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Analysis of Outdoor to Indoor Penetration Loss at 28 and 38 GHz Channels

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Résumé : La cinquième génération (5G) de réseau cellulaire, connue sous le nom de 5G, fonctionne à des fréquences d'onde millimétrique (mmWave) et introduit des avancées significatives dans la communication cellulaire mobile. L'une des bandes de fréquences prédominantes pour la communication mmWave en 5G est la bande des 28 GHz. La ligne de visée (LOS) joue un rôle crucial dans diverses transmissions radio car elle représente un chemin direct entre l'émetteur et le récepteur radio. Cette étude vise à examiner les caractéristiques des bandes de 28 et 38 GHz dans un environnement LOS. Plus précisément, elle étudie le nombre d'éléments d'antenne requis pour le scénario de microcellule urbaine dans la ville d'El-Oued, en Algérie. De plus, cette recherche analyse les performances de propagation radio en termes de délais de transmission (Racine Carrée Moyenne - RMS), d'atténuation du signal, de puissance reçue, d'angle de départ (AoD) et d'angle d'arrivée (AoA) tant en azimut qu'en élévation.

Mots-clés: propagation de l’exterieur vers l’interieur, mmWave, path loss, MIMO, Channal Modal.

ملخص :

يحقق الجيل الخامس (G5) من الشبكة الخلوية، المعروف باسم G5، تطورات كبيرة في الاتصالات الخلوية المتنقلة من خلال التشغيل عند ترددات الموجات المليمترية (mmWave). في عالم اتصالات mmWave، أحد نطاقات التردد البارزة في G5 هو النطاق 28 جيجاهرتز. في هذه الدراسة، نهدف إلى استكشاف خصائص النطاقين 28 و38 جيجاهرتز ضمن بيئة خط البصر (LOS). يعد LOS أمرًا بالغ الأهمية لعمليات الإرسال الراديوية المختلفة لأنه يمثل مسارًا مباشرًا بين جهاز الإرسال والاستقبال الراديوي. يركز بحثنا بشكل أساسي على سيناريو الخلايا الصغيرة الحضرية في الواد بالجزائر، وتحديداً في التحقق من عدد عناصر الهوائي المطلوبة لتحقيق الأداء الأمثل. علاوة على ذلك، نقوم بتحليل أداء الانتشار الراديوي من خلال فحص التأخيرات الزمنية (مربع متوسط الجذر - RMS)، وتوهين الإشارة، والقدرة المستقبلة، وزاوية المغادرة (AoD)، وزاوية الوصول (AoA) في كل من أبعاد السمت والارتفاع.

الكلمات المفتاحية: انتشار خارجي إلى داخلي، الموجة الميليمترية، خسارة المسير، MIMO، نموذج القناة.

Abstract:

The fifth generation (5G) of cellular network, known as 5G, brings significant advancements to mobile cellular communication by operating at millimeter wave frequencies (mmWave). In the realm of mmWave communication, one of the prominent frequency bands in 5G is the 28 GHz band. In this study, we aim to explore the characteristics of the 28 and 38 GHz bands within a

Line of Sight (LOS) environment. LOS is crucial for various radio transmissions as it represents a direct path between the radio transmitter and receiver. Our research primarily focuses on the Urban microcell scenario in El-Oued, Algeria, specifically investigating the number of antenna elements required for optimal performance. Furthermore, we analysed the radio propagation performance by examining time delays (Root Mean Square – RMS), signal attenuation, received power, angle of departure (AoD), and angle of arrival (AoA) in both azimuth and elevation dimensions.

Keywords: outdoor-to-indoor propagation, mmWave, path loss, MIMO, Channal Modal.

List of Acronym

1G	First Generation
2G	Second generation
3G	Third Generation
4G	Fourth Generation
5G	Fifth Generation
IoT	Internet of Things
FDMA	Frequency Division Multiple Access
TDMA	Time Division Multiple Access
OFDM	Orthogonal Frequency Division Multiplexing
CDMA	Code Division Multiple Access
3GPP	3rdGeneration Partnership Project
NGMN	Next Generation Mobile Networks
Mmtc	Massive Machine Type Communications
uRLLC	Ultra-Reliable Low-Latency Communication
ITU	Union Internationale des Télécommunications
ITU-R	International Telecommunications Union Radiocommunication
IMT	International Mobile Telecommunications
eMBB	Enhanced Mobile Broadband
RAN	Radio Access Network
IdO	Internet des Objets
TDD	Time Division Duplexing
FDD	Frequency Division Duplexing
MIMO	Multiple Input Multiple Output
MU-MIMO	Multi-User MIMO
SNR	Signal-to-Noise Ratio
SISO	Single Input Single Output
SIMO	Single Input Multiple Output.
MISO	Multiple Input Single Output
SU-MIMO	Single User MIMO
AWGN	Additive White Gaussian Noise

BS	Base Station
RF	Radio Frequency
Wi-Fi	Wireless Fidelity
mm Wave	Ondes Millimétriques
FCC	Fédéral Communications Commission
FSPL	Free-Space Path Loss
UHDV	Ultra-High Définition Vidéo
HDTV	High-Definition Television
LMDS	Local Multipoint Distribution Service
TNT	Télévision Numérique Terrestre
SEE	Société de l'Electricité, de l'Electronique
LOS	Line Of Sight
NLOS	Non-Line of Sight
LAN	Local Area Network
ISI	Inter Symbol Interference
PDP	Power Delay Profile
AoA	Angle of Arrival
AoD	Angle of Departure
UMi	Urban Micro Cell
UMa	Urban Macro Cell
RMa	Rural Macro Cell
RMS	Root-Mean-Square
UE	User Equipment
CSI	Channel State Information
SSCM	Statistical Spatial Channel Mode
HPBW	Half Power Beamwidth
URA	Uniform Rectangular Array
ULA	Uniform Linear Array
CIR	Channel Impulse Response
PLE	Path Loss Exponent
PL	Path Loss
P_r	Power received
Hz	Hertz
KHz	Kilo Hertz

MHz	Mega Hertz
GHz	Giga-Hertz
mm	Millimeter
cm	Centimeter
m	Meter
mbar	Millibar
dB	Decibel

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General Introduction

General Introduction

Wireless communication has undergone significant advancements in recent years, driven by the ever-increasing demand for faster, more reliable, and efficient connectivity. One of the most notable breakthroughs in this field is the emergence of 5G technology, which promises to revolutionize how we communicate and interact with the digital world. At the same time, the proliferation of wireless devices and the need for seamless connectivity indoors have presented unique challenges that need to be addressed.

In this master thesis, we explore a specific aspect of wireless communication: the analysis of outdoor-to-indoor penetration loss at the 28 GHz and 38 GHz frequency channels. The focus on these higher frequency bands is particularly relevant as they offer significant bandwidth for data transmission, but are also susceptible to increased attenuation and signal degradation when propagating through various indoor environments.

The research is grounded in three key chapters, each covering crucial aspects of the topic. In Chapter 1, we lay the foundation by discussing the fundamentals of 5G technology and pathloss models. We examine the transformative potential of 5G networks, such as their ability to deliver ultra-fast data rates, ultra-low latency, and massive device connectivity. Additionally, we delve into pathloss models, which play a vital role in understanding how wireless signals attenuate and lose power as they traverse through different environments.

Chapter 2 introduces the concept of Massive MIMO (Multiple-Input Multiple-Output), a revolutionary antenna technology that holds great promise for improving wireless communication systems. We explore the principles behind Massive MIMO and its ability to provide significant gains in capacity, spectral efficiency, and coverage. This chapter focuses on how Massive MIMO can potentially address the challenges of penetration loss encountered at higher frequency bands like 28 GHz and 38 GHz.

The third and final chapter is dedicated to simulation and results. He have to use a free software tool named NYUSIM with a state-of-the-art simulation tool used in the literature, to analyse the outdoor-to-indoor penetration loss at the targeted frequency channels. We describe the simulation methodology, including the setup, parameters, and considerations involved. Furthermore, we present and interpret the results, examining the influence of factors such as building, antenna heights, and frequency bands on the penetration loss phenomenon.

Finally with a conclusion we end this work.

Chapter I:

Introductions to 5G

I.1 Introduction

5G technology, the fifth generation of cellular network, has revolutionized the world of telecommunications with its unprecedented capabilities and potential. It represents a significant leap forward in mobile communication, promising faster speeds, lower latency, and massive connectivity. With 5G, we are entering an era where technology is set to reshape industries, drive innovation, and unlock new possibilities. The key distinguishing features of 5G lie in its ability to operate at higher frequencies, such as millimeter wave (mmWave), enabling the transmission of large volumes of data at lightning-fast speeds. This technology holds immense promise for various sectors, including healthcare, transportation, manufacturing, and entertainment, among others. The ultra-low latency of 5G opens doors for real-time applications like autonomous vehicles, remote surgeries, and immersive augmented reality experiences.

In this chapter, we explore millimetre wave characteristic and propagation models used by various researchers.

I.2 Some characteristic introductions of 5g

I.2.1 Introduction of milliwave (millimeter wave)

Millimeter wave refers to the lower portion of the wave that can avoid interference from other factors, but its disadvantage is that its propagation distance is less than 50 km. Millimeter wave has a wide range of applications in the civilian and military sectors due to its advantages of high communication capacity, narrow beamwidth, high resolution, high resistance to interference, high security, low weight, and ease of transport and assembly.

In the military, it is mainly applied to space and maritime navigation, locating, detecting and tracking research objects, monitoring, navigation, weather radar, metrology, and surveying and mapping in the public. Scientific applications include astronomy, cartography, image processing, precision distance measurement, and remote sensing of natural resources [1].

To meet the demands of this population, 4G technology is quickly reaching its limits. Therefore, technologies are being explored to increase the available bandwidth. Millimeter wave (mm Wave) technology, which communicates in the 3 to 30 GHz frequency range, appears to be one promising technology. Millimeter wave communication technology has existed for some time.

A typical feature of millimeter wave is that the short wavelength and millimeter wave portions have considerable frequency resources, effectively solving the difficult problem of lack of frequency resources. The shorter millimeter wave wavelengths yield more available spatial dimensions, making the transfer antennas smaller, allowing smaller base stations to become one group and allowing the emitter's low-frequency acer stations to achieve seamless access. Multi-antenna operating at millimeter wave is a highly directional characteristic of narrow beams and solves the problems of channel interference and low security. Millimeter wave is therefore the best choice for 5g systems [1].

I.2.2 MIMO

MIMO (Multiple input multiple output), means there is a quantity of transmitting and receiving antennas at the transmitter and receiver, can send and receive signals through multiple antennas at the transmitter and receiver end to improve communication quality. By fully utilizing spatial resources and multiplying multiple antennas, the capacity of the system channel can be increased without increasing frequency resources or the transmission power of the antennas, showing obvious advantages and is regarded as a core technology for the next generation of mobile communications.

MIMO technology has an important place in the history of telecommunications development because advanced signal processing effectively overcomes problems such as the absorption and attenuation effects of millimeter waves by the atmosphere and the shielding effects of terrain and ground surfaces [2].

I.2.2.1. Modulation

Figure II.1 shows the framework of a MIMO communication system that includes transmit antenna n and receive antenna m. The channel model of this framework is represented as follows :

$$y(t) = \int_{\tau}^{\tau} H(t,\tau)x(t-\tau)d\tau + n(t) \quad \text{(I. 1)}$$

X(t) is the vector of n1 dimension, which is the vector of the signal at the time of T, y(t) is the vector of M, which is a vector that receives the signal at the time t, H(t) is the matrix of mn. As illustrated in **Figure.1.1**

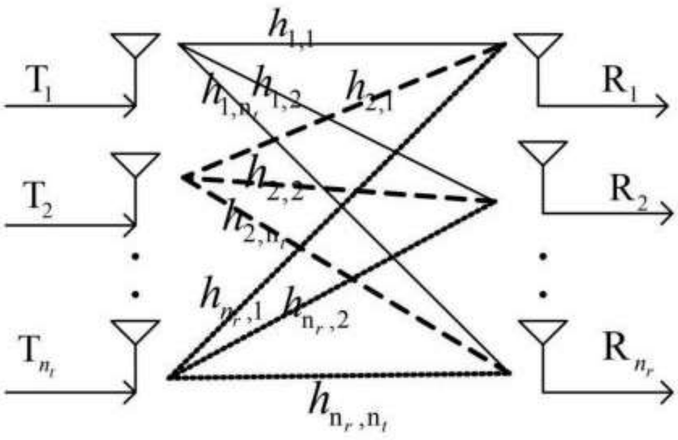

Figure.1.1. MIMO system [2]

I.2.2.2 Equalization

Inter-symbol interference occurs when the bandwidth of the modulated signal exceeds the coherence bandwidth of the channel. To reduce and counteract this effect, different types of equalization techniques are used in receivers [3].

For making the ISI part in the output reach the O, ZF will use a Linear Time Invariant Filter of an appropriate transfer function. If $F(f)$ is the channel frequency response, the zero forcing receiver C(f) can be expressed as :

I. 2 $$C(f) = \frac{1}{F(f)}$$

The frequency response is a linear equalization algorithm:

I. 3 $$y_1 = h_{1,1}x_1 + h_{1,2}x_2 + n_1 = \begin{bmatrix} h_{1,1} & h_{1,2} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_1$$

The second antenna will then receive the data:

I. 4 $$y_2 = h_{2,1}x_1 + h_{2,2}x_2 + n_2 = \begin{bmatrix} h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2$$

Y1 and Y2 are signals received by the first and second antennas, h1,1 is the channel from the first antenna to the first receiving antenna, h1,2 is the channel from the second antenna to the first receiving antenna, h2,1 is the channel from the first antenna to the second receiving X1, X2 are the transmit symbols. n1, n2 are the noise of the first and second receive antennas.

It can also be written in matrix notation:

I. 5 $$Y = Hx + n$$

Figure 1.2 shows the matrix for the expansion of h. ZF must satisfy the condition WH=1.

After the analysis we know the theory of MIMO and MIMO is a key technology for 5g. As illustrated in **Figure.1.2**

$$\mathbf{H} = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1n_t} \\ h_{21} & h_{22} & \cdots & h_{2n_t} \\ \vdots & \vdots & \ddots & \vdots \\ h_{n_r1} & h_{n_r2} & \cdots & h_{n_rn_t} \end{bmatrix}$$

Figure.1.2. matrix about the expand of h

I.2.3 large scale and small scale model

Fading mechanisms of wireless channels can be divided into large-scale and small-scale models; large-scale fading models are divided into path loss and shadow fading, while small-scale fading models are divided into multipath frequency selective fading, flat fading) and Doppler (fast fading and slow fading).

Generally large scale propagation models will have a large distance range changes between the transmitter and receiver signal amplitude phase changes, small changes in signal changes such as time domain and frequency domain airspace, mostly small scale models.

Large scales are typically within a few hundred thousand meters, with received signals decreasing with distance [4].

I.2.3.1 Large scale path loss model

In wireless communications, slow fading is the shadow fading caused by path loss due to distance and aging shelters. The most basic model is the free-space model, which is obtained by the principle of propagation of electromagnetic waves in free space.

