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An Investigation of 5G Propagation Models / Weather Effects

Zaid A. Sideeq

(B. Sc. in Communication Engineering)

M.Sc. Thesis

in

Communication Engineering

Supervised By

Dr. Younis M. Abbosh

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An Investigation of 5G Propagation Models / Weather Effects

A Thesis Submitted

By

Zaid A. Sideeq

(B. Sc. in Communication Engineering)

To

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in

Communication Engineering

Supervised By

Dr. Younis M. Abbosh

2019 A.D. **1440 A.H.**

To the man who supported me from my first heartbeat, without him I could not be here (my father).

Supervisor's Certification

I certify that the dissertation entitled (**An Investigation of 5G Propagation Models / Weather Effects**) was prepared by **Zaid Ayad Sideeq** under my supervision at the Department of Communication Engineering, University of Mosul, as a partial requirement for the Master of Science Degree in Communication Engineering.

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I certify that the linguistic reviewer of this dissertation was carried out by me and it is accepted linguistically and in expression.

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Report of the Head of Department

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Abstract

In the last few years, the number of devices that are connected to the wireless network started to increase in an exponential manner. New fields of applications and services that consume a large bandwidth appeared according to human requirements.

The fifth generation is expected to be able to handle the rapid increase in the number of users', even non-human users. The new generation is expected to create an environment that connects all kind of users and provides services that the fourth generation cannot provide.

Recently, huge efforts are being made in researches and developing techniques for the upcoming mobile generation. One of the points of interest is channel modeling, since the fifth generation will use frequencies never used before for cellular networks. It is important to study how these waves perform in different environments and conditions. The results of these channel models will help to build a system that operates well in the real world. Therefore, this work will review different channel models and simulators with their important characteristics in addition to investigate the weather effect on millimeter wave frequencies. NYUSim software program was used to study the effect of Mosul's weather factors on signal strength at different frequencies in day and night.

The work investigates weather factors' effect in different seasons then studying weather factors effect for different multiple inputs multiple output system configurations. The results of simulation at 28, 37, 60, 73 GHz showed that weather factors on signal level is small and rain rate have the largest impact.

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List of abbreviations

1G	First Generation
2G	Second Generation
3D	Three dimensions
3G	Third generation
3GPP	Third generation partnership project
4G	Fourth generation
5G	Fifth generation
AMPS	Advanced Mobile Phone System
AoA	Angle of Arrival
AoD	Angle of Departure
AR	Augmented Reality
AS	Angular Spread
ASA	Azimuth spread of arrival
BS	Base Stations
CI	Close-in free space reference distance
CIR	Channel Impulse Response
cm-W	centimeter Wave
CoMP	Coordinated Multipoint
COST	Cooperation in Science and Technology
CPS	Cyber-Physical-Systems
D-rays	Deterministic rays
D2D	Device to device
DS	Delay Spread
EB	Exa Bytes
EDGE	Enhanced Data rates for GSM Evolution
eMBB	Enhanced mobile broadband
ESA	European Space Agency
FCC	Federal Communications Commission
FDD	Frequency Division Duplex
FSL	Free Space Loss
FSPL	Free Space Path Loss
GPRS	General Packet Radio Service
GSCM	Geometry based Stochastic Channel Model
GSM	Global System for Mobile
GSMA	Global System for Mobile Association
HARQ	Hybrid Automatic Repeat Request
HetNets	Heterogeneous Networks

HF	High Frequency
HHI	Heinrich hertz institute
HPBW	Half Power Beam Width
HSDPA	High-Speed Downlink Packet Access
HSPA	High-Speed Packet Access
i.i.d.	independent and identically distributed
I2I	Indoor-to-indoor
ICT	Information and communication technologies
IEEE	Institute of Electrical and Electronics Engineers
IIC	Industrial Internet Consortium
IMT	International Mobile Telecommunications
IMT-A	International Mobile Telecommunications-advanced
IoE	internet of everything
IoT	internet of things
IP	Internet Protocol
ITU	International Telecommunication Union
LOS	Line of Sight
LSAS	Large-scale antenna systems
LSP	Large Scale Parameter
LTE	Long Term Evolution
LTE-A	Long Term Evolution Advanced
M2M	Machine-to-Machine
METIS	Mobile and wireless communications Enablers for the Twenty-twenty Information Society
MIMO	Multiple input multiple output
MiWEBA	Millimeter-Wave evolution for backhaul and access
MMC	Massive Machine Communications
mMTC	massive Machine Type Communications
mm-W	millimeter Waves
MPC	Multipath Components
MTC	Machine type communication
NGMN	Next Generation Mobile Networks
NLOS	Non Line of Sight
NMT	Nordic Mobile Telephone
NYU	New York University
O2I	Outdoor-to-Indoor
O2O	Outdoor-to-Outdoor
OFDMA	Orthogonal Frequency Division Multiple Access
OMG	Object Management Group

PDP	Power delay profiles
PLE	Path Loss Exponent
Q-D	Quasi-Deterministic
QuaDRiGa	Quasi Deterministic Radio channel Generator
R-rays	Random rays
RAN	Radio Access Network
RAT	Radio access technology
RF	Radio frequency
RMS	Root mean square
Rx	Receiver
SCM	Spatial Channel Model
SF	Shadowing factor
SISO	Single Input Single Output
SL	Spatial Lobes
SMS	Short Messaging Service
SON	Self Organizing Network
SSCM	Statistical Spatial Channel Model
TACS	Total Access Communication System
TC	Time Clusters
TCSL	Time cluster-spatial lobe
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
Tx	Transmitter
U	Unlicensed band
UK	United Kingdom
ULA	Uniform Linear Array
Uma	Urban Macrocell
UMi	Urban Micro
URLLC	Ultra-Reliable and Low Latency Communications
US	United States
V2I	Vehicle to infrastructure
V2V	Vehicle-to-Vehicle
VR	Virtual Reality
WCDMA	Wide Code Division Multiple Access
WiGig	Wireless Gigabit Alliance
WiFi	Wireless Fiedility
WINNER	Wireless world Initiative New Radio
WLAN	Wireless local area network
WWWW	Worldwide Wireless Web

XPR	Cross Polarization Ratio
ZB	Zetta Byte

List of symbols

AT	Attenuation	dB
c	Speed of light	m/s
d	Distance	m
$d_{\circ}$	free space reference distance	m
f	Frequency	Hz
H_2O	Water	
L	Path loss	dB
O_2	Oxygen	
R	Depth of foliage	m
x^{CI}_{σ}	Zero-mean Gaussian random variable	
A	Rain attenuation	dB/km
λ	Wavelength	m
σ	Standard deviation	dB
α	Attenuation factor	dB/m
η	Efficiency	
k	Rician factor	
μ	Permeability	H/m

Chapter One
Background

1.1 Introduction:

Wireless communications witnessed a large interest and through the last 40 years evolved at a rapid rate. The evolution represented by moving from all centric services technology to transparent technology. The attention dragged away from components and transmit/receive technologies to investigate resource allocation [1].

Mobile voice traffic around the globe was surpassed by mobile data traffic in 2009. Also, the increment rate of data traffic part is higher than the voice traffic part. Data traffic carried through cellular networks is growing in the term of folds year after year according to the Cisco report [2]. The main reason behind this augmentation is the rapid growth in the number of mobile phones and tablets in addition to data hunger of services and applications [3].

The fifth generation will be an environment that supports different types of traffic, wider spectrum range and various types of terminals. The expectation for the fifth generation (5G) is to embrace nodes of different capacities and characteristics, therefore; it is expected that heterogeneous deployment will be an important part of 5G. The radio access technology (RAT) of 5G supports RAT of 3G, 4G, WiFi and WiGig also different kinds of cells ranging from device to device (D2D) communication to ultra-dense small cells [4]. The fifth generation must meet different use cases and requirements, and able to handle 1000 times data rate increment with the proliferation of devices in what is called internet of everything (IoE), where many devices (tens) serve one person in networked society [3]. Devices have to be able to operate in multiple spectrum bands starting from radio frequencies (RF) to millimeter wave band, and compatible with legacy technologies such as 3G and 4G. All these features also can be considered as challenges that have to be overcome by mobile companies and system component manufacturers [4].

The user demand for higher data rates, lower latency, very high-reliability and better energy efficiency cannot be satisfied by 4G even though it uses advanced technologies. Hence, the goals and the requirements for the next wireless mobile generation became clear.

The spread of new services and applications depends on the abilities of 5G and its potentials to meet their requirements, such as 360-degree videos, device to device communication (D2D), machine type communications (MTC), transportation which includes vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication, robots, and actuators. 5G will change human life not only the personal communication level but also the whole society life manner and productivity. Based on the above-mentioned, 5G can be considered as an infrastructure of future societies, and information and communication technologies (ICT) [5].

5G research activities and projects already started all over the world. Europe has the antecedence in the field where the work started in 2011. The project contributors are equipment manufacturers, network operators, and academic institutions. The research project followed by other projects in countries like China, Korea, and Japan [6], [7].

1.2 Literature review:

E. E. Altshuler et. al. in 1968 published their investigation of weather effect on propagation at frequencies 15 and 35 GHz. The work had been done for Earth-to-space communication links. The work also included field measurements at 15 and 35 GHz. The research concluded that attenuation due to weather factors is small when a signal is transmitted at an angle near zenith and the attenuation reaches its maximum when angle closes to the horizon. Atmosphere attenuation is small for 15 and 35 GHz. Heavy rain had the largest impact on signal strength also attenuation is proportional with humidity and altitude [8].

In May 2011, Mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS), which is work of European 7th framework, was established in Europe with the objective of providing the next mobile generation concept. In 2013, this alliance identified the scenarios that represent a challenge to the next mobile generation (5G). These scenarios contained different applications where each application has specified requirements in terms of data rate, latency, reliability, number of supported devices and energy consumption [9]–[11]. The framework provided a map-based channel model by using a simple ray-tracing algorithm. METIS model implicitly addressed all the challenges of 5G because it uses physical principles with a reasonable number of parameters related to physical properties [12]. METIS model can be classified as a semi-deterministic model [13]. The METIS channel model covers the frequencies from cellular bands under 6 GHz up to 86 GHz. METIS channel model can mix map-based channel model and stochastic channel model in a model called a hybrid channel model [14].

In 2011, A. Maltsev started a work to develop statistical channel model for frequency 60 GHz (IEEE 802.11ad). The work focused on a wireless local area network (WLAN) indoor scenario like a conference room. It is found that each reflected multipath consists of a number of rays. The parameters of this model were extracted from measurements and ray tracing in the same environment type [15].

In the same year of METIS and IEEE 802.11ad work, Theodore S. Rappaport et al. introduced their experimental measurements and empirically based propagation channel models for the frequencies 28, 38, 60 and 73 GHz in New York City and Austin. The measurements were collected in the period from 2011 to 2013. In 2011, measurements had been done at the University of Texas in Austin while in 2012 and 2013 measurements were taken around the campus of New York University and New York City, which is a very crowded city. These measurements helped the researchers to provide directional and omnidirectional path loss models, temporal and spatial channel models, and outage probabilities. The work provided more detailed information about path loss, delay spread and key parameters for these frequencies. The researchers in this work also pointed out that the probability of signal blockage is higher in New York city than Austin because of higher population and taller buildings [16].

Mustafa R. Akdeniz et. al. made use of measurements that have been made in New York City at 28 and 73 GHz to estimate millimeter waves' performance in urban micro and picocells by collecting details of spatial statistical models of the channels to calculate channel parameters. The researchers found that millimeter waves could be detected at 100 m and 200 m distances even in non-line-of-sight environments and provide higher system capacity for the same cells deployment density. These results show that using small cells for outdoor scenarios is highly recommended [17].

In June 2014, Millimeter-Wave Evolution for backhaul and access (MiWEBA) published their mm-wave channel model. The quasi-deterministic channel model is applicable for outdoor and indoor scenarios around 60 GHz. MiWEBA model uses an abstract representation of surrounding objects of the specified scenario to include propagation properties like reflection attenuation, scattering, mobility, and effect of blockage. The proper simulation parameters were taken from experimental measurements and ray tracing. The challenges addressed by MiWEBA are spatial consistency, the large number of antenna elements, polarization and dual mobility for D2D. The major challenges in this model are complexity, a limited number of scenarios (open area like a campus, street canyon and hotel lobby) and performance [18].

In 2015, 5GCM white paper on 3D channel modeling published by the contribution of Nokia, Samsung, University of Bristol, etc. The model is built upon a large number of measurements and ray tracing in the range of 6 - 100 GHz. The model included new addressed scenarios of 5G and new cases such as spatial consistency. The paper specified the requirements that must be met to achieve acceptable channel model. The results of this model contributed to the developments of 3GPP channel models [19].

Mathew K. Samimi and Theodore S. Rappaport wrote a MATLAB code by following third generation partnership project(3GPP) procedures to generate channel coefficients, power delay profiles, and power spectra because 3GPP supports many frequencies, bandwidth, and antenna beam widths [20]. 3rd Generation Partnership Project (3GPP): is Geometry-based Stochastic Channel Models (GSCM). It produces statistical characteristics of parameters of the multipath channel for desired scenarios [6]. The channel coefficients from the simulation are compared with time cluster and spatial lobe model parameters that were extracted from field measurements at frequencies 28 and 73 GHz. The comparison showed good matching. They concluded that 3GPP channel model can be used for millimeter waves and it opens the way for future work such as millimeter wave system performance evaluation [20], [21].

In 2015, Quasi Deterministic Radio Channel Generator (QuaDRiGa) channel model was developed by Fraunhofer Heinrich Hertz Institute (HHI) based on wireless world initiative for new radio (WINNER) channel model. QuaDRiGa is a geometry-based stochastic channel model. It supports three-dimensional propagation, scenario changing and 3-D spatial consistency. QuaDRiGa can be considered as a statistical ray-tracing model but it is different from usual ray-tracing that uses specified geometrical representation of the surrounding object because it spreads the reflective objects randomly. QuaDRiGa version 2.0.0 is published in August, 2017 [22].

Mathew K. Samimi and Theodore S. Rappaport empirically derived large-scale and small-scale parameters for frequencies 28 and 73 GHz. These parameters help to discriminate between the properties of time and angles of multipaths. In this work, 3GPP make use of time cluster-spatial lobe (TCSL) modeling approach to recreate 3GPP model parameters to produce channel impulse responses and root mean square (RMS) lobe angular spreads. They found that RMS of delay spread (DS) and shadowing factor (SF) both have a negative cross-correlation coefficients at both frequencies also the azimuth spread of arrival (ASA) and SF have negative cross-correlation coefficients at 28 GHz but almost uncorrelated at 73 GHz [23].

In 2016, mm-wave based Mobile radio Access network for fifth Generation Integrated Communications (mmMAGIC) project published a white paper about their work. They made a campaign included taking measurements at the first stage according to a plan and inspecting for new ways of modeling for frequencies above 6 GHz. The main goal of the project is to provide advanced propagation and channel modeling for the frequency range from 6 GHz to 100 GHz. The researchers in the project aimed to provide new concepts for radio access technology (RAT) for deployment of the fifth generation of the mobile network [24].

In 2016, European Cooperation in Science and Technology (COST IC1004) released their white paper that contained glance of measurements and channel modeling efforts on 5G bands. The work designed for a fixed and mobile link for indoor, outdoor and indoor-to-outdoor environments. The goal of this work is to provide better characterization and modeling of millimeter waves propagation [25].

Sooyoung Hur et. al. made a comparison between 28 GHz measurements of Daejeon, Korea, and NYU campus, Manhattan with three-dimensional (3D) ray-tracing simulation for the same environment in order to discover the accuracy of ray-tracer and use the simulation results to reduce the cost and work time. The researchers used third generation partnership (3GPP) spatial channel model (SCM) methodology to get channel parameters for the street canyon environment. 3D ray-tracing results were very close to measurements for urban micro and urban macro scenarios as a consequent some parameters of 3GPP-SCM such as path loss exponent and averaged delay spread extracted from the ray-tracing simulation [26].

. 3rd Generation Partnership Project (3GPP)model is designed for 2D propagation then extensions added to provide 3D propagation and it works for frequencies below 6 GHz and bandwidth of 100MHz [7], [27]. In 2017, 3GPP introduced their study on modeling of the channel for frequencies above 6 GHz [28, p. 6]. After that 3GPP modified their models and made it able to support frequencies from 0.5 GHz to 100 GHz with 3GPP TR 38.900 [29]. One problem with 3GPP channel model is more optimistic in term of spectral efficiency compared to channel models based on mm-Wave channel measurements because the number of clusters in 3GPP is large which is not borne out in the real world [30].

Qiu Fang in 2017, studied in his MSc thesis the available millimeter wave channel models in order to review the advantages and disadvantages of those models and how each model characterizes mm-Waves. The research also included a comparison between different channel models based on literatures. The simulation of the work focused on making a comparison between WINNER 2 and QuaDRiGa channel models. The results showed that the received signal strength in WINNER 2 is higher than QuaDRiGa, channel capacity does not depend directly on distance for both models. He also concluded that line of sight propagation in WINNER 2 is very important and WINNER 2 showed larger capacity, higher bandwidth, and smaller fast fading compared to QuaDRiGa [31].

In 2017, A. Roivainen in his Ph.D. dissertation, claimed that centimeter wave frequencies (3-30 GHz) are exploited for mobile communications. The work included measurements in the lobby and urban small cell at 10 GHz and verification. The dissertation provided parameterizations for a three-dimensional (3D) geometry based stochastic radio channel model. The results of the simulation showed an agreement between constructed and simulated multipath components. The observations from the measurements and simulations are: the number of clusters is smaller than that at lower frequencies, loss caused by glass when the signal goes through the glass is in the same level of lower frequencies but concrete causes a little higher loss compared to lower band, and specular reflection has an effect greater than other propagation mechanisms [13].

T. S. Rappaport et al. made a comparison between two channel models and published the results in 2017. The two models were (3GPP) TR 38.900 Release 14 and NYUSIM, which is a statistical spatial channel model. The goal of this comparison is to resolve channel eigenvalue distribution and spectral efficiency for analog/digital hybrid beamforming in a multi-user multiple input multiple output (MIMO) system. The results showed that eigen channels per user in NYUSIM is less and stronger than 3GPP which means a fewer number of time clusters (TC) and spatial lobes and this corresponds with real-world measurements. The spectral efficiency in NYUSIM is larger than 3GPP due to fewer and stronger eigenvalue in NYUSIM. 3GPP channel models are more optimistic than NYUSIM, which means that NYUSIM is more realistic and this has a large effect on system performance evaluation [32].

1.3 Thesis Aims:

This work focuses on studying 5G channel models and their feasibility to implement, then focusing on one channel model to investigate path loss and atmosphere condition effect on signal strength of next-generation frequencies (millimeter wave frequencies) from 30 GHz up to 100 GHz. This study provides detailed information about the attenuation of free space and the effect of rain rate, temperature, and humidity on the signal strength in different seasons of the year in Mosul which have a large variation in temperature, rain rate and humidity between seasons. The effect of weather condition during day and night at four frequencies was studied. Investigating the losses due to free space and atmosphere condition on signal at different frequencies in the frequency range 30-100 GHz. The attenuation on signal strength with increasing the distance between transmitter and receiver including weather effect had been studied. Studying the effect of increasing the number of antenna elements on the received signal.

1.4 Thesis layout:

This thesis contains five chapters:

Chapter one contains a brief introduction to the fifth generation with a look at work and efforts that had been made in the research field of 5G and channel modeling.

In chapter two is information about the fifth generation, the motivation behind the intention of creating a new generation of the mobile system, goals of 5G, spectrum, new services and challenges that face the upcoming generation are described.

Chapter three gives theory with an overview of existing channel models according to literature published by research groups, institutions, and organizations.

Chapter four contains results of simulations of weather effect on signal strength in Mosul/Iraq at millimeter waves in day and night through months at 28 and 73 GHz, study of weather effect on signal strength through seasons at frequencies 28, 37, 60 and 73 GHz, study of weather effect on signal strength at different distances on 28, 37, 60 and 73 GHz, and weather effect for different MIMO system configurations at 28 GHz.

