Comparative Study of Rural Macrocell (RMa) and Urban Macrocell (UMa) Propagations and their Power Delay Profile (PDP) for Millimeter Wave 5G Cellular Network in LOS Communication

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***Abstract* – *This paper analyses the performance of Rural Macrocell (RMa) and Urban Macrocell (UMi) propagations based on their power delay profiles (PDP) for some specific frequencies to make a proper judgement on the selection of these frequencies in Urban Macrocell (UMa) and Rural Macrocell (RMa) propagation. The overall judgement was done for Line of sight (LOS) communication for the directional propagation. The simulation procedure has performed in NYUSIM software developed by New-York University (NYU) USA which uses the MATLAB in the backend to perform. Later on, the performances have evaluated based on their directional power delay profiles (PDP). Some parameters like the Pathloss, Pathloss exponent, and Received power has played the key role to measure the performance. The results have shown with their characteristics curve generated for the frequencies like 16, 20, 28, 37, 48, 56, 60, 71, 82GHz through Origin software and finally, the outcomes have compared with each other both in UMa and RMa propagation and some suggestions are suggested for the use of millimeter wave frequency bands in 5G cellular communication.*

Keywords – Rural Macrocell (RMa), Urban Macrocell (UMa), Millimeter Wave (mmWave), LOS Communication. 5G Networks, Power Delay Profile (PDP).

1. INTRODUCTION

Communication has become the fastest growing sector right now and the statistics shows that the amount of smart communicating devices like Mobile phones, Tablets, Computers, Smart gadgets are now expanding so rapidly [1]. Therefore, the concept has alco become very clear that the uses of these devices in our daily life are increasing and in most cases these devices are communicating wirelessly and thus the wireless communication has opened a new era of research. The quality of services (QoS) for the wireless communication has become a burning question as the demand of the users are changing vary frequently and thus the network researchers are always very busy in search of meeting those demands. It is predicted that by 2020, a huge number of these devices will be connected into our network and as the number of devices will be high so their demand of data transfer rate will also be high [2]. The network architecture and its some parameters like the network speed, data traffic, communication protocols are some experimental issues.

Now to ensure a stable network with the capacity of handling a vast number of users and ensuring a great amount of speed indicates to switch to the next generation of networks commonly known as the fifth-generation network or 5G. Now the network is still an experimental field under the 3rd generation partnership project (3GPP) [1][3]. Mainly the spectrum allocation is the most experimenting sector as their standardization has not done yet. The spectrum from 0.5GHz to 100GHz are now the most significant area where a vast number of researches are performing. These frequencies are called millimeter wave (mm Wave) bands [7]. Millimeter waves consist very short wavelengths which has a common range from 10 millimeter to 1 millimeter and sometimes the wavelength goes below 1 millimeter [4]. Now the frequencies under 30GHz are mostly considered as the millimeter wave but if we observe the frequencies above 30GHz, we will have some frequencies with high data transmission rate and wide channel of bandwidth. They can offer the data rates up to Gigabytes per second which could be a solution of ensuring better speed of communication in fifth generation networking. The use of these millimeter wave (mm Wave) bands may be a better solution for installing the internet of things (IoT) as well. Some applications like high definition (HD) video streaming with a low latency content can be performed using this millimeter wave (mm Wave) technology. It can ensure a high data transmission rate between the data center and receiver with great throughput and lower delay property [3]. Millimeter wave (mm Wave) is optimal for its high frequency and speed of data transmission. Mostly the data transmission speed increases as the frequency increases. But some environmental and physical factors may affect the propagation and its performances. High attenuation in the atmosphere, signal absorption by gases can be the factors for the loss of transmission performances. Again, the barometric pressure, Humidity, Rain rate, Transmission power are some common parameter that can change the propagation characteristics at the receiver end [3][9]. Therefore, the power delay profile (PDP) of millimeter wave (mm Wave) frequency bands consist some important parameters which can be used to compare the performance of different frequencies as well as their characteristics. As the frequencies are very high, so their strength is comparatively lower than high frequencies [11]. So, these high frequencies can be easily blocked by any physical equipment's like buildings, trees cars, human blockage etc. Therefore, the first probable concern should be the Line of sight (LOS) and Non line of sight (NLOS) propagation.