If the transmitted power is pt and the emitting sources are surrounded by power and are evenly distributed on a sphere of radius d, the power per unit area is obtained:

I. 6 $$P_d = \frac{P_T}{4\pi d^2}$$

The power of receive antenna:

I. 7 $$P_R = \frac{P_T G_T}{4\pi d^2} A_{eff}$$

and for

I. 8 $$A_{eff} = \frac{\lambda^2}{4\pi} G_R$$

and the active area is substituted into (2.3-2), resulting in

I.9 $$P_R = A_{eff} P_T G_T G_R (\frac{\lambda}{4\pi})^2$$

Path loss is:

I. 10 $$PL(dB) = 10\log\frac{P_\tau}{P_R} = -\log[\frac{G_T G_R \lambda^2}{(4\pi d)^2}]$$

This equation (2.3-4) is called the Fri is free space model. The applicable condition for this model is that the distance of the domain transmitting antenna satisfies the long-range condition. This is the well-known Bonheffer distance in antenna design:

I. 11 $$\mathrm{d} > d_f = \frac{2D^2}{\lambda}$$

d is the maximum effective size of the antenna and the transmission wavelength. The assumption that there is a ground reflection and only one reflection path, in fact, this agrees well with the actual results. when d>>√h.hr, the ground reflection model:

I. 12 $$P_R = P_T G_T G_R [\frac{h_T h_R}{d^2}]^2$$

Express This equation (2.3-6) use the dB:

I.13 $$PL(dB) = 40lgd - (10lgG_T + 10lgG_R + 20\ lgh_T + 20\lg h_R)$$

Large-scale outdoor propagation models are mainly based on topography, the nature of electromagnetic radiation, and actual measurements.

Actual measurements show that in the same frequency band, the amplitude of the signal can change very quickly, even within a short period of time. Because radio waves in mobile communication systems are usually transmitted under irregular geographic conditions [3].

The geographic environment of a given area, including altitude, vegetation cover or occlusion, and building shelter, should be fully considered when losing a budget path.

Although there are many propagation models that can predict uneven terrain path loss, their methods vary widely in terms of complexity, accuracy, and scope of application.

As for the other large model, it was produced by the Eurocost Organization; for the Hata model, the propagation distance is more than LKM, but the frequency used is 2.0 GHz, a macro mobile communication system, with the base station antenna at 30 m to 200 m and the mobile antenna at 10 m.

Compared to the Okumura and Hata models, the frequency attenuation coefficients are different and central attenuation in the metropolitan area is considered more. The applicable frequencies, propagation distances, and antenna heights of these path loss models are quite different.

Any communication environment can provide a reliable reference for link budget, coverage area, and capacity evaluation by measuring according to a specific science and selecting the appropriate parameters that serve these models.

I.2.3.2 Small scale path loss model

Unlike the large-scale model, the small-scale path loss model is characterized by fast changes in reception levels over a short period of time. This is because multiple signals from different paths reach the receiving antenna, causing interference due to the superposition of different phases.

In other words, the small model is due to multipath propagation, the speed of movement, the speed of surrounding objects, and the bandwidth of signal transmission. Due to multipath in the radio channel.

Time domain: multipath delay spread of a broadband signal causes frequency selective fading. The time domain parameters of the channel are equalized by the average added delay and the RMS delay spread, of which the average added delay is the first moment of the power delay profile (PDP, Power Delay Profile) [4].As It is shown in the following table, **Table.1.1**

Situation	Frequency	LOS/NLOS	Average additional delay	RMS delay Spread (ns)
Large building	850M	LOS		270
Large building	1.7 G	LOS		150
Large building	4.0G	LOS		130
Inddor hot-spot	2.4 G	LOS	30.37	420.39
Inddor hot-spot	2.4 G	NLOS	42.90	270.20
Inddor hot-spot	3.7 G	LOS	224.3	47.79
Inddor hot-spot	3.7 G	NLOS	303.8	64.66
Inddor hot-spot	3.7 G	LOS	387	50.9
Inddor hot-spot	3.7 G	NLOS	416.2	80
Inddor Office	28 G	LOS	17.2	16.4
Inddor Office	28 G	NLOS	17.8	12.5
Inddor Office	28 G	LOS best	4.1	1.6
Inddor Office	28 G	NLOS best	13.4	13.1

Table I.1 Small Scale characteristic parameters of channel

I.3. Path Loss model

I.3.1 introduction of CI, FI and ABG model

This paper presents and compares two candidate large-scale propagation path loss models: the Close-in (CI) free-space reference distance mode (1 m) and the Floating Intercept (FI).

(1) The Cl path loss model considers the frequency dependence of the path loss using the CI reference distance (1 m) based on Friis' law, which is given by :

$$\textbf{I.14}\ \ PL^{Cl}(f_c + d_{3D})[dB] = FSPL(f_c, 1m) + 10\ n\ log_{10}(d_{3D}) + \chi_{\sigma}^{Cl}$$

where shadow fading (SF), n represents a single model parameter, the path loss exponent (PLE), and 10n, d is the distance in dB of the 3D T-R separation at tens of times the distance starting at 1 m. FSPL(f,1m) is the free space path loss in dB at a T-R separation distance of 1m at carrier frequency f:

$$\textbf{I.15}\ \ FSPL(f_c, 1m)[dB] = 20\ log_{10}(\frac{4\pi f}{c})$$

Where c is the speed of light.

The Cl model is based on basic principles of radio propagation dating back to Friis and Bullington, and PLE has a value of 2 in free space as shown by Friis and 4 in the asymptotic 2-line ground bounce propagation model, providing insight into path loss in different environments.

2) For the FI PL model is :

$$\textbf{I.16}\ PL[dB] = 10\alpha log_{10}(d) + \beta + X_{\sigma}$$

a is the dependence coefficient on distance, and ǩ is the path loss offset typically determined by the measurement data.

3) ABG model

The equation for the ABG model is :

$$\textbf{I.17}\ PL^{ABG}(f + d)[dB] = 10\alpha log_{10}\left(\frac{d}{1m}\right) + \beta + 10\,\gamma\ log_{10}\left(\frac{f}{1\ GHZ}\right) + \chi_{\sigma}^{ABG}$$

Where $PL^{ABG}(f + d)[dB]$ means the path loss in dB over frequency and distance, a,7 are the parameters of path loss which shows the dependence about distance and frequency respectively. ß is the optimized offset value for path loss in dB, f is the carrier frequency in GHz,d is the 3D T-R(transmitter to receiver) separation distance in ABG meters, the X is the shadow fading standard deviation [5].

The CI model has always been the main model of choice for analysis in more and more papers, and while the FI and ABG models are similar, the FI PL model is more useful because it has fewer parameters. Therefore, this essay will focus on the Cl path loss model and the FI path loss model, and will simulate and analyze these two models.

I.3.2 the introduction of some scenarios

For this paper, we will select four major organizations from the past two years to review and compare in order to analyze their path loss. These organizations are:

1) 3GPP TR 38.901 (3rd Generation Partnership Project), which provides the channel model for the 0.5-100 GHz band, is an organization that is continuously working as an international industry standard for 5th generation cell phones.

2) 5G Channel Model (5GCM): an organization based on an extensive measurement campaign that seeded the 3Gpp understanding of TR 38.900.

(3) Mobile and wireless communication Enablers for the Twenty-twenty information society (METIS) lays the foundation for the fifth generation (5G) mobile and wireless communication system METIS envisions the main concept of a fifth-generation system that efficiently integrates new applications developed in the horizontal topics.

4) The mmMAGIC project is co-funded by the European Commission's 5G PPP program and brings together major companies and organizations (Samsung, Ericsson, Alcatel-Lucent, Huawei, Intel, Nokia), major European operators (Orange, Telefonica), research institutes and universities (Fraunhofer HHI , CEA LETI, IMDEA Networks), millimeter wave-based mobile radio access networks for 5G integrated communications (mmMAGIC), and measurement equipment vendors (Keysight Technology, Rohde & Schwarz), 5GCM is a simple and clear statistical and parameters, this essay focuses on the 5GCM data and compares the 28 GHz and 38 GHz large-scale path loss for the UMa and UMi scenarios. Also, for 5GCM, FI and ABG have the same parameters and formulas. In the UMi scenario, they are 5GCM UMi-street Canyon LOS, 5GCM UMi-street Canyon NLOS, 5GCM UMI-Open square LOS, UMi-Open square LOS, and in the UMa scenario, 5GCM UMa LOS and 5GCM UMA MLOS [6].

I.4 Conclusion

In this first chapter, we presented a concise introduction to the key technologies of 5G, including millimeter wave frequencies and MIMO systems. This led us to recognize the significance of utilizing mm Wave channels and the necessity of studying these frequency bands through channel models. Hence, our focus in this chapter has been to explore the diverse channel models suitable for this purpose. Additionally, through extensive literature review, we

Chapter II:

Technology massive MIMO of 5G

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Technology massive MIMO of 5G

II.1 Introduction

MIMO stands for Multiple-Input-Multiple-Output, which is a wireless communication technology that uses multiple antennas at both the transmitter and the receiver to improve the data throughput, coverage, and reliability of wireless communication. MIMO technology is widely used in modern communication systems, including 4G LTE, Wi-Fi, and 5G networks. The principle of MIMO technology is to exploit the spatial dimension of the wireless channel by transmitting multiple data streams simultaneously over the same frequency band.

II.2 Traditional MIMO

MIMO is a wireless technology that uses multiple transmitters and receivers to transfer more data at the same time. MIMO technology takes advantage of a radio wave phenomenon called multipath, where transmitted information bounces off walls, ceilings and other objects, hitting the receiving antenna multiple times at different angles and at slightly different times. different.

It exploits multipath behaviour by using multiple "smart" transmitters and receivers with an added "spatial" dimension to dramatically increase performance and range. MIMO allows multiple antennas to send and receive multiple spatial streams at the same time MIMO makes antennas work smarter by allowing them to combine data streams from different paths and at different times to efficiently increase capture power of the receiver signal. Smart antennas use spatial diversity technology, which makes the most of excess antennas. If there are more antennas than spatial streams, the additional antennas can add diversity to receivers and increase range [7] .

II.3 Principle of MIMO technology

The principle of MIMO technology is to use multiple antennas at both the transmitter and the receiver to exploit the spatial dimension of the wireless channel. By transmitting multiple data streams simultaneously over the same frequency band, MIMO technology can improve the data throughput, coverage, and reliability of wireless communication, As illustrated in **Figure.11.1**

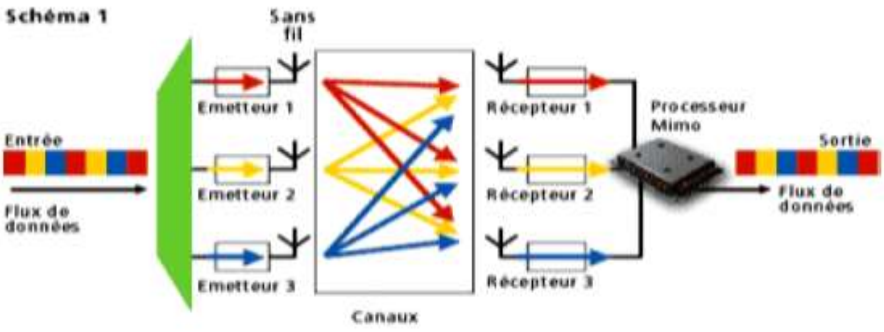


Figure II.1 Principle of MIMO technology [8]

The stream is divided into different streams of the same frequency which are sent through 3 transmitters to 3 receivers. The algorithm then makes it possible to identify the different streams in order to restore them in a single stream. This algorithm uses the reflection of signals on the walls, the floor, etc.

While these reflections could be considered bad, MIMO technology takes advantage of these different channels to improve the speed of data transmission [8] .

We can consider three categories of MIMO

1- MIMO Spatial Diversity:

MIMO Spatial Diversity is a technique that uses multiple antennas at the transmitter or the receiver to improve the signal quality by exploiting the spatial diversity of the wireless channel. In MIMO Spatial Diversity, the same data is transmitted over multiple antennas, and the receiver combines the received signals to improve the signal quality.

2- MIMO Spatial Multiplexing:

MIMO Spatial Multiplexing is a technique that uses multiple antennas at both the transmitter and the receiver to transmit multiple data streams simultaneously over the same frequency band. In MIMO Spatial Multiplexing, the transmitter divides the data into multiple streams and transmits each stream over a different antenna, and the receiver uses a process called spatial demultiplexing to recover the original data streams [9] .

II.4 Types of MIMO:

There are four types of MIMO systems: SISO, SIMO, MISO, and Massive MIMO. As illustrated in **Figure.11.2, Figure.11.3, Figure.11.4** and **Figure.11.5**

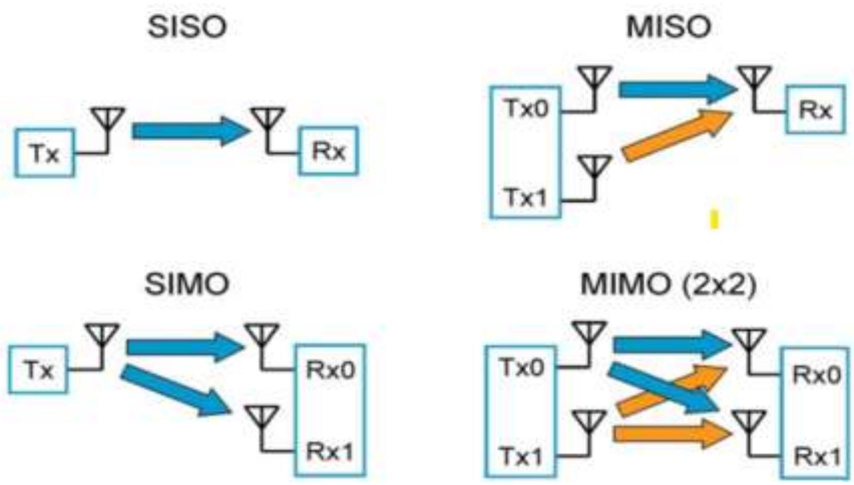


Figure II. 2 Different configuration of multiple antennas

II.4.1 SISO system

SISO stands for Single-Input-Single-Output, which is a wireless communication system that uses a single antenna at both the transmitter and the receiver.

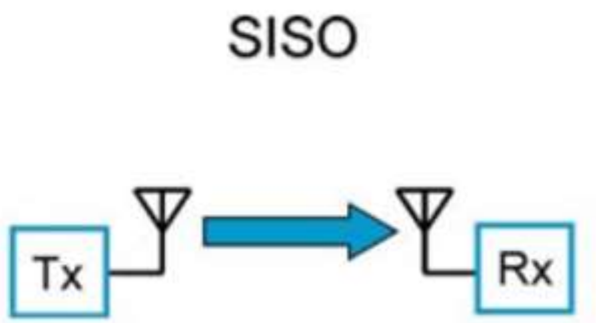


Figure II.3 SISO - Single Input Single Output [10].

The advantage of a SISO system is its simplicity. SISO requires no treatment in terms of the various forms of diversity that may be used. However, the performance of the SISO channel is limited. Interference and fading will have more of an impact on the system than a MIMO system using some form of diversity, and channel capacity is limited by Shannon's law - throughput depends on channel bandwidth and signal to noise ratio [10] :

$$C = W \log_2\left(1+\frac{P}{N_0 W}\right) \quad [bit/s]$$

(II. 1) Où :

P : la puissance du signal utile en Watt .

No : la densité spectrale de puissance du bruit calculé en W/Hz .

W : la bande passante donnée en Hz.

En normalisant la capacité par la bande utile W, on obtient:

$$C = W\log_2(1+SNR) \quad [bit/s] \qquad \textbf{(II. 2)}$$

Avec SNR est le rapport signal sur bruit.

II.4.2 SIMO system

SIMO stands for Single-Input-Multiple-Output, which is a wireless communication system that uses a single antenna at the transmitter and multiple antennas at the receiver [11] .