Chapter five contains conclusions and suggestions for future work.

Chapter Two
Fifth generation communication systems

2.1 Introduction:

The wireless communication is defined as data exchanging between two or more parties by electromagnetic waves. Since the invention of wireless communication, it experienced exponential growth in both the science field and commercial markets. After 1970, the development of wireless communication started to go at a faster rate. The standards of wireless communication from point of view of data rate and efficiency is controlled by the demand of society [33].

The humanity witnessed rapid growth and development in mobile wireless communication in the last few decades. This evolution consists of generations (G) and foreseen generations are still coming in the future. Mobile wireless generations started with first generation (1G) then followed by 2G,3G,4G and then the upcoming 5G which is still under research. These generations differ from each other in capacity, data rate, services, latency, technologies, and even challenges. One generation can be differentiated from others through the techniques and features of each one. For example, the first generation (1G) of wireless mobile was analog and offers one fundamental service which is voice calls only. The digital technology is adopted in the second generation (2G) and provided text messaging. The third-generation (3G) offers higher transmission data rate and system capacity compared to previous generations with additional multimedia service added to the mobile system. The fourth generation (4G) which is currently used represents an evolution to mobile technology because it provides internet to wireless mobile and overcomes 3G limitations. The fifth generation is still under study but it will give the user a revolutionary experience that he did not go through it before [34].

2.1.1 First generation:

This generation is introduced in 1982 and completed in 1990. This represents the first mobile phones for civilian users and the only offered service is voice service. The technology of this generation is based on an advanced mobile phone system (AMPS). The first generation of a wireless mobile system is like any other sunrise technologies and services it has pros and cons. It provides mobility but there are many cons like poor voice quality, poor battery life, few numbers of users, large phone size and poor security [34]. The system was analog and used frequency modulation to modulate the signals. Circuit switching method was used to exchange data (analog data). The spectrum in the 1G cell is divided into channels which add a huge limitation on the number of calls that can be made at the same time. Many 1G systems launched during its lifetime like AMPS which was deployed in the United States, Nordic mobile telephone (NMT), total access communication system (TACS) and other systems which were deployed in Europe. All mentioned 1G standards lead us to conclude that there was not a unified standard also 1G systems could not be in line with the large increase in the number of subscribers [35].

2.1.2 Second generation:

The second generation based on Global System for Mobile (GSM) appeared in 1991 in Finland [30]. It is controversial with 1G, it uses digital signals for the purpose of information exchanging. It can also transmit pictures at low speed (few tens of kbps). The bandwidth of the signal was 30 kHz to 200 kHz. The quality and capacity here improved compared to 1G and the data rate was up to 64kbps (after adding new enhancements) but it is still unable to deliver videos [34]. The 2G standards utilized Time Division Multiple Access (TDMA). The main features offered by 2G was a short messaging service (SMS), email, and other simple data applications that transmit their data through a circuit switched system. The maximum data rate of 2G at first was 9.6 kbps but through years different enhancements added to get it higher by allocating more than one-time slot for each user and new coding schemes [36]. The General Packet Radio Service (GPRS) made it possible to transmit digital data. Unlike the first generation which used circuit switching, GPRS used digital circuit switching. The highest data rate achieved in GPRS is 171kbps [30]. Over years, more extensions were added to the 2G to support packet data services. These extensions gave higher capabilities to the original 2G. It is also referred to 2G with extensions as 2.5G as an example of 2.5G is Enhanced Data rates for GSM Evolution (EDGE) [27]. EDGE provided data rate in the downlink up to 1.3 Mbps and 653 kbps in the uplink [30].

2.1.3 Third generation:

To increase system capacity which inherently means a larger number of users, a new technique called Wide Code Division Multiple Access (WCDMA) was adopted which allows the base stations to use the same frequency for a number of users; therefore, it utilizes radio frequency efficiently. Data divided into packets then transmitted using packet switching technology. The maximum data rate for each user is up to 2 Mbps. Some of the important features of 3G are fast data rates, multimedia access and making video calls [35]. This generation also witnessed enhancements and extensions; one of these enhancements which pushed data rate in the downlink to 14.4

Mbps, is high-speed downlink packet access (HSDPA). The name 3.5G called for the third generation that meets 3GPP Release 5 requirements [30].

2.1.4 Fourth generation:

The fourth generation is an extension to 3G or we can say it is an improvement to the previous generation since it has a larger bandwidth and supports new technologies like multiple input multiple output (MIMO) antennas [37]. By using orthogonal frequency division multiple access (OFDMA) with MIMO, the data rate is up to 100 Mbps and support multi-services (texting, data, and multimedia) [35]. The first release candidate system standard is called Long Term Evolution (4G-LTE). The whole system was built on packet switching and does not use circuit switching in order to achieve high data rates. The focus from the beginning was on data rate, latency, and capacity. One of the important requirements in 4G-LTE was mixing of frequency division duplex (FDD) and time division duplex (TDD). Some architecture components of the 4G system have significantly changed compared to the 3G system [27]. New important features of 4G are: it can handle high definition video, video call stream with high-quality audio and support internet multiplayer gaming since it fully supports end-to-end internet protocol (IP) [37]. 4G-LTE deployed for the first time at the end of 2009. Its specifications were the only portion of 3GPP release 8 specifications [27] which were: 100 Mbps at bandwidth of 20MHz with spectral efficiency of 5 bit/sec/Hz in the downlink, and 50 Mbps at 20 MHz with spectral efficiency of 2.5 bit/sec/Hz, 200 active users at minimum within each cell, provide high performance for moving mobile terminal at speed between 15 to 120 km/h, and spectrum flexibility. Release 9 does not carry significant changes to LTE. Two years later, 3GPP published release 10. Release 10 contains standards for

LTE-Advanced (LTE-A). Despite the first LTE offered a huge improvement compared to 3G technology but still does not fulfill the entire requirements set by the International Telecommunication Union (ITU) for the 4G system. Consequently, LTE-A came to overcome this issue. ITU put high requirements that must be met in order to call the system a 4G system. Some of these requirements are higher quality service, enhanced data rate (1Gbps for low-speed terminal and 100 Mbps for high-speed terminal), carrier aggregation and higher order MIMO. The releases followed Release 10 also carried new enhancements like coordinated multipoint transmission and reception (CoMP) in Release 11 [30]. Release 12 focused on small cell improvement and interference reduction, in Release 13 number of carriers that can be aggregated raised from 5 to 32 which can result in 25 Gb/s in downlink [27].

2.1.5 Fifth generation:

The fifth generation is expected to have great and important changes not only in the term of bandwidth but it will change the fundamental purpose of cell phones. The user is going to experience something like never before. The 5G will support worldwide wireless web (WWWW) [38]. Figure 2.1 shows the evolution of mobile generation over time [7]. More details of 5G will be discussed in the following sections.

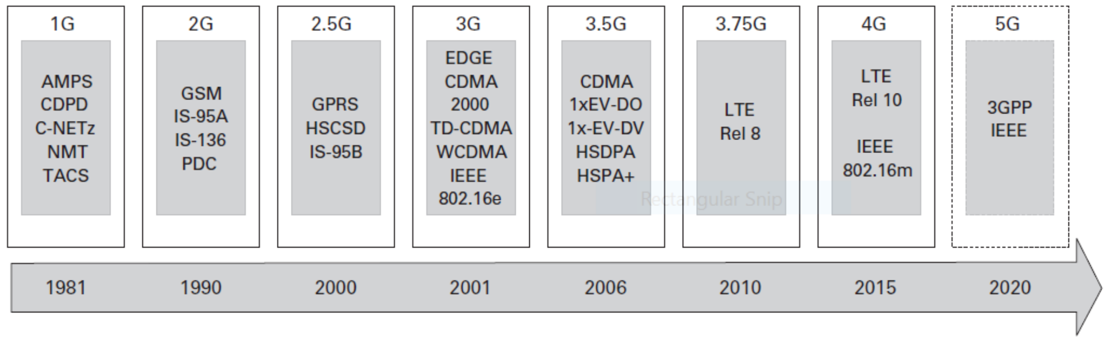


Figure 2.1: Evolution of mobile generations over years.

2.2 Introduction to 5G:

The demand for higher mobile data rates increases year after year in a dramatical manner especially in the last few years, which pushed existing mobile technology to its limits according to the Cisco report. In 2016 internet protocol (IP) traffic around the world was about 1.2 ZB per year (Zettabyte (ZB)=1000 Exabytes (EB)= one trillion gigabytes), by 2021 global IP traffic will reach 3.3 ZB per year. According to the report, the traffic will be three times larger in the upcoming 4 years. Personal computers took 46 percent of IP traffic and smartphones represents 13 percent in 2016 but these numbers are expected to witness significant changes in 2021 where PC share estimated to be 25 percent and smartphones portion will increase to 33 percent. Smart televisions, tablet devices, and machine type communication’s traffic will increase by 21 percent. IP traffic in the Middle East and Africa have the highest increase rate in the world [2]. The current technologies used in cellular networks are not capable to handle this rapidly increasing demand. Due to augmentation not only in the data traffic but also in the number of connected devices, the edge of a new era of mobile technology became near. Everyone and everything will be connected to the mobile network. The new technology must be able to cover the increasing demand and various requirements imposed by new services, applications and user terminals that the current generation of mobile networks cannot provide. In 2019, it is foreseen that mobile data traffic exceeds a fixed network. In 2014, 439 million devices added to the smartphones sector only and with tablets and other devices. The number will be as high as the human population. The previous numbers may be many folds with the internet of thing which means machines, sensors, wearable devices, and other devices are connected to the network and controlled remotely. The number of devices with IoT evaluated to be 50 billion in 2019 [9].

In addition to the previously mentioned factors that rule the next generation standards, one more factor concerns the network operators which is energy consumption. Energy consumption and energy efficiency is an important factor, as it limits operator expenditure. Increased mobile traffic led to increases in energy consumption which reached high levels since hardware equipment became more complicated and starving to power [3].

By looking to the near future of 2020, there will be a tremendous increase in mobile traffic data. IMT-2020 (5G) promotion group estimated that the mobile data traffic would increase 200 times between 2010 and 2020 over the worldwide and 20,000 times from 2010 to 2030. In China due to very high population, the growth rate is higher; the mobile data traffic evolution is expected to be 300 times between 2010 and 2020 and 40000 times for the period 2010 to 2030. Some fast-developing cities have a higher number than average. For example, the mobile data rate may reach 600 times for the period 2010 to 2020 in Shanghai alone while in Beijing, Hotspot traffic expected to be 1000 times for the same ten years as illustrated in figure 2.2 [39].

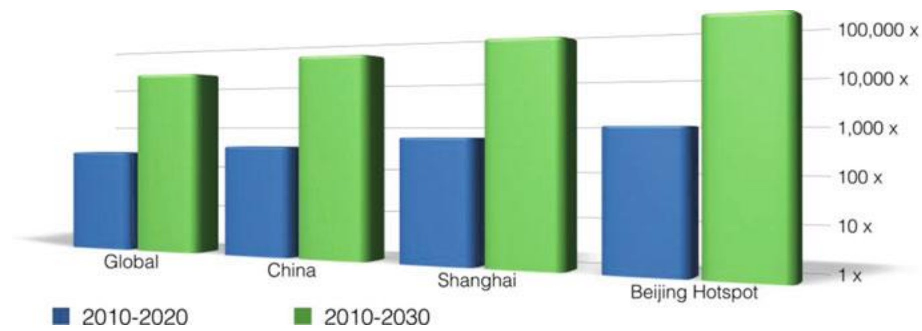


Figure 2.2: Mobile data rate growth [39].

If we want an abstract definition of the fifth generation of a mobile network, it will be a platform build upon gradually developed technologies. This platform basically carries new services and applications to the terminal. 5G is being built upon 4G systems, therefore; 5G is considered as 4G development. By taking this point of view, 5G will gather internet services with heritage standards of mobile network and this drives us to what is called ‘mobile internet' over Heterogeneous Networks (HetNets). The 5G roadmap is actually not completely paved by the stakeholder but it encompasses a comprehensive vision of targets and design of the next generation. The main goals or targets of the new generation have been proposed to meet future data growth expectations are 10-100 times peak data rate, 1000 times network capacity which means 1000 times larger terminals number, 10 times energy efficiency better than current technologies and 10-30 times lower latency [3]. Figure 2.3 shows the radar of 5G capabilities [40]. These proposed capabilities are widely accepted in the researchers’ community, they started working to evolve technologies based on the already clear set of accepted 5G goals [3].

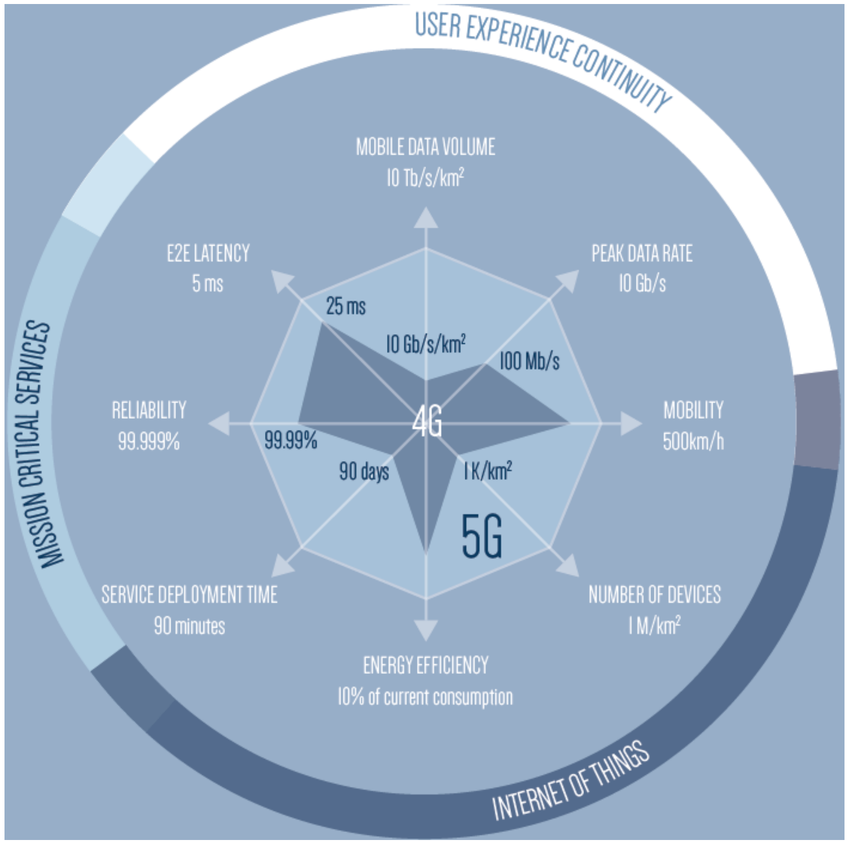


Figure 2.3: 5G capabilities [40].

5G communication desired to offer large data bandwidth, very high networking abilities and comprehensive service coverage to provide high-quality service and rich user experience. Consequently, 5G will use some of the current advanced technologies in addition to ingenious new techniques [3]. The International Telecommunications Union (ITU) scheduled 2020 as the year of defining the standardizations of next mobile generation networks although technical approaches to form 5G still undefined in details until this time. Several emerged techniques appeared such as massive MIMO and millimeter waves' communication (mm-W) to help 5G to arise. According to the purpose for which the connection made, the scenario of an environment (dense urban, urban macro, urban micro rural and indoor hotspot are determined) and technical 5G requirements, the researchers will be oriented towards technical specification of 5G [39].

Mobile internet and Internet of Thing (IoT) represents the primary motivations of 5G. These different use purposes can be sorted into three scenarios, which are: Enhanced mobile broadband (eMBB), Massive machine type communications (mMTC), and Ultra-reliable and low latency communications (URLLC). Those usage scenarios are different in their requirements such as data rate, latency, connection density, etc [39].

The work on 5G requirements, which is divided into two stages, is done by the different organizations. The first stage concentrates on the 5G vision, which includes use cases and high abilities of the 5G network [39]. In this stage, ITU released its vision testament and determined abilities of 5G in 2015 [41]. Third generation partner project (3GPP) also searched use cases and abilities of 5G in 2015. Next Generation Mobile Networks (NGMN) identified more use cases and abilities and published it in a white paper in the same year [42]. International Mobile Telecommunication (IMT-2020) shared their vision of 5G vision and its abilities in a white paper in 2014 [43]. In the second stage, the attention was on high detailed deployment scenarios and requirements of each scenario. The most remarkable report in stage 2 is IMT-2020, which is introduced by International Telecommunication Union-Radio communication Sector (ITU-R). IMT-2020 work completed in February 2017 [44]. The other work is done by 3GPP and completed in March 2017 [39], [45].

2.2.1 Keys of 5G:

We can say there are some features, which have the main contribution to the emergence of the fifth generation of mobile systems, these are:

2.2.1.1 Various types of Radio Access Technology:

5G will not use a specific type of radio access technology (RAT) but it will use different types of RAT starting from using enhanced versions of previous generations' RATs in addition to new RATs. It is more reasonable to use previous RATs from the economical point of view after enhancing their spectral efficiency. Energy efficiency and latency besides providing the ability of flexible radio access network (RAN) sharing among different manufacturers are required in order to obtain 1000 times capacity. One example of features that need to be improved is supporting massive/3D MIMO in long-term evolution (LTE) to achieve higher spatial diversity. beamforming leads to better interference cancellation, and improved interference coordination in different small cells scenarios [3].

2.2.1.2 Hyperdense small-cell deployment:

In order to meet the high increase in mobile data traffic, cell sizes are made smaller which also has leverage on energy and spectral efficiency. This technique is also called heterogeneous Networks (HetNet) [3], [6]. There are two types of HetNet, the first one is multi-tier HetNet which deploys small cells of the same technology which may be micro, Pico or femtocells. The second is multi-RAT HetNet which deploys small cells of the different technologies such as high-speed packet access (HSPA), LTE, WiFi and so on. According to Qualcomm, the capacity of the system double when small cell number doubles. It can be said, the relationship between system capacity and the number of cells is linear. The drawback of increasing cells number is increasing inter-cell interference which is solved by intercell interference management/cancellation techniques at both system and terminal [3].

2.2.1.3 Machine Type Communication:

Machine Type Communication (MTC) is another important feature of 5G, which provides a connection between a large number of devices, therefore; the cost and energy efficiency really matters for these devices. Machine type communication has a wide range of use cases which requires different requirements starting from devices that transmit a small discrete amount of data such as sensors and actuators to ultra-reliable and very low latency such as road safety, traffic efficiency, and industrial manufacturing [7].

2.2.1.4 Millimeter-Wave RATs:

Sub-3 GHz spectrum became crowded and current RATs capacity near Shannon's capacity limit made researchers look for new technologies. Despite millimeter waves offer a solution to some of the current generation problems but mm-Waves have some obstructions which need to be treated to become suitable for 5G. The main obstacles are higher path loss compared to sub-3GHz bands, mm-W band signals are more sensitive to blockage, which makes them more likely to propagate in line-of-sight (LOS), and loss due to material's penetration is higher which can isolate outdoor users from indoor users [3].

2.2.1.5 New backhaul links:

5G relays on small cells densification to achieve 1000 times capacity, therefore; backhaul link needs to be able to carry the tremendous data traffic. The first motivation of backhaul redesigning is the very high cost of using fiber cables to make a connection between base stations (BS) and cellular network. Since the number of base stations in 5G is large, microwave links represent a more economical solution. The second reason is to manage Inter-cell interference caused by a large number of base stations which requires inter-base station communication. Studies by 3GPP work groups concluded that latency has a considerable impact on cell-edge throughput and interference mitigation performance. The third reason is a large number of handovers because of small cell densification, which needs low latency between base stations (BS-to-BS) [4].