Regardless of some physical issues described above, millimeter wave (mm Wave) frequencies can offer some great performance for the massive multiple input and multiple output (MIMO) [17]. It is such a kind of technology where more than one antenna channels and access points can be used to propagate the signal for high speed of data transmission. The antennas on the both side of communication has the processing power of utilizing the different paths that exist between two entities of the network for ensuring the improvements in data transmission. Following this method, the single radio link volume can be multiplied to speed up the data transmission where the receiver antennas will exploit the multipath propagation with proper synchronization in a single time [5]. It allows the network to transmit and receive more than one data signal simultaneously over the same radio channel. The multiple input and multiple output (MIMO) devices mainly consist of more than one single antenna or channels [17]. The data transmission and its rate can be farther increased with the application of mote number of antennas with multiple channels. Again, we have some more sectors like beamforming, small cell, full duplex, which are now considered as the parameters of ensuring good quality of services (QoS) in fifth generation (5G) mobile network [8]. Based on the medium of wireless communication, millimeter wave (mm Wave) bands will be the best possible solution in the form of communication medium as it will provide large available spectral channels those will supports the ultra-high data rates [9].

To operate the fifth generation (5G) cellular network with millimeter wave (mm Wave) bands, there are some environmental criteria's where we need to be concern like the Line of Sight (LOS) and the Non-Line of Sight (NLOS) communication [13]. Two operational environment provides non identical data types for some performance measurement parameters like the Directional Power Delay (DPD), Omnidirectional Power Delay (ODP), the Path Loss (PL), Path Loss Exponent (PLE), Received Power (RP) etc. The functionality and environmental performance of these millimeter wave (mm Wave) bands can be far more evaluated when we take the propagation scenarios like Urban Macrocell (UMa) propagation and Rural Macrocell (RMa) propagation as a piece of concern [10].

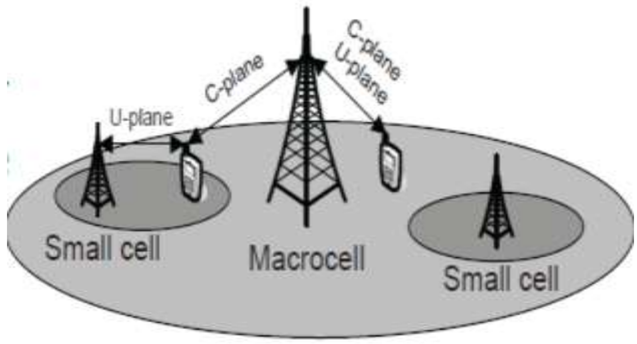

Fig-1: Macrocell Propagation.

A microcell is a cell in telecommunication network that provides radio coverage with larger cellular area and often operated with higher power. Its cellular coverage area is larger than other cells like Microcell, Picocell, Small cell etc [12]. The Macrocell propagation can be classified into two classes like Urban Macrocell (UMa) propagation and Rural Macrocell (RMa) propagation. As the density of obstacles and the number of users is very high in urban area, therefore in urban area, the cellular network is more robust where one Macrocell (MAc) antenna serves many Microcells (MIc) and Picocells to ensure a better service [9][4]. But for rural area the number of sub antennas like microcell are not so much higher under any specific Macrocell antenna as like as in urban area because of the presence of less buildings and obstacles in the area. Therefore, the network is not so much robust and complicated compared to in urban area [13] [16]. The purpose of this paper is to study the characteristics of Urban Macrocell (UMa) propagation and Rural Macrocell (RMa) propagation for some specific millimeter wave (mm Wave) frequency bands and to show the performance inefficiency, corresponding to their Directional Power Delay (DPD) profiles in terms of their path loss, received power at the receiver end and path loss exponent for Line of Sight (LOS) communication in millimeter wave 5G cellular network. Finally characteristics of different frequency bands both for UMa and RMa propagation are plotted according to their Power Delay Profile (PDP) and a judgment has made for the selection of effective frequency band to ensure a better quality of service (QoS) corresponding to their characteristics curve.

