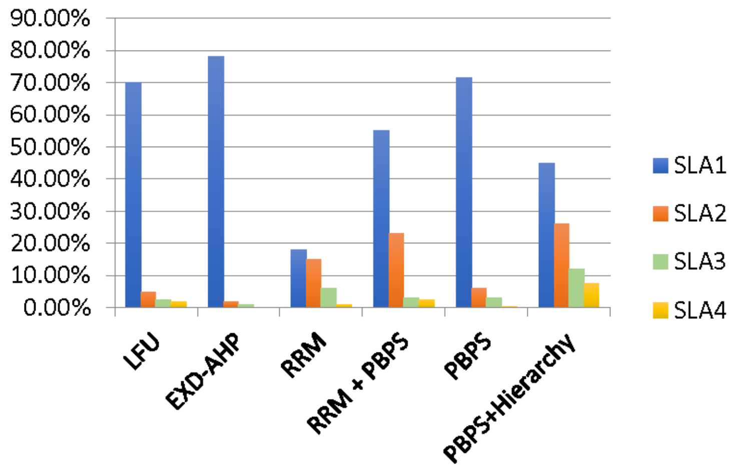
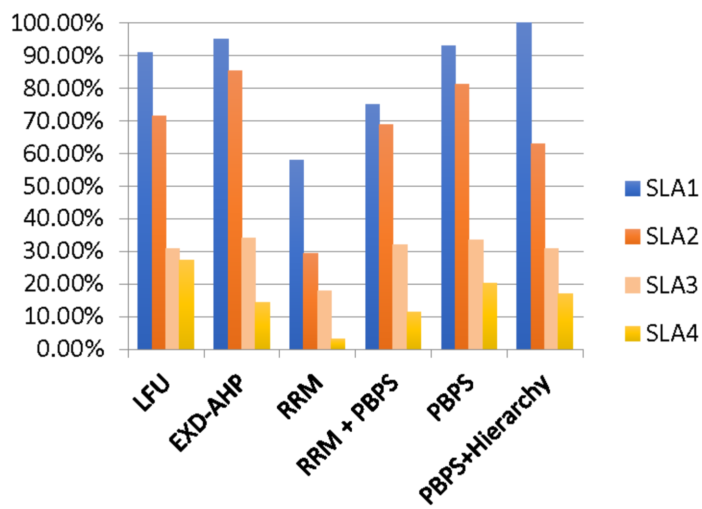


Figure 9. Cache hit rates with cache size of 3750 MB



Latency

Another metric used in evaluating the performance of the algorithms is latency. With a cache hit, the latency is simply the amount of time it takes in accessing and updating the UEC in the cache. With misses, the latency is the collective time it takes to evict an item from the cache if needed, write the evicted item to the cloud, and write the incoming UEC to the cache and cloud. Figure 10 and Figure 11 illustrate the average latency per request for each of the algorithms in subsequent cache sizes. Note that EXD-AHP offers the lowest latency on the best service level, but PBPS + Hierarchy and even RRM + PBPS offer better latency results on the lower service levels while still properly differentiating the types of QoS.

As seen in the larger cache sizes in Figure 11, PBPS, PBPS + Hierarchy, and EXD-AHP all offer better latency values overall amongst the various service levels than the other algorithms. PBPS +

Figure 10. Average request latency with cache size 1250 MB

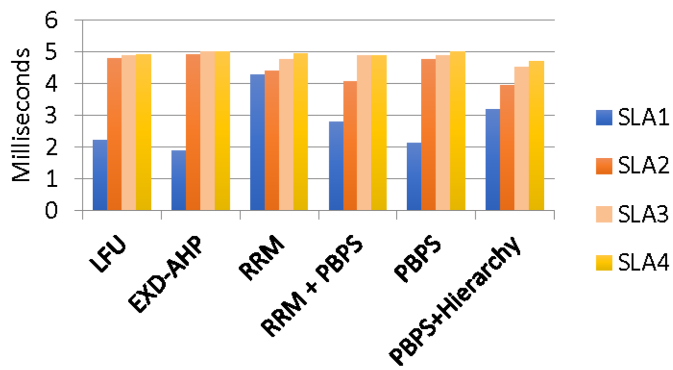
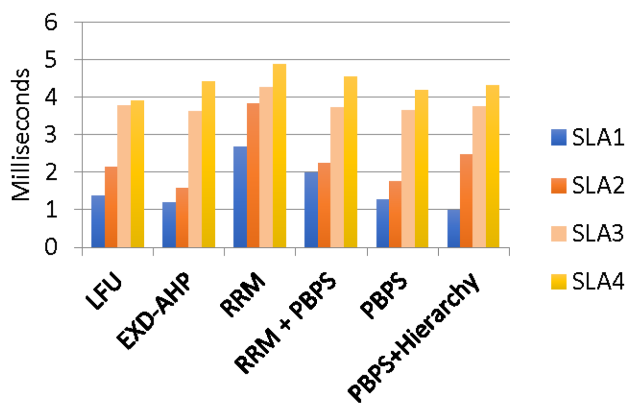


Figure 11. Average request latency with cache size 3750 MB

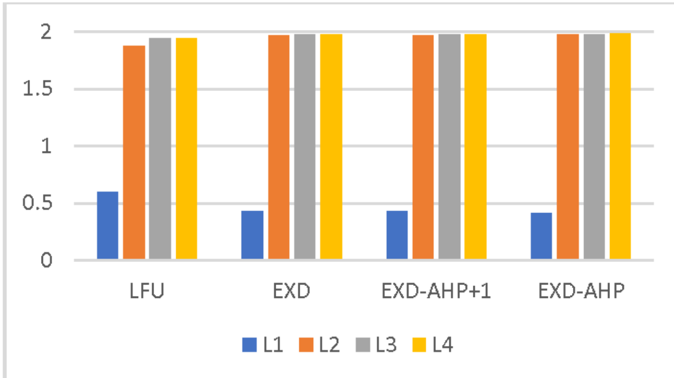


Hierarchy, due to the partitioning of the cache for various service levels, has the potential to offer the minimal amount of latency in the best service level. RRM does not offer substantial improvement in the latency of each request even with larger cache sizes, but its combination with PBPS has proven to be quite useful. LFU in larger cache sizes, though seemingly competitive overall, has trouble differentiating between the lower two service levels.

Cloud Write Rate

Cloud writes are represented as an average number of writes to cloud storage per UEC request. That is, whenever there is a cache hit, there is no write to cloud and therefore the number of cloud writes is 0. When there is a cache miss, the evicted UEC must be written to the cloud and the incoming UEC must also be written to the cloud, resulting in 2 writes to the cloud. The average number of writes per request, therefore, will be a number between 0 and 2. The number of cloud writes can be calculated using Equation (9) as (Tsai & Moh, 2018; Kaur & Moh, 2018):

Figure 12. Write rates of different service levels with cache size of 1250 MB



$$\text{Average \# } L_i \text{ Cloud Writes} = \frac{\#\, of\, Cloud\, Writes\, in\, L\_i}{\#\, of\, UEC\, Arrivas\, in\, L\_i} \tag{9}$$

According to the above definition, the value of write rate should be between 0 (the best case, 0 write rate implies 100% cache hit rate) and 2 (maximum write rate; the first one when the UEC first arrived and the second one when it is evicted). When the cache size is very small, 1,250 MB, Figure 12 shows that except for L1, all other levels have a write rate of almost 2 (Tsai & Moh, 2018).

For the two larger cache size, 3,750 MB (Figure 13), the write rates have decreased. Among all four algorithms, clearly see that EXD-AHP is able to provide a more distinctly different level of write rates. In particular, L3 and L4 receive almost equal write rates in all three algorithms, except in EXD-AHP the two levels receive noticeable different write rates (Tsai & Moh, 2018).

Smaller cache sizes (Figure 14) demonstrate that EXD-AHP offers the fewest writes on the best service level (Kaur & Moh, 2018). However, it has some of the highest number of writes on all the three other service levels. PBPS is comparable in the same aspects, and like EXD-AHP, it does not differentiate amongst the other service levels very well in terms of writes. With writes, PBPS + Hierarchy and even RRM + PBPS appear to offer better numbers of writes for the lower service levels.

Figure 13. Write rates of different service levels with cache size of 3750 MB

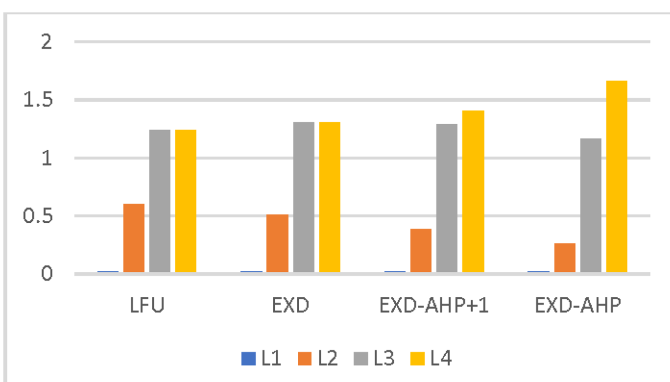
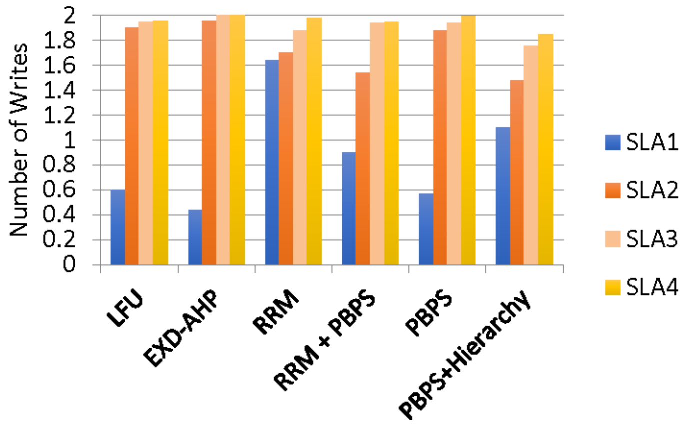


Figure 14. Average number of cloud writes with cache size 1250 MB

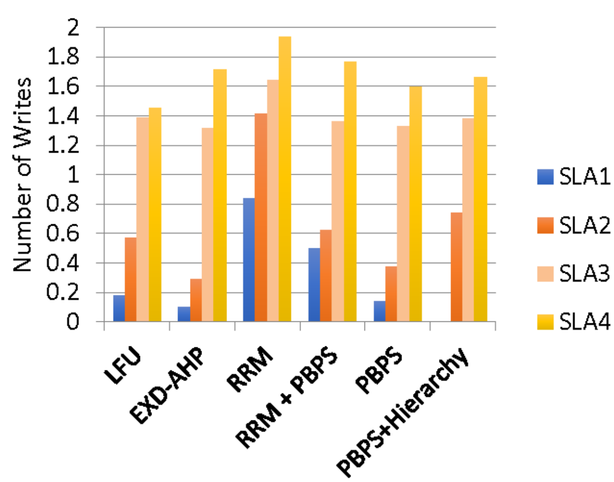


With larger cache sizes (Figure 15), EXD-AHP substantially reduces the writes on the better half of service levels, as does PBPS following in second. However, PBPS + Hierarchy offers potentially no writes on the best service level, since enough of the cache could be allotted to SLA1 to store all L1 users. RRM may be acceptable at the smallest cache size, but in general its combination with PBPS is preferred to decrease the writes.

Network Traffic

Whenever there is a cache miss on a UEC request, there is a need to travel across the data center network from the cache to the cloud storage in order to perform the necessary writes. As a result, there is a certain amount of traffic that is generated on the network as a result of misses (Kaur & Moh, 2018).

Figure 15. Average number of cloud writes with cache size 3750 MB



The performance is shown in Figure 16 and Figure 17. With smaller cache sizes, EXD-AHP and PBPS both result in less traffic on the network, resulting in faster service. They are followed closely by LFU, PBPS + Hierarchy, and RRM + PBPS.

As seen in Figure 17, as the cache sizes get larger, EXD-AHP always offers the lowest amount of network traffic resulting from misses. At the larger cache sizes, PBPS + Hierarchy outperforms PBPS alone. As seen in every metric, RRM alone is not very well suited for the 5G CRAN architecture type and service level differentiation but can certainly be used once implemented in conjunction with the PBPS enhancement (Kaur & Moh, 2018).

CONCLUSION

This chapter addressed the challenge of cache management in 5G CRAN for IoT communication support. The authors adopted the EXD scoring function which calculates the score of a UEC based on time internal between requests. They also introduce AHP to calculate the weighted value of each QoS level. The experiment concludes that EXD-AHP can achieve lowest number of writebacks which translate to

Figure 16. Network traffic with cache size 1250 MB

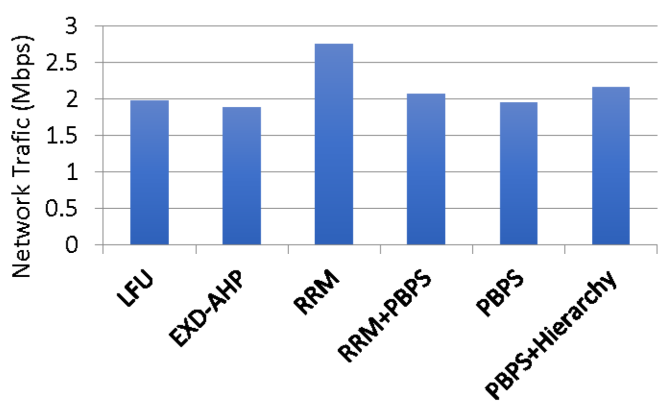
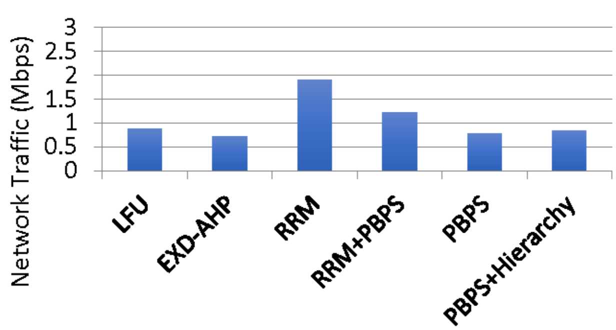


Figure 17. Network traffic with cache size 3750 MB



higher hit rate. However, number of reduced writebacks compare to the rest of scoring functions is only significant if a cache size is small. Furthermore, EXD-AHP provides capability of giving mobile users with high QoS level better cache performance (Tsai & Moh, 2018).

The other new algorithms (Kaur & Moh, 2018) are simpler in design, yet offer comparable performance than EXD-AHP, which is more complex in terms of computation. The newly adopted PBPS on its own certainly offers acceptable results, yet its combination with the hierarchy yields the greatest benefits, and its combination with the naive RRM is also a feasible option for use in 5G CRAN. While EXD-AHP consistently offered great service to the highest service level and performed well with large cache size, the newly proposed PBPS + Hierarchy offered more competitive distributions of results amongst the four service levels and may be preferred with smaller cache sizes.

Future work would continue in the use of hierarchical or partitioned caches, in dynamically adjusting partitions or levels of the cache to best serve users and service levels. Another aspect would be to achieve appropriate hit rates with the lowest possible computational. Outside of caching, other areas can also be researched to improve services, including the internal handlings of CRAN resources in order to maximize utilization and lower costs in other areas such as energy consumption.

ACKNOWLEDGMENT

This research was supported in part by Nokia Foundation; and SJSU RSCA. The authors appreciate helpful discussions with Alan Rottinghaus, David Baietto, Rick Van Egeren and Rob Edward of the RAN Dept of Nokia Research.

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KEY TERMS AND DEFINITIONS

Cache Hit: Data that is needed is readily available for access in the small cache memory.

Cache Memory: A limited memory resource that helps to store important data for easy and fast future access

Cache Miss: Data that is wanted is temporarily not found in the cache storage. Have to write the data from cloud in case of future access.

Cloud Memory: It is a secondary storage device which keeps all the data. If there is a cache miss, the data can be accessed from cloud memory.

Cloud Write: Cloud Writes are represented as an average number of writes to cloud storage per user request. It is zero if it is a cache hit. With miss, the evicted data has to written in cloud as well as incoming data also be updated in cloud. So, 2 cloud writes with cache miss.

Latency: With cache hit, it is the amount of time (delay) it takes to access and update the data. With cache miss, it is collective time it takes to evict data from cache memory and write it to cloud memory (if needed) and write and update the incoming data to the cache and cloud.

Network Traffic: With cache miss, there is a need to travel across the data center network from the cache to the cloud storage in order to perform necessary writes. As a result, there is a certain amount of traffic is generated on the network as a result of the cache miss.

Chapter 8
Enabling Device-to-Device Technology in 5G Heterogeneous Networks

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ABSTRACT

5G is the next step in the evolution of mobile communication. The evolving 5G cellular wireless networks are envisioned to provide higher data rates, enhanced end-user quality-of-experience (QoE), reduced end-to-end latency, and lower energy consumption. Device to device (D2D) is one of the key technologies provided to enhance 5G performance. Direct communication between two devices without involvement of any central point (i.e., base station) is defined as device to device (D2D) communication. It is a recommended technique to enhance the network performance of 5G in terms of energy efficiency, throughput, latency, and spectrum utilization. In this chapter, the authors provide a detailed survey on the integration of D2D communication into cellular network especially 5G network. The survey highlights the potential advantages; classifications and application for D2D technology have been indicated. Main D2D standards have been presented. Finally, the chapter addresses main topics that could be related to D2D and indicates all major possible challenges that face most researchers.

DOI: 10.4018/978-1-7998-1152-7.ch008

INTRODUCTION

No doubt telecommunication systems developments enhance lifestyle in unexpected ways. 5G wireless cellular network deployment is the main key technology of the next wireless cellular network evolution. 5G cellular networks commercial service is estimated to be launch in 2020 (Shafi et al., 2017). The main target of 5G is to provide ubiquitous connectivity for any kind of device and any kind of application. 5G network should satisfy some needs (Agiwal et al., 2016). in order to enhance the performance. It should support data rate from 1 to 10 Gb/s for reality applications (i.e. telemedicine and vehicle-to-vehicle applications). Also it is needed to have a latency less than one millisecond to support reality application. Tens of millions of devices and hundreds of billions of sensors (El-Basioni et al., 2016) are vital to be served. Hence, network has been extended especially in airplanes and remote areas.

Such requirements need special technologies to be deployed. The detailed 5G standards are still work in progress and uncertain yet. Carrier Aggregation, massive Multiple Input – Multiple Output (MIMO), beam forming, cloud computing, millimeter Waves (mmW), Cognitive Radio (CR) (Salem et al., 2017), Full Duplex (FD), Non-Orthogonal Multiple Access (NOMA), green communication, energy harvesting, and D2D are potential technologies under research to meet 5G needs and be applied on it. All these previous technologies are out of our scope except D2D.

D2D Communication is one of the competent technologies for 5G, which is predictable to have an essential part in enhancing the era of wireless cellular communication. In previous mobile generations (i.e. 1G-4G), applying D2D technology did not take much attention; however, it is predicted that such a technology will play a vital role in next generation. D2D communication in cellular networks is known as a direct communication between two or more terminal devices without evolving the Base Station (BS) or any core network (Jameel et al., 2016). In contrast to traditional a wireless cellular network, D2D technology can provide more power saving due to close distance among connected devices. Besides, this technology enhances energy efficiency, throughput, and delay. D2D has the availability to offload traffic from the cellular network with high efficiency.

Main organizations have been co-operated in order to examine the validation of D2D in cellular networks such as 3GPP (Third Generation Partnership Project) (Lin et al., 2014). Release 12 of 3GPP states that such a technology can be applied as a public safety network feature, cellular offloading, vehicle-to-vehicle (V2V) communication, and content distribution. Although, D2D technology introduces a lot of benefits; it faces a lot of challenges that should be taken into consideration (Zhang et al., 2017). Applying D2D technology leads to highly interference among Cellular Users (CUs) and D2D Users (DUs) due to sharing the same resources in the same area. Other concerns that face D2D technology such as peer discovery, handover, radio resource allocation management and optimization, and security issue.

In this chapter, the above-mentioned topics will be illustrated in more details. Also, other topics will be provided focusing on D2D communication. Chapter is organized as follows: Section 2 provides the potential advantages of D2D technology. Section 3 introduces the D2D classification with its three main categories, while D2D scenarios and applications are provided in section 4. 3GPP and IEEE are the main standards applied for D2D that stated in section 5. Section 6 discusses the prototypes and experiments (i.e. FlashLinQ, Data Spotting and Relay by smartphone). D2D integrated features are laid out in section 7; as Hyprid Automatic Repeat ReQuest (HARQ), IoT, and Vehicle to Vehicle (V2V). Section 8 details D2D's challenges such as peer discovery, handover, and resource allocation. Finally, the chapter has been concluded in section 9.

D2D TECHNOLOGY MAIN ADVANTAGES

D2D technology offers numerous numbers of benefits. From the definition, in case of devices that near in distance, using D2D technology leads to reducing latency between devices and consuming power. As shown in Figure 1, they communicate directly instead of sending data from transmitter to BS then to the receiver. Another advantage in applying D2D technology, that it can take some load off of the cellular network in a local area such as big shopping centers or stadiums. This direct transmission among devices leads to enhance system performance. Moreover, D2D technology can be an efficient solution in case of emergency networks (an urgent communication network can be established within a short time, replacing the damaged infrastructure). This case will be explained in details later. One of the big advantages is that DUs can extend network's coverage area by acting as a transmission relays for each other. Figure 2 shows the concept of D2D relay mode that act as multi hop sequence so as to increase D2D coverage area. Last but not least, using D2D communications beside cellular communications could be able to raise the spectrum utilizations and network capacity. A channel can be reused by multiple D2D pairs in a cellular communication if power control is applicable (Nardini et al., 2017). This feature also leads to increase network capacity.

D2D Main Classification

This section introduces high level overview on D2D classification. As shown in Figure 3, this classification is separated into three main categories; D2D control, D2D coverage, and D2D communication mode. Each category is illustrated with details in the following subsections.

Figure 1. Device-to-Device network layout

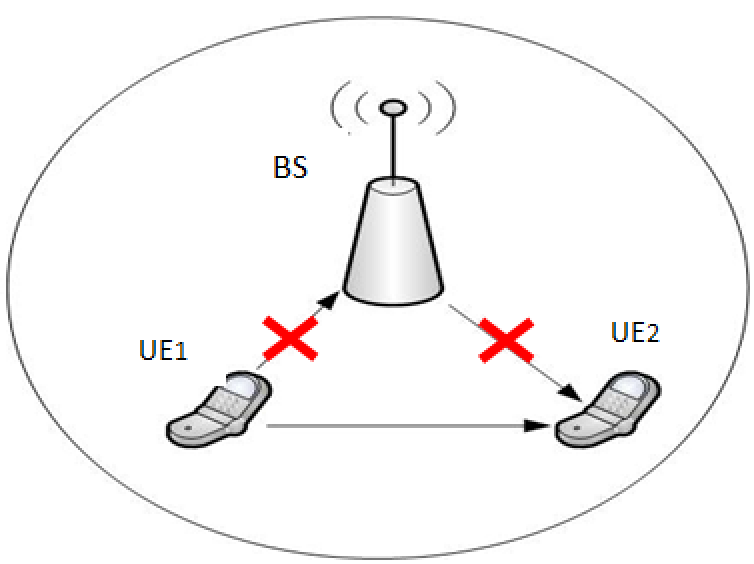


Figure 2. Device-to-Device relay mode

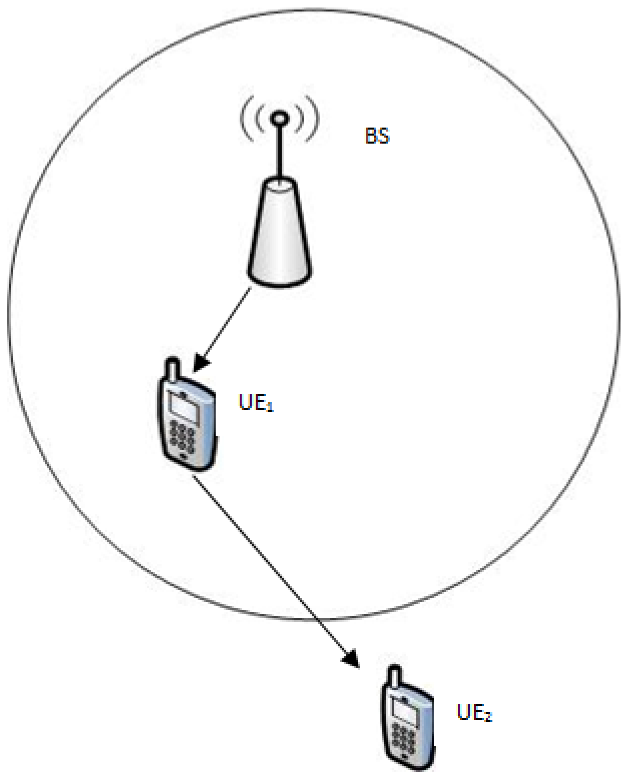


Figure 3. Device-to-Device classifications

D2D Control

D2D control category highlights how extremely the core network is controlling and managing D2D connectivity. This mode can be classified into two types. These types are called full control mode and autonomous mode. When devices are managed by a cellular network or operator is so-called controlled mode (Lei et al., 2012). The second mode named autonomous when D2D control is done by users themselves, not under the cellular network controller. To be clear, Table 1 illustrates meaning, advantages, and disadvantages of both types.

Table 1. Main advantages and disadvantages of device-to-device control category

Type	Full	Autonomous
Meaning	Network is in charge of the following: D2D authentication procedure, D2D pair discovery, D2D initiation procedure, D2D connection, power control and allocates radio resources.	DUs themselves are in charge totally or partially of the following: D2D authentication procedure, D2D pair discovery, D2D initiation procedure, D2D connection, power control and allocate radio resources.
Advantageous	● Core network controlling leads to achieving better QoS from a user perspective and network perspective. ● Less interference among CUs and DUs as core network control interference issue.	● negligible signaling overhead
Disadvantageous	● In order to control D2D communication, a highly signaling overhead is required.	● Interference caused by the D2D to the cellular users.

D2D Coverage

3GPP has classified D2D based on coverage (Chen et al., 2015) into three types as shown in Figure 4 (Lin et al., 2014). The first one is called "in coverage" which indicates that both DUs are within the cellular network coverage as in Figure 4 (a). This means that

DUs may access the licensed band that called in-band communication. The second scenario is "out of coverage" in which both DUs are out of the cellular network coverage as in Figure 4 (b). It is notable that this scenario could be applied in case of emergency, when failure connection occurs due to damages in the BS. Out of coverage communications means that communication performed in an unlicensed band such as ISM 2.4 GHz. The most famous standards that implement this type are WiFi direct, Zig Bee or Bluetooth.

The third type is called "partial coverage". It indicates that one DU is within cellular network coverage, while the second DU is out of the cellular network coverage as in Figure 4 (c) and Figure 2. DU may act as relay in order to retransmit data from outer DU to eNB or vice versa. A brief look of advantages and disadvantages of "in coverage" and "out of coverage" are given in Table 2.

A brief look of the advantages and disadvantages of in coverage D2D communication and out of coverage D2D communications are given in Table 2.

Figure 4. Release 12 Device-to-Device communications are divided into three scenarios: a) in-coverage; b) out-of-coverage; and c) partial coverage (Lin et al., 2014)

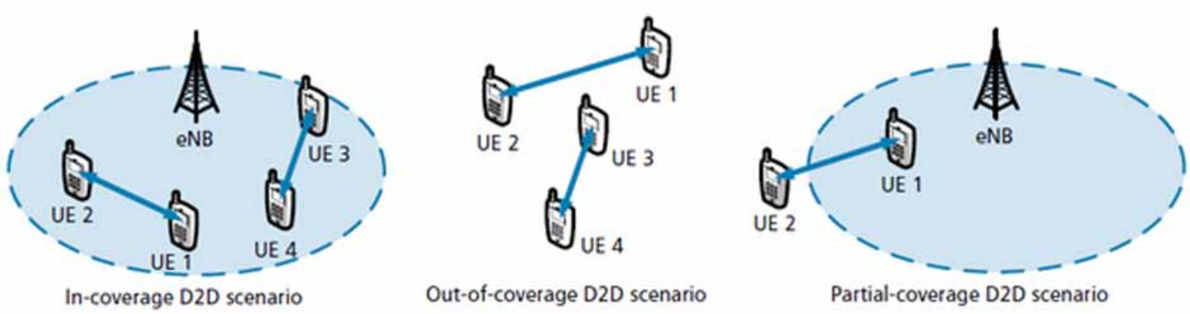


Table 2. Main advantages and disadvantages of out coverage and in coverage device-to-device communication

Type	Out coverage	In coverage
Advantages	● Resource allocation is easier. ● Interference between cellular and D2D users doesn't exist. ● Simultaneous transmission of D2D and cellular devices can occur.	● Increase spectrum utilization. ● Controlling D2D devices by BS become easier. ● No more additional interfaces required.
Disadvantage	● Additional interface is required for out of band communication. ● Less spectrum utilization. ● Out of band D2D devices become out of BS control.	● High interference between devices due to reuse channels. ● Smart power control and resource allocation mechanisms are required.

D2D Communication Mode

This category indicates whether the DUs share the same Resource Blocks (RBs) with other users (either CUs or DUs). Beside that deciding if the DUs communicate directly in distributed or centralized manner. So, D2D communication mode classifies into three types. The first one is dedicated mode which is allowing D2D pair to exchange data directly without evolving eNB. The allocated RB for this transmission is dedicated only for a certain pair without sharing with other users. Shared mode means that both DUs and CUs can share the same RB (underlay mode). Finally, cellular mode is the traditional cellular communication where all terminals transmit/receive data through the core network without applying direct communication among terminals (overlay mode). Table 3 shows advantages and disadvantages of each mode.

Based on previous categories, Table 4 shows the availability of mixing between D2D communication mode with existing communication band and control mode in order to have a deeper viewer about classification.

Table 3. Main advantages and disadvantages of dedicated, shared and cellular mode

	Advantages	Disadvantages
Dedicated mode	● Ease to manage interference	● Less capacity and low spectrum utilization
Shared mode	● Higher spectrum efficiency	● More interference either among DUs themselves or among CUs and DUs
Cellular mode	● Ease to manage interference ● There is no need to add a new feature.	● low spectral efficiency ● less performance than using D2D technology

Table 4. The availability of mixing between device-to-device communication mode with existing communication band and control mode

	In-band comm.	Out-band comm.	Full	Autonomous
Dedicated mode	Valid	Valid	Valid	Valid
Shared mode	Valid	Invalid	Valid	Valid
Cellular mode	Valid	Invalid	Valid	Invalid

D2D SCENARIOS OR APPLICATIONS

Based on D2D advantages, D2D technology used in several applications (as figure 5). The following subsections provided the main cases that can have benefits from this technology.

Local Voice Service

In some cases, devices may be proximity in distance such as people in the same meeting room want to talk privately or companions get lost in a certain area or in some applications such as Push-To-Talk (PTT). However, these cases may be rare to happen, but using such a technology as D2D can increase network performance by reducing delay between users.

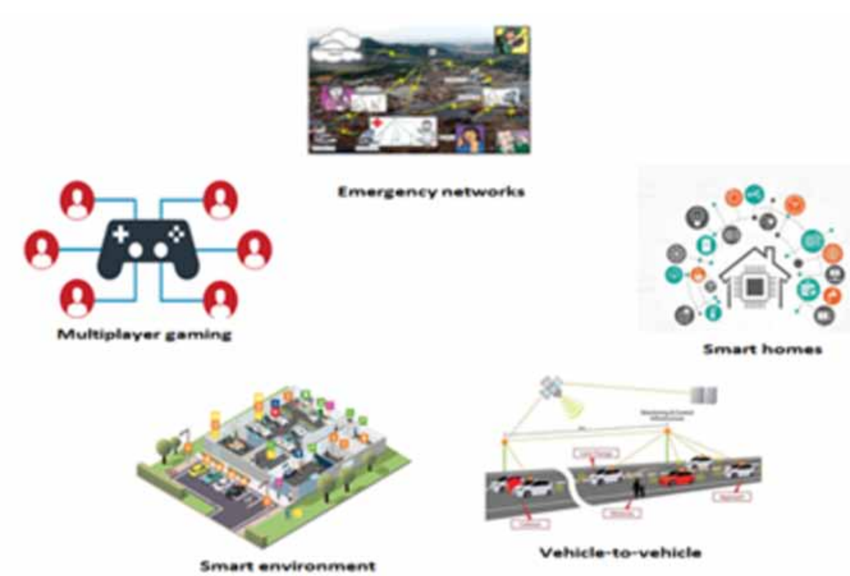
Local Data Service

Similar to the local voice service, local data service can be provided using D2D communication when two users or devices have the same covered D2D area that wants to exchange data. Some applications of local data service use direct D2D communications instead of using the cellular network. It leads also to reduce latency between these DUs.

Video Streaming

Video streaming is defined as sending contents in a compressed form over the Internet in real time. This means it is not necessary to wait until video had downloaded completely to watch it. As an alternative, video is sent in a continuous stream manner of data and is played as it arrives immediately.

Figure 5. Application scenarios for device-to-device in 5G environments



So, video streaming becomes one of the key internet traffic. Cisco stated that about 82% of the internet traffic will be videos by 2022 (Cisco, 2017). One type of video streaming that can unload the traffic from wireless networks is Point-to-Point (P2P) video streaming. P2P video streaming promote all users to share their videos with others through a direct connection. PPSTREAM and PPLIVE consider a vital example of P2P video services. In China, it is reported that there were more than 32,210,000 daily customers on PPSTREAM and more than 60,000,000 overall users on P2P video streaming in September 2012 (Chen et al., 2013). D2D technology can provide more performance improvement than normal cellular networks between devices that desire to share video streaming. Similar applications can also be like video chat or video conferences between the devices in the same cell or neighbor cells that are close in distance.

File Sharing

File sharing means interchange photos or videos between users through their smartphones. For example, people attend a conference that they need to download some files from a conference's server. Based on the report introduced by Cisco; file sharing (i.e. traditional P2P file sharing application) consumes a great portion from the Internet traffic (Cisco, 2017). Some examples based on cloud storage are iCloud, Google Cloud Storage, SkyDrive, and Dropbox. These applications based on a terminal device or a collection of devices with file sharing, which can be simply covered by a D2D region.

Multiplayer Gaming

A multiplayer game has several players, who may be independent. In Japan, "Dragon Quest IX" is one of the famous multiplayer gaming that has a co-operation manner involving up to four players based on local wireless connections in order to play together. These four players should be proximity in the distance.

Emergency Networks

Connection failure may exist due to natural disasters in a huge area for a long time. Unfortunately, huge amounts of local traffic data need to be transmitted (Ali et al., 2018). For example, the rescuers desire to establish a connection frequently with their rescuers, including the sending of image and video. Correspondingly in the medical sites, nurses and doctors need to have a medical data of patients from their hospital and sometimes need to have remote supports and consultancy for certain operations. Also, journalists and reporters need to report the news hourly….etc. D2D technology based on emergency network can afford broadband services temporary for all these requirements. Large numbers of devices can communicate with each other to create a small network and relay data for each other.

D2D STANDARDS

This section introduces two different standards that support D2D communications. These standards are 3GPP standard and D2DWRAN based IEEE 802.22 standard. The first subsection shows D2D communications characteristics and its different scenario in 3GPP while the next subsection shows IEEE 802.22 standard with its features, specifications, and limitations. Also, the main three ideas of D2DWRAN based IEEE 802.22 are explained.

D2D in 3GPP LTE Standardization

At the end of 2011, the 3GPP standardization group has recently worked on an integration of D2D communication in Release 12 (3GPP, 2013) which covers the D2D communications with and without infrastructure. The work item called ProSe (Proximity-based Services) in 3GPP TSG SA1 (Services working group) was complete in May 2013. The feasibility study for ProSe communication within 3GPP and description of use cases is introduced in (3GPP, 2013).

The purpose is to identify use cases and potential requirements for discovery and communications between UEs that are in proximity, including network operator control, authentication, authorization, accounting and regulatory aspects. In addition, standardization defines the major requirements and scenarios for direct communication between the DUEs. For example, D2D ProSe includes functionalities of one-to-one, one-to-many, and one hop relay, as well as considerations for access priorities and operation mode switch between D2D mode and cellular mode. It is expected to support fast and efficient voice, video or, more generally, data communication from one user to several groups at the same time in parallel, e.g. voice to one group, different streams of video or data to several other groups.

A part from Commercial/social use, it also addresses Public Safety communities that are jointly committed to LTE. While TSG SA2 (Architecture working group) evaluates possible 3GPP technical system solutions for architectural enhancements needed to support ProSe based on the SA1 service requirements. TSG RAN1 (Radio Access Network working group) study items have also been proposed for LTE Rel. 12 including two features: ProSe discovery and ProSe communications, to define the necessary support in the LTE radio interface.

The requirements for both phases are defined in (3GPP, 2013). The purpose of the discovery phase is to identify whether two UEs with D2D functionality (termed ProSe-enabled UE) are in proximity or not. However, the D2D communication phase enables an establishment of a new communication path between two (or more) ProSe-enabled UEs and manages all D2D communication. Both discovery and communication features are studied also from a radio perspective in (3GPP, 2014).

D2DWRAN: A 5G Network Proposal Based on IEEE 802.22 and TVWS

IEEE 802.22 considers first worldwide standard for Wireless Regional Area Networks (WRANs) applying CR technologies. It is working on unused channels in TV band, which called TV White Spaces (TVWS). The main advantages of TV band are huge free spaces, easy penetration and flexibility in band. But, it is limited in capacity. Hence, it could be overcome by enabling device to device (D2D) communications and employing multiple operating channels. But first, an overview about IEEE 802.22 and IEEE 802.22 based D2DWRANs will be showed mentioning the specifications, the advantages, and the limitations of the standard (Shi et al., 2014).