2.2.1.6 Energy efficiency:

Energy efficiency represents an issue for 5G from different points of view. Cellular network operators spend a lot of money every year on electricity bills, therefore; they pay large attention to energy efficiency to reduce operating costs [27]. Energy consumption is important for devices, where better efficiency leads to fewer recharging times besides some devices are deployed in wide areas which make the process of changing/recharging batteries hard and sometimes impossible. It is expected that 5G introduces 10 times better energy efficiency so some devices can work for years before requiring battery replacement [39].

2.2.1.7 New spectrum allocation:

Mobile data traffic and the number of connections are expected to increase in an exponential manner after 2020 [39]. The current spectrum shortage becomes more obvious with the increasing demand for larger capacity. The current bandwidths below 6 GHz are not satisfying 5G requirements while millimeter wave band has abundant bandwidth making its major part of 5G. Current researches are interested in 28 GHz band, 38GHz band, 60GHz band and E-band (71–76 GHz and 81–86 GHz) [46].

2.2.2 Spectrum:

Spectrum plays a very important role in wireless communications. Cellular communications were interested in increasing capacity by improving spectral efficiency. The first generation of the mobile system operated at a frequency below 1 GHz, the second generation had a frequency of 1.8/1.9 GHz, the third generation crossed 2 GHz and the fourth generation firstly operated at 2.5 GHz but later increased into 3.5 GHz. Figure 2.4 shows the spectrum of each mobile generation [27].

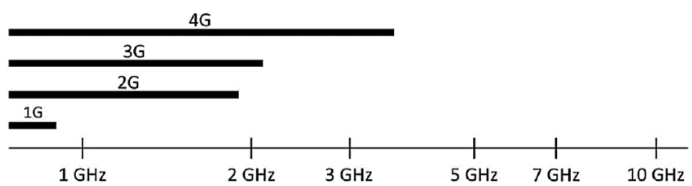


Figure 2.4: Spectrum of mobile generations.

In the last few years, video services such as video on demand, video calls, online gaming, learning through internet and remote health monitoring made available to personal computers, laptops, tablets, and smartphone. The number of these devices increased in a dramatical manner in the last few years. A large number of connections and increasing demand on services that require high data rate involved boost data throughput. To satisfy the high demand, a number of technologies were used in the 4G mobile systems like LTE and mobile WiMAX to enhance transmission data rate. These technologies used techniques to push spectral efficiency to its limits such as orthogonal frequency division multiplexing (OFDM), multiple-input-multiple-output (MIMO), multi-user detection, advanced channel coding, adaptive coding, adaptive modulation, hybrid automatic repeat request (HARQ), cell splitting and heterogeneous networking. The currently used frequency bands for mobile networks which are below 10 GHz have been used excessively; therefore, there is no chance to achieve a significant improvement in data rate. The researchers started looking for more bandwidth at higher frequency bands to increase system capacity and transmission rate [47].

The millimeter waveband lies between 30 GHz and 300 GHz as illustrated in Fig 2.5 (a). According to current semiconductor technology in the markets, it is expected that the maximum frequency that can be reached is 100 GHz. Of course, this limit will be overtaken with time [7].

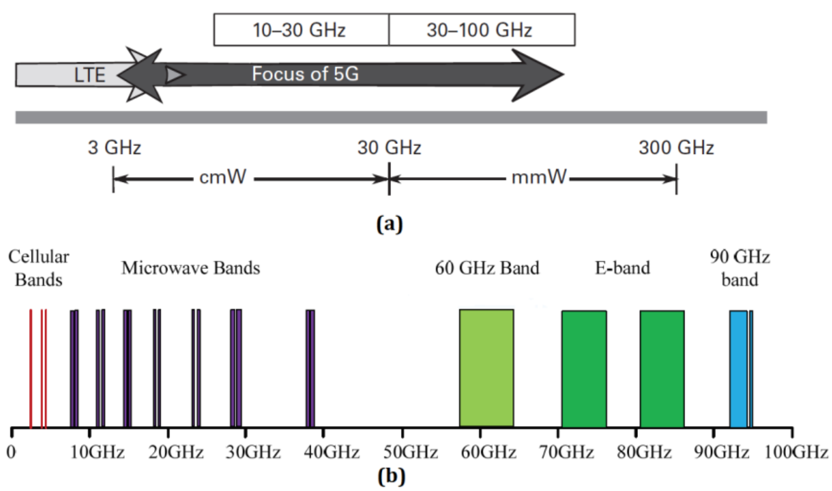


Figure 2.5: Radio spectrum a) frequency bands [7], b) frequency band allocation [47].

The millimeter waveband represents the key for the revolutionary next mobile systems. Some of the sub-bands are preferred not to be used because of high attenuation due to severe atmospheric absorption and 40% of the remaining millimeter waveband will be made available with time. Maybe, 100 GHz bandwidth of 300 GHz in the millimeter wave band be available for next communication technologies in the most optimistic opinion since the 100 GHz bandwidth is not continuous but segmented as illustrated in Fig. 2.5b. ITU named the frequency bands 71-76 GHz and 81-86 GHz which is also called E-bands for mobile broadband services. The bandwidth at E-band is 10 GHz, which is 50 times greater than the spectrum of current cellular systems. This massive bandwidth is much greater than ever-allocated bandwidth by the Federal Communications Commission (FCC). E-band can provide 5 GHz per channel, which give the ability to transmit multi-gigabits per second that inherently means higher data rates with lower latency [47]. Although of availability of huge bandwidth in the millimeter band but the complexity is high; therefore, lower frequencies in the centimeter wave (cm-W) band become attractive due to lower complexity but the available bandwidth smaller in the region 10-30 GHz [7].

It is worth to mention that higher mobile generations can be deployed at lower frequencies. For example, long-term evolution (LTE) which currently operates at 3.5 GHz can operate at a low frequency as 450 MHz. It is rational to make modern mobile systems operate at low frequencies in rural areas where the number of users is small. Lower frequencies have larger coverage area which means a smaller number of base stations [27].

2.2.3 Spectrum estimation for 2020 and beyond:

The used process to estimate the required spectrum for near and far future begins with making a comprehensive survey and study of current cellular companies' data followed by analysis of expected market needs and their data traffic requirements. The survey should be done in details by calculating data traffic of each radio access technology (RAT) type after that computing the wanted capacity and the last step is making the estimation.

The process of calculation is very difficult and complicated since there are different traffic types, environments and cell kinds of different RATs [39]. It is worth to mention; the process of traditional licensing takes a very long time in sometimes takes years besides the high licensing fees which depend on transmission data rate or bandwidth or both [47]. It is not that right to specify the demand of 5G in just a final number since there are different scenarios. Estimating the requirements of each scenario individually in terms of coverage, performance, capacity, and connections will give a more useful and realistic estimation. It is expected that 5G spectrum will carry a comprehensive vision and solutions to all scenarios [39].

2.2.4 Use cases and challenges of 5G:

Although engineers in 4G put high mobile broadband in their top priorities, they started looking and forecasting new applications and services that will need to be connected to wireless network. New applications and services impose different requirements on the network, it is intuitive these use cases have a direct impact on different economic sectors. Examples of these different requirements are high-resolution videos, autonomous facilities or factories and agriculture. Researchers chose to work on new technologies instead of extensions to 4G.

Emergence use cases and challenges that 4G cannot provide their requirements, and solutions lead to the need for 5G, it also helped stakeholder to set the goals of the new generation. These challenges are representing a problem for human users and for machine users. Definitely, new imposed applications and services show the importance of the development of 5G. Use cases can be grouped under three main titles: mobile broadband improvement, internet of thing (IoT) and critical infrastructure or public safety [29].

2.2.4.1 Enhanced mobile broadband (Human user):

The purpose of 3G and 4G networks is to provide users with broadband services, which are considered a very important thing for human users. The demand for better service, the appearance of new services and applications areas necessitate different requirements to be met for each usage scenario. ITU-R called the new set of use cases and requirements “Enhanced mobile broadband”. The term enhanced mobile broadband encompass a large number of use cases with their requirements including hotspots and large area coverage. Hotspots have to provide high data rates, high user density, and high capacity while large area coverages have to provide high mobility with the smooth user experience. A large area coverage use case is less stringent in terms of data rate and user density. In enhanced mobile broadband, the human user is the center of interest [27].

2.2.4.2 Massive machine type communications (Machine users):

Massive machine type communications (mMTC) refers to a tremendous number of devices that are connected together through a mobile network. These devices transmit a small discrete amount of data which have low delay sensitivity at zero/very low mobility. The machines or devices goes to active connection mode only when they intend to transmit in order to save energy to extend battery life. 5G networks should be able to handle very high connection density to support all these machines, see Table 2.1. mMTC also called massive internet of thing [39].

2.2.4.3 Critical communications and public safety:

Critical Communications and public safety are one of the most important applications that make use of 5G network technology [29]. It is also called ultra-reliable and low-latency communications (URLLC). In URLLC scenarios, low latency has the highest priority and in some scenarios the mobility [39]. The next mobile network generation must provide very high reliability (see table 2.1) and immune to intruders in order to prevent manipulation and unwanted actions [29].

2.3 Internet of things:

Mobile broadband importance emerges year after year as a part of mobile cellular communication. Mobile networks will have a new field of users beyond humans' also different scenarios. 5G is expected to be a platform that provides connectivity to all new services. The new connectivity concept makes sure that anything, anywhere and anytime can have access to the network. The term "networked society" refers to scenarios where users of the network beyond users' smartphone and tablets to sensors and devices that have direct leverage on the humans' life, this is called the Internet of things (IoT) [27]. The emergence of 5G significantly benefits from the vast growth of mobile internet and internet of thing. By 2020, users will get more stable and efficient new functions via mobile internet. Virtual reality, online gaming and augmented reality that the users ask for will be met. IoT represents the perfect utilization application of 5G technologies [6].

New terms appeared recently such as IoT, Cyber-Physical-Systems (CPS) and Machine-to-Machine (M2M) communication. These terms used to draw attention to new fields of Information and Communications Technologies (ICT). IoT which is also called 'Internet of Everything (IoE)' means all things are connected together through the internet and has a unique address. CPS points out to the integration of calculation and physical approaches (e.g. sensors) through a wireless network. CPS importance appears especially in observing the physical action, monitoring and controlling Insite machines and devices remotely according to observed action data. Power grids can be a perfect example of CPS. M2M means two or more machines can communicate with each other directly which also means monitoring and controlling processes can be moved from the local level to the global level [7].

Intensive industrial and academic researches to manufacture objects are consistent with evolving technologies and standards [48].

As told before, the wireless communication is able to improve humans' life in untold ways. As an example, wireless communication will inevitably be an important part of economy evolution as follows:

Agriculture: Rainfall, moisture, temperature, and wind speed need to be measured and monitored using deployed sensors. Deployed actuators need monitoring and controlling. The collected data will help the farmer or animals' owner to increase the quantity and quality of their products.

Automobile: In the last few years self-driving cars appeared. This technology requires Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) wireless communication with very low latency and high reliability to achieve intelligent transportation by collecting information and process it to avoid collision and road traffic congestion.

Health: exercise monitoring, blood sugar level and heartbeats continuous sensing etc. These form health report and medical alerts that sent through the wireless network to the hospital or in charge doctor to take the suitable action.

Media: Video consumes a lot of bandwidth and poses tight stress on current networks. 5G will present a perfect experience of 3D and 4K videos. In the last few years, new services appeared such as Virtual reality (VR) and Augmented reality (AR) which is a massive bandwidth consumer. These services currently restricted to wired networks and small wireless network, in foreseen future 5G will make it nomadic.

Manufacturing: controlling machines and processes could be more accurate, efficient and reliable with wireless communication. 5G will meet the increasing demands of higher reliability and very low latency for self-operating factories (massive machine connectivity means more wireless connected devices) [7].

Additional applications and services: public safety, aerospace, defense, chemicals and etc.[7]. Many objects that forming IoT will have limited resources and unable to have the high processing capability to apply protection mechanisms on their own. Where protection mechanisms include malware signature scanning and complex intrusion detection. Even if the objects have plenty of resources, implementing complicated security abilities on a large number of objects is very expensive [48].

Different application and services inevitably need diverse requirements, protocols, and architectures. Devices and machines work together and communicate with each other in one network is a challenge. IoT traffic differs by application and service type ranging from low to high bandwidth and from low latency to permissive delay, from tolerant error to high reliability and so on. All this considered additional complication [4]. Table 2.1 shows different use cases and their requirements that 5G should be met [7].

Table 2.1: IoT applications and requirements.

Use cases	**Requirements**	**Desired value**
Autonomous vehicle control	Latency Availability Reliability	5 ms 99.999% 99.999%
Emergency communication	Availability Energy efficiency	99.9% victim discovery rate 1-week battery life
Factory cell automation	Latency Reliability	Down to below 1 ms Down to packet loss of less than 10−9
High-speed train	Traffic volume density Experienced user throughput Mobility Latency	100 Gbps/km^2 in DL, and 50 Gbps/km^2 in UL 50 Mbps in DL, and 25 Mbps in UL 500 km/h 10 ms
Large outdoor event	Experienced user throughput Traffic volume density Connection density Reliability	30 Mbps 900 Gbps/km^2 4 subscribers per m^2 Outage probability < 1%
Massive amount of geographically spread devices	Connection density Availability Energy efficiency	1,000,000 devices per km^2 99.9% coverage 10 years of battery life
Media on demand	Experienced user throughput Latency Connection density Traffic volume density	15 Mbps 5 s (start application) 200 ms (after the possible link interruptions) 4000 devices per km^2 60 Gbps/km^2

	Availability	95% coverage
Remote surgery and examination	Latency Reliability	Down to below 1 ms 99.999%
Smart city	Experienced user throughput Traffic volume density Connection density	300 Mbps in DL, and 60 Mbps in UL 700 Gbps/km^2 200 000 users per km^2
Tele protection in a smart grid network	Latency Reliability	8 ms 99.999%
Traffic jam	Traffic volume density Experienced user throughput Availability	480 Gbps/km^2 100 Mbps in DL, and 20 Mbps in UL 95%
Virtual and augmented reality	Experienced user throughput Latency	4–28 Gbps 10 ms RTT

2.4 Millimeter wave antennas:

The wavelength is in order of 10mm to 1mm for the frequency range 30 GHz to 300 GHz. Previously, millimeter wave band was usually used for military and space applications but not for commercial purposes because of high costs and complexity. The small wavelength in the mm-W region gave the manufacturers the ability to fabricate small and compact antennas. The antenna needs to be carefully designed to get the desired specifications. Losses at mm-W are higher than lower frequencies. Small antenna size opens the way to provide pencil beamforming or massive MIMO technology [49].

2.5 Multiple inputs multiple outputs (MIMO):

Multiple input multiple output system consists of a number of antennas at both transmitter and receiver. MIMO systems introduce a considerable improvement in data rate and coverage area without increasing bandwidth. MIMO system produces better data rate and large coverage area by realizing high spectral efficiency (b/s/Hz) and diversity which mitigate fading. The necessary mixing MIMO and millimeter wave technologies emerged to enhance spectral efficiency for mm-W applications in order to meet the 1000 times capacity of 5G [50].

In the last twenty years, researchers were interested in MIMO technology because of its ability to satisfy the increasing demand for more data throughput. The maximum number of antenna elements that can be implemented at the base station in the third-generation partnership project (3GPP) long-term evolution (LTE) is ten elements. The spectral efficiency can be furthered improved to a large degree by using a very large number of antennas at the base station. The technique of implementing a large number of antennas at the base station is called massive MIMO. Massive MIMO is considered as a key for the fifth-generation mobile network [51].

The implementation of a large number of antennas at the base station poses challenges and problems that need to be overcome. These challenges can be seen at different levels such as channel capacity implications, array antenna design, and signal processing implications [1]. Accurate channel state information which base station need to provide reliability also considered as a challenge in massive MIMO [31].

Chapter Three
Channel modeling

3.1 Introduction:

Channel modeling is a study of how physical channel affects the transmitted signal in terms of amplitude, phase, frequency, and delay. Channel modeling in communication engineering has two goals. The first goal is to make our vision of how the channel behaves more comprehensive which is useful in designing new efficient communication schemes. It also gives us a better view of the physics of communication systems since the medium used for transmitting the wave has a variation in time, frequency, and space. It is intuitively that the better approximation of channel behavior and channel characteristics the better-designed technology works in the real world. As a consequence of the first goal, the second goal of channel modeling is the estimation of the performance of new technology and proposed technological solutions in semi-realistic environments. Due to the high complexity and time consumption of modeling environments with very high details a simplification and approximations are needed to reduce the complexity of simulation to get attainable tools to simulate a large number of communication links simultaneously [52]. Channel modeling can be defined as a deterministic or a stochastic numerical description of a specific environment depending on measurements campaigns in that environment or depending on the analysis. the Channel models have two levels which they are link-level and system-level. Performance evaluation, optimization and making comparisons between technologies, algorithms and products can be made by utilizing channel models [6].

The fifth generation will use millimeter wave band frequencies which have unique characteristics. The characteristics of mm-W frequencies create new requirements that mm-W channel models must provide, therefore; modifying existing channel models and creating new channel models are required [53].

Channel models can be classified in several ways such as classifying according to propagation. For example, models can be divided into flat fading (narrowband) and frequency selective channel (wideband) or time-variant and time-invariant models. Models can be also classified into analytical and physical models, in this type of classification, there is a basic difference between models. The analytical models characterize the propagation channel directly where the effect of transmission/reception antennas is calculated within. While the physical models have two-part, propagation channel part and antennas part which means they are separated. Table 3.1 shows the categorization of channel models [13].

3.1.1 Analytical channel models:

Analytical channel models provide impulse response or channel transfer function for any transmitter and receiver antenna pairs. Analytical channel models are divided into correlation based and propagation-motivated models as illustrated in Table 3.1. Correlation-based models include independent and identically distributed (I.I.D.) model, Kronecker model, and Weichsel Berger model. Propagation-motivated models include finite scatterer model, maximum entropy model, virtual channel representation and α-η-k-μ fading model. Correlation-based channel models determine the MIMO channel matrix statistically by using correlation while propagation-motivated models determine the MIMO channel matrix by using propagation parameters [13].

Table 3.1: Classification of MIMO channel models [13].

Analytical models	Physical models
1. Correlation-based: i.i.d model Kronecker model Weichsel Berger model 2. Propagation-motivated: finite scatterer model Maximum entropy model Virtual channel representation α-η-k-μ fading model	1. Deterministic Ray tracing Stored measurement data Finite difference time domain 2. Semi-deterministic METIS map-based model 3. Geometry-based stochastic COST models WINNER-family models NYU wireless model 4. Standardized 3GPP spatial channel models IMT-Advanced model 5. Non-geometrical stochastic Saleh-Valenzuela model Zwick model

3.1.2 Physical channel models:

Physical models can be divided into five categories. They are deterministic, semi-deterministic, Geometry-based stochastic, standardized and non-geometry stochastic models. The deterministic models refer to determining the channel parameters in a deterministic manner which means the simulation contains accurate details without any randomness. An important example of a deterministic model is ray tracing which generates channel parameters by representing the propagation scenario accurately [13]. Ray tracing can make use of three-dimensional maps to get channel characteristics. The Map-based deterministic channel model creates channel characteristics for specific transmitter and receiver locations which are considered as a drawback. The accuracy of results depends on how accurate scatterers and objects details and locations are modeled [54]. Another example of deterministic models is stored measurement data which requires a massive amount of data. The last example is the finite difference time domain models [13].

A semi deterministic channel model has been developed within the METIS project [13]. It is called semi deterministic because the locations of objects and scatters are randomly assigned [54]. METIS channel model addresses all fifth-generation challenges since it depends on physical principles by using a small number of parameters related to those principles [12]. METIS model requires more measurements data for validation [13].

