BASHIR ABDIRAHMAN
HUSSEIN

MILLIMETER WAVES FOR 5G AND BEYOND
IN SMART IOT APPLICATIONS

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A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By

BASHIR ABDIRAHMAN HUSSEIN

In Partial Fulfilment of the Requirements for the Degree of Master of Science In Electrical and Electronics Engineering

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Bashir Abdirahman Hussein: MILLIMETER WAVES FOR 5G AND BEYOND IN SMART IOT APPLICATIONS.

Approval of Director of Graduate School

Prof. Dr. Kemal Hüsnü Can Başer

We certify this thesis is satisfactory for the award of the degree of Masters of Science in Electrical and Electronics Engineering

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DECLARATION

I hereby declare that all information in this document has been obtained and presented in accordance with the academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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To my parents and my wife…

ABSTRACT

Fifth-generation (5G) mobile networks are going to work in high bandwidths of the underused millimeter wave (mmWave) frequency bands that enable wireless communication of multi-gigabits per second (Gbps) data speeds. Though the large bandwidths offered, mm-Wave communications have basic technological limitations such as high path loss, susceptibility to obstruction, directivity, and a limited beam width owing to high frequencies. It is essential to have realistic channel modelling that incorporates various 5G capabilities and scenarios to successfully assist network architecture and implementation. This study will present extensive millimeter-wave measurement results at 38, 73 and 6 GHz carrier Dense-Urban Micro-cell (UMi) and dense Urban Macro cell (UMa) scenarios. Directional/omnidirectional Power-Delay-Profiles (PDPs), Path-Losses (PL), Shadow-Fading (SF), and Path Loss Exponent (PLE) that play a crucial role in wireless channels have been simulated and discussed. The results show that omnidirectional PDPs have low path loss and path-loss exponent in comparison to the directional-PDPs. On the other hand, the directional PDPs have provided more excellent results for the received power at the Rx locations. Finally, the results proved that mmWave communications have the capabilities to utilize the requirements for 5G under a specified coverage.

Keywords: Directional, Omnidirectional, Power-Delay-Profiles (PDPs), Path-Loss Exponent, Shadow-Fading (SF).

ÖZET

Beşinci nesil (5G) hücresel sistemlerin, saniyede çoklu gigabit (Gbps) veri hızlarının kablosuz iletişimini sağlayan az kullanılan milimetre dalga (mmWave) frekans bantlarının yüksek bant genişliklerinde çalışması çok olasıdır. Sunulan büyük bant genişliğine rağmen, mm-Wave iletişimleri yüksek yol kaybı, tıkanıklığa duyarlılık, doğrudanlık ve yüksek frekanslar nedeniyle sınırlı ışın genişliği gibi temel teknolojik sınırlamalara sahiptir. Ağ mimarisine ve uygulamasına başarıyla yardımcı olmak için çeşitli 5G yetenekleri ve senaryoları içeren gerçekçi kanal modellemesine sahip olmak önemlidir. Bu çalışma, Görüş Hattı (LoS) ve Görüş Hattı Olmayan (nLoS) Kentsel Mikroseller (UMi) ve Kentsel Makroseller (UMa) senaryolarında 6, 38 ve 73 GHz taşıyıcı frekanslarında kapsamlı milimetre dalga ölçüm sonuçları sunacaktır. Kablosuz kanallarda önemli bir rol oynayan yönlü ve çok yönlü Güç Gecikme Profilleri (PDP'ler), Yol Kayıpları (PL), Gölge Soldurma (SF) ve Yol Kaybı Üstel (PLE) simüle edilmiş ve tartışılmıştır. Sonuçlar, çok yönlü PDP'lerin yönlü PDP'lere kıyasla düşük yol kaybına ve yol kaybına sahip olduğunu göstermektedir. Öte yandan, Yönlü PDP'ler Rx konumlarında alınan güç için daha mükemmel sonuçlar sağlamıştır. Son olarak, sonuçlar mmWave iletişiminin 5G gereksinimlerini belirli bir kapsama altında kullanma yeteneklerine sahip olduğunu kanıtlamıştır.

Anahtar Kelimeler: Yönlü, Çok Yönlü, Güç Gecikme Profilleri (PDP'ler), Yol Kaybı Üstel, Gölge Solma (SF).

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LIST OF ABBREVIATIONS

3GPP	Third Generation Partnership Project
5G	Fifth Generation of mobile technology
AoA	Angle-of-Arrival
AoD	Angle-of-Departure
CDMA	Code-Division Multiple-Access
eMBB	enhanced Mobile Broadband
FSPL	Free Space Path Loss
GSM	Global System for Mobile communications
HDTV	High Definition Television
HPBW	Half Power Beam Width
IMT	International Mobile Telecommunications
IoT	Internet of Things
ITU	International Telecommunications Unit
LoS	Line of Sight
LTE	Long-Term Evolution
M2M	Machine-to-Machine
MIMO	Multiple Input Multiple Output
mMTCs	massive-Machine Type Communications
mmWave	millimeter Wave
NFC	Near-Field Communication
NLoS	Non Line of Sight

O2I	Outdoor to Indoor
OFDMA	Orthogonal frequency-Division Multiple-Access
PDP	Power Delay Profile
PL	Path Loss
PLE	Path Loss Exponent
QoE	Quality of Experience
RFID	Radio-Frequency Identification
SF	Shadow Fading
SNR	Signal-to-Noise Ratio
TDMA	Time-Division Multiple-Access
UHDV	Ultra-High Definition Video
UMa	Urban Macrocell
UMi	Urban Microcell
URLLC	Ultra- Reliable Low-Latency Communications
WSN	Wireless-Sensor Network

CHAPTER ONE

INTRODUCTION

1.1 Overview

Over the last few decades, the term "internet" has increasingly expanded its reach to include all facets of life. However, researchers found it exceedingly difficult to determine the optimal ability of Internet usages. The increase in internet usage has resulted in the evolution of the IoT. IoT equipments are linked to the Internet via RFIDs, WSNs, Bluetooth technologies, NFCs, LTEs, and a variety of many intelligent technological advancements. The IoT is often said as "devices connected to the internet." This organization is in charge of disseminating information gleaned from various sources through the internet and specified locations (Khanna & Kaur, 2020).

IoT is a well-known and groundbreaking technology that aims to reshape the global environment by using linked physical objects. IoT is a term that refers to low power devices that communicate through the internet(Akpakwu et al., 2018). It is also groundbreaking connectivity architecture that will allow the expansion of existing networks. Until recently, people ran devices that connected to the internet mainly. These devices included mobile phones, laptops, and tablets. Any system having ability of connecting to the internet, like sensors and intelligent tags, will be eligible. Network ubiquities mean that any equipment is linked to networks at all times, from any place, and for everyone (Ding et al., 2020). The revolution in the IoT brings in an advanced era of applications and services. i.e. the implementations of the intelligent Cities, such that variety of sensors and Internet of Things devices follow day to day city tasks and help in fore-casting, reduced-energy use, and, among other things, to avoid road congestion problems (Fadlullah et al., 2011).

Additionally, supply chain management, logistics, and healthcare are also possible applications(Goudos et al., 2017). IoT links various "units" and encourages Machine-to-Machine (M2M) communication, which is a method of exchanging information between systems without human control. This can be accomplished by the use of coherent communication mediums (Uddin et al., 2019).

In addition to that, cellular and wireless networking systems had seen significant progress over the years, improving end-user connectivity experiences. Every decade or so, a slew of new criteria and specifications are provided to re-define new communication norms to enhance the performance of existing specifications. Cellular technologies evolved from analog systems to digital systems to deliver high quality broadband services following its launch in the late twentieth century (Gupta & Jha, 2015).

Cellular network generations have evolved mostly in reaction to the increasing trend of mobile phone users, data consumption, and the need for a better degree of Quality of Experience (QoE). Within the next several decades, experts anticipate that there will be almost 50 billion mobile devices on the market, generating a substantial rise in data traffic(Panwar et al., 2016).

Mobile networks in fifth-generation (5G) will provide the different needs of IoT. A 5G wireless communication is critical to ensuring the appropriate help of big devices and new ecosystems and network services. 5G cellular networks for IoT are anticipated to successfully meet critical needs such as maximum bandwidth, minimal data latency, and accessibility to support a greater number of users, reliable power usage infrastructures, and the accessibility of integrated end-user networking solutions (Uwaechia & Mahyuddin, 2020).

In addition to that, the large bandwidth available in the mmWave range between 30GHz and 300GHz, millimeter wave connectivity has been proposed as a critical component of 5G wireless technologies to support multi gigabits networking capabilities (Niu et al., 2015). The millimeter-wave frequency bands are considered a possible ranges for meeting the growing demand for capacity due to its enormous bandwidth availability.

In comparison to semi omnidirectional and sectored microwave signals, the directional mmWave channels support a broader range of channel conditions. Realistic channel modells for millimeter wave is critical for fifth-Generation and beyond the design and analysis of mobile communication networks. Numerous novel applications such as remote cognition, imaging, and precise positioning will be allowed by using mmWave and sub-Terahertz technology (Ju et al., 2019).

In addition to that, given the high carrier frequencies, mmWave connectivity faces a major propagation loss. In this thesis, we are going to study and analyze the behaviors and capabilities of the mmWave frequency spectrum in consideration with the atmospheric impairments like rain, humidity, temperature and etc. We will analyze the wireless channel propagation schemes that affect the fulfilment of networks in time-delays, Shadow Fading (SF) receiving power, Path-Loss (PL) and Path-Loss Exponent (PLE).

1.2 Problem Statement

The demands of reaching optimum efficiency and low latency for IoT devices is crucial. The existence of larger bandwidth delivers good data rates amongst all users since there is a tremendous amount of users that are interconnected in a limited geographical area, often referred to as IoT.

Moreover, the deployment of fifth-generation (5G) technologies, as well as their functionality, has resulted in vast frequency spectrums of high bandwidths, among the majority of which fall within the millimetre wave frequency ranges. Mobile communication's spectrum scarcity has prompted the deployment of the underutilized mmWave frequencies of 5G broadband cellular networks. Successful mm - wave wireless communications device implementation involves a thorough understanding of the mmWave channel modeling.

Because of the high-carrier frequencies, mmWave systems suffer from substantial propagation losses compared to other low-frequency communication systems. Rain attenuation, molecular absorptions, and other environmental characteristics all restrict the range of mmWave communication.

Additionally, mmWave communications are susceptible to interference from artefacts such as individuals, buildings, and many others due to their low diffraction capacity. In this thesis, we will address the cellular channel transmission characteristics which influence the performance of the system.

1.3 Objectives of the thesis

One of the key objectives of the thesis is studying and analyzing the relevant problems and evaluate 5G network performances to meet the purposes of smart IoT implementations.

The principal goals for this thesis can be concluded as follows:

- To utilize the mm-wave spectrums in the deployment of 5G networks in densely populated areas.
- To study different frequency ranges of mm-Wave channels for various conditions utilizing MATLAB based NYUSIM-simulator.

1.4 Organizations of the thesis

This thesis includes of these chapters

- The first is introduction to the thesis, and it consists of several sections, including the overview of the study, problem statements, and objective of the project, research questions, and lastly, the organizations of the study.
- Chapter two studies the literatures available on the evolutions of the arising smart Internet of Things applications and cellular network systems. The enhancement of mobile communications nowadays will also be mentioned, and we will also overview the current trends and requirements of 5G cellular systems. The significance of millimeter waves as an empowering technology is briefly discussed as well.
- Chapter 3 contains the methods for implementing mmWave channels and system designs. The attempts and challenges associated with modelling mmWave channels are discussed, accompanied by an introduction to the system design considerations, models, and scenarios that will be used in this study.
- Chapter 4 show our simulation results in the different frequency bands for the 5G urban dense network in various scenarios.
- Lastly, in chapter 5, we will establish our conclusions depending on the previous chapter findings and provide proposals for future work.

CHAPTER TWO

LITERATURE REVIEW

In this chapter, we are going to discuss the topics related to the enabling technologies for 5G and the related ideas of our thesis.

2.1 Overview

With the growing movement toward the creation of smart things, the industrial world is developing around the idea of "smart cities(Shahid et al., 2018). The word "smart cities" relates to the topic of a community or region's utilization and deployment of technology that determines how frequently power is needed and what production ratio is accomplished with those technologies. The concept of a smart city is not limited to industrial development and operational fields, but also affects the climate and atmosphere. Pollutants generated by industrial or instrument materials are a significant concern for smart city developers. The ever-growing populations and territorial borders of cities and towns often contribute significantly in human contact, influencing their everyday activities (Benzi et al., 2011).

On the other hand, to meet this extremely complex set of specifications, future 5G networks would require revolutionary breakthrough technologies. Furthermore, unlike its counterparts, 5G is intended to be compatible for technologies such as Wi–Fi, UMTS, and LTE, which is expected to be a critical component of its ecosystem.

This will necessitate a paradigm change in the design of cellular networks. The demand for state-of -the-art technologies has been further stimulated by the academia and industry, mobile telephony providers, as well as users of this technology (including those who are constantly working to improve their own abilities and those of their customers.

Several European initiatives have been pursued, including METIS, One5G, Fantastic 5G, MCN, etc., which have addressed the advancement of 5G wireless networks during these recent years. Several academic papers have also tackled this issue in the research. Through our analysis, many technologies have been found to be important to include (Alsharif, 2016).

2.2 The Evolution of Cellular networks

Over the past few years, wireless communication has contributed to the economy and the social development of developed and developing nations. wireless systems had become an essential part of the daily lives of huge amount of people globally, a trend that is expected to continue. cellular networking systems had developed over time, beginning with the first wave of analog mobile network in 1979 and ending with the latest 4G. LTE was launched in 2010s and had since been gradually introduced around the world. LTE has consolidated its role as the de facto mobile standard (Onoe, 2016).

About every ten years, a new generation of wireless communication networks is introduced globally, as shown in Figure 2.1. Each generation is usually used for an extended period and reaches its subscriber height. For instance, 2G GSM is still extensively implemented on a global scale. On the other hand, a distinct tendency may be seen in Japan's more developed market: As is customary in sophisticated mobile communication markets, each generation reaches its peak around ten years after its original introduction. This implies that the subscriber base and coverage area of each new-generation system have grown quickly in response to increased consumer demand, as well as rapid migration from legacy to new technology. Thus, in Japan, 1G and 2G were phased out 20 years after their introduction, despite the fact that their maxima were only being achieved on a global scale! Notably, such a developed market enables technologies to eventually enter the global market.

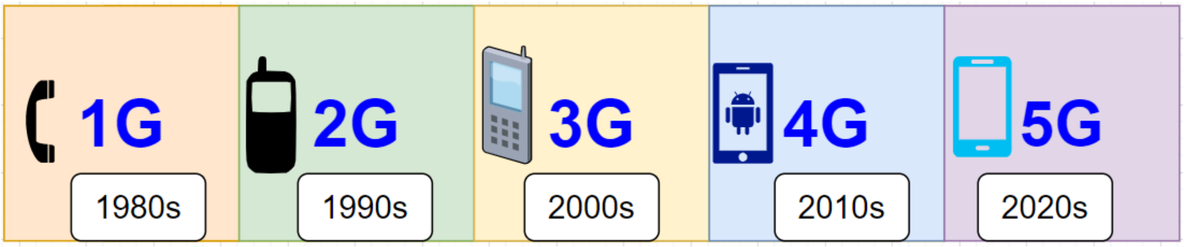


Figure 2.1: Progression of mobile technology.