IEEE 802.22 CR and TVWS Specifications

The base standard 802.22 published in July 2011 (Shi et al., 2014). The main purpose of the 802.22 standard is to provide a wireless broadband access in rural areas typically 17-30 km (possibly up to 100 km) from the base station (BS) to the Customer Premises Equipment (CPE). It thus belongs to the category of Wireless Regional Area Network (WRAN). The IEEE 802.22 uses a cellular topology with a cell consisting of BS and zero or more CPEs associated with and under control of this system. The coverage area of this cell extends up to the point where the signal received from the BS is sufficient to allow CPEs to associate and maintain communication with the BS.

The Spectrum Manager (SM) is a central part of the WRAN BS, which shall be responsible for ensuring the protection of incumbents and efficient spectrum utilization while complying with regulatory policies.

It is possible to distinguish the most important functions of SM:

- Maintain spectrum availability information.
- Channel classification and selection.
- Accessing the database service.
- Scheduling quiet periods for spectrum sensing.
- Enforcing IEEE 802.22 and regulatory domain policies.
- Making channel move decisions for one or more CPEs or the entire cell.
- Self-coexistence with other WRANs, etc.

Features of IEEE 802.22 as Follows

- Point to multi point
- Time Division Duplex (TDD)/ Frequency Division Duplex (FDD).
- Adaptive Modulation QPSK, 16, 64-QAM, Spread QPSK.
- OFDMA on uplink and downlink.
- Use multiple contiguous TV channels when available (up to three channels).
- Clustering support
- Collaborative sensing.

IEEE 802.22 limitations

Unfortunately, even IEEE 802.22 has several benefits; it also has several disadvantages such as:

- Low data rate (1.5 Mbps in downlink and 384 kbps in uplink).
- MIMO is not considered.
- Channel bonding is not considered in case of non-adjacent channel which reduce spectrum utilization.
- Direct communication between devices is not supported which degrade network performance.
- Spectrum sensing technique uses Quite Periods (QPs) frequently (some cases need to be sensed each frame) that leads to reduce the capacity of the network.
- Spectrum usage is not flexible.

Hence for all these reasons, a new task group has been working on a modified version of IEEE 802.22b in March 2012 (Mody & Chouinard, 2010) called D2DWRAN based on IEEE 802.22. New standard aimed to increase data rates. This standard is still under research and there is no finalized documentation. D2DWRAN can be considered as a vital solution for IEEE 802.22b networks.

D2D WRAN Based on IEEE802.22

In order to increase network capacity, have flexibility in spectrum and overcome IEEE 802.22 limitations, three main features were suggested in D2DWRANwhich are as follows:

1. **CPE-CPE Communication (D2D):** The downstream in D2DWRANs is the same as WRANs because a cell is still centrally managed by the BS. Hence, CPE-CPE directional communication is enabled in the upstream. Note that so far only intra-cell CPE-CPE communication has been considered since inter-cell CPE-CPE communication is more complicated.

Direct CPE-CPE communication in a cell can avoid the unnecessary routing via the BS with several benefits such as decreased end-to-end delay and decreased traffic load on the BS. In WRANs, the BS in a cell is not just the central management unit and gateway as in a regular cellular network, but it also manages spectrum allocation. The BS needs to access the incumbent database for channel information, it senses both the in-band (currently in use) and out-band (currently not used) channels frequently, processes the sensing results, and allocates resources in every frame (5 ms). Therefore, offloading some of the tasks of BS may improve the network performance significantly.

When using TVWS, D2DWRANs are required to protect all PUs efficiently. Therefore, spectrum management in D2DWRANs is centrally controlled by BSs. If a CPE attempts to start a communication with another CPE in the same cell, it sends the request to the BS and then waits for the allocation decision by the BS. This way, the destination CPE can receive packets from another CPE properly.

2. **Channel Reuse:** As mentioned earlier, one of D2D advantage is channel reuse. In this standard researchers state that this technique should be used to increase network capacity, spectrum utilizations and to avoid other IEEE 802.22 limitations.
3. **Multiple Operating Channels:** WRANs supported channel bonding only for adjacent free TV channels, which are up to three channels are combined as one channel with wider bands. Therefore, each cell can use only one TV channel if the vacant channels are scattered in the bands. For example, if two TV channels are available, but they are not adjacent, then they cannot be used simultaneously. This leads to wastage of resources. Therefore, multiple non-adjacent channels are considered to enhance channel utilization in D2DWRANs. Channel aggregation can be used to achieve multiple operating channels in both downstream and upstream.

D2D PROTOTYPES AND EXPERIMENTS

Prototype 1: FlashLinQ

Qualcomm company had invented a point-to-point wireless PHY/MAC network architecture called FlashLinQ (Wu et al., 2013). FlashLinQ's main purpose is to discover the maximum number of surrounding devices that could connect directly. FlashLinQ is a synchronous TDD/ OFDM structure established over the licensed spectrum (carrier frequency at 2.586 GHz and 5 MHz bandwidth). This structure designed for enabling DUs to realize each other automatically and communicate directly together without access point intervention. FlashLinQ can support also link management, rate scheduling and peer discovery in an autonomous way.

Based on FlashLinQ architecture, the prototype will schedule links for devices based on their priorities only in the case of agreement between both transmitter and receiver. This agreement depends on that the assigned link will not cause more interference on any established links and also depends on that Signal to Interference Ratio (SIR) of the link itself will exceed the threshold level. For peer discovery process, dedicated small time slots have been reserved for this process. The system allocates resources fairly among all links by randomizing the priority assignment at each time slot. Dedicated small time slots are occupied for peer discovery and each peer discovery slot is also divided into orthogonal resources. The network can support link management by assigning a certain channel (i.e. Connection ID channel (CID)). Similar CID will be assigned by the network for those links that are able to transmit simultaneously. It is predictable FlashLinQ will introduce new types of applications (e.g. secure mobile payments, content sharing, advertising, and any other application that may exploit D2D benefits). A prototype modem of FlashLinQ has been implemented on TI DSP chipset TMS-C6482 and XiLinX Virtex-4 FPGA. The main experiments and the results obtained in (Wu et al., 2013) are as follows.

Experiment 1: It is executed based on four-terminal devices allocated in the same room forming two links. At the begging both transmitters are away from their receivers (3 m link length) then transmitters get closer to their receivers (1 m link length).

Results 1: Significant throughput has been showed in the network applying IEEE 802.11 CSMA/CA protocol using RTS/CTS.

Experiment 2: Outdoor and indoor deployments have been addressed. For the outdoor scenarios, links are distributed randomly in a (1000 m * 1000 m) square area. Link lengths are approximate to be 20 m. While the indoor scenario links are distributed randomly in a (50 * 100 * 20 m) building with five floors each of height 4 m. Link lengths are approximate to be 20 m. For 60% of the links, both devices are on the same floor, while for the remaining links, the devices are one floor apart. In both deployments, only slow fading is taking into account.

Results 2: It displays the capacity gain of this protocol compared to the WiFi protocol for indoor and outdoor scenarios. Throughput of the network has an increase of 450% in spectrum efficiency with 256 links by using FlashLinQ than WiFi for both indoor and outdoor deployments.

Prototype 2: Data Spotting

“DataSpotting” is a system designed for checking the possibility to offload communication from base station by applying D2D technology. The system was designed by a group of researchers from Alcatel Lucent and Duke University, KAIST (Bao et al., 2013). The main target of dataspotting system is applying peer-to-peer (P2P) highly demand content sharing (i.e. videos and pictures). Data spot defines as a crowded small area that has various numbers of devices request data or desire to transfer data to each other (for example rush hours, sports stadiums, train stations, concerts, etc.). Cellular operator necessities to know the locations of all DUs inside the data spot via GPS. The system operates at dual-band (i.e. 3G band and ISM band). 3G spectrum is assigned for control channel that used for setup a connection through WiFi ad-hoc mode; while content transmitting/receiving established in the ISM spectrum through WiFi interface.

The procedure of this system to achieve its target is as follows. 1) Dataspotting system activates the content sharing system via the cellular operator in case of crowded areas or rush hours. 2) It gathers all DUs’ locations and lists their available contents. 3) The size of each data spot is assigned based on DUs’ locations and contents. For example, presume a user Alice exists in a certain data spot; first, it records its location and then asks for the desired content. The cellular operator tries to match the Alice’s request based on its location and content. After that operator performs whether there exists a DU Bob (or a WiFi access point), that provides Alice’s content. If so, the operator allocates a temporary IP to requester Alice and provider Bob and guides Bob to transmit the required content to Alice through WiFi ad-hoc mode. The Dataspotting prototype system has been implemented on Android Nexus One devices. The main important three experiments and their results obtained in (Bao et al., 2013) are as follows.

Experiment 1: In the Manhattan area, a measurement was derived with Bluetooth and GPS as it is not easy to detect the availability of mobile devices. In their analysis, dumb devices as printers and headphones are discarded and take into consideration mobiles and laptops only. The aim of this experiment is to figure out the available number of devices around a biking user at any time, and also the average expected contact duration between DUs.

Result 1: it shows that most of the time, there are at least 30 devices around the biking user. Moreover, most of these detected devices stay nearby the user for more than 30 seconds. Also based on their implementation, the measured data rate is around 1 MB/s, so 30 seconds is more than enough to transfer a medium-sized file

Experiment 2: the main purpose of this experiment is to understand how user density changes inside a data spot. They implemented the same previous experiment for two waiting areas in NY Penn Station at rush hours but in a static manner.

Result 2: the outcome measurements indicate that in both different places, the number of nearby DUs is large and stable. Besides, the average contact duration is 80 seconds, more than enough to transfer multiple files.

Experiment 3: testing five terminal devices that communicating directly.

Result 3: D2D data rate range varies from 300 Kb/s to 2.5 Mb/s depends on the location of DUs (outdoor or indoor) and also depends on the mobility mechanism.

Prototype 3: Relay by Smartphone

Tohoku University's academics introduce a system called "Relay by Smartphone" (Nishiyama et al., 2014) to be a supported system in case of disaster. It supports multi-hop D2D communication dissimilar from "FlashLinQ" and "Data Spotting" which support one-hop D2D communication. This system designed to transmit a small package of information such as voice, photo, SMS, etc., out of disaster area where the communication infrastructure is either physically damaged or energy lacked. In Relay by Smartphone, each smartphone can operate with one of two routing types either MANET type or DTN type. The routing selection process subjected to mobility, battery power, neighbor density…etc. This system operates in the ISM band and performs WiFi ad-hoc mode for peer discovery and D2D communications.

So as to have a stable connection through D2D multihop, several issues should be taken into consideration. 1) Choosing a suitable access interface such as Bluetooth, LTE-A, ZigBee, WiFi, etc. The proper selection is analyzed based on transmission range, data rate and used frequency of each. 2) Selecting the best routing technology (i.e. DTN or MANET) as routing is a dominant technology in multi-hop D2D communication. MANET-type and DTN-type perform in different ways depending on the environment and situation of users. 3) The capability of the network gateway to interconnect with other kinds of networking techniques, such as Movable and Deployable Resource Units (MDRUs) and Unmanned Aircraft Systems (UASs). 4) Ensuring secure information in the procedure of message delivery. 5) Checking the operating systems of the smartphone (i.e. Android, iOS, Windows, TIZEN, etc.,), the system should support emergency operation mode and compatible with applicable smartphone operating systems.

A number of preliminary experiments have been executed in Sendai city, Japan. The reason behind selecting this city is that it suffered from numerous disasters such as tsunami and the Great East Japan earthquake. The main two experiments and their results obtained (Nishiyama et al., 2014) are as follows.

Experiment 1: It was consisting of 20 smartphones that were distributed along the streets with a mutual distance of around 50–200 m. The main purpose of this experiment is to test the mechanism of message delivery in the urban area.

Results 1: The prototype successfully delivered a message with a total route length of around 2.5 km from a park designated as a refuge area to a railway station.

Experiment 2: It tends to test the interconnection function of the gateway module in the system from the Aobayama campus of Tohoku University to Katahira campus via a UAS flying in the air.

Result 2: It shows that a data package of 100 KB can be efficiently delivered through the mentioned place, resulting in a delivery delay of fewer than 20 seconds over 3 km distance.

Table 5 summarized the features of the different prototypes such as data rate, number of hops, implementation platform, operating band, and application.

D2D INTEGRATED FEATURES

A lot of features could be integrated with D2D technology in order to get better performance. A lot of researchers have studied how to integrate this technology with different applications (i.e. HARQ, V2V and IoT). This section states other technologies and the potential advantages of combing them with D2D.

Table 5. Technical comparison between different device-to-device's prototypes

	FlashlinQ	Data Spotting	Relay by Smartphone
D2D Discovery	Autonomous	Operator assisted	Autonomous via routing protocol
Peer discovery Range	1km	~100m	~100m
D2D communication	Operator controller	Operator controller	Autonomous
Operating band	Dedicated cellular band	Control channel: 3G band Data channel: ISM band	ISM band
Radio access	OFDMA	WiFi adhoc	WiFi adhoc
Number of hops	single hop	single hop	Multi hop
Data Rate	1.5 Mb/s	300kb/s~2.5 Mb/s	~5kb/s
Implementation platform	TI DSP chipset TMS-c6482 Xilinx virtex-4 FPGA	Android Nexus one	Android smartphones
Application and used cases	Advertising, content sharing, secure mobile payments, p2p communications	peak hours, train stations, sports stadiums	Emergency network

D2D Integrated with Vehicle to Vehicle (V2V) Communication

Nowadays, Vehicle-to-Vehicle (V2V) communications (Nabeel et al., 2013) have taken more concerns. Vehicular communication systems are networks which vehicles and roadside units are the communicating nodes, providing each other with certain information and data, such as speed, location, direction of travel, braking, loss of stability, safety warnings and traffic information….etc.. These data can be effective in avoiding accidents and traffic congestion.

Consequently, V2V communications become one of the main topics of wireless communications that have already been the focus for several years. For example, IEEE has already launched a standard called 802.11p for wireless communication between vehicles. Basically, Intelligent Transportation System (ITS) applications is essential depends on Dedicated Short Range Communication (DSRC) technology that applied on IEEE 802.11p (Araniti et al., 2013). Unfortunately, applying DSRC technology to support vehicle communication leads to poor network performance (e.g. less reliability) due to shortage in data rate and transmission range.

Other proposed technologies for V2V are ad-hoc communications, Bluetooth, Ultra-Wide Band (UWB) and WiFi Direct. The following table 6 states these protocols names and their specifications. From the mentioned table; it is clear that the main problem with all mentioned communication systems is that they basically assigned for a wireless LAN environment. Hence, the main drawbacks are weaker mobility support and lower coverage area that may degrade network performance. For all previous reasons, finding a better solution to backing V2V communications becomes a vital issue. Due to table 6 LTE-A and 5G systems offered better transmission range, massive data rate and support high speeds. That is why most researchers tend to studying applying V2V on LTE-A or 5G system. 5G network supports licensed spectrum, higher data rate (up to 5Gb/s), higher mobility (up to 350 Km/h), higher higher coverage region (around 1Km), and lower latency. From V2V communication perspective, it usually occurs among vehicles that close in distance (e.g. same roadside).

Table 6. Comparison between different vehicle communication's supportive technologies

Technology	DSRC	ZigBee	Bluetooth	UWB	WiFi Direct	LTE-A
Standardization name	IEEE 802.11p	802.1504	Bluetooth SIG	802.1503a	802.11a	3GPP LTE-A Rel12
Transmission distance (max)	~200m	~100m	~100m	~10m	~200m	~1km
Data rate (max)	~27Mb/s	~1250kb/s	~24Mb/s	~480Mb/s	~250Mb/s	~1Gb/s
Frequency band	5.86-5.92 GHz	868/915 MHz - 2.4 GHz	2.4 GHz	3.1-10.6 GHz	2.4/5 GHz	Licensed Band
Supporting mobility	Up to 60 Km/h	Low	Very low	Very low	Low	Up to 350 Km/h
V2I	Available	available	Available	Available	Available	Through eNB
V2V	Ad hoc	Ad hoc	Ad hoc	Ad hoc	Ad hoc	Through D2D

Furthermore, V2V depends on real-time requirements. Hence, V2V communication requires low latency (1ms approximately) and high reliability (99.99% approximately). These QoS are necessary for V2V communications to be achieved by exploiting the offered advantages of D2D technology. Thus, D2D technology can be a strong candidate for achieving V2V's requirements 38. The main challenges that face V2V communication are mobility, interference and resource allocation. The notion of extending D2D technology in V2V communication scenario is cleared in LTE-a band in (Mumtaz et al., 2015). Simulation results proved that D2D is one the suitable solutions in order to eliminate latency with respect to IEEE 802.11p. A different topic is covered in (Mumtaz et al., 2015)-(Liang et al., 2018). They tend to optimize SINR for cellular users while optimizing latency and reliability for communicating vehicles.

D2D Integrated With Internet of Things (IoT)

The Internet of Things (IoT) holds the promise to improve our lives by introducing innovative services conceived for a wide range of application domains (Wang et al., 2018). IoT defines new kind of connectivity that introduces free flowing transferring information among human and machine, software and hardware. It is expected that will be 30 billion connected devices in the market by 2020 and the economic value of IoT to be around $1.46 trillion in 2020, while Ericsson expected that will be 24 billion to 50 billion total connected devices in the market by 2020 (Salem et al., 2018).

In order to enhance the performance of IoT, some requirements need to be fulfilled (Cheryshev et al., 2017) as minimizing energy consumption, supporting massive Machine-Type Communication (MTC) without degradation in network performance, supporting interoperability and Handling Big Data for complicated IoT applications (i.e., storage and analysis of the huge amount of data generated by IoT devices). In addition, IoT should have a high-level network recovery capacity, quickly identify connectivity failures, and automatically establish alternative communication paths. Smart multimedia devices shall be properly included to sustain multimedia services in IoT networks. Some of the multimedia services such as patient monitoring, military surveillance, smart home integrated monitoring systems for security, ambient multimedia services….etc.

By applying D2D, it will meet previous IoT requirements. Performance of IoT network will be enhanced by achieving larger data rate and low delay which could sustain Internet of Multimedia Things, minimizing energy consumption for IoT devices, extending both coverage area and capacity increasing to fund MTC and supporting interoperability in Multi-RAT heterogeneous networks.

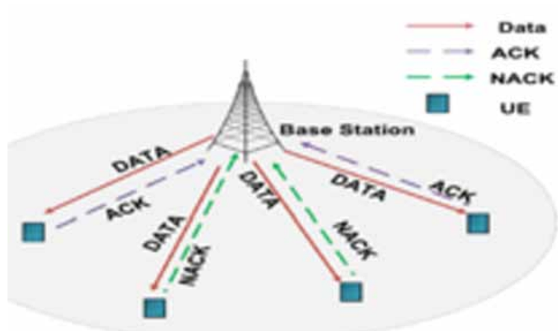
The resource multiplexing has been investigated in the multicell D2D communication scenario (Li et al., 2018). Cross-cell Frequency Resource Multiplexing (CFRM) scheme has proposed to maximize the network throughput and to decrease the interference between CUs and DUs. CFRM allocates resources to CUs according to the cell region division and provides efficient resource multiplexing for DUs. The simulation results demonstrate that CFRM can enhance the stability of the cellular network and increase the network throughput for IoT by exploiting D2D.

D2D Integrated with Hybrid Automatic Repeat Request (HARQ) Technique

A combination between Forward Error Correction (FEC) and Automatic Repeat Request (ARQ) is defined as Hybrid Automatic Repeat Request (HARQ) technique. Applying HARQ technique makes direct communication among devices more robust. Integrating HARQ with D2D technology has two types that are direct HARQ and indirect HARQ (Miao et al., 2014). Indirect HARQ is happening when D2D Rx sent an acknowledgement/negative acknowledgement (ACK/NACK) to the base station. Then, BS retransmit (ACK/NACK) to D2D Tx. In this case, it is probable to reuse resources of the uplink and down link. While in direct HARQ, ACK/NACK is transmitted directly without a base station evolving. Direct HARQ may apply in case of out-coverage and in-coverage.

Multicasting procedure for some UEs by eNB is shown in figure 6. The HARQ feedback messages clarify the received packet status. Based on whether the packet has received correctly (ACK) or not (NACK) which sent back to the eNB by UEs. In case of failure packet, eNB retransmit it again. But the disadvantages of this approach are consuming more energy, huge amount of signaling overhead and more latency due to multiple retransmissions. A compressed HARQ technique has been introduced in (Du et al., 2012), which has improved results in case of signaling overhead. It is highly recommended for multicast mechanism and has an enhanced performance evaluation than traditional multicast. Novelists in (Miao et al., 2014) design a crosslayer depends on HARQ technology. This paper suggested three types of HARQ in order to design this cross layer. Applying cross layer optimization and HARQ technology lead to enhance throughput and data rate of D2D connection.

Figure 6. HARQ multiplexing mechanism



D2D CHALLENGES

D2D technology takes more consideration thanks to its numerous advantages. However, it faces a lot of challenges such as peer discovery, handover, and radio resource management. Following subsections highlight these challenges.

Peer Discovery

One of the main challenges that face researcher is D2D discovery peer process. D2D discovery process defined as the way to gain knowledge about surrounding devices that may communicate directly together. Discovery initiation and discovery control are the main two stage of this discovery process (Mumtaz et al., 2014). The D2D discovery initiation stage may be priori or posteriori process. Priori process means initiating D2D discovery before the DUs start to communicate by sharing certain information between devices. On the other hand, posteriori process occurs during on-going communication. The common use of this kind of process could be happen when mobile devices change their locations. Second stage is D2D discovery control that can be fully controlled via base station (i.e. eNB), or autonomously by the DUs themselves.

Utilizing allocated resources for D2D discovery discussed in (Nguyen et al., 2014). UEs execute procedures in order to discover surrounding nodes. First state is search/listen period; second one is discoverable interval state and finally frequency multiplexed discovery channel. Paper's results show that the suggested procedures are capable of raising the amount of discovered devices during one discovery period.

Time division multiplexing (TDM) technique based on synchronous OFDM system applied for a fully distributed D2D discovery network has suggested in (Jung & Chang, 2014). Each allocated radio resource has a discovery period, which includes the process of transmitting or receiving discovery signals. This period permits each device to acknowledge its presence and to discover other proximity devices. The main target for (Lu et al., 2014) is to minimize discovery process overhead. This could happen by assign a minor part form frames of the physical layer for the D2D discovery process.

D2D Handover

Unfortunately, there are very less literatures are available on handover for D2D communication. In case of enabling D2D connection, when communicating devices (both or one of them) are moving toward neighbor cell, they enter into this cell at some point then a joint handover happens. In case of only one of the communicating devices moves to the neighbour cell, it is called half handover or partial handover (Chen et al., 2015). A general handover scenario has been clarified in Figure 8, showing the handover scenario of UE1 from source to target eNB.

Four parameters are effective parameters in any handover decision method (Yilmaz et al., 2014). These parameters are Hand Over Margin (HOM), Time To Trigger (TTT) timer, LTE threshold (LTEth), and D2D threshold (D2Dth).

Figure 7. Handover Scenario case, (a) Before Handover; (b) After Handover

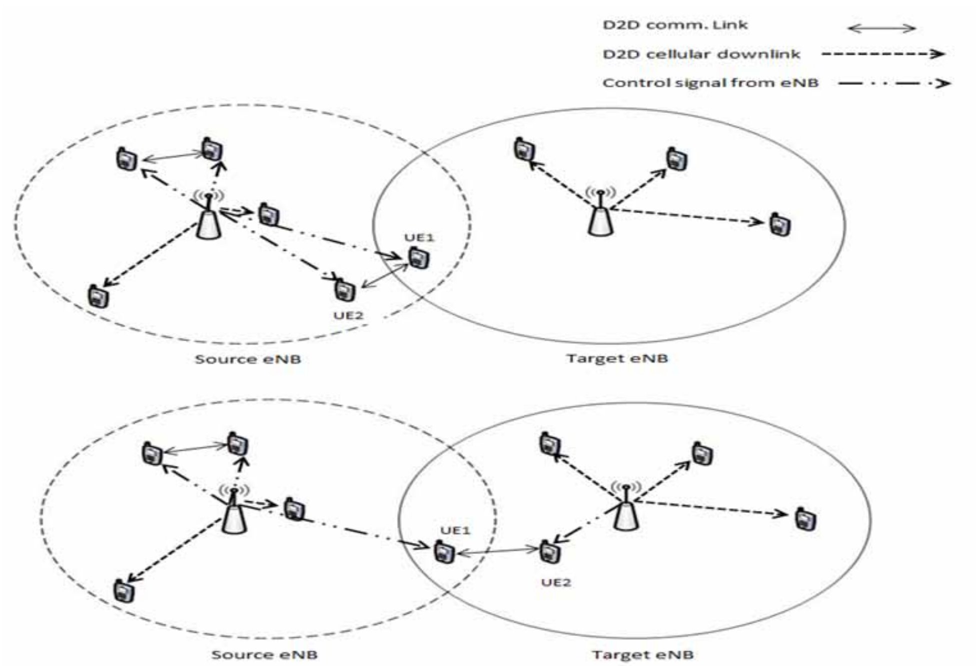
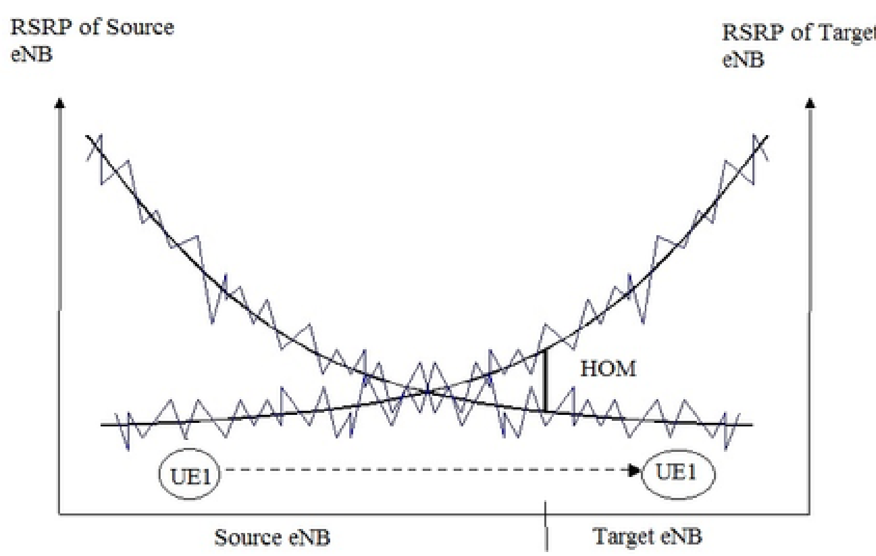


Figure 8. Reference Signal Receiving Power of source and target eNB when UE1 moving from cell to another (Chen et al., 2015)



1. HOM considered as a fixed variable that denote a margin level between the received signal power level of the current eNB and the received signal power level to the target eNB. In LTE system, the received signal power level is defined as Reference Signal Receiving Power (RSRP). HOM avoiding unnecessary handover “Ping-Pong effect” that undesired handover in the network.
2. TTT is the time interval value that is vital to accomplish HOM. The HO considered completed once TTT condition is satisfied.
3. LTE Threshold (LTEth) is applied to check the received signal power level of UEs.
4. D2D threshold (D2Dth) is applied to check the received signal power level of DUs.

The conditions for triggering handover are represented in Figure 8 and due to the following equations:

$$RSRP_T > RSRP_S + HOM \tag{1}$$

$$HOTrigger > TTT \tag{2}$$

where, RSRPT, RSRPS represents the values of RSRP of target eNB and source eNB, correspondingly and HOTrigger is the trigger of the handover. As soon as equation (1) satisfied, the HOTrigger turned on. After that, eNB take the decision of the handover, provided all important cases. Therefore, based on handover decision (e.g. equation (1) and equation (2)), one of two procedures will be executed either a full/a half handover or no handover. In case of full handover, both terminals (transmitter and receiver) move to the target eNB. While in case of half handover, either transmitter or receiver only is moved to the target eNB.

Several solutions for mobility management issue have proposed in (Yilmaz et al., 2014). Two smart algorithms for handover execution have provided which are D2D triggered handover and D2D aware handover. These algorithms presented lower signaling overhead and latency in simulation results. However, in (Radwan & Rodriguez, 2014), horizontal and vertical handover have represented to eliminating consumed energy in 5G heterogeneous networks.

D2D Resource Allocation Optimization and Management

Radio resource management optimization issue indicates how to optimally allocate frequency resources to overall DUs so as to optimize some performance parameters (i.e. SINR, latency, power consumption, reliability, QoS, interference, channel utilization, energy efficiency …etc.). Resource blocks should be distributed among DUs depending on certain rules based on cellular network design. Optimization procedures may be executed by eNB or by D2D pairs themselves. Basically, CUs should have a priority than DUs in optimizing procedures. One of the technical challenges in optimization procedures comes from the nature of dynamicity of the network where DUs and CUs always have variable states and locations. Heuristics, fuzzy logic, and game theory are some examples of solution types used to solve optimization problems relating to D2D communication.

Various papers supposed (Yu et al., 2011)- (Yu et al., 2009) simple scenarios that include a single CU and a single D2D pair. Optimization of resource allocation in terms of SNR had highlighted in detail with certain restrictions, (i.e., maximum transmit power and energy limitation (Yu et al., 2011), spectral efficiency restrictions boundaries (Yu et al., 2009), and average Channel State Information (CSI) (Yu et al., 2009).

Another network scenario is introduced in (Hussein & El-Kader, 2017), (Xiang et al., 2012) where there is one DU pair and multiple CUs. The mode selection technique is applied in order to optimize SINR based on DU pair distance and number of users (Hussein & El-Kader, 2017). Also, the mode selection example for selecting optimal relay nodes mentioned in (Xiang et al., 2012). While the opposite scenario is investigated in (Omorinoye et al., 2019), where there are multiple DUs accessing the same channel with a single CU. An optimization problem is addressed to minimize total power consumption for both CUs and DUs subjected to users' QoS. The property of the Z-matrix is examined to be exploited by a power allocation mechanism.

Multiple DUs/multiple CUs scenario is remarked in (Jung et al., 2012)-(Wang et al., 2013) to allocate appropriate resources that optimize a certain parameter(s) under specific constraints. Maximizing the system energy efficiency is proposed in (Jung et al., 2012), which based on searching all possible mode combinations of overall DUs and CUs to achieve this target. A list-coloring theory-based resource allocation algorithm is highlighted in order to increase utilization probability (Tsolkas et al., 2012). In this algorithm, additional tasks were supposed for DUs to report their desired UL resource block to the eNBs. The eNB constructs a Node Contention Graph (NCG) to overall DUs based on their desired UL resource block and then completes an interference-free allocated resource. Finally, the main target of authors in (Wang et al., 2013) is to maximize spectrum utilization and throughput of the network. A Stackelberg game framework was settled for multiple CUs and DUs to form a leader-follower pair where CUs are the leader while others are followers. A joint scheduling and resource allocation algorithm was proposed to solve the optimization problem due to interference constrains.

A comparison of different related works can be found in Table 7. This table classifies the research works based on their network scenario, main objective(s), main restriction(s), and finally a proper tool or solution that fits the problem.

CONCLUSION

An intensive overview has been obtained about D2D communication technology in the existence with cellular network. The D2D communication technology underlying mobile network provides numerous benefits such as raising overloaded cellular network efficiency, reducing latency and minimizing consumed energy. Some standards have been summarized such as recent 3GPP accomplishments on direct connectivity and D2D WRAN based IEEE 802.22 evaluation. Moreover, current D2D's prototypes and experiments, such as FlashLinQ, Data Spotting, and Relay by Smartphone have been showed, and mentioned with details their architecture, implementations and current experiments with their results. Major research topics such as IoT, V2V, and HARQ were explained. Also, the importance of attaching D2D technology with these different features has been illustrated. Besides that, the D2D technology faces a lot of vital challenges such as handover, peer discovery, and resource allocation; that have been highlighted. Finally, applying D2D technology in 5G becomes a very richly material for investigation; till now most researches and prototypes are still under work.

Table 7. Comparison between resource allocations related works

Scenario	Related works	Objective(s)	Restrictions(s)	Solution/tool
1 D2D / 1 CUE	(Yu et al., 2011)	Maximize SINR	maximum transmit power and energy limitation	Linear optimization
	(Yu et al., 2009)		minimum and maximum spectral efficiency restrictions	
	(Yu et al., 2009)		average Channel State Information (CSI)	
1 D2D/ M CUs	(Hussein & El-Kader, 2017)	Maximize SINR	D2D pair distance and number of cellular users	Basic math derivation and mode selection
	(Xiang et al., 2012)		Number of relay nodes	Basic math derivation
M D2D/ 1 CUs	(Omorinoye et al., 2019)	Minimize power consumption	Users' QoS	Z-Matrix
	(Liang et al., 2017)	Maximize SINR and reliability	Minimize outage probability, maximize transmit power	Hungarian method
M DUs/ M CUs	(Sun et al., 2015)	Maximize SINR, reliability and minimize latency	Maximize transmit power, resource blocks orthogonally, guarantee of users QoS	Heuristic two-stage scheme
	(Liang et al., 2018)	Maximize SINR and reliability	Minimize outage probability, maximize transmit power and reuse channels	weighted 3-dimensional matching problem
	(Jung et al., 2012)	Maximizing energy efficiency	Guarantee of users QoS and maximize time frame	Basic math derivation and mode selection
	(Tsolkas et al., 2012)	Maximize spectrum utilization	Minimize interference among DUs and CUs	List coloring graph theory
	(Wang et al., 2013)	Maximize spectrum utilization and throughput	CUs fairness and DUs interference	Stackelberg game

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Chapter 9
The State of the Art in Cognitive Radio Networks in 5G Hetergeneous Networks

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ABSTRACT

This chapter addresses cognitive radio systems (CRSs) in the 5G network and presents the existing, emerging, and potential applications employing CRS capabilities and the related enabling technologies, including the impacts of CRS technology on the use of spectrum from a technical perspective. The description of such technologies, operational elements, and their challenges are also presented. Furthermore, this chapter provides high level characteristics, operational and technical requirements related to CRS technology, their performances, and potential benefits. Finally, factors related to the introduction of CRS technologies and corresponding migration issues are discussed.

DOI: 10.4018/978-1-7998-1152-7.ch009

INTRODUCTION

One of the most important technology used in the 5G mobile network is Cognitive radio systems (CRSs) are expected to be a driver of innovation and development of future wireless systems. CRSs would be one of the foreseen technical solutions to address the growing traffic demand in the future. CRSs could allow more efficient use of radio resources including limited spectrum resources, compared with conventional radio communication systems.

The key technical features and capabilities of a CRS as identified in

- The capability to obtain knowledge of its radio operational and geographical environment, its Internal state and established policies, as well as to monitor usage patterns and users' preferences;
- The capability to dynamically and autonomously adjust its operational parameters and protocols according to the knowledge in order to achieve predefined objectives; and
- The capability to learn from the results of its actions to further improve its performance.

Due to rapidly increasing wireless traffic and the need for a larger amount of spectrum, studies in 5G networkhave identified important aspects related to the use of CRS technologies. CRS technologies could be an enabler for spectrum sharing and radio resource management on a more dynamic basis, thus providing increased spectral efficiency and mitigating the problem of congestion, e.g., through enhancing capacity.

As described in (FCC et al., 2002), CRSs may provide several benefits to both system operators and end users, however, the extent of the benefits and suitability of CRS technologies depends on the deployment scenarios and use cases for these systems as well as the technical conditions of CRS operation.

In principle, the introduction and deployment of CRS can take place without the need for any changes to the Radio Regulations. In addition to that, as stated in (Salem et al., 2014) - (Haykin et al., 2005), it should be noted that any system of a radiocommunication service that uses CRS technology in a given frequency band will operate in accordance with the provisions of the Radio Regulations governing the use of that band. A CRS is not a radiocommunication service, but a set of technologies that in the future may be implemented in a wide range of applications in the 5G network. However the deployment of CRSs in the 5G networkmay require identification of unique and detailed characteristics such as security mechanisms to ensure appropriate operation which can be achieved by future studies and further technical analysis.

This chapter provides a detailed description of CRS capabilities and enabling technologies as well as the relationship between them. It describes also the key technical features related to these technologies as enablers for enhanced sharing and coexistence as well as more efficient use of resources. It also discusses the impact of CRSs on the use of spectrum from a technical perspective. The report describes the high level characteristics, operational and technical requirements of a CRS. As well general performance criteria and metrics are presented in this report to help the performance evaluation of 5G networkradio system employing CRS technology. In this report the initial set of potential benefits introduced in (Lee et al., 2011), are further expanded. Furthermore, factors related to the introduction of CRS technologies are discussed in addition to related migration issues.

DEFINITIONS AND TERMINOLOGY

The following definition and terms are used in the chapter.

Definitions

Cognitive radio system (CRS): A radio system employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained.

Software-Defined Radio (SDR): A radio transmitter and/or receiver employing a technology that allows the RF operating parameters including, but not limited to, frequency range, modulation type, or output power to be set or altered by software, excluding changes to operating parameters which occur during the normal pre-installed and predetermined operation of a radio according to a system specification or standard

Terminology

For the purpose of this chapter, the following terms have the meanings given below. However, these terms do not necessarily apply for other purposes.

Coexistence: Coexistence refers to the situation where two or more radio systems operate in adjacent frequency bands.

Node: Node refersto a generic network element(e.g. a base station, an access points, radio terminals, core network element) that is involved in the related network operations.

Policy

1. A set of rules governing the behavior of a system,
2. A machine interpretable instantiation of policy as defined in (a).

Spectrum Sharing: Spectrum sharing refers to the situation where two or more radio systems use the same frequency band.

TV White space: A portion Of spectrum in a band allocated to the broadcasting service and used for television broadcasting that is identified by an administration as available for wireless communication at a given time in a given geographical area on a non-interfering and non-protected basis with regard to other services with a higher priority on a national basis.