The geometry-based stochastic channel models can be divided into two categories depending on the modeling approach. The first category contains cooperation in science and technology (COST) models. COST models generate scatterer clusters [13]. COST supports spatial consistency but cannot be utilized for dual mobility [12]. The second category use geometry for the line of sight (LOS) components only, while scatterer clusters generated stochastically [13]. The wireless world initiative new radio (WINNER) family members are stochastic models. WINNER family contains WINNER, IMT-Advanced, and third generation partnership project (3GPP) stochastic channel model and D2D model. WINNER family models are designed for two-dimensional propagation but enhancements are added to support three-dimensional propagation such as WINNER+, quasi-deterministic radio channel generator (QuaDRiGa), and 3GPP-3D. These models work for frequencies below 6 GHz and make benefit of measurements data at this frequency band. The GSCM family has a serious challenge in satisfying 5G channel model requirements. For example, WINNER models are incapable of providing correlated realizations for two users close to each other's which results in no spatial consistency. WINNER models give nonrealistic amplitude representation for subpaths and optimistic massive MIMO performance [12]. New York University (NYU) wireless model is a statistical spatial channel model (SSCM). NYUSim is a simulator created by researchers in New York University depending on extensive measurements at 28 and 73 GHz in a various outdoor environments. NYUSim is SSCM and uses time clusters (TC) and spatial lobes (SL) to represent omnidirectional channel impulse response (CIR) and the corresponding angle of departure and angle of arrival. Time cluster is a number of multipath components reaching the receiver from different angles within a short excess delay. Spatial lobes are ranges of angles that energy received/transmitted from within several hundreds of nanoseconds [55].

3GPP spatial channel models (SCMs) and IMT-Advanced (IMT-A) model are standardized models. 3GPP SCM at its beginning used COST model with some facilitation at different points, after that 3GPP SCM versions were depending on WINNER models. The IMT-A model also depends on WINNER models with modifications on its parameters. Figure 3.1 shows the development of GSCM and standardized models with time.

In non-geometrical stochastic models, the geometry of the surroundings does not contribute in calculating channel parameters, i.e. it is determined stochastically. Examples of non-geometrical stochastic models are Saleh-Valenzuela model and Zwick Model [13].

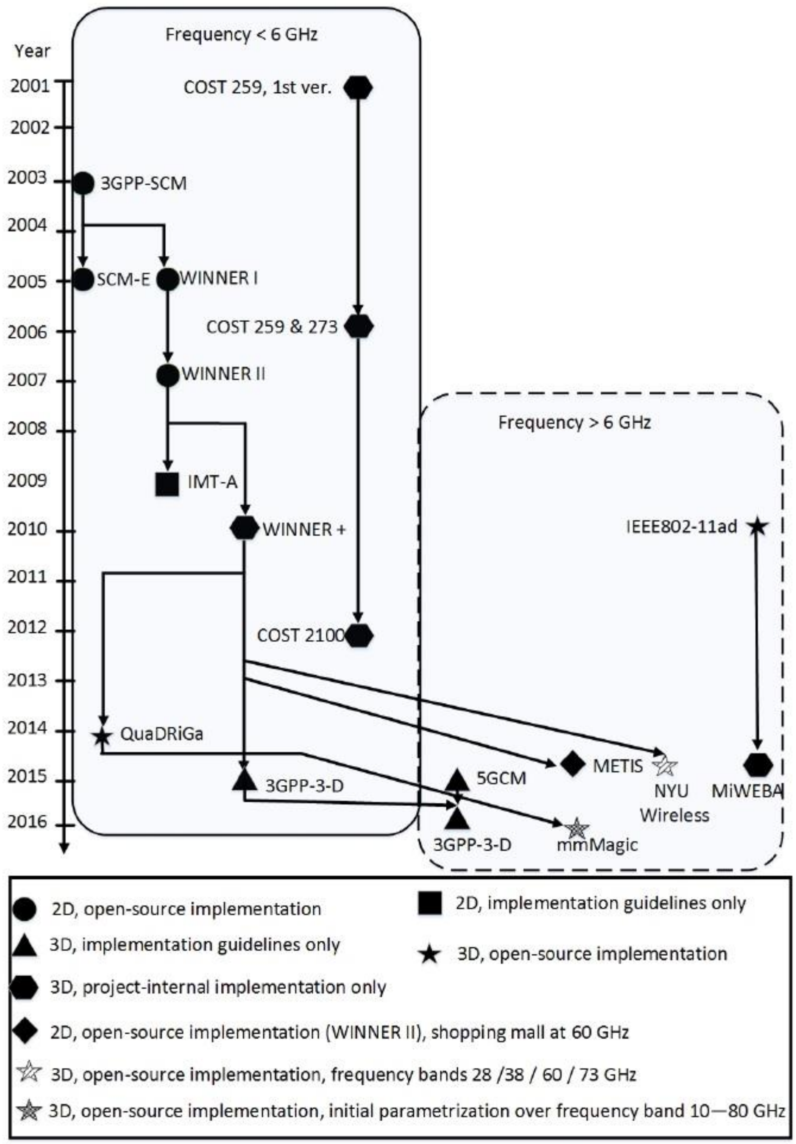


Figure 3.1: Development of GSCM and standardized models [13], [22].

3.2 5G channel model requirements:

The fifth generation communication systems will enter all fields of life such as work, entertainment, and transportation which includes covering new different scenarios such as indoor office, shopping malls, stadiums, highways, rural areas, and open-air festivals. 5G has more scenarios compared to previous generations. The new scenarios have different requirements that need to be covered by propagation models such as traffic volume, connection density, and very high mobility [6]. The new channel models involve supporting various link topologies in different scenarios such as outdoor-to-outdoor (O2O), outdoor-to-indoor (O2I) and indoor-to-indoor (I2I). 5G will present new link types that need to be modeled such as cellular access, point-to-point like backhaul and peer-to-peer links which encompass device-to-device (D2D) communication, massive machine communications (MMC), and vehicle-to-vehicle (V2V) communication [12]. The new technologies like massive MIMO and millimeter wave communication represent imposed challenges on new channel models [6].

The new technologies and scenarios are the main factors used to determine the requirements for wireless channel models [7]. Some of the requirements which are also considered challenges that channel model must satisfy are:

1. Supporting new scenarios, link types and network topologies:

The mobile networks since the early beginning serve the user through a stationary base station and channel models were developed based on this type of links. The 5G architecture will exceed normal cellular network link to support device-to-device, machine-to-machine (M2M) and vehicle-to-vehicle besides interconnected network. 5G models should provide terminal to terminal links and networks [6]. 5G will include different link types starting from conventional link types like macro and micro to picocell and femtocell in addition to moving base stations [7].

2. Supporting millimeter-wave frequencies and large bandwidth:

5G will operate at both below and above 6 GHz, including frequencies at centimeter and millimeter wave band. Some of the frequency ranges gained higher interest than others; these frequency ranges are 10 GHz, 18–19 GHz, 28–29 GHz, 32–33 GHz, 36 GHz, 41–52 GHz, 56–76 GHz and 81–86 GHz. It is worthy to mention, the frequency ranges between 30 and 100 GHz have higher priority than those below 30 GHz because of the high bandwidth in this region. All research efforts aim to create channel models encompassing propagation parameters and effects for the entire range of frequencies between below 1 GHz to 100 GHz [7].

3. Supporting massive antennas:

In order to compensate the high losses due to blockage and diffraction, narrow beams (high directivity) are required. Pencil beamforming and massive antenna arrays will be employed in 5G cellular systems to compensate high losses and to achieve high spectral efficiency [12]. Signal waves are sent from transmitter antenna array at different angles of departure and receiver antenna array receives the waves from a different angle of arrival. The difference in angles of arrival and departure generate small change in phase. The 5G will use massive MIMO and beamforming technologies which involve employing a large number of antennas. The use of a large number of antennas imposes two procedures which they are: planar wavefront assumption must be replaced with spherical wavefront assumption and every element of the array has a scattering cluster which impacts its signal [6].

4. Spatial consistency and dual mobility

The term spatial consistency is called for two cases, the first case when two adjacent links are highly correlated and the second case when propagation channel changes gradually without discontinuity and interruption this is also called “the ability of dynamic simulation”. 5G will support different link types and all these link types must be supplied with spatial consistency [6]. The two ends of the communication link in D2D and V2V are moving and this is called dual mobility, in this case, the model must support spatial consistency. The channel model is considered spatially consistent when two terminals are close to each other and experience the same angle, delay, power, and polarization domains. The absence of spatial consistency results in large errors in radio network estimation [12].

5. Complexity versus accuracy

Channel models should be able to produce propagation characteristics with a good level of accuracy but in the same reasonable level of complexity. The complexity must not be high to allow system level performance estimation. There is a trade-off between accuracy and complexity [53].

6. High mobility

5G will be able to provide service to users moving at high speed up to 500 km/h even for high user density transportation methods like subways. The lag in service at high-speed roads is in order of milliseconds for end-to-end communication level. Due to moving at high speeds, the propagation characteristic at high mobility has different characteristics from those at low mobility. The characteristics changes at a faster rate such as the period of time during which the channel characteristics appear stationary are shorter or one can say it is non-stationary. Doppler shift is larger at high speeds for V2V or device to a base station and the fading is stronger. While conveyance at high speeds the user will get through several scenarios such as high-speed trains which pass through rural areas, cities tunnel and platform, therefore; channel models should support transition between scenarios [6].

3.3 Channel models:

The common channel models and simulators with their important characteristics are:

3.3.1 METIS model:

METIS stands for Mobile and wireless communications Enablers for the Twenty-twenty Information Society. METIS expected the need for providing information access and content sharing by anything at any time and anywhere. METIS contributed in setting next mobile generation system technical goals. The goals envisaged in the next system are 1000 fold higher data volume per area, a 10 to 100 times higher number of devices, 5 times lower latency, and better energy efficiency. From the beginning, METIS defined five new scenarios and 12 use cases which are considered as a challenge. METIS objective was to build a model encompass 5G scenarios and use cases with realistic results [14].

In order to identify the requirements to fulfill the objective, analytic efforts have been made to analyses test cases and requirements to get requirements associated with a radio channel and propagation modeling. The requirements encompass: "very large frequency range (up to 86 GHz), large bandwidth (hundreds of MHz), fully three dimensional and accurate polarization modeling, spherical wave modeling and high spatial resolution, support of extremely large array antennas, dual-mobility for device-to-device (D2D), machine-to-machine (M2M), vehicular-to-vehicular (V2V) communications, and spatial consistency between link types (e.g. micro/macro cellular, D2D) and between users/ devices in a dense deployment" [14].

METIS channel models have three categories. The first category is a map-based model, the second category is a stochastic model and the third category is a hybrid model which is a combination of both. These various models give options to meet the different requirements for simulation in terms of accuracy and complexity. Map based models depend on ray tracing and make use of three-dimensional maps. Map based channel model includes the propagation mechanisms: reflection, diffraction, scattering, blocking …etc. As a consequent, the results are realistic and accurate. It is possible to evaluate the performance of technologies such as massive MIMO with the map-based model [14].

Stochastic based model work in the same way as the geometry based stochastic channel model (GSCM) which with some extensions. GSCM already modified by WINNER/3GPP to provide multi-dimensional shadowing maps with low complexity, millimeter wave parameters, and frequency dependent path loss models. The hybrid model can be considered as complementary to the map-based model, stochastic model or measurements. Table 3.2 shows a comparison between the three METIS models [14].

METIS project specified the frequency bands that have project researchers' attention than others. The frequency bands are 10 GHz, 28 – 29 GHz, 32 – 33 GHz, 43 GHz, 46 – 50 GHz, 56 – 76 GHz, and 81 – 86 GHz [14].

METIS measurements campaigns had been made in different scenarios at different frequencies by using different equipment's. These differences give diversity in measured data which will be useful in the future [14].

Table 3.2: METIS channel models [14].

Feature	METIS model		
	Stochastic	**Hybrid**	**Map-based**
Valid Center Frequencies	up to 70 GHz	up to 70 GHz	up to 100 GHz
Valid Bandwidths	100 MHz for 6 GHz, 1 GHz at 60 GHz	100 MHz for 6 GHz, 1 GHz at 60 GHz	10 % of the center frequency
Path loss	separate, empirical	implicit	implicit
Shadowing	separate	implicit	implicit
Explicit building model / generic	generic	explicit	explicit
Parametrization by measurements	easy	easy	easy
Support massive-MIMO	limited	limited	yes
Support spherical waves	no	no	yes
Support extremely large arrays beyond stationarity interval	no	no	yes
Support dual mobility	limited	limited	yes
Support 3D maps	yes	yes	yes
Support mmW	partly	partly	yes
Dynamic modeling	no	no	yes
Polarization modeling	XPR	XPR	Ray-based
Complexity in terms of definition	medium	high	high
Complexity in terms of calculation of channel realizations	medium	medium-high	high
Public implementation available	no	no	no

3.3.2 QuaDRiGa model:

In 2011, the Fraunhofer Heinrich Hertz Institute within the Wireless Communications and Networks Department, with the contribution of European Space Agency (ESA) started developing QuaDRiGa model. The work assisted by many parties such as the European Commission who contributed to mmMAGIC and METIS project, and the German Federal Ministry of Economics and Technology [31].

QUAsi Deterministic Radio channel GenerAtor (QuaDRiGa) is an enhancement of the WINNER+ channel model where it is built upon WINNER and 3GPP-3D channel models. QuaDRiGa is a geometry based stochastic channel model which permits two-way direction radio channel implementation. QuaDRiGa channel model supports different antenna arrangements and element patterns. Measurements campaign's data are used to stochastically extract channel parameters [22].

The main features of the QuaDRiGa channel model are:

- Supports single-input-single-output (SISO) link, MIMO link, and multi MIMO link.
- Use the same modeling way for indoor, outdoor and satellite scenarios with the ability to mix them.
- Operates over the frequency range 450 MHz up to 100 GHz with 1 GHz bandwidth.
- No interruption or discontinuity in large-scale or small-scale parameters' time evolution.
- The model produces accurate polarization characteristics
- Supports three-dimensional representation of antenna and environment.
- Supports massive MIMO.

Enhancements were made to WINNER and 3GPP-3D to obtain new features in QuaDRiGa channel model that original models do not have. These features are:

- "Time evolution": by updating delays, the angle of departure, the angle of arrival, polarization, shadow fading, and K-factor with corresponding to device location, the short-term evolution of channel coefficients can be obtained.
- "Scenario transitions": when the mobile device travels through a fading channel it will experience multiple scenarios. QuaDRiGa supports seamless transition between these neighboring segments.
- "Variable speeds for mobile terminals": supporting changeful vehicle speed.
- "Common framework for Nonline of sight (NLOS) and LOS simulations": On the contrary, of WINNER model, QuaDRiGa will use the same procedures for LOS and NLOS. By this QuaDRiGa has lower complexity and ability to represent multicell scenarios with a high degree of freedom.
- "New functions for modifying antenna patterns": support radiation pattern of antenna elements and the radiation pattern of the antenna array can be rotated in the space without limit.
- "New MATLAB / Octave implementation": more efficient code had been written with lower hardware requirements.

QuaDRiGa also includes spatial and WINNER channel models features [22].

QuaDRiGa differs from traditional ray-tracing approach since it does not recreate the propagation environment with accurate objects and scatterers positions. The scatterers and objects are randomly spread [22]. The model calculates the departure angle, arrival angle and delays for each individual path separately. QuaDRiGa can be described as "statistical ray-tracing model" [22].

3.3.3 MiWEBA:

Millimeter-Wave Evolution for Backhaul and Access (MiWEBA) is a channel model for outdoor scenarios at millimeter wave band which contains 60 GHz frequency.

All of the measurements campaigns and analysis efforts had a problem how to deal with human body shadowing, reflection from moving surroundings and attenuation due to a large number of trees. It is also needed to get clearer results whether mm-Wave systems are noise limited or interference limited [18].

Due to mentioned reasons, a need for new quasi-deterministic (Q-D) method appeared to model outdoor and indoor scenarios at 60 GHz. The model uses the superposition method to represent mm-Wave channel impulse response [18].

All 3D channel models in MiWEBA project were used for open areas, street canyon and hotel lobby in the framework of Q-D way. The parameters are chosen depending on measurements and ray-tracing simulation. The diversity of Q-D approach opens the way to channel models to be applicable for other usage models. The Q-D channel model can support D2D link with simple modifications [18].

MiWEBA channel model identified the following challenges and tried to resolve them:

- Build a model for LOS and NLOS and operate in the frequency range 57-66 GHz.

- Supporting shadowing.
- Supporting spatial consistency.
- Supporting massive MIMO.
- Supporting dual mobility.
- Frequency dependent parameter because of insufficient amount of measurement data.
- The proportion of diffuse to specular reflections.
- Polarization.

There are two different types of challenges. The first type is providing large-scale parameters estimation for the channel model such as delay spread (DS), angular spread (AS), Rician factor and shadow fading in addition to small-scale parameters. The second type is related to implementation and simulation such as complexity, performance, and availability.

Through different deliverables; requirements, scenarios, use cases, challenges and technologies are mentioned. For example, using millimeter wave frequencies for backhauling and front hauling. Identifying two indoor scenarios in small areas like closed offices and large indoor areas. For outdoor coverage scenarios, the suggestion included hotspot that can provide very high-speed data rate, areas with high speed and large areas. The deliverables also carried the results of measurements campaigns and recommendations [18].

3.3.4 mmMAGIC model:

Millimeter-Wave Based Mobile Radio Access Network for Fifth Generation Integrated Communications (mmMAGIC) goal was building a channel model applicable to the entire frequency range 6-100 GHz. mmMAGIC was looking for making use of the results of measurements campaigns in different environments at different frequencies within the mm-Wave band. The channel parameters are extracted from measurements and simulations in different environments [56].

The first stage of building a 5G channel model was identifying the requirements. The focus of the model after specifying requirements was evaluating the dependency of channel parameters on frequency such as delay spread. The model also focused on studying the effect of ground reflection at mm-Wave, enhancing cluster and subpath modeling, small-scale fading, attenuation due to penetration and blockage and spatial consistency [56].

Since the mmMAGIC project was going at the same time as 3GPP38.900, 3GPP38.901, ITU-R and QuaDRiGa, the mmMAGIC partners participated in these models with some approaches. The mmMAGIC is a geometry based stochastic channel model. It consists of essential model components with some extensions related to accuracy and applicability. The model contains the following features:

- Including ground reflection effect.
- Blockage effects.
- Building penetration loss.
- Supporting massive MIMO.
- Support large bandwidth.
- Spatial consistency.

The mmMAGIC became part of QuaDRiGa v2.0 and provides a basic model containing the features [56].

The channel model is designed for urban micro scenario (UMi) and indoor environments, and cover the link topology outdoor-to-indoor. The model support different antenna models since the channel and antenna modeling are independent [56].

3.3.5 3GPP SCM/3D/D2D/HF models:

Third generation partnership (3GPP) developed a spatial channel model (SCM) for MIMO systems. It is suitable for the frequency range 1-3 GHz and supports three scenarios. SCM forms an infrastructure for the following channel models and can be used for parameterization. SCM calculates path loss by employing modified models such as COST 231 and Hata urban model. The channel is represented by six clusters where each cluster consists of twenty rays. The model calculates the characteristics of each cluster [6].

3GPP made use of parameters produced by WINNER+ and WINNER II to create two new models which they are 3GPP 3D MIMO and 3GPP D2D. 3GPP 3D MIMO supports two scenarios (urban micro and urban macro) and two link topologies, outdoor-to-indoor and outdoor-to-indoor. 3GPP 3D model works for frequency range 1-4 GHz. 3GPP D2D model applicable to an urban micro scenario with outdoor-to-outdoor, outdoor-to-indoor, and indoor-to-indoor link topologies. 3GPP D2D provide dual mobility and the backbone of the model calculate Doppler shift. The model provides two system simulation scenarios. The first system simulation type is generic which operate at 2 GHz and support moving terminals at speed 3 km/h. The second type is public security; it operates at 700 MHz and supports mobility at 60 km/h [6].