Prior to 4G, a solid systems idea and technologies for the future generations developed almost quickly following the market introduction of the past generation As a result, 2G (TDMA: Time Division Multiple Access), 3G (CDMA: Code Division Multiple Access), and 4G (OFDMA: Orthogonal frequency Division Multiple Access) systems were implemented (Atarashi et al., 2001).

Indeed, although nobody intended using the name "4G," a relevant 4G solution (OFDMA) was developed in the early 2000s. Furthermore, although everybody is talking of 5G nowadays, there is no specified solution that embodies it. Thus, 5G's present state is distinct from that of 4G a decade ago. This does not imply that 5G innovation may not exist; instead, it means that many potential solutions exist. Among them, OFDMA based wireless system remains a strong contender. However, experts in this field believe that radio system development has reached a point of saturation, even though 4G radio access has nearly reached Shannon capability at the link level. Nevertheless, novel technological arrangements will remain to provide novel technological responses for developing new use cases. Activities that are thought inconceivable now will become feasible in the 5G era beginning in 2020 and beyond. For instance, higher frequency ranges (over 6GHz) were deemed unsuitable for cellular networks so far. Therefore, effective utilization of higher frequency ranges is now regarded a critical element of 5G in order to address the anticipated traffic boom. The novel technology variations will enable quality options for widespread mobile service, such as the utilization of higher frequency ranges with wider bandwidths.

2.3 Industry Trends and requirements for 5G

The telecommunication industry is still in the early periods of 5G expansion. wireless networks have remained relatively unchanged for an extended period, owing to developers' numerous guidelines network features introduced by carriers to increase LTE efficiency (Ahad et al., 2020). However, many in the sector believe that a profound change must follow the development of LTE in the fundamentals of mobile devices over the next few years. A technological transition in technology, infrastructures, and organizational operations for the industry to continue meeting customer demand for mobile networks as they expand(Barakabitze et al., 2020).

Two major factors are driving the deployment of 5G. The first is a reason to encourage or develop Internet of Things (IoT) applications, such as machine-to-machine (M2M) technologies. The second is a desire to satisfy the rising demand for broadband solutions that span multiple cellular systems. Figure 2.2 summarizes these drivers and requirements.

Improved network capacity - It is predicted that user usage in the 2020s would become at least 1000 times more than in 2010. Thus, 5G Wireless networks should be capable of managing traffic levels several times higher than those of traditional network This criterion will become the hardest difficult to meet for 5G connectivity access

Increased data rate - 5G should theoretically support greater throughput than any of those now implemented. Additionally, given the fast growing movement toward better material and cloud computing, 5G would prioritize impressive feature for a more consistent degree of consumer experience than LTE.

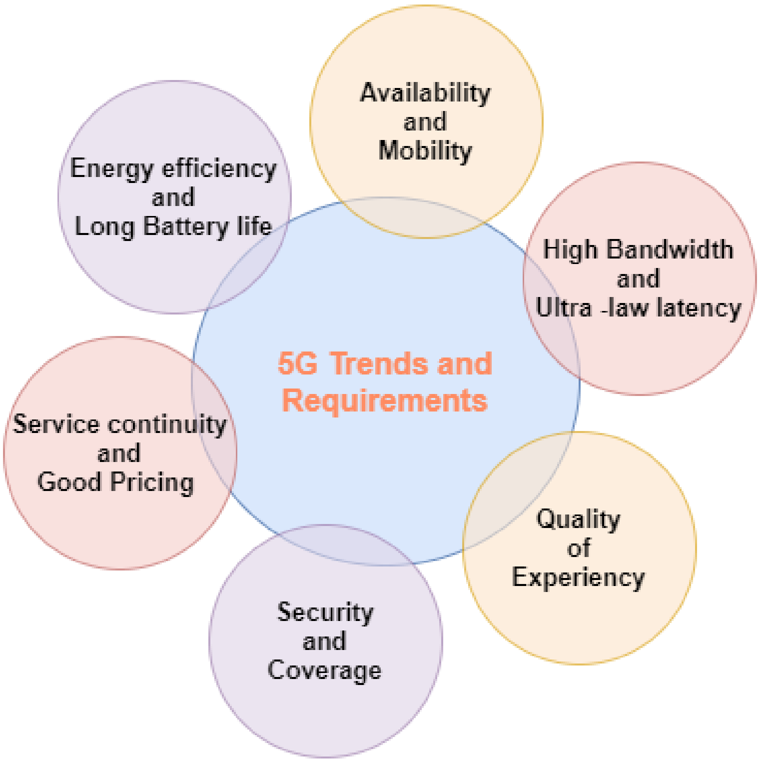


Figure 2.2: Summary of 5G trends and requirements.

Massive machine throughput – 5G should enable the precedent cases connection of a massive number of sensors to the network in order to support always-connected cloud services even in dense crowds, as well as the addition of computer phones for the Internet of Everything (IoE).

Improved latencies - 5G should deliver not just increased data rates, but also userplane delay of about 1ms across the Radio-Access Networks (RAN), a significant improvement over LTE's 5ms. In certain instances, even milliseconds end-to-end delay is required.

Reduced latency enables upcoming cloud computing and the development of new prospective candidate such as tactile Internet, artificial intelligence, and real time and adaptive management for Machine-to-Machine (M2M) use scenarios.

Energy conservation and reduced cost — The 5G system's capacity per unit network cost must be enhanced, while being energy efficient and robust to natural catastrophes. Efficiency in energy consumption is critical for M2M terminals in particular, since it enables extended battery life (e.g., more than 10 years).

Traditional needs for mobile communication systems up to 4G include increased capacity, increased data rate, energy efficiency, and reduced network/terminal cost. However, lower latency is a relatively recent need identified by 4G and is now a critical enabler of packet-based mobile Internet.

These objectives will remain constant needs for future mobile broadband. However, several additional criteria for 5G have emerged: For instance, enormous connection with ultra-low power consumption is a new need for IoE support. Additionally, the ability to enable new business models and ecosystems is being actively explored. Collaboration with specialized verticals becomes critical as the company expands outside telecom.

2.4 Smart IoT Applications

The Internet of Things is a network of interconnected computer devices. These computing devices should be both power-driven and digital, and they should be capable of data transmission across a network without requiring human-to-human or human-to-computer contact(Zhang et al., 2012). In the Internet of Things, statistics are sent between computer devices without the need for human contact. Essentially, Internet of Things (IoT) solutions are comprised of web-enabled smart devices, which are constructed using a network of processors, sensors, and hardware (Magsi et al., 2018). These devices, particularly those capable of data transmission in dispersed settings, may interact with one another. The Internet of Things enables people to live and work more intelligently and has far-reaching benefits. The Internet of Things is critical for employment since it provides producers with an instantaneous view into how their businesses' systems really function, disseminating perceptions across anything from apparatus development to stock management and coordinating activities. Even though the Internet of Things is primarily concerned with the synchronizing things (items) through the Internet. This idea is made possible with a little amount of human direction (Khanna & Kaur, 2020). The connection between the three facets of IoT is shown in Figure 2.3

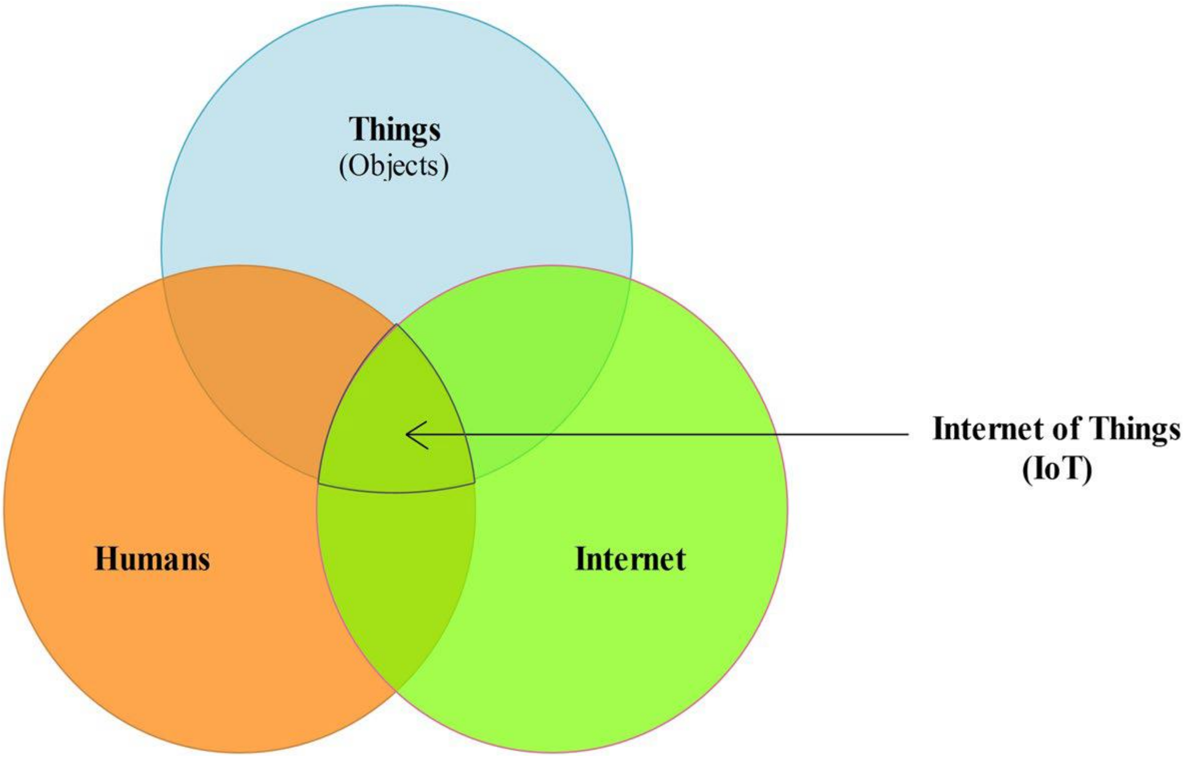


Figure 2.3: The relationship between Internet, Things and Humans.

The Internet of Things is a subset of software applications that provide action authority, the real-time collection of data from distant places in order to regulate equipment and circumstances.

The Internet of Things was founded in 2008, and Gartner, a market research firm, including "The Internet of Things" technology in their study in 2011. The Internet of Things is one of the most pervasive technologies in daily life. The Internet of Things (IoT) is very beneficial in our daily lives, for example, smart toilet balances that operate in conjunction with treadmills, or food preparation ideas that are sent to computers or smartphones to help people stay healthy.

Security systems examine houses, switching on and off lamps when occupants entered and exited rooms. It facilitates and manages video streaming, allowing one to check in while abroad.

Clever estimating assistants engage conventional ready-to-wears, place orders on demand, and make it simple to get fresh nourishment delivered to one's door. The IoT has many features, including the following:

a) IoT enables time and cost savings.
b) IoT may be used to visualize occupational processes.
c) Through IoT, consumers may access data from any location at any time.
d) Ensure that devices linked to the network communicate quickly.
e) Enhance the business's quality
f) it provides a high level of security.
g) Through the usage of IoT, users may make more informed business decisions.

IoT has the ability to have a significant social, economic, and economic effect on its adaption. Mobility, Smart Grids, Smart Home/Buildings, Public Security and Environmental Surveillance, Medicine and Universal health care, Commercial Operations, Agricultural and Breeders, and Independence life are just a few of the Internet of Things-based ideas.

All of these apps are connected to us in some manner. The use of these apps and their many advantages is critical, and there is now a strong reliance on their continued survival.

Its presence and usefulness have reached a futuristic level in latest days and are becoming critical. It would not be inaccurate to assert that the Technology's future is entirely dependent on the idea and concept of IoT, that essentially propels us into the beyond. Fig. 2.4 illustrates several IoT possible applications.

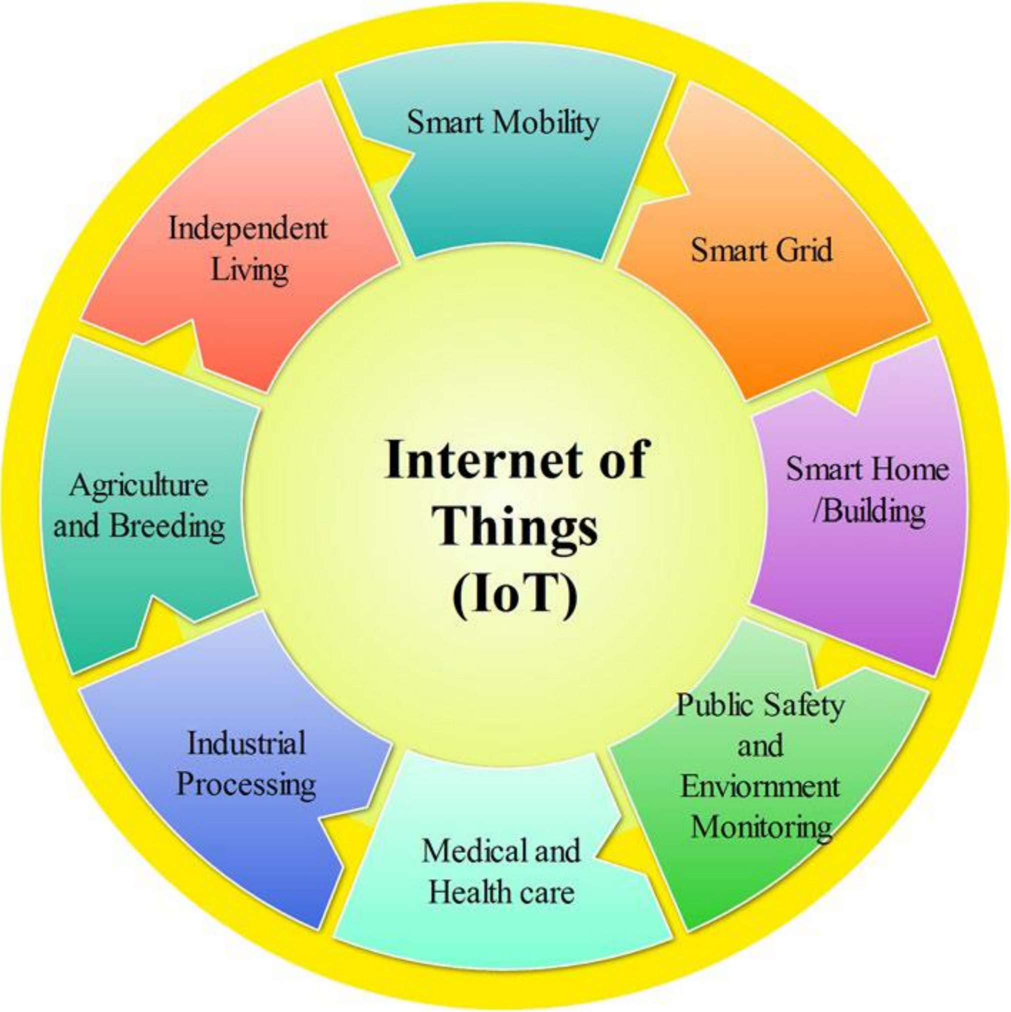


Figure 2.4: Internet of Things use cases.