APPLICATIONS

The CRS capabilities encompass a number of techniques that can be applied to different wireless systems. A CRS can offer several benefits to system operators and end users, such as improved efficiency of spectrum use, additional flexibility, self-correction and potential for new mobile communication applications.

Actually, there are already existing applications (i.e. radio local area networks (RLANs) using dynamic frequency selection (DFS)) or planned applications (i.e. radio systems using TV white space) that employ some of the CRS capabilities in order to obtain knowledge of their radio environment. Based on the obtained knowledge they are able to select parameters such as their frequencies and/or adjust their transmit power to enhance coexistence and sharing with the aim of avoiding harmful interference being caused.

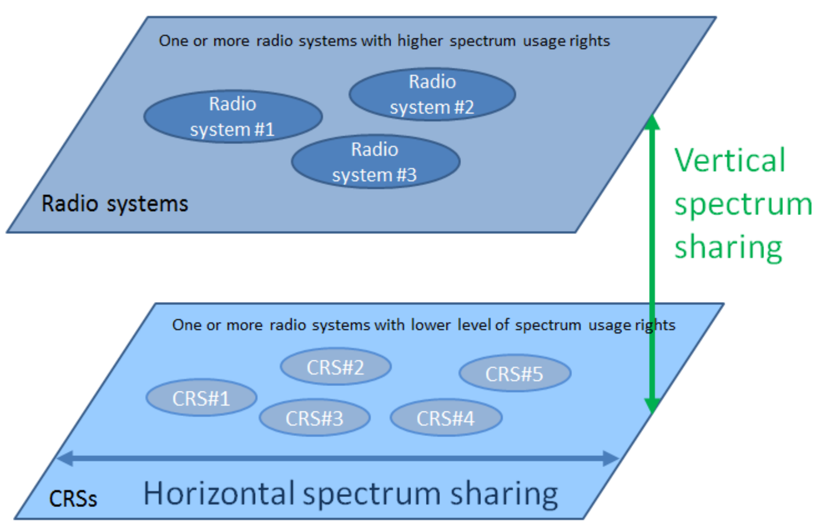
CRSs may share spectrum with other radio systems that are not necessarily CRSs, as well as with other CRSs. In this context, pertaining only to sharing involving CRSs, sharing can be described as follows:

- **Vertical Spectrum Sharing:** The case where one or more radio systems with CRS capabilities share the band of another radio system that does not necessarily have CRS capabilities. The radio systems with CRS capabilities are only allowed to utilise frequencies within the band as long as the other radio system is not affected by harmful interference from the CRSs;
- **Horizontal Spectrum Sharing:** The case where multiple radio systems with CRS capabilities are accessing the same shared spectrum band.

A graphical illustration of vertical and horizontal spectrum sharing is given in Figure 1. In this illustration, vertical sharing refers to situation where CRS(s) with lower level of spectrum usage rights share spectrum band with radio systems having higher spectrum usage rights. One example of this kind of sharing is the use of TV white spaces. It should be noted that radio systems with higher spectrum usage rights may also possess CRS capabilities. As well, the figure illustrates the horizontal sharing that could also take place between radio systems with/without CRS capabilities at the same level of spectrum usage rights.

Vertical and horizontal spectrum sharing are not mutually exclusive and both of them are present in the examples of applications employing CRS capabilities that will be given in this section. Vertical and horizontal spectrum sharing can also exist separately.

Figure 1. Vertical and horizontal spectrum sharing involving CRSs



Coexistence essentially refers to the interference issues that a CRS operating in a certain band may imply on another radio system (that is not necessarily a CRS) that operates in the adjacent bands.

In this section, existing and emerging applications as well as potential applications for the future are reviewed.

EXISTING AND EMERGING APPLICATIONS EMPLOYING CRS CAPABILITIES

There are already examples of existing or emerging applications employing CRS capabilities, such as obtaining knowledge with spectrum sensing and geo-location with access to database. These example applications can also make decisions and adjust their operational parameters based on the obtained knowledge.

GHz RLANs Utilizingdynamic Frequency Selection (DFS)

RLANs can operate in the 250- 350 MHz and 470- 725 MHz bands on a co-primary basis with radiolocation systems and radars. RLANs operate within the mobile service allocation and radars in the radiolocation service allocation, both having a co-primary status.In this band, Radio Regulations have been adopted by the ITU (cf. Resolution 229 (WRC-03)) to facilitate sharing between the two systems with the aid of a DFS protocol (cf. Recommendation ITU-R M.1652). This protocol specifies the sensing/detection and operational techniques to be used by the RLANs to avoid interference to the radar systems. Recommendation ITU-R M.1739 provides the protection criteria. Prior to operation, RLANs are required to use DFS to ensure that radiolocation systems are not operating in the same channel they intend to use. The mobile systems must also vacate channels when new radiolocation systems come into operation.

Use of TV White Space

Due to various reasons some channels have had to be left unused by TV applications to provide guard bands between the active broadcast channels. The guard bands have been needed to accommodate TV receiver characteristics for strong or weak signals and adjacent channel performance. Some channels have also been left unused as there has been limited TV service deployment in some geographic areas.

Recently, some administrations have allowed or are considering to allow license-exempt devices to operate on a non-interfering basis within these TV white spaces. To facilitate spectrum sharing and to protect incumbent services from interference, a variety of technical approaches for the operation in these bands have been considered. These approaches include:

- Geo-location capability with access to a database;
- Sensing capability.

With respect to the capabilities of a CRS to obtain knowledge of its environment, in the case of TV white spaces the key capability isgeo-location coupled with access to a database which in this application is referred to as the TV white space database approach.

Potential Applications

The following subsections address the potential applications of CRSs.

Cognitive Networks Exploiting Reconfigurable Nodes

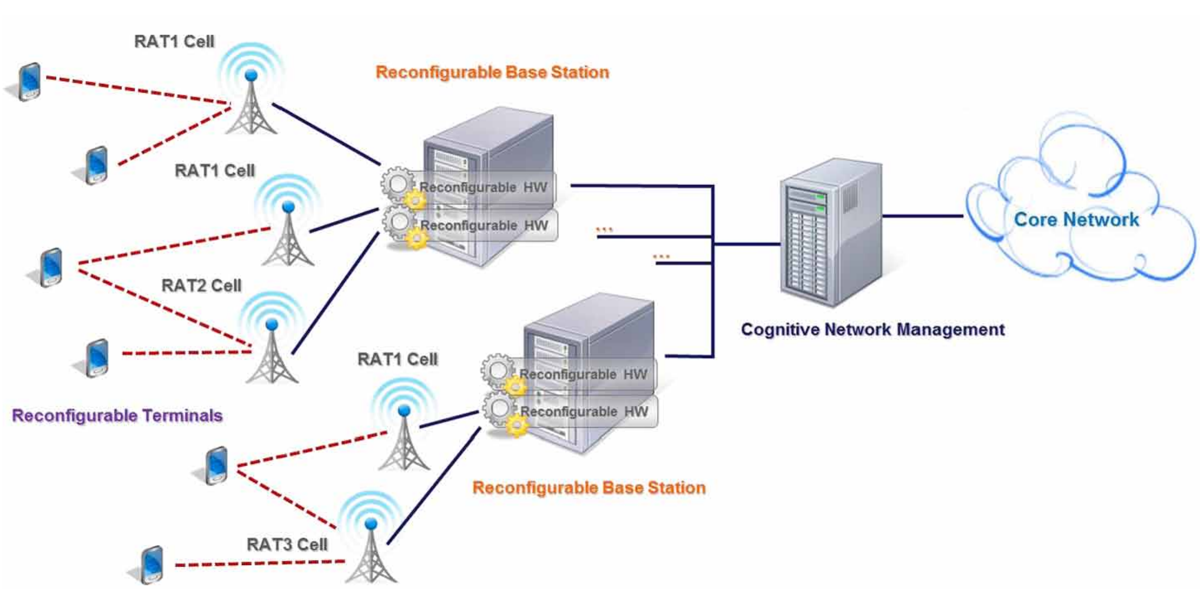
Cognitive networks are networks in which CRS capabilities are implemented at the infrastructure level. This includes, for example, network elements such as O&M (Operation & Maintenance) and base stations. In particular, a cognitive network is a network that could dynamically adapt its parameters, functions and resources on the basis of the knowledge of its environment.

In the context of this section, cognitive networks are intended to be deployed using reconfigurable nodes. In principle, the application of such cognitive networks includes the following functionalities and entities (see Figure 2):

- Cognitive network management;
- Reconfigurable base stations;
- Reconfigurable terminals.

The cognitive network management functionality spans different Radio Access Technologies (RATs), managing and controlling the nodes inside the network, with the goal of self-adapting towards an optimal mix of supported RATs and frequency bands. This functionality could act on the basis of some input parameters, for example the available resources, the traffic demand, the capabilities of the mobiles within the network (supported RATs, frequency bands, etc.), the requested bearer services (bandwidth,

Figure 2. Cognitive networks functionalities and entities



quality of service (QoS), etc.), etc. In addition, this functionality could exploit a collaborative cognitive radio resource management scheme, where the decision making functions are shared among different network nodes.

In this approach, the Reconfigurable Base Stations (RBSs) are the nodes establishing the cognitive network. The hardware resources of a reconfigurable base station could be dynamically reconfigured in order to be used with different RATs, frequencies, channels, etc., and they could support multi-RAT operation with dynamic load-management.

The reconfigurable terminals are the nodes connecting to the base station in the cognitive network. The software and hardware of a terminal could be reconfigured dynamically. Thus it could support operating on different RATs, frequencies, resource utilization modes, etc. Therefore, the reconfigurable terminals could facilitate the flexible and efficient adaptation of the cognitive network to the dynamic environment. For example, they could support multi-RAT operation, such as joint admission control and vertical handovers to balance the load of different RATs more efficiently.

In addition, cognitive networks enable the introduction of the CRS concepts and technologies in a multi-RAT environment.

The availability of reconfigurable base stations in conjunction with cognitive network management functionalities could give the network operators the means for managing the radio and hardware resource pool with better overall efficiency.This enables the adaption of the network to dynamic variations of network traffic.

The main features of cognitive networks can be summarized as follows:

- The dynamic self-adaptation of the network configuration towards an optimal mix of supported RATs and frequency bands can be achieved by the exploitation of the reconfigurable nodes and the application of cognitive network management functionalities;
- The dynamic self-adaptation (e.g. network configuration) can be based on the traffic patterns variations in time and space for the different deployed RATs;
- Ability to provide sufficient information to the terminals for initiating a communication session appropriately in a dynamic context (e.g. wireless control channels).

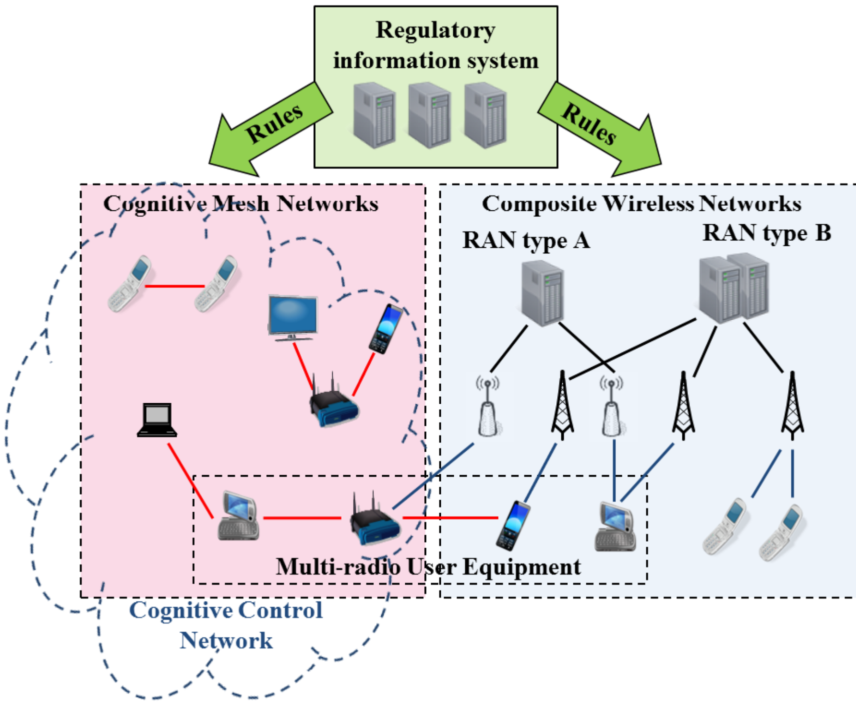
An example of cognitive network application could be the enhancement of spectrum efficiency and high data rate provision based on GSM system frequency reuse. For cellular systems like GSM, in order to ensure that the mutual interference among cells remains below a defined threshold, adjacent cells use different frequencies. However in cells that are separated by a certain distance, frequencies can be reused. On this basis, a cognitive network management could efficiently reuse appropriate GSM frequencies to activate micro cells within the coverage area of a GSM macro cells by using a low transmission power in order to avoid harmful interference to the GSM system. Such micro cells can be deployed using a different radio access technology to provide high date rate transmission (Sherman et al., 2008).

Cognitive Mesh Networks

In addition to the centralized concept described in the a later section, decentralized CRS concept may also be considered as illustrated in the Figure 3 (Firoz et al., 2008)-(Milanic et al.,2007).

In Figure 3, multi-radio user equipment (MUE) represents a user device with reconfigurable radio capabilities and ability to have connections to multiple radio networks at the same time. Such radio

Figure 3. Centralized and decentralized CRS concepts



networks can be identified as i) composite wireless network (CWN) representing a set of radio networks operated by a network operator using a common network management system that may also have cognitive capability and ii) cognitive mesh networks (CMNs). In general, mesh networks can be seen as a group of nodes which all communicate with each other creating a mesh typically using short-range radios. Every node can send and receive messages, but the nodes may also function as routers. CMNs introduce the possibility to use opportunistic spectrum access in collaborative manner so that different CMNs active in the same geographical area can coordinate their use of radio frequencies. Interworking between CMNs may be arranged in a decentralized manner by using logically separate cognitive control network (CCN) to exchange information between CMNs. CCN may be implemented with the cognitive control channel (CCC).

It should be noted that a MUE could be simultaneously connected to both CMN and CWN, however, the CMN domain is separated by the CWN domain, in terms of used radio frequencies and RATs. Inside CMN domain, MUEs do not act as relay entities towards CWN for others MUEs, while each of them may connect directly to CWN by the appropriate RAT (Raychaudhuri et al., 2003).

Heterogeneous System Operation Using CRS Capabilities

In a heterogeneous network environment, CRS capabilities provide users with the optimal wireless access that best suits the users' needs as well as operators' objectives towards efficient use of radio resource and spectrum. CRS capabilities can be utilized for handover across different RATs and across different systems. In the following, the use of the CRS capabilities to enhance the handover operations within an operator's networks is considered first, followed by a multi-operator situation.

Intra-System Inter-RAT Handover

Intra-system handover is considered within heterogeneous radio environment, where multiple RATs are deployed by a single operator on one or different frequency bands assigned to it, for example an operator deploys two different radio interface technologies within a single radio acess network (RAN) of a cellular system. In order to implement such intra-system handover functionality, the capabilities of a CRS and its enabling technologies described in a later section could be exploited by the system.

When a terminal in connected mode moves close to the cell edge of a RAT, it needs to handover to another cell. The candidate cell to handover may be the same type of RAT, or may also be different types of RATs. Therefore, the intra-system handover functionality may consist of RAT discovery, RAT selection, and terminal reconfiguration. For example, a terminal discovers available RATs and selects an optimal RAT among them by obtaining knowledge of its operational and geographical environment, its internal state and the established policies provided by the network operator. After an optimal RAT is selected, the terminal adjusts its parameters and protocols dynamically and autonomously according to its obtained knowledge and the network policies by reconfiguration procedure and executes the handover to the selected RAT. There may be cooperation between terminals and wireless networks for the universal access functionality to find an optimal wireless access.

A possible functional architecture for the intra-system handover based on IEEE P1900.4 (Akyildiz et al., 2008) and IEEE802.21 (Yang et al., 2008) is illustrted in Figure 4.Entities described IEEE P1900.4, for example network resource manager (NRM), terminal resource manager (TRM) and cognitive base station (CBS), are applied for the optimization of radio resource management and an entity from IEEE802.21, i.e. entity which has media independent handover function (MIHF), is used as a toolbox for handover between heterogeneous radio access networks. A terminal may have various kinds of RATs through software-defined radio (SDR) technology and it reconfigures its parameters in order to access an optimal RAT determined by the universal access functionality. Context information of the core network is transferred to terminals through cognitive pilot channels (CPC), which are used for RAT discovery and selection procedures whenever terminals require context information of access networks.

Another example of intra-system handover application is shown in Figure 5, where one operator deploys multiple radios systems on different frequency bands. These systems have different coverage areas from small to large cell. The resource manager collects the radio operational environment information from the base stations and user terminals on the geo-location basis, which is one of CRS capabilities (i.e. obtaining knowledge). The radio environment information may include the information of signal strength, throughput, and transmission delay. The resource manager provides the information to the control equipment. Based on this information, the control equipment selects the appropriate connectivityfor the user terminal, which is another CRS capability (decision and adjustment).

Figure 4. Functional architecture for Inter-RAT handover

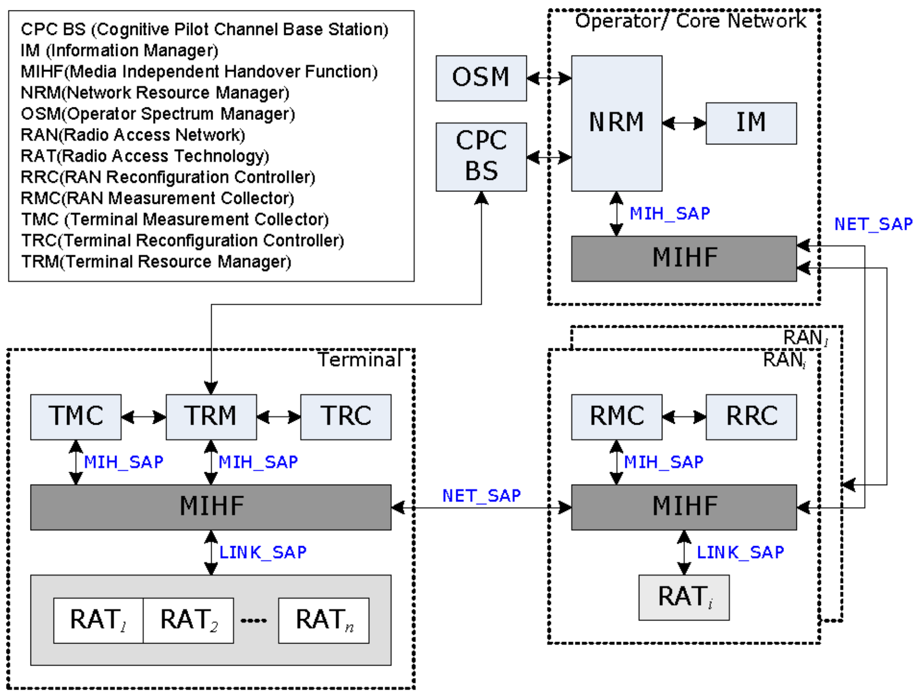
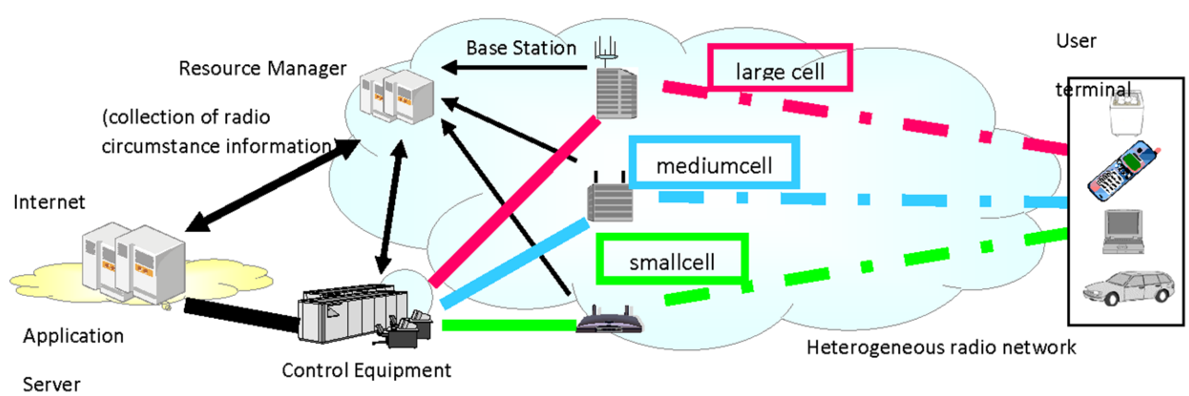


Figure 5. Network configuration consisting of multiple RATs



Inter-System Handover

Inter-system handover is considered within heterogeneous radio environment, where multiple operators operate multiple RATs on different frequency bands assigned to them, for example one operator operates a radio interface technology in a single RAN, i.e. a cellular system while another operator operates an RLAN technology as a public RLAN system. There are many ways to utilize CRS capabilities for inter-system handover, e.g. implementing the capabilities to terminals, base stations, and core networks.

Inter-System Handover Using Cognitive Radio Terminals

An example of inter-system handover using cognitive radio terminals is shown in Figure 6 (Nguyen et al., 2010).Some terminals may also have reconfiguration capability. The terminals in this application have capability to support several simultaneous connections with different radio access networks. The solid lines show the data paths and the dotted lines show the signalling. In this example reconfigurable terminal performs an inter-system handover.

The terminal utilizes multiple wireless networks concurrently so that communication bandwidth for applications becomes large. Following terminal movement and/or change of radio environment, suitable wireless link(s) are adaptively and actively utilized in order to keep stability.

Another example is shown in Figure 7 (Acharya et al., 2006).In this example reconfigurable terminal performs inter-system handover.Decision making is being supported by selecting the appropriate parameters. A common signalling channel between ubiquitous networking server and the terminal, drawn in orange solid line in the figure, is used in order to obtain knowledge in addition to the sensing performed by the terminal. On the other hand, Figure 8 (Xiao et al., 2009) shows the same potential application with different implementation of CRS features. The example implements a dedicated radio system as the common signalling channel shown in an arrow, named basic access network (BAN) in (Wang et al., 2010), between BAN-BS and BAN-component. Terminals exchange information with management entity on network, named signaling home agent (SHA), for adjusting its parameter and selection of RANs.

Figure 6. Inter-system handover using cognitive radio terminals

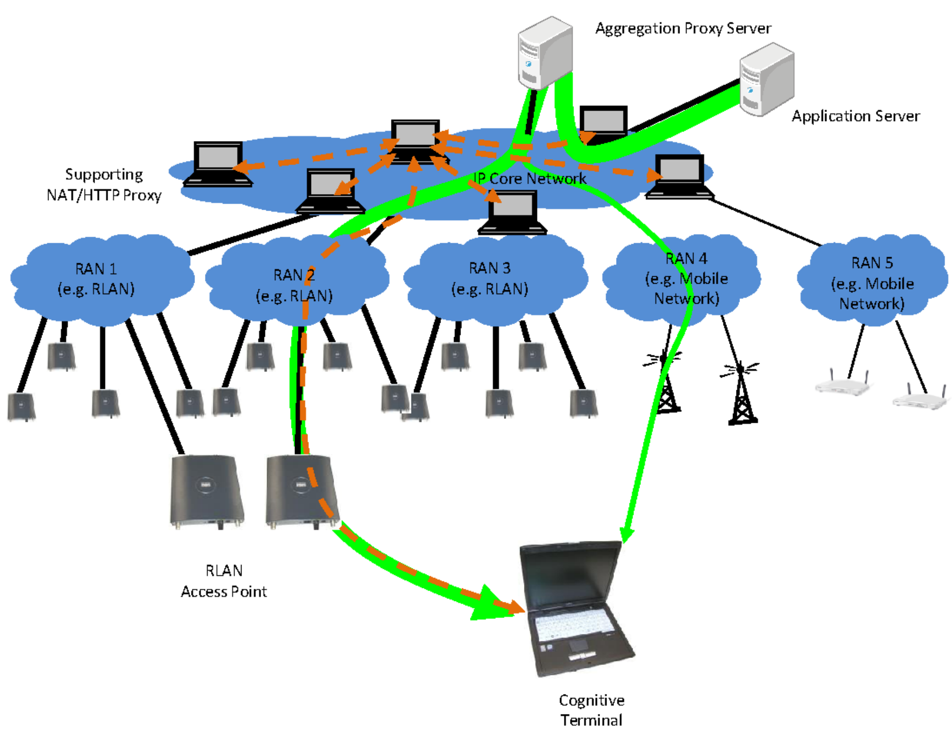


Figure 7. Inter-system handover using in-band signaling

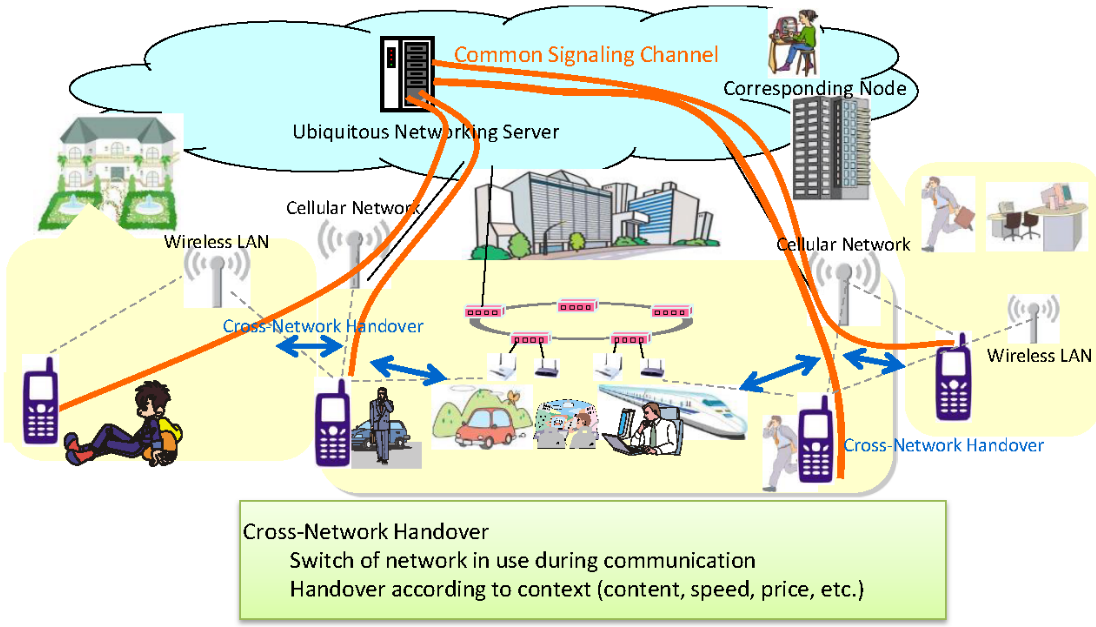


Figure 8. Dedicated radio system for signalling

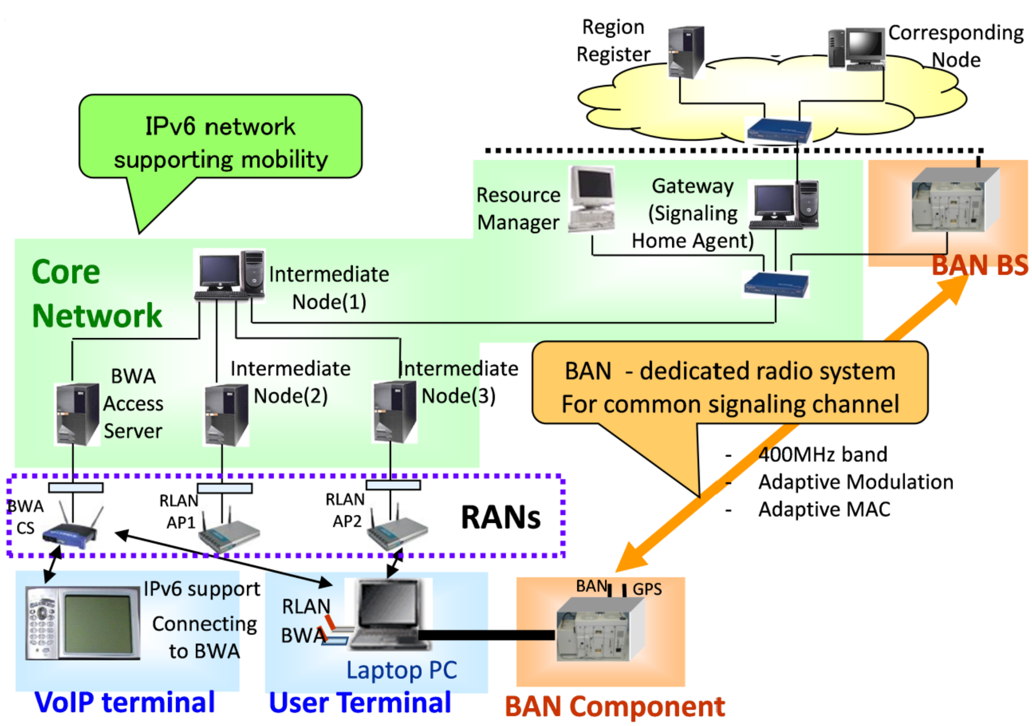
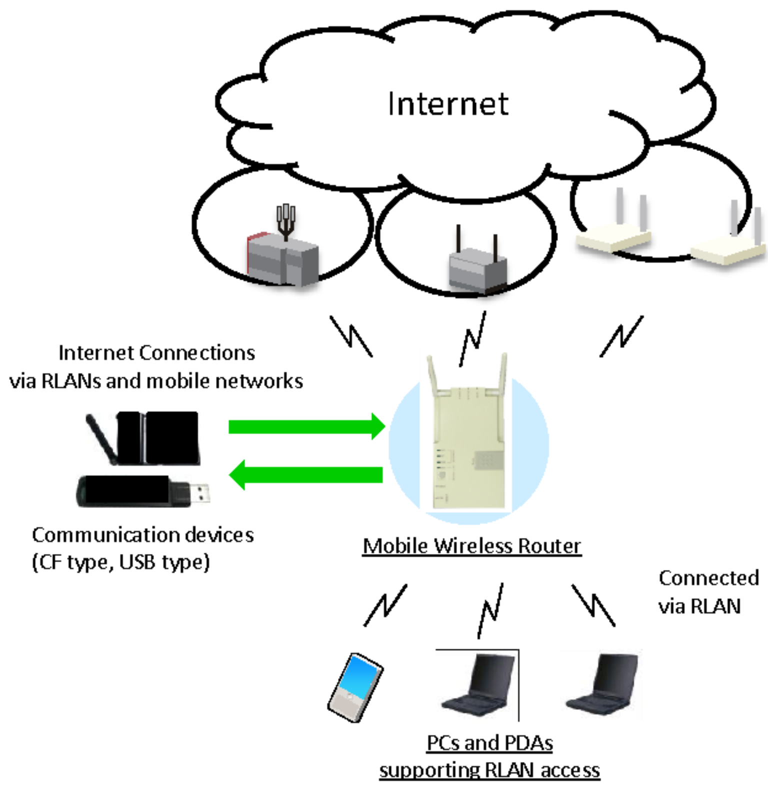


Figure 9. Mobile wireless router



Inter-System Handover Using CRS Supporting Network Entities

Compared to potential applications in the previous subsection, the applicationsin this subsection can address terminals without cognitive capabilities. Instead of using CRS supporting terminals, the CRS capabilities are provided by CRS supporting network entities, e.g. mobile wireless router (MWR) which has CRS capability itself and resource manager which realizes CRS capabilities with existing base stations.

An example of MWR application is shown in Figure 9 (Wang et al., 2011). In this example MWR reconfigures itself to provide the best suitable service application for its terminals. A mobile wireless router serves as a bridge between multiple radio systems and terminals. Such MWRis required to have a CRS capability to obtain knowledge which RANs (and mobile networks) are available at its location, and also to adjust its operational parameters and/or switch the attaching radio access systems. The thresholds are configured by the obtained users' preferences and they are used for RAN's selection.

The MWR conducts network address Translation (NAT) routing between the Internet and local wireless network to which terminals are connected. When the MWR is turned on, the best frequency channel is selected, e.g. based on the lowest interference level. Then the MWR selects and conducts the various RAN authentication procedures according to the selected RAN.

Coordinated Spectrum Access in Heterogeneous Radio Environment

In this section, coordinated spectrum access is considered within a heterogeneous radioenvironment, where particular frequency band(s) can be shared by several radio systems in order to optimize spectrum usage. Improvement in spectrum usage is based on the fact that different radio systems in the same geographic area at some time intervals may have different levels of spectrum usage.

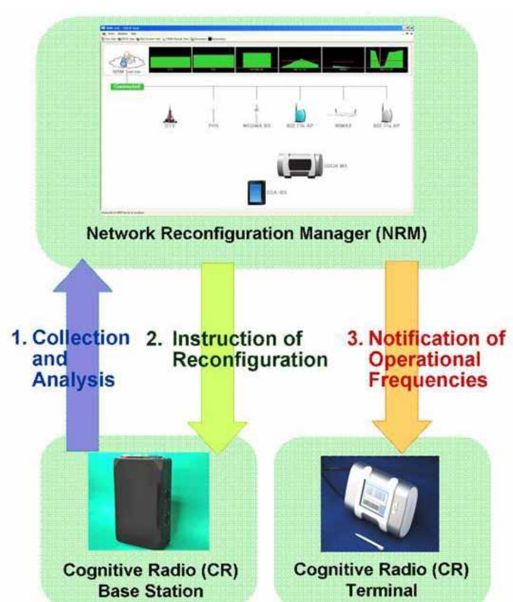
One possibility in this scenario is that one radio system is not a CRS while another radio system is a CRS. Another possibility is that both radio systems are CRSs.

One example of coordinated spectrum access is shown in Figure 10 (Feng et al., 2009). In this example base station and terminals with CRS capabilitiesof obtaining knowledge can sense the spectrum usage at their location.The sensing information of base station and terminals are gathered to network reconfiguration manager (NRM) (Hsu et al., 2007), which has a CRS capability of decision making. The NRM analyzes the measurements and detects temporary vacant frequency bands. Then, the NRM instructs the base station to reconfigure correspondingly. After the base station reconfiguresitself to use these vacant frequency bands and starts its operation, NRM notifies the terminals of the operation frequencies of the base stations.

Vertical and Horizontal Spectrum Sharing Enabled by CRS technologies

Potential applications of the vertical and horizontal spectrum sharing are currently under study by several administrations. Such access to shared spectrum is foreseen to be facilitated by CRS technologies and their capabilities. In general, vertical and horizontal sharing application would then allow additional users to access spectrum with existing incumbent usage.

Figure 10. Coordinated spectrum access in heterogeneous radio environment



One administration is currently studying the application of vertical and horizontal sharing (Ma et al., 2009). Specifically, one application in the 3.5GHz band is intended to make spectrum, when not used by incumbent systems, available for the operations of other radio systems while ensuring the protection of incumbent radio systems from interference using vertical sharing. In this application radio systems with QoS needs (e.g. mobile broadband systems) could be granted exclusive access with respect to other non-incumbent radio systems. Furthermore, the application under study would allow the use of selected portion(s) of the 3.5GHz band by radio systems employing CRSs technology on an opportunistic and non-protected basis, where and when this spectrum is otherwise not in use. In this case, spectrum sharing would be accomplished using horizontal and vertical sharing methods.

In Europe, there is currently an on-going standardization activity to define a solution for vertical sharing in the 2.3-2.4 GHz band [x] between mobile broadband systems and one or more incumbent systems already existing in that spectrum band. The mobile broadband systems are allowed to use the band on a time period or geographical area that it is not being used by the incumbent. This band offers a first possibility to implement a solution that provides both the incumbent and mobile broadband systems a certain QoS by guaranteeing them an exclusive access for a spectrum resource at a given place and at a given time (Yoon et al., 2010). However, the incumbent maintains higher level of spectrum usage rights and the mobile broadband system needs to evacuate spectrum band if so requested by the incumbent. Thus, unlike the sharing proposal described in the previous paragraph, only two levels of spectrum usage rights are considered and both incumbent and mobile broadband systems are protected from harmful interference.

More specifically, the potential applications depicted above are foreseen to be based on solutions that would include appropriate geo-location and controller functions to enable spectrum sharing between the various radio systems. For example, such solutions would take dynamic inputs from incumbent systems regarding their spectrum usage and protection criteria requirements. Based on such inputs and other factors, the spectrum availability (e.g. described in terms of band, geographical and time constraints) and operational parameters are communicated to the radio systems accessing the shared spectrum.

The applications described above have the potential to maximize the efficiency of the overall use of the band, while providing appropriate protection for incumbent systems and other radio systems that could have exclusive access.