The 3GPP-high frequency (HF) is the first standardized model working in the frequency range 6-100 GHz shared for the public. The model includes typical scenarios which are defined in 5GCM in addition to new scenarios such as backhaul, D2D/V2V, stadium, and gymnasium. 3GPP-HF channel model was built upon 3GPP-3D MIMO channel model and utilizes measurement-based and ray-tracing methods. The parameters used in this model are the same used in 5GCM, and 3GPP-HF. 3GPP use some modifications and revisions in order to make the model able to simulate carrier aggregation, enhanced rays' modeling in terms of power delay and angles, support large bandwidth and massive MIMO. The model can provide a spatial domain to calculate LOS/NLOS probability, indoor or outdoor probability and some small-scale parameters. SCM-HF can evaluate or estimate system performance by using digital maps to study the effect of surroundings and their materials. This is called a map-based hybrid model which is evolved by ZTE Ltd. The model is embraced by SCM-HF after using ray-tracing to generate deterministic clusters and stochastic modeling to generate random clusters [6].

3.3.6 NYUSim model:

NYUSim is an open source simulator created by researchers at New York University. NYUSim is built upon data collected from measurements campaign at frequencies between 0.5-100 GHz having bandwidth of up to 800MHz. The statistical spatial channel model provides accurate results. NYUSim utilizes time cluster and spatial lobes ideas to characterize multipath behavior in omnidirectional channel impulse response [32]. The one terabyte of data at frequencies between 28-73 GHz in urban microcell, urban macrocell (UMa), and rural microcell provide an accurate rendering of the channel impulse response in time and space beside realistic multipath power levels.

NYUSim results match the measurements data in contrast to 3GPP TR 38.901 Release 14 which produces optimistic results [55].

NYUSim calculate the free space path loss according to close-in free space reference distance (CI) path loss model with a 1 m anchor point with additional loss due to atmosphere condition. Close-in free space reference distance (CI) path loss model can be expressed in equation 3.1 [55], [57]:

$$PL^{CI}(f,d)[dB] = FSPL(f,1m)[dB] + 10n\log_{10}(\frac{d}{d_\circ}) + AT[dB] + \chi_\sigma^{CI} \quad ......(3.1)$$

Where $d > d_\circ$ m, f refers to the carrier frequency in GHz, d is the 3D distance between transmitter and receiver, FSPL(f,1m) refers to free space path loss in dB at distance 1m, n is path loss exponent (PLE) which is characterizes signal power loss, $d_\circ$ represents free space reference distance in meters. $d_\circ$ should not exceeds 5 m to guarantee free space propagation within $d_\circ$. AT is the attenuation due to atmospheric factors and x^{CI}_σ is a zero-mean Gaussian random variable of standard deviation σ in dB. The free space path loss (FSPL) equation is:

$$FSPL = (\frac{4\pi f d}{c})^2 \quad .... \quad (3.2)$$

Where c is the speed of light and f is the frequency in GHz. Since the frequency is in GHz and the reference distance of 1m, then equation 3.2 can be written as:

$$FSPL(f,1m)[dB] = 20\log_{10}\left(\frac{4\pi f * 10^9}{c}\right) = 32.4 + 20\log_{10}(f) \ ... \ (3.3)$$

In equation 3.3, the frequency is in GHz. The term AT in equation 3.1 can be expressed by:

$$AT[dB] = \propto \left(\frac{dB}{m}\right) * d(m) \qquad \ldots\ldots\ldots\ldots \qquad (3.4)$$

Where $\propto$ is the attenuation factor in dB/m at the frequency range between 1-100 GHz, it encompasses the effect of dry air, water vapor, rain, and haze [57].

3.4 Losses at millimeter waves:

The wave at the millimeter frequencies cannot propagate for long distances or penetrate wall and barriers without large degradation in signal power. While wave at lower frequencies can propagate for few kilometers and penetrate solid barriers easily. These characteristics of millimeter waves can be manipulated to achieve new features such as dense deployment, improve spectrum utilization and enhance security.

3.4.1 Free space loss:

The frequency and distance have their effect on loss between two isotropic antennas. Equation 3.2 shows the relationship between frequency, distance, and loss. The equation can be rewritten in another form:

$$L_{FSL}(dB) = 92.4 + 20log_{10}(f) + 20log_{10}(d) \ \ldots\ldots \qquad (3.5)$$

Where *f* the frequency is in gigahertz and the distance in a kilometer [58].

3.4.2 Atmospheric losses:

At the millimeter wave band, there are other factors that cause losses besides free space loss such as gaseous, dust, and rain.

3.4.2.1 Rain:

The raindrops have different diameters and barely the same size of radio wavelength at mm-waves. As a consequence, the signal suffers scattering. Figure 3.2 shows the attenuation caused by different rain rates at different frequencies. The path loss caused by rain can be calculated approximately by using equation 3.6:

$$A\ (dB/km) = ar^{b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.6)$$

Where r is the rain rate. Parameters a and b are functions of polarization and frequency, and can be obtained from ITU-R [59].

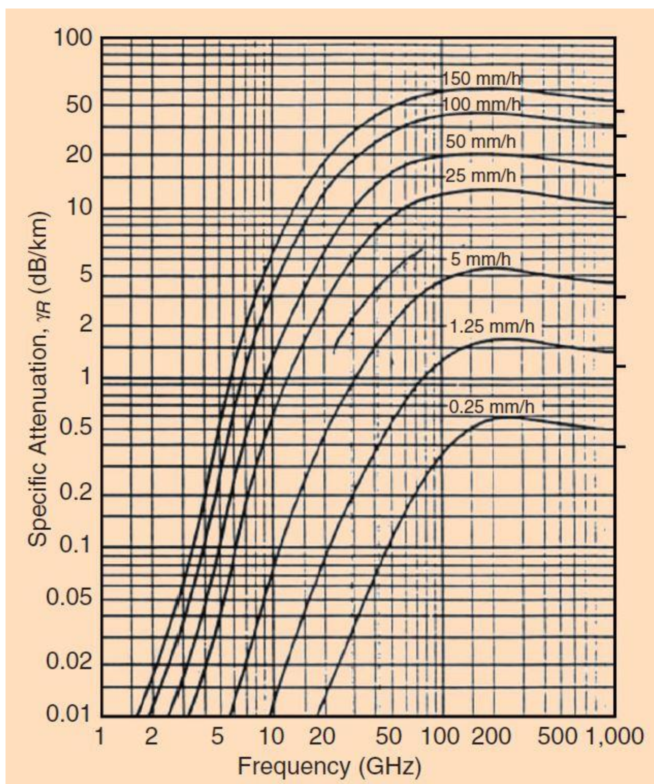


Figure 3.2: Losses due to rain at microwave and millimeter wave bands [58].

3.4.2.2 Atmospheric Gases:

When millimeter waves pass through the atmosphere layers, the molecules of the gases that forms the atmosphere cause losses by absorption. Some of the frequencies suffer from larger losses compared to other frequencies because of mechanical resonance as depicted in figure 3.3. There are peaks in figure 3.3 where these peaks are caused by absorption of oxygen (O_2), water vapor (H_2O) and other gases. The peaks appear at 24 and 60 GHz between these peaks the wave can propagate easily in these spectral windows [58].

3.4.3 Foliage losses:

Foliage can cause considerable losses at millimeter band. In some environments, foliage can limit the propagation. Foliage can be estimated by using the equation 3.7:

$$L_{foliage} = 0.2 f^{0.3} R^{0.6} \quad \ldots\ldots\ldots\ldots\ldots\ldots.. \quad (3.7)$$

Where f is the frequency in MHz and R is the depth of foliage in meters. The equation is applicable for foliage depth <400m and frequency range 0.2–95 GHz [58] .

3.4.4 Scattering/ Diffraction:

If the direct path between transmitter and receiver does not exist, the signal still reaches the receiver by reflection or diffraction. The diffraction at millimeter band is low. Reflection is the main source of power for NLOS paths. Reflection and diffraction depend largely on the reflectivity of the materials. When the frequency goes higher the surface of the reflecting material seams rougher, which causes diffusion of the signal in all directions. Since diffusion makes the signal spread in the direction, the diffusion has a lower contribution in received power than reflection [58].

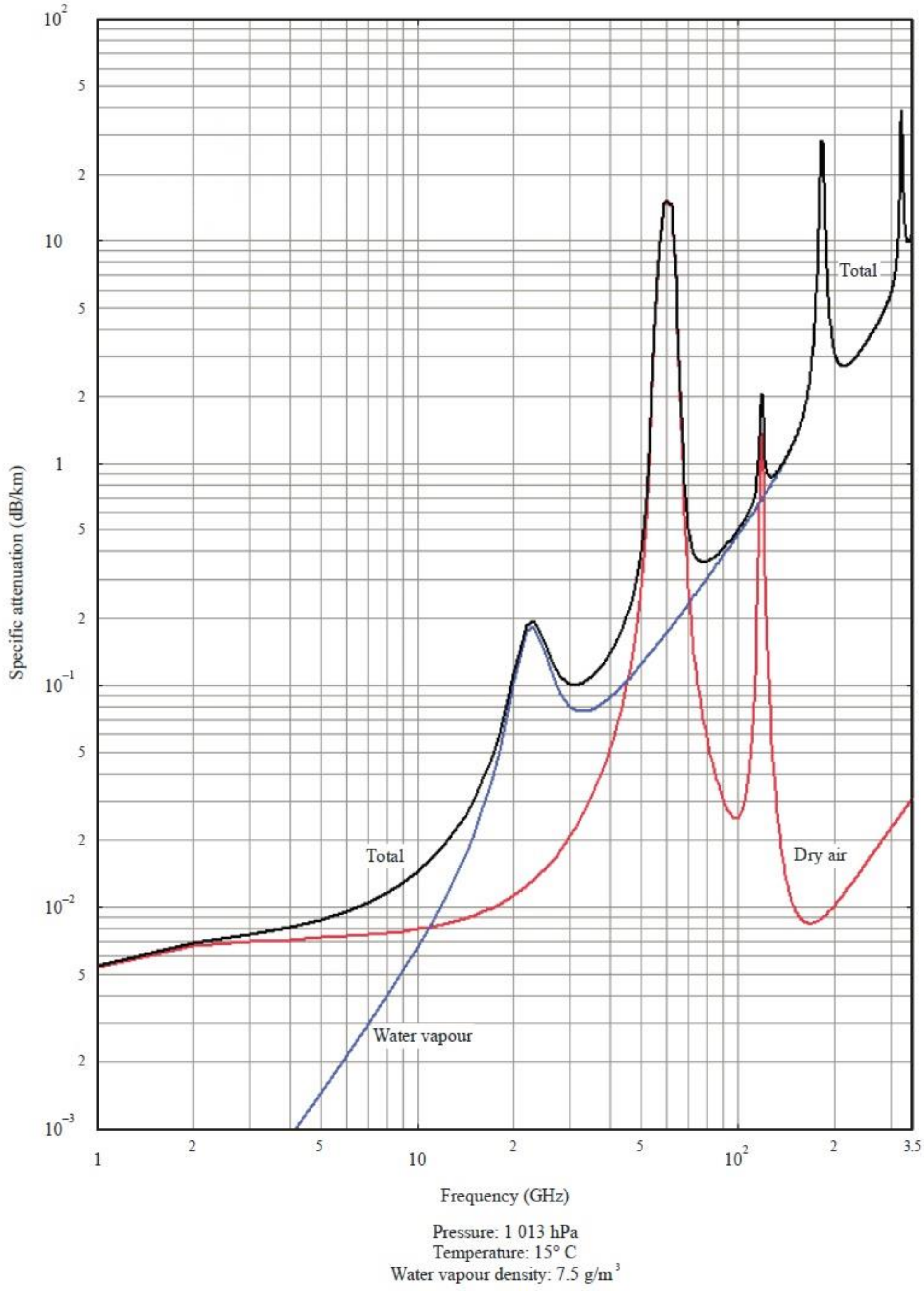


Figure 3.3:Atmospheric losses at millimeter wave band [62].

3.4.5 Dust

The sandstorms do not have effect only on human and animal health but also on communication systems [60]. Sandstorms make the sand particles go above the ground level and stay in the air for a period of time. The sandstorms and dust can reduce the coverage, quality of communication link or even breaks the communication link. The dust produces loss by absorption and scattering which causes degradation in signal energy and phase shift. The degree of loss depend of particles shape [61]. The sandstorms does not affect only on millimeter-wave links but also on microwave links [60].

Chapter Four
Simulation and results

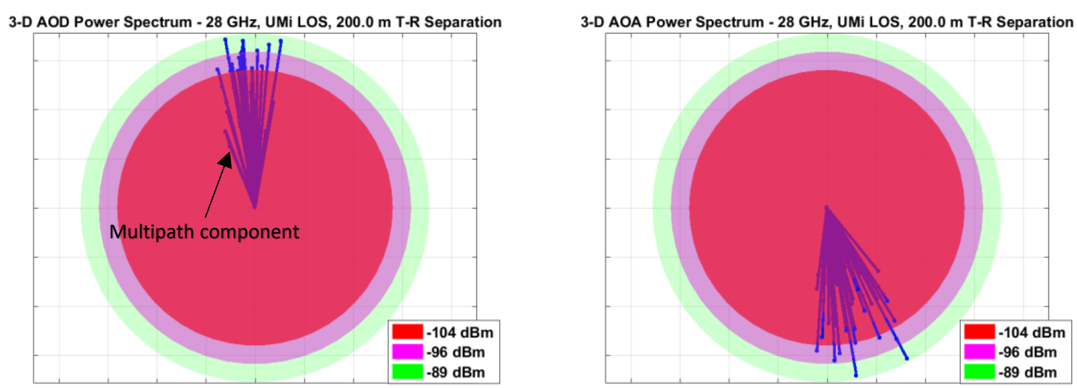
4.1 NYUSim program:

NYUSim is a computer program that provides a precise rendering of channel impulse responses in time and space for millimeter waves, and realistic signal powers in different scenarios. The measurements and analysis of collected data lead to creating NYUSim simulator. One of the important features of the NYUSim is that it is an open source program and the main code is available and can be modified.

The program has 30 input parameters. These parameters can be divided into two groups. The first group is channel parameters, which consist of 18 input parameters, and the second group is the antenna properties of a transmitter (Tx) and receiver (Rx) which has 12 input parameters [57].

NYUSim is used in this work to simulate the effects of weather conditions in each month of the year and their effects on millimeter wave signals. It should be noted that the average of weather conditions of each month through twenty years between 1988-2007 for the city of Mosul, Iraq was taken from Iraqi ministry of transportation / Iraqi meteorological organization and seismology / Mosul station for twenty years (appendix A). The results produced by NYUSim were obtained and processed by MATLAB program to calculate the average path loss and finding the multipath components with a smallest and largest loss between Tx and Rx. The results for each month are collected and grouped in Microsoft Excel. The average path loss, minimum path loss, and largest path loss have been drawn.

We made a simulation for frequency 28 GHz with the distance between transmitter and receiver as 200 m for each of 100 simulations run at different receiver's locations. Antenna configuration is 4X4 MIMO and average weather conditions were for February. Each transmitter and receiver antennas have a half power beam width (HPBW) of 23.8˚ and 44.7˚ for E and H plane respectively. These values for typical mm-wave systems [49]. The gain of Tx/Rx antenna is 14.3 dBi. The simulation does not impose an obstacle between the transmitter and receiver which means line-of-sight (LOS) exists in an urban micro scenario. The simulation represents a downlink where the base station transmits a signal of power 1 watt. Figure 4.1 shows the multipath components emitted by the transmitter (a) and the multipath components (MPC) that reach the receiver (b).



(a) (b)

Figure 4.1: Multipath components with power levels and angles. a) Angles of departure (AOD). b) Angles of arrival (AOA).

Figure 4.1(a) shows the angles of departure (AOD) of multipath components emitted by uniform linear array antenna at the transmitter while figure 4.1(b) shows the angles of arrival (AOA) of received signals by receiver uniform linear array antenna. The number of strong multipath components that reach the receiver is little and it should be noted that the wave ray that follows the shortest path between Tx and Rx is not always the strongest signal but according to field measurements, it is almost the strongest.

The number of weak multipath components is higher than strong components as illustrated in figure 4.1. The indirect multipath component hits one surface of one of the surrounding objects before it reaches the receiver (one reflection). Another important point that can be observed in figure 4.1(b) is the number of spatial lobes is one at the receiver side and after repeating the simulation for 100 times, the number ranged between 1 to 5 spatial lobes as illustrated in figure 4.2. Spatial lobes (SL) are the main directions of arrival / departure where energy arrives over several hundreds of nanoseconds [55].

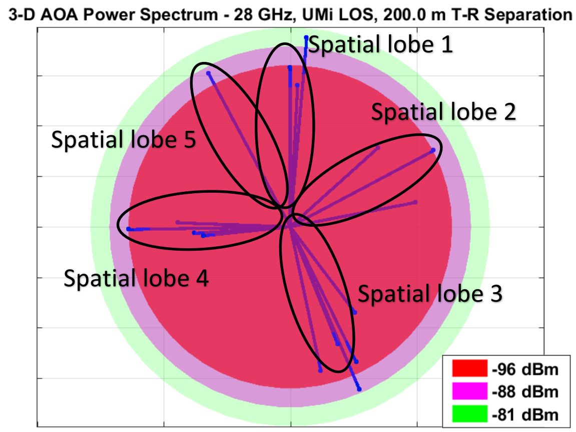


Figure 4.2: Spatial lobes at 28 GHz.

The wave rays do not follow the same path when travel from Tx to Rx, therefore they reach the receiver at different times. The number of time clusters in results ranged from 1 to 5 time-clusters (TC). Time cluster (TC) consists of multiple path components that reach the receiver with a short time interval between them from different directions within the short excess delay time window as illustrated in figure 4.3, where σ_τ is root mean square delay spread [55].

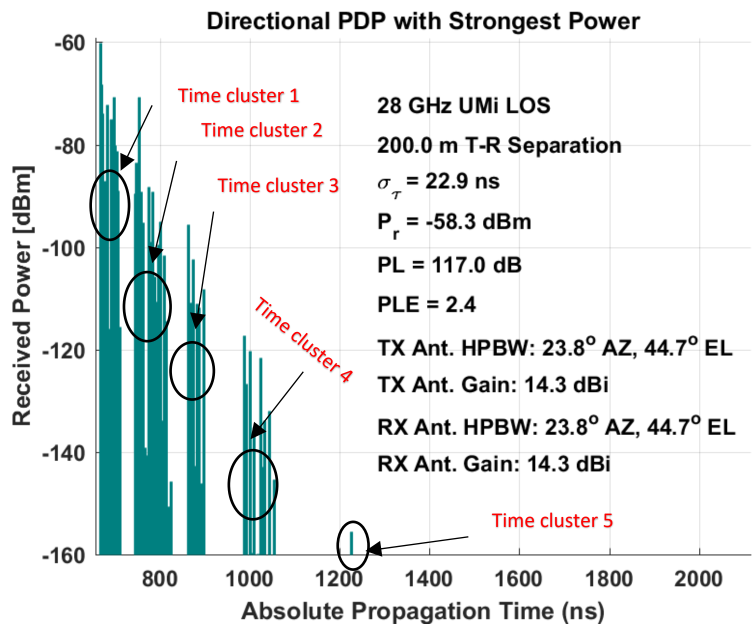


Figure 4.3: Time clusters.

Figure 4.4 Shows two power delay profiles (PDP) of two simulation runs at the same distance between transmitter and receiver (200m). The same channel and antenna parameters were used for the two simulations.