2.5 Millimeter waves as important enabler for 5G

It is observed that millimeter wave technology plays a huge position in addressing the demands of 5G networks (Rost et al., 2017). millimeter wave technologies are utilized in 5G cellular operators to improve connectivity bandwidth by using the vast amounts of frequency available in the millimeter wave ranges (from 30 to 300 GHz), which meets the anticipated requirements for 5G (Shurman et al., 2019). As potential enablers for 5G, network slicing and mmWave communications provide the required robustness and versatility to configure the network to each particular use case scenario, as well as high throughput and multi-gigabit-per-second wireless connections that fit in to targeted use case environment. The Evaluation and implementations of these technology remains an open research study. that includes improvements at various levels of its network architecture (Pagin et al., 2020).

In addition, the short wavelengths of millimeter wave signal and the advancements in low power radio frequency circuits allow larger multiple antennas to be installed in a compact size, such as a smartphone, thus allowing larger antenna arrays to be installed to enable beamformings and multiple-input multiple-output (MIMO) Technologies (Chekired et al., 2019).

2.6 Dense-Urban Installations of 5G

Increased density of 3G mobile systems aimed to increase data rate by achieving a level of 4-5 BSs/km2. With 4G LTE-A, hotspots and femtocell base stations were installed at a ratio of 8-10 base stations per km2. To meet 5G standards and take use of mimo Systems and mmwave technology, 5G is expected to have a level of 40-50 BSs/km2, putting this an ultra-dense cellular network (Niu et al., 2015).

Among the ten deployment models examined by 3GPP [31], the high density scenario is one of those suggested for enhanced-mobile-broadband (eMBB). The emphasis of this diverse installation approach is on mega cells combined with microcells in urban areas and crowded metropolitan regions with a higher usage density. This kinds of scenarios primary features are outdoors and outdoor to indoor connectivity with significant traffic volumes The Inter-Site-Distances (ISDs) of the macrocells in this case is 200 meters, with each macrocell holding three microcells. Macrocells and microcells have heights of 25 and 10 meters, correspondingly. The carriers frequencies for macrocells is four GHz, whereas the carriers frequencies for microcells is between thirty and seventy GHz. At four GHz the capacity is up to 200 MHz and increases to 1GHz at approximately 30 GHz and 70 GHz. In this situation, 80 percent of consumers are inside traveling at a speed of 3 km per hour, whereas 20% are in automobiles traveling at a speed of 30 km per hour. The compelling argument for increasing density in 5G systems appears to be the promised potential of mmwave, that will be extensively explained in the following sections.

2.7 Wireless channel Modelling

2.7.1 Deterministic modelling

To conduct deterministic channels modelling, we require a comprehensive characterization of the surroundings, such as the locations of nearby things the substances utilized, the characteristics of the reflective surfaces and the transmitters and receiver's precise locations.

Various methods to modeling the channels in a deterministic manner may be distinguished, most notably Ray-tracing approaches, recovered impulses response and numerical analytical strategies such as the FDTD (Finite-Difference-Time-Domain).

Such mathematical models are accomplished via the solution of Maxwell equation , which serve as the basic instrument and basis for all electro-magnetic studies FDTD observations demonstrated a higher degree of precision because they calculate the temporal variations of the electromagnetic fields throughout each location of the surroundings while considering each of the materials and geometrical characteristics. Nonetheless, this technique is extremely time and complexity intensive.

The recovered responses are derived from channels testing, the simplest method of displaying wireless networks. Every channel estimation data gathered in the research can be considered as this type of channels modeling. Radiation retracing methods are frequently recorded as channels impulses responses obtained from Maxwell's deterministic interpretation of formulas or other approximations depending on the geographic and architectural characteristics of various mobile scenarios. Ray-Trace modeling are used to aid in the time consuming and expensive process of determining the channel's propagating characteristics scope and effectiveness. Ray-tracing has become a popular method for researchers since it enables them to simulate wireless-channels having a low computing cost.

2.7.2 Stochastic channel modeling

Numerous studies are being conducted to create new mathematical methods for Mm-wave channel, given traditional channel models such as Rayleigh and Rician are really no longer relevant. The very primary explanation seems since such methods are more suitable for limited devices, while Mmwave systems have bandwidths of up to fifty GHz. The other problem seems as such methods overlook the Mm-wave channel's significant dispersion loss and molecule absorbance.

Numerous studies has being conducted with the objective of defining the multipath elements the dispersed rays from sharp edges, by estimating statistic distribution for their amplitude and frequency, phases.

Comprehensive ray-tracing simulation was performed using 220 distinct receivers locations at 300 GHz in an interior office environment. Surprisingly, the received power from dispersed beams of the identical reflections is limited to a single region (Sun et al., 2018). Those regions relate with a band of azimuthal angle for which multi-path elements exhibit comparable or identical multi-path properties (delay, phase, direction). Those regions are produced when dispersed rays within the identical incident-wave collide alongside each other over a curved medium.

The purpose of classifying every Non - los pathway into a region is to emphasize the importance of dispersed signals from rougher surface to multipath elements. The reflecting parabolic beam is perhaps larger significant as the dispersed beams for every region (have the most high-power).

2.7.3 Combined model

For the channels modelling process, the Base-station (BS) and user-equipment (UE) should usually be plotted on a chart before anything further can be done. It is determined how much path-loss (PL) and shadow is present on a map-by-map base, and randomized shadow particles are produced using the modelling technique used for ray-tracing.

The stochastic procedure then goes on to solve the remaining problems. It is well recognized in mm-wave modeling that mixed simulations takes use of the benefits of both stochastic and deterministic approaches at the same time. In the mm-Magic technique, the current QuaDRiGa channels modelling is expanded via the use of the previously estimated in simulation, which is based upon by channels strategy (Sun et al., 2018).

2.8 Millimeter-Wave Propagations

The frequencies range from 30 to 300 GHz, having wave lengths between 10 to 1 mm, is known as the extremely-high frequencies (EHFs) band by the International Telecommunication Union (ITU). It is also referred to as millimeter-wave. Nevertheless, owing to this same comparable propagations model of the superhigh frequencies (SHF) spectrums beginning 3GHz to 30GHz or centimeter-waves, and particularly in the sense of 5G, the SHF spectrum ranging from (3-30) GHz or centimeter waves has also been referred to as millimeter waves. As a result, the term millimeter wave is usually used to refer to frequency ranges ranging from 3 to 300 GHz.

Some applications in the millimeter-wave range, including as satellite communications, radars, and point-to-point communication, have previously made use of this spectrum, but wireless cellular networks have just lately begun to take use of it. Since mm-Waves have weak propagation properties, they have had limited penetration through structures and barriers, have had significant atmospheric absorption, and have been very sensitive to blocking, the mmWave spectrum has largely been underutilized.

While mmWave frequencies suffer from significant path loss and shadowing effects, they continue to be very desirable for the forthcoming mobile networks. Figure 2.5 shows the mmWave spectrum ranges (Pi & Khan, 2011).

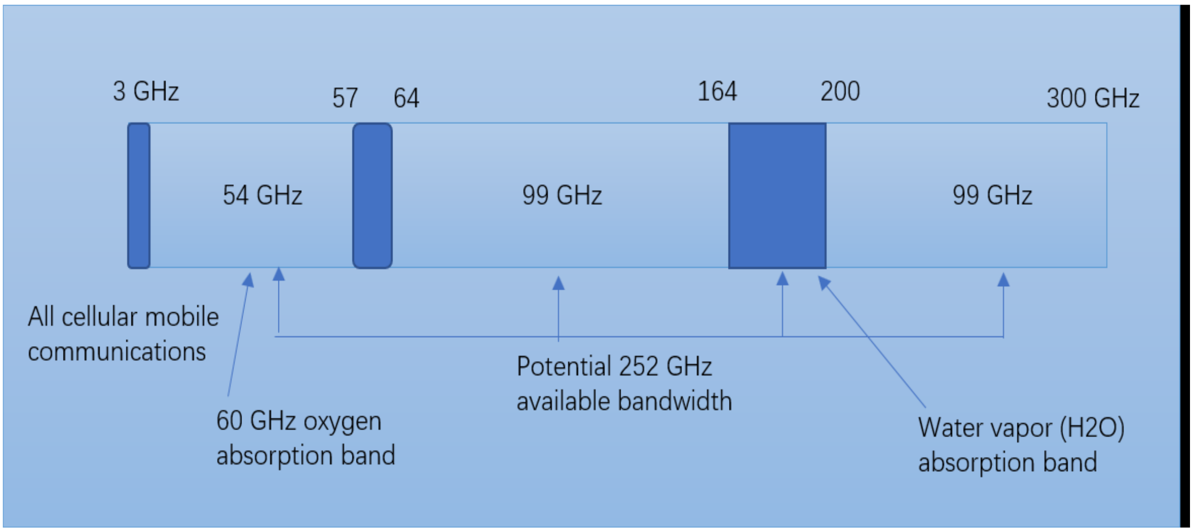


Figure 2.5: mmWave Spectrums

Mmwave frequencies is split and designated under various band depending on how they are used and what wavelengths are used in those frequencies. Mmwave frequency allocation should consider the distribution properties of radio-transmissions in this frequency range Although transmissions at lower frequencies may travel for kilometers and readily pass into structures, mmwave transmissions have a range of just a few kilometers fewer and do not pass solid objects effectively.

Nevertheless, such millimeter-wave propagations properties may never always unfavorable. Millimeter-waves provide greater tightly compacted communication connections, resulting in extremely effective frequency use, as well as increased communication safety. Table 2.1 shows these categorization of band ranges (Marcus & Pattan, 2005).

Table 2. 1: mmWave Band ranges and wavelengths

Description	Ranges	Wavelengths
Q-Band	30 GHz to 50 GHz	10 to 6 mm
U-Band	40 GHz to 60 GHz	7.5 to 5 mm
V-Band	50 GHz to 75 GHz	6 to 4 mm
E-Band	60 GHz to 90 GHz	5 to 3.33 mm
W-Band	75 GHz to 110 GHz	4 to 2.73 mm

2.8.1 Millimeter Wave Propagation Loss Factors

Various Factors affect the mmWave propagations. MmWave propagation losses happen whenever oxygen, water-vapor, and other gas elements capture mm Waves. There are some bands where such effects seem to be higher than others, and those bands coincide with the fundamental resonance frequency of the gaseous particles. Rain additionally has an effect on mmWave propagations. Water droplets are approximately the same magnitude of radio-wavelengths and therefore disperse the radio waves. Foliage loss is considerable at mmWave frequency ranges. Indeed, in certain instances, leaf loss could be a major bottleneck in propagations. Millimeter-wave frequency ranges are similarly susceptible to penetrating loss, and in contrast to lower frequencies, the mm-wave rarely penetrate most solid objects, including buildings, door, and rooms.

2.9 Millimeter-Wave channel modelling problems

Several channels model have being generated and presented. Furthermore, given the mm-wave application cases, particularly for 5G, the massive bandwidths, and the mm-wave character, those frameworks could rarely capture all of the mm-wave features. The primary objective is to create a one-channel paradigm that can be utilized through the whole mm-wave band by simply changing the variables in relation to the frequency band, situation application, or location being used.

The primary constraints of presently established channel conditions are briefly discussed, including the absence of measurement methods, the accessibility of enormous bandwidths, a double accessibility instances, directional-antennas, as well as the use of tremendous arrays, which are all significant constraints for millimeter wave channel modelling work (Hemadeh et al., 2018).

While numerous measuring efforts at milliemeter-waves were conducted, the broad spectrum of millimeter-waves requires more investigation. The earlier designs had been established for sub 6 GHz limited band, where the enormous capacity of mm-wave presents certain constraints.

Due to the fact, since these devices are shifting during device to device (D2D) communication, a greater Doppler dispersion is anticipated, that has significant effect also for channel. For mm-Waves, the use of directional-antennas in conjunction of large array or MIMO may reduce the increased Doppler dispersion and loss, and this must be accounted for in the channel estimation (Rappaport et al., 2017).

2.10 Similar studies

There are several related studies in the literature. This section will summarize these studies. An article suggested by (Alfaresi et al., 2019) examines the characteristics of Palembang's channel models. It generates a model of a 5G channel for the 28GHz frequency band. The research employed Orthogonal Frequency Division Multiplexing and added Cyclic Prefixes (CPs).

Also, research proposed by (Alfaresi et al., 2020) performs computer simulations and tests the characteristics of 5G channels in Palembang based on humidity effects. The authors determined the power delay profiles and the impact of humidity on the channel's efficiency. The results indicated that while humidity does impair the channel's output slightly at high humidity levels, this effect can be ignored.

In addition, authors in [14]addressed a radio propagation mechanism that affects network output in time delay, received power, AoA, AoD, and path loss in LOS and NLOS environments. The authors of (Hasan et al., 2020) conducted simulation analyses and studies for 5G MIMO mobile communications in the 60 GHz wideband range using statistical propagation channel models. The authors discovered channel coefficients using drop-based modes. Finally, Another research conducted in (Mou et al., 2019) examines the power delay profile at 60GHz, 28GHz, and 73GHz in LOS and NLOS conditions in an airport setting.

CHAPTER 3

MMWAVE CHANNEL MODELLING AND SYSTEM DESIGN

In this chapter, we are going to address the details of mmWave channel modelling schemes in urban micro-channel and macro-channels. The mmWave communications usually have significantly less than the sub6 GHz band's range because its wavelength is considerably shorter.

As a result, designing 5G wireless communication systems requires precise and dependable analysis of mmWave-channel propagation properties. Accepting the wireless transmission channel is critical for developing the forthcoming 5G wireless development. To understand wireless signals in densely suburban mmWave mobile media, comprehensive experiments in practical channels are needed to describe those frequencies for potential wireless and backhaul networks in indoor and outdoor conditions.

However, the NloS path loss characteristic is unknown, resulting in additional analysis and experiments. To characterize radio propagation in general, propagation factors such as path loss, frequency dependent material losses, propagation mechanism (reflections, diffractions and scattering), delay spread, the effects of rain, foliage losses, atmospheric, and many attenuation losses have been used.

The above parameters should be determined primarily across the analysis of measured data collected from multiple channel measurement projects performed in various environments.

3.1 Study Flowchart

The implementation of this project is only going to be software simulations. The approaches to design this project is shown in figure 3.1. This figure shows the steps that this work is going to be done from the start to the end, and it helps us find a way to take till the end of this project.