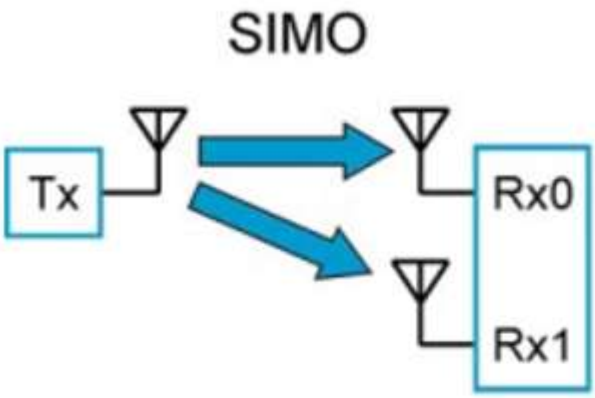


Figure II.4 SIMO - Single Input Multiple Output

SIMO has the advantage of being relatively easy to implement, although processing is required in the receiver. The use of SIMO can be quite acceptable in many applications, but when the receiver is located on a mobile device such as a cell phone handset, processing levels can be limited by size, cost and battery charge

II.4.3 MISO system

MISO stands for Multiple-Input-Single-Output, which is a wireless communication system that uses multiple antennas at the transmitter and a single antenna at the receiver

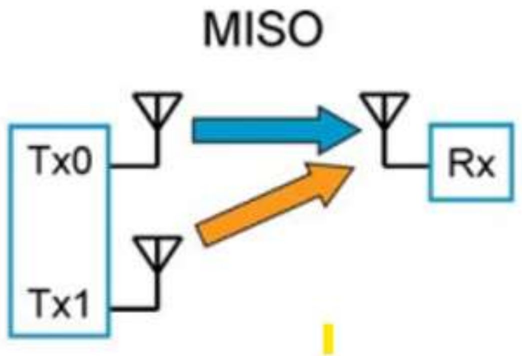


Figure II.5 MISO - Multiple Input Single Output [12].

One of the fundamental ideas of space-time signal processing of MIMO wireless systems, in which time is supplemented by the spatial dimension inherent in the use of multiple antennas distributed in space, i.e. the use of several antennas located at different points. Accordingly, MIMO wireless systems can be seen as a logical extension of the smart antennas that have been used for many years to improve wireless technology.

It is found between a transmitter and a receiver; the signal can take several paths [12].

II.5 Massive MIMO system

Massive MIMO is a wireless communication system that uses a large number of antennas at both the transmitter and the receiver to improve the data throughput, coverage, and reliability of wireless communication, As illustrated in **Figure.11.6**

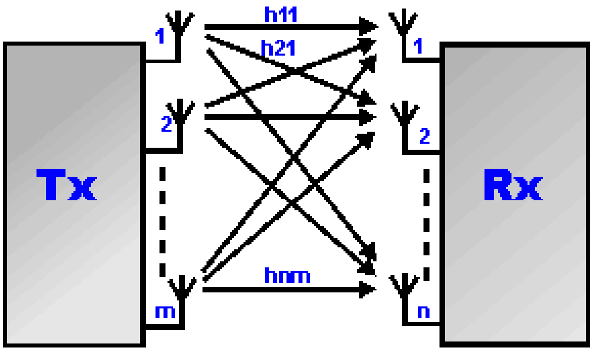


Figure II.6 Typical view of a MIMO network.

✓ We now consider a MIMO link where the transmitter and the receiver are equipped with N and M antennas respectively as illustrated in figure II.6

$$\mathbf{H} = \begin{bmatrix} h_{11} & h_{12} & \dots & h_{1M} \\ h_{21} & \ddots & \ddots & h_{2M} \\ \vdots & \ddots & \ddots & \vdots \\ h_{N1} & h_{N2} & \dots & h_{NM} \end{bmatrix}$$

• hNM is the complex gain of the channel between the N th transmitting antenna and the M th receiving antenna.

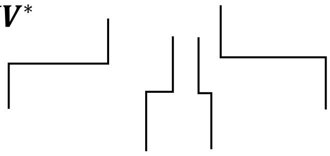
• H is the M x N matrix of the channel.

$$\mathbf{y} = \mathbf{Hx} \;\; \mathbf{n} \qquad \mathbf{(II.3)}$$

With X =$[x_1 , x_2, \dots \dots . x_M]^T$ *et* y =$[y_1, y_2, \dots \dots , y_N]^T$

• Proper decomposition of H

$$\mathbf{H} = \mathbf{DU}\boldsymbol{V}^* \qquad \mathbf{(II.4)}$$



$\boldsymbol{N}$**×M** **N×m** **m×m** **m×M**

With m = min(M, N)

• **U** and V are unit matrices (U U^H= V V^H=1).

• **D** is a diagonal matrix whose nonzero elements are the eigenvalues of H.

• The capacity of a MIMO channel is then:

$$\mathbf{C}=\sum_{i=1}^{m} \boldsymbol{C_i} \qquad \mathbf{(II.5)}$$

$$\mathbf{C}=\sum_{i=1}^{m} \boldsymbol{log_2}\left(\mathbf{1} + \frac{\boldsymbol{\rho}}{\boldsymbol{M}}|\boldsymbol{\lambda_i}|^2\right) \;\; \textbf{[bit/sec/Hz]} \qquad \mathbf{(II.6)}$$

Massive MIMO offers three major innovations

✓ **MIMO – Beamforming**

MIMO Beamforming is a technique that uses multiple antennas to focus the transmitted signal in a specific direction to improve the coverage and reliability of wireless communication [13]**.** As illustrated in **Figure.11.7**

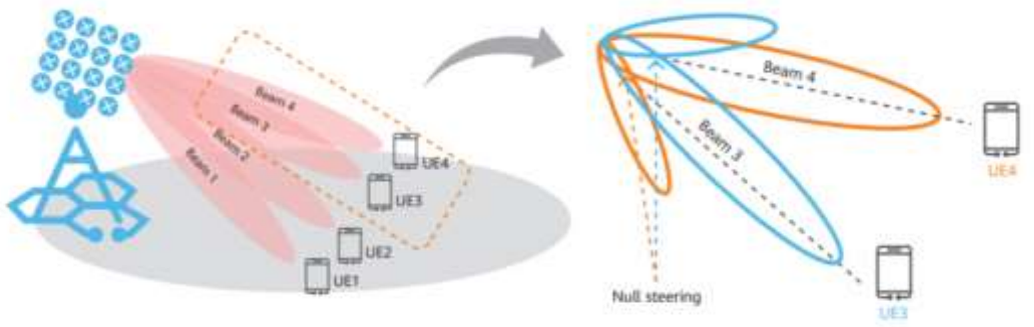


Figure II.7 Beamforming [13]

- **Réseaux à Petites Cellules:**

Réseaux à Petites Cellules, also known as Small Cells, are low-power cellular base stations that are used to enhance the coverage and capacity of wireless networks, particularly in high-density areas.

- **MU-MIMO**

Further increases total capacity per base station by enabling communication with multiple devices using the same resources, creating a virtually unified edge side. Simultaneous use of the antennas of several devices makes it possible to create large-scale MIMO virtual channels. The combination of these two innovations makes it possible to increase the wireless transmission speed by increasing the number of base station antennas without consuming more bandwidth or increasing the modulation values [14].

II.6 Massive MIMO Types

II.6.1 Single-User MIMO

Single-user MIMO (SU-MIMO) is a multi-transmitter and receiver technology for wireless communication that allocates the bandwidth of a wireless access point to a single device (Figure II.8).

SU-MIMO is commonly compared unlike Multi-User MIMO (MU-MIMO) A potential downside of using SU-MIMO over another strategy such as Multi-User MIMO is only able to send data to one device at a time. SU-MIMO also requires transmit and receive technologies to support MIMO to operate. Also, both devices have to use multiple antennas, which can be a burden for smaller devices, As illustrated in **Figure.11.8**

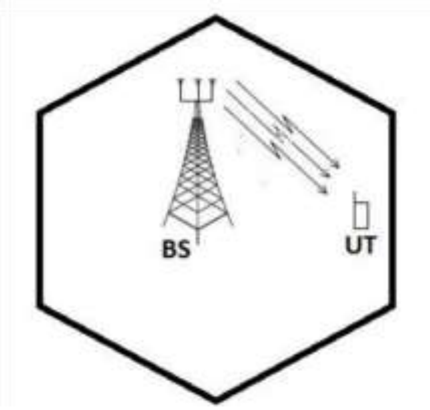


Figure II.8 Single-User Massive MIMO

$$Y = \sqrt{P_u}\, hs + W \qquad \text{(II. 7)}$$

Denote by *Pu*, the uplink SNR, by h the channel response vector, by s the symbol vector and by *w*, the AWGN noise vector

II.6.2 Multi-User Massive MIMO

Multi-user MIMO (MU-MIMO) is a set of multiple-input, multiple-output (MIMO) technologies for wireless communication, in which a set of wireless users or terminals, each with one or more antennas. As shown in Figure II.9, moreover MU-Massive MIMO with Multi-Cell scenario is a wireless communication system that uses a large number of antennas at multiple base stations to serve multiple users simultaneously, thereby improving the data throughput and capacity of the wireless network [15]. As illustrated in **Figure.11.9**

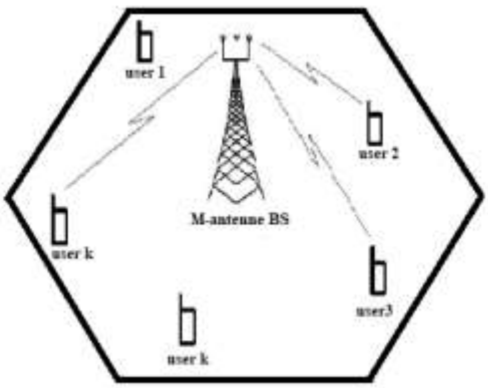


Figure II.9 Massive MU-MIMO system [15]

M-antennas of BS serves K simple antenna UT

II.6.3 MU-Massive MIMO with Multi-Cell scenario

MU-Massive MIMO with Multi-Cell scenario is a wireless communication system that uses a large number of antennas at multiple base stations to serve multiple users simultaneously, thereby improving the data throughput and capacity of the wireless network, we envision the restriction of non-cooperative cellular multi-user MIMO systems as M grows unbounded. For a single cell, as well as for multi-cell MIMO, letting M increase unbounded has the final effect of making thermal noise disappear and Rayleigh fading out on a small scale. However, interference from separate cells due to pilot contamination will persist with multiple cells. The pilot pollution idea is novel in a cellular MU-MIMO context and is illustrated in Figure II. 10next. However, it used to pose a problem in the context of CDMA generally under the heading of "pilot contamination" [16]. The channel estimate calculated using the base station in cell l is contaminated by the pilot transmission of cell j. As illustrated in **Figure.11.10**

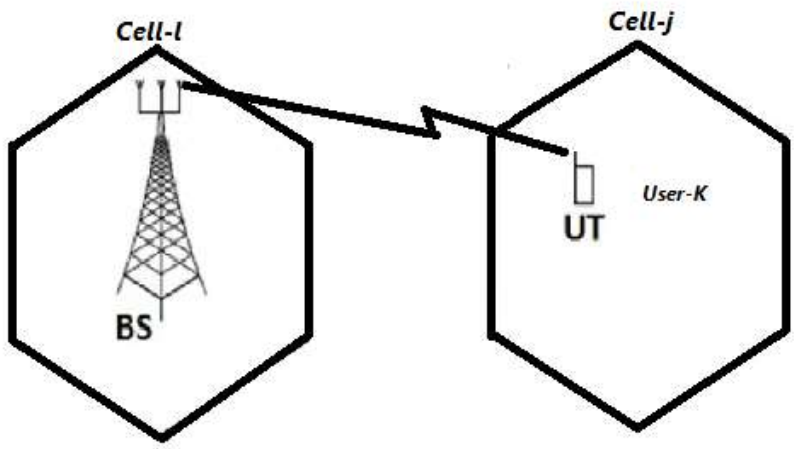


Figure II.10 The BS in the ith cell and the k th UT in the j th cell [16] .

II.6.4 Distributed Massive MIMO

Distributed massive MIMO refers to a wireless communication technology that uses a large number of scattered antennas, positioned either on the same or different base stations, to transmit and receive signals. This technology allows for cooperation between base stations in different cells to increase system capacity and reduce interference. However, synchronization is a crucial challenge in distributed massive MIMO systems, especially when the antennas are distributed across different locations. In some cases, the antennas may be positioned in unique locations, which can further complicate synchronization and introduce additional challenges related to the RF front-end, As illustrated in **Figure.11.11**

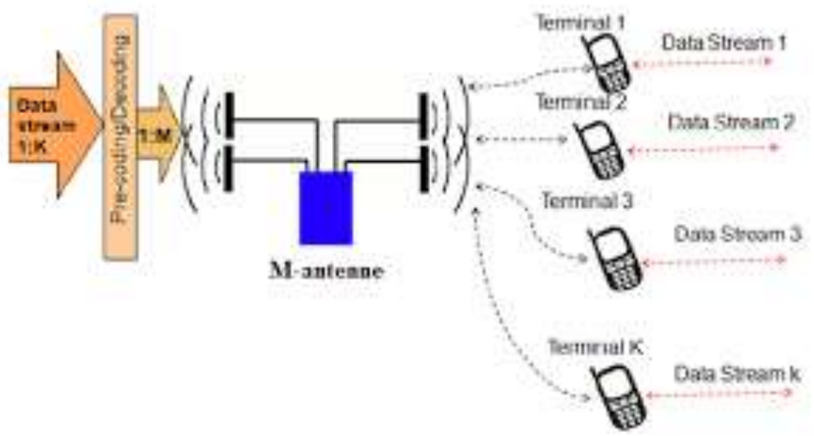


Figure II.11 Massive MIMO system model [17] .

II.7 General characteristics of Massive MIMO systems

A massive MIMO system is a type of multi-user system that falls under the MU-MIMO category. The main characteristic of a massive MIMO system is the large number of antennas at the base station, which can be in the thousands. This allows the system to serve a high number of users, ranging from tens to hundreds, all while utilizing the same frequency resources.

Another important feature of massive MIMO systems is their ability to reduce interference between users. With the large number of antennas available, the system can direct signals towards specific users, while minimizing the impact on other users. This results in higher system capacity and overall better performance.

Finally, the massive MIMO system also relies on advanced signal processing techniques, such as beamforming and spatial multiplexing, to further improve system performance. These techniques help to improve the signal quality, increase data rates, and reduce signal fading effects.

Overall, massive MIMO systems are a powerful tool for achieving high-capacity and high-performance wireless communications in dense user environment [18]

II.7.1 Preference of the TDD scheme in Massive MIMO

The Time Division Duplexing (TDD) scheme is a preferred choice in Massive MIMO systems due to its ability to handle uplink and downlink communication through the same frequency channel. In TDD, the same frequency is used for both uplink and downlink transmissions, but the time slots are allocated differently for each direction of communication. This is in contrast to Frequency Division Duplexing (FDD), where separate frequency bands are used for uplink and downlink communication. also TDD is more suitable for Massive MIMO because it allows for more flexibility in adapting to varying traffic loads and channel conditions. In a TDD-based Massive MIMO system, the base station can adjust the ratio of uplink and downlink time slots based on the traffic demands of the users, which can vary over time and across different cell locations. This dynamic allocation of time slots helps to improve the system efficiency and capacity, as the base station can focus more resources on the direction with higher traffic demand.Moreover, TDD can also reduce the amount of interference between adjacent cells, since it allows the base station to adjust the timing of uplink and downlink transmissions in each cell. By carefully synchronizing the time slots, the base station can mitigate the interference caused by neighboring cells, which is a critical challenge in Massive MIMO systems due to the large number of antennas and users [19].

Overall, TDD is a preferred scheme for Massive MIMO systems due to its flexibility, efficiency, and ability to reduce interference.