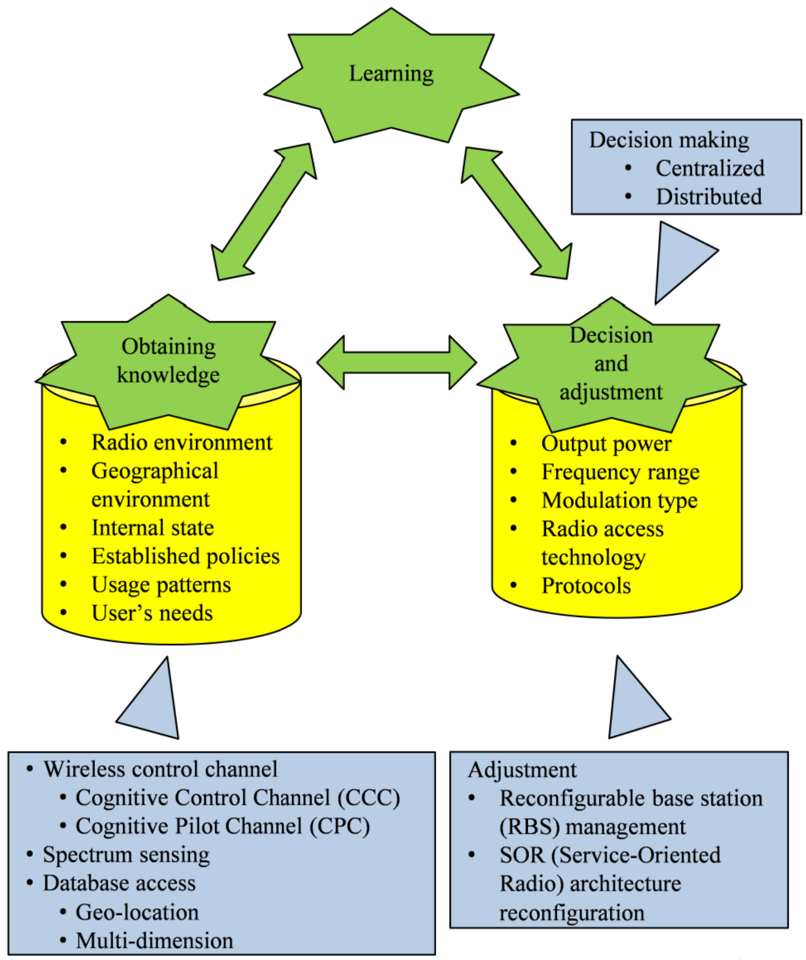
CRS CAPABILITIES AND ENABLING TECHNOLOGIES

This section describes examples of enabling technologies, which are part of the CRS capabilities of obtaining knowledge, decision and adjustment, and learning. The relationship between these technologies and the CRS capabilities are illustrated in Figure 11. The section further identifies and describes technical features related to these technologies.

Obtaining knowledge

The first key capability of a CRS node is to obtain knowledge of its operational and geographical environment, established policies and its internal state.

Figure 11. Example of enabling technologies for CRS capabilities



Three most commonly suggested methods for obtaining knowledge in a CRS are listening to wireless control channels, spectrum sensing and access to databases. They are covered in detail in the following sections. Also combinations of the methods can be considered.

Listening to a Wireless Control Channel

Control channels could be used for transmitting control information between two or more entities belonging to the systems which use the same spectrum resources. They facilitate more efficient CRS operation, spectrum use and coexistence of different radio systems. One of the key challenges with control channels is to decide how much and what control information should be exchanged to find the balance between the increased overhead and the gain achieved from exchanging that information. There also needs to be a way to ensure the reliability and accuracy of the control information sent on the channel. Following we have two examples of such control channels including cognitive control channels (CCC), and cognitive pilot channels (CPC).

CCCs may enable different CRSs to exchange information related to the local spectrum between each other. The CRS can use the CPC to obtain knowledge of radio operational environment and by doing this the CPC facilitates the efficient operation and spectrum use. It may be possible to use or extend control channels already defined for the existing radio systems operation for cognitive control information exchange.

The purpose of CCC is to enable distributed information exchange directly between the CRS entities which have operation in the same area, whereas CPC conveys elements of the necessary information to let the mobile terminal know e.g. operators, policies, and access technologies and their associated assigned frequencies in a given region to enable efficient RAT discovery and selection. CPC covers the geographical areas using a cellular approach. The focus of CCC is on enhancing coexistence between secondary systems which are using the same available spectrum resources, i.e. the networks operating in the same area and frequency band.

Cognitive Control Channel (CCC)

The CCC is a suggested approach for a real time communication channel between different distributed CRS nodes in a specific geographical area. The CCC has been introduced and studied in EU FP7 Project E3 as the Cognitive Control Radio (CCR). In deliverables (Song et al., 2010) and (Zhu et al., 2007) the CCR concept and its functions as an awareness signalling mechanism are described, while analysis and comparison to other awareness signalling mechanisms are reported in (Hou et al., 2010), (Khalifa et al., 2008), and (Shiang et al., 2008). The CCC is based on the CCR definitions and it is further considered as a coexistence solution in IEEE P802.19.1 (Luo et al., 2007) and ETSI RRS (Zhao et al., 2007).

The CCC is primarily targeted for enhancing the coordination of the CRS devices. The CCC enables different CRS entities to exchange information related to the sharing and coexistence, spectrum usage rules or policies and/or specific capabilities and needs of different entities. The CCC may be used for:

- **Sharing and Coexistence:**Exchanging the information on the network capabilities and characteristics, network's spectrum need and use, and agreeing spectrum use with other networks in the geographic area;
- **Cooperative Sensing:** Agreeing on the common quiet periods for sensing the signal from other radio nodes which are not connected to the CCC, and exchanging spectrum sensing outcomes between the other networks in the area;
- **Network Access:** Discovering the networks or devices to connect to, their capabilities and provided services;
- Access local policy and etiquette information, e.g. sharing rules for accessing specific bands and local availability of the bands.

The CCC may be implemented with a physical or a logical channel approach (Ye et al., 2011):

- In the physical channel implementation approach a specific physical radio channel targeted for CCC operation is included in the entities exchanging cognitive control information. This enables direct communication between any entities within range on the used physical radio channel;
- In the logical channel implementation approach the CCC operates over any physical radio channel using a transport networking protocol such as Internet Protocol. If the entities, which need to ex-

change cognitive control information, do not support the same physical radio channel, direct communication between the entities is not possible. Thus, the communication is routed through the other entities, e.g. through internet servers or wireless router nodes. As an example IEEE 802.19.1 assumes logical channel implementation approach for coexistence communication (Mishra et al., 2012).

The CCC can be applied e.g. in a context of heterogeneous networks, consisting of centralized and decentralized CRS concepts, operating in the same area (Aslan et al., 2012). The CCC enables the networks to share and exchange various information directly with each other to enhance simultaneous operation.

The information which a network may exchange on the CCC can be collected by a combination of means, e.g.:

- Querying a local database for spectrum availability;
- Spectrum sensing, e.g. estimating spectrum availability or recognizing other spectrum users by evaluating the detected radio waves;
- Informationreceived from other CRS entities e.g. over CCC or CPC.

Cognitive Pilot Channel (CPC)

The CPC is a pilot channel (physical or logical) that broadcasts radio environment information intended to aid the decision processes of a cognitive terminal in a dynamic and flexible heterogeneous environmentincludingbroadcast platforms, asalsodescribedin (Song et al., 2007)- (Hoyhtya et al., 2010). Theradio environment information includes information with regard to operators, frequency bands, available RATs, services, and load situation etc.

This information can be used to aid a variety of different usage including:

- Initial camping;
- Network association;
- Policy distribution;
- Simplify inter-system handovers;
- Spectrum brokering;
- Pre-emptive access;
- Real-time adaptations;
- migration to new standards.

In some proposed radio environment, the CRS capability of the terminal (or possibly, base station) appears to be a crucial point to enable optimisation of radio resource usage.

Indeed, in order to obtain knowledge of its radio environment, a CRS may need to obtain information of the parts of the spectrum within the considered operable frequency range of its radio hardware: it is important that this action is reliable and would be carried out within an acceptable time and with acceptable power-consuming performance. On this basis, the CPC concept consists of conveying the necessary information to let the terminal or base station know the status of radio channel occupancy through a kind of common pilot channel.

In addition, the CPC is anticipated to be conveyed by two approaches: the "out-band" CPC and the "in-band" CPC. The first one, out-band CPC, considers that a channel outside the bands assigned to component RATs provides CPC service. The second one, in-band CPC, uses a transmission mechanism (e.g. a logical channel) within the technologies of the heterogeneous radio environment to provide CPC services. Figure 12 depicts the out-band and in-band CPC deployments.

Out-band and in-band CPC approaches are considered to be used jointly by broadcasting the general information over out-band CPC and detailed information over in-band CPC. In principle, the CPC covers the geographical areas using a cellular approachfor out-band deployment. While for in-band deployment case, CPC is carried in system resource, e.g. as an extended system information message on broadcast channel of RATs or other resource partition part. With CPC, information related to the spectrum status in the cell's area is broadcast, such as:

- Indication on bands currently assigned to cellular-like and wireless systems; additionally, pilot/ broadcast channel details for different cellular-like and wireless systems could be provided;
- Indication on current status of specific bands of spectrum (e.g. used or unused).

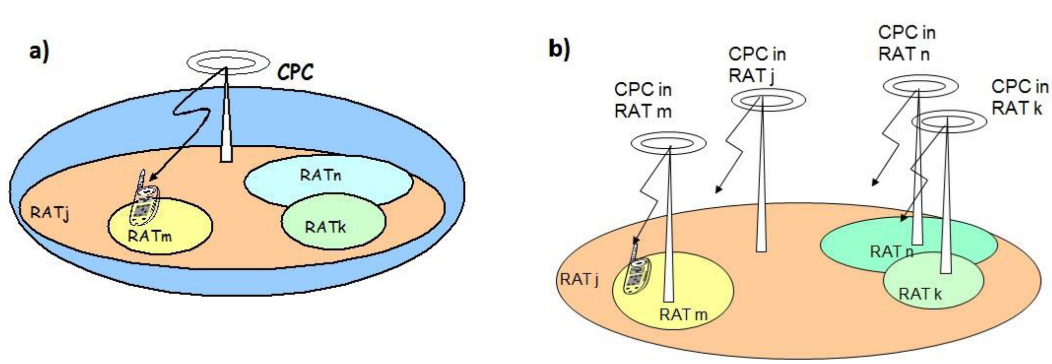
By considering such a CPC, the following advantages are pointed out:

- Simplifying the RAT selection procedure;
- Avoiding a large band scanning, therefore simplifying the terminal implementation (physical layer) for manufacturers;
- The CPC concept seems particularly relevant for the implementation of DSA/FSM;
- The CPC concept as a download channel could be useful to the operator and user where it is necessary to download a new protocol stack to connect to the network.

Challenges of CCC and CPC

Some challenges arise when considering listening to a wireless control channel for obtaining knowledge of the operational environment.

Figure 12. Out-band and in-band CPC deployments



Various sources in literature have proposed the use of a predetermined common coordination channel for spectrum etiquette, network establishment and adaptation to changing interference environments, see (Vartiainen et al., 2010). Local coordination and exchange of information provides low delay and accurate sharing limited to the involved networks.

The CCC usage may increase the power consumption of the devices. The power consumption should be considered carefully and particularly if the nodes are mobile. In such case the challenges related to the power consumption are to limit the signalling overhead and to enable efficient power save mode which still enables low latency information exchange. Thus, it is important to find the optimal amount of exchanged information and the latency for the information exchange. In addition, in the case the nodes have to connect over the internet, the appropriate network access to be used should be selected.

Further challenges of CCC such as the synchronization between the involved nodes, the contention resolution mechanisms when accessing the spectrum band, and the reliability of the exchanged information should be investigated.

According to [x], the CPC concept could provide the necessary supportfor obtaining knowledge of the spectrum occupancy. However, also the use of CPC would require further investigations on some technical challenges before being considered as a mature approach, such as: the CPC delivery should strictly satisfy the timing requirements coming from the opportunistic spectrum use; the CPC content should be updated in a proper timeframe, according to the one related to opportunistic spectrum use.

Arising from the above consideration, it can be concluded that further research and development in order to improve the maturity of both CCC and CPC are needed e.g. in ETSI RRS and IEEE 802.19.1. For this purpose a feasibility study on different approaches and implementation options of control channels for CRSs has been carried out in the scope of (Hoyhtya et al., 2008).

Spectrum Sensing

Spectrum sensing is a capability to detect other signals around the CRS node and is one method to determine unused spectrum bands. Spectrum sensing is usable in particular in cases where the level of the detected signal is sufficiently strong, and/or the signal type/form is known beforehand.

Considerable research is focused on sensing techniques, which has resulted in a number of sensing methods, which are described in the following sections.

Sensing Methods

Currently different spectrum sensing methods are considered for CRSs. These methods include energy detection, matched filtering, cyclostationary feature detection and waveform based detection etc. These existing sensing methods differ in their sensing capabilities, requirements for a priori information, and also their computational complexities. The choice of a particular sensing method can be made depending on sensing requirements, available resource such as power, computational resource and application/ signal to be sensed. These sensing methods can also be used in a cooperative way where several CRS nodes do sensing and reporting.

Performance indicators which are related to the impact of different spectrum sensing techniques to other users of the spectrum include e.g. the following:

- Detection thresholdfor the signals of the existing system
  - The minimum signal-to-noise ratio (SNR) which is needed by a spectrum sensing method to achieve a certain probability of detection.
- Pre-determined detected signal intensity
  - The minimum detected signal intensity which is needed by a spectrum sensing method to achieve a certain probability of detection.
- Detection time for the signals of the existing system
  - The duration which is used by each spectrum sensing method to detect the signals of existing system.
- Detection probability
  - Probability that the signal is correctly detected when it is present.
- False alarm probability
  - Probability that the signal is detected when it is not present.
- Time between failures in detection
  - Average time period between failures in signal detection (i.e. signal is not detected when it is present).
- The lost spectrum opportunity ratio
  - The expected fraction of the OFF state (i.e., idle time) undetected by CRS nodes.
- The interference ratio
- The expected fraction of the ON state (i.e., the transmission time of the networks of the existing systems) interrupted by the transmission of CRS nodes.

Implementation of Sensing Methods

Currently several implementations of sensing methods are studied. Besides incorporating the sensor directly into the user device, the following implementations are under consideration:

- **Dedicated Listening Devices:** A dedicated listening device could be used to detect incumbent systems at a distance if mounted outside such as on a tower or rooftop. CRSs communicate with the dedicated listening device to follow its instructions when the listening device detects the channels that incumbent systems are using. A dedicated listening device could also be used in conjunction with a database as well.
- **Community Sensor Networks:** A network of sensors may be used either alone or in conjunction with a database to identify and communicate the presence of incumbent transmissions and the availability of particular frequencies to end-user devices.

Challenges of Spectrum Sensing

Some challenges arise when considering spectrum sensing for obtaining knowledge of the operational environment.One of themis the hidden node problem. The hidden node problem occurs when a CRS node cannot sense another node transmitting (for example, due to radio propagation conditions) or not sense the presence of a receive only node and therefore incorrectly assumesthat the frequency channel is not in use (Report ITU-R M.2225).

Furthermore, spectrum sensing requires high sensitivity, sampling rate, resolution, analogue to digital (A/D) converters with large dynamic range, and high speed signal processors. When wideband sensing is considered terminals are required to capture and analyse a wide band, which imposes additional requirements on the radio frequency (RF) components. Wideband sensing also means that a wide range of signals with different characteristics needs to be detected which adds to the complexity of sensing since it needs to adapt to e.g. different energy levels or cyclostationary features of the primary signal (Clancy et al., 2006).

Therefore it might be useful to utilize sensing technologies in a limited frequency range in which the range of technologies used by the other existing systems in the band is limited (Liu et al., 2006). Moreover, considering the constrained energy and limited processing capacity of some CRS nodes, the power consumption and complexity of spectrum sensing algorithms should also be considered. For example, the order of channels to be sensed, sensing interval, and complexity should be optimized while maintaining sensing accuracy.

An important issue that has to be considered is the reliability of sensing, that is how reliable is the information obtained through sensing the spectrum band. Indeed, in the case of unreliable information, there could be consequences for the primary system (and even for the secondary system). Several recent studies and statements as the ones reported in (Fourati et al., 2011)- (Wang et al., 2008), show that the reliability of the information obtained through sensing is one of the most critical challenge to spectrum sensing.

In addition to the challenges reported above, in general, also the following ones should be addressed while investigating the sensing approach:

- algorithm complexity may be related with power and processing consumptions;
- the complexity of each spectrum sensing method (in terms of power and processing consumptions) related to the observed bandwidth;
- sensing signalling cost (e.g. including cost in sensing measurement and sensing reporting);
- for cooperative sensing, the cost of aggregating and processing the sensing reports as well as synchronization issues.

Based on the current studies that have been referred, the sensing techniques are not mature enough and further research effort is needed on spectrum sensingin order to understand how such a technique can be implemented and what would be the sensing requirements in each band and with relevant primary services.

DECISION MAKING AND ADJUSTMENT OF OPERATIONAL PARAMETERS AND PROTOCOLS

The design of future CRSs will face new challenges as compared to traditional wireless systems. Future CRSs need take into account the underlying policies in the different spectrum bands that determine the rules for using the bands and transform the policies into adjustment actions. The operational environment will be heterogeneous consisting of several RATs with diverse sets of terminals to support a wide range of services.

In addition, the operational environment will be more dynamic as the number of users and the applications they are requesting vary in time leading to changing requirements for resource management. As a result the resource management in a dynamic and complex environment becomes a multivariable optimisation problem with conflicting requirements where optimal solutions are difficult to find.

The decision making in CRSs including e.g. the resource allocations among the CRS nodes such as frequency channels, output power levels, RAT, transmission timing and modulation types, can be done with mathematical or heuristic methods. Mathematical algorithms have good performance and reliability, but they can be complex and their applicability depends on the characteristics of the target system. In dynamic environment mathematical models may not be suitable for the target problem leading to performance degradations. Heuristic methods could be based on mathematical understanding and statistical knowledge, human-kind thinking or artificial intelligence (AI) applied to problem to solve. Techniques like rule-based expert systems, fuzzy logic, neural networks, genetic algorithms, or combinations of them may be attractive to tackle problems that hinder using mathematical algorithms. With heuristic methods the decision making system can be designed to handle such unusual, or even unpredictable, cases that are difficult to implement using mathematical methods.

For decision making in CRSs, the nodes may use various parameters, which can be categorized into radio link quality and network quality parameters. Radio link quality parameters include metrics such as received signal strength and signal to interference-plus-noise ratio (SINR). Network quality parameters include traffic load, delay, jitter, packet loss, and connection drop/block statistics. This two-level information covering both physical level and network level can be used for the decision making. For instance, network congestion cannot be observed at the physical layer, while its effects will be shown on network level monitoring as decreased throughput and/or increased delays and packet losses. Another example is that if packet losses start to increase, they might be caused by low or alternating signal strength, which will be shown immediately at the physical layer. Then again, high overall SINR combined with packet losses is an indication that there could be sporadic shot noise interference, problems with link layer delivery, or problems somewhere behind the radio link. All this information, taken together, can contribute to the decision making process of the CRS.

Decision Making Methods

Centralized and distributed decision making methods are hereafter described. In general, their specific application depends on the considered scenario and the trade-off between the two methods should be studied case by case. Sometimes hybrid solution may bridge the gap between the two extremes (Wang et al., 2008).

Centralized Decision Making

A simple architecture to support the dynamic adaptation of the operational parameters in a CRS is to have a centralized entity for decision making, which could coordinate the operational parameters and resources and consequently realize and issue decisions for utilizing the spectrum resources or channels.

The central entity obtains the knowledge of its radio operational and geographical environment, its internal state and the established policies, and monitors spectrum usage patterns and users' needs, for instance, by sensing the spectrum use, using a database and/ or receiving control and management information through listening to a wireless control channel. Based on all obtained information, the central entity makes a decision on the adaptations of its operational parameters including e.g. spectrum resources to CRS nodes in the area it manages.

The centralized architecture is simple and easy to control from the operator's view.However, when the amount of components increases greatly, a single centralized entity would not be able to cope with the coordination, decisions making and management for a large number of CRS nodes' resources. This will not only lead to scalability issues, but will also introduce significant delays in the resource management decisions being conveyed. Besides, the centralized entity may not be easy to collect dynamic information from all involved network entities and make fast decision.

Distributed Decision Making

A distributed approach is based on localized decisions of distributed CRS nodes. Distributed decision making approach could be used when a set of ad hoc CRS nodes operates in the same area, and in the same frequency band using dynamic access. In this case, each CRS node would have to gather, exchange, and process the information about the wireless environment independently. The decisions on the actions would be carried autonomously based on the available information.

The delay is substantially shorter to facilitate dynamic change of situations when compared with centralized approach. However, there may be an issue with stability (especially when entities act independently without coordination) as it is difficult to prove that the proposed solution will always behave in a predictable manner. Distributed decision making can be useful in networks employing relay transmission schemes which help to avoid interference by selecting appropriate transmission power levels and paths.

There is a wide range of techniques for distributed decision making including e.g. game theory, metaheuristics (e.g. genetic and search algorithms), Bayesian networks and neural networks. Different decision making techniques are more suitable depending on the operational environment, network conditions and the use of coordinated or non-coordinated mechanisms. The main aspects of the coordinated and non-coordinated mechanisms are reported in the following.

In general, in the coordinated mechanisms a CRS nodes will make a decision on e.g. spectrum access to achieve the best overall performance of the network whereas in the non-coordinated mechanisms CRS nodes will make a decision only to maximize its own benefits. In both mechanisms CRS nodes have to collect information such as information on RATs, operating parameters, capabilities and measurement results to make the decision.

In the non-coordinated mechanisms such information are gathered and processed locally by each of the CRS nodes that can make the decision independently by choosing the actions that optimize their own performance while fulfilling the given constraints arising e.g. from policies. If the nodes decide independently e.g. their channel and power allocations, the overall performance of the network in terms of e.g. throughput may not be good. Examples of non-coordinated mechanisms are, CSMA, frequency hopping, and adapting transmission power based on interference level.

In the coordinated mechanisms, the actions can be optimized to obtain better overall network performance. The CRS nodes can collaborate using e.g. control channels or databases to optimize the operation of the network based on policies to ensure fairness and effectiveness taking into account the different CRS nodes characteristics and other aspects e.g. load balance between CRSs.

EXAMPLES OF POSSIBLE CRITERIA TO BE USED FOR DECISION MAKING

Frequency Channel Selection Based on Channel Usage

The CRS may be able to recognize the utilization probability of different frequency channels, the state transition probability from idle to busy of different channels, the usage model of different channels from periodically-collected statistical information though out-of-band and in-band spectrum sensing.

In order to select most suitable channel that improves the utilization of available spectrum,the CRS needs to identify the opportunity utilization quality of the different channels by integrally considering the information obtained by the CRSs. The considered information could include e.g. the following aspects:

1. Utilization of channel probability;
2. State transition probabilityfrom idle to busy of channels;
3. The usage model of different channels;
4. Traffic pattern in different channels;
5. Bandwidth as well as traffic requirements of the cognitive radio users;
6. Channel collision problem for the scenario of multi-cognitive radio users.

Frequency Channel Handover

Frequency channel handover occurs when a CRS user changes frequency e.g. in case the frequency is reclaimed or,due to the channel conditions, the communication cannot be maintained. Frequency channel handover may cause delay and packet loss to the CRS user. Frequency channel handover strategy is trying i) to maintain the seamless connectivity of CRS users and ii) to guarantee the QoSrequirements of the CRS user.

The considered information may include e.g. the following aspects:

1. Usage model of different channels;
2. Predicted vacant time of channels;
3. Quality of channels, such as SNR and path loss;
4. Bandwidth as well as traffic requirements of the cognitive radio users;
5. Handover delay.

Adjustment Methods

A CRS node could dynamically and autonomously adjust its operational parameters, protocols, and configurations according tothe obtained knowledge and past experience based on appropriate decision methods. This section reports an example of cognitive network management.

Cognitive Network Management

Based on the knowledge of its environment, a cognitive network (as described in section 5.2.1) candynamically adjust its parameters, functions and resources by means of appropriate methods. To accomplish such tasks, appropriate management functions need to be identified.

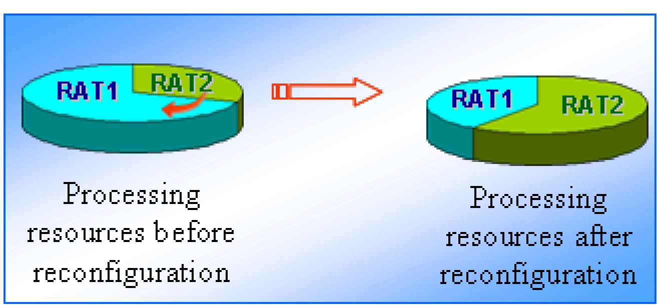
The availability of reconfigurable nodes in the networks (i.e. nodes whose hardware and processing resources can be reconfigured in order to be used with different RATs, frequencies, channels, etc.), coupled with appropriate cognitive network management functions, will give the network operators the means for managing in a globally efficient way the radio and processing resource pool, with the aim to adapt the network itself to the dynamic variations of the traffic offered to the deployed RATs and to the different portions of the area. In some cases cognitive network management could be used for energy saving purposes.

As an example of self-adaptation on the basis of traffic load, it could be considered to deploy RAT1 and RAT2 systems in a geographical area with a network built with reconfigurable base stations, thus having reconfigurable hardware shared between RAT1 and RAT2 functionalities. During the daily life of the network, it could be needed, for instance due to different traffic loads on the two RATs, to increase the percentage of processing resources devoted to the over-loaded system while decreasing the resources given to the other (supposed under-loaded). In Figure 13, a reconfiguration example increasing RAT2 resources is depicted.

As another example, sometimes the traffic loads of a RAT could be low so that such RAT could be switched into dormant mode for energy saving. The dormant mode operation saves power by allowing the CRS to power down part of the reconfigurable hardware shared between the two RATs, while all residual resources are allocated to the active system.

As anticipated before, in order to perform such network reconfigurations, an appropriate cognitive network management function need to be introduced. Such function is devoted to:

Figure 13. Reconfiguration example



- Monitor periodically the current activity status of the cells (for each supported RAT) in terms of measurement of the number of the requests and rejects (if any) from the different systems;
- Execute a reconfiguration algorithm that decides which base station(s) are to be reconfigured, e.g. with the aim to adapt the percentages of processing resources devoted to each supported RAT and to dynamically shape the active radio resources to the behaviour of the traffic;
- Control the network reconfiguration by sending appropriate reconfiguration commands to the reconfigurable base stations in order to perform the appropriate actions (e.g. to activate/deactivate processing resources and/or radio resources – such as frequency carriers – for each supported RAT).

It is worth noting that the cognitive network management function can reside in any radio network control node, a core network or O&M node as well as inside each reconfigurable node (e.g. in case of flat-architecture) supposing that it can opportunely interact with the other network management functions e.g. radio resource management (RRM) and the reconfigurable node entities. Distributed solutions of the cognitive network management function are also possible.

Learning

Learning can enable performance improvement for the CRS by using stored information both of its own actions and the results of these actions and the actions of other users to aid the decision making process. The learning process creates and maintains knowledge base where the data is stored.

Learning techniques can be classified into three major learning schemes such as supervised learning, unsupervised learning, and reinforcement learning. Supervised learning is a technique which uses pairs of input signals and known outputs as training data so that a function that maps inputs to desired outputs can be generated. Case-based reasoning is an example of supervised learning technique where the knowledge base contains cases that are representations of past experiences and their outcomes. Reinforcement learning uses observations from the environment in learning. Every action has an impact in the environment and this feedback is used in guiding the learning algorithm. Q-learning is an example of this class. Unsupervised learning techniques aim at determining how the data are organized. Clustering is an example of unsupervised learning technique[53]. Also aspects of "game theory" and "policy engines" are among the techniques under investigation for CRS management (Hu et al., 2007).

Major learning schemes can include several specific learning techniques such as genetic algorithms, neural networks, pattern recognition, and feature extraction. Neural networks provide a powerful tool for building classifiers. Pattern recognition and classification can be seen as crucial parts of an intelligent system that aims at observing its operating environment and acting based on observations. Feature extraction and classification are complementary functions. A very important task is to find good distinguishing features to make classifier perform efficiently.

Learning makes the operation of CRSs more efficient compared to the case where only information available at the design time is possible. For example, learning enables use of traffic pattern recognition. A CRS can learn the traffic patterns in different channels over time and use this information to predict idle times in the future. This helps to find channels offering long idle times for secondary use, increasing throughput for secondary users and simultaneously decreasing collisions with primary users. Moreover, a CRS could also be able to recognize the type of the application generating the traffic by looking at the statistical features of the traffic. Thiswould help the management of the network since different applications have different QoS requirements, e.g., VoIP and media downloading.

Learning helps also in fault tolerance since patterns of faults can be identified as logical sets that can be interconnected as a constraint network or a reactive pattern matching algorithm. This approach can enable a more efficient fault isolation technique as it identifies multiple potential causes concurrently and then chooses the most likely based on precedence and weighting factors.

A major challenge in learning is the maintenance of knowledge base which is a key requirement for efficient learning and reasoning. The knowledge base should be able to adapt to the possible changes in the environment to offer relevant information to the decision making. The size of the knowledge base is not allowed to grow uncontrollably. Rather the size should remain at the reasonable level. Thus, a management element might be needed in the system to take care of these tasks. All the unnecessary information should be taken away from the database on a regular basis. Management element might be also needed to restrict the amount of changes in the knowledge base to avoid chaotic situations. Moreover, the knowledge base could be tailored to operate efficiently with the specific learning techniques used in the system (Salami et al., 2011)- (Buddhikot et al., 2005).

Implementation and use of CRS Technologies

The implementation and use of CRS technologies in the different applications in 5G network would depend on the particular application and the band where certain radiocommunication services are used and the particular CRS technologies for obtaining knowledge such as sensing and access to database that are required.

As described in section 4, applications that are employing CRS technologies would have an implication on sharing and coexistence issues.

In the following some examples are given of how the use of CRS technologies could enhance sharing and coexistence, specifically when the existing radio systems undergo technical upgrades and technology evolution. These and other technical solutions for sharing and coexistence are subject to study before they can be implemented. It should be noted that sensing and database are examples of CRS technologies with potential for technical suitability in the applications of a CRS as addressed in section 4. However, this does not preclude that other CRS technologies can also be applicable.

Use of sensing allows the CRS nodes to detect changes of the existing radio systems around them and to act accordingly, based on the appropriate policy. The changes can usually be related to change of frequencies used by the existing radio system around the CRS nodes. But also technical changes of the signals to be detected may be handled as the sensing method may be sufficiently flexible or broad to cover a range of signals or technical changes in the signals of the existing radio systems. More fundamental technical changes of the radio systems, due to technology evolution and technology upgrades, can be handled through reconfiguration of the CRS nodes. It should be noticed, that also policy updates can be delivered to the CRS nodes.

Use of access to database by CRS nodes can ensure no harmful interference to the existing radio system practically under any changes and evolution of the radio systems. CRS nodes are following the updated orders from the database, where the changed protection requirements have been taken into account. Thus dealing with evolution of the existing radio system is more straightforward when the database approach is in use. The valid policies are implemented in this case by the database and the CRS nodes just continue to follow the orders, even if they are changed.

Therefore, particular sets of CRS capabilities and related technical solutions may be needed to allow spectrum sharing and radio resource management on more dynamic basis, depending on particular bands and applications.

In addition, there is a need to utilize appropriate policies and condition under which CRSs could operate. For example, in the case where CRSs would share spectrum bands with other radio systems (in particular for the vertical sharing approach presented in section 5), such policies and conditions could be set under a framework defined by the rights of spectrum usage. The framework should describe the condition of use and provide possible mechanisms for sharing.

In the horizontal spectrum sharing arrangement where several CRSs share the same spectrum band, there is a need to define some rules of accessing the shared spectrum band such that all CRSs have an equal chance to access the spectrum band, i.e. the CRS capabilities are used to ensure fair access to the spectrum.

In order to exploit the opportunities of CRS technologies in the LMS to their fullest harmonized technical solutions could be beneficial. However, it should be noted that CRS technologies can be applied to the various systems for the various applications. Harmonised technical solutions would be useful to address possible CRS applications in various bands.

DIMENSIONS OF FLEXIBILITY

The CRS technology may offer flexibility in following dimensions: time, space, frequency and other operational parameters. Each of them is discussed in the following:

Time

A CRS can receive guidance about the time validity of the available frequencies from the database or from some other source. If sensing is used, it may also provide some information about the instantaneous changes in the environment around the CRS nodes.

Another approach may be that the CRS operates according to policies that define the timing of the transmit/receive signals.

The CRS itself can be able to make the timely changes rapidly.

Space

CRS operation may be location specific. For example if geo-location database is used, it can instruct the CRS in a manner that facilitates flexibility in the space domain. Thus the CRS may operate differently in different locations.

The spectrum occupancy and the resulting spectrum availability can vary significantly depending on the location indicating that different frequency channels can be available in different locations. A CRS can exploit the spatial variations in the spectrum availability by adapting its operations according to the local situation.

Frequency

A CRS can obtain knowledge of the available frequencies based on its own observations, through sensing, or by receiving the information from other sources, such as geo-location database. It can then change its operation to available frequencies.

Other Operational Parameters

The CRS nodes may need to adjust various other operational parameters, like the transmit power control (TPC), modulation, coding, used RAT, protocols, etc. Especially if the CRS is implemented using SDR, the CRS node characteristics can be changed flexibly.

Ability to change the operational parameters improves the ability of a CRS to ensure avoidance of harmful interference and can improve its operational capabilities.

CRS PERFORMANCES AND POTENTIAL BENEFITS

Aspects Related to the Performance of the CRS Radio Operations

In this section, general performance criteria and metrics are presented to help the performance evaluation of LMS radio systems employing CRS technology.

A metric is a quantitative value to be used to evaluate performance(s). In the case of a CRS, since some metrics may be interdependent, distinguishing their basic attribute may not be straightforward. Appropriate metrics should be selected for specific applications depicted in section 5.

CRS technology introduces additional dynamic radio operations and functionalities whose performances may require the introduction of new metrics. For example, metrics for the CRS to respond to dynamic availability of spectrum in time domain in addition to geographical domain. The impact of learning as one of the key characteristics of a CRS is not straight forward to quantifywith metrics used for conventional radio systems. In fact, LMS radio systems employing the CRS technology can function in a more dynamic radio operational environment and adjust their operations accordingly, which calls for new metrics to measure this dynamic behaviour.

Radio Performance Metrics for CRS Operations

For CRS radio operations, performance metrics can be categorized into two levels: radio link level and radio access network level. Radio link level quality would give an indication and measure of physical characteristics and performances of CRS transmissions, whereas radio access network level quality could be used to provide a quantified measure and indication of the overall CRSs system performance.

The following metrics could be used to evaluate radio link level quality:

- Received signal strength indicator (RSSI).
    - The received power, including thermal noise and noise generated in the receiver, within the bandwidth defined by the receiver pulse shaping filter[1].
- Signal-to-interference plus noise ratio (SINR).

 - ◦ The ratio of the power of the wanted signal to the total power of interfering signals and noise, evaluated in specified conditions at a specified point of a transmission channel[2].
- Error ratios (e.g. BER, frame error ratio (FER)).
  - ◦ The ratio of the number of errored bits/frames received to the total number of bits/frames received over a given time interval[3].

Additional radio link level metrics can be defined according to different CRS applications.

In the case of horizontal and/or vertical spectrum sharing, the LMS employing CRS capabilities might experience interference from other radio systems. The interference term in the SINR metric would consist of both LMS internal and external system interferences. It may be useful to differentiate these interferences as the LMS system has different level of control over them to take actions accordingly using the CRS capabilities.

In addition to the SINR, the interference only can be also used as a metric by comparing its value with defined thresholds instead of using the transmitted signal as a reference. More in general, which metrics to consider and how such metrics are used depends on the different applications.

Radio access network level metrics can be divided into system performance metrics and users related performance metrics. System performance metrics refer to overall operation of the radio network, while user performance metrics refer to the quality of service (QoS) and quality of experience (QoE) of the end user.

The radio access network level system performance metrics include, but are not limited to:

- Accuracy of obtained knowledge (e.g. radio environment)
  - ◦ It refers to the accuracy of information that CRS systems obtain to use for decision making and adjustment of operational parameters and/or protocols. This mainly impacts on interference management.
  - ◦ Accuracy of the knowledge obtained by the CRS may be affected e.g. by the following metrics or a combination of them;
  - ◦ Propagation channel measurement error which is a metric of difference between actual radio propagation channel state information values and their estimated values.
  - ◦ Geographical position error which is a metric which is a displacement of recognised position from a real position.
  - ◦ Other metrics related to specific CRS technologies for obtaining knowledge can be found in section 6
- Base station reconfiguration time
  - ◦ It refers to the duration from the time when a reconfigurable base station receives a particular reconfiguration command to the time when it starts to operate again with the new configuration.
- Time-scales related to CRS specific characteristics
  - ◦ It refers to delays introduced by the CRS capabilities operations. As an example, these metrics could include decision delay and control delay.
  - ◦ Decision delay is the time required to take decisions. Such metric may be relevant because information that was collected at the past instance may no longer be appropriate or out of date due to the dynamic nature of land mobile radio systems. Control delay is the required time to adjust radio parameters after the decision of adjustment.

- System capacity
    - It refers to the peak aggregate throughput that can be achieved over a communications system under certain conditions.
- Aggregate average throughput
    - Aggregate average throughput is throughput in a cell summed from all users over the time divided by the number of users.
- Peak spectral efficiency
    - The peak spectral efficiency is the highest theoretical data rate (normalized by bandwidth), which is the received data bits assuming error-free conditions assignable to a single mobile station, when all available radio resources for the corresponding link direction are utilized.
- System spectral efficiency
    - System spectral efficiency is defined as the aggregate throughput of all users divided by the channel bandwidth. The system spectral efficiency is measured in bit/s/Hz.
- Successful communication establishment probability
    - It refers to the probability of successfully establishing communications links.
- Frequency channel handover time
    - It refers to the time for a CRS device to handover from current frequency channel to another frequency channel.
- Radio network level's users related performance metrics include:
- Delay and Jitter
    - Communications delay and delay variation of the end user traffic.
- Connection reliability
    - Connection reliability measures the probability that the user session will be maintained during a session.
- Percentage of users with low quality
    - Defines the percentage of network user's whose selected user performance metric(s) have remained below a certain threshold(s) for a predetermined duration of time.
- Metrics for evaluation of spectrum use
- The CRS aims at enabling more efficient use of spectrum. This may be evaluated e.g. in terms of:
- Spectrum occupancy
    - The utilization rate of the frequency channel, thus, the fraction of time that the power in a frequency channel exceeds a certain threshold. Measurements of the spectrum occupancy enable monitoring on how efficiently the current spectrum allocations are being used in reality. Measurements are influenced by detection method, measurement channel bandwidth, number of channels, observation time per channel, revisit time and duration of monitoring. Spectrum occupancy can be given in three different levels:
- Frequency channel occupancy: A frequency channel is occupied as long as the measured level is above the threshold.
- Frequency band occupancy: The occupancy of a whole frequency band counts every measured frequency and calculates a total figure in percent for the whole band, regardless of the usual channel spacing.