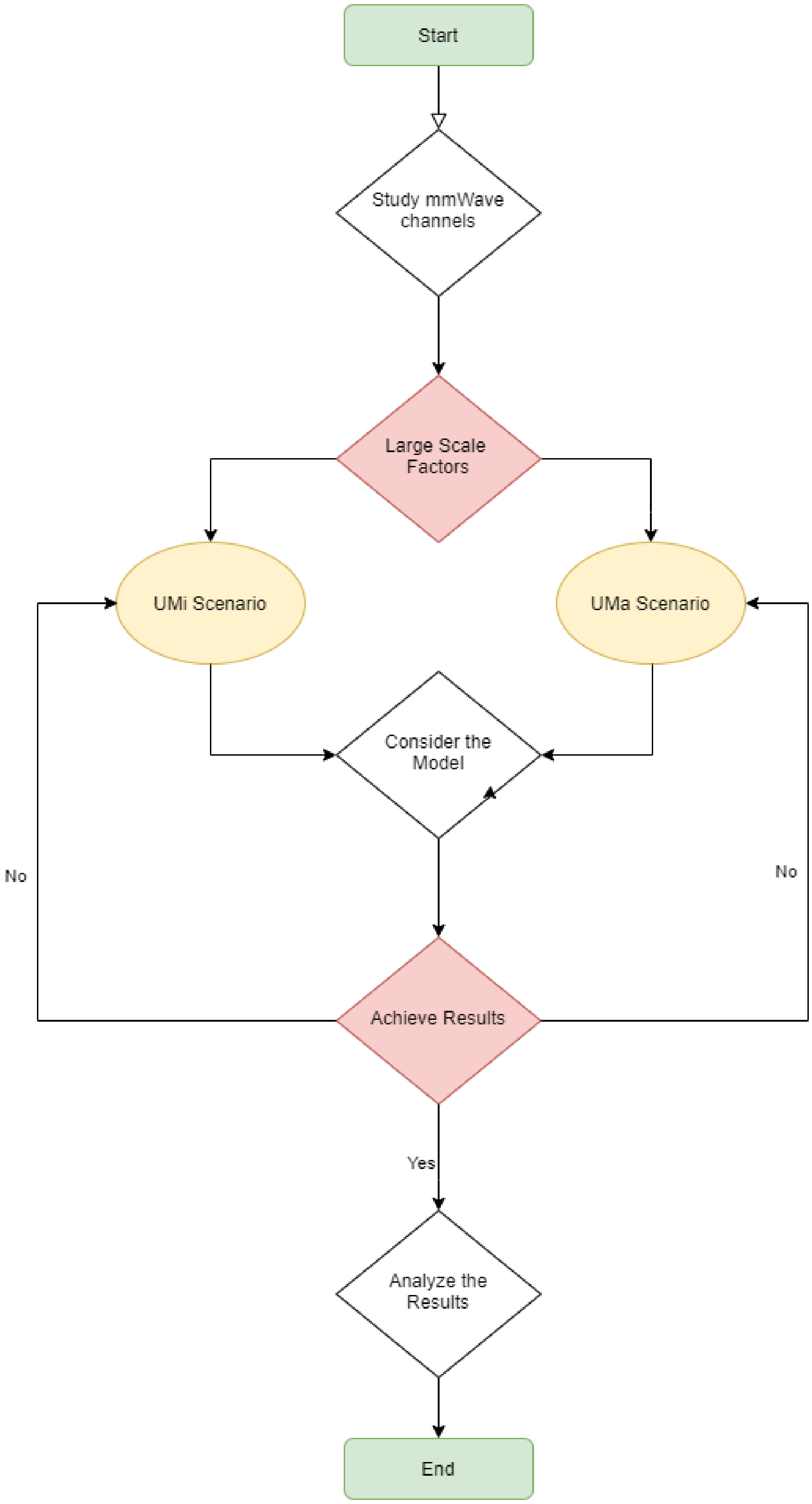


Figure 3.1: Study Flow chart

3.2 Free-space losses, attenuation and other losses

3.2.1 Free-space losses

The free-space path loss (FSPL) is the ratios of the attenuation of signals intensity between two isotropic antennas in free-space (Nossire et al., 2018). That is, the difference in gain among two isotropic antennas which are not influenced by the Earth is referred to as the FSL and can be calculated as following. Let us say G = 1 (i.e., 0 dB, which means no loss or gain) and $\lambda = c/f$ Then the power ratio between the input transmitting antenna and sink antennas can be calculated as (Uwaechia & Mahyuddin, 2020):

$$\frac{P_t}{P_r} = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi df}{c}\right)^2 = \left(\frac{4\pi}{c}\right)^2 + d^2 + f^2 \qquad (1)$$

Where c is the speed of light in a vacuum ($3 \times 10^8\ ms^{-1}$) while also f is he frequency carrier. On the other hand converting the above equation in to decibel gives us (ITU, 2015):

$$10\log\left(\frac{P_t}{P_r}\right) = 10\log\left[\left(\frac{4\pi}{c}\right)^2 + d^2 + f^2\right] \text{dB} \qquad (2)$$

So, the FSL between the input and sink antenna gives

$$\begin{aligned} FSL = & \quad 10\log\left(\frac{P_t}{P_r}\right)\text{dB} \\ = & \quad 20\log\left(\frac{4\pi}{c}\right) + 20\log d_{[m]} + 20\log f_{[Hz]} \\ = & \quad 20\log(4\pi) - 20\log(3 \times 10^8) + 20\log d_{[km]} \\ & \quad -20\log 10^3 + 20\log f_{[GHz]} - 20\log 10^9 \\ = & \quad 92.4 + 20\log d_{[km]} + 20\log f_{[GHz]} dB. \qquad (3) \end{aligned}$$

3.2.2 Rain, Foliage and atmospheric induced attenuations

When interacting with cellular technology signals beyond the operational frequencies of 10 GHz, rain attenuations is typically the most significant propagation weakness. The explanation for this is because the scale of rain-drops is roughly equivalent to radio wavelength at mmWave frequency ranges resulting in a signal scattering effects. Consequently, mmWave transmissions are more prone than sub-6 GHz signals of longer wavelengths to be blocked by rain-drops. The rain induced attenuations A (dBs)

$$A_{0.01\%}[\mathrm{dB}] = \gamma_R[\mathrm{dB/km}]d_{\mathrm{eff[km]}} = \gamma_R[\mathrm{dB/km}]d_{[\mathrm{km}]}r_{0.01\%} \qquad (4)$$

Where γ_R stands for the specific attenuations determined in dB/km, d_{eff} is the propagation's path length in kilometer. $d_{\mathrm{eff\{km\}}=}d_{[\mathrm{km}]}r_{0.01\%}$, and d is the path-length propagation distance and $r_{0.01\%} = \frac{1}{1+d/d_0}$ is the distance-factor, for this occasion, $d_0 = 35e_{0.01\%}^{-0.015R}$ when $R_{0.01\% \leq 100mm/hr}$. After that the attenuation can be derived as follows

$$\gamma_{R[dB/km]} = KR_{0.01\%}^{-\alpha} \qquad (5)$$

α and k are regression constants obtained as function of frequencies and the polarization types.

On the other hand, during good conditions, that is, when there is no concentrated water in the way of fog or rain, the main influence influencing radio wave transmission is attenuations due to natural gas. The atmosphere's nitrogen structure, viewed as a mixture of various elements, is largely indicated by the size of molecular oxygen and nitrogen's on a regular basis. Although water vapors are slight gaseous elements, their existence has a significant effect on the transmission of electromagnetic emission (Siles et al., 2015). The foundation of attenuations due to gas are based on the theory of molecular-radiation interactions that are referred to as absorption mechanisms.

Moreover, another imminent attenuation is the foliage-induced attenuation (Rahim et al., 2017). Getting the mm - wave mobile systems to a large number of people would be challenging related to the significant signal attenuation caused by foliage. Differences in foliage attenuations can be seen between locations in the tropics and those in the temperate zone. Plants in the tropics are wide while those in the mild zones are usually needle like. Foliage attenuations are expected to be greater in tropical regions where foliage is comparable to or larger than the wavelengths and the humidity situation.

Foliage induced attenuations predicted by the ITU-R standards in situations of foliage depths under 400 meters, $\gamma_{Foliage[dB]}$ is calculated as:

$$\gamma_{Foliage[dB]} = 0.2 f_{[MHz]}^{0.3} + D_{[m]}^{0.6}, \qquad D < 400m \qquad (6)$$

For D < 400 m, f means frequency in MHz, and D means foliage depth in meters. This describes specific, meaning (6) is possible for a range of frequencies from 200 MHz and around 95 GHz. When looking at the 12-meter penetration at 38 GHz, the foliage-induced attenuation adds a further 21 dB of attenuation. For this purpose, the word loss due to foliage cannot be ignored(Marcus & Pattan, 2005).

Other losses include material penetration loss(Zhao et al., 2013). Penetration failure at mmWave frequency ranges will represent a major difficulty for frequency ranges above sub 6GHz. In the meantime, the loss rate of penetrations depend more on the medium and increases with an increased mm - wave frequency range(Ryan et al., 2017).

3.3 Radio-channel propagation mechanisms

The primary processes of NLOS propagation are usually due to reflection, refraction, and spreading. In general, for the non-line-of-sight route between the source and destination, signals may still spread to the recipient via reflections from nearby surfaces, bendings, or diffractions(Abdulrasool et al., 2017). When the obstructing target is larger than the size of the radio wave, diffractions and scattering occur. Therefore, mmWave signals with small wavelength become quite susceptible to fading and reflections, due to the poor scattering of the very low frequency. Different mm - wave propagation measurement activities have been undertaken to investigate the propagation processes at various mm-Wave frequency ranges (Hao Xu et al., 2002), (Zhao et al., 2013), and (Janaswamy, 2006). A research in (Hao Xu et al., 2002) discovered how the reflecting multipath spectrum is closely associated with the propagation condition throughout the 60 GHz range. Another study in (Janaswamy, 2006) provided multidirectional approaches at 83.5 GHz primarily for indoor settings, based on 3000 observations in LOS and NLOS environments towards a distance of 160 m. Nevertheless, in (Janaswamy, 2006), no clear path was identified due to high penetrating failure, whereas the diffracted routes found had a transmitting power of 11-23 dB less than the reflected routes.

Generally, parameters like path loss, delay-spreads, shadow fading, and angular distribution are used to describe wireless propagations. This is accomplished mainly through examining the FSPL, rain induced attenuations, atmospheric attenuations, foliage-induced attenuations, material penetration failure, and wireless channel transmission processes information gathered during multiple channel evaluation projects in a variety of conditions The following sections detail these criteria.

3.3.1 Path losses and shadow fading

Path loss, represented in decibels (dB), is a term that refers to the depletion of the power intensity of any transmitting electromagnetic radiation as it travels across spaces [134]. Moreover, shadow-fading arises primarily in NLOS situations caused by barriers, allowing for substantial signal attenuation(Nourkhiz Mahjoub et al., 2019).

3.3.2 Power Delay Profiles and delay spread

The power delay profiles (PDPs) describe the statistical power transmission of a received power due to propagation delays across multipath channels, Whereas the delay distribution provides the gap in propagation period among the widest and shortest paths for a huge amount of energy. Hence, PDPs and delay spreads are both critical variables in describing mm-wave radio propagations.

3.4 Antenna properties and MIMO Transmission

3.4.1 Antenna Properties

The antennas can experience interferences from signals travelling in directions other than the primary gain path. The below methods are several probabilistic methods to designing one's specific antenna design centred on a given Half-Power Beamwidth (HPBW), with all antennas benefits defined in terms of an isotropic antenna. The antenna patterns have the following form:

$$\begin{aligned} &G(\theta,\phi) = max\left(G_0 e^{-\alpha\theta^2-\beta\phi^2}, \frac{G_0}{100}\right) \\ &\alpha = \frac{4\ln(2)}{\theta_{3dB}^2}, \beta = \frac{4\ln(2)}{\phi_{3dB}^2}, G_0 = \frac{41253\eta}{\theta_{3dB}\phi_{3dB}} \end{aligned} \tag{7}$$

Where (θ andϕ) represent azimuthal and elevational angle deviation from the boresight position in degree, G0 represents the peak boresight-gain in linear units, (Θ3dB; ϕ3dB) represents azimuthal and elevational HPBWs in degrees, (α; β) denotes variables that rely on the HPBW amounts, and ŋ = 0.7 denotes a standard typical antenna efficiencies.

The radiation-patterns of sectored cell-site antennas, such as the azimuthal radiation-pattern, is described in the following as a cardioid (Rappaport & Brickhouse, 1999).

$$r(\theta) = \alpha[1 + \sin(\theta + \frac{\pi}{2})] \qquad (8)$$

Where r stands for the antenna gain at azimuthal angle from antenna's maximum lobe.

The elevational-pattern of cell-site antennas are modelled using an ellipse with the base station as the focal point (Rappaport & Brickhouse, 1999). The basic formula for an ellipse with its origin at its centre is as follows:-

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \qquad (9)$$

By selecting proper values for a and b, you may replicate typical directional-antenna radiation patterns.

3.4.2 Multiple-Input Multiple-Output (MIMO) Transmissions

A fundamental technical enabler for fifth-generation (5G) mmWave cellular mobile communications is MIMO spatial-multiplexing and beamforming. Spatial-multiplexing needs appropriately spaced and incoherent array antenna elements, whereas beamforming needs coherence and precisely spaced array antenna elements. MIMO Antenna arrays have been implemented in 4G LTE mobile technologies and is expected to get utilized in 5G to boost maximum data rate in conjunction with beamforming for low Signal to Noise Ratios (SNRs) circumstances such as tower boundary clients. Beamforming techniques suited for millimeter waves may be generally characterized as analog, hybrid analog-digital, or lower resolution digital, which all have unique consequences for deployments in mm-wave MIMO channel models. For example, analog beamforming involves analogue phase-shifters that are flexibly altered to modify the phase of antenna components, raising the signal gain to compensate for pathway losses in both LOS and (NLOS) millimeter wave transmission (Lota et al., 2017).

Multi - antenna elements are required for Mm - wave transmissions to accommodate for such increased route failures caused by mm-Wave's greater degradation during first metre of transmission according to Friis laws (Sun et al., 2016).

Creating an extremely directional antenna with narrow beam widths that can be steered across a wider angle band for the AoA at the receivers (Rx) side will assure a better gain. Such adaptable beamforming needs various components with excellent coherence, as well as beam steering, which needs co-polarized antenna arrays that are generally positioned near together at λ /2, where λ is the carrier's frequency. Furthermore, MIMO propagation needs spatial-multiplexing, which is accomplished through distinct spatial pathways of parallel propagations.

This imposes the contrarian need of guaranteeing that no coherence exists among antenna elements broadcasting parallel data streams concurrently, i.e. antenna components that have either been cross-polarized, orthogonal in spatial beam patterns or are comparatively separated so far apart (Sun et al., 2014).