2. LITERARUE REVIEW

The path loss model for long distance in rural area like Rural Macrocell (RMa) for 73GHz has been presented in [11]. They showed that their proposed model is comparatively better in performance compared to the existing 3GPP RMa path loss model. Another pathloss model form 2-73.5GHz frequency band has been presented in [12] especially for urban Macrocell (UMa) communication. The pathloss model for the Rural Macrocell (RMa) communication has been described in [13]. They have described how the 3GPP RMa pathloss model in multi frequency close in free space reference distance performs better than the existing ITU-R RMa model. The Line of Sight (LOS) and Non-Line of Sight (NLOS) propagation, a brief comparison has been shown in [14]. The performance of 28GHz and 38GHz millimeter wave (mm Wave) frequency bands and their path loss model has been shown in [15] specially for the New York city. The Omnidirectional and spatial temporal 3-dimensional statistical channel model has been shown in [16]. The multi-tire drone architecture for 5G cellular network has been explained in [01]. A mechanism of using millimeter wave (mm Wave) for installing the next generation mobile communication network has been proposed in [02]. The Omnidirectional and Directional Power delay profiles for millimeter wave (mm Wave) frequencies at LOS environment and their performances has been studied in [03]. The article of millimeter wave channel simulator and the application of it in for 5G cellular network has been discussed in [04]. They have used the NYUSIM channel simulator for the measuring the performance of different frequency bands in 5G cellular network. The performance of millimeter wave channel simulator for machine to machine communication has been studied in [05]. They have shown the output of using millimeter wave (mm Wave) in indoor scenario. The propagation challenges for 5G millimeter wave enabled communication system has been discussed in [07]. They have shown the overall performance of using millimeter wave frequency bands specially in Urban Microcell (UMi) and Urban Macrocell (UMa) communication. A statistical model of mm Wave 5G cellular network in 28GHz and 45GHz with the Massive Multiple Input and Multiple Output System has been shown in [08]. Later on, the propagation scenario of Urban microcell (UMi) and Urban Macrocell (UMa) and their capabilities of implementing 5G cellular network has been explained in [08].

After the reviewing of literature, it has realized that, millimeter wave has been examined by different researchers in their research work both in LOS and NLOS environment, where some parameters like pathloss, pathloss exponent, received power has played a crucial role for the absolute measurement of the performance of Radio wave propagation in different scenarios of cellular areas like Urban Macrocell (UMa), Rural Macrocell (RMa) and Urban Microcell (UMi) area [3]. Several research works are existing related to the comparison of UMa and UMi propagations corresponding to their preferences for millimeter wave 5G cellular network. However, there is a lack of study of millimeter wave frequency bands and their performances corresponding to their Directional Power Delay profile (DPD) for Urban Macrocell (UMa) and Rural Macrocell (RMa) propagation [3][7].

In this paper, a details comparison of performances based on the Directional Power Delay (DPD) profiles for different millimeter wave frequency bands has been presented corresponding to their Urban Macrocell (UMa) and Rural Macrocell (RMa) propagation. The performance has been analyzed in terms of Path loss, Pathloss exponent and the Received power at 16, 20, 28, 37, 48, 56, 60, 71 and 82 GHz operating frequencies for Line of Sight (LOS) communication.

3. METHODOLOGICAL ANALYSIS

Several channel simulators have been developed by the researchers and technological giants. After the study of different channel simulator designed for 5G cellular network, we have realized that the open source simulation software named NYUSIM actually performs very well for the millimeter wave channel simulation [12]. The software consists a wide range of parameters for simulating the millimeter wave (mm Wave) frequency bands [14]. It is especially developed by New York University based on the real-world scenario to perform the general and extensive simulation procedure especially for 5G cellular network. The software is very much effective for the wide band channel propagation measurements for multiple millimeter wave (mm Wave) frequencies having a range from 0.5 GHz to 100 GHz. The simulator mainly consists of 30 different input parameters which are grouped into two categories named channel parameters and antenna properties [14]. Middle of those 30 parameters, 18 parameters are the channel parameters and rest of the 12 parameters are as the antenna parameters. Our main objective is to observe the variations of UMa and RMa propagations in LOS environment. The parameters used in the simulation procedure are listed in the table-1 below.