- Spectrum resource occupancy: The ratio of the number of channels in use to the total number of channels in a whole frequency band.
- Spectrum utilization efficiency (SUE)
  - SUE is a measure of spectrum efficiency given as the ratio between the useful effect obtained by the radio systems through the utilization of the spectrum and the spectrum utilization factor (Recommendation ITU-R SM.1046). Considering a CRS that operates at a particular frequency, at a given location, and at a particular time, the spectrum utilization factor is defined as the product of the bandwidth, the geographic space, and the time. The useful effect for CRSs (and mobile systems in general) increases with the amount of information that can be transferred.

The first metric describes how efficiently a spectrum band is used in the course of time by all radiocommunication systems that are allowed to use it. The second metric describes the spectral efficiency of a CRS but it may not be valid for all applications. It may be used to study and compare the efficiency of different CRSs providing the same service or a CRS with another system providing the same radiocommunication service.

Metrics for Performance Evaluation in the Context of Spectrum Sharing and Coexistence

Performance metrics in the context of spectrum sharing refer to the situation between a LMS employing CRS capabilities and other systems operating in co-channel frequency bands. Sharing considerations are particularly important as the protection of the existing radio systems in co-channel bands may influence the performances of the CRS.

Performance in the context of spectrum sharing may be evaluated e.g. in terms of:

- SINR degradation
  - Reduction in SINR in the radio systems involved in sharing.
- Co-channel interference
  - The interference between different radio systems utilizing the same frequency bands.
- Sharing delay
  - Set of delays due to the sharing and coordination mechanisms. It may include the delays related to the channel access, channel evacuation and others. Metrics to evaluate the net transmission time that may occur during the channel evacuation procedure can be defined for interference remark purposes.

Performance metrics in the context of coexistence refer to the situation between a LMS employing CRS capabilities and other systems operating in adjacent frequency bands. Coexistence considerations are particularly important as the protection of the existing radio systems in adjacent bands may influence the performances of the CRS.

Performance in the context of coexistence may be evaluated e.g. in terms of:

- SINR degradation

Reduction in the SINR in the coexisting radio systems.

- Adjacent channel interference

The interference between different radio systems utilizing adjacent frequency bands.

Benefits of CRSs

In Report ITU-R M.2225 an initial set of CRS benefits have been identified. This section further expands and develops on the potential benefits.

Cognitive radio systems are expected to increase the efficiency of the overall radio resources (e.g. including spectrum) usage by offering new and enriched radio resource management mechanisms and also to provide more flexibility to applications as a result of their ability to adapt their operations e.g. to external and internal factors. CRSs are enablers for technological evolution of wireless technologies and are likely to become a key means for future innovation of LMS radio systems.

Benefits Related to Vertical and Horizontal Spectrum Sharing

CRS could be an enabler for vertical and horizontal spectrum sharing to allow more flexible access to spectrum. The benefits associated with vertical and horizontal spectrum sharing include:

- Interference minimization: for example when utilizing CRS capability of obtain knowledge like database, the CRSs will get information on the current protection requirements thus adapting the radio systems to operate in accordance within the given rules and policies.
- Efficient spectrum use: enabling radio systems to share spectrum with each other leads to increased efficiency of spectrum use. Additional spectrum can be made available by allowing radio systems to share spectrum with other radio systems (vertical sharing) on a geographical or time basis. This can lead to capacity enhancements for the system employing CRS technologies.
- Flexible operations: in sharing and coexistence situation CRS system would have advantages over conventional radiocommunication systems. As CRS technology is flexible and could operate over various system configurations and with its advance capabilities in obtaining knowledge and adapting dynamically to policies, information shared between the involved CRS nodes would ensure that the relevant nodes have the most accurate information of available spectrum in a timely manner.

Optimization of the System Operator Network

In general, the main challenge from system operator perspective is to answer user needs in a timely and adapted manner satisfying the requirements in terms of capacity and QoS. A CRS having the potential to obtain knowledge from and analyse the radio operational environment, can make the system operator's network react accordingly by optimizing the choice of radio access technologies and associated radio resources. Some of the potential benefits that a CRS may introduce are the following (Kulkarni et al., 2006):

- Dynamic spectrum reconfiguration: a particular situation is that of spectrum reconfiguration in the context of technology evolution and periodical emergence of new families of standards. This implies their progressive introduction/coexistence in the legacy "bands" rather than a simple and quick switchover which is not appropriate due to the large amount of legacy equipment and the corresponding investments. A CRS may allow a smooth spectrum transition period in this case taking into account the traffic constraints and user requirements.
- Radio Resource optimization: considering a cell set in a certain area, the traffic of different services on a specified RAT may change from one sub-area to another according to the day period. Moreover, in case of deployment of different RATs in the same area, the offered traffic of different service s may vary depending on the RAT in both time and space domains. In such contexts, a CRS may provide to the network operator the means for managing in an efficient and dynamic way the radio resources (e.g. reducing of radio access blocking percentages, redistributing resources among different RATs and/or minimizing system interference problems, energy saving purposes, etc.).
- Enabler for dynamic device context provision: considering a heterogeneous or multi-RAT context managed by an operator in which radio resource management mechanisms could be performed dynamically in time (e.g. spectrum refarming, radio resource optimization, etc.), solutions to provide appropriate information for the mobile devices operations are needed. In this context, a CRS may provide the tools to achieve such objective in an efficient manner e.g. through the utilization of an in-band control channel.

FACTORS RELASTED TO THE INTRODUCTION OF CRS TECHNOLOGIES AND MIGRATION ASPECTS

In this section, factors related to the introduction of CRS technologies are discussed followed by related migration issues. Some the factors being introduced are currently under practice in today's LMS networks, i.e., pre-cognitive features already exist in current practice. On the other hand some other factors are not yet introduced and still subject to further study and investigations. In Report ITU-R M.2225, four different deployment scenarios for a CRS were identified. Each of these four scenarios is summarized below for which there will be different factors related to the introduction of CRS in the LMS. In the following, these factors are discussed.

Scenario 1: Reconfiguration of Connections Between Terminals and Radio System

Multiple radio systems employing different radio access technologies (RATs) are deployed on different frequency bands to provide wireless access. For this scenario factors would include but are not limited to e.g. terminals should be reconfigurable, able to obtain knowledge and able to adjust operational parameters and protocols dynamically and automatically. Also the terminals may be equipped with learning capability. Other enabling factors to improve the performance of the CRS in scenario 1 include radio interface enhancements and network architectural changes to enable radio systems to assist terminals in obtaining knowledge and guide terminals in their reconfiguration decisions.

Scenario 2: An Operator of a Radiocommunication System Improving the Management of its Spectrum

A network operator managing two or more RATs can dynamically and jointly manage the resources of the deployed RATs. For this scenario operator benefits from techniques such as traffic pattern recognition and prediction, load balancing algorithms between RATs and RAT reforming. These techniques are currently under discussion in standardization bodies, and some deployments of techniques are foreseen in the near future.

Scenario 3: An Enabler of Cooperative Spectrum Access

Utilizing parts of the spectrum remaining unused due to variations in the spectrum occupancy using CRS technology. Enabling factors for the scenario include:

- Exchange of spectrum use information among systems;
- Identification of spectrum occupancy variations;
- Sharing mechanisms between a CRS and non-CRS or between CRSs.

Scenario 4: An Enabler for Opportunistic Spectrum Access

The CRS accesses parts of unused spectrum in bands shared with other radio systems and services without causing harmful interference. Enabling factors for the scenario include:

- Methods to obtain knowledge;
- Sharing mechanisms between a CRS and non-CRS or between CRSs.

CONCLUSION

This chapter has been addressed cognitive radio systems (CRSs) in the 5G networkand introduces the offered, up-and-coming and possible applications employing CRS capabilities and the related enabling technologies, including the impacts of CRS technology on the use of spectrum from a technical perspective. The description of such technologies, operational elements and their challenges have been presented. Furthermore this chapter has been provided high level characteristics, operational and technical requirements related to CRS technology, their performances and potential benefits. Finally, factors related to the introduction of CRS technologies and corresponding migration issues have been discussed.

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Section 4

Fifth Generation Applications

Chapter 10
Importance of Cloud Computing in 5G Radio Access Networks

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ABSTRACT

The fifth generation of wireless networks (5G) will kick off with evolved mobile broadband services as promised by several mobile-related associations, researchers, and operators. Compared to 4G, 5G aims to provide greater data rates with lower latency and higher coverage to numerous users who stream ubiquitous multimedia services. 5G benefits the innovation of internet of things (IoT) as well. To this end, several modifications in the network architecture are required. This chapter is discussing the role of cloud computing centers in 5G networks, and how such integration could be implemented as found in the literature. The benefits of cloud/5G integration will be explained as well. In addition, some challenges related to the integration will be demonstrated.

DOI: 10.4018/978-1-7998-1152-7.ch010

INTRODUCTION

The fifth generation of mobile communication systems (5G) will kick off with evolved mobile broadband services as anticipated by several mobile-related associations, researchers and operators. For example, with faster connectivity, it is possible to develop a new radio access network (RAN) for user equipments (UEs). A Cloud-RAN or Centralized-RAN (C-RAN) can be developed leveraging Cloud Computing and 5G networking to provide a new centralized and powerful RAN to resolve capacity and coverage issues in a more effective way. More on Cloud Computing technology and the C-RAN approach will be introduced in the following sections.

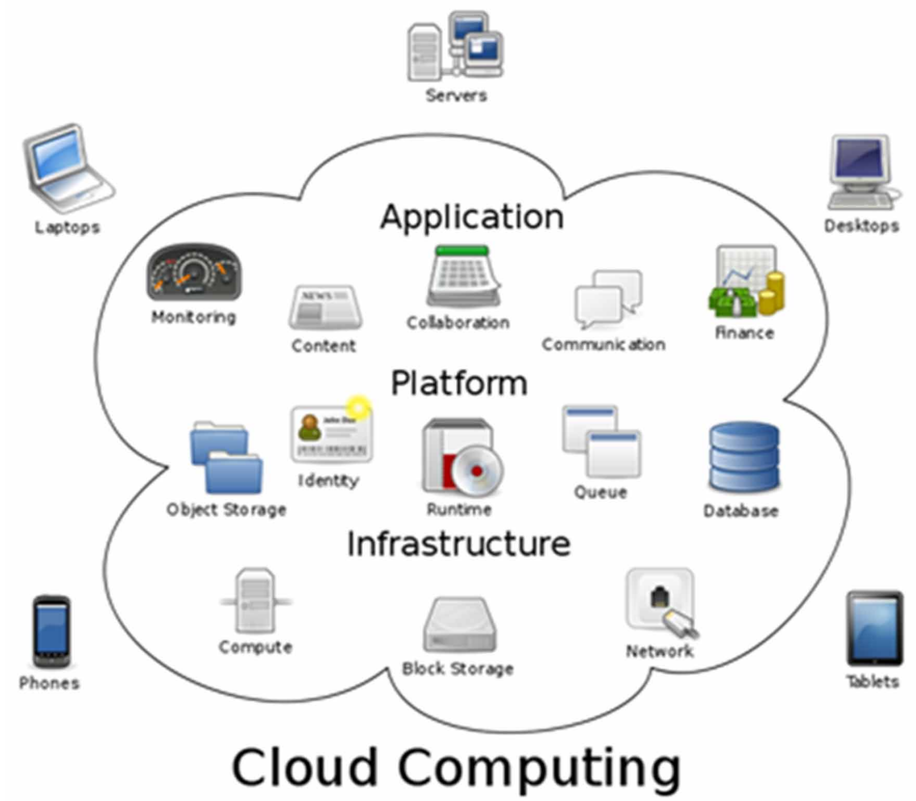
CLOUD COMPUTING

Cloud Computing refers to the transfer of on-demand computing services - everything from software programs to hardware-like machines - and storage capacity over a network media based on a pay-per-use model to a large variety of end-users (IBM, Microsoft Azure and Prajapati, Sharma, & Badgujar, 2018). The Cloud concept is called so as it obscures from users the infrastructure details of the underlying hardware. Also, “Cloud” indicates a distance between the service provider and the end-user as it is the case in the shadow resulted by the sky clouds, and provided over long distances. There are several definitions that were put for Cloud Computing by Information Technology (IT) experts in the field (Geelan, 2010). The definition of Cloud Computing as stated by the National Institute of Standards and Technology (NIST) considers it as a model that enables ubiquitous, on-demand and convenient network access to a congregation of configurable and shared computing resources (e.g., networks, servers, storage, applications, and services) as shown in Fig. 1. These resources can be rapidly provisioned and released with minimal management effort or service provider interaction (NIST).

Cloud Computing aims to authorize the use of user’s data, software and computation resources over a network with adequate prices, depending on the usage time. At the same time, Cloud end-users relieved from the inconvenience of IT firmware establishments and hardware installations (Prajapati et al., 2018). Through only a web browser on top of a PC/laptop or a mobile app, end users could access Cloud services running on servers in remote locations efficiently and effectively. Cloud Computing provides enterprises with faster and well-managed applications that require less maintenance compared to non-Cloud applications. Furthermore, Cloud services could be readjusted multiples of times to cope with fluctuating and unexpected business needs more quickly. Like the electricity grid, the sharing of Cloud Computing resources over the internet is based on consistent scale economies proportional to the utility. The foundation of Cloud Computing is the broader concept of converged infrastructure and shared services (Hurwitz, Bloor, Kaufman, & Halper, 2010).

Although Cloud and Virtualization are entirely different, Cloud Computing adopts the virtualization technology to enable the optimum utilization for available computing resources. The Cloud uses a monitoring software (i.e., hypervisor) to allow multiple instances with different operating systems to run concurrently on the same machine with total isolation from each other (VMware). With virtualization, each running instance is assigned to the appropriate physical hardware resources as required, enabling different clients to access them in a cost-effective manner.

Figure 1. Cloud computing (NIST)

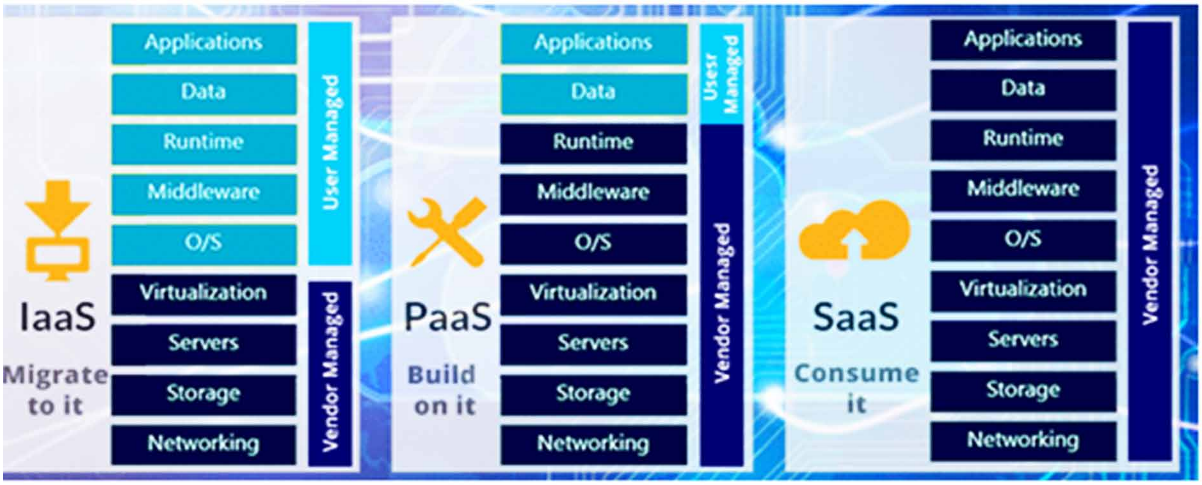


Cloud Computing is deemed as a service-oriented architecture that provisions "everything as a service" (simply abbreviated as "Xaas"). Cloud Computing providers offer their "services" according to different models. The three standard models according to "NIST" are: Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS) (NIST). These models offer increasing abstraction, and are often portrayed as layers in a stack as shown in Fig. 2.

Cloud Computing has changed every business and industry. When the Cloud Computing gets involved in IT missions, numerous benefits could be gained, such as (Prajapati et al., 2018):

1. **Cost Savings**: End-users only pay as they go with the resources or services they use solely.
2. **Flexibility, Scalability and Elasticity**: Users could scale up and down their reserved resources while their operations are running.
3. **Mobility**: Mobile users are capable of accessing Cloud resources as well as their data on the Cloud during their movement using today's smart phones and portable devices.
4. **Centralized Control, Management, S/W and H/W Updates and Maintenance:** Managing such services centrally keeps the integration process complexity to the lowest level possible.
5. **Increased Collaboration and Multitenancy** (Baldin, Ruth, Wang, & Chase, 2018): Cloud-based workflow and file sharing apps help multiple users edit and share documents simultaneously at any time, from anywhere, and do more together, and do it better.

Figure 2. Types of cloud services (NIST)



Despite the ubiquitous benefits that have been acquired from introducing and utilizing the Cloud technology into IT platforms and computational systems, few challenges still need to be considered while operating with, or designing and administrating the Cloud (Prajapati et al., 2018) and (Taherkordi, Zahid, Verginadis, & Horn, 2018). For instance, the centralized control and management feature in Cloud Computing may be representing a "single point of failure" from a user perspective. Thus, selecting the most well-trusted Cloud service provider for user data outsourcing is necessary to avoid possibilities of failures resulting from low experience in Cloud administration.

Another challenge that should be considered when dealing with user data is the efficiency of used security and privacy levels in the Cloud. Solid security and privacy mechanisms have been innovated to prevent the vulnerability of hosted data from being attacked (Ladole, Chhajed, & Shelke, 2018). On the other hand, Service-Level Agreements (SLAs) are kinds of contracts that should be coincided between the Cloud company and Cloud users to regulate transactions between both sides (Jinyuan & Sun, 2018). Hence, to ensure the optimum performance when dealing with situations of such challenges, SLAs are first put to reserve the rights of both providers and users for surpassing any sudden Cloud crisis during operation.

Although these challenges of the Cloud technology, its great benefits have attracted enormous decision makers to involve it into their work, invest in it and depend on it in large-scale data processing (Prajapati et al., 2018). In the communication community, the R&D sectors in top cellular networks groups and associations (IBM, China Mobile Research Institute, Alcatel-Lucent, Huwaei, ZTE, Nokia Siemens Networks, Intel, Texas Instruments and Chih-Lin, Rowell & Han, Xu, Li, & Pan, 2014) have announced that the technology of the Cloud should be considered as one of the leading technologies in the new radio generation (i.e., 5G) to achieve the possible peak performance standards as will be demonstrated in the following sections.

The Need for Cloud Computing in 5G Architecture

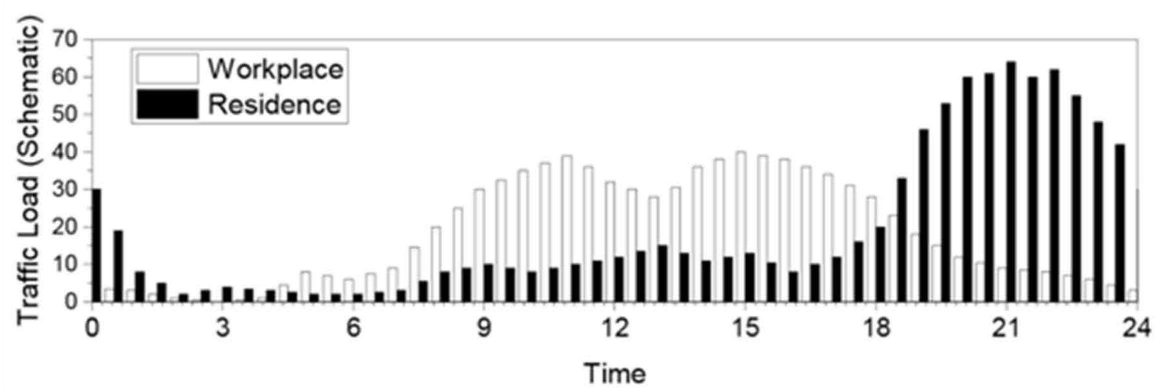
Since 2011, wireless network operators are encountering a serious situation in maintaining their profits. With the excessive streaming of multimedia services through smart devices, traffic of mobile Internet is rapidly increasing. Nevertheless, the new trend of Internet of Things (IoT) is putting more burden on mobile network operators as it will certainly and rapidly increase the load on the network. Therefore, operators are forced to enrich their networks with more resources (e.g., cells, frequencies, technologies …etc) to meet excessive users' requirements, which add implicitly to the underlying capital expenditure (CAPEX) and explicitly to the persistent operating expense (OPEX). On the other hand, these increasing expenses cannot be substituted by the average revenue per user (ARPU) (Wu & Zhang & Hong & Wen, 2015). It has been witnessed since 2011 that the traffic is doubling year after year (Taoka, 2011), and to cope with this excessive increasing load, mobile operators have to expand their infrastructure, build more towers, cells and processing units, and upgrade to the latest technology adopted once there is any update in one of the composed infrastructure entities. However, this adds to the cost, while the final revenue gained by operators is barely achieving a small increase per year.

At the beginning of the current decade, cellular network operators begin to think of ideas to enlarge their profits and at the same time, enhance the level of Quality of service (QoS) provided to users. To approach this goal in an energy-efficient way, various alternatives have been applied. For instance, the spectrum efficiency could be improved by using novel transmission techniques such as Beam Forming (BF) and Multiple-Input-Multiple-Output (MIMO) systems. Although applying these two techniques have improved the transmission performance especially in crowded areas, both techniques have theoretical limits as depicted in (Larsson, Tufvesson, Edfors, & Marzetta, 2014). Another venue is to take advantage of under-utilized radio frequencies from the available spectrum through dynamic spectrum access and spectrum sharing using the technology of Cognitive Radio (CR) (Sasipriya & Vigneshram, 2016). However, The CR technology is still under investigation in the research community to ensure its consistency and reliability in providing services. Another typical option is to add more small cells to the network coverage area - even inside big cells - to exploit the full frequency bundle given to each cell (Dahlman, Parkvall, & Skold, 2018). Although this option has been utilized to cope with the tremendous subscriptions of mobile users, it comes at the cost of the added interference and increased OPEX.

Another challenge that operators should consider is the Energy Efficiency (EE). Increasing EE inevitably reduces operational costs and carbon dioxide emissions. The entity in the network structure that consumes the highest power is the RAN base station (BS), as reported by China Mobile. However, the promising trials in the literature manage to reach only about 50% of BS power efficiency (Wang, 2010), putting more burden on operators when thinking of increasing cell sites. Nevertheless, as the number of cells per area increases, more frequent cell handovers occurs by mobile users, resulting in growing overheads across the network (Gupta, 2010).

Along the day, user density fluctuations at the same cell has lead to a phenomena called "Tidal Effect" in which the load of the network changes in a time-geometry style based on the type of the cell or area (i.e., residential or business) as shown in Fig. 3 (Zhizhen Zhong, Nan Hua, Haijiao Liu, Yanhe Li, & Xiaoping Zheng, 2015). In conventional RAN architecture, the BS processing capacity is fixed in each cell and dedicated only to its associated subscribers located in its area of coverage rather than being shared in a larger geographical area. Accordingly, in the evening for instance, BSs covering residential cells/areas are over-associated with subscribers while BSs in business cells/areas are under-subscribed, lifting the idle BS to remain online and dissipate power needlessly, and vice versa in the morning.

Figure 3. Tidal traffic scheme



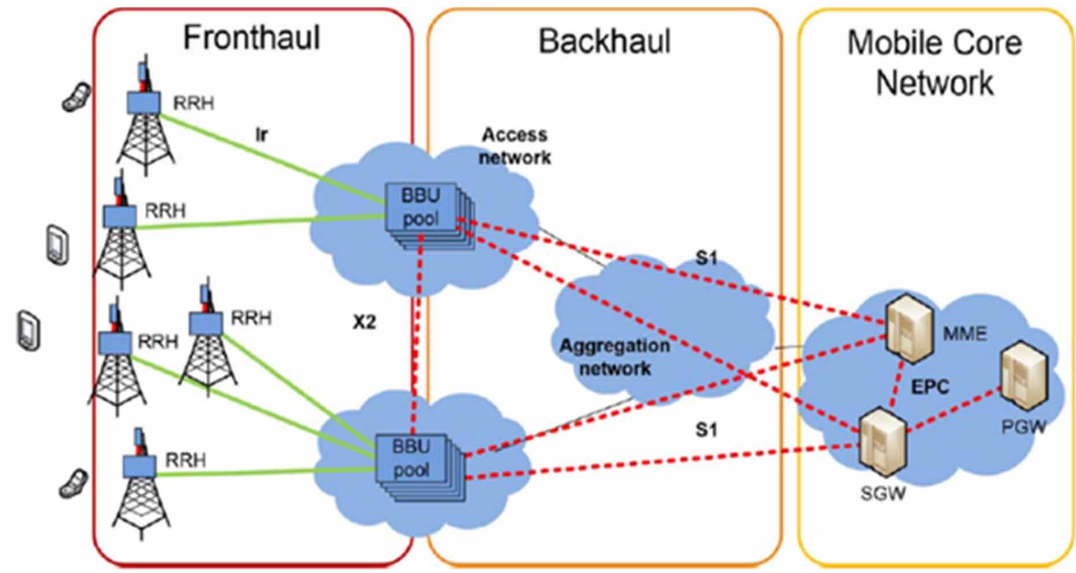
To solve this problem, the existing RAN architecture should be modified to approach a better utilization for BS resources along the day, and over the whole network coverage area. Nowadays and thanks to the evolution of both Cloud and multi-core processors technologies, servers become computationally-powerful, and as a result, the Cloud Computing centers adopting those servers become promising alternatives in both IT and communication domains. By collecting dispersed BSs processing resources which are currently distributed across the whole network cells, in one shared pool, and reconstructing based on the Cloud facility, network operators could then target low-cost operation as well as exploiting other Cloud benefits. In addition, C-RAN would allocate BS resources for each cell according to the cell's needs instead of having fixed BS resources per cell as the case in traditional RANs. Hence, the "Tidal Effect" could be revoked and resource utilization could be enhanced as well.

Cloud computing has attracted mobile operators due to its nature and capabilities that could be used to enhance current RAN architecture. The following requirements should be attained by the new RAN:

- Support for new protocols adopted by authorized 5G associations.
- Flexibility for any upgrade in hardware/software.
- Optimization among capacity, mobility, coverage and costs in mobile cordless systems.

C-RAN is a novel approach proposed by many operators and communication research communities to combine powerful features together such as: Cloud computing as well as its associated benefits, centralized processing, collaborative radio and resource scheduling, and power efficient architecture. This modern paradigm combines previously distributed BS processing resources into a single and shared pool, leaving only the radio resources to be distributed (usually per cell) in Remote Radio Head (RRH) units. RRHs are connected with the central pool via Optical Transmission Networks (OTNs) as shown in Fig. 4 (Khan, He, Xue, & Ratnarajah, 2015). C-RAN aims to reduce the amount of BS resources per cell site while maintaining similar (or even better) coverage, and reducing CAPEX and OPEX, while offering better services. In the next section, the C-RAN concept is explored in more details.

Figure 4. 5G network architecture (Khan et al., 2015)



C-RAN: 5G/CLOUD POWERFUL INTEGRATION

Although the concept of C-RAN is investigated in details for the first time in the China Mobile Research Institute (2011), it is formerly suggested in IBM (2010). Many famous mobile network operators and mobile companies (e.g., China Mobile Research Institute, Nokia Siemens Networks, Huawei, IBM, Alcatel-Lucent, Intel, ZTE and Texas Instruments) have considered the C-RAN architecture as one of the most promising technologies in the targeted 5G New Radio (5G-NR). C-RAN is also considered as one of the green technologies that could be perfectly attained in the year of 2020 as planned by network operators supporting 5G (Chih-Lin et al., 2014).

C-RAN aggregates baseband processing of the whole network in a central location called Baseband Unit (BBU) pool and makes it shared to all composite sites. In this way, C-RANs are capable of adapting to non-uniform traffic and approaching the optimum resource utilization. Hence, number of required BBUs could be decreased using C-RANs compared to the classical RAN architecture which lead to significant diminishing in costs resulted from the frugality in total power and energy consumption. According to the instant traffic load on the network, new BBUs can be added easily as well as upgrading, scaling and maintaining them very simply when needed. Different network operators could share the same Virtualized BBU pool, allowing them to rent a RAN as a Cloud service (RANaaS) (Rost, Bernardos, Domenico, Girolamo, Lalam, Maeder, Sabella, & Wübben, 2014) (Sgambelluri, Paolucci, Castoldi, Sambo, Iovanna, Imbarlina, Pepe, & Valcarenghi, 2018), depending on the load. Locating BBUs from many sites in one pool make them interact between each others with lower delays (e.g., reducing delay during intra-BBU Pool handover (Checko, Christiansen, Yan, Scolari, Kardaras, Berger, & Dittmann, 2015)). Therefore, mechanisms put for the Long Term Evolution - Advanced (LTE-A) to increase throughput and spectral efficiency (e.g., Coordinated Multi-Point "CoMP" and improved Inter-Cell Interference Cancellation "ICIC"), become greatly simplified to apply now. Also, developing load balancing methods between the cells becomes applicable. As a result, network performance is enhanced as overall.

Gathering most of network BBUs in the centralized pool (established based on a Cloud architecture) and keeping RRHs distributed across cells according to Radio Frequency (RF) strategies allow operators to adaptively implement a real-time virtualization platform that is able to route radio data from/to each RRH to/from the responsible BBU instance in the Cloud pool. Hence, C-RAN is considered as a centralized Cloud Computing-based architecture for 5G-NR and beyond. Several advantages could be introduced by C-RAN compared to traditional RANs as follows:

- **Reduced Cost**: C-RAN combines most of the computationally heavy signal processing functions to be manipulated in the BBU pool, whose architecture is based on the high-performance Cloud Computing technology resources, leaving only fewer functions - especially those related to radio operations - to be processed in RRHs. Accordingly, this will save considerable operation and management cost. In addition, virtualization which is one of the fantastic features of Cloud technology provides great opportunities to high scalability and load balancing algorithms, which will in turn, reduce BS resource wasting.
- **Energy Savings**: Thanks to C-RAN, most of heavy-load processing resources are now combined in one Cloud center in the network. As a result, processing functionalities could be dynamically assigned to the appropriate BS resources based on the load to reduce traffic congestion and power consumption as much as possible. Task migration (e.g., from one BBU instance to another) could be handled easily now in the Cloud pool as well. Thus, algorithms of BS offloading (e.g., BS sleeping and BS switching to low power) are now facilitated, depending on the size of collective load processing and load distribution (Sigwele, Alam, Pillai, & Hu, 2017) (Alnoman, Carvalho, Anpalagan, & Woungang, 2018).
- **Improved Spectrum Utilization**: Unlike conventional RAN, C-RAN permits the sharing of mutual data/information (either traffic or control packets) among cooperating BSs in the same Cloud center (or even on the same server). This saves a lot of communication overhead needed in such operations over the radio interface as currently executed in LTE BSs.
- **Business Model Transformation**: More business models could be generated by the Cloud concept (Harada, 2009) (Lin, 2010), such as implementing robust solutions for RANaaS that could be rented when requested by any network operator. Accordingly, multiple operators could hire BS resources from a shared BBU pool without the need of owning individual pools. On the other hand, an operator could lease additional BS resources from a foreign BBU pool when needed (as could be generated in rush-hour times).
- **Flexibility and Scalability**: When the majority of subscribers move from one cell type (i.e., business or residential) to another as usually happen in specific times (e.g., peak time) during the day, the BS resources in the old cell will be wasted especially in the current cellular design of fixed processing power resources per site. In similar cases, the resulted peak traffic load generated in the new cell can reach to 10 times higher than during other normal times as reported by the China Mobile Research Institute. In C-RAN, the overall utilization rate can be improved. Instead of the fixed capacities assigned to each cell through current traditional BSs, the BBU pool will supply the required baseband processing capacity for each cell based on its load density. Hence, Operators could ensure that situations of resource-wasting and resource-scarcity are no more encountered in any cell inside the network.

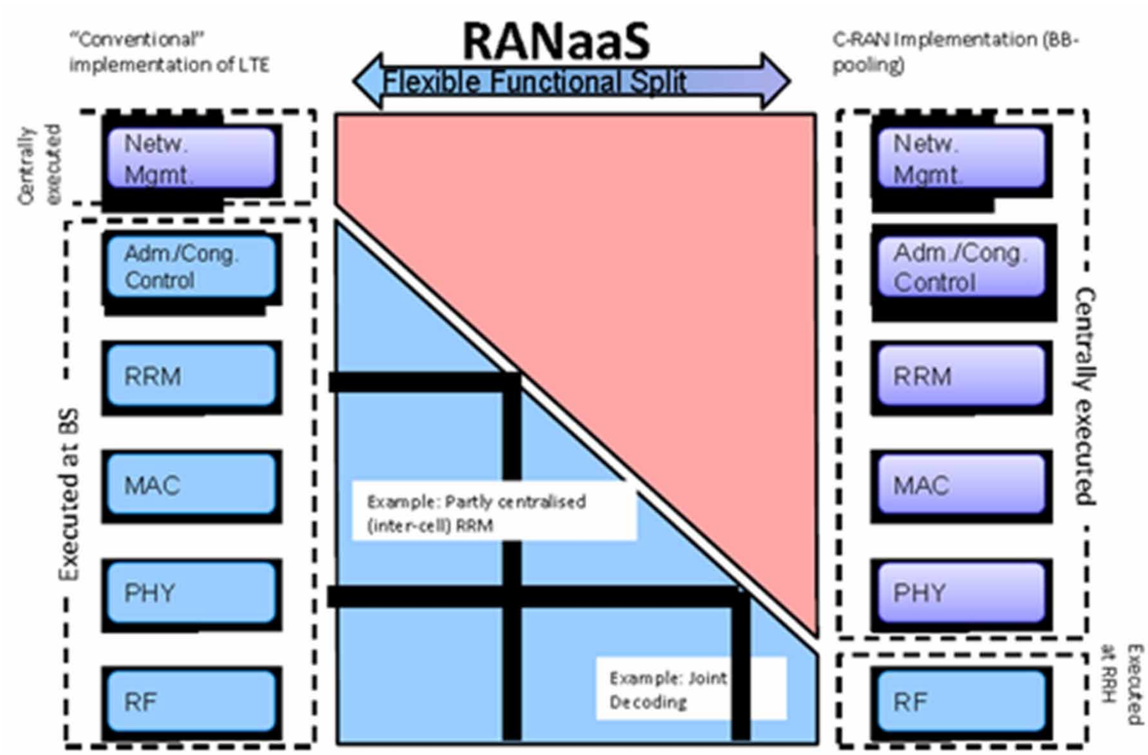
- **Network Function Virtualization (NFV) and Software-Defined Network (SDN)**: NFV switches the network functions from being implemented mostly in hardware, to be completely implemented in software running above typical servers deployed in data centers. Accordingly, the traffic load could be handled using virtualization approaches. Rather than implementing network tasks on application-specific hardware, NFV aims at reducing network life time by relying on software installed on general-purpose hardware, which reduces costs at the end (Parvez, Rahmati, Guvenc, Sarwat, & Dai, 2018). European Telecommunications Standards Institute (ETSI) has created a separate study group for NFV after it attracts many people in the network industry (Checko et al., 2015). When getting into work, NFV could benefit from the massive virtualization approaches provided by Cloud Computing. SDN is a novel approach that disengages the network controlling functions and routing functions, aiming at making the network control completely programmable and abstracting the underlying infrastructure, so that the network services and applications could be regulated dynamically (Wu et al., 2015). In SDN, the network brain is logically located in SDN controller as a software that is able to preserve a network layout. Herein, the SDN controller is represented as a single logical switch to any application or other network elements. Accordingly, network administrators are capable of monitoring, configuring, securing, managing and optimizing network resources very rapidly through an adaptive SDN program which could be tuned anytime and when needed. SDN facilitates network design and management because instructions are released from SDN controllers rather than diversified, vendor-specific software/hardware. Although SDN and NFV are related to each other, their objectives are totally different. SDN separate the control layer from the forwarding layer in the network, while NFV approaches the "softwarization" of near all network functions to get rid of closed proprietary appliance hardware. In cellular networks, virtualizing the core network based on SDN and NFV is currently under exploration (Alnoman, 2018) (Ramantas, Antonopoulos, Kartsakli, Mekikis, Vardakas, & Verikoukis, 2018) (Valastro, Panno, & Riolo, 2018). However, implementing RAN with SDN and NFV is rarely researched (Taoka, 2011). C-RAN becomes an application of NFV when NFV is used for logically centralizing the base band processing within the RAN.

C-RAN Challenges

Determining the optimum split point between what functions should be centralized in the BBU pool, and what should be left distributed in spread RRHs, is still under research. Several options for the functional split are explored in the literature (Rost et al., 2014) (Line, Larsen, Checko, & Christiansen, 2019) (Harutyunyan & Riggio, 2018) and depicted as a recap in Fig. 5. Although this functional split permits some flexibility in both processing design and actual execution of functions, implementing such a functional split formulates a challenge for the RAN to ensure achieving a better or even the same performance. The challenge issues of the functional split could be summarized in the following two main points:

- The limited data rate that could be acquired from the currently constrained fronthaul and backhaul links.
- The exploitation of virtualized resources on commodity hardware, which may not provide the same real-time characteristics as currently deployed hardware.