The multi-carrier propagation addressed is orthogonal frequency division multiplexing (OFDM), which adds towards the MIMO channel parameters for an OFDM sub-carrier of every retrievable multipath element. For example, the channel coefficients for Tx and Rx are as follows(Mantoro et al., 2017).

$$\begin{aligned} &h_{m,k}(f) = \sum_p \alpha_{m,k,p} e^{j\Phi_{m,k,p}} e^{-j2\pi f \tau_{m,k,p}} \\ &e^{-j2\pi d_T\, m\sin(\phi_{m,k,p})} \\ &e^{-j2\pi d_R\, k\sin(\varphi_{m,k,p})} \end{aligned} \quad (10)$$

Where $h_{m,k}(f)$ represents the MIMO channel coefficients among the m^{th} transmitting antenna and the k^{th} receiving for subcarrier frequency f. p indicates the p^{th} retrievable multipath element., α stands for the gain's amplitude, Φ represents the multipath component's phase, τ is the delay time, d_T and d_R denote the antenna array positioning at the Tx-Rx, respectively, and ϕ and φ indicate the Azimuth Angle of Arrival and Angle of departure, respectively.

3.5 mmWave Channel Modelling Efforts

Numerous large institutions have participated in the development of mmWave channels for 5G and for different conditions such as LOS and NLOS and numerous frequencies(Uwaechia & Mahyuddin, 2020). These projects or institutions include i) COST 2100 channel model (Liu et al., 2012), ii) MiWEBA (Weiler et al., 2016) iii) QuaDRiGa (Jaeckel et al., 2014), iv) METIS (Carton et al., 2016) v) International Mobile Telecommunications-2020 (IMT-2020) channel model, vi) 3GPP-mmWave channel models (TR) 38.901, and various other projects.

Additionally, we see many comparable channel and modeling methods in different current model relying on the relevant material, since they are developed concurrently and individuals in one program frequently contribute actively to another. For example, the mmMagic project's members regularly assist in 3GPP and IMT 2020 compliance. Each version, on the other hand, is distinct and brought originality. The requirement / expectations for the info actually available on higher frequencies channels may be found in the 3GPP-NR document titled "Assessment of the frequency band modeling over 6 GHz".

We will quickly discuss a few of those of the most often cited standard patterns for the millimeter wave medium.

3.5.1 METIS

METIS channel models absorb the spirit of famous channel models, such as Winner model Families. Models are developed via a thorough review of the literature, analysis of huge amounts of real measurement data, and ray tracing simulations. The models developed for 5G scenarios include both massive MIMO and mmWave capabilities. Additionally, METIS categorizes overall modeling methods as map, stochastic, or hybrid models. This is very instructive for future channel ideas. The user must decide whether to utilize several models to simulate the desired propagation scenario techniques. The model used will be determined by the frequency spectrum, accuracy, complexity, and duration of the calculation (which relies mostly on the simulated system like the number of BSs and UEs).

3.5.2 Third Generation Partnership Project

This 3GPP model is standard model that take into account the architectural techniques developed after the WINNER series versions originally created. This is a system level channels model which incorporates everything for a channel's capability along for all of its related large scale and small scale characteristics.

This channels prototyping calibrated analysis is formulated in order to offer a clear path for commercial and scientific organizations interested in implementing 3GPP channel simulations. It incorporates the time cluster lag timeline (TDL/CDL) paradigm to facilitate the evaluation of connectivity levels. 3GPP-NR is often abbreviated 3GPP-NR to refer to the more current advancements that enable channels greater than 6 GHz.

3.5.3 MM-MAGIC

The mm-MAGIC channel-model is a stochastic geometric modeling scheme that augments the standard simulated systems with additional capabilities to increase its accuracy and usage possibilities. Surface reflections and obstructing effects, construction penetrating losses, broad bandwidth coverage, huge array antennas, and spatial stability are all features of the concept. Over twenty channel evaluations were taken in a variety of settings, notably UMi urban canyons and UMi openness.

The frequency range spans the range below the 6 GHz-100 GHz, and includes the outdoors, workplace, airline registration areas, and interior environment. Various experiments have been conducted to evaluate the reflective and diffused dispersions, the impact of material reflections obstruction, and frequency dependent channel properties. Specifically, the blockage concept relying on the METIS functions is created and verified in real-world data using the Kirchhoff's diffraction formulas. The technique for spatial precision modeling started by the 3GPP was evaluated.

CHAPTER 4

RESULTS AND DISCUSSIONS

In this section, we are going to make a comparison and analysis of mm-wave channels in terms of path-loss, shadow fading and power delay profiles by simulating two frequencies that are in the range of mm-wave frequency bands to see the performance of each of these in dense-urban conditions.

MATLAB based NYUSIM simulator is used to investigate and analyze these frequency bands. The software can perform Monte Carlo simulation results providing number of samples of channel impulse response (CIR) for specific Transmitter and receiver distance.

4.1 Simulation settings and Wireless channel parameters

To investigate and analyze the performance of mm-wave channels, different settings have been used for the wireless channel in both LoS and NLoS conditions. These settings mainly consist of antenna configurations and channel properties.

4.1.1 Channel and Antenna Properties.

As we have mentioned in section 3.4, MIMO array configurations and beamforming are fundamental technical enablers for 5G. We have selected MIMO array configurations with 16×4 and 8×2 Uniform Linear Arrays (ULAs) for UMi and UMa scenarios in both of our scenarios, respectively. These array elements are 0.5λ spaced. The base station antenna has an azimuthal Half Power Beam Width (HPBW) angle of 15° for the UMa scenario and 10° for the UMi indoor scenario, and 10° of the elevation HPBW angle. For the receiver Rx or the mobile station, both the azimuth and the elevation HPBW angles are 10°.

On the other hand, 800 MHz channel bandwidth is selected for all scenarios and frequencies to provide the best results in both Los and NLoS conditions. The Base Station (BS) and the Mobile Station (MS) antennas have a height of 30 and 1.5 meters, respectively, in the UMa scenario.

For the UMi condition in the indoor environments, the BS antenna has a height of 10 m and 1.5m for the MS, which is the same as the UMa scenario. These antennas (Tx and Rx) are separated with a distance range from 10-500 m, and the power for the transmitting antenna is 30 dBm.

Table 4.1: 5G mmWave system parameters.

Parameters	**Descriptions**	
	UMi conditions	UMa condition
Frequencies	38 GHz and 73.5 GHz	6GHz
Bandwidth	800 MHz	800 MHz
Heights of Base stations	10 m	30 m
Temperatures	21°C	
Tx/Rx separation	10-500m	10-150
Foliage attenuation	No Foliage	0.4 dB/m x 10 m
Foliage space	------	10 m
Tx Power	30dBm	
Modulation Type	OFDM	
Antenna Properties	**Descriptions**	
Tx Array type, Nt	ULA, 16	ULA,16
Rx Array type, Nr	ULA, 4	ULA, 4
Environments	LOS/NLOS	LOS/NLOS
Tx Antenna Spacing	0.5λ	
Rx Antenna Spacing	0.5λ	

In addition to that, the atmospheric impairment parameters in Nicosia and foliage losses has been taken into account; 1014 mbar, 50% and 21°C are taken for the biometric pressure, humidity level and temperature, respectively. For the foliage attenuation, we have accounted that foliage exists within a distance of 10 meters, considering an attenuation of 0.4 dB/m. The summary of these parameters is given in table 1.

4.2 Simulation Results

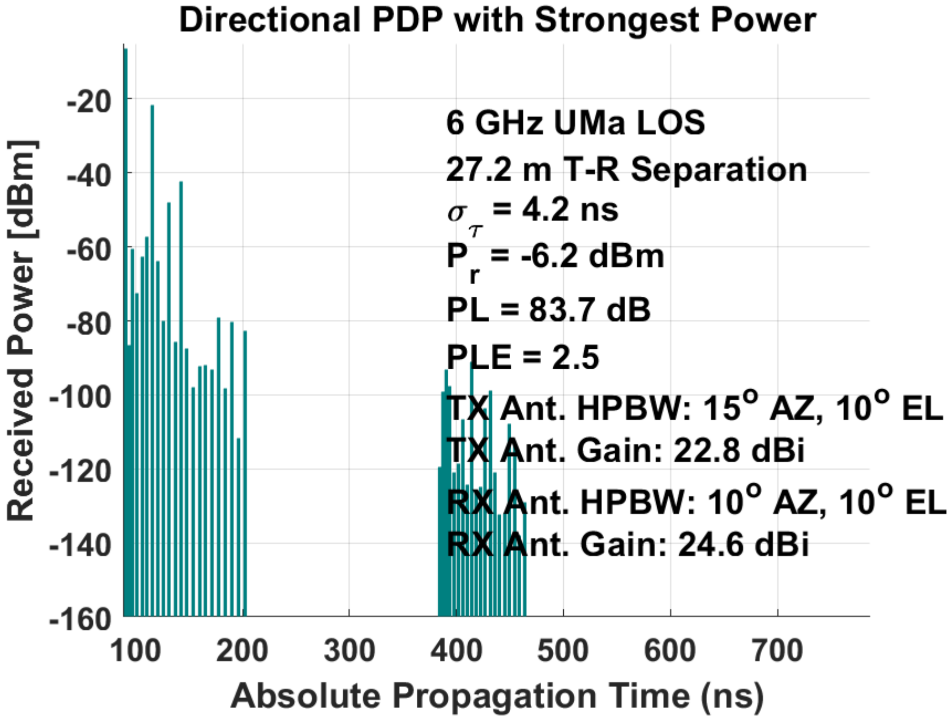
This section will analyze the simulated results based on three frequencies within the sub-mmWave and mmWave frequency ranges. These frequencies are 6 GHz, 38 GHz and 73.5 GHz. As we have mentioned in the previous section, we will look for two scenarios: UMa and UMi.

For the UMa, we will see the performance of the mmWave frequencies in outdoor environments where we simulated both LoS and NLoS conditions with a range of up to 500 m. For the UMi Scenario, this study aims to see the performance of these frequencies in indoor environments where there are lots of populations and obstacles. Omnidirectional PDPs, Directional PDPs and Path losses will be discussed for this study.

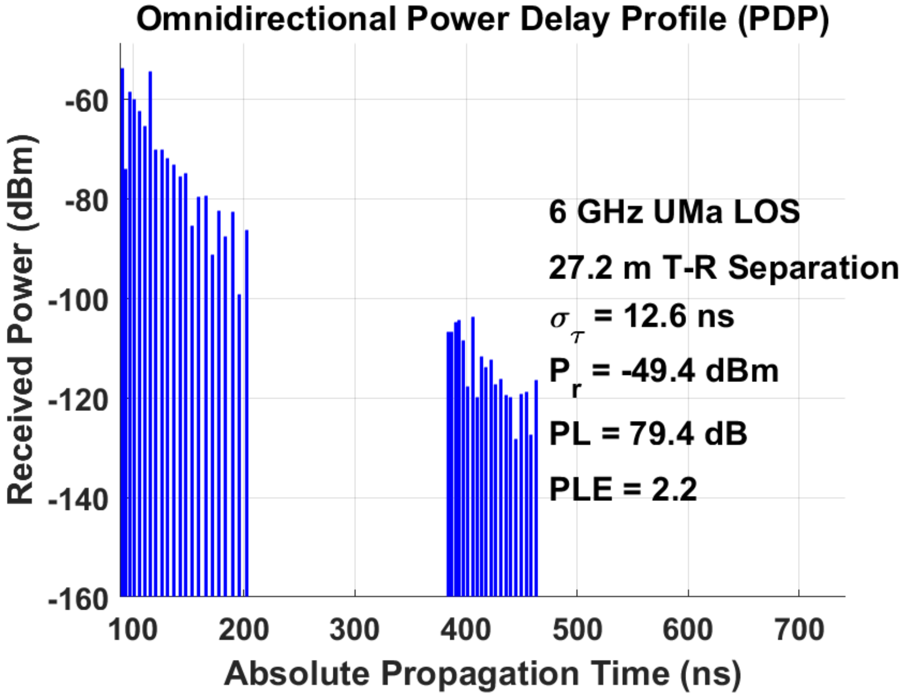
4.2.1 6GHz mmWave for Urban Macrocell Environment

For the dense UMa condition, we have simulated ten different Tx and Rx combinations selected randomly for the UMa Scenario. At first, when we come to LoS condition where there is no obstacle or reflectors/refractors like buildings, cars or any other materials. Figure 4.1 a) shows the Directional PDP with the strongest power for 27.2 m separation between the transmitting base station and the mobile station.

The simulations show that the delay-spread(σ_τ) of 4.2 ns and a path loss exponent (PLE) of 2.5. In terms of the signal strength, the received power is -6.2 dBm, where the path loss (PL) for the same Rx gives a value of 83.7 dB, which means the RSSI level of this Rx location is outstanding. Nonetheless, Figure 4.1 b) shows the omnidirectional PDPs for the same Tx and Rx combination.



(a)



(b)

Figure 4.1 (a) and (b): UMa LoS Directional/Omnidirectional Power delay profiles (PDPs) for 6 GHz.

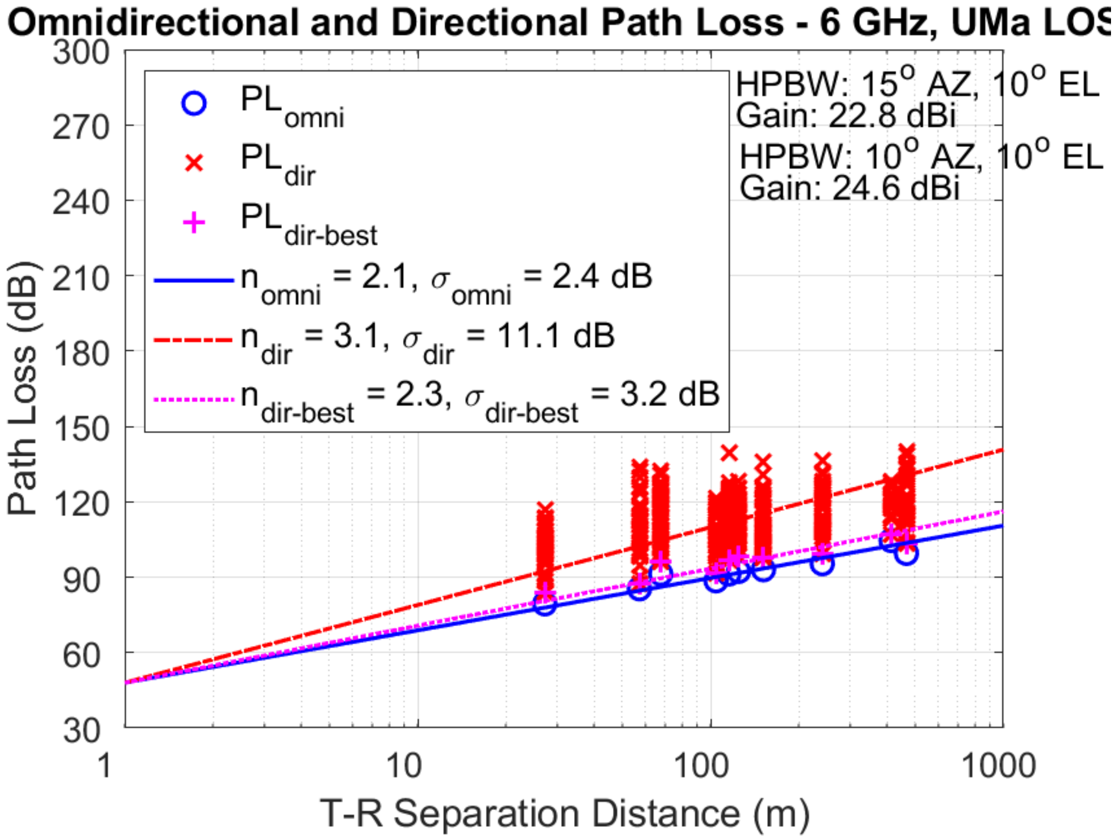


Figure 4.2: UMa LoS Omnidirectional and Directional Path Losses for 6 GHz.