Table - 01: Parameters used in simulation.

Antenna Properties		Channel Parameter	
Parameter's Name	**Value**	**Parameter's Name**	**Value**
Number of TX Antenna Elements	2	Propagation Scenario	UMa
Number of RX Antenna Elements	2	Radio frequency bandwidth	800 MHz
TX Array Type	ULA	Upper bound of T-R Separation Distance	100 m
RX Array Type	ULA	Lower bound of T-R Separation Distance	100 m
TX Antenna Spacing	0.5 wavelength	Propagation Environment	LOS
RX Antenna Spacing	0.5 wavelength	TX Power	30 dBm
Number of TX Antenna Elements Per Row	2	Barometric Pressure	1013.25 mbar
Number of RX Antenna Elements Per Row	2	Humidity level	50^0C
TX Antenna Azimuth HPBW	10^0C	Temperature level	20^0C
TX Antenna Elevation HPBW	10^0C	Polarization	Co-Pol
RX Antenna Azimuth HPBW	10^0C	Foliage loss	No
RX Antenna Elevation HPBW	10^0C	Rain rate	0 mm/hr

The main change of the value of parameters are applied in "Propagation Scenario" which has been changed to RMa for Rural Macrocell propagation and to UMa for Urban Macrocell Propagation. NYUSIM software provides channel impulse responses in time and space which are closer to real experiment [14][15]. The system is utilized such as that support realistic physical layer and link layer simulations. It uses the MATLAB application software runtime environment to perform the Monte Carlo simulations for calculating the perfect impulse response of channels respect to their input parameters value [14][3].

The simulation of every single frequency for path loss mode generates six output figures with some additional data sheets. For every single frequency band, the simulation is performed twice. Initially the RMa simulation has performed for any specific frequency band and later on the UMa simulation is performed for that specific frequency band. Continuous simulation process has performed for same input parameters except the change in frequency band. During the simulation, the antenna properties are considered as an important factor. For NYUSIM simulator, considering the Half Power Bean width, the antenna gain is considered in relative to the traditional Isotropic antenna. The antenna used in simulation procedure, consist the pattern of the following properties-

$$G(\theta, \emptyset) = \max\left(G_0 e^{-\alpha\theta^2 - \beta\emptyset^2}, \frac{G_0}{100}\right)$$

$$\alpha = \frac{4ln\,(2)}{\theta^2{}_{3dB}}, \beta = \frac{4ln\,(2)}{\emptyset^2{}_{3dB}}, G_0 = \frac{4123\eta}{\theta_{3dB\emptyset 3dB}}$$

A details antenna property is described in [13], where the azimuth and elevation angle offsets in the propagation from the bore sight direction in degree is denoted by $(\theta, \emptyset)$. The maximum directive gain from the bore sight is denoted by G0, $(\theta_{3dB}, \emptyset_{3dB})$ represents the azimuth and elevation in HPBWs (Half Power Beam Width) in degree, the two parameters (α, β) are the parameters those are depended on the HPBW values. The typical antenna efficiency is denoted by η, in average the value of η is 0.7 [14].

For calculating the receiving singnal strength at the receiver end, the angle of arival is an important parameter. The angle of departuer actually discrobes the angle of the transmitting signal. The pathloss exponent denotes the signal loss in communication which is dependable in antenna hight and size.