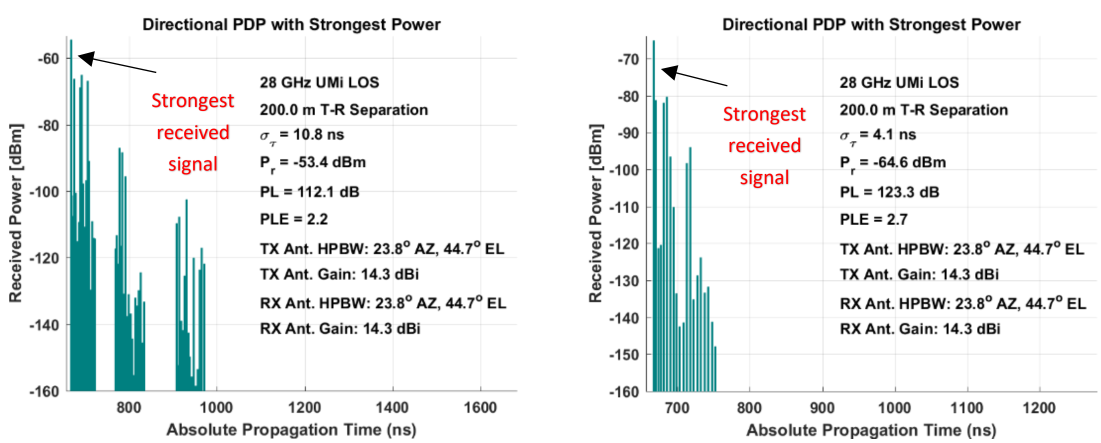


Figure 4.4: Directional power delay profile.

Figure 4.4 shows time-clusters that contain many multipath components with few nanoseconds between each other, also the PDPs consistent with the measurements that the first received signal is almost the strongest. Figure 4.3 shows 5 time-clusters and each time cluster consists of many MPCs where real-world measurements at 28 and 73 GHz in [16] and [57] have shown that time cluster may contain up to 30 MPCs [63]. The results of the simulation in figure 4.3 and figure 4.4 agree to a large degree with field measurements performed by [16]. Simulation results showed that a maximum number of time clusters is five and the number of time clusters from measurements ranged between 1 to 6 TCs. Path loss exponent ranged between 1.6 and 2.7.

In this work, 4x4 multiple input multiple output (MIMO) system is used with half wavelength ($\lambda/_2$) spacing between antenna elements and the carrier frequency is 28 GHz. The relation between frequency and wavelength is [1]:

$$\lambda = \frac{c}{f} \qquad \text{……………………........} \qquad (4.1)$$

$$\frac{\lambda}{2} = 5.353\ mm$$

The power delay profile (PDP) of the 4 antenna elements at the receiver is shown in figure 4.5, where it represents one of 100 simulations run.

Figure 4.5 shows the intensity of the received signal in each time cluster. It is noticeable that the strongest multipath component is not the first received ray.

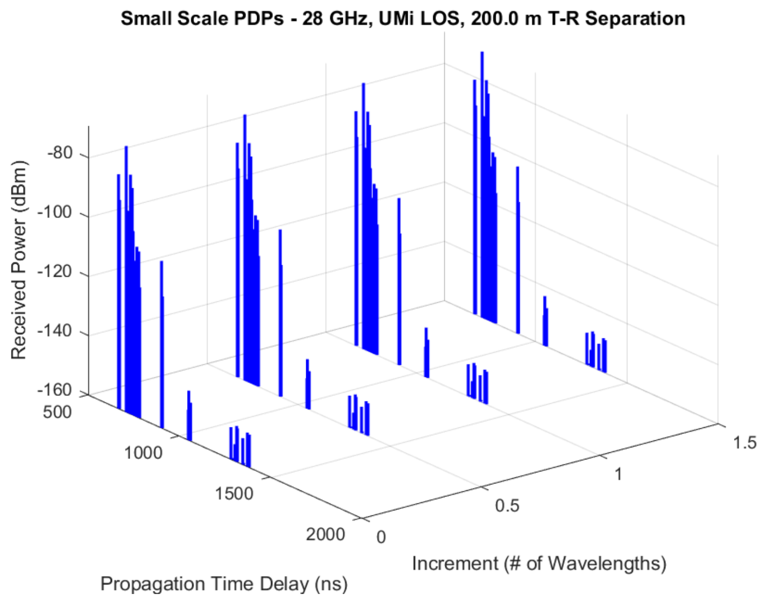
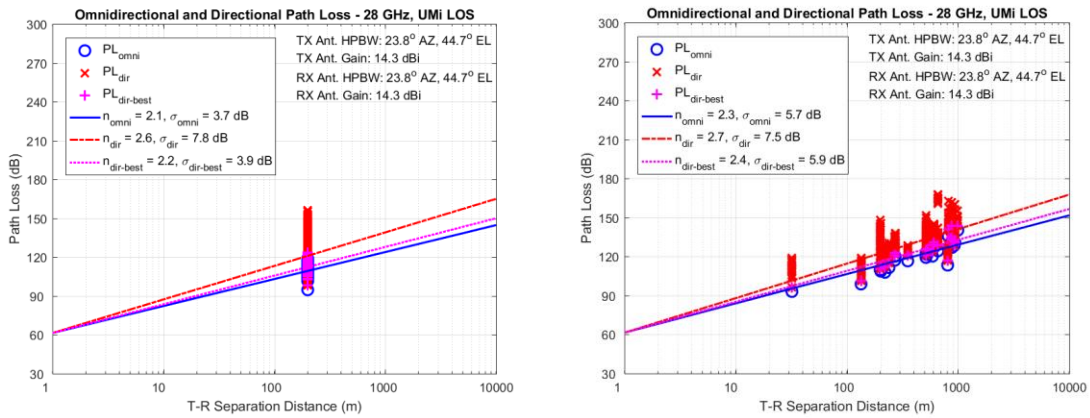


Figure 4.5: Power delay profile (PDP) of the receiving antenna.

A parameter that characterizes signal power loss with distance is path loss exponent (n) which changes according to distance as the environment layout and objects locations varies. Figure 4.6 shows path loss exponent effect at different locations wherein figure 4.6(a) the simulation was performed for 200 m distance with 100 times run and in figure 4.6(b) the simulation made for 25 different random locations.

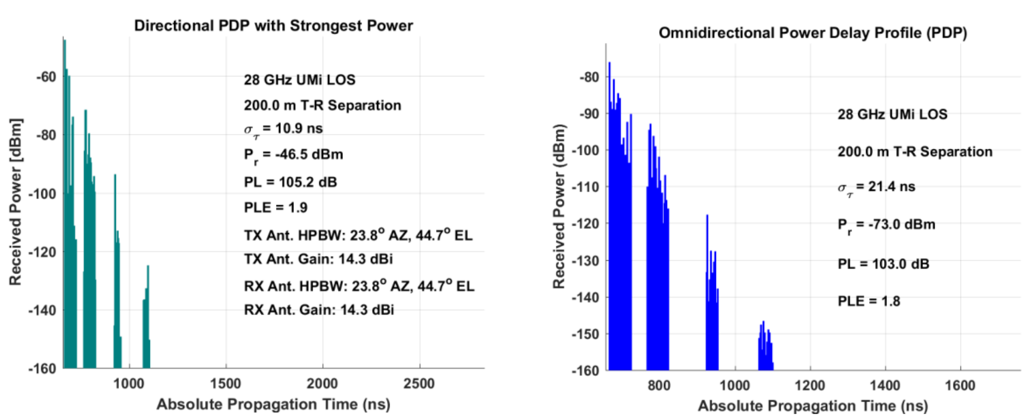
Figure 4.6 shows the path loss when using omnidirectional antenna and path loss when the antenna pattern is applied (directional antenna).



(a) (b)

Figure 4.6: Variation of path loss with distance at (a)200m (b) different distances.

σ denotes shadow fading standard deviation. The environment produces more losses when the distance between the transmitter and receiver increases.



(a) (b)

Figure 4.7: Power delay profile antenna (a) directional antenna (b) omnidirectional antenna.

A directional antenna is used to compensate the high free space loss of millimeter wave frequencies. The received power (P_r) is -46.5 and -73 dBm for directional antenna and omnidirectional antenna respectively.

4.2 Weather effects:

It is important to study the effect of weather through various months as well as during day and night at the candidate frequencies to be used, which are 28 and 73 GHz.

4.2.1 28 GHz simulation:

The signal is transmitted from the base station at power 30 dBm to a terminal. The simulation was done for constant distance between transmitter and receiver at 1Km for 100 random locations in urban macrocell scenario. It is assumed that the line of sight exists in the simulation environment. The weather condition during day and night was taken from measurements of the Iraqi ministry of transportation / Iraqi meteorological organization and seismology / Mosul station for twenty years (Appendix A). The base station and receiver height are not applicable to UMa in NYUSim [57]. Uniform linear array antenna of four elements which has HPBW 23.8˚ and 44.7˚ for azimuth and elevation respectively used at both sides of the communication link [49]. The results of the simulation are collected then the average path loss was calculated through MATLAB program and organized in the Tables 4.1 and 4.2.

Table 4.1: Average path loss at 28GHz for 1km distance during the day.

Month	Temp. (C)	Max. received signal (dBm)	Min. received signal (dBm)	Average loss (dB)
January	12	-122.52	-180.25	157.08
February	15	-121.05	-178.79	155.78
March	19	-121.26	-178.99	154.61
April	25	-117.12	-175.76	152.15

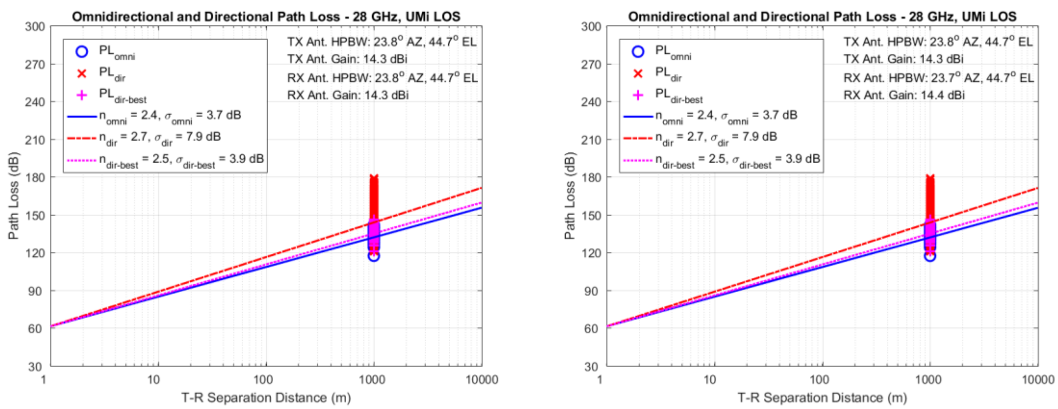
May	31	-113.08	-171.72	148.06
June	39	-110.63	-169.27	145.59
July	43	-110.36	-169	145.32
August	43	-110.38	-169.02	45.34
September	38	-110.36	-169	145.32
October	31	-115.23	-175.35	148.13
November	21	-120.54	-172.36	150.67
December	15	1-20.88	-178.61	155.6

Table 4.2: Average path loss at 28GHz for 1km distance during the night .

Month	Temp. (C)	Max. received signal (dBm)	Min. received signal (dBm)	Average loss (dB)
January	2	-122.47	-180.21	157.03
February	3	-121.00	-178.74	155.74
March	7	-121.19	-178.92	155.91
April	11	-120.51	-180.63	153.46
May	16	-112.99	-171.63	147.96
June	21	-110.54	-169.18	145.50
July	25	-110.26	-168.90	145.22
August	24	-110.27	-168.91	145.22
September	19	-110.26	-168.90	145.22
October	14	-115.14	-175.25	148.03
November	7	-120.47	-172.28	150.59
December	4	-120.82	-178.55	155.54

The results of the simulation show that path loss caused by small change in temperature between day and night across a whole year is about 1 dB, which means no considerable attenuation caused by temperature changing on received signal strength.

Figure 4.8 shows the path loss for February in day and night. It can be observed from figure 4.8 that signal received with the omnidirectional antenna in some very crowded environments is stronger than that received from the directional antenna because it receives the signal from different directions which is a rare case.



(a) (b)

Figure 4.8: 28 GHz path loss in February during a) day b) night.

4.2.2 73 GHz simulation:

A simulation has been made to study weather effect during day and night through all months at 73 GHz frequency. It is an assumed a downlink between the base station and terminal. The transmission power is 30 dBm and the T-R separation is 1 km. The simulation scenario is UMi and line of sight between transmitter and receiver is assumed to exist. The same weather factors of day and night that were mentioned in (Appendix A) are used. By using horn antenna which has HPBW of 10˚ for both azimuth and elevation such as antenna was used in [17], the results have been recorded in Tables 4.3 and 4.4 after repeating the simulation 100 times for every day and night in all months.

Table 4.3: Average path loss at 73GHz for 1km distance during an average day .

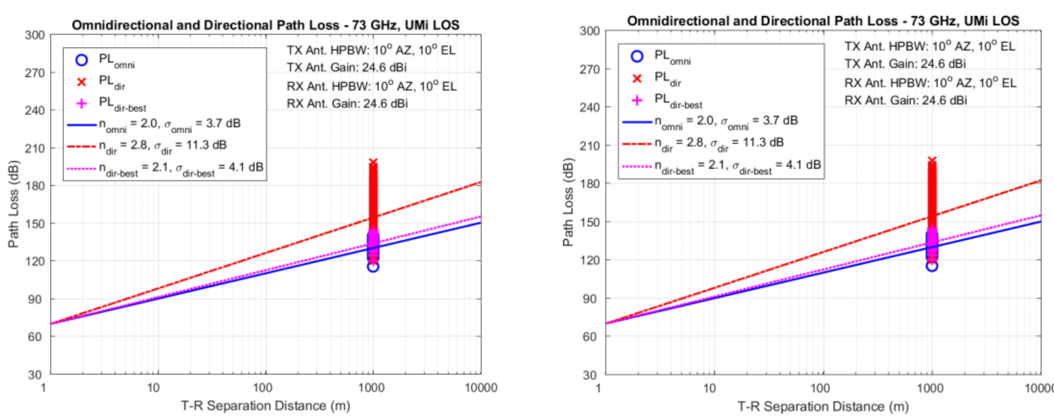
Month	Temp. (C)	Max. received signal (dBm)	Min. received signal (dBm)	Average loss (dB)
January	12	-146.39	-214.19	192.25
February	15	-146.64	-214.54	190.07
March	19	-144.27	-212.83	190.10
April	25	-139.56	-210.31	184.56
May	31	-128.28	-202.61	178.32
June	40	-121.33	-195.66	171.85
July	43	-119.88	-197.87	170.96
August	43	-119.92	-197.92	171.01
September	38	-119.89	-197.89	170.98
October	31	-127.61	-200.79	174.76
November	21	-141.78	-207.82	183.69
December	15	-143.61	-212.17	190.52

Table 4.4: Average path loss at 73GHz for 1km distance during an night.

Month	Temp. (C)	Max. received signal (dBm)	Min. received signal (dBm)	Average loss (dB)
January	2	-146.26	214.06	192.11

February	3	-143.74	-212.30	190.65
March	7	-144.08	-212.64	190.93
April	11	-136.53	-208.31	185.07
May	16	-128.03	-202.36	178.06
June	21	-121.08	-195.41	171.63
July	25	-119.64	-197.63	170.84
August	24	-119.64	-197.64	170.85
September	19	-119.63	-197.63	170.84
October	14	-124.62	-198.95	174.76
November	7	-136.83	-208.60	185.30
December	4	-143.44	-212	190.34

The results show that the average path loss difference between day and night is very small even for 73 GHz frequency and even over large distance like 1 km because small change in temperature leads to small change in humidity. In figure 4.9, the path loss of 100 simulations run in August during day and night at 73 GHz.



(a) (b)

Figure 4.9: 73 GHz path loss in August during a) day b) night.

4.3 Weather effect through seasons on millimeter wave frequencies:

All weather factors change in a gradual manner when time moves from one season to the next as depicted in figure 4.10. The difference between weather factors of winter and summer is larger compared to the difference between day and night; therefore, it is expected that the loss difference is higher compared to the case of day and night.

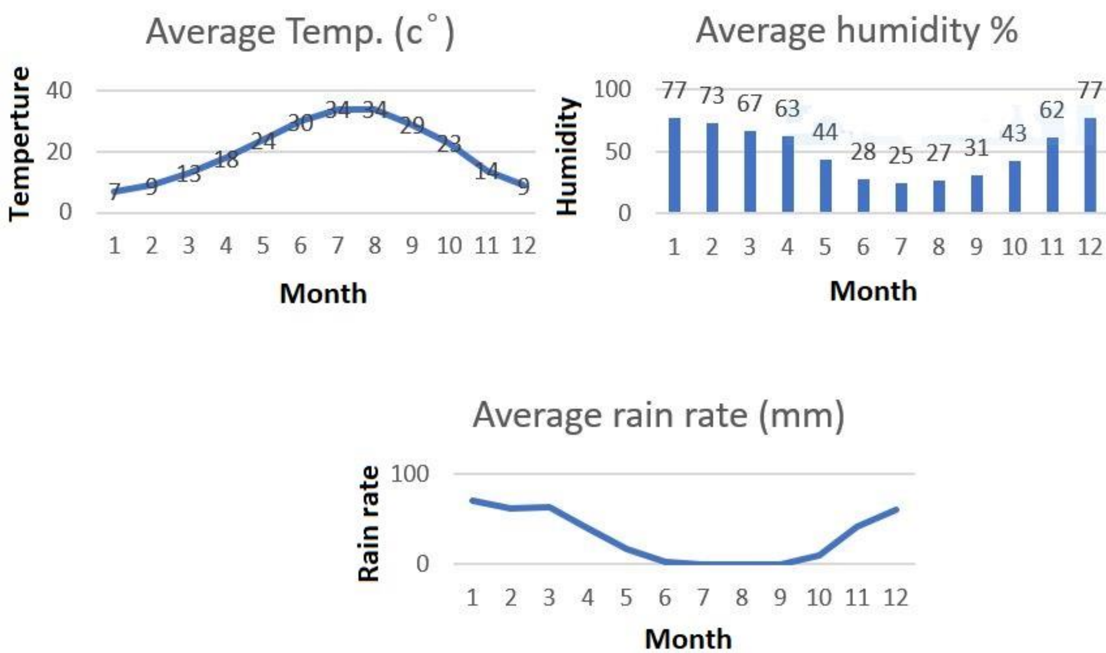


Figure 4.10: Mosul average weather factors.

4.3.1 Weather effect at 28 GHz:

The same input parameters of the previous simulation have been used for simulation at 28 GHz such as transmitter power, number of antenna elements, HPBW, LOS …. etc. The only parameters that have been changed are temperature and T-R separation, where the average temperature of each month used (see the appendix) and 100 m distance between transmitter and receiver. The results of the simulation are processed by MATLAB and organized in table 4.5.

Table 4.5: Average path loss at 28 GHz through seasons for LOS.

Month	Temp. (C)	Max. received signal (dBm)	Min. received signal (dBm)	Average loss (dB)
January	7	-91.41	-149.15	126.13
February	9	-91.27	-149	125.98
March	13	-91.29	-149.02	126
April	18	-90.87	-148.60	125.59
May	24	-90.47	-148.20	125.19
June	30	-93.51	-145.32	123.56
July	34	-90.19	-147.93	124.99
August	34	-90.20	-147.93	125
September	29	-90.19	-147.93	124.99
October	23	-90.33	-148.07	125.14
November	14	-90.89	-148.62	125.61
December	9	-91.25	-148.98	125.97

The path loss difference between two consecutive seasons is about 1 dB. The line of sight (LOS) does not always exist between the base station and terminal; therefore, another simulation has been made for the NLOS case with the same weather factors such as rain, humidity and temperature, antenna parameters, transmit power of 30 dBm, UMi scenario, and the number of simulation runs. The results of the simulation are listed in table 4.6.

Table 4.6: Average path loss at 28 GHz through seasons for NLOS.

Month	Max. received signal (dBm)	Min. received signal (dBm)	Average loss (dB)
January	-115.31	-173.96	147.61
February	-118.16	-173.72	147.91
March	-115.17	-173.83	147.37
April	-114.76	-173.42	146.96
May	-117.36	-172.92	147.06
June	-114.11	-172.77	146.30
July	-114.0	-172.74	146.27
August	-117.09	-172.64	146.79
September	-114.08	-172.74	146.27
October	-114.22	-172.88	146.41
November	-117.78	-173.33	147.48
December	-115.14	-173.79	147.33

The signal strength variation is small between seasons as we can see from the results in table 4.6. The path loss difference between the LOS and NLOS case is 20 dB for the same month but the path loss difference between seasons for the same case is still about 1 dB for both LOS and NLOS cases.