Figure 4.2 shows The path losses for the randomly selected 10 Rx locations for the LoS condition. We see that the path losses increase as the distance between the Tx and the Rx increases. Shadow Fading (SF) Factor, which plays a significant role in the wireless channel, is shown in this figure, σ_{SF} In both directional and omnidirectional are 11.1 dB and 2.4 dB, respectively. The best directional σ_{SF} in LoS among the 10 Rx locations is 3.2 dB. On the other hand, the figure shows the Path Loss Exponent (PLE) for the 6 GHz LoS UMa scenario in omnidirectional and directional settings. The best directional PLE (η) among all 10 Rx locations is 2.3. For the UMa NLoS condition, we have also simulated ten random Rx locations for the same antenna and channel settings as for the LoS condition. In conclusion, Figure 4.3 shows the results obtained for the NLoS condition.

We see an increase in path losses, shadow fading, PLE for both directional and omnidirectional compared to those of the LoS condition. The main reason is that for the LoS, there is a clear sight between the BS and the MS. But for the NLoS, the MS may not have a clear sight of the BS.

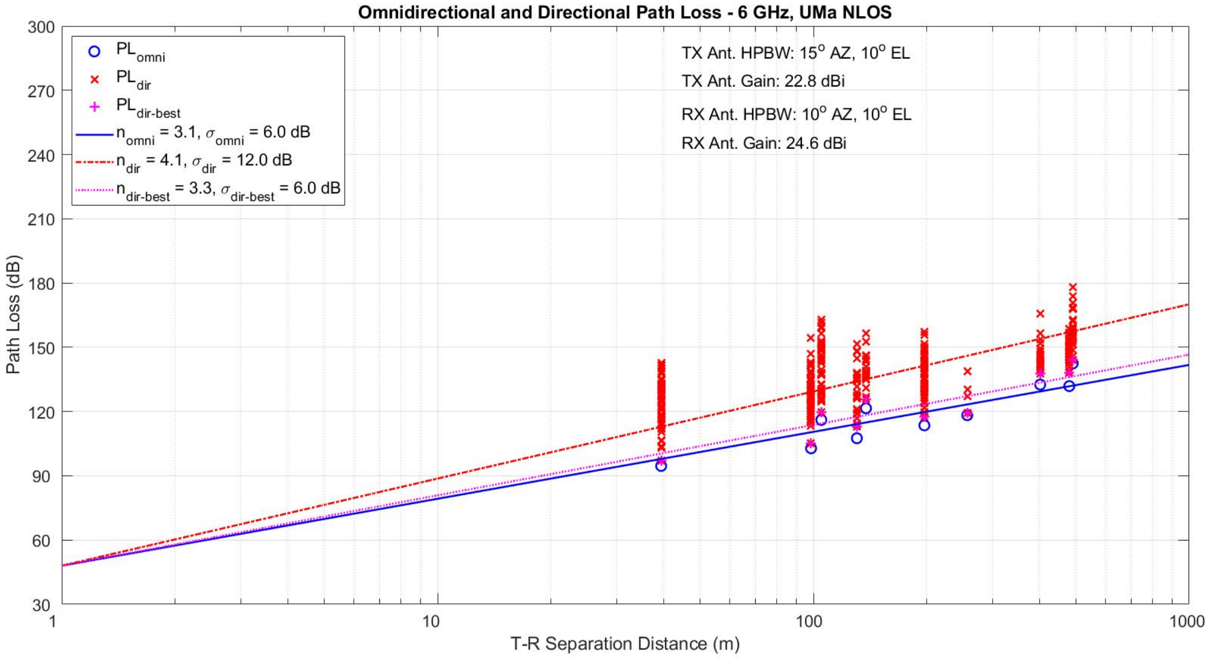


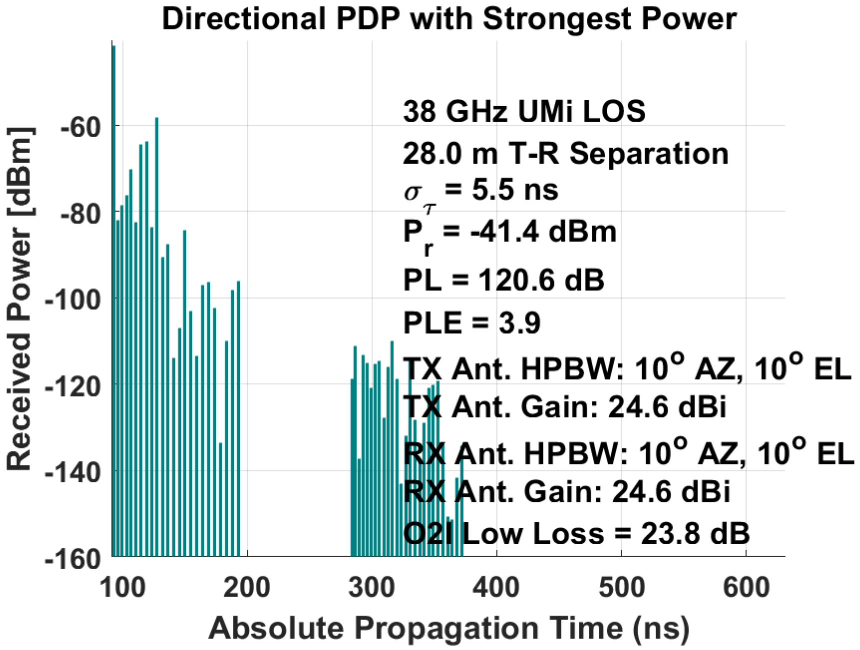
Figure 4.3: UMa NLoS Omnidirectional and Directional Path Loss for 6 GHz.

4.2.2. 38 and 73.5 GHz mmWave for Dense Urban Microcell Environment

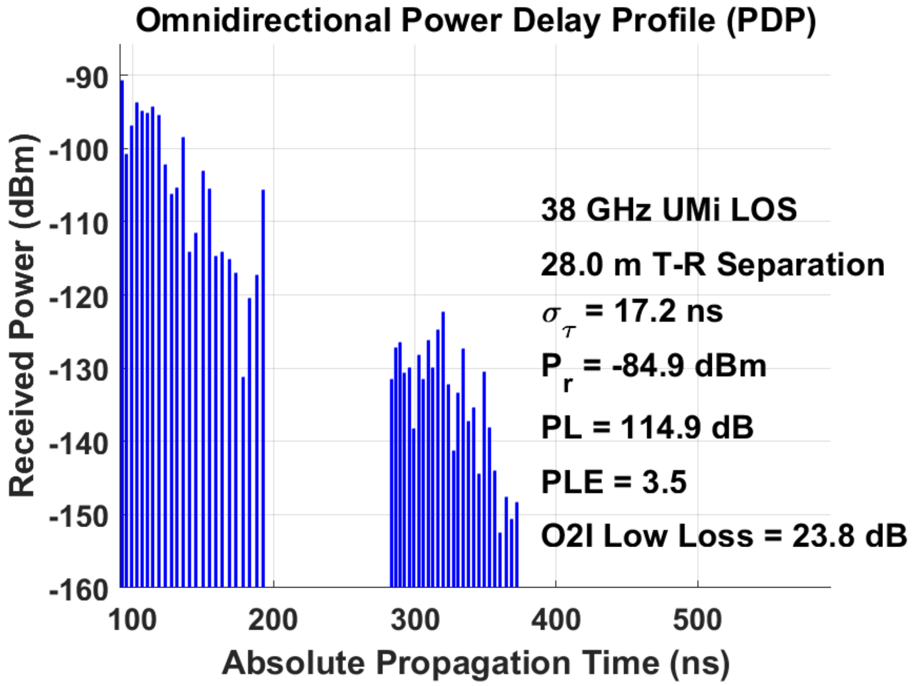
This section will analyze the simulation we have simulated for an indoor dense UMi environment with many populations and obstacles. There are many differences between the previous LoS/NLoS UMa environment, and these include the BS height where we have reduced to 10 m; also, the distance between the Tx and Rx is now 10-150 while previously it was 10-500 m. In addition to that, there will be no consideration for foliage since the indoor environment rarely includes trees. The channel bandwidth is the same as for the previous condition.

I. 38 GHz mmWave for UMi Conditions

First, when we look at the results of the 38GHz frequency band. The results show that the mmWave frequencies can play a significant position in the developments of 5G. Figure 4.4 (a) and (b) show the UMi LoS environment directional and omnidirectional PDPs for the 38 GHz mmWave band. Since the environment is indoors, the directional PDP for PLE is 3.9 for 28 m Tx-Rx separation with a delay spread of 5.5 ns. We also see that the received power of this Rx is -41.4 dBm, and the Path Loss (PL) for this Rx is 120.6 dB.



(a)



(b)

Figure 4.4 (a) and (b): UMi LoS Directional and Omnidirectional PDPs for 38 GHz.

In this situation, we have also added the channel properties for the Outdoor-to-Indoor (O2I) penetration loss with low loss, and the O2I low loss is 23.8 dB.

On the other hand, figure 4.5 shows the 38 GHz mmWave band UMi LoS omnidirectional and directional path losses for the ten random Tx and Rx combinations. The results show that the average directional and best directional PLE (η) are 4.0 and 3.0, respectively. And the omnidirectional PLE is 2.8. Another factor that we see in this figure is the shadow fading (σ_{SF}) for both the directional and omnidirectional settings. The omnidirectional σ_{SF} is 7.2 dB, while the directional and the best directional σ_{SF} are 14.0 and 9.4 dB, respectively. In addition to this, we see that path loss increases linearly with the distance between the Tx and Rx.

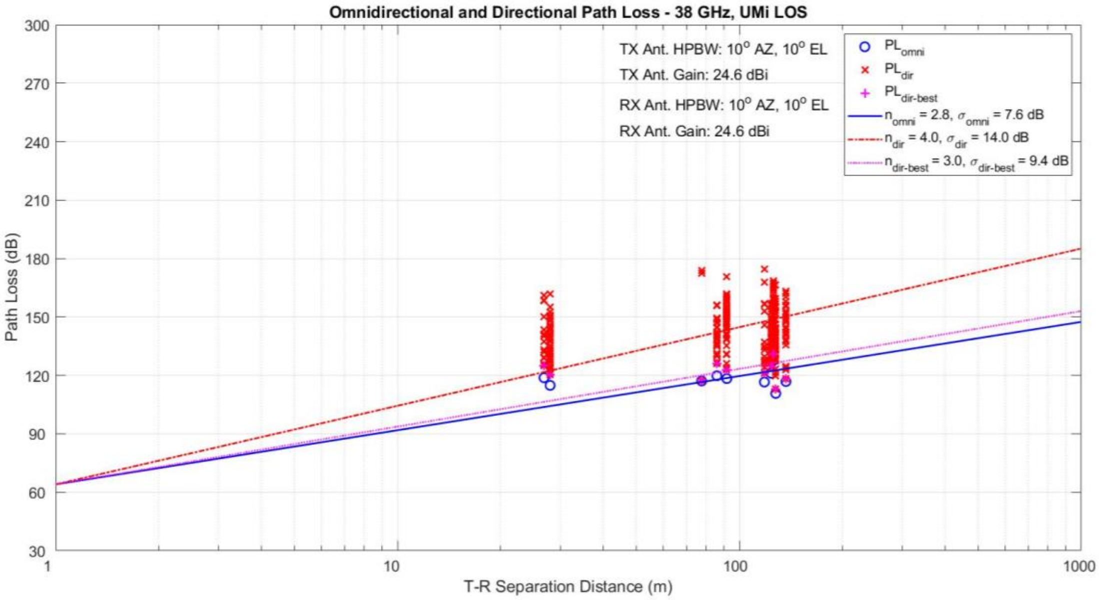


Figure 4.5: UMi LoS Omnidirectional/Directional Path-Loss for 38 GHz.

For the UMi NLoS condition in figure 4.6, the results are different from the previous LoS. We have average directional and best directional PLE (η) of about 5.4 and 4.6, respectively And omnidirectional PLE of about 4.4. The omnidirectional σ_{SF} for the NLoS is now about 8.1 dB, while the directional and the best directional σ_{SF} values are 15.1 and 7.9 dB, respectively.