II.7.2 Scalability

In TDD therefore, the BS performs an estimation of the channel during the uplink. The time required for the channel estimation does not depend on the number of BS antennas. Therefore, this number can be made as large as possible without extension in the channel estimation period (number of pilots)

It is the unlimited scalability of the number of base station antennas in TDD.

II.8 Comparison between traditional MIMO and massive MIMO

Massive MIMO and traditional MIMO (also known as small MIMO) are two different antenna technologies used in wireless communication systems. Traditional MIMO uses a small number of antennas at both the transmitter and receiver to improve the system's performance by reducing interference and increasing the capacity. In contrast, massive MIMO employs hundreds or even thousands of antennas at the base station to serve multiple users simultaneously, utilizing the spatial domain to enhance the system's performance.

One of the main differences between these two technologies is their ability to handle multi-user interference. Traditional MIMO systems can mitigate interference up to a certain level, but as the number of users increases, the system's performance starts to degrade due to interference. In contrast, massive MIMO can effectively handle interference by using spatial processing techniques, which makes it a suitable technology for high-capacity networks with a large number of users [20].

Another difference between these technologies is their signal processing complexity. Traditional MIMO systems use simple linear processing techniques, while massive MIMO systems use advanced signal processing techniques such as beamforming, precoding, and channel estimation algorithms to achieve better performance. However, these techniques require a considerable amount of processing power and can be computationally expensive. Finally, traditional MIMO systems typically use a time-division duplexing (TDD) or frequency-division duplexing (FDD) scheme, whereas massive MIMO systems are primarily deployed using the TDD scheme due to its ability to handle large numbers of antennas without increasing the channel estimation time. Overall, massive MIMO provides a significant improvement over traditional MIMO systems in terms of performance, capacity, and spectral efficiency, making it an ideal technology for future wireless networks. It is shown in the following **Table.11.1**

Technology Content	**Traditional MIMO**	**Massive MIMO**
The antenna number	≤8	≥100
Channel angular domain value	Uncertain	Certain
Channel matrix	Low requirement	High

		requirement
Channel Capacity	Low	High
Diversity Gain	Low	High
Link stability	Low	High
Noise resistance	Low	High
Array Resolution	Low	High
Antenna correlation	Low	High
Coupling	Low	Low
Pilot pollution	NO	YES

Table II.1 Comparison between Traditional MIMO and Massive MIMO

II.9 Advantages of massive MIMO

Massive MIMO (Multiple-Input Multiple-Output) is a revolutionary technology that has gained widespread attention in recent years due to its numerous advantages. One of the primary advantages of massive MIMO is its ability to dramatically increase spectral efficiency, which is the amount of data that can be transmitted over a given bandwidth. By utilizing hundreds or even thousands of antennas at the base station, massive MIMO can serve multiple users simultaneously using the same frequency resources, thereby increasing the capacity of the system. This makes it particularly useful for areas with high data traffic or dense populations. Another advantage of massive MIMO is its ability to reduce interference and improve the signal quality, leading to higher data rates and improved coverage. In addition, massive MIMO can also improve energy efficiency, reduce latency, and enhance the overall user experience. These benefits make massive MIMO a promising technology for the future of wireless communication systems [21].

II.10 Conclusion

Massive MIMO technology has been recognized as one of the most promising solutions for enhancing the spectral and energy efficiency of 5G wireless networks. With the ability to use hundreds of antennas at the base station to simultaneously serve tens or hundreds of users, massive MIMO offers a significant increase in system capacity and throughput. It also provides a high degree of flexibility, adaptability, and resilience to channel conditions, making it suitable for diverse use cases and scenarios. Moreover, massive MIMO can support advanced features such as beamforming, spatial multiplexing, and interference suppression, which further improve the network performance and user experience. Although there are some challenges associated with massive MIMO, such as increased hardware complexity, power consumption, and synchronization requirements, ongoing research and development efforts are addressing these issues and optimizing the technology for practical deployment. Overall, massive MIMO is expected to play a critical role in the evolution of 5G and beyond, enabling new applications and services that require high data rates, low latency, and massive connectivity.

Chapter III:

NYUSIM - A Simulation Tool for Millimeter-Wave Wireless Systems

Chapter III:

Simulation and Analysis of Results

III.1 Introduction

Millimeter-wave (mmWave) technology has emerged as a promising solution for next-generation wireless networks due to its potential to provide high data rates, low latency, and support for a large number of devices. However, the unique characteristics of mmWave signals, such as high path loss, susceptibility to blockage, and sensitivity to antenna misalignment, pose significant challenges for designing and optimizing mmWave systems. In this chapter we use a free software tool developed by researchers at New York University (NYU) to simulate and study the millimetre wave channels address.

III.2 Features and Capabilities

NYUSIM is a MATLAB-based simulation tool that provides a range of features and capabilities for simulating mmWave wireless systems. The tool includes a channel model that captures the key characteristics of mmWave propagation, such as path loss, shadowing, and multipath. The channel model is based on extensive measurements of mmWave channels in various environments, such as indoor and outdoor environments, line-of-sight (LOS) and non-line-of-sight (NLOS) scenarios, and different types of materials. NYUSIM also supports various modulation and coding schemes, beamforming algorithms, antenna arrays, mobility, multiple access, and interference.

III.3 Applications

NYUSIM has been used in various research projects and applications related to mmWave wireless systems. Researchers have used NYUSIM to study and optimize the performance of mmWave systems for 5G and beyond, evaluate the impact of various factors such as mobility, interference, and antenna configurations on the performance of mmWave systems. NYUSIM has also been used to study and optimize the performance of mmWave systems for automotive communications, such as vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications.

III.4 Simulations

In this section, we will simulate the O2I penetration loss for the most used millimeter wave channels (28 GHz, 38 GHz) for different scenarios using NYUSIM_v3_WIN The simulation with different choice of parameters is carried out in this section. For the simulation, assumptions were made for both channel and antenna properties represented in **Figure III.1 Figure III.2, Figure III.3 Figure III.4Figure III.5Figure III.6Figure III.7Figure III.8Figure III.9 Figure III.10 Figure III.11 Figure III.12 Figure III.13 Figure III.14 Figure III.15 Table III.3 Figure III.16** related on 28 GHz and 38 GHz in four season

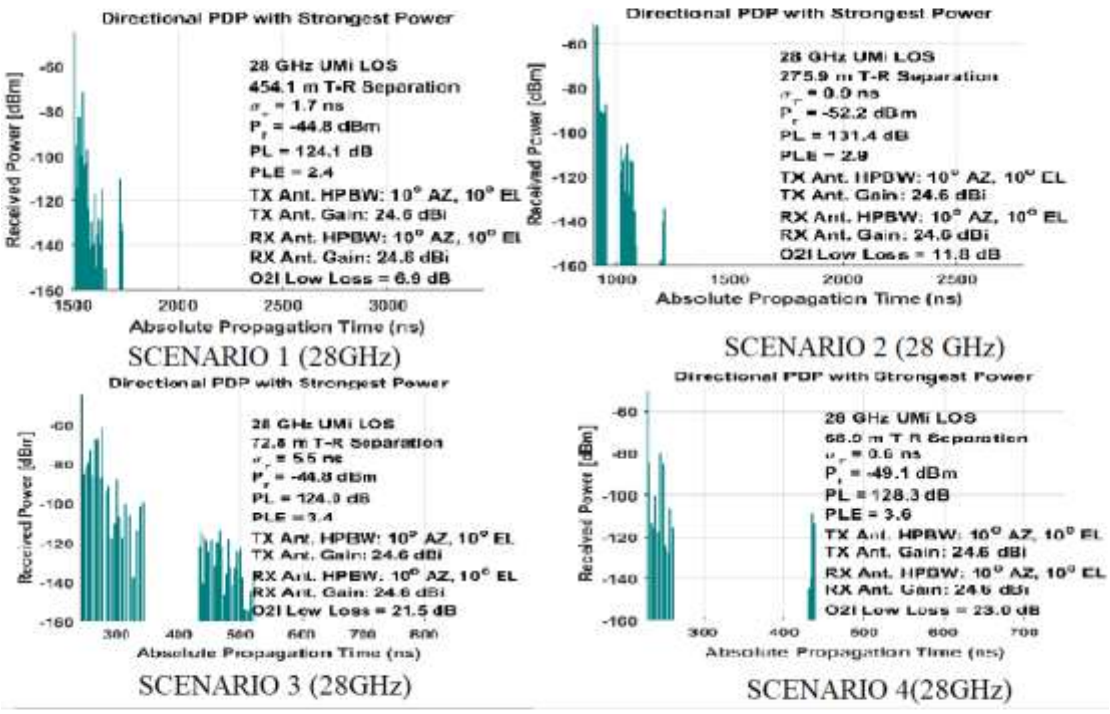


Figure III.1: Directional Power Delay Profile channel 28 GHz.

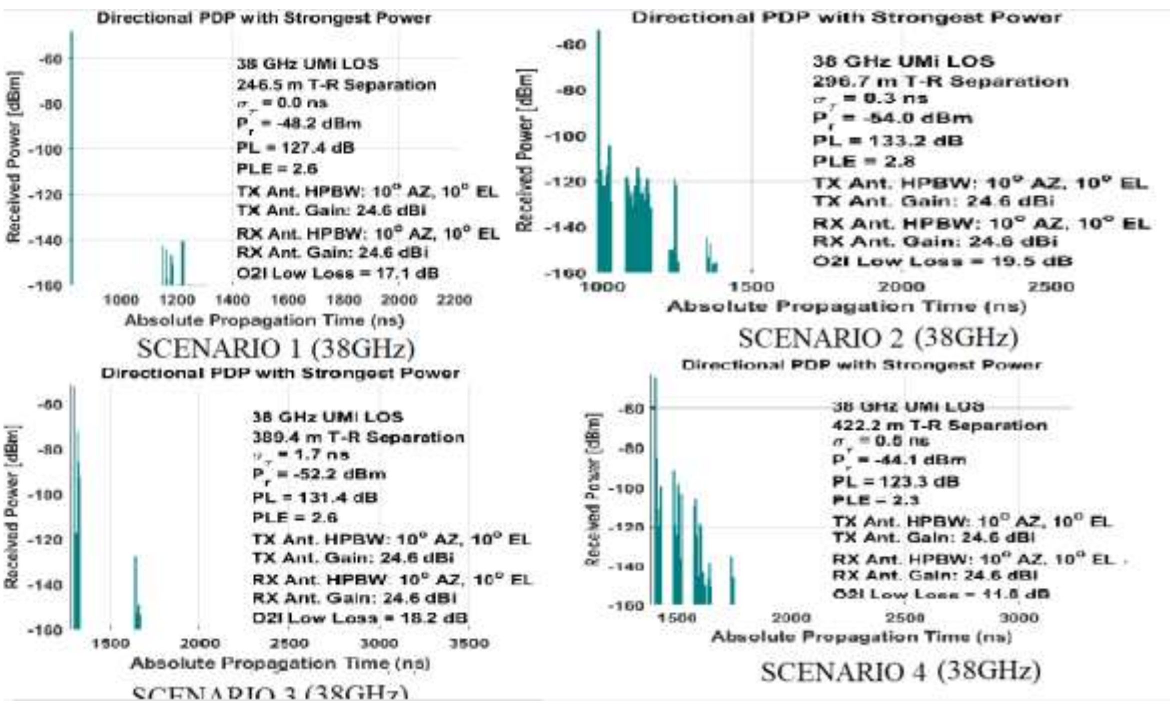


Figure III.2: Directional Power Delay Profile channel 38 GHz

Figure III.1 and Figure III.2 show the Directional PDP output from a NYUSIM run with O2I penetration loss at 28 and 38GHz respectively for the four scenarios. From figure Figure III.1 and Figure III.2, we can summarize results in table III.1 III.2 III.3 III.4, as it is shown in the following tables, **Table III.1, Table III.2**, **Table III.3 and Table III.4**

In scenario 1, channel 38 GHz has a lower O2I penetration loss:

Freq Channel[GHz]	Scenario	O2I penetration loss [dB]
28	1	6.9
	2	11.8
	3	21.5
	4	23
38	1	17.1
	2	19.5
	3	18.2
	4	11.8

Table III.1 Results for directional PDP.

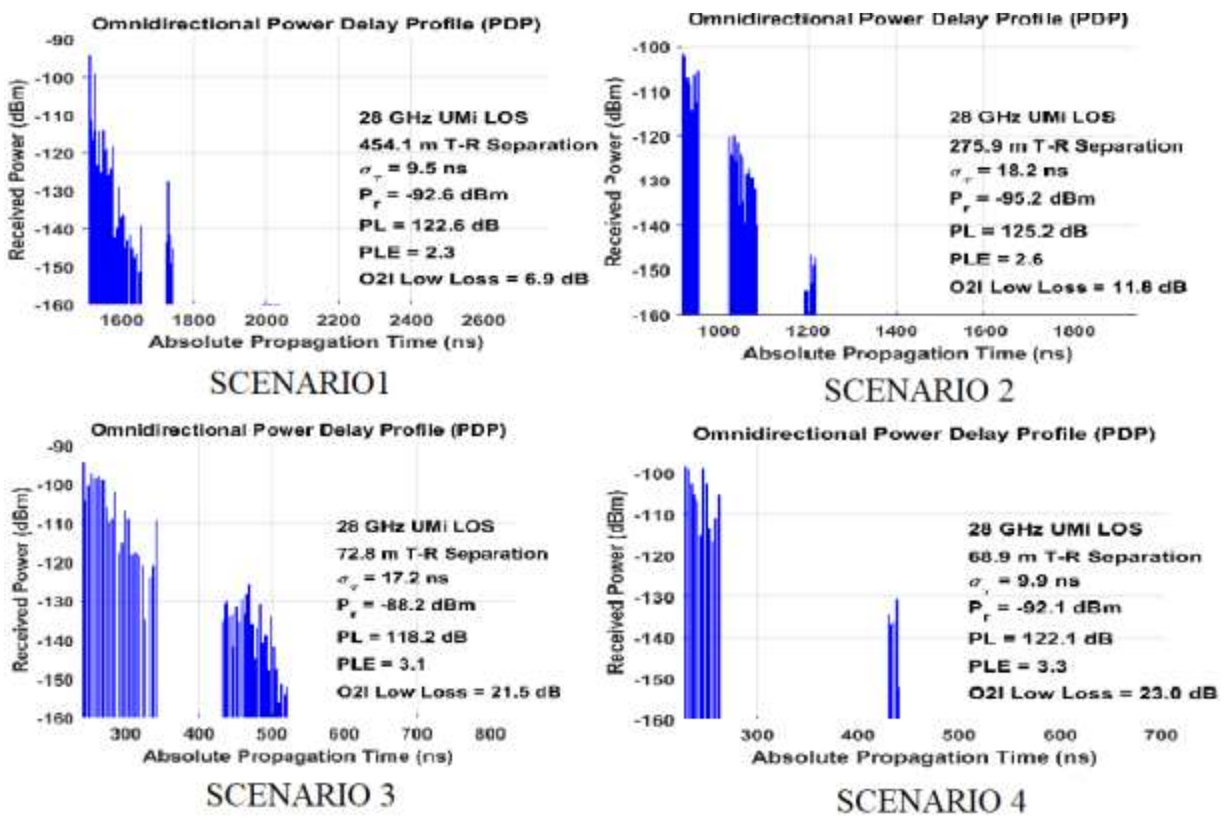


Figure III.3: Omnidirectional Power Delay Profile channel 28 GHz

The 28 GHz bands were found to be similar in their propagation delays due to their similar separation distances. As the separation distances increased in simulation, the absolute propagation delay also increased. The slight differences in attenuation can be noted between the two separation distances, and it is suspected that, a shading factor may have come into play, indicating a greater shading variability at higher millimeter wave frequencies. The increased shadowing effect can be attributed to increased diffuse scattering, loss of diffraction and weaker reflections