Figure 5. Functional split flexibility (Rost et al., 2014)



The functional split and its associated issues described above represents the main challenge for researchers and developers in C-RAN technique. However, other minor challenges for C-RAN are also investigated as follows:

- Extended costs resulted from the very high-speed fiber links, required to connect BBU pool with remote RRHs (China Mobile Research Institute).
- A novel trend in 5G researches to combine heterogeneous networks (used in dense LTE/5G deployments) with C-RAN (termed then as heterogeneous C-RAN or "H-CRAN") introduces more requirements and restrictions on the C-RAN design (Peng, Li, Jiang, Li, & Wang, 2014).
- A standard solution for Cloud Computing and Virtualization technologies has to be developed exclusively for C-RAN, to avoid restrictions and incompatibility issues anticipated from current Cloud Computing/Virtualization vendors' proprietary (Chih-Lin, Haung, Duan, Cui, Jiang, & Li, 2014).

These issues introduce additional design complexity, computational latency and jitter, that need to be considered in the Cloud-based RANaaS design. Fortunately, several works have been started to solve these issues by introducing high-capacity fronthaul and backhaul links (Giglio & Pagano, 2019) (Alimi, Teixeira, & Monteiro, 2018), and exploring novel algorithms of processing large amounts of data efficiently (e.g., stronger parallelization and joint processing) (Wübben, Rost, bartelt, Lalam, Savin, Gorgoglione, Dekorsy, & Fettweis, 2014). Nevertheless, many works have been accomplished in the literature to enhance the overall performance of C-RAN, as will be surveyed in next section.

Recent Progress in C-RAN

Several works in the design and development of C-RAN architecture have been published so far. Recent works in the implementation of C-RAN have been comprehensively surveyed in (Mohammad Asif Habibi, Meysam Nasimi, Bin Han, & Hans D. Schotten, 2019). Thanks to the offered benefits from Cloud Computing to cellular networks, several deployments for C-RAN have proven that the new Cloud-based architectures outperforms classical RAN architectures, especially in terms of economy savings (Harada, 2009) (Lin, 2010), energy efficiency (Sigwele et al., 2017) (Alnoman et al., 2018), load balancing (Mouawad, Dziong, & El-Ashmawy, 2018), reduced latency (Parvez et al., 2018) (Bhaumik, Chandrabose, Jataprolu, Kumar, Muralidhar, Polakos, Srinivasan, & Woo, 2012), and spectral efficiency (Ortín, Caballero, & Rost, 2014). Consequently, telecommunication industry and cellular network operators believe that C-RAN is a key emerging technology in 5G-NR, as it represents a great paradigm shift in evolving current RAN architectures.

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Chapter 11
Optimizing 5G in V2X Communications:
Technologies, Requirements, Challenges, and Standards

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ABSTRACT

Recently, the automotive industries have accelerated the deployment of Cellular V2X as a motivation to integrate vehicular communication with NewRadio-5G (NR-5G) technology. Nowadays, two critical technologies are concurrently supporting V2X communication: IEEE802.11p and cellular technologies. C-V2X is standardized and designed by the Third Generation Partnership Project (3GPP) for automotive services. C-V2X supports two communication modes through a single platform to provide Wifi-short-range and cellular-long-range communication. Wifi-short-range communication doesn't require network subscription or coverage while the cellular-long-range requires network subscription and coverage. LTE-V2X is the current standard of C-V2X which completed in March-2017 as the 3GPP-Release 14 and enhanced to support the upcoming 3GPP-Release 16 which support the NR-5G capabilities, enhancement, and services. In this chapter, the authors propose the Optimizing of 5G with V2X and analyzing the current V2X standards, introducing the evolution of 5G, challenges, features, requirements, design, and technologies.

DOI: 10.4018/978-1-7998-1152-7.ch011

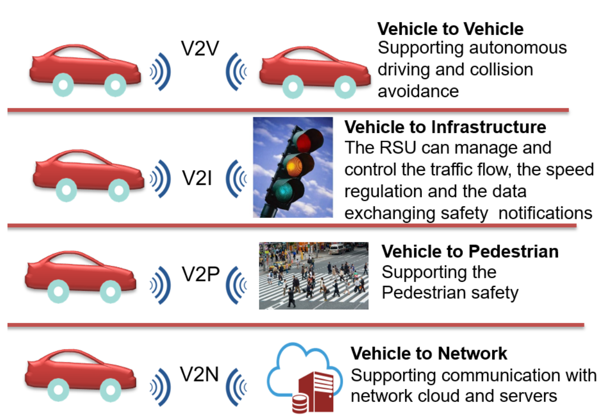
INTRODUCTION

Intelligent Transportation Systems (ITS) recently depend on V2X communications with many industrial cooperative efforts. Vehicles, infrastructures, and pedestrians communicate wirelessly to gather and exchange information about the road environment within real time as shown in Figure 1. For that, a lot of dangerous and critical accidents can be avoided as the communicating vehicles are computers with extended onboard sensors. Dedicated Short Range Communications (DSRC) (Kenney et al., 2011) is designed as a standard for Wireless Access in Vehicular Environments (WAVE) which supports the V2X communications specially safety-applications. DSRC protocol stack and messages format are defined by the cooperation between European Telecommunications Standards Institute (ETSI) and IEEE, for ETSI, V2X has two types of messages: Cooperative Awareness Messages (CAMs) and Decentralized Environmental Notification Messages (DENMs) (Xu et al., 2004). CAMs messages are exchanged periodically every 100ms, to share the road status within a specific communication range while DENMs are only triggered by accident events to alert the road drivers.

Many industrial projects, research organizations, and too much regulatory efforts have been cooperated to enhance and deploy the V2X services in different countries, one of these projects are the Car 2 Car Communication Consortium (C2C-CC) (CAR2CAR et al., 2019) in Europe and Crash Avoidance Metrics Partnership (CAMP) in America (Shulman et al., 2007). DSRC protocol stack has a lot of disadvantages such as collisions due to the hidden node and asynchronous problems which degrade the total performance. One of the critical issues of DSRC is the cost-effectiveness of the Road Side Units' (RSUs) deployment, as well as that, DSRC has no clear steps about evolution, latency, network coverage, and network security.

The mobile industry has made significant progress within the last years as the Long Term Evolution (LTE) technology has been introduced to support different communication types including unicast and broadcast modes which can enhance V2X applications (Sun et al., 2016). Moving from DSRC vehicular technology to LTE based V2X is defined in the Third Generation Partnership Project (3GPP) standardization. 3GPP is planned to enhance V2X performance satisfying the industrial market within its Release

Figure 1. V2X Communication modes



14 in 2016 and 2017 to apply LTE technology in the automotive industry. LTE-V2X reuses application layer protocols of the DSRC standards while focusing on the development of the network and physical layers with an efficient radio air-interface.

China has officially allocated about 20MHz frequency for LTE-V project validation and deployment in six different areas. Many projects such as Next Generation Mobile Networks Alliance (NGMN) (Ngmn et al., 2019) and 5G Automotive Association (5GAA) cooperate with the automotive industry to evaluate the 5G New Radio (5G-NR) and LTE based V2X services. C -V2X is a complete traffic efficiency and road safety solution which allows different communication modes between vehicles to guarantee full coverage and service continuity. C-V2X communication is integrated with the existing vehicle technology to assist vehicles in automated or semi-automated driving-modes. C-V2X introduces two transmission modes of Vehicle-to-Vehicle (V2V) communication and Vehicle-to-Infrastructure (V2I) communications within the radio spectrum 5.9GHz frequency band, and Vehicle-to-Network (V2N) communication using the licensed mobile spectrum.

The former communication mode does not require the assistance of a mobile network, while the latter can use the existing cellular network infrastructure and the new 5G mobile networks. IEEE 802.11p is the current short-range wireless standard technology that has been developed over the past decade to support V2V and V2I communication, both IEEE 802.11p and C-V2X provide safety and efficiency benefits to the automotive industry.

Japan and America have followed China with 90 percent LTE penetration which supports evolution from LTE to 5G mobile standards, technology, trials, development, and demos. Many growing requirements and demands from a 5G perspective target higher data capacity, increasing throughputs and decreasing latency to support better multimedia broadband services. 3GPP actively continued focusing on the enhancements and deployments of LTE while at the same time has many trials of defining the 5G specifications and applications.

5G is recently a hot research area that addresses the demands of 2020 and after, one of the most critical 5G scenarios is the high mobility which has been proposed clearly. Low delay, reliability and high mobility metrics define 5G performance metrics. Such key metrics should significantly meet the specified requirements in V2X communications. 5G is a competitive radio technology as it will support the V2X needs with high capabilities, high mobility, high data capacity, reliability, full coverage, and guaranteed delivery, as well as it promotes compatibility with different enablers.

Therefore, this chapter is proposed to introduce the 5G based V2X challenges, comparison between DSRC and cellular V2X (C -V2X) aiming to discuss the significant technical issues and scenarios as well as the security directions for the proposed 5G. We consider this chapter to be the first technical tutorial that analyzes the 5G based V2X requirements and the ongoing standardization trials of the LTE-based V2X deployment as all the existing efforts are white papers and announcement articles from the automotive, commercial side.

Chapter Objectives

In the following sections, we are going to discuss the following:

- Studying the previous vehicular communication technologies as well as the drawbacks of each technology
- Providing detail description of the Celluar V2X requirements and enhancements

- Discussing the cellular evolution from the Long Term Evolution (LTE-4G) radio technology to the expected 5G
- Introducing the currently proposed technologies for enhancing and evolving the 5G within vehicular communications
- Offering the new V2X requirements while adopting the 5G-NewRadio
- Studying the supported V2X use cases in the 5G mobile networks
- Introducing the new V2X system structure for the new radio spectrum and explaining the supported services with the critical requirements of each service
- Description of the expected security solutions for the 5G-V2X and the previously applied methods
- Explaining in details the advantages of 5G over LTE and IEEE802.11p standards
- Defining radio design, system features, performance metrics and the critical challenging in 5G based V2X
- Summary of the standard efforts in vehicular communication from the academic perspective and automotive-industrial perspective
- Proposing the conclusions and the future trends of cellular V2X within 5G

Vehicular Communication Technologies

As we mentioned before that the main target from vehicular-communication is providing safety and decreasing the cost of traffic accidents. Worldwide Road accidents annually cause nearly 1.2-million deaths according to the World Health Organization (WHO) and more than 50-million persons injured in traffic road accidents. American Automobile Association (AAA) announced that car accidents cost America 300-billion dollars per year. Vehicular-communication infrastructures are deployed according to many standards, such as DSRC/WAVE, IEEE 802.11P, and Infrared techniques. The extensive deployments of vehicular-communication infrastructures are of a high cost which demands a significant investment overhead. Further, Wide Area Networking (WAN) technologies such as 2G/GPRS/EDGE,3G/UMTS/HSPA/HSPA+, and 4G/LTE have also been used for vehicle communications, but these suffer from location accuracy which could be improved by a secondary mechanism such as GPS. On the other hand, the concept of vehicles communicating with each other has been the subject of research and development initiatives for many years.

However, the level of adoption of V2V techniques in modern vehicles has only recently started to increase, and it is still far below satisfactory levels. Lately, through the connectivity available coverage, vehicles have started getting connected to the internet, giving birth to several applications that fall in the realm of V2B (Vehicle-to-Business) communications. Last but not least, the increasingly rising utilization of smart devices has produced a new generation of mobile applications so that a driver can connect to his/her vehicle remotely (Geiger et al., 2012).

With the term V2X, Vehicle to Everything communication, the possibility for a network of communicating in all possible modes is intended; V2V, V2I, and V2P. V2X has been standardized both in US and EU through different architectures, respectively by WAVE (Wireless Access Vehicular Environment) and ETSI (European Telecommunications Standards Institute), both based on dedicated short-range communication (DSRC) technology. VANETs architecture differs between standards, although there are some basic blocks that we can mention and that characterize the network:

- **Road Side Unit (RSU):** A fixed access point along the road to provide security services and infotainment services for the road vehicles
- **On-Board Unit (OBU):** A communication facility equipped with each vehicle to provide connection.

The communication from vehicle to infrastructure and vice versa are handled by the RSU which communicates with the vehicle within its communication range. V2V communications can happen outside the coverage area in different ways through the onboard units present in vehicles. V2V and V2I differ among each other in the purpose and the need for infrastructure. V2I needs a centralized network in which the nodes are moving at high speed (vehicles), so they can create wireless links for a short time. V2I communication is proposed to support non-safety-oriented applications (Dey et al., 2016). In the next section, we discuss the existing standards of V2X: The DSRC/WAVE/IEEE802.11p and the next generation of V2X (C-V2X), then moving to the upcoming V2X based 5G-NR. Analyzing the drawbacks of IEEE802.11p standard and comparing the use cases with addition to the radio technical features.

V2X Based DSRC/ IEEE802.11 p

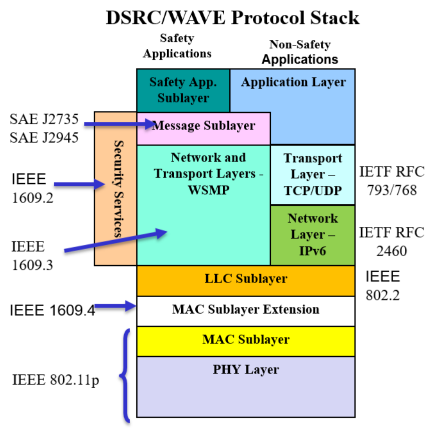
DSRC standard was designed to meet V2X services requirements with higher performance. The American Federal Communications Commission (FCC) in 1999 defines the 5.9 GHz as the communication range for V2X, IEEE802.11p is the extension of Wi-Fi standards (IEEE802.11a) which operates without a base station in the ad-hoc mode. IEEE802.11p is optimized to handle the mobility conditions generated by high speeds under the existence of obstructions such as Doppler shifts, and multi-path reflections. Carrier Sense, Multiple Access with Collision Avoidance (CSMA-CA) (Yin et al., 2004) and Distributed Congestion Control (DCC) in IEEE802.11p, handle the high-density congested scenarios efficiently. DSRC standards propose many V2X requirements for safety and non-safety services and applications. IEEE 802.11p is one of the DSRC protocol stacks developed to support the ad-hoc communications between vehicles and infrastructure. A lot of changes are made to the DSRC Physical and MAC layers to enhance and support the ad-hoc communication mode. The main goals of the 802.11p/DSRC are supporting road traffic safety and preventing traffic accidents within the bandwidth spectrum from 5850 to 5925 MHz for all vehicular communication modes (V2V, V2I).

DSRC Protocol Stack Layers

Figure 2. describes the DSRC protocol layers which are illustrated briefly in this section. The main significant functions of DSRC layers are defined as follows:

- **IEEE 1609.4:** It's a MAC sublayer extension on top of 802.11p layers and supports the upper layer operations across multiple channels without any knowledge of the physical layer parameters.
- **IEEE 1609.3:** Is responsible for connection set up and management of WAVE integrated devices
- **IEEE 1609.2:** Defines the security framework functions and requirements for the safety and non-safety application messages.

Figure 2. DSRC/WAVE protocol stack



- **The PHY layer of IEEE 802.11p:** Defines the modulation, coding, error correction mechanism, demodulation, etc. and supports 10MHz channel bandwidth.
- **IEEE 802.11p MAC sublayer:** Defines messages frequency and format to establish a connection in a harsh vehicular environment. It describes the signaling mechanisms and interface functions as well, to provide direct communication between vehicles without infrastructure assistance. The physical and MAC layer messages formats, modules and frame structure in 802.11p are similar to the defined Wi-Fi IEEE 802.11a standards.

V2X REQUIREMENTS IN IEEE 802.11P

Reducing the Communication Overhead

V2X safety services and applications depend on beaconing messages which are broadcasted periodically by each vehicle and that leads to a considerable communication overhead. Significant communication overhead affects the network performance by consuming the shared bandwidth and increasing the latency due to higher erroneous retransmissions. While a lot of the proposed adaptive approaches for beaconing aim to reduce the latency and the communication load (Defelice et al., 2012), still the IEEE 802.11p current status is not suitable for ultra-low latency and high data capacity applications.

Supporting a Variety of Applications

V2X networks can host different types of applications besides safety services; the non-safety applications such as infotainment, gaming, chatting and internet sharing. These types of applications introduce some new requirements compared with the safety-applications as safety beacon messages are too sensitive for delays while non-safety-applications like gaming can tolerate different levels of delays. IEEE

802.11p supports a diverse type of services and applications by depending on the RSUs infrastructure to cope with the intermittent connectivity effect which is essential for infotainment applications. For early deployment phases of V2X, RSUs are not entirely widespread; therefore, IEEE 802.11p for functional applications diversity does not meet the requirements.

An Efficient Congestion Control Mechanism

The dedicated IEEE 802.11p spectrum is fully optimized due to the periodical broadcasting of beacons which makes the communication range spectrum quickly reaches its capacity and doesn't scale for high-density networks. Any communication standard should incorporate congestion control techniques to minimize congestion and increase the probability of sending event-driven messages. IEEE 802.11p includes contention-window techniques, power transmission, channel capacity, vehicles density, and messages frequency to decrease the congestion, but all of these methods are not sufficient for high-density and large-scale networks.

Fairly Access to Network Resources

Due to the mobility conditions and variations of communication patterns in V2X, each vehicle within a single communication range has different views about the network state and topology. According to the traffic situations, each vehicle has different communication requirements including the transmitted power, the messages frequency and the channel access time. In IEEE 802.11p, all vehicles share the same communication medium and same network resources, to ensure fairness access concept, IEEE 802.11p must define an efficient accessing approach to enable management and coordination between vehicles about the topology and network states.

Practical Reliability Solutions

V2X safety-applications require reliable and low latency delivery for high priority messages. Because of the limited validation of beaconing messages, there are no practical retransmission and acknowledgment mechanisms for wrong messages. Furthermore, the received messages are considered not valid according to the attached timestamp and dropped if the sender is not legitimate. An efficient priority mechanism must be introduced to improve the reliable delivery and time-constrained conditions of beaconing messages conditions. However, in IEEE 802.11p especially for large scale networks, a lot of wrong messages still occur because of the limitation of the available spectrum that results in unreliable delivery within this standard.

Security Measures in IEEE 802.11P

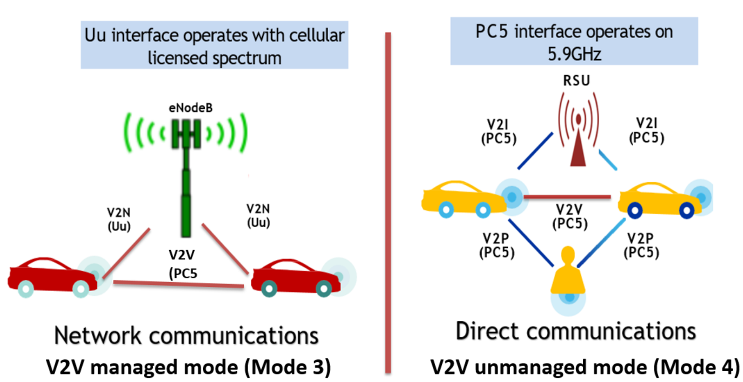
IEEE P1609.2 standards are proposed to define the cryptography mechanism such as elliptic curve cryptography, safety messages formats, certificate formats, and hybrid authentication methods (Samara et al., 2010). It is responsible for message broadcasting which are related to safety-applications. The messages format contains adding a time stamp to ensure the freshness of the message and avoid sending it again with outdated information to all vehicles which prevent the replay attack, for that a tight synchronization is needed.

The standard security mechanism in 802.11p depends on the Public Key Infrastructure (PKI) protocol which maintains the Elliptic Curve Digital Signature Algorithm (ECDSA) (Haidar et al., 2017) to sign the messages between vehicles. However PKI has many drawbacks such as attaching the certificate with each message that results in high communication overhead and high processing time. As the network density increases, low latency applications are proposed, and new security requirements are introduced and become a challenge. For that, PKI solution can't satisfy the new conditions which needs a lot of security enhancements and lightweight solutions to provide message and driver authentication, integrity, anonymity, privacy, certificate unlinkability. As mentioned earlier, IEEE 802.11p does not entirely satisfy the requirements of the V2X network and that motivates moving from WAVE standard to cellular standard especially the 5G technology. Nowadays, a few documentation and trials of standards about introducing the 5G in V2X communications are proposed (Al-kahtani et al., 2012). In this chapter, we present the primary lines of 5G based V2X communication.

C-V2X RELEASE 14/15

The newest standards related development is Phase I and Phase II of V2X support in 3GPP. Phase I has been completed for Long Term Evolution (LTE) in Rel-14 [3GPP17- 23285]. Phase II is aimed for evolution towards 5G in Rel-15 and beyond (Tseng et al., 2015), Phase I is specified for supporting limited messaging services, such as Cooperative Awareness Message (CAM) or Decentralized Environmental Notification Message (DENM). There is no advanced QoS support, no Study on the enhancement of Ultra-Reliable Low-Latency Communication (URLLC) support in the 5G Core network. 3GPP LTE-V2X (PC5) (LTE side-link) which is the radio interface specified for Proximity Services (ProSe) D2D SL in Rel-12 and Rel-13 is enhanced for high velocity, high network density, and shorter latency V2V support. LTE-V2X was standardized by the 3GPP in 2016 under the umbrella of LTE Release 14 and encompassed two interfaces as shown in Figure 3:

Figure 3. C-V2X Communication modes



Wide area Network LTE Interface (Uu): It's responsible for connecting end-users and vehicles to the base stations of mobile network, as well as supporting the Internet and Vehicle to Network (V2N) services.

Direct communications Interface (PC5): It's responsible for connecting Vehicles to Vehicles (V2V), Vehicles to Pedestrians, Vehicles to Infrastructure (V2I) in addition to other vulnerable road users (V2P), for provision of low-latency and high-reliability vehicular services.

The LTE-V2X (PC5) interface does not necessarily require assistance from a mobile network; PC5 enhancement for V2P is mainly from the power efficiency point of view. V2V communication with PC5 interface can provide two different modes:

- **PC5 Mode 3 (managed mode)** operates while the UE is scheduled and regulated by the cellular infrastructure, and
- **PC5 Mode 4 (unmanaged mode)** is turned when the UEs communicate independently from the cellular infrastructure. PC5 Mode 4 interference and scheduling management of traffic between vehicles are provided based on some distributed algorithms, while PC5 Mode 3 interference management and scheduling for the V2V traffic is supported by the base station (eNB) control signaling over the Uu interface.

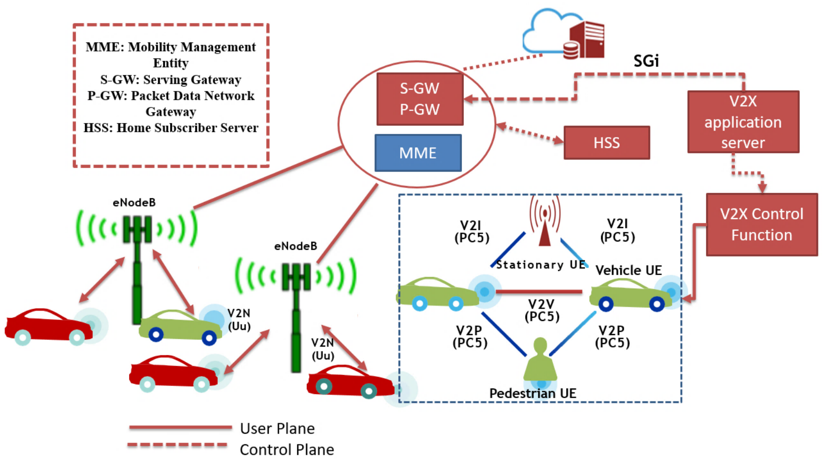
The Uu interface is enhanced with Uplink (UL) Semi-Persistent Scheduling (SPS) and Multimedia Broadcast Multicast Service (DL MBMS) for V2X. RSU is a stationary infrastructure to support V2X applications and exchange messages with other network entities supporting V2X applications via PC5 or LTE-Uu interface. LTE-V2X contain different types of RSU: UE-type RSU and eNodeB (eNB)-type RSU. The stationary RSU is not considered as a fundamental architectural entity, but it's an implementation option (Tseng et al., 2015). The LTE-V2X network structure is a collection of the V2X application server with additional network entities as described in the next section.

LTE-V2X Network Architecture

LTE-V2X structure (Sun et al., 2016) is composed of five fundamental components according to the 3GPP-Rel14/15 definitions; the architecture is described below and shown in Figure 4:

- **User-Equipment (UE):** Is defined as the end-user devices which are directly connected with the stationary RSUs, the eNodeB and other UEs.
- **Evolved Node B (B):** Is the cellular base station to provide the communication interface for the LTE network. ENodeB allows sending and receiving messages between all UEs through one cell or between different cells.
- **V2X Application Server:** Is the network entity responsible for V2X messages distribution to many specific areas.
- **V2X Control Function:** Is the network entity which manages vehicles authentication and revocation processes. After successful vehicle authentication and key generation phase, it provides many security services for vehicles.
- **Multimedia Broadcast Multicast Service:** It is responsible for supporting efficient multicast services delivery over broad areas covered by multiple communication cells.

Figure 4. Network architecture for supporting V2X in LTE



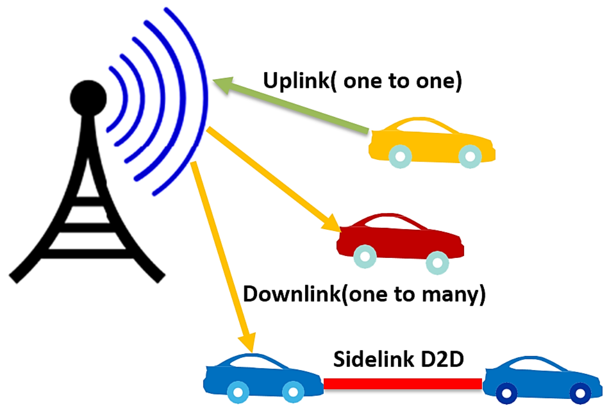
In LTE-V2X communication, two different links to recognize the connection between the eNB and UEs. The uplink communication to define any transition from UE to eNB and the downlink communication represents the transmission from eNB to a UE as shown in Figure 4. The cellular based communication covers a high-density with a vast communication range network and used by the V2X application server to provide a broadcast connection to all vehicles within one cell or to send them to the network server via a unicast-connection. LTE-V2X supports the one-to-one communication between the UEs and eNB through the uplink communication in addition to supporting one-to-many communication through the downlink connection.

LTE Sidelink connection is the adaptation of LTE core standard which allows the communication between two or more devices by using Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) technology without the assistant of base station coverage.

D2D technology is used within the out coverage network scenario and used with the conventional LTE mobile network connections to create a wide variety of vehicle services. D2D connection supports any LTE frequency band through the 5.9 GHz which are allocated for ITS applications and services. eNB uses the service of single-cell point-to-multipoint for any transmissions through a single cell and the multimedia broadcast multicast service for multiple cells communications.

Device-to-Device communication (D2D) (Doppler et al., 2009), enables what's called with side-link direct communication between the nearby UEs without any assistant of eNB as shown in Figure 5. D2D connection can support multi-hop transmission between vehicles which enhances the end-to-end reachability. Moreover, it promotes short-range communication with low latency for vehicular safety messages. D2D communication allows the UEs to directly connect without network coverage and enable data transmission directly between UEs over the side-link. Each D2D pair connection can communicate via two modes (Inband or Outbound) as described in details in Table 1. According to all new features in LTE considering the D2D communication, we conclude this section by mentioning the benefits of LTE technology for V2X communication compared to DSRC and WAVE standards.

Figure 5. LTE-V2X different communication Links



The Advantages of LTE-V2X Over DSCR

- **Better Comprehensive Coverage:** In LTE, receivers have high sensitivity compared to DSRC receivers which enhance the coverage performance over the DSRC especially when the signals are weak. LTE uses Turbo coding (May et al., 2010) which improves the signal gain rather than the DSRC convolutional coding in addition to the single-cell and multi-cell techniques which provides broader V2X network coverage.
- **Cost-Effectiveness:** The effective infrastructure penetration of the LTE network such as eNB base stations and core network servers makes the deployment of LTE considered as an efficient technology to support full connectivity for road pedestrians and vehicles without adding extra cost. As mentioned before RSU can be deployed as eNode while the V2X application server is placed inside the Evolved Packet Core (EPC) of the LTE (Chen et al., 2017).
- **Efficient Multiplexing:** As LTE supports at the same time multiple-transmission from multiple-UEs within one frequency domain multiplexing while in case of DSRC only single vehicle can access a channel at one specific time. LTE is using the frequency domain multiplexing which enhances the performance, especially with high-density scenarios.
- **Higher Scalability:** LTE supports the orthogonal resource-allocation to each UE which decreases the collisions between vehicles and enhances scalability, even if the network density is very high. DSRC standards provide random network access which makes it unable to scale with high-density networks and results in a lot of messages collisions. DSRC can't provide reliable delivery in highly congested networks.

Table 1. Inband and outband device to device communication

Inband-mode	Outband-mode
• It uses the mobile spectrum for D2D and cellular communications. • Both D2D and cellular communication can reuse and share the same spectrum resources and improving the radio spectrum efficiency. • The possible collisions and interferences between D2D and mobile connections are considered one critical drawback for in-band communication. • Overlay communication entity allocates the cellular resources for D2D communications between the transmitter and the receiver to minimize the collisions and interference between D2D and mobile links	• It uses the unlicensed radio band like 2.4 GHz medical radio band, industrial, scientific. • It must support a new interface to provide Wi-Fi and Bluetooth direct connections. • RSU can be deployed in two different ways; first as stationary UE which receives the V2X messages through the sidelink. • Second, as eNB where it gets all V2X communication via the LTE-radio interface Uu and in this case, the V2X-application in vehicles communicates with the analogy V2X-application server in eNB.

V2X Requirements in LTE-V2X

- Communication with or without coverage of base station as in 3GPP project Rel-14 depend on PC5 interface which allows V2X entities to broadcast messages directly to each other if the network coverage exists or not.
- In LTE cell mode, the V2I communication leverages a lot of benefits such as a convenient scheduling and coordination management which is achieved by a series of n base stations.
- LTE cell mode can't be applied in many scenarios such as rural areas without coverage, high-mobility users with handovers and highways for that, some reliable situations without strong coverage should be addressed in LTE-V2X scenarios.
- Standalone communication on a licensed or unlicensed spectrum.
- Improving the D2D functionality to support high-density scenarios with low-latency and high speed. Although, a lot of standardization efforts and recent contributions are introduced still a lot of issues are not discussed yet which makes LTE-V2X not reach its maturity yet.
- Supporting vehicular communications with mature and widely deployed LTE, that is, LTE for the vehicle (LTE-V), is becoming a rising star for vehicular communication networks.
- Currently, the standardization and commercialization of LTE-V are both under active development. As the next generation of the cellular network, 5G, is coming forward. Different from all previous standards, 5G for the first time lists the Vehicular communication network as one of the typical application scenarios.
- 5G-enabled vehicular communication is calling nowadays to support additional future applications for vehicles, such as intelligent and autonomous vehicles, for higher reliability and lower latency transmission of an enormous amount of data. As a result, the research and design of 5G-VCN are very challenging and are receiving significant attention.

Security Measures in LTE-V2X

LTE security is designed based on the LTE communication architecture mentioned previously in Figure 4. The mutual authentication between the user devices and the LTE core network can be done by depending on the Evolved Packet Core, which is responsible for authentication, key generation, and integrity. UEs establish different sessions with different keys while the session keys are generated using the integrity and ciphering key. When a UE communicates to the LTE network through the Uu interface, the Mobility Management Entity (MME) is executing the mutual-authentication with the UE end user device. First, The UE sends an authentication authorized request to the MME entity to ask for access rights to the LTE resources. Second, the MME checks the validity of the request and forwards it to the Home Subscriber Server (HSS), which is connected beside the authentication-center to monitor and manage the end user authorizing. Third, the authentication-center generates the authentication keys and cryptographic material for the requested UE and sends them to MME (Zhao et al., 2017). However, the requested token which is sent by the UE clear and not protected, after the mutual authentication is done, the session key is exchanged between the MME and UEs, which allows the UEs to access the LTE core network. UE uses the pre-shared session key and integrity protocol for packets transmitted over the LTE network. However, for the user-plane data, the only encryption algorithm is applied between the eNB and UE (Ahmed et al., 2018).

Before vehicles start D2D communication, it must finish the authentication phase with the LTE core network (Toukabri et al., 2014) as the LTE core network is capable of handling the authentication parameters depending on the network availability which directly affects the level of security for the D2D communications.

UEs connectivity is based on three scenarios, as described below:

- **In-Network Coverage:** When the UEs are located in the same network coverage, they securely communicate by the core network assistance.
- **Partial Coverage:** When one of the connected UEs is located within the network coverage, all communications are managed securely by the LTE core network. Also, the LTE core network can handle the security of the communicated UEs. While both of end user devices are located at the edge of eNB network coverage, they can be connected to the covered UEs using the D2D interface to forward their requests the eNB.
- **Out-Network Coverage:** When the UEs cannot be connected to the LTE network core, each UE must keep the authentication-vector and security parameters assigned previously by the authentication center while the UE was in the network coverage. UEs use the already generated authentication vector to secure the D2D communication while the end user devices are located in the out-network coverage.

C-V2X ADVANTAGES AND FEATURES

Readiness and Time-To-Commercialization

C-V2X is ready for production in vehicles by 2019 using Qualcomm technologies and ecosystems such as 9150 C-V2X chips (Patzold et al., 2018). 3GPP Rel14/15 with a direct PC5 interface is prepared and supported by broad ecosystems including the suppliers, automakers, module manufacturers, automotive developers, semiconductor companies, mobile operators, test-equipment sellers, road operators, telecom-suppliers, traffic signal suppliers. One of the evidence of the readiness of C-V2X can be seen in many 5G Automotive Association (5GAA) (Papathanassiou et al., 2017) announcements which has more than 80 essential members evolving major carmakers from different regions. C-V2X Design requires the utilization of the ITS-software and standards developers, promoting great investments which are compatible despite the radio swapping out. C-V2X's makers reduced the time of development by radio swapping-out, that is very common in any wireless technology, and changing the features of the PHY/MAC while preserving the upper layer's applications and software. Implementing C-V2X into wireless communication modems can accelerate the commercial market while supporting the integration of C-V2X within vehicles.

Superior Radio Performance

LTE technology brings a lot of significant improvements in coding and modulation in addition to better enhancements in the LTE receiver's designs. LTE technology advances offer to allow the up-coming C-V2X increase the communication range by two times in case of Line-of-Sight and even better performance of Non-Line-of-Sight, decreasing of the packet error rate to enhance reliability, supporting higher network capacity, and offering superior congestion control mechanisms especially in denser networks compared to previous LTE and IEEE 802.11p radio technologies. IEEE 802.11p CSMA protocol suffers from the existence of the hidden terminal problem in the physical layer which leads to many packet collisions. C-V2X is designed to take care of resource allocation to make sure that two vehicles in the same communication range do not use the same resources in the same subframe which leads to performance improvements, especially in dense scenarios. A lot of automakers with years of experience prove that C-V2X/Pc5 has superior performance over EEE 802.11p. The Initial test results from Qualcomm show the benefits of C-V2X with direct communications over 802.11p-based solutions (Mavromatis et al., 2018).

Significant Expected Enhancement

C-V2X direct communications are not like 802.11p as it is designed to enhance the performance by the 4G minimum radio requirements to deliver practical scenario enhancements. 3GPP defines the minimum Block Error Rate requirements for different speeds up to 500 km/hr to provide reliable communication in the existence of fading, time errors, frequency errors, high Doppler effects. The C-V2X chipset vendors should comply with C-V2X direct communication specifications leading to a uniform and predictable performance. 802.11p standards do not define the minimum performance requirements; for that, its performance can't be suitable or predictable for automotive practical safety applications. The lack of time interleaving between symbols makes 802.11p prone to interference and susceptible to short bursts.

Compatibility

C-V2X is the evolution path to 5G and should support backward and forward compatibility. Through the design of C-V2X it depends on the latest wireless communication advances while still preserving backward compatibility. Rel-14/15 C-V2X has an expected evolution to C-V2X based 5G New Radio (NR) with additional capabilities. Rel-14 is essential for basic safety applications between vehicles. C-V2X based 5G -NR is proposed to support the advanced high reliability and high throughput vehicular automotive driving applications. C-V2X based 5G -NR is designed to support wideband, high throughput, ultra-low latency, reliability, and carrier support for autonomous driving cases, such as 3D HD map updates, sensor sharing, and internet sharing. The direct communication of C-V2X does not rely on mobile cellular networks, R14/15 and future expected releases might operate without network infrastructure assistant or depending on the wireless network coverage. The evolution path for C-V2X technology from Rel14/15 to the upcoming C-V2X based 5G-NR will offer safety, reliability, robustness and various rice experiences.

Cost-Effective

C-V2X technology can be combined with cellular chipset products to make the C-V2X solutions cost-effective and cheap compared to the 802.11p/DSRC. According to the North America consulting firm P3 about the full integration of C-V2X with the LTE based units, the integration process will be cost-effective amongst all V2X implementations.

ITS Spectrum Investment

Like any new wireless technology, C-V2X communications is defined to work on the ITS spectrum which reduces the development time by a radio swap-out and reusing the previous software and applications. It’s expected to benefit from previous V2X standards, and security protocols. Furthermore, it will uses the transport layer’s protocols that proposed in ETSI/ISO/SAE/IEEE1609 (Naik et al., 2018).

Supporting High-Speed Scenarios

Cellular communication has been proposed for high-speed mobility compared to Wi-Fi technologies which were designed to replace the Ethernet. There is a lack of improvements in the physical layer of the DSRC stack, which needs a new receiver implementation to cope with the high speeds. C-V2X communications have the advantage of cellular heritage which designed are for high-speed autonomous use cases. R14/15 C-V2X communications support up to 500 km/h relative speed in ITS spectrum 5.9 GHz band. The signal C-V2X design offers reliable performance at high-speed scenarios without any advanced implementation for receivers.