4.3.2 Weather effect at 37 GHz:

37 GHz is also a candidate frequency to be used for the cellular mobile system. A simulation had been made to see weather effects on 37 GHz at distances 100m in LOS and NLOS environment for all months. Some of the simulation parameters remain the same like transmitted power and propagation scenario. Antenna configuration consists of 5 elements at the

transmitter and 5 elements at receiver with 0.6 λ spacing, the antenna array has HPBW of 15.2˚ in azimuth and 45˚ in elevation for both Tx and Rx such as antenna used in [64]. The results of simulation listed in the tables 4.7 and 4.8.

Table 4.7: Average path loss at 37 GHz through seasons for LOS.

Month	Max. received signal (dBm)	Min. received signal (dBm)	Average loss (dB)
January	-94.66	-157.32	133.32
February	-97.68	-159.95	133.82
March	-94.49	-157.16	133.14
April	-97.15	-159.42	133.28
May	-93.37	-156.03	132.15
June	-96.20	-158.47	132.65
July	-92.94	-155.60	131.73
August	-96.15	-158.42	132.61
September	-92.94	-155.60	131.73
October	-96.38	-158.65	132.81
November	-93.95	-156.62	132.71
December	-97.65	-159.93	133.80

Table 4.8: Average path loss at 37 GHz through seasons for NLOS.

Month	Max. received signal (dBm)	Min. received signal (dBm)	Average loss (dB)
January	-118.83	-181.32	155.26
February	-121.57	-178.14	155.19

March	-118.66	-181.15	155.09
April	-121.03	-177.61	154.62
May	-117.54	-180.39	154.53
June	-120.09	-176.66	153.68
July	-117.11	-179.96	154.10
August	-120.04	-176.61	153.63
September	-117.11	-179.96	154.10
October	-120.27	-176.84	153.87
November	-118.13	-180.62	154.54
December	-121.54	-178.12	155.16

The average path loss in the tables 4.7 and 4.8 indicates that weather effect across seasons is small for 37 GHz.

4.3.3 Weather effect at 60 GHz:

Millimeter wave frequency band 57-64 GHz is an unlicensed band. This band was under research for ten years. The bandwidth at 60 GHz is much greater than bandwidth at 5.8 GHz. The maximum achieved data rate at 60 GHz is 7 Gbps according to IEEE standard 802.11ad [65]. One problem with 60 GHz frequency is the oxygen absorption that reaches its maximum value at this frequency which is 15 dB/km as shown in figure 3.3 [19]. In order to investigate performance of the 60 GHz under Mosul’s weather, a simulation had been done. The simulation parameters were the same as previous simulation except antenna configuration consist of 8 elements uniform rectangular array antenna at both Tx and Rx with HPBW of 50˚ and 20˚ for azimuth and elevation respectively and has gain of 14.6 dBi [66], [67].

Table 4.9: Average path loss at 60 GHz through seasons for LOS.

Month	Max. received signal (dBm)	Min. received signal (dBm)	Average loss (dB)
January	-104.72	-164.27	135.49
February	-101.12	-160.10	133.54
March	-104.40	-163.95	135.16
April	-100.21	-159.19	132.62
May	-102.53	-162.08	133.25
June	-98.47	-157.45	131.06
July	-101.59	-161.15	132.50
August	-98.30	-157.27	130.90
September	-101.65	-161.20	132.56
October	-98.89	-157.87	131.49
November	-103.59	-163.14	134.34
December	-101.08	-160.06	133.50

Table 4.10: Average path loss at 60 GHz through seasons for NLOS.

Month	Max. received signal (dBm)	Min. received signal (dBm)	Average loss (dB)
January	-124.15	-174.56	153.02
February	-123.85	-174.25	152.71
March	-123.83	-174.23	152.69
April	-122.94	-173.34	151.85
May	-121.96	-172.36	150.89
June	-121.2	-171.60	150.13

July	-121.02	-171.43	149.95
August	-124.15	-179.46	152.30
September	-121.08	-171.48	150
October	-124.75	-180.06	152.89
November	-123.02	-173.43	151.94
December	-126.93	-182.25	155.13

The signal strength is suffering attenuation about 5 dB at 60 GHz due to weather factors changing between summer and winter as apparent in tables 4.9 and 4.10.

4.3.4 Weather effect at 73 GHz:

Horn antenna was assumed at 73 of HPBW of 10˚ in azimuth, 10˚ in elevation, transmitter power is 30 dBm, and the T-R distance is 100 m. the results of the simulation in the tables 4.11 and 4.12.

Table 4.11: Average path loss at 73 GHz through seasons for LOS.

Month	Max. received signal (dBm)	Min. received signal (dBm)	Average loss (dB)
January	-102.04	-173.81	150.97
February	-101.79	-173.56	150.71
March	-101.82	-173.60	150.75
April	-101.07	-172.85	150.21
May	-100.22	-172	149.36
June	-99.53	-173.86	149.34
July	-99.38	-173.71	149.19
August	-99.38	-173.72	149.2

September	-99.38	-173.71	149.19
October	-99.88	-174.21	149.37
November	-101.10	-172.87	150.24
December	-101.76	-173.53	150.68

Table 4.12: Average path loss at 73 GHz through seasons for NLOS.

Month	Max. received signal (dBm)	Min. received signal (dBm)	Average loss (dB)
January	-125.88	-188.74	169.73
February	-125.63	-188.49	169.48
March	-125.67	-188.53	169.52
April	-124.92	-187.78	168.83
May	-127	-189.46	167.88
June	-123.37	-186.23	167.63
July	-123.23	-186.09	167.49
August	-126.16	-189.3	167.8
September	-123.23	-186.09	167.49
October	-123.72	-186.59	167.89
November	-127.88	-188.78	168.37
December	-123.85	-189.33	169.68

By making use of the antenna details in [17], a comparison between 28 and 73 GHz has been made and the results are in figure 4.11.

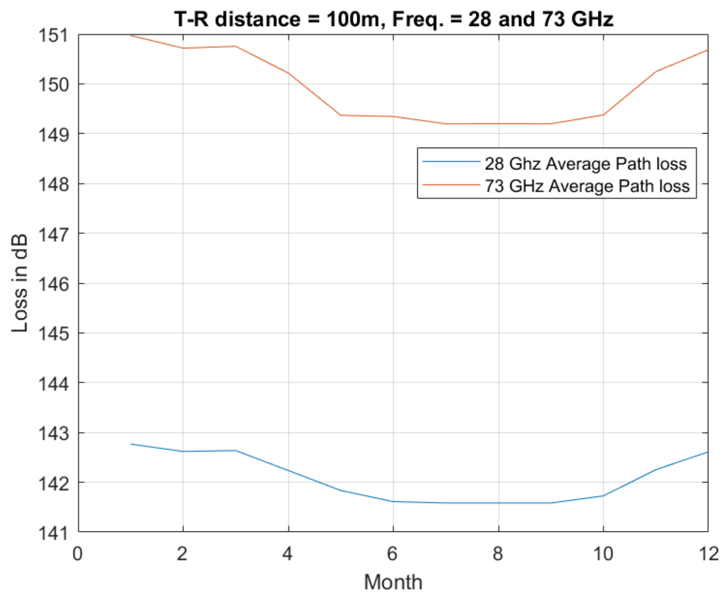


Figure 4.11: Path loss at 28 and 73 GHz for LOS case.

4.4 Weather effect versus distance:

To clarify weather factors in Mosul on millimeter-wave frequencies with distance, a simulation made for frequencies 28, 37, 60 and 73 at different distances. Due to the large difference between summer and winter, the simulation had been made in February and August.

4.4.1 Path loss versus distance at 28 GHz:

A simulation had been made for a 4X4 MIMO system, where antenna consists of a 4X1 uniform linear array (ULA) of HPBW 23.8° in E-plane and 44.7 in H-plane with 0.5 λ spacing between elements. The simulation made in months 2 and 8 at distances 10, 100 and 1000m. The results of the simulation are plotted in figure 4.12.

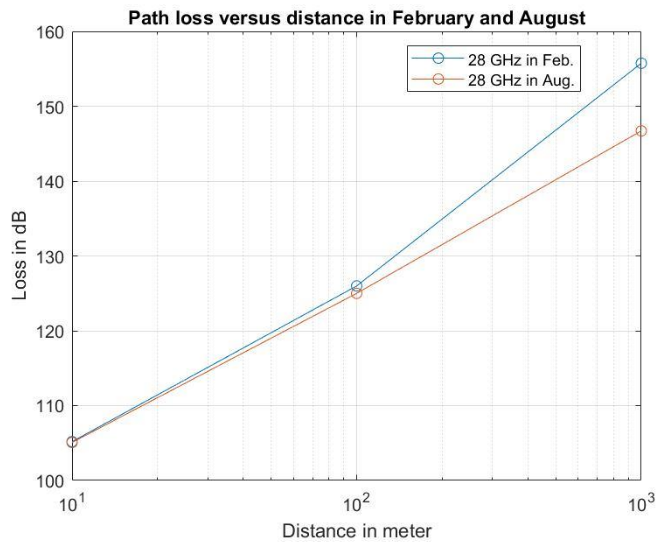


Figure 4.12: Path loss with the distance at 28 GHz.

4.4.2 Path loss versus distance at 37 GHz:

In the same way of the 28 GHz simulation, a simulation had been made to show path loss of 37 GHz signal at different distances. The simulation parameters like transmit power, and scenario of interest are not changed. The antenna consists of 5 elements with HPBW 15.2˚ in E-plane and 45˚ in H-plane at both transmitter and receiver with 0.6 λ spacing between elements. The simulation also made in February and August and the results of simulation gathered and plotted in figure 4.13.

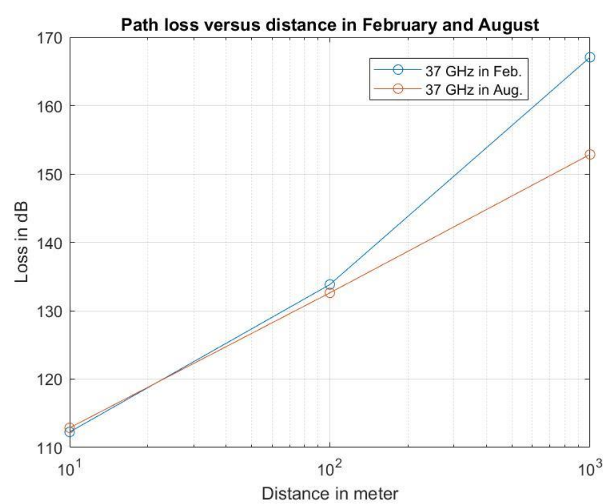


Figure 4.13: Path loss with the distance at 37 GHz.

4.4.3 Path loss versus distance at 60 GHz:

To see how loss changes with distance at 60 GHz, the following simulation parameters were utilized: 8 elements antenna array at Tx and Rx with 50° and 20° HPBW in E and H plane respectively with 0.5 λ spacing between elements. The simulation were made for February and August weather conditions. Figure 4.14 represents the results of the simulation.

60 GHz suffers from higher attenuation compared to other frequencies due to oxygen absorption; therefore, it is not preferable for outdoor scenarios. The 60 GHz is usually used for wireless local area network (WLAN) for the indoor scenario.

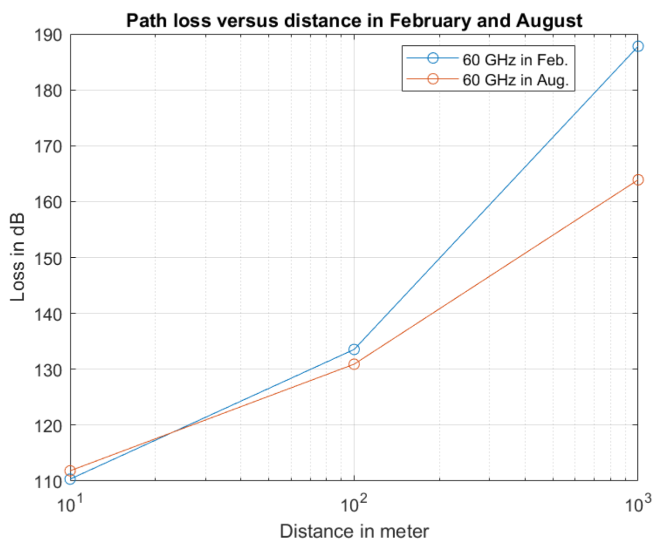


Figure 4.14: Path loss with the distance at 60 GHz.

4.4.4 Path loss versus distance at 73 GHz:

Loss due to weather factors at 73 GHz is calculated in a simulation. The antenna used for 73 GHz is horn antenna of beam width 10° in E-plane and 10° in H-plane. The transmitter power and scenario are the same as the previous simulations. Weather factors of February and August were used. Figure 4.15 shows the results of the simulation.

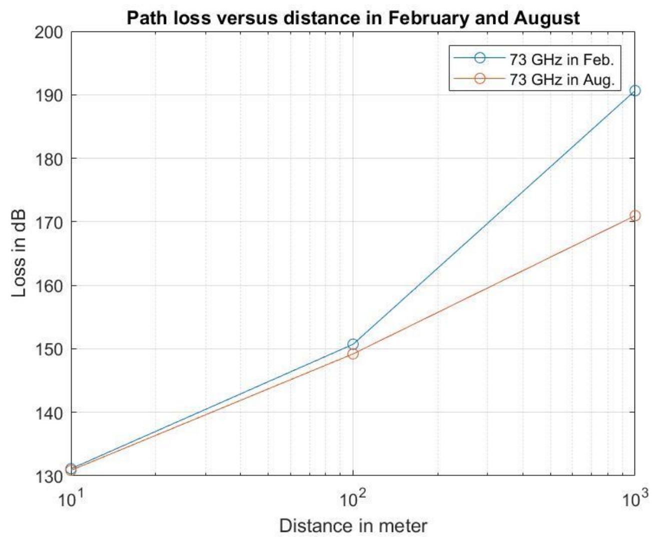


Figure 4.15: Path loss with the distance at 73 GHz.

Figure 4.16 shows a comparison at 28 and 73 GHz. Horn antenna of beam width 10° in both azimuth and elevation was used in the simulation. The results of the simulation are shown in figure 4.16.

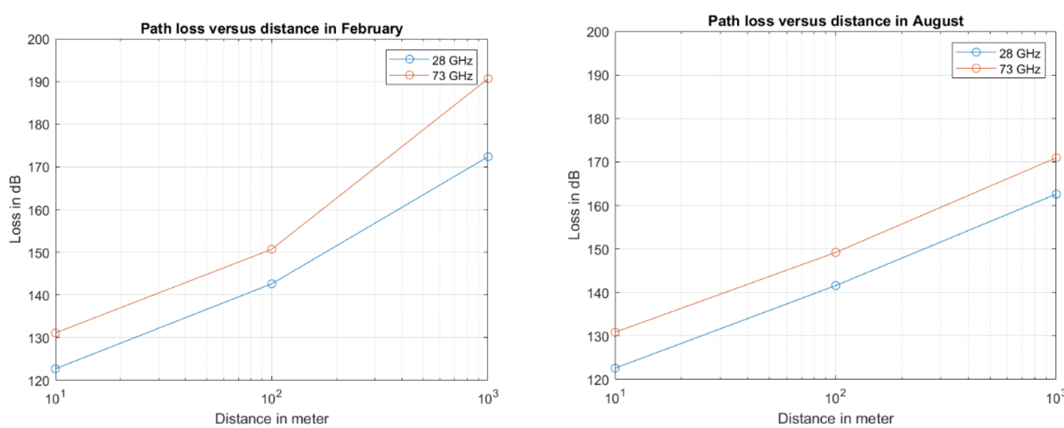


Figure 4.16: Path loss with the distance comparison between 28 and 73 GHz.

February and August weather factors were chosen for simulation because the difference between their rain rate, temperature and humidity are the largest in Mosul. It is noticeable from the results that the signal strength attenuation caused by rain rate is the largest among other weather factors.

4.5 Weather effect on MIMO system:

The MIMO system consists of a number of antennas at transmitter and receiver where each antenna transmits a data stream of lower data rate than the mainstream data rate. MIMO system gives better performance without increasing system bandwidth and power. The increased spectral efficiency and diversity is behind the improvement in throughput and performance. This is also applicable to the millimeter and centimeter waves, so MIMO and mm-wave technologies are an important combination.

The simulation is that made to study the effect of weather on different multiple-input-multiple-output systems that operate at 28 GHz of configurations 2X2, 4X4 and 8X8. These MIMO systems have antenna HPBW of 45.2° and 45° for azimuth and elevation respectively in the 2X2 system, 23.8° and 44.7° for azimuth and elevation respectively in the 4X4 system and 13.1° for azimuth and 35.4° in elevation for the 8X8 system [49]. The simulation had been made for all months with 200 m distance between transmitter and receiver and the results of simulation processed with MATLAB are shown in table 4.13.

Table 4.13: Path loss of different MIMO configurations.

	MIMO System configuration		
Month	2x2 Path loss (dB)	4x4 Path loss (dB)	8x8 Path loss (dB)
1	130.43	133.16	140.11
2	127.56	134.08	139.79
3	128.57	131.5	137.69
4	129.49	132.13	139.03
5	126.13	132.58	138.29
6	126.4	129.67	135.95

7	126.34	130.67	137.66
8	128.13	131.98	137.74
9	126.34	129.55	137.66
10	128.41	130.96	137.94
11	126.98	133.36	139.10
12	127.52	131.42	137.61

Table 4.13 shows the path loss of different MIMO system configurations. The path loss difference between summer and winter of 2x2 and 4x4 MIMO system is 4 dB, and the path loss difference is about 5 dB for 8x8 MIMO system.

Chapter Five
Conclusions and suggestions

5.1 Conclusions

The following points had been concluded from the results of simulations depending on NYUSim simulator:

1. The small change in Mosul's weather factors across day and night does not have a significant impact on signal power level. The effect is negligible even for high frequencies as 73 GHz where the change in power level is about 1 dB between day and night.
2. Weather factors difference between seasons is larger than that between day and night. The weather effect across seasons have a larger impact on signal power level where the effect is about few decibels (1-2 dB) for 100m.
3. The attenuation due to weather factors does not represent a problem for 100m at 28, 37, 73 GHz.
4. The difference in loss between winter and summer for 100m at 28 GHz is about 1 dB. The loss difference between winter and summer is about 2 dB at 37 GHz, about 5 dB at 60 GHz and about 2 dB at 73 GHz.
5. The rain has the largest impact on the signal power level and its effect increases with rain rate and distance.
6. Increasing the number of antenna elements does not have a significant effect on losses caused by weather.

5.2 Suggestions

There are different channel models and simulators that may give different predictions of how will millimeter wave frequencies perform. Therefore, there is a need for some more work considering other channel models taking into the account other factors such as sandstorms and snow.

The best way to see which one of the channel models is the most suitable in Nineveh environments, field experiments are required to be taken to validate the results of simulations and making comparisons between different channel models to see which on gives the most realistic results.