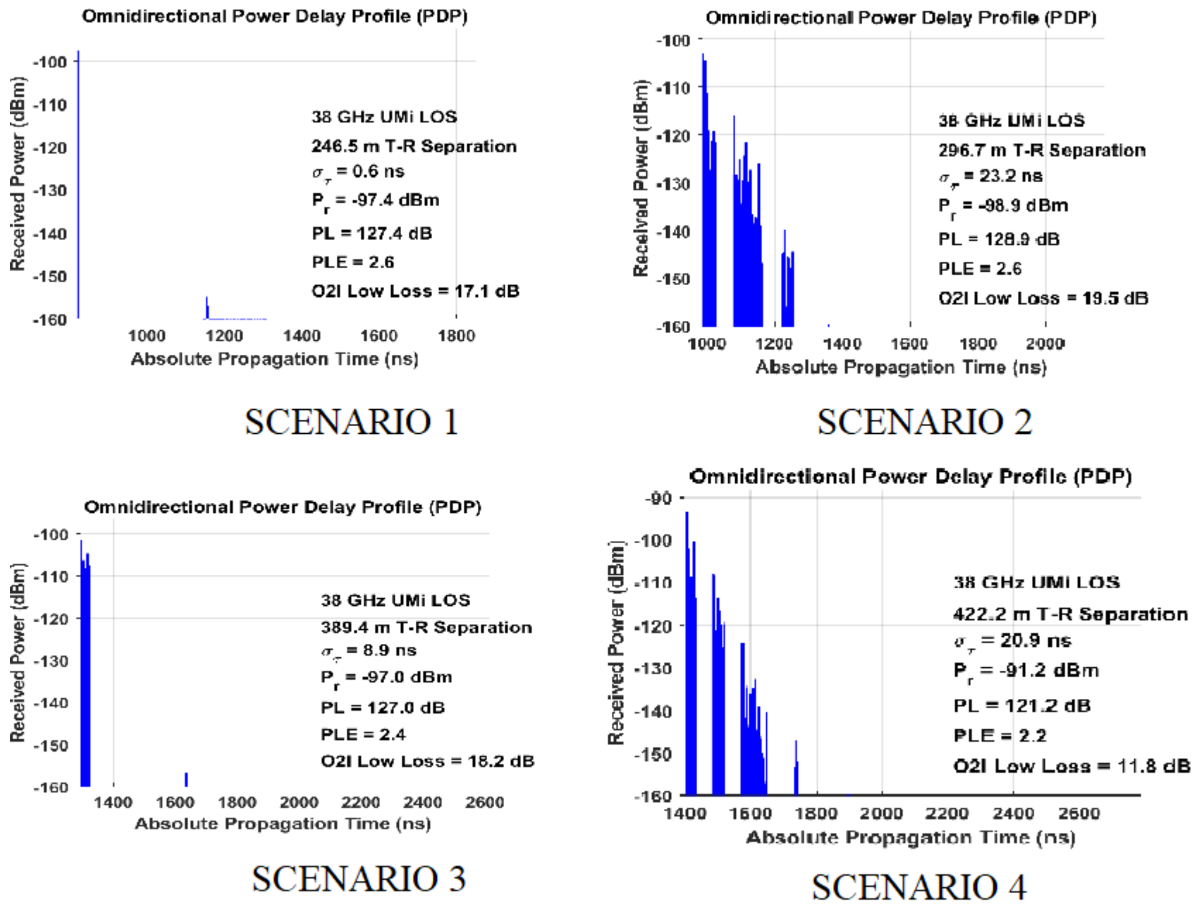


Figure III.4: Omnidirectional Power Delay Profile channel 38 GHz

At 38 GHz, the wavelength of the electromagnetic waves is shorter than at 28 GHz, which means that the signals are more sensitive to obstacles and atmospheric conditions. This can result in a higher degree of attenuation and propagation delay compared to lower frequency bands.

As the separation distances between the transmitting and receiving antennas increase, the absolute propagation delay also increases due to the increased distance that the signal needs to travel. The slight differences in attenuation can be noted between the two separation distances, and it is suspected that a shading factor may have come into play, indicating a greater shading variability at higher millimeter wave frequencies. The increased shadowing effect can be attributed to increased diffuse scattering, loss of diffraction, and weaker reflections.

Overall, at 38 GHz, the increased attenuation, propagation delay, and shadowing effect may pose challenges for wireless communication systems, and careful planning and optimization of the network design are required to ensure reliable and efficient performance [11], as illustrated in **Table III.2.**

Freq Channel [GHz]	Scenario	O2I penetration loss [dB]
28	1	6.9
	2	11.8
	3	21.5
	4	23
38	1	17.1
	2	19.5
	3	18.2
	4	11.8

Table III.2. Results for Omnidirectional PDP.

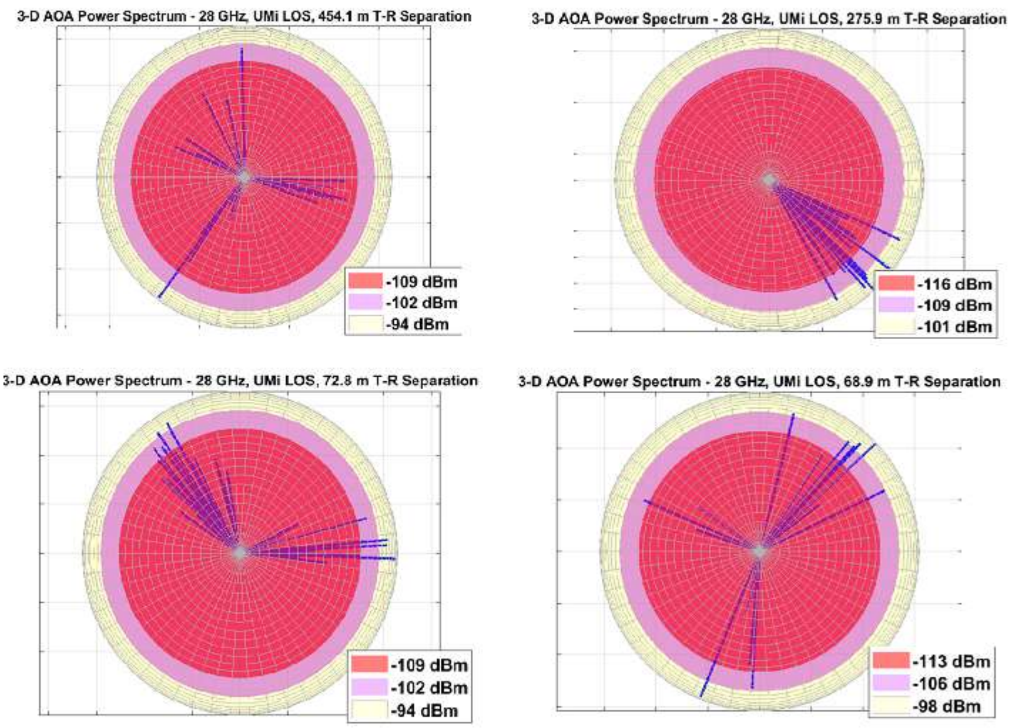


Figure III.5: 3D Angel of arrival (AOA) Power spectrum of Umi-Los in 28 GHz in four season

The AOA power spectrum of Umi-Los channels at 28 GHz was studied in four seasons (spring, summer, fall, and winter). The power spectrum varied significantly across seasons, with higher angular spread in summer and fall, indicating more scattering and reflection. The power spectrum in summer and fall also had a stronger line-of-sight component, indicating a more dominant direct path. In addition, the AOA power spectrum in summer and fall showed higher spatial correlation, indicating more consistency across locations. This information is useful for designing wireless communication systems that are optimized for different seasons and predicting system performance in different environments

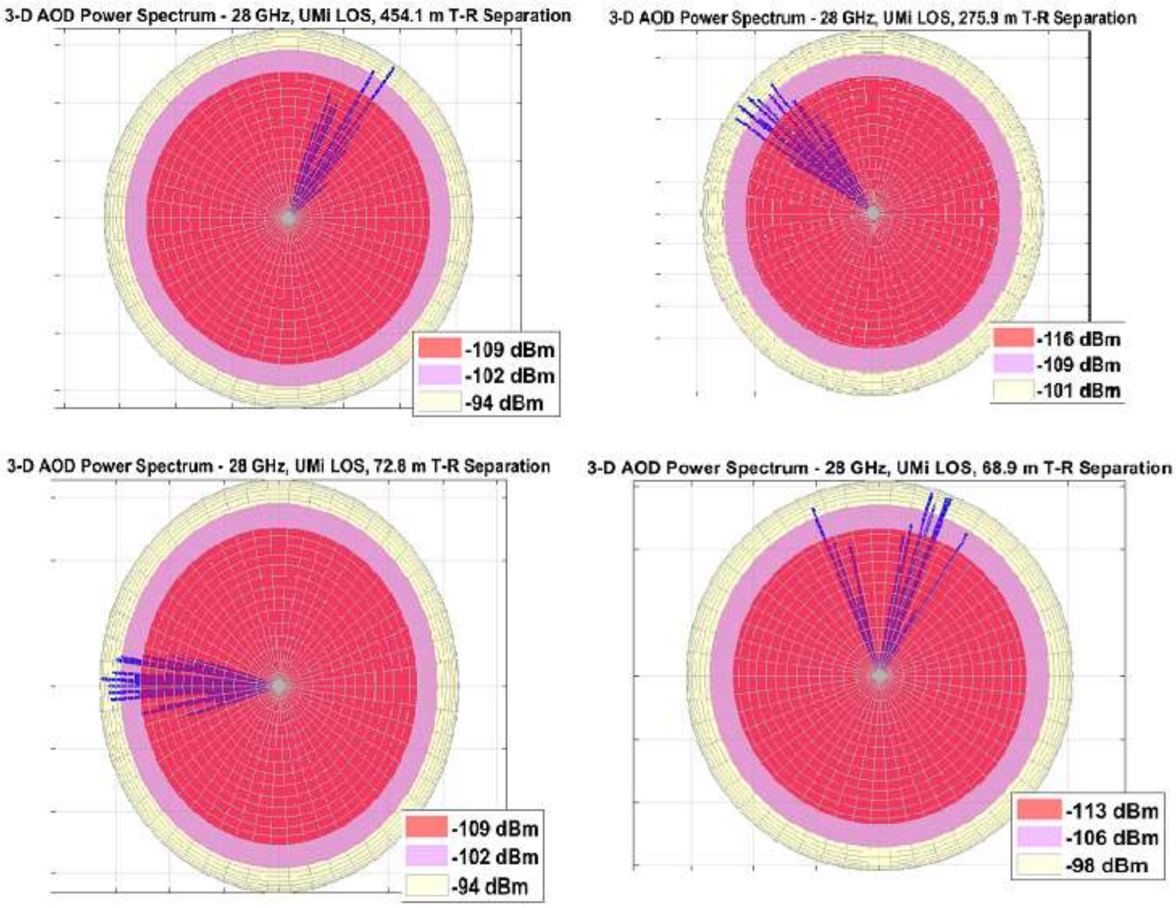


Figure III.6: 3D Angel of Departure (AOD) Power spectrum of Umi-Los in 28 GHz in four season

The 3D Angel of Departure (AOD) power spectrum of Umi-Los (urban microcellular line-of-sight) channels at 28 GHz has been studied in four different seasons, namely spring, summer, fall, and winter. The AOD power spectrum provides information about the direction of arrival and departure of electromagnetic waves in a wireless channel, which is useful for designing antenna arrays and beamforming algorithms.

The study found that the AOD power spectrum of Umi-Los channels at 28 GHz varies significantly across different seasons. In particular, the power spectrum in summer and fall exhibited a higher degree of angular spread compared to spring and winter, indicating that the electromagnetic waves experience more scattering and reflection in these seasons. Additionally, the power spectrum in summer and fall exhibited a stronger line-of-sight component, indicating that the direct path between the transmitter and receiver is more dominant in these seasons.

The study also found that the AOD power spectrum at 28 GHz showed a higher degree of spatial correlation in summer and fall compared to spring and winter, indicating that the channel is more consistent across different locations in these seasons. This information can be useful for designing wireless communication systems that are optimized for different seasons, as well as for predicting the performance of these systems in different environments.

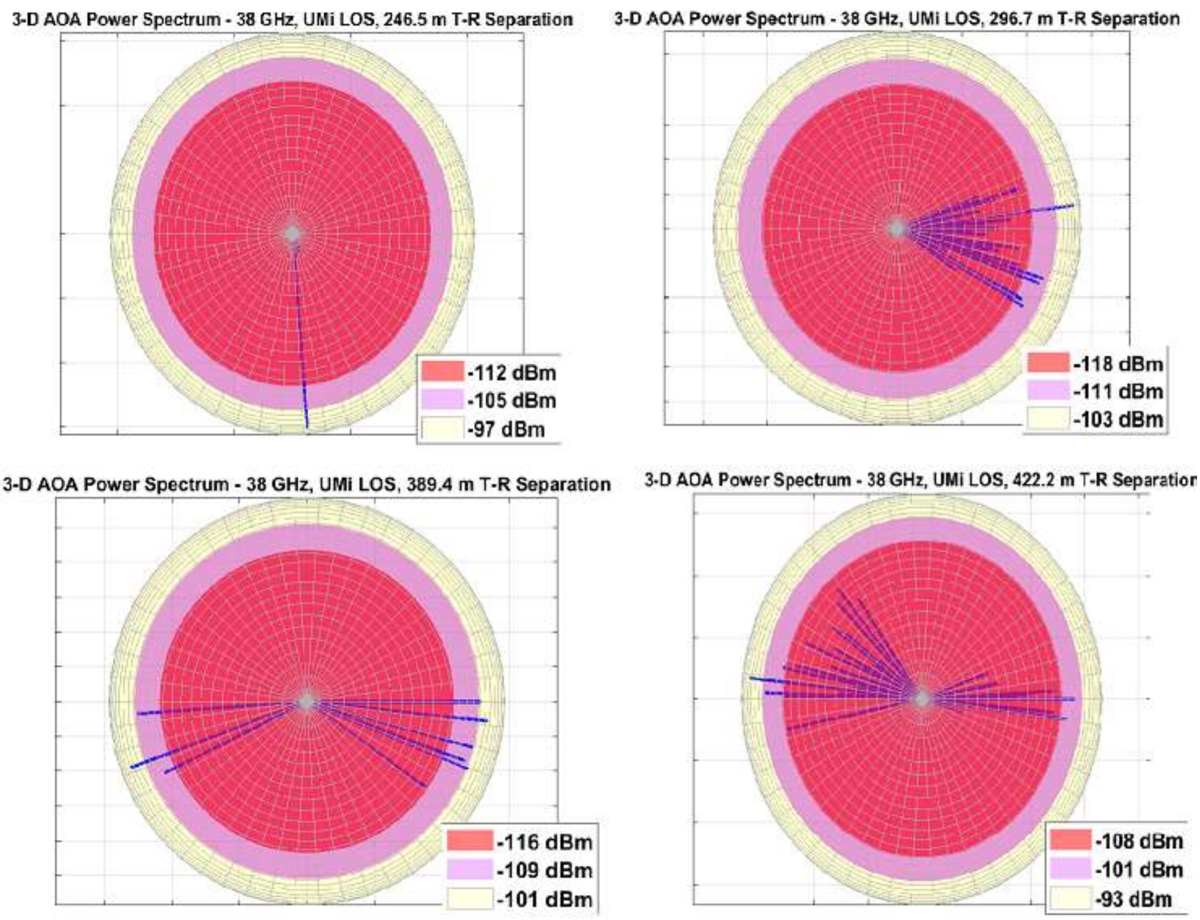


Figure III.7: 3D Angel of arrival (AOA) Power spectrum of Umi-Los in 38 GHz in four season

The study found that the AOA power spectrum of Umi-Los channels at 38 GHz varied across seasons, with more scattering and reflection in summer and fall, indicating a higher degree of angular spread. Additionally, the direct path between the transmitter and receiver was stronger in summer and fall, meaning that the signal experienced less obstruction and was less likely to be reflected or scattered.