Ultra -Low-Latency

The purpose of designing C-V2X is to support low latency communications such as safety road messages which can be sent in the global 5.9 GHz ITS band with low latency at most 4ms or less according to the type of application.

Robust and Tight-Synchronization

C-V2X offers robust tight mechanisms to support synchronization and precise positioning based on different sources while the Global Navigation Satellite System (GNSS) does not exit. V2X applications rely on the GNSS techniques for the location information, which is vital for V2X safety services.V2X entities can lose the positioning-accuracy in case of weak GNSS signal coverage. If the GNSS is weak, 3GPP defines another synchronization source such as RSU timing, eNodeB, and other nearby vehicles.

Security in C-V2X

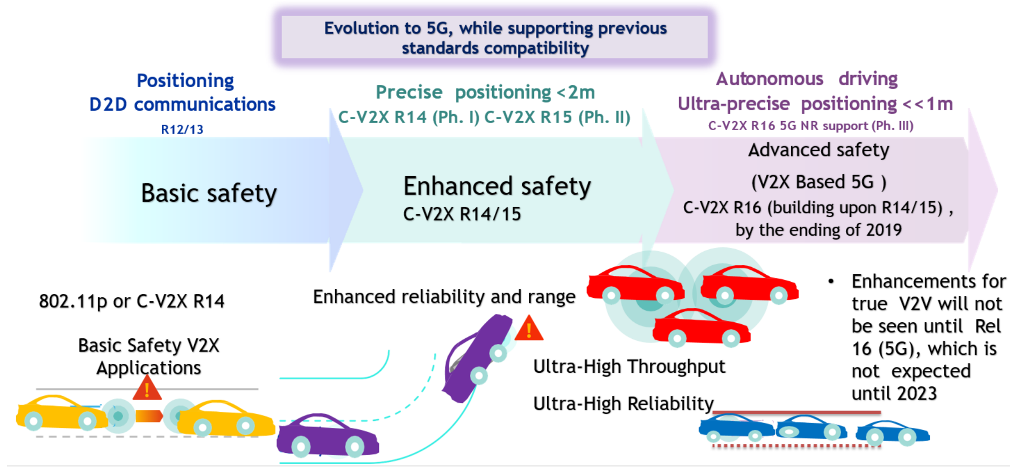
Security is essential for vehicular applications as C-V2X can depend on the established security layers and application protocols defined by the standards communities and automakers agencies. Moreover, the revocation and certificate distribution can be done using the cellular infrastructure communications.

CELLULAR NETWORK EVOLUTION: FROM 4G TO 5G

LTE the fourth mobile generation which provides the skeleton for 5G. The predicted 5G signals are going to be transferred through a massive number of small base stations located in different places like building roofs and light poles. 5G unlike 4G which is based on large high power base station towers to transmit signals over a long distance, depends on multiple small base stations to support the millimeter wave-spectrum between 30 GHz -300 GHz to generate the 5G ultra-high-speed signals that travel short distances and immune to weather and building obstacles interference (Wang et al., 2014). Previous generations of wireless technologies depend on the lower frequency spectrum bands. The millimeter wave challenges related to distance and interference are introduced. The mobile industry is using lower frequency spectrum for upcoming 5G networks so the radio operators can use their spectrum to construct the new network structure. The previous Lower frequency spectrum transfers the signals for long distances but with low capacity and speed than the millimeter wave. 5G represents the latest effort of telecommunication and industry communities to evolve the already existing wireless technologies towards the well-performing 5G new generation. 3GPP has been working on Rel 15 and 16 during some years ago and called them 5G phase 1 and phase 2; Rel 16 is about to be announced as shown in Figure 6.

A 5G must be a platform which enables many wireless connections to different existing and future services which moves the wireless networks towards the extensive mobile broadband networks. 5G is predicted to be the next new generation of mobile communication which targets high requirements applications with ultra-low latency, ultra-high throughput, and high reliability to provide promising C-V2X use cases. A lot of new features for 5G NR are proposed, such software-defined networks, Proximity Service (ProSe), and fog/cloud computing. 5G is not only predicted to support the inter vehicles communication but also participating as an integrated part of the future C-V2X system. One of the critical 5G features is the Proximity Service (ProSe) which is provided by the D2D communications. ProSe service is to present awareness by identifying the nearby devices and the deployed services depending on the relative locality data. The ProSe is proposed in 3GPP Rel 12 specifications; ProSe is a D2D technology which allows the LTE enabled devices to discover each other and communicate directly. ProSe depends on various improvements to the existing LTE- standards by including many new functions with a sidelink radio interface for the direct communication between the LTE devices. In comparison to the current D2D

Figure 6. Evolving LTE-V2X towards 5G



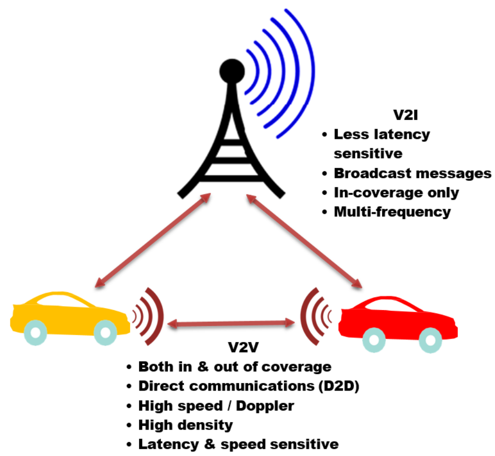
and the future proposed proximity service technologies, ProSe is going to offer many benefits including better manageability, scalability, privacy, battery-efficiency, and security. Currently, many efforts have been done to commercialize the ProSe technology by the public Intelligent Transportation System, and essential communication sectors, to support the ongoing enchantment from the Land Mobile system to the LTE and 5G networks.

C-V2X is intended to be completely compatible with 5G, expecting great investments in 5G infrastructure and modules. The effective deployment of commercial 5G technology by 2020 onwards by the 3GPP will target the C-V2X applications in several different ways to support:

- High-precise ranging and positioning to encourage cooperative and automotive driving.
- Higher throughput and lower-latency to enable infotainment applications which require critical timing conditions.
- High throughput to build and update the dynamic maps by the help of camera and data sensors, which can be distributed at roads intersections.
- High reliability and low latency for the high-density platooning scenarios.
- 5G is expected to support massive numbers of concurrent connections in a small road area to allow vehicles to gather information about the surroundings.

In the following sections, we introduce the key features for 5G and the challenges expected for the future of V2X. In the future C-V2X based 5G, V2V and V2I will be enhanced by defining some different metrics and requirements for their applications. The V2V and V2I performance metrics in V2X based 5G is expressed in Figure 7. For V2V communications, to support the high data rates, low latency, and availability of direct communication, while the network coverage modes are IN or Out, for that a lot of D2D enhancements are needed. For the case of V2I connections, it’s less sensitive than V2V; it supports one-to-one communication with addition to one-to-many communications, which is supported only as the base station covers vehicles.

Figure 7. 5G V2V and V2I performance metrics in 5G



5G Challenges in Vehicular Communication

Although 5G-NR is a promising technology for vehicular communications and applications, it still faces many critical challenges. In this section, we describe these challenges and the predicted 5G enhancements.

Ultra-Low Latency and Ultra-High Rate

Autonomous driving requires real-time data exchanging and self-driving mode to facilitate the connectivity between vehicles and the LTE/5G network core. This information may include speeds, locations, or video streaming and high-resolution 3D maps. For Ultra-low latency requirements, a time delay must be on the scale of microseconds, and the data exchanging rate should be ten times per second. However, a lot of 5G techniques such as mm Wave communications, Massive MIMO and D2D have been tested and proposed to achieve the ultra-low latency and ultra-high data rate communications, still all tests and experiments are run with static and low mobility conditions. The network architecture and channel conditions in V2X networks are different from the traditional cellular networks structure, due to the high mobility in V2X leading to critical interference and fast channels fading, and this will degrade the 5G network communication performance. Moreover, the vehicles' high movement, the frequent changes of network topology, and the Quality of Service (QoS) requirements, still the data dissemination and network resource accessing designs face significant challenges (Yilmaz et al., 2015).

System Architecture for 5G C-V2X

The design of the 5G based V2X network architecture for V2X networks should be carefully analyzed to choose the particular requirements of vehicular applications and services. An entirely centered distributed architecture is required to adopt the real-time communication requirements to control the information exchanging and coordination between vehicles. This 5G C-V2X system architecture must be safe, open, and efficient that allows efficient data broadcast, end-to-end communication delay, self-organization, and dynamic control of the high-mobility vehicles. Scalability of the network is a critical requirement to ensure the expected future integration with the upcoming smart grid networks with electric powered cars.

Environmental Sensing Technology

5g is expected to provide beyond visual Range (BVR) environmental information for inter-vehicle communication. 5G serves as a virtual sensor for the inter-vehicle connectivity in addition to the vehicles' onboard sensors like millimeter radar, multi-beam LiDAR, and video camera. Optimizing the remote heterogeneous and local sensors connectivity with various levels of latency and resolution is considered another critical task for 5G C-V2X. Once this issue is correctly solved, this could significantly improve the environmental sensing perception of each vehicle.

THE PROPOSED TECHNOLOGIES FOR 5G

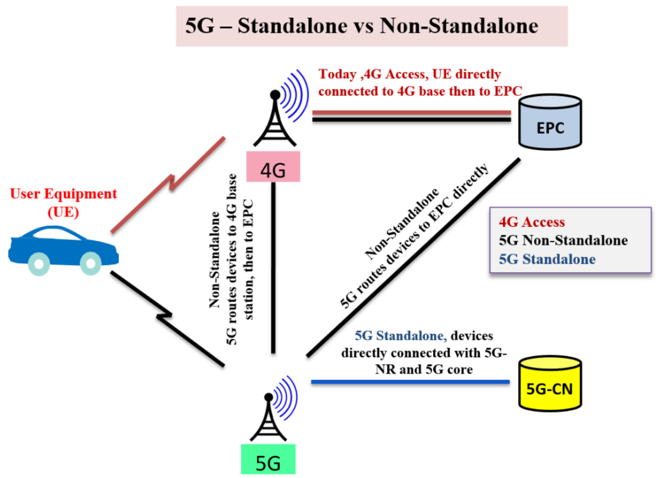
5G-New Radio (5G-NR)

Besides enhancing the LTE-Uu and PC5 interfaces, 3GPP has announced the launching of NR standardization as the first phase of 5G system design in Release 16 to enhance C-V2X applications in different ways within the 5G NR Release 16. The NR will include new flexible access techniques with high frequencies to achieve the high capacity, ultra-low latency, massive connectivity, and high-reliability of autonomous driving applications. 5G-New Radio (5G-NR) is the new air interface that is improved for the upcoming 5G technologies. 5G-NR is implemented from the ground up to enhance and support a wide variety of devices, services, and 5G deployments with a diverse spectrum. 5G development is implemented based on the previous LTE technologies to ensures the forwards and backward compatibility (Ghosh et al., 2018). 5G was initially developed by the improvements and enhancements of the available LTE, LTE-Advanced and LTE-Pro technologies, and soon 3GPP introduces the new air-interface for 5G. The 3GPP has made a lot of decisions about the previous mobile technologies to be used in the 5G-NR as a fundamental part of the new architecture.

Today, the devices are attached directly to the LTE Radio and the Evolved Packet Core (EPC) within the 4G/LTE access. Early 5G is called Non-Standalone, as network devices attached to the 5G-NR redirect them through the 4G base station to EPC or route them directly to EPC. While in Standalone mode, devices are attached to 5G radio interface directly and to the 5G network core. The network is shown in Figure 8. The 5G-NR Standalone

(SA) mode was completed by the end of 2018 to provide full control and user plane capabilities using the new 5G core architecture. 3GPP puts compatibility and congeniality at the heart core of 5G NR design for that, the features and skills can be proposed in the subsequent releases of 5G. The accelerated of standards will allow many deployments and trials compliant with the 3GPP standards starting from 2019. 5G-NR is being planned to improve the flexibility, performance, scalability and current mobile networks efficiency and make use of most of the spectrum, licensed, unlicensed or shared, through a wide variety of frequency bands.

Figure 8. 5G standalone and Non-standalone communication modes



Moreover, the 5G-NR interface is only one component of the expected 5G network structure, so it should be efficiently designed as a part of a more extensive manageable network structure. 5G-NR should be ready to deliver a large number of different services presented over a various set of devices with varied latency and performance requirements. 5G-NR should support different large-scale deployment models from traditional macro model to hotspot deployments by allowing new methods for devices connectivity, such as multi-hop mesh and device-to-device. 5G-NR must make all improvements at extreme levels of power and cost abilities.

5G-NR METHODOLOGY

The 5G-NR core design will include three essential elements:

Multiple Access With Optimized Waveforms Based OFDM

OFDM (Orthogonal Frequency-Division Multiplexing) is announced as the multiple-access techniques; however, the exact multiple-access methods and waveforms are not being decided. OFDM waveforms and techniques are used previously by Wi-Fi and LTE, which makes 5G the first generation that doesn't require a complete waveform and multiple access designs like the previous generation. The previous multiple-access methods will be enhanced with advanced abilities to deliver high performance and low complexity while supporting different spectrum bands and types for several applications.

Flexible and Integrated Framework

5G-NR aims at providing a diverse of 5G services with forwarding compatibility to enable efficient multiplexing of 5G services compatibility for the future services.5G-NR will support scalability with lower latency than what's already provided in the LTE previous technologies.

New Wireless Technologies

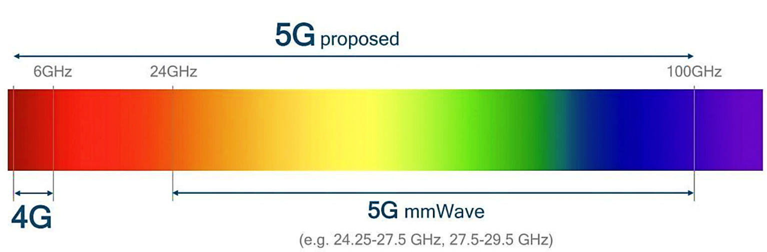
To support new performance metrics and efficiency which will provide a wide variety of the 5G use cases, 5G services are categorized into three types; we introduce them below in addition to the suggested wireless techniques to make them applicable and practical.

- **Enhanced Mobile Broadband (eMBB):** Within 5G a new proposed data-intensive-applications like immersive gaming and video streaming, which need high bandwidth to support high efficiency. The proposed technologies to make this happen include massive MIMO, Gigabit LTE, spectrum sharing techniques, mmWave technologies, and the channel coding advanced techniques.
- **Ultra-reliable and Low-latency Communications (uRLLC):** Sensitive Latency services and Mission-Critical Control applications which need high availability, reliability, and efficient security, like autonomous driving and internet real applications. A lot of technologies are being developed with a particular specification for real-time applications. C-V2X applications with a no-failure requirement and higher priority must use redundant links to support network availability for the end-user.
- **Massive IoT or Massive -Machine -Type Communications (mMTC):** Low energy, low-cost devices with small data exchanging like smart cities Narrowband internet of things services are recommended to be enhanced with a lot of capabilities like low latency, voice support, locations service, mobility and efficient firmware updating over the air. Qualcomm proposes the Resource Spread Multiple Access (RSMA) for the design of efficient uplink multiple-access, as well as an enhanced WAN with multi-hop mesh network architecture to increase the network coverage (Dai et al., 2015).

Millimeter Wave Technology

5G and mmWave technology are used synonymously; however, there are a lot of principal differences between both of them. Mmwave technology is a single part of future 5G technologies. Low band frequencies and sub-6GHz, both of them will represent part of the 5G standards to offer faster data and low latency to customers. The mmWave refers to a particular portion of the radio spectrum between (24-100) GHz as shown in Figure 9, that have very short wavelengths. This portion of the spectrum is unused; for that, mmWave technology aims to use this frequency band with a significant increase of the available

Figure 9. 5G mm Wave radio frequency spectrum



bandwidth. Lower frequencies are congested with radio and TV signals, in addition to the current 4G-LTE networks, which exist between 800 and 3,000MHz. One of the upsides of the short wavelength, it transfers data with faster; however, the preferred distance is shorter.

The objective of mmWave is increasing the available data bandwidth over the small densely populated area. mmWave is a vital part of future 5G to cover many cases such as malls, stadiums, clubs, and any places where the population congestion is the problem. While for long distance coverage such as rural villages and towns, the low-frequency bands like sub-6GHz and below 2GHz will play a vital role in continuing consistent coverage. The mmWave technology has many limits, most of them are in terms of area and sensitivity to the obstacle; however, it runs. 5G's guarantee for faster data rates could displace the demand for the wired fiber lines, lower-latency applications, and improve connections with high mobility. MmWave is the critical technology to build the next 5G generation with highly demanding applications such as autonomous driving applications. To guarantee a high bandwidth and excellent throughput, which can be especially interesting for:

- **V2V communications** among very near vehicles, to support the collaborative-sensing in high-density use cases like a platooning,
- **V2I communications** for mass data transfer, such as objects data recognition and detection, exchanging and updating of the HD-3D-maps from/to the RSU within short time message. The hard propagation conditions may, however, hinder such privileges. Challenges start due to the beam training overhead under high-mobility conditions like the effect of pedestrian bodies (Sakaguchi et al., 2017).

Non-Orthogonal Multiple Access (NOMA)

LTE network was considered as a promising technology to support V2X services and benefits from the already deployed infrastructure. However, with an expected huge number of vehicles which access the system, and make the familiar LTE-OFDM face many issues like congestion due to its low efficiency of the orthogonal access, it results in significant access delay and acting as a great challenge particularly for safety-critical applications. As a promising 5G technique, NOMA is cooperative with new critical enabling technologies for 5G communications. As an example, the different network architecture will present a vital role in 5G networks, as small cell and macro base stations have co-operated for spectrum sharing. The advantages of NOMA for the heterogeneous V2X networks has been demonstrated, as more significant number of vehicles can be served within a small cell by utilizing the NOMA principle. A lot of applications are benefiting from the NOMA technology within the new 5G-NR such as ultra-dense networks (UDN), Machine-to-Machine (M2M) communications, and massive Machine Type Communications (mMTC), while the use of NOMA technology can efficiently support IoT applications and the enormous connectivity of 5G. The Non-Orthogonal Multiple Access (NOMA) method has been proposed as an efficient solution for the upcoming 5G based V2X communications to support broadband and massive connectivity (Islam et al., 2015). NOMA-based C-V2X services become different from the traditional OMAV2X techniques in many aspects; we describe them below:

- **Scheduling Method:** In the conventional OMA-based V2X, the Semi-Persistent-Scheduling (SPS), is deployed as the network resources are reserved by the vehicles each few communication periods. Although, NOMA receiver decoding demands a real-time Channel State Information (CSI) about multiple transmitters for improving the quality of the CSI decoding, an effective scheduling design of the dynamic-power control with the SPS must be considered.
- **Spectrum Management:** NOMA method compared to OMA-based case, offers co-channel-interference by allowing many vehicles to share the same spectrum, which contributes additional dimension enhancing the spectrum efficiency and resources fairness.
- **Power control:** In highly dense networks when the transmitter vehicles broadcast messages in their communication range, an interference happens at the side of the receiver, which requires an efficient design of power control system for transmitter vehicles with NOMA based V2X applications. We consider the applicability of NOMA method for holding different V2X services with 5G based unicast V2X applications and other common scenarios as listed below.
- **NOMA-5G based unicast V2X applications:** The defined unicast model for V2X consists of many V2V partners sharing the same channel concurrently for direct communication. Maybe one vehicle receiver suffers from the co-channel interference from neighboring transmitter's vehicles, and one vehicle transmitter can cause interference to multiple Rx users nearby. Dynamic power control with efficient SPS management system of users is required to be considered.
- **NOMA-5G based V2X broadcast systems:** V2X broadcasting communication is required for critical safety-applications, in which each vehicle can broadcast a periodic packet carrying safety-critical information to all neighbors within one communication range. In addition to the mentioned issues within the unicast scenario, resource allocation in the time domain and Rx-Tx selection of the base station requires to be considered for management of interference.

Multi-Radio Access Technologies

5G will support selection between different Radio Access Technologies (RAT) as the existing 4G LTE and the previous IEEE 802.11p RATs. V2X offers enhancements for RAT selection to provide a reliable and available service for the end user. In V2X communications, use of multiple RATs can accelerate the V2N/V2I communication capacity and throughput to provide dynamic behavior of mmWave technology with beam form techniques, or to provide a redundant connection to improve the performance of remote autonomous use cases. 5G is assumed to support forward and backward compatibility to provide integration with the old radio techniques and any future radio enhancements. The QoS management of V2X applications over the radio air interface Uu and the D2D sidelink interface, depending on the parameters received from the 5G vendors, enablers, software developers.etc., would be the critical enabler for all features which require low-latency, high data rates, and high reliability.

Transceiver Design and Antenna Design

Advanced transceivers can be used on board since vehicles are not limited by small form factors, processing, and power consumption issues. 5G will rely on massive Multiple Input Multiple Output (MIMO), among other techniques, to improve system capacity. The high vehicle speed may, however, hamper massive MIMO operation due to outdated CSI. Multi-antenna algorithms need to be designed that are robust against imperfect CSI, as well as advanced receivers that take advantage of vehicle characteristics (Kim et al., 2017).

In-band Full Duplex (FD)

It is another disruptive technology that improves the spectral efficiency, theoretically doubling the achievable throughput by simultaneous transmitting and receiving over the same frequency band. Recent advancements have pushed research in this area in Self-Interference Cancellation (SIC) and mitigation techniques. The main barriers for the take-off of FD deployment are the harsh and fast time-varying V2X propagation environment that complicates SIC procedures, and the need to revisit the MAC design entirely. The potential of FD techniques has been disclosed for 802.11-based V2X communications, but similar considerations may apply for 5G V2X communications.

Positioning

Satellite-based positioning systems are unable to provide sufficiently accurate position information especially the relative positioning to critical V2X applications (e.g., VRU detection, platooning, and autonomous driving, self-parking) and in specific challenging but typical environments like urban canyons and tunnels. Highly-accurate (sub-meter) positioning can be achieved by combining traditional satellite systems with onboard sensing and infrastructure-based wireless communication technologies (e.g., 802.11, LTE) and 5G radio-assisted techniques (Rosado et al., 2016).

V2X KEY REQUIREMENTS FOR 5G

Dynamic Mobility and High Relative Velocities

5G solutions must support the mobility-on-demand, varying from very high-mobility to low-mobility. However, the principal basis for different speeds depends on the operation and Deployment Scenarios. In general, high mobility limits impose several challenges on the design, modeling, analysis, and evaluations of 5G based C-V2X network. We must note that to support high-mobility conditions in C-V2X based 5G, there are many critical problems to be investigated, for example, the optimal network deployment of the distributed antenna systems and mobile relays, efficient channel-estimating, and massive MIMO technique supporting the high mobility scenarios. Improving the deployed synchronization techniques and signal enhancements with a more significant number of reference symbols to support the high mobility conditions in 5G. Enhancing mobility to support high relative vehicular speeds up to 280 km/h in C-V2X based LTE, and it’s expected to support up to 500 km/h relative speeds for the 5G target (Elayoubi et al., 2018).

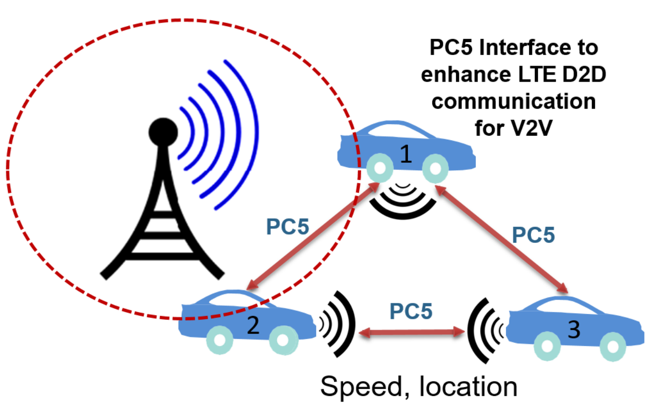
Extremely Low-Latency

One of the fundamental demands in 5G radio systems is reducing the message transmission latency for the Ultra-Reliable and Low Latency (URLLC) services. One of the most leading cases will be V2X communications, V2X inevitably involves moving vehicles with broadband applications; however, latency isn't an issue there. Low latency feature in cellular connection is a requirement for securing autonomous vehicles. Autonomous vehicles must sense road conditions, other vehicles, pedestrians, and all other obstacles. Usually, there should be environmental sensors to supply this information; such data will often be available to autonomous vehicles via RSUs or other vehicles. The Low-latency links among these RSUs, vehicle-based-systems, and the V2X application server lead to quicker decision and improved safety.

As section of a current project, Rohde & Schwarz and Huawei adopted an accurate end-to-end time measurement system in the field of tests. Over-the-air IP communications in 5G-V2X in a moving vehicle were examined for the particular application case of collaborative driving. The accuracy of measurements was less than two μs for each transmitted packet. The broadcasted data included different IP packets such as the ITS beaconing messages, video streaming, and a LIDAR for a remote-controlled vehicle. The accuracy of the total times on both sides was guaranteed by depending on two accurate GPS receivers. The test in Munich focused on vehicles remote control, while tests at Shanghai focused on beaconing V2X communication of platooning scenario, which is V2X use case with several vehicles moving with the same direction and speed.

The packet latency must include end to end transmission time from the source till the destination by adding all transit times, processing time, transmission time, propagation time and any delay caused by the receiver. As latency is one of the most critical indicators for 5G performance and safety-applications so that these measurements could enhance future tests (Cattoni et al., 2015). For 5G based V2X, a direct communication interface is needed for both in and out network coverage to reduce latency and enhance network communication between vehicles. Based on the LTE-V2X, PC5 interface will represent the direct radio interface between vehicles in case of network out coverage. As shown in Figure 10, three vehicles 1, 2, 3 are communicating using the PC5 interface in case of (in or out) network coverage modes to provide extremely low latency in the V2V applications. For that a lot of enhancements for direct D2D techniques such as the physical/MAC layer improvements, and channel estimation with enhanced OFDM to support less than 1ms as a latency design target in 5G.

Figure 10. PC5 interface for D2D mode in 5G



High Capacity for High Message Volume

Concerning V2X communication, a lot of simultaneous transmitters generate messages and broadcast it to all neighbors within the same communication range to share network status or to send accident alerts which result in high network load. Different applications in V2X require different message types to share more than short status messages, like the pre-crash warning messages which represent V2V communication with local broadcasting to only vehicles in the communication range. For high network overhead, 5G must enhance the resource allocation and improve the receiver's techniques using the new 5G technologies for antenna design like adaptive-beam-forming and tracing. Efficient resources allocation can support multiple transmitters requests as shown in Figure 11. Vehicles directly send a unicast request for the evolved base station for resources allocations and future D2D communications. The base station assigns the transmitters resources which allows them to communicate directly using the PC5 interface.

High Reliability and Availability

V2X applications specially safety-applications, need high reliability and availability. To provide precise positioning and ranging, 5G offers using the Global Navigation Satellite System (GNSS) to provide accurate synchronization in addition to the enhancements of LTE GPS timing, especially when vehicles are out of the network coverage. The availability requires modification of the D2D Physical/MAC layers to allow an efficient resource allocation, in addition to multiple redundant connections to avoid network failure as shown in Figure 12. Vehicles can connect to various base-stations at the same time using the radio air Uu interface, while the timing and synchronization processes are done using GNSS.

Figure 11. Resources allocation in V2V with (D2D) communication

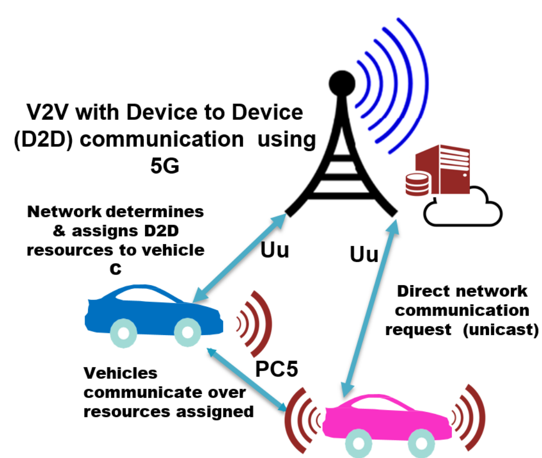
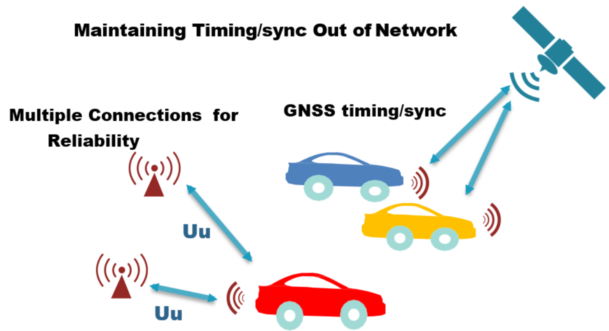


Figure 12. Availability and reliability requirements in V2X based 5G



V2X USE CASES SUPPORTED BY 5G

With the increasing availability of vehicles that can support higher automation levels, the demand for coordination between vehicles becomes more critical. All vehicles depending on the fact that they continuously use their trajectories to select the driving trajectory based on the surrounding environment. Due to safety requirements, autonomous driving sets critical performance requirements for the communication in terms of reliability, delay and capacity. Collective collision avoidance, Cooperative lane change, and convoy management (platooning) are typical models of the V2X use cases which are finally expected to support the fully connected automated vehicles. The connected vehicles trigger a particular use case for protection reasons such as emergency maneuvering or efficient traffic flow using the collected data from onboard sensors, together with the received information from the surrounding vehicles (Boban et al., 2017). 5G based C-V2X will support the deployment of many valuable use cases as shown in Table 2 which are essential for providing highly, cooperative, and fully automated driving for basic requirements of safety and traffic applications. The new generation of autonomous vehicles requires to carry larger traffic volumes and many traffic types with tight synchronization, higher security protection, reliability, and availability. 5G based V2X consists of a programmable multi-layer and multi-technology framework that provides SDN workflow automation and real-time network services.

Table2. 5G based C-V2X use cases

Use cases	Importance
Extended real-time sensors	To enable the exchange of raw and processed data which are collected by the local sensors or live-video data between vehicles, pedestrian, RSUs, and the V2X application-servers in addition to sharing the intentions and trajectories of vehicles to provide coordinated and safe driving.
High-density Platooning	To allow the moving vehicles to dynamically form a group to travel together and to reduce the distance between the vehicles necessarily.
Real-time situation	It is used to exchange the awareness messages and high-definition local maps in the surrounding environment of vehicles in hazardous situations and updating dynamic HD maps.
Tele-operated Driving	to allow a remote driver in a V2X application or an operations center to drive a vehicle remotely for those drivers who cannot drive themselves or to control a remote vehicle that is located in hazardous environments.

5G based V2X supports multiple RAN, including the LTE, LTE-Advanced Pro, and distributed-cloud infrastructure for RAN virtualization and network core functions.

The progress in 5G networks is not only because of utilization and equipment optimizing but also somewhat to the overall framework fulfillment to the requirements of complicated use case as well as meeting the services defined quality. The earlier mentioned use-cases as well as, its general features are supported by 3GPP Rel.14/15 systems, particularly from the radio access perspective. However, 5G will provide optimal principles for these scenarios due to the great support of specific requirements such as supporting of scalability of the vehicle devices edge connectivity with ultra-low latency, and optimum radio access technology. A critical advantage of the 5G is supporting the network slicing to provide exceptional support for the C-V2X applications as a distinct-slice or as a sub-slice. The 5G network slicing technology will support many types of use-cases and services for the C-V2X by enhancing the IoT as well as the MBB critical communications (Campolo et al., 2017). 5G and functionalities like slicing will offer operators unique opportunities to create new sustainable business models.

5G VULNERABLE-ROAD-USERS SCENARIO

This chapter is targeting vehicle communications; however, the Vulnerable-Road-Users (VRU) use case can be proposed to benefit from C-V2X direct communications. It is expected that C-V2X technology will be integrated into consumer electronic devices (electric bicycles, motorbikes, wheelchairs) and smartphones. The basic requirements for any end-user device to integrate and implement the featured V2X use cases must be the following (Jahn et al., 2015):

Precise Location Accuracy

To find the exact position of the VRU user, if the VRU location accuracy is low, this will lead to confusion about the VRU movement behavior and result in collisions probably. Therefore, High position accuracy is needed to avoid any overflow of wrong information. The current 3GPP standardization efforts, as well as the latest chipset vendor's publications, we can note a lot of efforts to increase the position accuracy of the end-user devices. The support of GNSS position correction signals such as Precise Point Positioning (PPP), Real Time Kinematic (net-RTK), and others within the 5G technology can increase the position accuracy of consumer's devices. All these position technologies are expected to be integrated into the consumer's devices very soon.

Machine Learning Techniques

A lot of smart algorithms and machine learning methods are needed to predict and detect the VRU movement behavior and filter the relevant information, on both transmitter and receiver communication sides (VRU and Vehicle). The individualization of the machine learning algorithms to investigate the distinct characteristics of the VRU movement behavior. Many efforts from the smartphone side to improve movement detection performance and enhance its features. Based on a large variety of sensors (e.g., accelerometer, gyro meter…), algorithms can detect staircase movements, steps, and others, to deliver outcomes for healthcare, sports, and other applications. Continuous enhancements are made on the vehicle side to provide an environmental perspective of the vehicle surroundings, using sensorial data-fusion process. It is expected that the future of 5G-V2X, will witness a lot of high-level intelligence algorithms which aim at improving the VRU movement detection (Ye et al., 2018).

Up-to-Date High Definition Maps (HD-Maps)

Continuously updating the HD-maps to decide whether the VRU location is safe (safe from collision probability with a vehicle), or whether the VRU is close by the vehicle or on the road. HD-maps are the following step towards full automation driving. Great efforts are offered to generate and continuously update the HD-maps. Moreover, there are provided 3GPP efforts concerning the vehicle and VRU positioning accuracy improvements for V2X based LTE. It's expected to add the bike lanes, VRU's footpath, etc. as a part of the HD-maps to set restrictions for the driving modes possibilities for the vehicle. The enhancement of HD-maps is expected to be available in the near 5G based V2X.

PC5 Communication Modem

It's expected to integrate a PC5 modem with a 5.9 GHz antenna in the future 5G modem; this integration can be enabled at the consumer's devices. The standard Wi-Fi frequencies include the 5.8 GHz spectrum, for that the new design for the 5.9 GHz antenna is not great effort from a technological perspective.

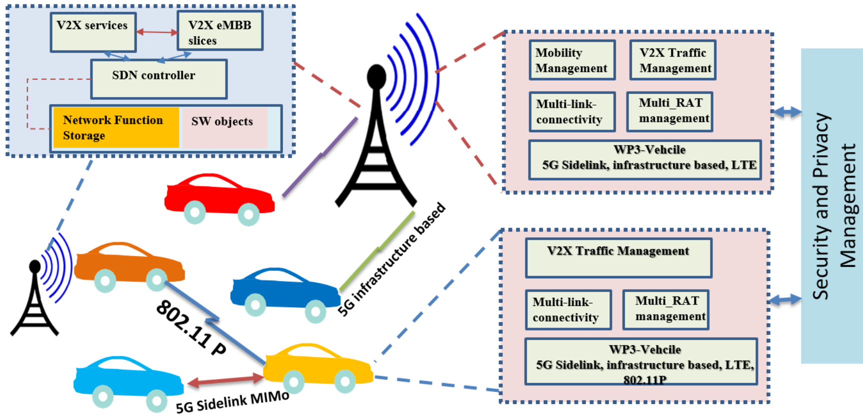
Integrating of Battery Consumption Modules

These battery modules are involved in making sure that a C-V2X application on the consumer's device do not drain the battery. Battery consumption is considered a critical issue in the consumer devices, and it highly depends on the type of use case. Power consumption may be not crucial if the VRU using unlimited power resource like an electric bicycle. VRUs could be visible through connecting with a network a server to provide you with all positions' information about the VRUs. In general, incorporating the VRU's use case into the 5G future of C-V2X system is considered a big challenge with an excellent opportunity to enhance road safety and efficiency. For now, it's not seen as VRUs scenario are going to market phase but within the next 5G enhancements, it could be for later stages.

5G V2X SYSTEM ARCHITECTURE

In the future, vehicles will be able to be managed by themselves, but the imagination for the future of vehicles mobility dramatically depends on a set of automated technologies. All associated entities such as vehicles, pedestrians, public transports, and connected things will benefit from connectivity to each other and the network. Endless information exchanging is the key to improving the knowledge of each vehicle surroundings behind the communication range of the board sensors, to enhance the traffic-safety and efficiency. The 5GCAR project is one of the critical 5G projects that aim at defining protocols, techniques, and designing network architecture to support C-V2X connectivity using the up-coming 5G networks. In this section, we introduce the V2X based 5G architecture, which is the result of the collaboration of universities, companies, national projects as wells as chipset maker's enterprises. The system architecture is illustrated below in Figure 13, as mentioned in 5GCAR plan it is built by including

Figure 13. End to end 5G based V2X architecture design



the management of the traffic flows, the multi-Radio Access Technology (RAT) and the inter-operator connectivity. As well as, the 5G core aspects proposed, including the network management via Software Defined Networking (SDN), the virtualized functions, and the slicing technology, also, security, authentication and privacy concerns are studied [40](Trivisonno et al., 2015).

Network Management

The V2X based 5G system architecture includes five areas of network management, network security, multi-connectivity, edge-computing improvements, and the network procedure. Network management involves all the necessary operations for the effective deployment and automation of the V2X critical network functions. 5GCAR classified the Infrastructure-as-a-Service (IaaS) as a basic concept for effective network management, using the Software Defined Networking (SDN) and Network-Function-Virtualization (NFV) technologies to support the effective deployment of the V2X services and applications according to the geographic region where the vehicle is. Security violations can produce probably damaging effects on the vehicular uses, therefore, it's studied heavily in previous V2X technologies like DSRC standards. The 5GCAR project introduces two distinct methods for the 5G V2X integrity and security check for vehicular messages, respectively by applying the security-checks at the application layer of the User equipment (UE), while utilizing the presence of network connectivity (Fallgran et al., 2018).