The pathloss model used in NYUSIM simulator has been expressed like the following below:

$$PL^{CI}(f, d)[dB] = FSPL(f, 1\,m)[dB] + 10nlog_{10}\left(\frac{d}{d_0}\right) + AT[dB] + X_{\sigma}^{CI},$$

$$\text{Where, } d \geq d_0 m$$

Were the carrier frequency in GHz is denoted by f, the transmitter and receiver separation distance is denoted by d, the path loss exponent (PLE) is represented by n, the free space reference distance is calculated in meters, and set to 1 meter in NYUSIM channel model [14]. For the propagation of radio wave, the attenuation term AT is induced by the atmosphere, χ_{σ}^{CI} is a zero-mean Gaussian random variable with a standard deviation σ in dB, and FSPL(f, 1 m) denotes the free space path loss in dB at a T-R separation distance of

1 meter at the carrier frequency f. Now the value of FSPL(f, 1 m) can be calculated as

$$FSPL(f, 1\ m)[dB] = 20log_{10}\left(\frac{4\pi f + 10^9}{c}\right) = 32.4[dB] + 2$$

Where, c is the speed of the light, and f is the frequency in GHz. The term AT is characterized by:

$$AT[dB] = \alpha[dB/m] \times d[m]$$

Where α is the attenuation factor in dB/m for the frequency range of 1 GHz to 100 GHz.

The following theorems are applied in NYUSIM channel simulator for 5G cellular network simulation to perform the Monte-Carlo estimation technique for estimating the probability of intermodulation interference in the cellular wireless network [5][14].

4. RESULT & DISCUSSION

The total outcome of the simulation process are classified under three different sectors with the main objective of comparing the performance of different frequency bands respect to their Urban Macrocell (UMa) and Rural Macrocell (RMa) propagation. The outcomes are evaluated based on the categories like path loss, path loss exponent and receive power for the directional power delay (DPD) in the line of sight communication respect to their UMa and RMa propagation of the simulated frequency bands.

4.1 Path Loss

The pathloss for the Urban Macrocell (UMa) and Rural Macrocell (RMa) propagation corresponding to their Directional Power Delay Profiles at 16, 20, 28, 37, 48, 56, 60, 71 and 82 GHz operating frequencies in Line-of-Sight communication are shown in figure – 02. 16GHz frequency has the lower pathloss both for Urban Macrocell (122.7 dB) and Rural Macrocell (120 dB) propagation. The highest path loss (140.1 dB for UMa and 137.4 dB for RMa) obtained for both of them at 60GHz. The graph also shows that the path loss increases from 16 GHz to 60 GHz frequency linearly and after that it decreases at 71GHz. One more characteristic is observed that the UMa propagation has higher pathloss compared to RMa propagation.

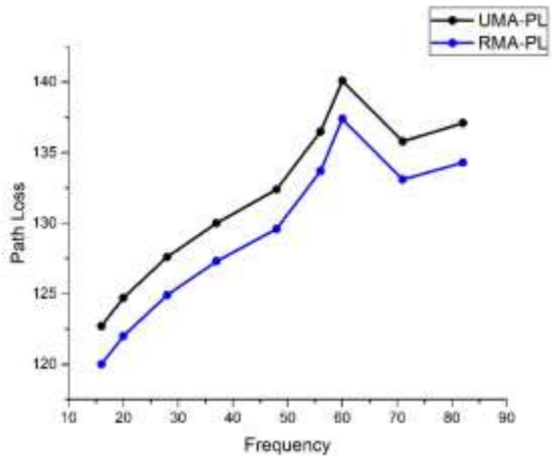

Fig-2: Path Loss at 16, 20, 28, 37, 48, 56, 60, 71 and 82 GHz frequency for UMa and RMa propagation in Line-of-Sight communication.

4.2 Path Loss Exponent

Figure-3 shows the pathloss exponents for the Urban Macrocell (UMa) and Rural Macrocell (RMa) propagation for 16, 20, 28, 37, 48, 56, 60, 71 and 82 GHz operating frequencies respect to their Directional Power Delay Profiles in LOS communication. The graphs are identical both for UMa and RMa propagation corresponding to their received power but in terms of finding the best frequency corresponding to their pathlosses exponents, the 60GHz gives the highest value (2.8 for UMa and 2.7 for RMa). Again the graph also shows that, form 16GHz to 48GHz the pathlosses exponents of all frequency bands are constant (2.5 for UMa and 2.4 for RMa) but after crossing the 48GHz frequency, the pathloss exponent suddenly increases and at 60GHz its become the highest, Path loss exponent decreases again after crossing the 60GHz frequency and becomes constant (2.5 for UMa and 2.4 for RMa) at 71GHz and 82GHz frequency. The graph also shows that the UMa propagation has higher Path loss exponent compared to RMa propagation in wireless communication.