Moreover, the study found that the spatial correlation of the AOA power spectrum at 38 GHz was higher in summer and fall compared to spring and winter, meaning that the wireless channel was more consistent across different locations in these seasons. However, the correlation was lower than that of the 28 GHz AOA power spectrum, which suggests that the higher frequency of 38 GHz is more sensitive to obstacles and experiences more spatial variation due to its smaller wavelength.

Overall, this information can be helpful for designing wireless communication systems that operate at 38 GHz in different environments and seasons, as the wireless channel characteristics can vary significantly depending on the time of year and location

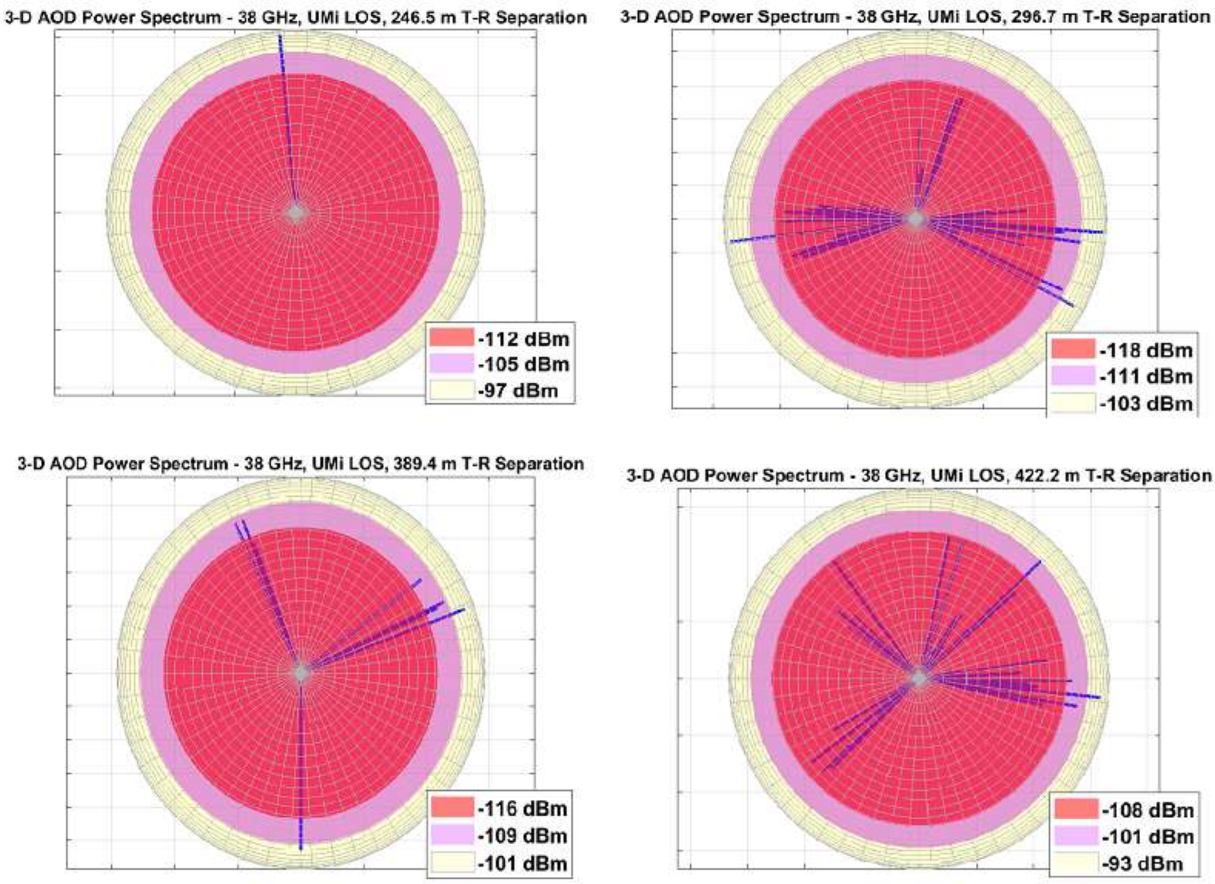


Figure III.8: 3D Angel of Departure (AOD) Power spectrum of Umi-Los in 38 GHz in four season

The study found that the AOD power spectrum of Umi-Los channels at 38 GHz varied across seasons. In general, the power spectrum showed more scattering and reflection in summer and fall, indicating a higher degree of angular spread. However, the direct path between the transmitter and receiver was stronger in summer and fall, meaning that the signal experienced less obstruction and was less likely to be reflected or scattered.

Additionally, the study found that the spatial correlation of the AOD power spectrum at 38 GHz was higher in summer and fall compared to spring and winter. This suggests that the wireless channel was more consistent across different locations in these seasons. However, the correlation was lower than that of the 28 GHz AOD power spectrum, indicating more spatial variation due to the higher frequency of 38 GHz.

Overall, this information can be useful for designing wireless communication systems that operate at 38 GHz in different environments and seasons, as the wireless channel characteristics can vary significantly depending on the time of year and location.

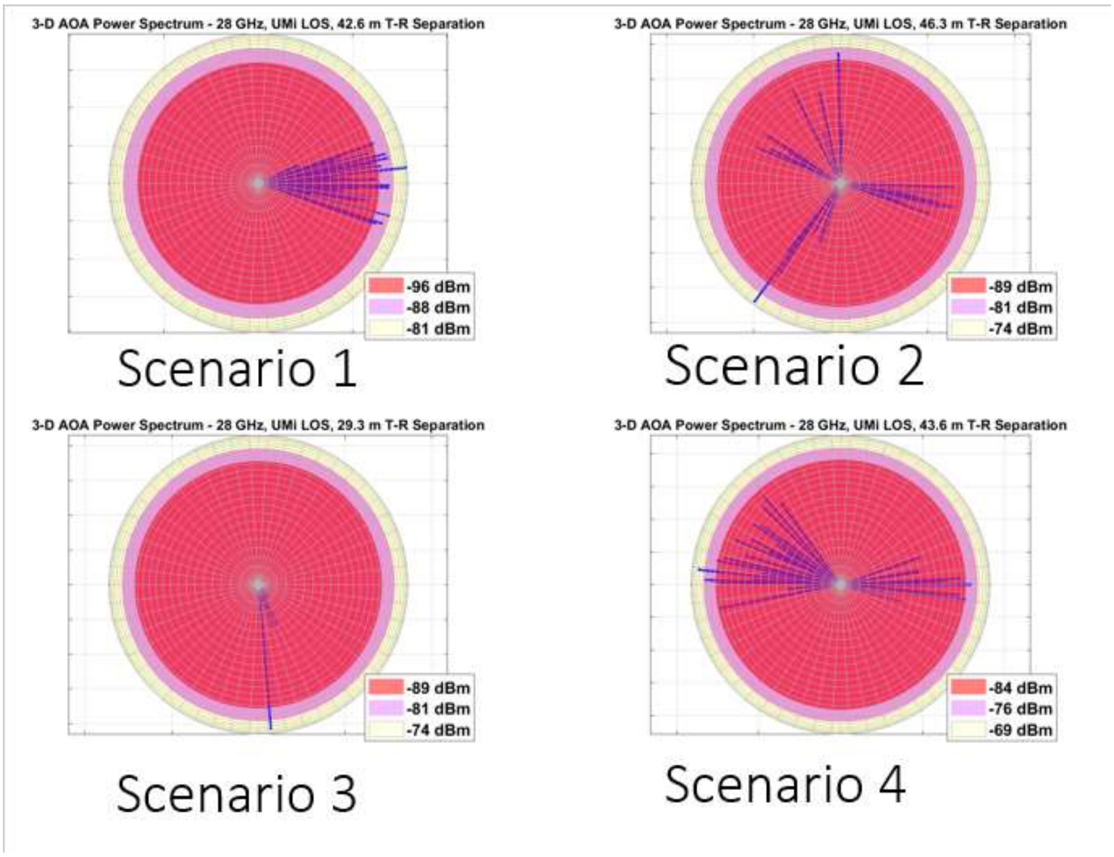


Figure III.9 3D Angel of Arival (AOA) Power spectrum of Umi-Los in 28 GHz in four season in massive mimo

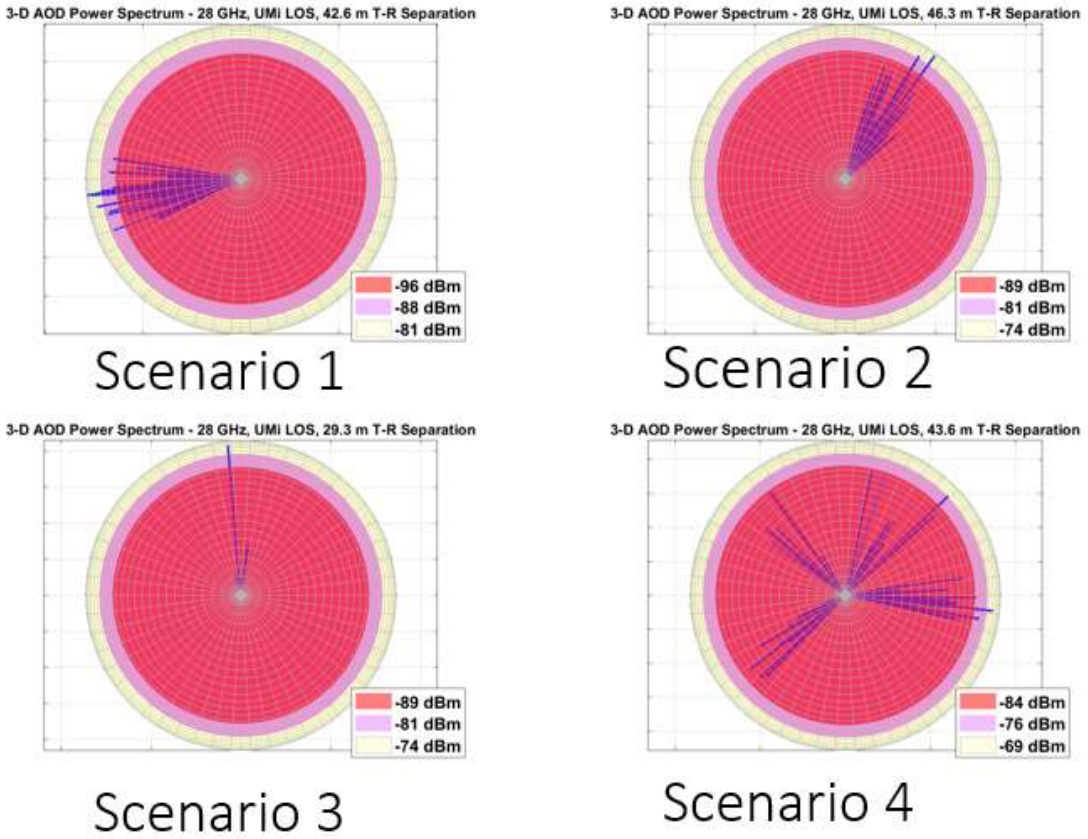


Figure III.10 3D Angel of Departure (AOD) Power spectrum of Umi-Los in 28 GHz in four season in massive mimo