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Appendix A

Weather factors of Mosul:

STATION :Mosul					Mean Relative Humidity %									
year	JAN.	FEB.	MAR.	APR.	MAY.	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.		AVG.
1988	81	75	75	72	47	32	24	27	31	45	63	74	646.0	53.83
1989	73	66	70	50	34	26	24	26	30	44	74	85	602.0	50.17
1990	78	76	62	64	36	25	20	24	27	39	50	73	574.0	47.83
1991	79	70	75	58	40	26	27	29	28	45	58	83	618.0	51.50
1992	80	79	64	61	53	34	27	27	29	36	72	85	647.0	53.92
1993	77	75	63	72	66	35	28	28	34	45	76	88	687.0	57.25
1994	85	78	74	69	47	27	28	26	30	51	77	81	673.0	56.08
1995	83	76	70	67	44	32	28	28	32	36	57	65	618.0	51.50
1996	76	72	75	65	44	27	21	25	34	45	58	78	620.0	51.67
1997	79	70	72	62	47	28	25	31	32	54	72	85	657.0	54.75
1998	85	74	68	64	47	24	25	24	30	39	49	61	590.0	49.17
1999	75	70	53	47	28	25	24	25	31	42	56	73	549.0	45.75
2000	77	67	56	44	32	22	19	23	30	45	59	85	559.0	46.58
2001	81	72	72	66	43	24	24	26	32	40	60	80	620.0	51.67
2002	81	68	63	69	44	25	25	30	32	46	56	84	623.0	51.92
2003	0	0	70	0	0	0	0	27	32	43	64	84	320.0	53.33
2004	84	78	62	56	46	28	25	29	30	41	0	0	479.0	39.92
2005	0	0	0	0	44	31	28	29	34	40	58	73	337.0	42.13
2006	78	76	65	69	47	27	28	27	34	52	69	65	637.0	53.08
2007	30	78	69	70	46	30	26	29	29	40	53	59	559.0	46.58
	76.78	73.33	67.26	62.5	43.95	27.79	25.05	27	31.05	43.4	62.16	76.89		50.43

STATION :Mosul Mean Min . temp c°

year	JAN.	FEB.	MAR.	APR.	MAY.	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.		Aveg
1988	4.0	4.3	5.9	10.0	14.8	19.7	25.0	24.3	17.5	14.6	4.9	4.7	149.7	12.48
1989	--1.0	-0.4	8.6	12.2	16.1	20.5	24.9	24.1	18.5	14.4	8.7	3.3	149.9	12.49
1990	0.5	3.6	6.4	9.8	14.4	20.0	25.8	23.0	18.5	13.4	7.8	3.0	146.2	12.18
1991	1.5	1.4	7.7	11.3	14.4	21.8	25.6	24.5	18.4	14.8	7.5	3.4	152.3	12.69
1992	-0.5	1.6	2.9	8.2	14.2	19.4	22.4	23.3	17.7	11.2	6.7	2.5	129.6	10.80
1993	0.2	2.0	3.8	10.2	14.3	18.2	23.5	23.4	17.1	12.6	6.2	5.2	136.7	11.39
1994	4.9	3.3	7.0	12.0	15.0	20.8	24.3	22.3	20.8	14.7	9.3	1.7	156.1	13.01
1995	3.5	4.3	6.7	10.3	15.5	20.7	23.2	23.0	18.5	11.8	5.4	0.2	143.1	11.93
1996	3.9	4.9	7.8	10.3	17.0	20.0	25.8	23.3	19.0	12.3	6.6	7.6	158.5	13.21
1997	3.0	0.2	4.3	8.9	15.2	20.8	24.0	22.7	17.1	15.0	7.9	4.4	143.5	11.96
1998	2.4	2.3	6.4	11.0	15.3	22.8	26.0	25.0	19.8	13.3	9.6	4.5	158.4	13.20
1999	3.7	4.2	5.9	11.2	18.2	22.9	27.0	25.3	19.4	14.7	6.4	3.2	162.1	13.51
2000	2.4	2.3	4.3	13.6	17.3	21.9	27.4	24.8	19.6	13.0	6.9	5.1	158.6	13.22
2001	3.0	4.1	9.5	10.8	15.0	21.2	25.3	25.6	19.9	14.1	5.6	8.8	162.9	13.58
2002	2.0	3.0	7.5	11.7	15.2	20.9	25.5	24.1	20.6	16.3	7.3	3.7	157.8	13.15
2003	0.0	0.0	6.1	0.0	0.0	0.0	0.0	0.0	19.4	16.2	0.0	0.0	41.7	13.90
2004	5.1	4.7	7.6	13.4	0.0	21.7	0.0	0.0	19.0	0.0	0.0	0.0	71.5	11.92
2005	2.2	3.3	7.5	12.1	17.0	21.4	25.7	25.7	19.8	13.6	6.9	5.4	160.6	13.38
2006	1.6	6.4	8.5	13.8	17.4	21.6	25.7	27.3	20.2	16.2	6.3	0.5	165.5	13.79
2007	1.1	5.1	7.2	10.6	19.7	23.4	27.2	26.3	21.0	15.5	8.0	2.0	167.1	13.93
	2.289	3.189	6.58	11.13	15.89	21.04	25.24	24.33	19.09	14.09	7.111	3.844		12.79

STATION :Mosul						Mean Max. temp C°								
year	JAN.	FEB.	MAR.	APR.	MAY.	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.		Ave
1988	10.5	14.4	16.9	23.3	32.5	37.7	34.2	42.0	37.8	29.2	18.7	14.6	311.8	25.98
1989	11.2	15.0	20.1	30.0	34.3	38.9	44.3	42.8	37.3	30.4	19.7	12.8	336.8	28.07
1990	10.7	13.0	20.3	23.4	33.6	39.7	43.8	41.9	38.3	31.2	24.4	15.9	336.2	28.02
1991	13.1	14.2	18.6	26.1	31.5	40.1	42.9	42.5	38.1	30.4	23.5	12.4	333.4	27.78
1992	8.3	9.7	16.0	23.6	29.0	37.0	41.2	42.1	37.2	31.6	19.0	11.1	305.8	25.48
1993	11.4	13.1	18.6	23.1	27.9	37.9	43.2	42.3	38.5	31.5	17.7	15.1	320.3	26.69
1994	14.9	14.7	19.5	27.1	33.8	39.6	42.9	42.3	39.3	30.6	19.0	10.6	334.3	27.86
1995	13.6	16.5	20.2	23.7	33.9	38.7	41.6	42.6	37.5	30.3	20.5	15.3	334.4	27.87
1996	13.1	16.7	17.7	23.3	34.5	38.6	44.8	43.1	37.0	29.8	23.5	16.4	338.5	28.21
1997	13.6	13.3	15.6	23.3	33.7	39.8	42.1	40.8	36.5	30.2	21.9	14.1	324.9	27.08
1998	10.8	14.4	18.9	26.2	33.8	41.9	44.3	44.8	38.1	32.3	26.4	19.5	351.4	29.28
1999	16.1	17.3	21.2	27.5	36.1	40.4	43.2	43.9	38.0	31.7	21.8	16.8	354.0	29.50
2000	12.0	15.2	19.3	28.5	34.1	40.5	46.4	43.6	38.2	29.4	22.2	13.9	343.3	28.61
2001	14.1	15.8	22.2	26.2	32.3	40.6	44.1	44.0	39.2	31.4	20.6	15.2	345.7	28.81
2002	12.1	17.5	21.9	22.9	32.6	39.2	43.3	41.6	38.5	32.0	24.1	12.1	337.8	28.15
2003	0.0	0.0	17.1	0.0	0.0	0.0	0.0	0.0	35.6	0.0	0.0	0.0	52.7	26.35
2004	13.5	14.2	22.4	25.8	0.0	39.7	0.0	0.0	39.6	0.0	0.0	0.0	155.2	12.93
2005	12.6	14.0	20.0	27.5	32.7	38.9	44.1	43.2	38.1	31.0	21.6	18.5	342.2	28.52
2006	11.1	15.3	21.4	25.2	33.2	39.8	42.1	45.1	38.2	30.7	18.9	14.3	335.3	27.94
2007	12.5	15.2	19.3	22.4	34.7	40.6	43.7	43.5	40.0	32.9	23.1	16.3	344.2	28.68
	12.38	14.71	19.36	25.22	31.27	39.45	42.9	42.89	38.05	30.92	21.48	14.72		27.09

STATION :Mosul mean Air Temperature C°

year	JAN.	FEB.	MAR.	APR.	MAY.	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.		Aveg
1988	6.8	9.3	11.7	16.5	23.9	29.5	34.9	33.2	27.4	22.1	10.9	9.0	235.2	19.60
1989	4.3	6.8	14.1	21.3	26.1	30.4	34.7	33.6	28.0	22.1	13.8	7.6	242.8	20.23
1990	5.1	8.2	13.4	16.8	24.7	30.6	35.3	32.9	28.3	22.0	15.2	8.6	241.1	20.09
1991	6.8	7.5	13.1	19.0	23.3	32.0	34.5	33.6	28.4	22.3	15.0	7.7	243.2	20.27
1992	3.7	5.8	9.8	16.4	21.9	29.0	32.2	33.2	27.7	21.0	12.4	6.6	219.7	18.31
1993	5.6	7.4	11.3	16.6	21.1	29.1	34.0	33.4	28.1	22.0	11.5	9.8	229.9	19.16
1994	9.2	8.9	13.2	19.4	24.8	31.0	34.3	32.7	30.4	22.4	13.9	5.8	246.0	20.50
1995	8.3	10.3	13.5	17.1	25.6	30.7	33.0	32.9	28.0	20.6	12.2	6.8	239.0	19.92
1996	8.3	10.6	12.4	16.8	26.0	30.2	35.8	33.4	27.7	20.5	14.0	11.4	247,1	20.59
1997	7.5	6.2	9.6	16.1	24.9	31.1	33.5	31.7	26.7	22.0	14.0	8.8	232.1	19.34
1998	6.2	8.2	12.4	18.4	24.9	33.3	35.7	35.4	29.0	22.0	17.3	11.1	253.9	21.16
1999	9.1	10.4	13.6	19.6	27.6	32.2	35.4	34.8	28.7	22.8	13.4	9.4	257.0	21.42
2000	6.7	8.3	11.8	21.2	26.3	31.9	37.4	34.5	28.6	20.8	13.8	9.2	250.5	20.88
2001	7.9	9.7	15.7	18.3	24.0	31.7	35.3	34.9	29.4	22.6	13.1	12.0	254.6	21.22
2002	6.5	9.8	14.4	17.1	24.1	31.0	34.8	0	0	0	0	0	137.7	19.67
2003	0	0	11.5	0	0	0.0	0	34.6	28.8	22.4	13.8	9.0	120.1	20.02
2004	9.0	9.1	13.9	17.9	0	31.3	34.8	34.2	28.7	23.5	0	0	202.4	22.49
2005	0.0	0.0	0.0	0.0	24.9	30.5	35.1	34.5	28.7	21.7	13.4	10.7	199.5	24.94
2006	7.2	10.5	14.6	19.2	25.7	32.7	34.3	35.9	28.1	22.8	11.6	6.5	249.1	20.76
2007	6.0	9.5	12.8	16.1	27.1	32.2	35.9	34.7	30.1	23.6	14.8	8.1	250.9	20.91
	6.9	8.694	12.78	17.99	24.83	31.07	34.78	33.9	28.46	22.06	13.56	8.783		20.57

STATION :Mosul	ELEMENT:MONTHLY RAINFALL TOTALS (mm)												
year	JAN.	FEB.	MAR.	APR.	MAY.	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	Total
1988	198.3	104.3	98.2	45.2	2.5	9.9	0.0	0.0	0.0	3.6	18.8	95.3	576.1
1989	14.9	45.4	97.6	1.3	3.4	0.0	0.0	0.0	0.0	7.3	133.5	25.8	329.2
1990	52.4	77.5	38.6	29.7	0.3	0.0	0.0	0.0	0.0	4.0	6.2	47.9	256.6
1991	28.5	32.0	205.6	9.0	2.1	0.0	0.0	0.0	0.0	0.2	44.6	82.6	404.6
1992	97.8	132.8	24.6	27.2	55.4	6.2	0.0	0.0	0.0	0.0	109.2	123.9	577.1
1993	49.8	85.9	18.8	171.4	144.7	5.5	0.0	0.0	0.0	17.1	66.7	73.1	633.0
1994	76.5	47.3	93.8	63.7	2.9	0.0	0.0	0.0	0.0	18.2	68.6	68.6	439.6
1995	37.2	65.7	104.7	39.0	0.9	7.7	0.0	0.0	0.0	0.7	30.2	10.1	296.2
1996	166.9	34.9	121.6	38.7	16.5	0.0	0.0	0.0	2.4	6.1	8.7	132.9	528.7
1997	45.6	75.9	48.7	12.9	11.5	7.3	0.0	0.0	0.0	38.9	23.3	96.6	360.7
1998	81.8	32.6	48.5	19.5	24.8	0.0	5.3	0.0	0.0	0.0	0.001	9.7	222.2
1999	36.8	48.2	19.9	11.7	1.2	0.0	0.6	0.0	0.0	10.5	8.2	28.0	165.1
2000	52.6	23.7	31.1	22.3	0.3	0.0	0.0	0.0	0.001	12.4	46.7	83.7	272.8
2001	25.9	37.9	82.5	36.2	17.6	0.0	0.0	0.0	0.3	2.6	11.1	48.3	262.4
2002	55.4	17.9	126.1	77.4	1.1	0.0	0.0	0.0	0.0	9.2	14.4	104.2	405.7
2003	M	M	50.6	7.6	1.2	0.0	0.0	0.0	0.0	11.8	83.5	72.9	M
2004	87.0	60.0	4.1	76.0	4.6	0.0	0.0	0.0	0.0	3.5	92.8	29.1	357.1
2005	94.0	84.2	21.3	8.1	20.8	3.2	0.0	0.0	0.6	1.4	20.6	40.3	294.5
2006	143.2	134.6	21.9	92.5	5.1	0.0	0.0	0.0	0.0	34.0	39.6	40.3	511.2
2007	28.0	73.9	26.2	38.9	19.1	0.0	0.1	0.8	0.0	1.1	0.7	5.0	193.8
2008	21.5	23.5	28.9	0.8									
AVG.	69.7	61.9	62.5	39.5	16.8	2.0	0.3	0.0	0.2	9.1	41.4	60.9	373.0

الخلاصة

شهدت السنوات الأخيرة نمواً مضطرداً في عدد الأجهزة المتصلة بشبكات الاتصال اللاسلكية بالإضافة لظهور تطبيقات وخدمات جديدة تستهلك النطاق الترددي بشكل كبير, نتيجة لذلك فان الجيل الرابع من خدمات الهاتف الخليوي لم يعد قادراً على مواكبة هذه الطفرة, لذلك توجه الباحثون والشركات المصنعة نحو دراسة جيل جديد يستطيع ان يفي بهذه المتطلبات.

من المتوقع ان يكون الجيل الخامس من خدمات الهاتف الخليوي قادراً على احتواء الزيادة الهائلة بعدد المستخدمين من البشر والالات. سيوفر الجيل الجديد بيئة تواصل بين كل المستخدمين بالإضافة لتوفير متطلبات التطبيقات والخدمات الجديدة والتي لم يستطع الجيل الرابع توفيرها.
موخرا تم بذل جهود حثيثة في مجالات البحث والتطوير للوصول للجيل الخامس. احد مجالات البحث هي أنظمة محاكاة القنوات. سيستخدم الجيل الخامس ترددات لم يتم استخدامها من قِبَلْ شبكات الهواتف الخليوية السابقة حيث انه من المهم دراسة اداء الأنظمة عند هذه الترددات في البيئات والظروف المختلفة. ستساعد نتائج نمذجة القنوات على بناء نظام يعمل بصورة جيدة على ارض الواقع.

تم في هذه الرسالة التقصي عن أنظمة محاكاة القنوات واستعراض اهم الخصائص لكل نظام محاكاة بالإضافة لدراسة تاثير عوامل الطقس في مدينة الموصل على انتشار الموجات الكهرومغناطيسية. (NYUSim) هو البرنامج الذي تم استخدامه لدراسة تاثير عوامل الطقس خلال النهار والليل وعبر مواسم السنة على قوة الإشارة ثم دراسة تاثير عوامل الطقس على تشكيلات مختلفة من أنظمة ال (MIMO). نتائج المحاكاة بينت ان اختلاف تاثير عوامل الطقس على شدة الإشارة بين الليل والنهار اقل من 1 dB. كما اظهرت نتائج المحاكاة ان اختلاف تأثير عوامل الطقس على قوة الإشارة خلال عام كامل للترددات 28 GHz و 37 GHz و 60 GHz و 73GHz كان بمقدار 1dB و 2 dB و 5 dB و dB2 على التوالي.

إقرار لجنة المناقشة

نشهد نحن أعضاء لجنة التقويم والمناقشة بأننا قد اطلعنا على هذه الرسالة الموسومة (دراسة نماذج قنوات الانتشار للجيل الخامس / تأثير الظروف الجوية) وناقشنا الطالب (زيد أياد صديق) في محتواياتها وفيما له علاقة بها بتاريخ 27/ 3 / 2019 وقد وجدناه جديراً بنيل شهادة الماجستير- علوم في اختصاص هندسة الاتصالات.

التوقيع:

رئيس اللجنة:د. خليل حسن سيد مرعي

التاريخ: 24/ 4 / 2019

التوقيع:

عضو اللجنة: د. يسار عز الدين محمد علي

التاريخ: 24/ 4 / 2019

التوقيع:

عضو اللجنة د. ضياء محمد علي

التاريخ: 24/ 4 / 2019

التوقيع:

عضو اللجنة (المشرف):د. يونس محمود عبوش

التاريخ: 24/ 4 / 2019

قرار مجلس الكلية

اجتمع مجلس كلية هندسة الالكترونيات بجلسته الخامسة عشر المنعقدة بتاريخ 7 / 5 / 2019

وقرر المجلس منح الطالب شهادة الماجستير - علوم في اختصاص هندسة الاتصالات.

مقرر المجلس: د. صدقي بارذنوت

التاريخ: 7/ 5 / 201

رئيس مجلس الكلية: د. محمد حازم الجماس

التاريخ: 7/ 5/ 2019

إقرار المشرف

أشهد بأن هذه الرسالة الموسومة (دراسة نماذج قنوات الانتشار للجيل الخامس / تأثير الظروف الجوية) قد تم اعدادها من قبل الطالب (زيد أياد صديق) تحت اشرافي في قسم هندسة الاتصالات كلية / هندسة الالكترونيات / جامعة الموصل, كجزء من متطلبات نيل شهادة الماجستير- علوم في اختصاص هندسة الاتصالات.

التوقيع:

الاسم: د. يونس محمود عبوش

التاريخ: 20 / 12 / 2018

إقرار المقوم اللغوي

أشهد بانه قد تمت مراجعة هذه الرسالة من الناحية اللغوية وتصحيح ما ورد فيها من أخطاء لغوية وتعبيرية وبذلك أصبحت الرسالة مؤهلة للمناقشة بقدر تعلق الامر بسلامة الأسلوب أو صحة التعبير.

التوقيع:

الاسم: د. مروان نجيب توفيق

التاريخ: 7 / 1 / 2019

إقرار رئيس قسم هندسة الاتصالات

بناءاً على التوصيات المقدمة من قبل المشرف والمقيم اللغوي ارشح هذه الرسالة للمناقشة.

التوقيع:

الاسم: د. يونس محمود عبوش

التاريخ: 9 / 1 / 2019

إقرار رئيس لجنة الدراسات العليا

بناءاً على التوصيات المقدمة من قبل المشرف والمقيم اللغوي ورئيس قسم هندسة الاتصالات ارشح هذه الرسالة للمناقشة.

التوقيع:

الاسم: د. يونس محمود عبوش

التاريخ: 9 / 1 / 2019

بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

﴿ يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنْكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ وَاللَّهُ بِمَا تَعْمَلُونَ خَبِيرٌ ﴾

صدق اللهُ العظيم

المجادلة : 11

دراسة نماذج قنوات الانتشار للجيل الخامس / تأثير الظروف الجوية

رسالة تقدم بها

زيد اياد صديق

إلى

مجلس كلية هندسة الالكترونيات

جامعة الموصل

كجزء من متطلبات نيل شهادة الماجستير

في

هندسة الاتصالات

بإشراف

الدكتور يونس محمود عبوش

1440هـ 2019م

جامعة الموصل

كلية هندسة الالكترونيات

دراسة نماذج قنوات الانتشار للجيل الخامس / تأثير الظروف الجوية

زيد اياد صديق

رسالة ماجستير

علوم في

هندسة الاتصالات

بإشراف

الدكتور يونس محمود عبوش

1440هـ 2019م