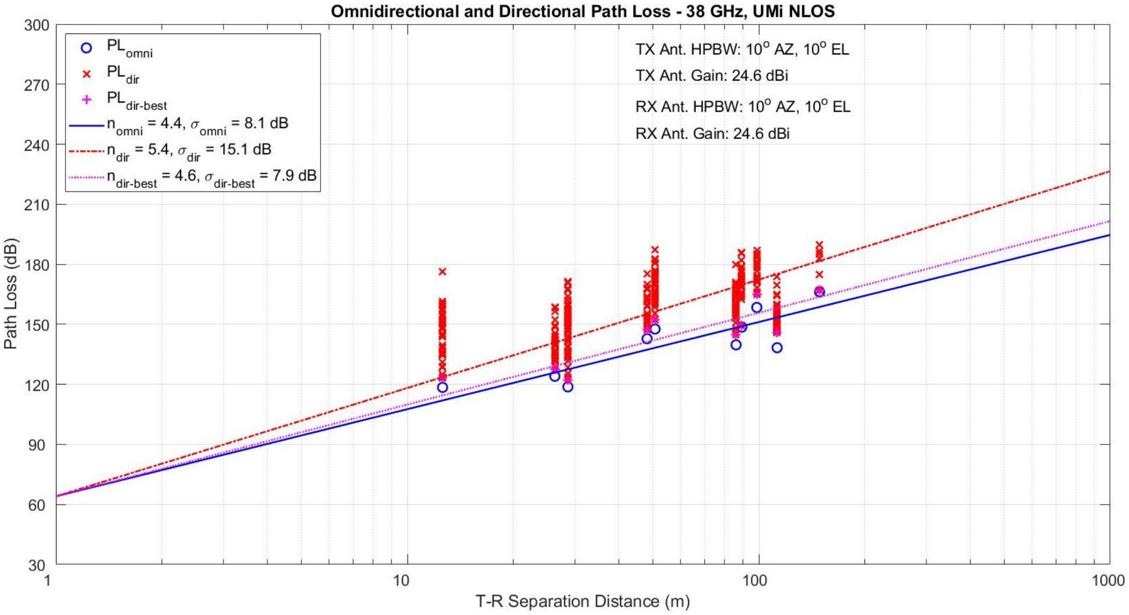
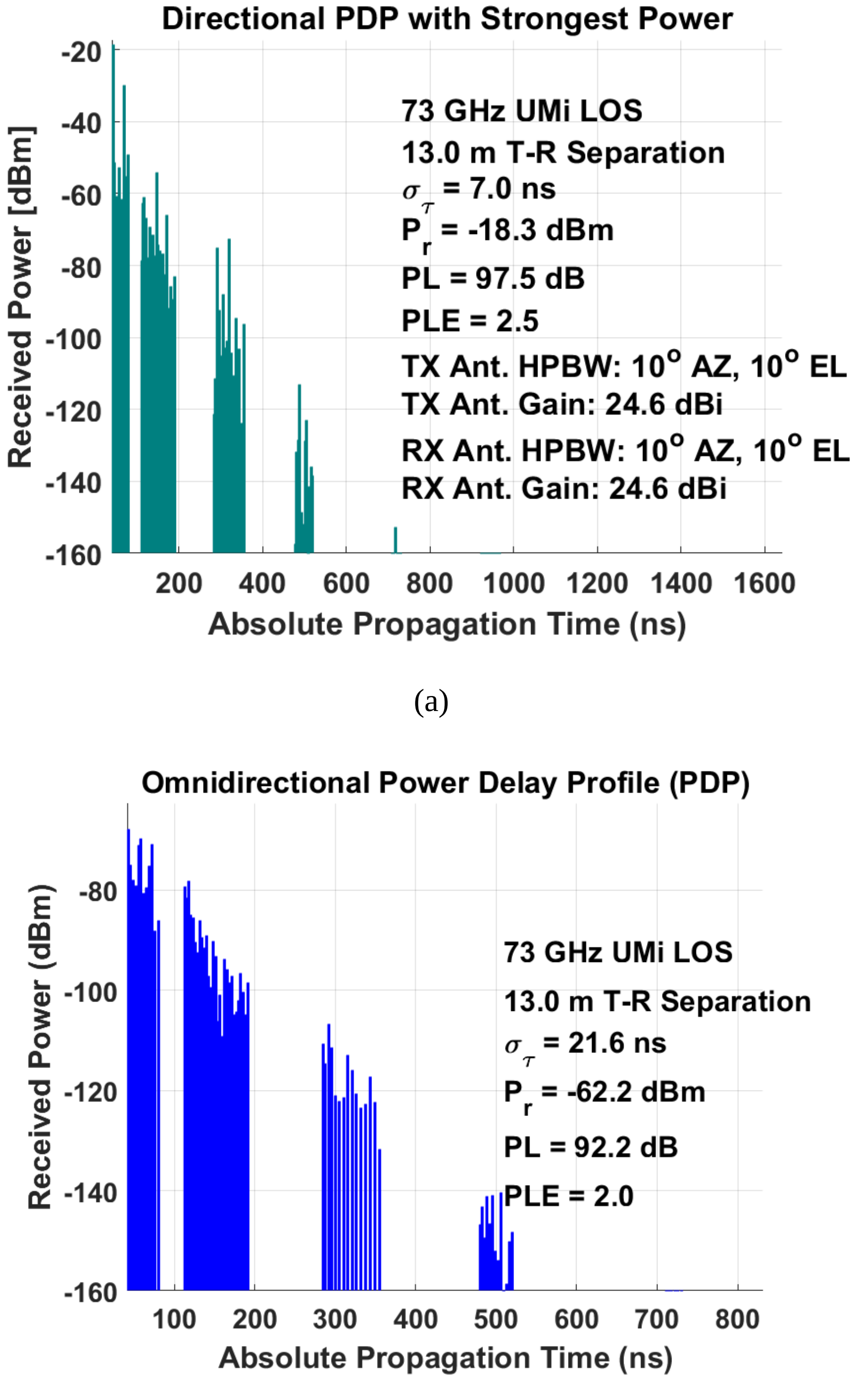


Figure 4.6: UMi NLoS Omnidirectional/Directional Path-Loss for 38 GHz.

II. 73 GHz mmWave for UMi Conditions

Since 73 GHz band has attracted industries and researchers worldwide by providing greater multi-gigabits per second channel characteristics. This frequency band is instrumental for 5G applications. Similar to previous results, the 73 GHz mmWave frequency band provided a greater signal strength and performance.

Figure 4.7 (a) and (b) show the UMi LoS directional and omnidirectional PDPs for this band. The received power for directional PDP at Rx distance of 13 m is -18.3 dBm, while the omnidirectional PDP at the same Rx distance is -62.2 dBm. For the PL, the 13.0 m Rx gives a value of 97.5 dB and 92.2 dB for the directional and omnidirectional, respectively. Moreover, Figure 4.8 displays the Directional and omnidirectional PLs and other parameters from the ten Rx locations we have simulated. Similar to previous results, both the directional and omnidirectional PLs increase as the distance between the Tx and Rx increases. The normal directional path loss exponent (η) is 3.4, but for the omnidirectional, the Pathe Loss Exponent (PLE) is 2.3, and the shadow fading (SF) is 2.9 dB. Lastly, the best directional PLE (η) and σ_{SF} are 2.5 and 3.4, respectively.



(a)

(b)

Figure 4.7 (a) and (b): UMi LoS Directional and Omnidirectional PDPs for 73 GHz.

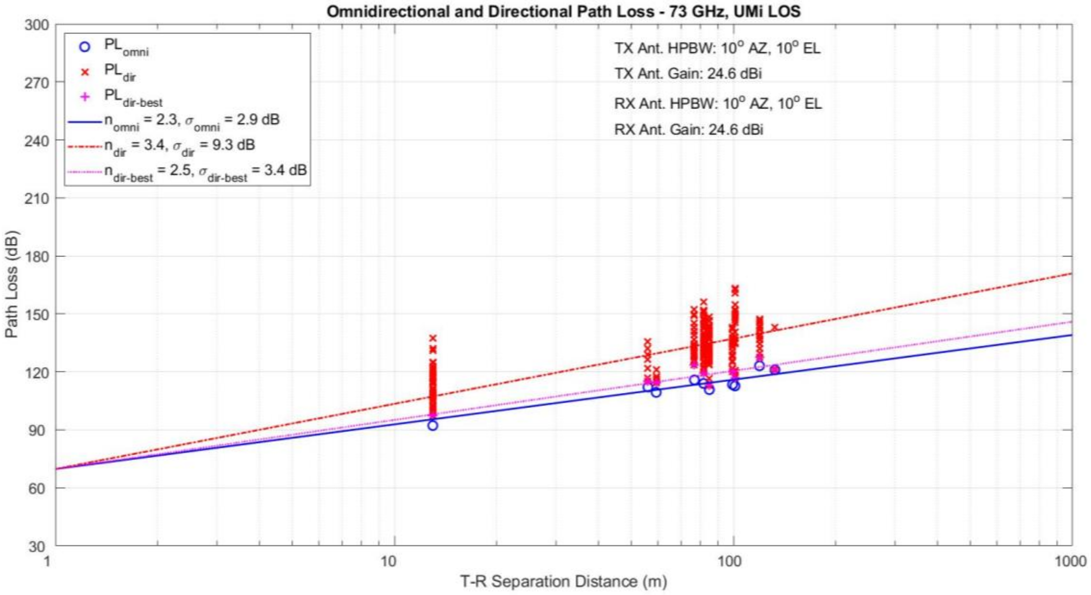


Figure 4.8: UMi LoS Omnidirectional/Directional Path-Loss for 73 GHz.

The last figure of our results shows the 73 GHz UMi NLoS condition. For this, our primary goal was to see the performance of the 73 GHz mmWave band in an indoor condition where the signal meets with various reflectors, dispersions, blockages or obstacles. We have simulated 10 Rx locations. The results we have can match the 5th generation of mobile networks where we need to have enhanced Mobile Broadbands (eMBBs), Ultra- Reliable Low-Latency Communications (URLLC) and many other specifications.

In summary, figure 4.9 displays the results we have obtained. The NLoS received signals for this band aren't the same as those for the LoS condition. Due to the multipath problems, ee see an increase in path losses, shadow fading, and the PLE (η) for both directional and omnidirectional compared to those of the LoS condition. We have average directional and best directional PLE (η) of about 5.5 and 4.7, respectively And omnidirectional PLE of about 4.5. The omnidirectional σ_{SF} for the NLoS is now about 8.0 dB, while the directional and the best directional σ_{SF} values are 12.2 and 8.7 dB, respectively.

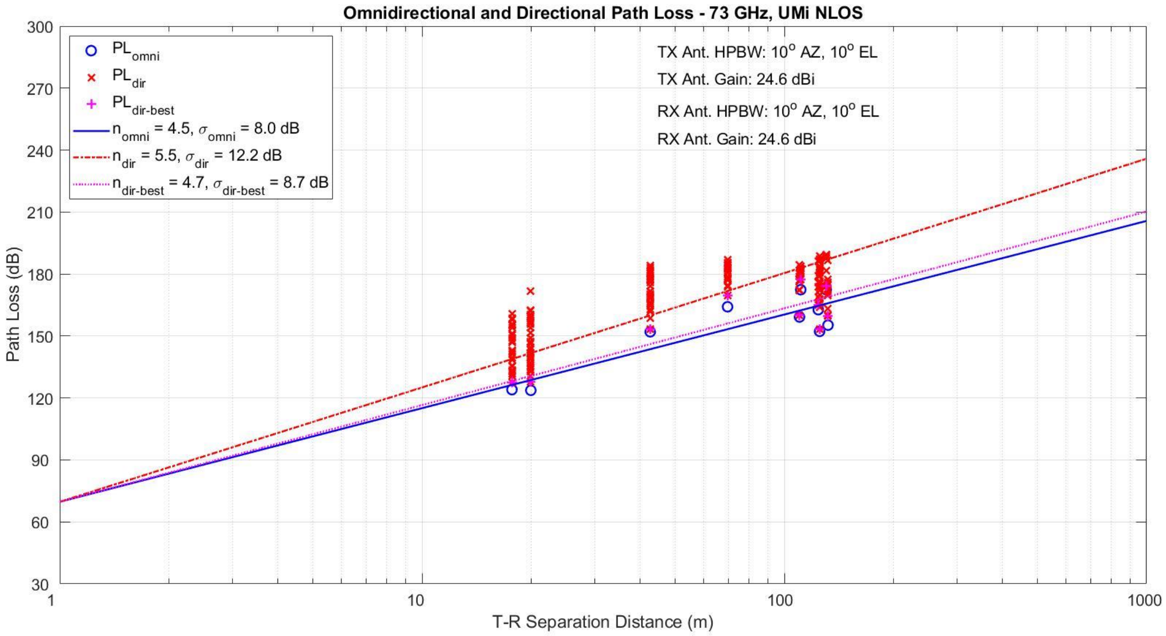


Figure 4.9: UMi NLoS Omnidirectional/Directional Path-Loss for 73 GHz.

4.3 Summary of our results.

In this study, we have simulated and analyzed three different frequencies in the mmWave range. Various parameters which play a significant role in wireless communication channels have been investigated to achieve our main objectives, including Path Loss (PL), Received Power (P_r) Path Loss Exponent (η), and Shadow Fading (σ_{SF}) for directional and omnidirectional Power Delay Profiles (PDPs). The simulations have shown that omnidirectional PDPs have low path loss and path loss exponent than directional PDPs. On the other hand, The directional PDPs have provided more excellent results for the received power at the Rx location.

Finally, the mmWave frequency bands 6, 38 and 73 GHz are capable of providing the requirements for 5G by overcoming problems faced by wireless channels. The results show that mmWave bands perform better for the shorter distances, as the space between the transmitting base station and the receiving mobile station become far, the performance of the channel degrades dramatically, meaning that there is a greater need for many base stations to cover a wide range of areas.

CHAPTER 5

CONCLUSIONS AND FUTURE WORK

5.1 Conclusion

The mmWave frequency ranges have been identified as crucial enablers for the fulfilment of IoT in the 5G era.

This thesis examined the propagation properties of mm-wave, emphasized the variations between mm-Waves and conventional mobile technology in perspective of increased rainfall and atmospheric attenuation, and increased susceptibility to obstruction. The work toward mm-Wave channel estimation was addressed, as well as some established channels models. Additionally, we discussed the specifics of the channels concept that was examined for urbanized crowded settings.

The findings of this research indicate that mm-wave is capable of being utilized in 5G Mobile communication outdoors systems after eliminating certain transmission difficulties associated with enormous interconnectivity in congested metropolitan settings. We have carried extensive millimeter-wave measurements at 38, 78 and 6, GHz carrier-frequencies inUrban Microcells (UMi) and Urban Macrocells (UMa) environments.

Each frequency carrier has provided a tremendous result for its application. The channel path loss, received power and path loss exponents have been simulated and analyzed. The 6 GHz frequency band can be used in outdoor environments, while the 38 GHz and 73 GHz carries can be used in indoor environments.

Nevertheless, the path loss within NLOS scenario under directional propagation is more than the path loss in the omnidirectional scenario and rises quickly as the range between the BS and the MS is increased. The large-scale properties of the investigated mmWave frequencies indicate that they have excellent capability for use in densely populated areas. In certain situations, high-gain directional antennas using MIMO systems are the best solution for overcoming significant path loss problems.

In summary, the large scale features for these investigated mm-wave frequencies indicate that they offer significant opportunity to be used in congested metropolitan areas. In certain situations, high-gain directional antennas using MIMO Systems is regarded being one best solution for overcoming significant route losses problems.

5.2 Future Work

Additionally, the future study will examine other mm-Wave transmission situations, like outdoor-to-indoor(O2I) and penetrating to structures, that provide additional difficulties for mm-wave implementation in 5G and even future cellular connections.

Additionally, we will investigate and suggest practical beam forming methods for reducing directional propagation characteristics at mm-Wave frequency ranges using large array-antennas. This necessitates the consideration of time efficient beams strength and conditioning methods for channels condition determination at mm-Waves using smaller beam having strong directional cues.

Throughout such respect, the upcoming research would concentrate upon incorporating novel channels analysis techniques into hybrids beam forming architectures like a viable paradigm for upcoming mm-Wave cellular networks.