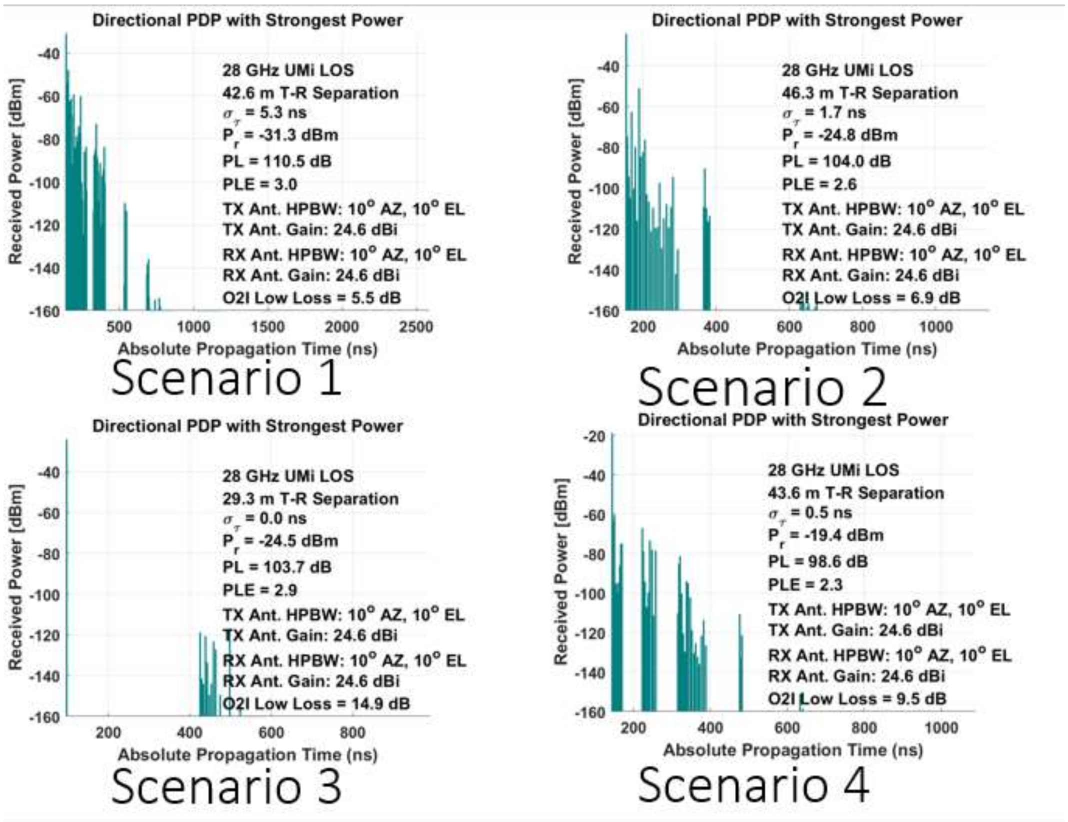


Figure III.11 Directional Power Delay Profile channel 28 GHz

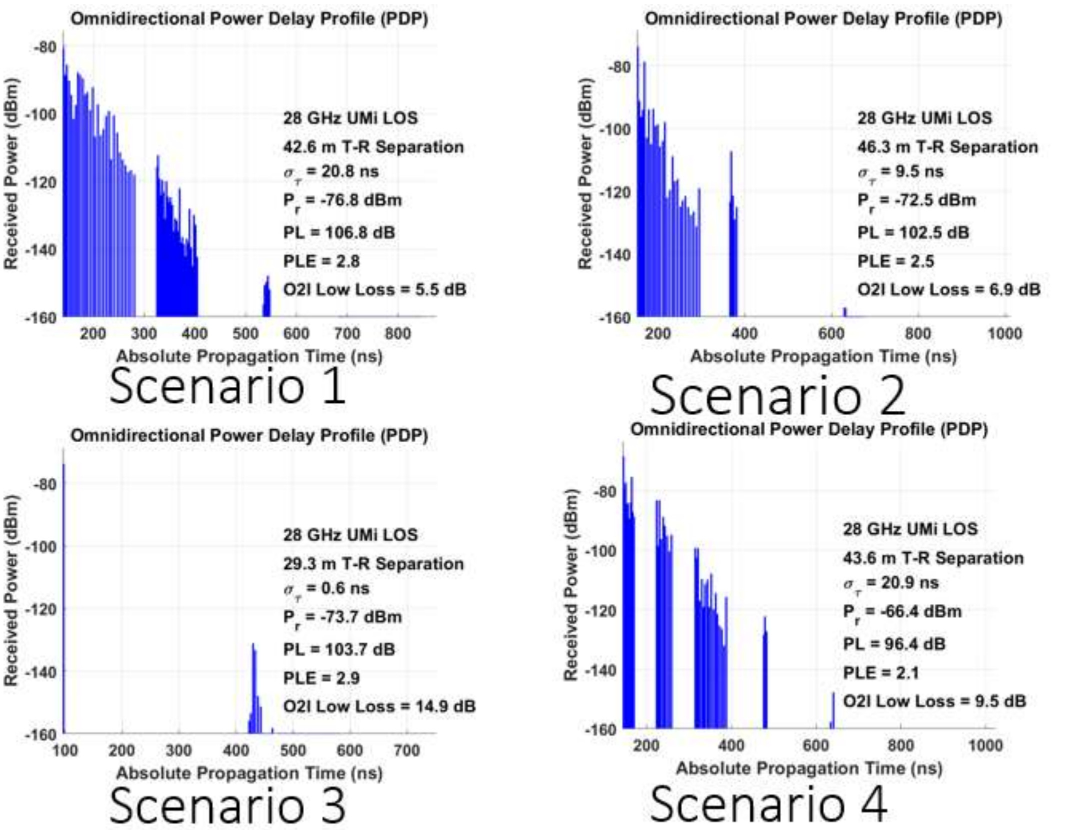
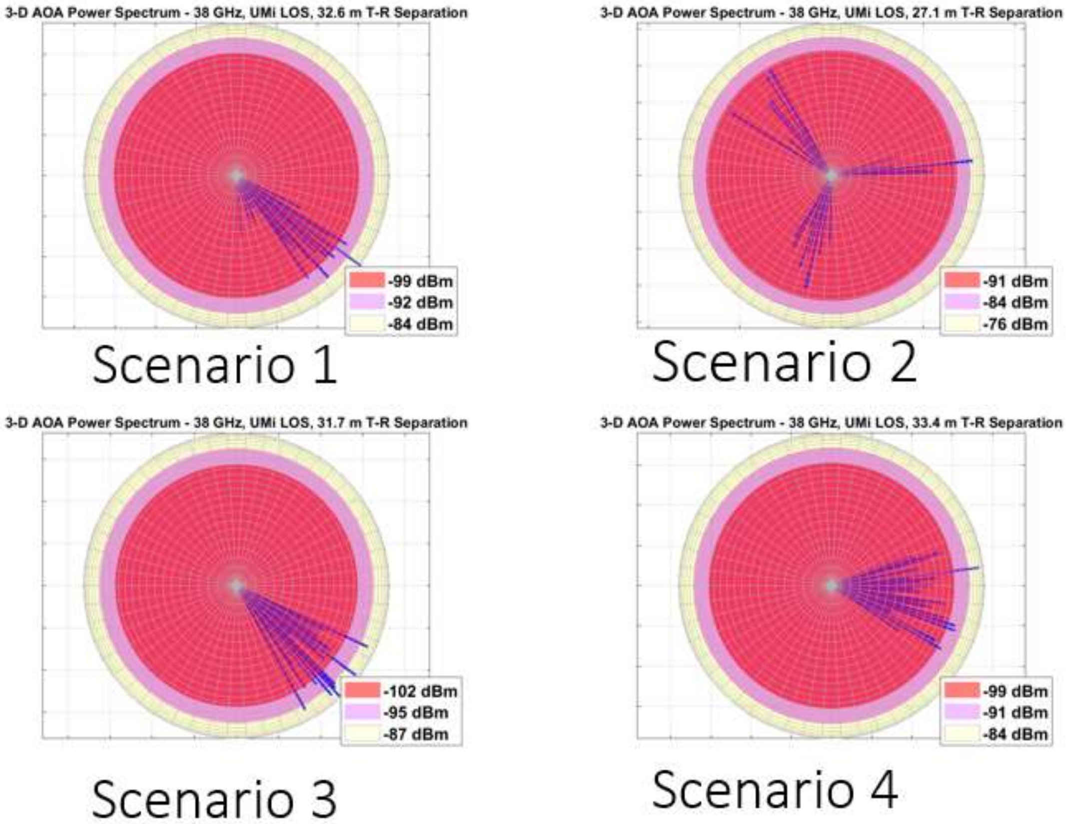
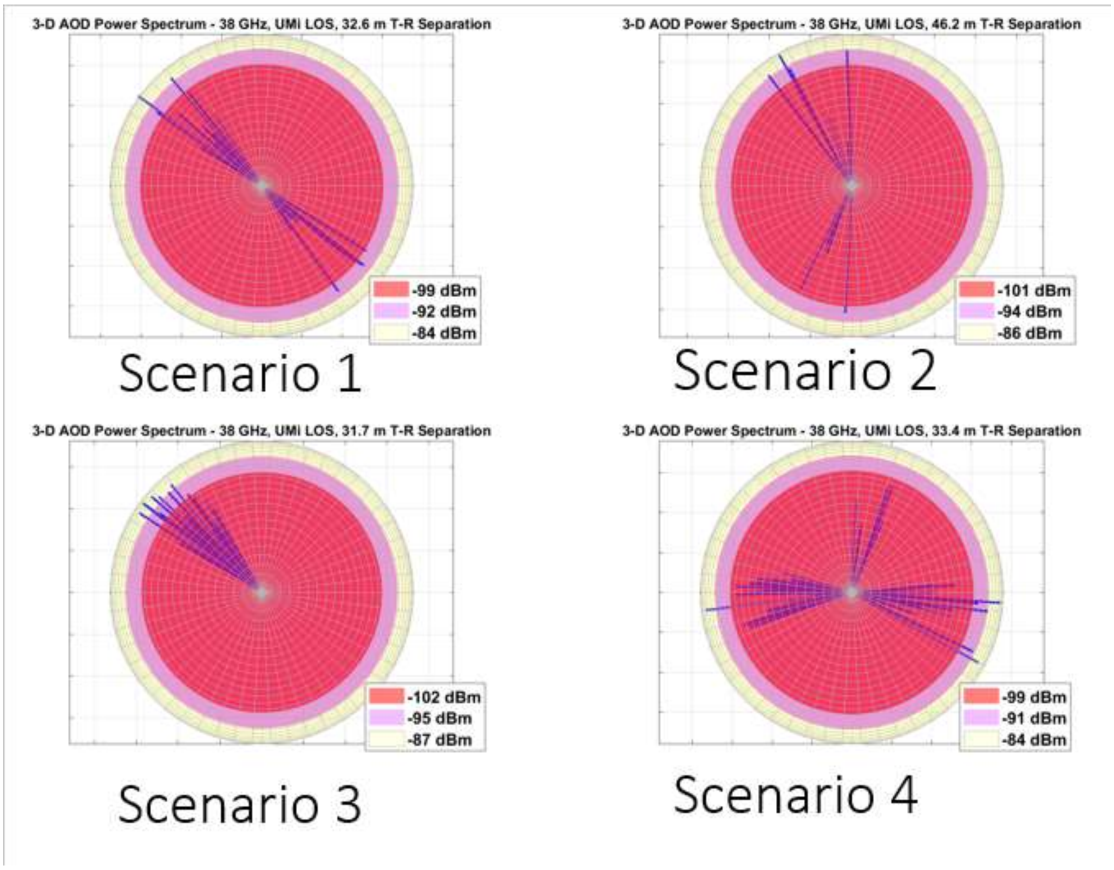


Figure III.12 Omnidirectional Power Delay Profile channel 28 GHz



3D

Figure III.13 Angel of Arival (AOA) Power spectrum of Umi-Los in 38 GHz in four season in massive mimo



3D

Figure III.14 Angel of Departure (AOD) Power spectrum of Umi-Los in 38 GHz in four season in massive mimo

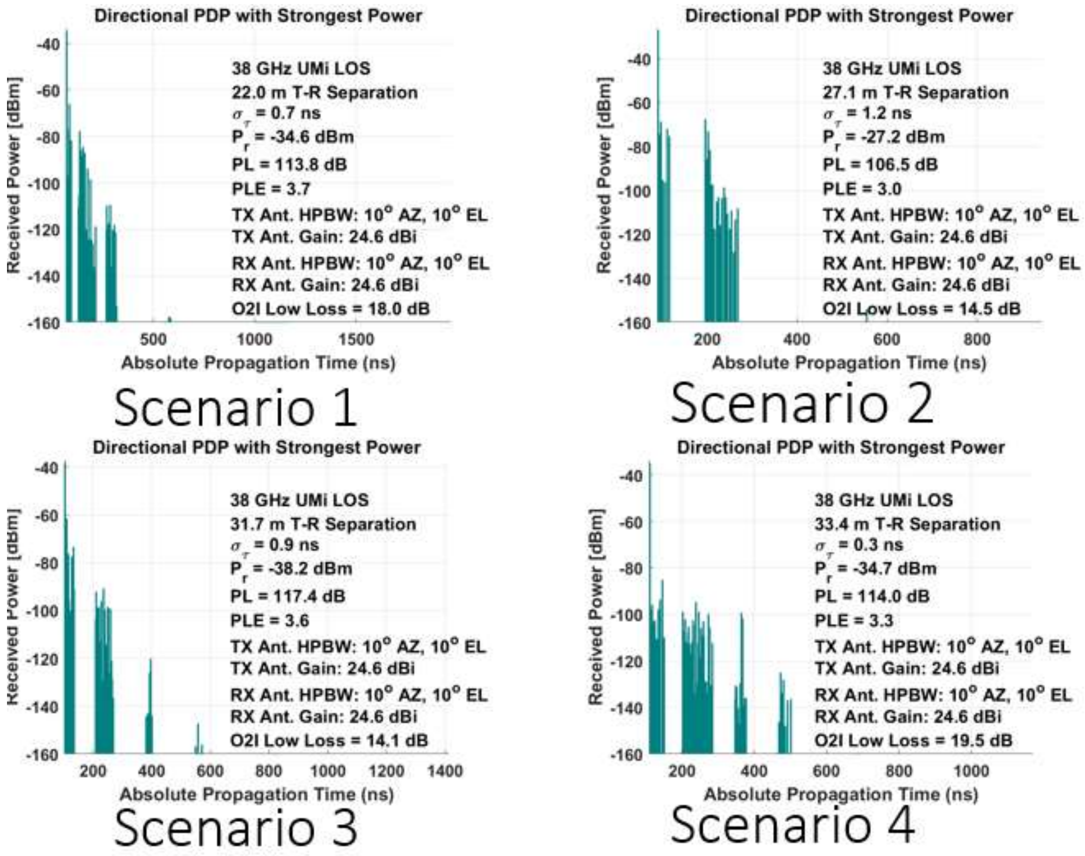


Figure III.15 Directional Power Delay Profile (PDP) for channel 38 GHz

we can summarize results in table III.3, As illustrated in **Table III.3**

Freq Channel[GHz]	Scenario	O2I penetration loss [dB]
28	1	5.5
	2	6.9
	3	14.9
	4	9.5
38	1	18
	2	14.5
	3	14.1
	4	19.5

Table III.3 Results for Directional PDP

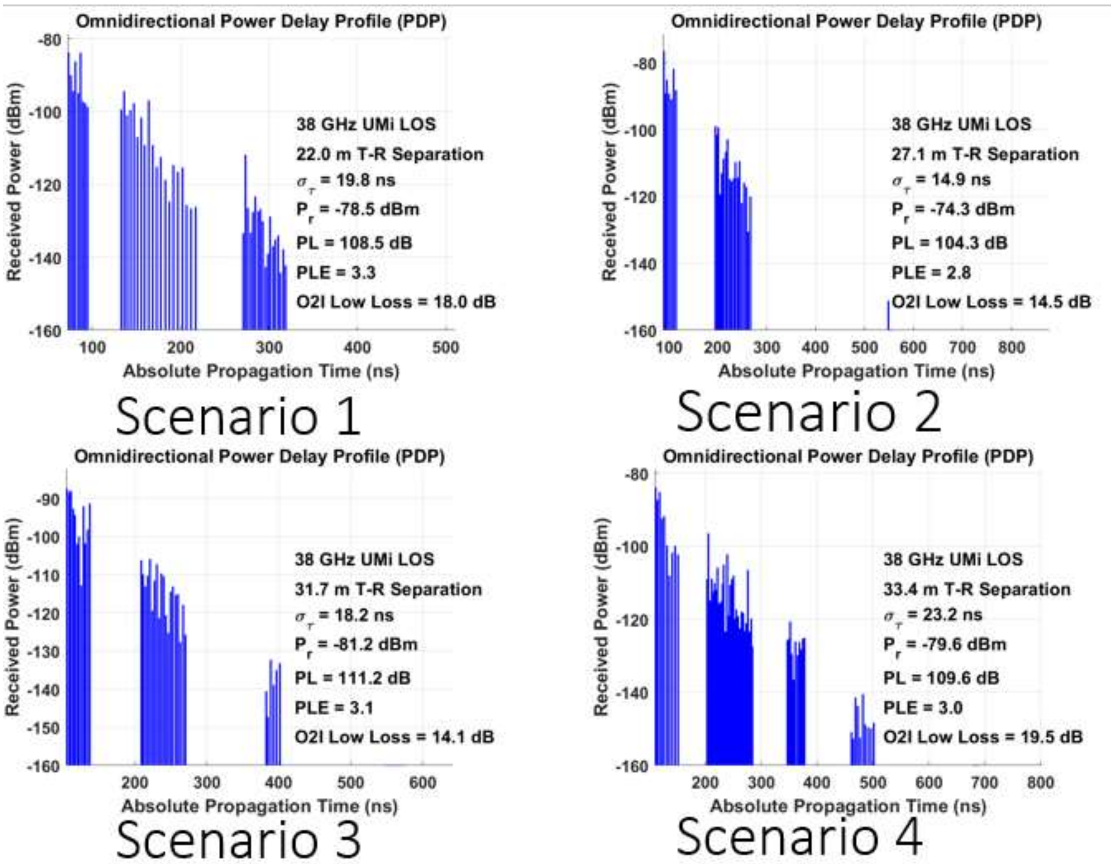


Figure III.16 Omnidirectional Power Delay Profile (PDP) for channel 38 GHz

Freq Channel[GHz]	Scenario	O2I penetration loss [dB]
28	1	5.5
	2	6.9
	3	14.9
	4	9.5
38	1	18
	2	14.5
	3	14.1
	4	19.5

Table III.4 Results for Omnidirectional PDP.

Scenario For massive MIMO in the LOS environment

In this scenario we adopt the parameters bellow:

Average precipitation rate for the city of EL Oued: 00 mm / h.

Average barometric pressure for the city of EL Oued: 1015.3 mbar.

Average humidity for the city of EL Oued: 43.4%.

Temperature: 43.7 C.

Number of receiver slots: 100.

Scenario: Urban Micro Cell.

Transmitter power: 30 dBm.

Array Type: Uniform Rectangular Antenna Array (URA).