Multi-Connectivity

Vehicular applications are supposed to utilize the infrastructure Uu communication links and direct sidelink links connectivity. These two communication types have various characteristics and different features. For example, V2V sidelink communication is assumed to provide better resource allocation efficiency, out-network-coverage support, and low-latency. On the other hand, the Uu radio interface is expected to give higher-reliability and significant data-rates. 5GCAR recognized that using only one communication link can be enough to satisfy the complex V2X requirements. Also, systems with the ability of multiple RATs are considered, they can extend the recognized challenges, supposing that each RAT technique has its features.

Edge Computing and Network-Slicing

The availability of the computing abilities at the network edge is a critical enhancement to support the V2X use-cases. Fully exploiting of the edge computing capabilities requires a lot of network and radio access enhancements. From the 5GCAR point of view, a lot of control and management enhancements to all the running jobs on the edge-computing servers for high mobility UEs can be done. Especially, when a vehicle is assumed to hand-over from one base station to another which are connected to different MEC servers, the continuing jobs are transferred to the newly connected server, to minimize any job delay generated by the handover. 5GCAR also recognized methods for linking the edge-computing capabilities with the millimeter waves (mm Wave) techniques to allow maximum optimization of the radio access resources and concurrently taking into concern the heavy load of the computing tasks. Network slicing is a crucial enabler to support a variety of automotive services with a single infrastructure presented by various participants. This heterogeneity indicates that vehicular UEs will stay connected all the time to different network slices; every slice is serving a particular use-case, proposed by a specific holder (Zafeiropoulos et al., 2018).

5G BASED V2X SECURITY ASPECTS

The New 5G Radio system is supposed to provide many advanced business models and methods which attract more new threats and vulnerabilities, therefore proposing one security architecture for all cases will not be valid and applicable. The primary security solutions deployed in LTE-V can be used again for 5G, but a more flexible end-user authentication scheme is needed as 5G will maintain various use-cases evolving IoT, V2X, and a diverse of new access methods. The 3GPP-SA3 working group (SA3 et al., 2019), has to propose an obligatory primary-authentication phase and an optional secondary-authentication phase. The secondary-authentication phase requires successful passing from the primary first phase. Primary-authentication phase provides 5G core network access, while, the secondary-authentication stage is based on the Protocol Configuration Options (PCO) as the UEs use the PAP/CHAP user's credentials. Both PAP and CHAP authentication protocols (Amdune et al., 2018) support the EAP mechanism (Arkko et al., 2015). For that, authentication in the 5G ecosystems can satisfy diverse services requirements and various applications. Nowadays, the 3GPP standardization focuses on proposing solutions in many security areas of 5G to support a different set of applications as the following:

- The termination point of the user-plane (UP) security,
- UEs Identity management, authentication, and authorizing,
- RAN architecture security,
- User security (including the storage security, processing, managing of users credentials in the eSIM)
- Network slicing framework security,
- Privacy-preserving of IMSI,

For V2X applications, SIM/IMSI security mechanisms (Norman et al., 2016) can't support the user's privacy as it provides only the network authentication and access. Privacy is a significant issue in vehicular communications to avoid drivers tracking and to allow users to freely communicate anonymously using anonymous identities to hide their real information. Traceability is considered as one crucial security requirement for V2X certificate authorities for revocation process, but in case of cellular security deployment, the Mobile Network Operators (MNOs) must not be able to retrieve user's identity, speed, and location. In C-V2X vehicles should communicate without any pre-shared keys to provide lightweight, flexible, efficient security performance. As predecessors, V2X technologies such as DSRC/Wave standards, Public Key Infrastructure (PKI) is proposed again to manage, control and redistribute the digital certificates of the drivers, a simplified and enhanced version of the traditional PKI structure which is offered previously, with improved separation of authorities functions. The IEEE 1609 security framework will be reused with a simplified Security Credential Management System (SCMS) (Brecht et al., 2018) as shown in Figure 14. As the security functions are divided between the certificate authority registration organization and pseudonymous organization to provide vehicles pseudonymous certificate generation, renewing, revoking for the misbehaving vehicles according to the applied misbehavior techniques. For the interested readers in V2X misbehaving techniques, you can refer to (Khan et al., 2015) for more details. 5G system is expected to be an essential part of the connected society with a variety of services and use cases. It is supposed that the security of 5G will provide high trustworthiness level to meet the critical requirements of the end user, service provider and regulators use cases. The 5G integrity not only arises from implementing a set of security characteristics but further from the system design implementation and principles considerations which have been applied with a risk-based mindset (Bhat et al., 2014).

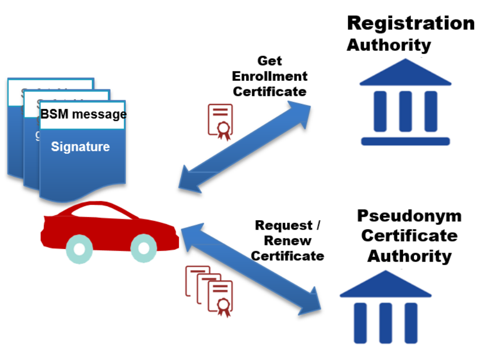
COMPARISON BETWEEN 5G-NR and IEEE 802.11P

In this section, we introduce a brief comparison of 5G and IEEE 802.11p as follows:

Licensed Radio Spectrum

Most of the proposed 5G technologies will be in the licensed spectrum while there is no current or future proposal or evaluation path to licensing IEEE 802.11p. The licensed spectrum has many advantages over unlicensed as it provides high-quality QoS with centralized management of channels and frequencies. All communicated devices can guarantee high QoS without any interferences, as well as there is no transmit power limitations; even many devices can be connected within a limited coverage area. 5G will have

Figure 14. 5G Simplified Security Architecture of SCMS



different spectrum bands with high frequencies beyond 24 GHz to support broad covering, intended to have a diverse set of spectrum bands for allowing full area coverage and supporting a highly significant number of devices with very high data rates to provide low latency and ultra-high capacity applications.

Coverage

The implementing of cellular base-stations solves the connectivity problem of IEEE 802.11p. Particularly in IEEE 802.11p urban scenarios, a lot of large buildings and obstacles can fade out the signals in the NonLine of Sight (NLOS) propagation paths which leads to poor connectivity. The cellular base stations are positioned at higher locations to support great coverage of more than1km. Hence, 5G affords acceptable performance in NLOS situations. D2D connectivity can work under no or limited LOS. In limited connectivity, D2D links slowly change the Channel-State-Information (CSI) or gradually alter the control information of Radio-Resource Management (RRM). D2D links under no connectivity, code slotted Aloha and self-organized time division multiplexing will be used.

Scalability and Cost

5G offers a high bandwidth compared to IEEE 802.11p, and this can support access to many devices. The broadcast mechanism of IEEE802.11p can't cover a large number of devices while the D2D links of 5G can support more. 5G D2D connections can support vehicles speeds up to 350 km/hr. Whereas 802. 11p, the already deployed cellular base stations reduce the total cost of maintenance and installation while offer great communication coverage more than 1000m. While in IEEE 802.11p, the deployment and installation of a large number of RSUs infrastructure to provide full connectivity can increase the total cost.

Latency

IEEE 802.11p latency is very high because of the CSMA/CA protocol which generates a delay of more than 60ms in channel access. While in 5G, some proposed projects such as METIS project offer a latency of about 1ms with high reliability of about 99.9%. This enhancement in end-to-end latency improves the transmission of emergency warning messages. The D2D communication can inform the vehicles the network status of and for that, the network traffic can be decreased wherever the vehicles can accept their services respectively. D2D communication can use the ProSe or can depend on the base station scheduling and management.

COMPARISON OF VEHICULAR NETWORK TECHNOLOGIES

In this section, we compare the earlier mentioned V2X technologies and summarize the comparison between them in case of the radio design, features, and the offered use-cases in Table 3, Table 4 and Table 5. As discussed before, IEEE 802.11p is a part of the DSRC protocol standards to support the ITS services and applications. IEEE 802.11p has many advantages such as mature technology, easy deployment, low-cost, and the natively support of V2V communications in the ad-hoc mode. Nevertheless,

Table 3. Comparison between 802.11p, C-V2X Rel 14/15 and the expected 5G in terms of radio design

Radio design	802.11p	C-V2X Rel-14/15	C-V2X based 5G (The expected Rel 16)
Synchronization	Asynchronous	Synchronization via (GNSS)	Tight synchronization via (GNSS)
Channel width	10 MHz	Rel-14:20MHz Rel-15:100MHz	Up to 100 MHz
Multiplexing of resources between vehicles	Support only TDM	Support TDM &FDM	Support TDM &FDM
Channel-coding	Convolutional coding	Turbo Coding	Advanced LDPC and polar channel coding
Hybrid automatic repeat request retransmission	Not supported	Rel-14: yes Rel-15: yes with addition to advanced ultra-reliable communication	yes with addition to advanced ultra-reliable communication
Resources Allocation	Multiple-users share the same medium so 802.11p addresses collisions by adopting the CSMA/CA protocol	LTE-V2X does not support CSMA/CA, but resources allocation is kept via a semi-persistent allocation	Semi-Persistent Allocation with addition to many available options
MIMO	Not supported	Support 2Tx/Rx antennas mandatory Support antennas diversity	Support up to 8Tx/Rx antennas Support both spatial-multiplexing and diversity
Modulation	QAM up to 64	QAM up to 64	QAM up to 256

Table 4. Comparison between 802.11p, C-V2X Rel 14/15 and the expected 5G in terms of features

Features	DSRC / IEEE802.11 p	C-V2X based LTE (Rel 14/15)	C-V2X based 5G (The expected Rel 16)
Standardization Process	Completed and no proposed improvements	Release 14/15 are completed by 2018	It's expected to be completed by the end of 2019 (December 2019) and to commercially ready by 2022
Low latency applications supporting	Supporting and varying according to packet length (typically .4 ms)	Release 14 supporting 4 ms. Release 15 supporting 1 ms	<1 ms
Network communication supporting	Short connectivity based on the existence of RSUs	Support V2I communication based on the centralized architecture	Support V2I communication with some enhancement and new radio technologies
Working without infrastructure assistant	Native (Adhoc mode)	Potentially, through D2D	Potentially Supporting V2V communication using 5G Millimeter-Waves (mm Waves)
Supporting 5.9 GHz spectrum	Support	Support	Support
Security and authentication supporting	Support according to the IEEE wave and ETSI security standards	Support according to the IEEE wave and ETSI security standards	Support according to the IEEE wave and ETSI security standards
Improvements and compatibility	No proposed improvements or new enhancements, evaluation path stopped.	It's evaluated to support 5G, the next Rel (16) and beyond with strong evolution towards 5G	Compatible with (Rel 14/15)

Table 5. Comparison between 802.11p, C-V2X Rel 14/15 and the expected 5G in terms of use cases and target performance

Use Cases and target applications	**DSRC / IEEE802.11 p**	**C-V2X based LTE (Rel 14/15)**	**C-V2X based 5G (The expected Rel 16)**
Target applications and cases	Basic Safety only	Enhanced safety (enhanced reliability and range)	● Advanced safety with Local 3D HD-map updates, high throughput and low latency, higher reliability including precise positioning, onboard intelligence and unified connectivity with C-V2X ● Building upon release 14.
Target Performance			
High-density network support	Support but suffering from higher packet loss	Support with a guarantee of no packet loss	Support with the assurance of no packet loss
High mobility	Can support high speed with maximum 500km/hr. with advanced receivers enchantments	Support up to 500 km/hr.	Support up to 500 km/hr.
Transmission range with 280 km/hr. relative speed	Support up to ~ 225 m	● Support more than 450 m, using D2D communication ● Support extensive communication range using the cellular infrastructure	● Support more than 450 m, using advanced D2Dcommunication ● Support extensive communication range using the cellular infrastructure with mm-wave radio technology ● Based on 5G NR with different channels than Rel 14/15
Periodic transmission frequency	Support beaconing messages every 100-300 ms	Support every 100 ms, and 20 ms is also possible	Support every a few ms due to the applications nature
Latency	Higher latency	Low latency for the enhanced safety -applications	Ultra-low latency
Throughput	Low throughput	High throughput for enhanced safety	Ultra -high throughput
Reliability	Low reliability	Reliability for the enhanced safety -application	Ultra -high reliability
Positioning	No	Share all positioning information Precise-positioning <2m	Wideband-ranging and precise positioning anytime anywhere with accuracy <<1m
Communications	Only Broadcasting	Only Broadcasting	Broadcasting with addition to multicast /unicast

this technology experiences some critical issues like unbounded delays, scalability issues, and the lack of Quality of Service (QoS) guarantees for many applications. IEEE 802.11p supports a short-range communication under 1km, low latency about~2ms, and high-reliability according to the US Department of Transportation.

Moreover, due to the radio ranges limitations without the existence of roadside infrastructure 802.11p offers only short-range and intermittent V2I connectivity. The mentioned issues drive the new growing interest in the LTE technology as a likely radio access technology to support the communications in events networks and paving the way to introduce V2X based Cellular communication. C-V2X offers many advantages compared to the previous V2X-technologies as DSRC. We are going deeply into the LTE and its improvements towards the new 5G-NR technology which supports new V2X use-cases with higher throughput, low-latency, and precise positioning techniques. We will introduce its advantages and disadvantages which explain why it has been chosen as the new V2X technology for the future. C-V2X Rel-14 specification is considered as a part of the 3GPP Rel14 standards, and LTE Advanced Pro was finalized in March 2017, while Qualcomm's announced the first C-V2X chipset, the 9150 in September and it was ready for commercial use by the second half of 2018. Qualcomm introduced the Reference Design of the featuring 9150 C-V2X chipsets with positioning GNSS capability, a Hardware Security Module (HSM) (Hakeem et al.,2019) and an application processor running with the ITS protocol stack. Contrasted to IEEE 802.11p, C-V2X is many years later in terms of the V2X deployment in the commercial market. In this section, we mention some technical radio design and use-cases comparisons between the IEEE 802.11p and the current and future C-V2X-specifications according to Qualcomm V2X chipset maker (Elsharief et al., 2014).

CONCLUSION AND FUTURE WORK

In March 2017, 3GPP project announced an agreement to accelerate the evolution of the 5G NR which was an important step on the road to 5G, and the fulfillment of non-standalone (NSA) and stand-alone (SA) 5G NR.5G NR-enabled products are expected to be commercially ready in 2019 with Qualcomm new released RF modules and antennas. A lot of efforts still need to make 5G real and applicable. However, the 5G progress indicates that the actual deployment of 5G will be late by the end of 2020. A lot of industrial research activities and white papers are announced to address the 5G communication structure, capabilities, use cases, technology directions, with no deliverables, only, and trails. In this chapter, we proposed a 5G tutorial consisting of the previous V2X technologies, the improvements over the 4G and IEEE802.11P, the 5G vital requirements, challenges, technologies, security enhancements, and the 5G system structure.

A lot of white papers are interested in the 5G as the new radio communication era with little descriptions about the suggested structure or used technologies. As the standardization process of 5G by the 3GPPP is not finished yet and predicted to be announced by the end of 2019, this makes all research areas just expecting what will be going on the 5G. In this chapter, we tried to cover the previous DSRC/wave standards, the LTE-V, the cellular V2X, the structure of C-V2X, the evolution of LTE towards 5G, the enhancement of the proposed 5G technologies, and finally the security aspects of the proposed 5G within V2X communications. 5G V2X demands to be on the center point of the new 5G radio progress, because it needs a high-reliability, low-latency, and probably high-throughput to ensure efficient transportation with an accident-free. To that end, all the current and future work in the different 5G area is aiming to enable the high-reliability and ultralow-latency communication for the 5G system overall, which evolves different vertical industries scenarios. More lately, the 5G Automotive Association (5GAA) was directed especially on the 5G V2X enhancements, with great encouragement and support from the automotive industry. The recent activities in the 5G are expected to accelerate the 5G V2X industry and continue the standardization process by the 3GPP to design the 5G system which meets the requirements of the V2X use cases.

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Chapter 12
M2M in 5G Communication Networks:
Characteristics, Applications, Taxonomy, Technologies, and Future Challenges

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ABSTRACT

Machine type communication (MTC), additionally called machine-to-machine (M2M) communications, broadly is referring to a number of cooperating machines exchange sensed data or information and make decisions with slight or zero human intervention. M2M technology will let a massive number of devices to be interconnected over the internet leading to a rapid development in recent time, which can be a promising enabling key for many areas, particularly for the internet of things (IoT) and 5th generation (5G) networks. This chapter presents a summary and state of art of M2M communications characteristics, taxonomy, applications, different technologies for deploying of M2M communications, and future challenges.

DOI: 10.4018/978-1-7998-1152-7.ch012

INTRODUCTION

Machine Type Communication (MTC), additionally called Machine-to-Machine (M2M) communications, broadly is referring to a massive number of cooperating machines exchange sensed data or information and make decisions with slight or zero human intervention (Shariatmadari, 2015). M2M has been in demand; it is a newly improved communication technology with rapid development in recent time, which can be a promising enabling key for many areas, particularly for the Internet of Things (IoT) and 5G Networks (Condoluci, 2016). A serious challenge brought in by M2M communications is a way to connect a huge number of MTC devices (MTCDs) to the network. It's foreseen that in total regarding 11.6 billion devices ought to be connected by 2020 (Salem, 2019).

The term of IoT to begin with showed up within the late 1990s, and after that it was presented formally by International Telecommunication Union (ITU) in 2005. The aim of IoT is to make a network, where people and things can be associated anytime, wherever, with anything and anyone in a perfect world utilizing any path/network and any service. The IoT is a heterogeneous concept that combines many different technologies, application domains, equipment facilities, and different services, etc. In IoT, a huge number of sensors and devices will be connected through M2M communications which are anticipated to support many industries with deferent utilizations such as smart grids and cities, telemedicine applications, vehicular telematics, surveillance systems and manufacturing (Condoluci, 2016), (Al-fuqaha, 2015). According to Ericsson (Cerwall, 2015), the expected number of IoT Stations (STAs) is expected to be 23.3 billion worldwide in 2023. The digitalization of equipments, vehicles and different processes lead to an exponentially increasing in the number of connected STAs (Salem, 2019). The density of the network could be about 1~10 devices/m^2.

Both H2H and M2M communications need the support of mobile cellular systems that creates new issues within the design of the next generation cellular networks. Cellular communication networks are anticipated to act a great role in realizing of M2M/IoT, cellular networks provide many features especially a global infrastructure. Existing technologies are not able to offer efficient resources for massive M2M communications. Additionally, radio resource allocation is becoming challenging to support traditional mobile communications (Biral, 2015). The incoming of new wireless services makes the radio frequency spectrum overcrowded. 5G networks carry many utilizations and enabling techniques to solve these limitations such as traffic offload through Wi-Fi and small cells, millimeter wave (mmWave), massive multiple input multiple output (massive MIMO) and cognitive radios (Jaber, 2016), (Salem, 2015), and (Salem,2017).

The remainder of this chapter is structured as follows: Section 2 presents the characteristics of M2M communications such as (Bursty traffic, Low power …etc). M2M communications required that the network has different QoS support like high or low data rates, throughput and latency; therefore M2M communications are anticipated to support many industries with deferent utilizations, M2M applications are illustrated in section 3. Taxonomy of M2M architectures is described in section 4; in the same section, different technologies for deploying of M2M communications (Wi-Fi, LoRaWAN, LTE-M…etc) and comparison between them is illustrated. Section 5 describes the role of M2M in 5G communications. Most of the current M2M communications challenges require modifications in the current conventional networks or design of new network architecture. Cost, energy efficiency, reliability, heterogeneity and others are many research challenges in M2M communications, section 6 presents the future challenges of M2M communications.

CHARACTERISTICS OF M2M COMMUNICATIONS

Machine communications behavior has unique characteristics differ from current human type communications (HTC) and legacy networks, which lead us to new challenges to modify the current technologies to be more suitable for the both HTC and M2M communications. M2M communications requirements characteristics are summarized below (Biral, 2015), (Alonso-Zarate, 2017), (El-Basioni, 2017), and (El-Basioni, 2011).

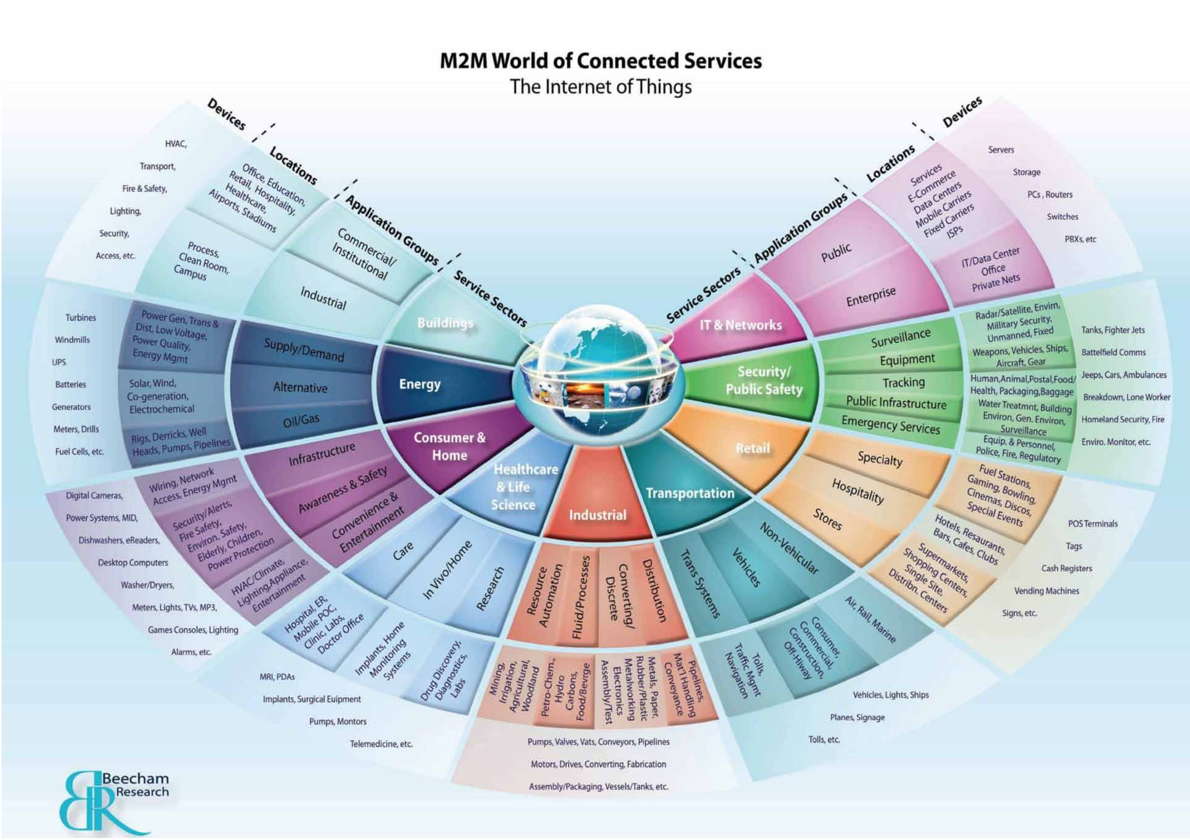
- **Bursty Traffic:** In general, machines send a small amount of traffic, so the current networks must be modified to support small data transmissions to overcome some problems like inefficient resource blocks utilization and enormous signaling overhead.
- **Low Power:** Mostly, machines or sensors are powered on batteries. Therefore M2M communications must be power and energy efficient for the purpose of extending battery and network lifetime.
- **Interoperability:** Due to heterogeneity of M2M devices, applications and services, upcoming networks must support this diversity which will make M2M/IoT communications achieving the required big scale.
- **QoS Diversity:** Due to different application and needs, M2M communications required that the network has different QoS support like high or low data rates, throughput and latency.
- **Massive Transmissions:** Massive number of sensors and devices will be connected through M2M communications, so the upcoming networks must support the massive number of M2M devices and transmissions.
- **Various Mobility Models:** M2M devices can have high, low or no mobility.
- **Security:** Massive devices and transmission in M2M/IoT communications initiates many opportunities for hackers and make M2M transmissions more vulnerable, therefore the security in M2M communications is very crucial.

M2M APPLICATIONS

As shown in Figure 1, M2M communications are anticipated to support various industries, and markets with deferent utilizations such as smart grids and cities, telemedicine applications, vehicular telematics, surveillance systems and home automation. Smart metering is anticipated to play a major role in smart grid. Sensors will collect different kinds of data then send it to servers to start processing it (Wu, 2011). Some of M2M Applications are summarized below.

- **Smart Grid:** In the recent years, the smart grid attracts a lot of attention in both industry and academia. The smart grid will play a crucial role in the way of energy distribution, consumption and generation improvement. M2M communication is a major key technique for enabling the smart grid through smart metering and monitoring which are considered to be the vital elements (Merline, 2017). Smart meters send its data to the central server for processing to deliver a higher level of energy distribution and consumption.

Figure 1. M2M/IoT various applications and industries (Duke-Woolley, 2013)



- **Telemedicine:** The goal of telemedicine or e-health is to decrease the risks and the medical care costs, and to enhance the medical administration for all people (De-Mattos, 2016). M2M communications are playing a promising rule to apply telemedicine through body sensors which collect many vital measurements such as body temperature, blood pressure and heart rate, etc. Then send these measurements periodically to M2M servers, then M2M servers forward it to the corresponding hospital or medical service providers for analysis and make a report on the physical condition of the patient. These procedures will save more time for the patient by allowing the physicians to prepare the required devices and treatments before the arrival of the patient (Selem, 2019).
- **Vehicular Telematics:** As a result of growing number of vehicles, logistics and transportation are another challenge for M2M communications. Safety, security, accident avoidance, navigation, auto driving, smart parking, traffic managements, and vehicle diagnostics, etc (Rezgui, 2017). All of these applications can be provided by M2M communications throughout sensors located in the vehicles and the roads.
- **Surveillance Systems:** Security of people and industrial, public and all kind of locations draws attention of M2M communications market. M2M communications provide fast, economical and reliable placement for surveillance applications such as open areas monitoring, objects and personal

tracking, public infrastructure protection, and also can detect any prospective dangerous incidents (Abu-Lebdeh, 2016). All of these can be done by collecting data throughout M2M equipments like sensors, actuators and cameras then forward it to M2M servers to make analysis for a rapid decision.

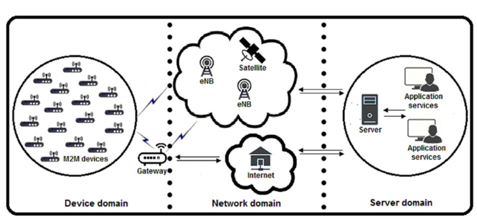
- **Building Automation:** Building automation applications are supported devices wont to give services in industrial buildings. Building automation systems aim to produce a secure, comfy and productive facility for its occupants. the main target is incredibly often targeted on operational potency by reducing energy consumption and operations workers levels. Building automation is characterised by a very important set of sensors, switches, observance and measurement devices, all connected first to a non-public and second to a public wired or wireless public network using a gateway. samples of applications embrace cooling instrumentation maintenance and observance, carry maintenance and observance, power supply observance, etc (De Mattos, 2016), (Abu-Lebdeh, 2016).

M2M ARCHITECTURE TAXONOMY AND ENABLING TECHNOLOGIES

As shown in Figure 2, general architecture of M2M communication network includes three essential domains; device domain, network domain and server domain (Mehmood, 2017).

- **Device Domain:** M2M devices start to sense and collect data depending on the used application through built-in sensors (e.g. blood pressure or heart rate in telemedicine application, vehicle speed or fuel level in vehicular telematics application). M2M devices can be cooperated and exchange the sensed data, the collected data, the connectivity between M2M devices (sensors or actuators) is introduced by a small area network (e.g. Wi-Fi, ZigBee or Bluetooth) for sending or receiving data to or from the network domain. M2M can communicate directly to the network domain or through a gateway.
- **Network Domain:** The communication link (wired or wireless) between the device domain and the server domain is provided by the Communication network domain (e.g. DSL, GSM, UMTS, LTE or WiMAX).
- **Server Domain:** The server domain act as a service middleware layer, its forward the collected data from M2M devices to the corresponding application services to start the processing operation on these data to take the proper decision.

Figure 2. M2M Communications Architecture



The wired network architecture is more reliable; introduce low latency and afford higher bitrates, but it is not sufficient for several M2M communication applications because of many required advantages such as cost efficiency, mobility and scalability. Therefore, wireless network architecture is preferred to achieve these requirements. M2M wireless architecture taxonomy divided into two classes, capillary and cellular M2M communication networks.

CAPILLARY M2M COMMUNICATIONS ARCHITECTURE

In capillary communications architecture, M2M devices are connected through short range communication (e.g. Wi-Fi (IEEE 802.11), Bluetooth, ZigBee, and UWB, etc). The connectivity to the cellular network is provided by a gateway as shown in Figure 3.

Capillary architecture has many features such as scalable, low complexity devices, low cost and low power. But the drawbacks like limited coverage, lower bitrates, lower security and higher interference make capillary architecture not suitable for many M2M applications (Novo, 2015). On the contrary, cellular architecture can support higher bitrates, more coverage, handover support and more security. Therefore, cellular architecture is more suitable for M2M/IoT applications in the next generation networks.

CELLULAR M2M COMMUNICATIONS ARCHITECTURE

In cellular architecture, as shown in Figure 4, M2M devices have the ability to communicate directly with the cellular communication network (Ghavimi, 2014). As abovementioned in the previous section, cellular architecture can support higher bitrates, more coverage, handover support and more security. The current wireless networks are designed for human communications which have characteristics differ from M2M communications, M2M communications has unique characteristics of small amount of data transmissions, uplink originated traffic, energy efficient and heterogeneity; thus create many challenges to modify the current technologies to accommodate massive M2M communications.

Figure 3. Capillary M2M Communications Architecture

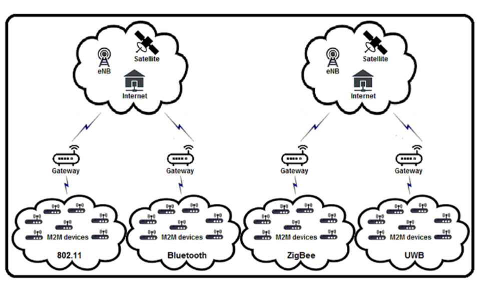
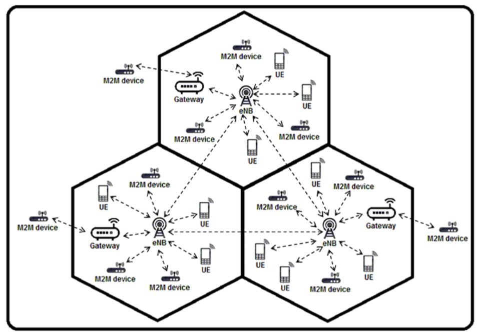


Figure 4. Cellular M2M communications architecture



M2M COMMUNICATIONS ENABLING TECHNOLOGIES

Many low power technologies are anticipated to provide the deployment of M2M communication networks. These technologies are divided into two classes

- Capillary-based M2M communications technologies such as IEEE 802.11 (WLAN), LoRaWAN (Long Range Wide Area Network), Sigfox.
- Cellular-based M2M communications technologies such as LTE-M (LTE based M2M Communication Solutions), and NB-IoT (Narrow Band-IoT).

IEEE 802.11ah is a promising key for M2M communication networks, it's an amendment of the IEEE 802.11 published in December 2016. IEEE 802.11ah provides wider coverage and low power connectivity, working at sub 1 GHz frequency which is not efficiently utilized and not crowded yet unlike the conventional IEEE 802.11 which working at 2.4 and 5 GHz.

LoRaWAN is a Low Power, Wide Area Network (LPWAN) technology developed by SemTech; working at 433, 868 or 915 MHz ISM band. It provides ubiquitous connectivity for outdoor M2M applications, while keeping network structures and management simple. Sigfox is another LPWAN technology working at sub 1 GHz frequency.

LTE-M and NB-IoT are cellular-based LPWAN technologies developed by 3GPP in the Release 13 specification which support M2M/IoT communications and can coexist with GSM, UMTS, and LTE mobile networks. LTE-M provides voice services, Mobility, and higher data rates, but it needs more bandwidth.

Table 1 provides a comparison between different enabling technologies for M2M communications (Mekki, 2019), (Raza, 2017), (Wang, 2017), (Persia, 2017), (Persia, 2016), and (Hejazi, 2018).

Table 1. Comparison between different enabling technologies for M2M communications

Technology	IEEE 802.11ah	LoRaWAN	Sigfox	LTE-M	NB-IoT
Frequency band	Sub-1 GHz Unlicensed ISM bands	Sub-1 GHz Unlicensed ISM bands	Sub-1 GHz Unlicensed ISM bands	Licensed LTE frequency bands	Licensed LTE frequency bands
Channel Bandwidth	1 – 16 MHz	125 kHz and 250 kHz	100 Hz	1.4 – 20 MHz	200 kHz
Bit rate (Uplink)	Up to 8.67 Mbps	Up to 50 kbps	Up to 100 bps	Up to 1 Mbps	Up to 250 kbps
Modulation	OFDMA	CSS	DBPSK	SC-FDMA	SC-FDMA
Interference immunity	Very high	Very high	Very high	Low	Low
Max Range	Up to 1 km	Up to 20 km	Up to 40 km	Up to 11 km	Up to 10 km
Latency	Varies depending on services type, number of active stations	1 – 2 s	1 – 30 s	10 – 15 ms	1.6 – 10 s
Authentication & Encryption	Supported	Supported	Not supported	Supported	Supported
Applications	Real time services, WSN backbone network, home automation, smart grid and smart meter, agricultural monitoring	Smart metering, parking meter, logistics	Smart metering, parking meter, logistics	Real time services, Connected car, fleet management, remote health monitoring, WSN gateway	Smart metering, parking meter, logistics
Standardization	IEEE	LoRA Alliance	Sigfox	3GPP	3GPP

M2M IN 5G COMMUNICATIONS

5G will be the next generation of wireless communication networks which could roll out as early as 2020. Lately, researches on 5G networks attract a lot of attention in both industry and academia to fulfill the requirements and a generic framework. A massive growing in data traffic is anticipated in the next years (10-100X in devices, 10000X in traffic volume, 50 billion devices in 2020) (Agiwal, 2016), (Hussein, 2017). Supporting of M2M communications is one of the major challenges in 5G networks due to unique characteristics of machines communications differ from the conventional human communications. 5G networks are anticipated to enhance the following terms for human and machine communications: latency, reliability, coverage, and data rates; reduce complexity and power consumption; support heterogeneity, massive transmissions and a global infrastructure. According to METIS project (Monserrat, 2015), the following services in 5G networks are anticipated for M2M communications:

- **Extreme Mobile Broadband (xMBB):** The ability to produce higher data rates and improved QoE (Quality of Experience) via reliable supplying of moderate data rates, this means providing higher reliability for moderate rates.

- **Ultra-reliable MTC (uMTC):** Many M2M applications (e.g. telemedicine and vehicular telematics) contain sub-services which require high reliability and very low latency features to make a fast accurate decision. Therefore, 5G networks must provide a high reliability for M2M communications.
- **Massive MTC (mMTC):** The main aim of this service is to provide support to massive machine transmissions via less expensive and power efficient M2M devices.

Therefore, 5G networks are anticipated to support high reliability, different data rates, low latency and maintain QoE for massive M2M devices depending on the application requirements. Not all application services required all features in the same time; for example, very low latency is required for vehicular telematics and high energy efficiency is required for battery driven M2M devices (Mohammed, 2019), (Salam, 2018), and (Dalla-Cia, 2017).

FUTURE RESEARCH CHALLENGES

Most of the current M2M communications challenges require modifications in the current conventional networks or design of new network architecture. Cost, energy efficiency, reliability, heterogeneity and others are many research challenges in M2M communications. In this section, some of research challenges for M2M communications in 5G are summarized below.

- **Heterogeneity:** The combination between conventional networks (especially designed for human communications) and M2M communications represent a wide research area due to different characteristics and technologies (Ide, 2012). Sharing of the same resources, infrastructures can exceedingly extend the coverage; ease managing of M2M networks and lead to cost effective deployments. Various access control schemes in M2M communications and legacy networks need more coordination between them to provide more energy efficiency, QoS assurance and cost efficiency.
- **D2D (Device to Device) Communications:** Enabling direct communication between devices can solve the problem of the simultaneous massive transmissions in M2M communications (Laya, 2014), D2D communications also can help in traffic offload from the core network and can reduce energy consumption, latency.
- **Multi-Vendor compatibility:** The ability to exchange data and use information between different devices will make M2M communications able to achieve scalability and needed flexibility for various applications. Therefore, Multi-Vendor compatibility is one of enabling techniques for M2M communications.
- **Random access:** It's expected that a large number of M2M devices will be connected per cell. Therefore, simultaneous connectivity of these devices will lead to high congestion in the network and inefficient resource allocation. Accordingly, high collision and packet loss rate, high latency, inefficient resources utilization, excessive overhead signaling and low energy efficiency will be expected. Hence, efficient random access mechanisms required to overcome abovementioned challenges and provide efficient resource allocations (Abbas, 2017).

- **Battery Lifetime:** Reduction of power consumption in M2M communication is a major issue, especially in battery driven M2M devices to increase the battery lifetime without needing of replacing it frequently. Reduction of power consumption also helps in reduction of operational costs (Aboul-Dahab, 2019).
- **Security:** Massive devices and transmission in M2M/IoT communications initiates many opportunities for hackers and make M2M transmissions more vulnerable, also some applications will contains a personal information and private data that must not published in public. Therefore, M2M devices security is a critical challenge to continue keeping data and devices protected (Barki, 2016).

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