REFERENCES

Abdulrasool, A. S., Aziz, J. S., & Abou-Loukh, S. J. (2017). Calculation Algorithm for Diffraction Losses of Multiple Obstacles Based on Epstein–Peterson Approach. International Journal of Antennas and Propagation, 2017, 1–9. https://doi.org/10.1155/2017/3932487

Ahad, A., Tahir, M., Aman Sheikh, M., Ahmed, K. I., Mughees, A., & Numani, A. (2020). Technologies Trend towards 5G Network for Smart Health-Care Using IoT: A Review. Sensors, 20(14), 4047. https://doi.org/10.3390/s20144047

Akpakwu, G. A., Silva, B. J., Hancke, G. P., & Abu-Mahfouz, A. M. (2018). A Survey on 5G Networks for the Internet of Things: Communication Technologies and Challenges. IEEE Access, 6, 3619–3647. https://doi.org/10.1109/ACCESS.2017.2779844

Alfaresi, B., Nawawi, Z., Malik, R. F., & Anwar, K. (2019). 5G Channel Model for 28 GHz frequency in Palembang. Journal of Physics, 10. https://doi.org/10.1088/1742-6596/1500/1/012001

Alfaresi, B., Nawawi, Z., Malik, R. F., Anwar, K., & Nur, L. O. (2020). HUMIDITY EFFECT TO 5G PERFORMANCES UNDER PALEMBANG CHANNEL MODEL AT 28 GHZ. SINERGI, 24(1), 49. https://doi.org/doi.org/10.22441/sinergi.2020.1.006

Alsharif, M. H. (2016). Evolution towards fifth generation (5G) wireless networks: Current trends and challenges in the deployment of millimetre wave, massive MIMO, and small cells. Wireless Networks, 21. https://doi.org/DOI 10.1007/s11235-016-0195-x

Atarashi, H., Abeta, S., Sawahashi, M., & Yokosuka-shi, H. (2001). Broadband Packet Wire ess Access Appropriate for High-speed and Hig 1-capacity Throughput. IEEE, 5. https://doi.org/10.1109/VETECS.2001.944906

Barakabitze, A. A., Ahmad, A., Mijumbi, R., & Hines, A. (2020). 5G network slicing using SDN and NFV: A survey of taxonomy, architectures and future challenges. Computer Networks, 167, 106984. https://doi.org/10.1016/j.comnet.2019.106984

Benzi, F., Anglani, N., Bassi, E., & Frosini, L. (2011). Electricity Smart Meters Interfacing the Households. IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, 58(10), 8. https://doi.org/10.1109/TIE.2011.2107713

Carton, I., Wei Fan, Kyosti, P., & Pedersen, G. F. (2016). Validation of 5G METIS map-based channel model at mmwave bands in indoor scenarios. 2016 10th European Conference on Antennas and Propagation (EuCAP), 1–5. https://doi.org/10.1109/EuCAP.2016.7481518

Chekired, D. A., Togou, M. A., Khoukhi, L., & Ksentini, A. (2019). 5G-Slicing-Enabled Scalable SDN Core Network: Toward an Ultra-Low Latency of Autonomous Driving Service. IEEE Journal on Selected Areas in Communications, 37(8), 1769–1782. https://doi.org/10.1109/JSAC.2019.2927065

Ding, J., Nemati, M., Ranaweera, C., & Choi, J. (2020). IoT Connectivity Technologies and Applications: A Survey. IEEE Access, 8, 67646–67673. https://doi.org/10.1109/ACCESS.2020.2985932

Fadlullah, Z. M., Fouda, M. M., Kato, N., Takeuchi, A., Iwasaki, N., & Nozaki, Y. (2011). Toward intelligent machine-to-machine communications in smart grid. IEEE Communications Magazine, 49(4), 60–65. https://doi.org/10.1109/MCOM.2011.5741147

Goudos, S. K., Dallas, P. I., Chatziefthymiou, S., & Kyriazakos, S. (2017). A Survey of IoT Key Enabling and Future Technologies: 5G, Mobile IoT, Sematic Web and Applications. Wireless Personal Communications, 97(2), 1645–1675. https://doi.org/10.1007/s11277-017-4647-8

Gupta, A., & Jha, R. K. (2015). A Survey of 5G Network: Architecture and Emerging Technologies. IEEE Access, 3, 1206–1232. https://doi.org/10.1109/ACCESS.2015.2461602

Hao Xu, Kukshya, V., & Rappaport, T. S. (2002). Spatial and temporal characteristics of 60-GHz indoor channels. IEEE Journal on Selected Areas in Communications, 20(3), 620–630. https://doi.org/10.1109/49.995521

Hasan, R., Mowla, M., & Hoque, N. (2020). Performance Estimation of Massive MIMO Drop- based Propagation Channel Model for mmWave Communication. 2020 IEEE Region 10 Symposium (TENSYMP),. https://doi.org/10.1109/TENSYMP50017.2020.9230462

Hemadeh, I. A., Satyanarayana, K., El-Hajjar, M., & Hanzo, L. (2018). Millimeter-Wave Communications: Physical Channel Models, Design Considerations, Antenna Constructions, and Link-Budget. IEEE Communications Surveys & Tutorials, 20(2), 870–913. https://doi.org/10.1109/COMST.2017.2783541

ITU. (2015). Technical feasibility of IMT in bands above 6GHz. ITU-R, 134. https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2376-2015-PDF-E.pdf

Jaeckel, S., Raschkowski, L., Borner, K., & Thiele, L. (2014). QuaDRiGa: A 3-D Multi-Cell Channel Model With Time Evolution for Enabling Virtual Field Trials. IEEE Transactions on Antennas and Propagation, 62(6), 3242–3256. https://doi.org/10.1109/TAP.2014.2310220

Janaswamy, R. (2006). An Indoor Pathloss Model at 60 GHz Based on Transport Theory. IEEE Antennas and Wireless Propagation Letters, 5, 58–60. https://doi.org/10.1109/LAWP.2006.870361

Ju, S., Kanhere, O., Xing, Y., & Rappaport, T. S. (2019). A Millimeter-Wave Channel Simulator NYUSIM with Spatial Consistency and Human Blockage. ArXiv:1908.09762 [Cs, Eess, Math]. http://arxiv.org/abs/1908.09762

Khanna, A., & Kaur, S. (2020). Internet of Things (IoT), Applications and Challenges: A Comprehensive Review. Wireless Personal Communications, 114(2), 1687–1762. https://doi.org/10.1007/s11277-020-07446-4

Liu, L., Oestges, C., Poutanen, J., Haneda, K., Vainikainen, P., Quitin, F., Tufvesson, F., & Doncker, P. (2012). The COST 2100 MIMO channel model. IEEE Wireless Communications, 19(6), 92–99. https://doi.org/10.1109/MWC.2012.6393523

Lota, J., Sun, S., Rappaport, T. S., & Demosthenous, A. (2017). 5G Uniform Linear Arrays With Beamforming and Spatial Multiplexing at 28, 37, 64, and 71 GHz for Outdoor

Urban Communication: A Two-Level Approach. IEEE Transactions on Vehicular Technology, 66(11), 9972–9985. https://doi.org/10.1109/TVT.2017.2741260

Magsi, H., Chachar, F. A., Sodhro, G. H., Sodhro, A. H., Abro, S. A. K., & Pirbhulal, S. (2018). Evolution of 5G in Internet of Medical Things. IEEE, 7. https://doi.org/10.1109/ICOMET.2018.8346428

Mantoro, T., Ayu, M. A., & Nugroho, M. R. (2017). NLOS and LOS of the 28 GHz bands millimeter-wave in 5G cellular networks. 2017 International Conference on Computing, Engineering, and Design (ICCED), 1–5. https://doi.org/10.1109/CED.2017.8308131

Marcus, M., & Pattan, B. (2005). Millimeter wave propagation: Spectrum management implications. IEEE Microwave Magazine, 6(2), 54–62. https://doi.org/10.1109/MMW.2005.1491267

Mou, M. A., Mowla, M. M., & Dutty, H. B. H. (2019). Statistical mmWave Channel Modeling and Characterization in Indoor Airport Environments. 2019 22nd International Conference on Computer and Information Technology (ICCIT), 1–5. https://doi.org/10.1109/ICCIT48885.2019.9038494

Niu, Y., Li, Y., Jin, D., Su, L., & Vasilakos, A. V. (2015). A survey of millimeter wave communications (mmWave) for 5G: Opportunities and challenges. Wireless Networks, 21(8), 2657–2676. https://doi.org/10.1007/s11276-015-0942-z

Nossire, Z., Gupta, N., Almazaydeh, L., & Xiong, X. (2018). New Empirical Path Loss Model for 28 GHz and 38 GHz Millimeter Wave in Indoor Urban under Various Conditions. Applied Sciences, 8(11), 2122. https://doi.org/10.3390/app8112122

Nourkhiz Mahjoub, H., Tahmasbi-Sarvestani, A., Osman Gani, S. M., & Fallah, Y. P. (2019). Composite $\alpha - \mu$ Based DSRC Channel Model Using Large Data Set of RSSI Measurements. IEEE Transactions on Intelligent Transportation Systems, 20(1), 205–217. https://doi.org/10.1109/TITS.2018.2803628

Onoe, S. (2016). 1.3 Evolution of 5G mobile technology toward 1 2020 and beyond. 2016 IEEE International Solid-State Circuits Conference (ISSCC), 23–28. https://doi.org/10.1109/ISSCC.2016.7417891

Pagin, M., Agostini, F., Zugno, T., Polese, M., & Zorzi, M. (2020). Enabling RAN Slicing Through Carrier Aggregation in mmWave Cellular Networks. 2020 Mediterranean Communication and Computer Networking Conference (MedComNet), 1–8. https://doi.org/10.1109/MedComNet49392.2020.9191462

Panwar, N., Sharma, S., & Singh, A. K. (2016). A survey on 5G: The next generation of mobile communication. Physical Communication, 18, 64–84. https://doi.org/10.1016/j.phycom.2015.10.006

Pi, Z., & Khan, F. (2011). An introduction to millimeter-wave mobile broadband systems. IEEE Communications Magazine, 49(6), 101–107. https://doi.org/10.1109/MCOM.2011.5783993

Rahim, H. M., Leow, C. Y., Rahman, T. A., Arsad, A., & Malek, M. A. (2017). Foliage attenuation measurement at millimeter wave frequencies in tropical vegetation. 2017 IEEE 13th Malaysia International Conference on Communications (MICC), 241–246. https://doi.org/10.1109/MICC.2017.8311766

Rappaport, T. S., & Brickhouse, R. A. (1999). A simulation of cellular system growth and its effect on urban in-building parasitic frequency reuse. IEEE Transactions on Vehicular Technology, 48(1), 286–294. https://doi.org/10.1109/25.740107

Rappaport, T. S., Xing, Y., MacCartney, G. R., Molisch, A. F., Mellios, E., & Zhang, J. (2017). Overview of Millimeter Wave Communications for Fifth-Generation (5G) Wireless Networks—With a Focus on Propagation Models. IEEE Transactions on Antennas and Propagation, 65(12), 6213–6230. https://doi.org/10.1109/TAP.2017.2734243

Rost, P., Mannweiler, C., Michalopoulos, D. S., Sartori, C., Sciancalepore, V., Sastry, N., Holland, O., Tayade, S., Han, B., Bega, D., Aziz, D., & Bakker, H. (2017). Network Slicing to Enable Scalability and Flexibility in 5G Mobile Networks. IEEE Communications Magazine, 55(5), 72–79. https://doi.org/10.1109/MCOM.2017.1600920

Ryan, J., MacCartney, G. R., & Rappaport, T. S. (2017). Indoor office wideband penetration loss measurements at 73 GHz. 2017 IEEE International Conference on Communications Workshops (ICC Workshops), 228–233. https://doi.org/10.1109/ICCW.2017.7962662

Shahid, A., Khalid, B., Shaukat, S., Ali, H., & Qadri, M. Y. (2018). Internet of Things Shaping Smart Cities: A Survey. Internet of Things and Big Data Analytics Toward Next-Generation Intelligence, Studies in Big Data 30, 24. https://doi.org/10.1007/978-3-319-60435-0_14

Shurman, M., Taqieddin, E., Oudat, O., Al-Qurran, R., & Nounou, A. A. A. (2019). Performance Enhancement in 5G Cellular Networks Using Priorities in Network Slicing. 2019 IEEE Jordan International Joint Conference on Electrical Engineering and Information Technology (JEEIT), 822–826. https://doi.org/10.1109/JEEIT.2019.8717469

Siles, G. A., Riera, J. M., & Garcia-del-Pino, P. (2015). Atmospheric Attenuation in Wireless Communication Systems at Millimeter and THz Frequencies [Wireless Corner]. IEEE Antennas and Propagation Magazine, 57(1), 48–61. https://doi.org/10.1109/MAP.2015.2401796

Sun, S., Rappaport, T., Heath, R., Nix, A., & Rangan, S. (2014). Mimo for millimeter-wave wireless communications: Beamforming, spatial multiplexing, or both? IEEE Communications Magazine, 52(12), 110–121. https://doi.org/10.1109/MCOM.2014.6979962

Sun, S., Rappaport, T. S., Shafi, M., Tang, P., Zhang, J., & Smith, P. J. (2018). Propagation Models and Performance Evaluation for 5G Millimeter-Wave Bands. IEEE Transactions on Vehicular Technology, 67(9), 8422–8439. https://doi.org/10.1109/TVT.2018.2848208

Sun, S., Rappaport, T. S., Thomas, T. A., Ghosh, A., Nguyen, H. C., Kovacs, I. Z., Rodriguez, I., Koymen, O., & Partyka, A. (2016). Investigation of Prediction Accuracy, Sensitivity, and Parameter Stability of Large-Scale Propagation Path Loss Models for 5G Wireless Communications. ArXiv:1603.04404 [Cs, Math]. http://arxiv.org/abs/1603.04404

Uddin, H., Gibson, M., Safdar, G. A., Kalsoom, T., Ramzan, N., Ur-Rehman, M., & Imran, M. A. (2019). IoT for 5G/B5G Applications in Smart Homes, Smart Cities, Wearables and Connected Cars. 2019 IEEE 24th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD), 1–5. https://doi.org/10.1109/CAMAD.2019.8858455

Uwaechia, A. N., & Mahyuddin, N. M. (2020). A Comprehensive Survey on Millimeter Wave Communications for Fifth-Generation Wireless Networks: Feasibility and Challenges. IEEE Access, 8, 62367–62414. https://doi.org/10.1109/ACCESS.2020.2984204

Weiler, R. J., Peter, M., Keusgen, W., Maltsev, A., Karls, I., Pudeyev, A., Bolotin, I., Siaud, I., & Ulmer-Moll, A.-M. (2016). Quasi-deterministic millimeter-wave channel models in MiWEBA. EURASIP Journal on Wireless Communications and Networking, 2016(1), 84. https://doi.org/10.1186/s13638-016-0568-6

Zhang, M., Sun, F., & Cheng, X. (2012). Architecture of Internet of Things and Its Key Technology Integration Based-On RFID. 2012 Fifth International Symposium on Computational Intelligence and Design, 294–297. https://doi.org/10.1109/ISCID.2012.81

Zhao, H., Mayzus, R., Sun, S., Samimi, M., Schulz, J. K., Azar, Y., Wang, K., Wong, G. N., Gutierrez, F., & Rappaport, T. S. (2013). 28 GHz millimeter wave cellular communication measurements for reflection and penetration loss in and around buildings in New York city. 2013 IEEE International Conference on Communications (ICC), 5163–5167. https://doi.org/10.1109/ICC.2013.6655403