As It is shown in the following tables , **Table III.5, Table III.6, Table III.7, Table III.8, Table III.9, Table III.10, Table III.11, Table III.12, Table III.13, Table III.14, Table III.15 and Table III.16**

MIMO utiliser	PLE	PL (dB)	Puissance reçue (dBm)	RMS retard de propagation (ns)
2*2	2.8	117.9	-38.7	5.3
3*3	2.5	110.7	-31.5	1.7
4*4	2.7	114.4	-35.2	0.0
5*5	3.1	122.4	-43.2	0.9
6*6	2.9	118.6	-39.4	0.3
7*7	2.7	114,6	-35.4	1.7

Table III.5 Path Loss: received power and RMS delay propagation, (for the 28 GHz LOS scenario at 100 m distance, for the directional antenna).

MIMO utiliser	PLE	PL (dB)	Pr (dBm)	RMS retard de propagation (ns)
2*2	2.6	114.3	-84.3	20.8
3*3	2.4	109.2	-79.2	9.5
4*4	2.7	114.4	-84.4	0.6
5*5	2.7	116.2	-86.2	18.2
6*6	2.6	114.2	-84.2	23.2
7*7	2.4	110.2	-80.2	8.9

Table III.6 Path Loss: received power and RMS delay propagation, (for the 28 GHz LOS scenario at 100 m distance, for the omnidirectional antenna).

MIMO utiliser	PLE	PL (dB)	Pr (dBm)	RMS retard de propagation (ns)
2*2	2.7	124	-44.8	5.3
3*3	2.4	116.7	-37.5	1.7
4*4	2.7	124.6	-45.4	0.3
5*5	3.3	137.6	-58.4	0.6
6*6	2.2	111.9	-32.7	0.5
7*7	2.9	128.4	-49.1	1.1

Table III.7 Path Loss: received power and RMS delay propagation, (for the 28 GHz LOS scenario at 200 m distance, for the directional antenna).

MIMO utiliser	PLE	PL (dB)	Pr (dBm)	RMS retard de propagation (ns)
2*2	2.6	120.3	-90.3	20.8
3*3	2.3	115.3	-85.3	9.5
4*4	2.6	120.2	-90.2	23.2
5*5	3	131.4	-101.4	9.9
6*6	2.1	109.7	-79.7	20.9
7*7	2.8	126.2	-96.2	17.2

Table III.8 Path Loss: received power and RMS delay propagation, (for the 28 GHz LOS scenario at 200 m distance, for the omnidirectional antenna).

MIMO utiliser	PLE	PL (dB)	Pr (dBm)	RMS retard de propagation (ns)
2*2	2.7	128.9	-49.7	5.3
3*3	2.4	121.6	-42.4	1.7
4*4	2.5	125.4	-46.2	0.0
5*5	2.8	133.4	-53.2	0.9
6*6	2.7	129.5	-50.3	0.3
7*7	2.9	135.0	-55.8	0.6

Table III.9 Path Loss: received power and RMS delay propagation, (for the 28 GHz LOS scenario at 350 m distance, for the directional antenna).

MIMO utiliser	PLE	PL (dB)	Pr (dBm)	RMS retard de propagation (ns)
2*2	2.5	125.2	-95.2	20.8
3*3	2.3	120.2	-90.2	9.5
4*4	2.5	125.4	-95.4	0.6
5*5	2.6	127.2	-97.2	18.2
6*6	2.5	125.1	-95.1	23.2
7*7	2.8	131.7	-101.7	19.3

Table III.10 Path Loss: received power and RMS delay propagation, (for the 28 GHz LOS scenario at 350 m distance, for the omnidirectional antenna).

MIMO utiliser	PLE	PL (dB)	Puissance reçue (dBm)	RMS retard de propagation (ns)
2*2	2.9	122.9	-43.6	5.3
3*3	2.6	115.6	-30.4	1.7
4*4	2.8	119.4	-40.1	0.0
5*5	3.2	127.4	-48.2	0.9
6*6	3.0	123.5	-44.3	0.3
7*7	3.2	129	-49.8	0.6

Table III.11 Path Loss: received power and RMS delay propagation, (for the 38 GHz LOS scenario at 100 m distance, for the directional antenna).

MIMO utiliser	PLE	PL (dB)	Pr (dBm)	RMS retard de propagation (ns)
2*2	2.8	119.2	-89.2	20.8
3*3	2.5	114.1	-84.1	9.5
4*4	2.8	119.4	-89.4	0.6
5*5	2.9	121.2	-91.2	18.2
6*6	2.8	119.1	-89.1	83.2
7*7	3.1	125.7	-95.7	19.3

Table III.12 Path Loss: received power and RMS delay propagation, (for the 38 GHz LOS scenario at 100 m distance, for the omnidirectional antenna).

MIMO utiliser	PLE	PL (dB)	Pr (dBm)	RMS retard de propagation (ns)
2*2	2.6	123.7	-44.4	1.2
3*3	2.9	124.4	-50.7	0.6
4*4	3	132.8	-53.6	0.7
5*5	2.4	130.4	-51.2	0.2
6*6	3.4	142.5	-63.3	0.6
7*7	2.7	125.6	-46.6	1.7

Table III.13 Path Loss: received power and RMS delay propagation, (for the 38 GHz LOS scenario at 200 m distance, for the directional antenna).

MIMO utiliser	PLE	PL (dB)	Pr (dBm)	RMS retard de propagation (ns)
2*2	2.5	121.5	-91.5	14.9
3*3	2.8	127.8	-97.8	10.5
4*4	2.8	127.6	-97.6	19.8
5*5	2.6	124.4	-94.4	15.2
6*6	3.1	136.3	-106.3	9.9
7*7	2.5	121.2	-91.2	8.9

Table III.14 Path Loss: received power and RMS delay propagation, (for the 38 GHz LOS scenario at 200 m distance, for the omnidirectional antenna).

MIMO utiliser	PLE	PL (dB)	Pr (dBm)	RMS retard de propagation (ns)
2*2	2.7	133.6	-54.4	0.2
3*3	3.0	139.5	-60.2	0.3
4*4	2.7	133.6	-54.4	8.2
5*5	2.8	124.1	-54.9	5.8
6*6	2.7	133.2	-54	3.2
7*7	2.7	133.8	-54.6	5.3

Table III.15 Path Loss: received power and RMS delay propagation, (for the 38 GHz LOS scenario at 350 m distance, for the directional antenna).

MIMO utiliser	PLE	PL (dB)	Pr (dBm)	RMS retard de propagation (ns)
2*2	2.6	130.8	-100.8	7.2
3*3	2.8	135.6	-105.6	15.9
4*4	2.6	129.2	-99.2	19.1
5*5	2.5	128	-98	18.3
6*6	2.6	129	-99	18.8
7*7	2.6	130.2	-100.2	20.8

Table III.16 Path Loss: received power and RMS delay propagation, (for the 28 GHz LOS scenario at 350 m distance, for the omnidirectional antenna).

- path loss (for the 28 GHz LOS scenario at 100 m distance, for the directional antenna and for the omnidirectional antenna:
  - MIMO value is 2*2

The path loss value of the directional antenna was greater compared to the value of the omnidirectional path

- The value of MIMO 3 * 3

The loss path value of the directional antenna is very close to its omnidirectional value

- MIMO value is 4*4

The loss path value was about the same

- MIMO value is 5*5

The value of the path loss for the directional antenna was greater compared to its value in all directions, as well as at the value of MIMO 6 * 6 and the value of MIMO 7 * 7

- Path loss (for the 28 GHz LOS scenario at 200 m distance, for the directional antenna and for the omnidirectional antenna:

The path loss value of the directional antenna is slightly larger than that of the omnidirectional

Summary of 28 GHz in Mimo: We notice that in all directions, the loss track ratios are lower compared to the air direction, and increasing the distance slightly affects its decrease.

- Path loss (for the 38 GHz LOS scenario at 100 m distance, for the directional antenna and for the omnidirectional antenna:
  - MIMO value is 2*2

The path loss value of the directional antenna was greater compared to the value of the omnidirectional path

- The value of MIMO 3 * 3

The loss path value of the directional antenna is very close to its omnidirectional value

MIMO value is 4*4, The loss path value was about the same

- MIMO value is 5*5

The value of the path loss for the directional antenna was greater compared to its value in all directions, as well as at the value of MIMO 6 * 6 and the value of MIMO 7 * 7

- Path loss (for the 38 GHz LOS scenario at 200 m distance, for the directional antenna and for the omnidirectional antenna:

The path loss value of the directional antenna is slightly larger than that of the omnidirectional

- Path loss (for the 38 GHz LOS scenario at 350 m distance, for the directional antenna and for the omnidirectional antenna:

The path loss value of the directional antenna is slightly larger than that of the omnidirectional

summary of 38 GHz in Mimo: we note that the value of the lost path at 28GHz and 38 GHz at omnidirectional is less than the antenna direction and that increasing the distance has no effect to reduce or increase the lost path

III.5 Conclusion

This chapter presents Analysis of O2I penetration loss of mmWave channels at 28 and 38 GHz operating frequency for different scenarios Low loss / High loss and TX/RX Antenna HPBW azimuth/Elevation 10°/15°. The type of building (standard glass, wood, IRR glass and concrete....) and Antenna properties (HPBW) affects channel characteristic O2I penetration loss. After the studies of the channels mentioned above, the channel 28 GHz is less affected, but the 38 GHz channels is better for supporting the impact of this change. In case of High loss, channel 38 GHz is more affected by the change of the Antenna properties HPBW, but the 28 GHz channels is better for supporting the impact of this change. In case of HPBW=10°, channels 38GHz is more effected by the change of the type of building, but channel 28 is less effected than the other channels. In case of HPBW=15°, channel 38 GHz is more effected by the change of the type of building , channels 28 GHz is less effected than 38 GHz. Directional PDP and Omni-directional PDP have the same values of O2I penetration loss for all channels.

General Conclusion

General Conclusion

Despite the unique capabilities of technologies used by millimeter waves to provide propagation models for the next generations of wireless communication systems, these technologies still face many challenges that hinder their practical use, especially in communication systems cellular.

It is expected that millimeter wave communication technology will be one of the alternatives that will drastically change the design and performance of the communication system for future generations due to the wide frequency bandwidth. This study included the examination of the most important problems related to the characteristics of the propagation of the millimeter waves in particular the distance traveled by the wave in the presence of natural phenomena.

In this work, channel modeling for 5G mmWave cellular communication of an urban microcell in the case of LOS is simulated at an operating frequency of 28 GHz for different number of antenna elements at the transmitter and receiver (MIMO). The different parameters affecting the channel have been taken into account in the simulation using the NYUSIM model. The study of the 28 and 38 Ghz channel is studied for the case of different distance between the transmitter and the receiver of which, the channel parameters such as AoA/AoD power spectra...etc. are recorded and discussed.

At the end of our study, we propose as important solutions the use of beamforming techniques in combination with MIMO technology.

REFERENCES

REFERENCES

[1] Horváth, Péter, and István Frigyes. "Application of the MIMO concept in millimeter-wave broadband wireless access networks." International Journal of Wireless Information Networks 11 (2004): 217-225.

[2] LANG, SHUANGQING. "Study on propagation path loss in 28GHz and 39GHz and key parameters for 5G." (2019).

[3] Jain, Aishwary, Pankaj Shukla, and Lokesh Tharani. "Performance of MIMO system under different fading channels with ZF and MRC." 2017 Recent Developments in Control, Automation & Power Engineering (RDCAPE). IEEE, 2017.

[4] Rappaport, Theodore S., et al. "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 (2017): 6213-6230.

[5] Samimi, Mathew K., et al. "28 GHz millimeter-wave ultrawideband small-scale fading models in wireless channels." 2016 IEEE 83rd Vehicular Technology Conference (VTC Spring). IEEE, 2016.

[6] Sun, Shu, et al. "Path loss, shadow fading, and line-of-sight probability models for 5G urban macro-cellular scenarios." 2015 IEEE Globecom Workshops (GC Wkshps). IEEE, 2015.

[7] Rappaport, T. S., Sun, S., Mayzus, R., Zhao, H., Azar, Y., Wang, K., ... & Shu, C. (2013). Millimeter wave mobile communications for 5G cellular: It will work!. IEEE Access, 1, 335-349.

[8] ZEKRI, Abdelbasset BEDDA et AJGOU, Riadh. Study of mmWave channels for different scenarios. In : 2019 6th International Conference on Image and Signal Processing and their Applications (ISPA). IEEE, 2019. p. 1-6.

[9] Alkhateeb, A., Ayach, O. E., Serpedin, E., & Heath Jr, R. W. (2015). Spatially sparse precoding in millimeter wave MIMO systems. IEEE Transactions on Wireless Communications, 14(9), 4786-4799.

[10] Sun, S., MacCartney, G. R., Samimi, M. K., & Rappaport, T. S. (2015, December). “Synthesizing omnidirectional antenna patterns, received power and path loss from directional antennas for 5G millimeter-wave communications“. In 2015 IEEE Global Communications Conference (GLOBECOM) (pp. 1-7). IEEE.

[11] Wang, H., Zhang, X., & Xu, W. (2020). Millimeter-wave V2X communication: An overview and future directions. IEEE Wireless Communications, 27(5), 146-153.

[12] NYUSIM: A Simulation Tool for Millimeter-Wave Wireless Systems. Retrieved from https://wireless.engineering.nyu.edu/nyusim/

[13] M. Ghosh, T. Thomas, M. Cudak, R. Ratasuk, P. Moorut, F. Foukalas, and T. Kim, "Millimeter-Wave Enhanced Local Area Systems: A High-Data-Rate Approach for Future Wireless Networks," IEEE Journal on Selected Areas in Communications, vol. 32, no. 6, pp. 1152-1163, June 2014.

[14] ZEKRI, Abdelbasset Bedda, AJGOU, Riadh, et HETTIRI, Messaoud. Impact of Azimuth and Elevation Half Power Beam Width on Human Blockage scenarios in mmWave Channels. In : 020 1st International Conference on Communications, Control Systems and Signal Processing (CCSSP). IEEE, 2020. p. 41-45.

[15] CHALLITA, Frédéric, MARTINEZ-INGLES, Maria-Teresa, LIÉNARD, Martine, et al. Line-of-Sight Massive MIMO Channel Characteristics in an Indoor Scenario at 94 GHz. IEEE Access, 2018, vol. 6, p. 62361-62370».

[16] «millimeter-wave frequencies,” in 2015 IEEE Global Telecommunications Conference (GLOBECOM 2015), 2015, pp. 3948– 3953».

[17] The Role of Massive MIMO in 5G. Michael Wang. Oct 23, 2018 [Enligne]. https: //medium.com, 06/06/2020, 11:08.

[18] S. N. Sur, R. Bera and B. Maji, “Capacity Analysis of MIMO in Non-Uniform Nakagami Channel with Linear Receiver”. IETE Journal of Research, vol. 63, pp.795-804, May 2017».

[19] Ko, J., Cho, Y. J., Hur, S., Kim, T., Park, J., Molisch, A. F., ... & Cho, D. H. (2017). Millimeter-wave channel measurements and analysis for statistical spatial channel model in in-building and urban environments at 28 GHz. IEEE Transactions on Wireless Communications».

[20] Alkhateeb, A., Ayach, O. E., Leus, G., & Heath Jr, R. W. (2014). Channel estimation and hybrid precoding for millimeter wave cellular systems. IEEE Journal of selected topics in signal processing, 8(5), 831-846.

[21] ZEKRI, Abdelbasset Bedda, AJGOU, Riadh, CHEMSA, Ali, et al. Analysis of Outdoor to Indoor Penetration Loss for mmWave Channels. In : 020 1st International Conference on Communications, Control Systems and Signal Processing (CCSSP). IEEE, 2020. p. 74-79.