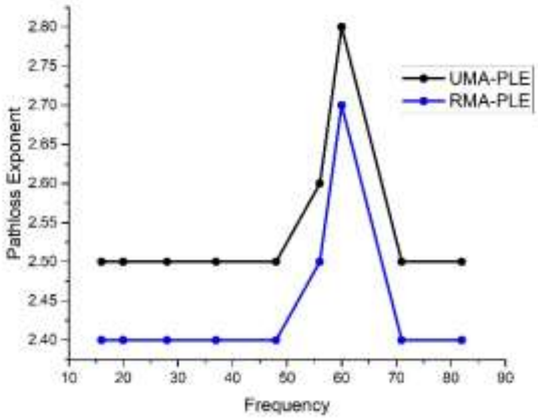

Fig-3: Path Loss Exponent at 16, 20, 28, 37, 48, 56, 60, 71 and 82 GHz frequency for UMa and RMa propagation in Line-of-Sight communication.

4.3 Received Power

Figure-4 shows the calculated received power for the Urban Macrocell (UMa) and Rural Macrocell (RMa) propagation for 16, 20, 28, 37, 48, 56, 60, 71 and 82 GHz operating frequencies respect to their Directional Power Delay Profiles in LOS communication. More negative received power refers to small signal power at the receiver end in wireless communication system.

The graphs shown in figure-4 both seems identical for UMa and RMa propagation corresponding to their received power but in terms of finding the minimum output corresponding to their received power, the 60GHz provides the minimum value (-60.9 dBm for UMa and -58.1 dBm for RMa propagation). Again, the generated curve also shows that, form 16GHz to 60GHz the received power decreases with an increase in frequency bands, but after crossing the 60GHz frequency, the received power increases and again the received power decreases after crossing the 71GHz frequency. More over the graph shows that the RMa propagation has higher received power compared to the UMa Propagation.

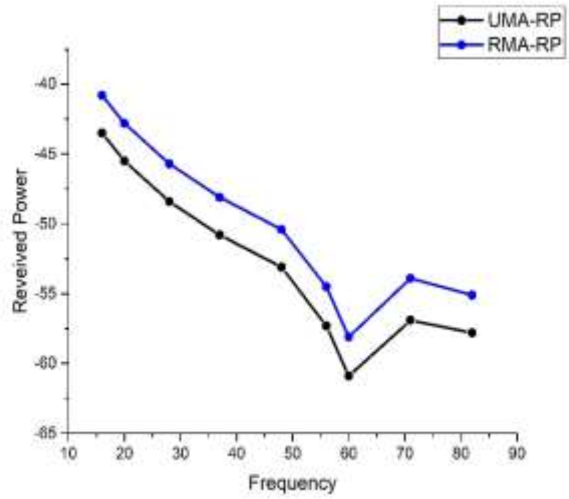

Fig-4: Calculated Received Power at 16, 20, 28, 37, 48, 56, 60, 71 and 82 GHz frequency for UMa and RMa propagation in Line-of-Sight communication.

The final summary of Line of sight communication for Urban Macrocell propagation and Rural Macrocell propagation corresponding to their path loss, path loss exponent and received power has been shown in table-2.

Table-02 Summary of Path loss, Pathloss exponent and Received power at the receiver end.

Frequency bands in GHz	Path Loss (dB)		Path Loss Exponent		Received Power (dBm)	
	UMa	RMa	UMa	RMa	UMa	RMa
16	122.7	120	2.5	2.4	-43.5	-40.8
20	124.7	122	2.5	2.4	-45.5	-42.8
28	127.6	124.9	2.5	2.4	-48.4	-45.7
37	130	127.3	2.5	2.4	-50.8	-48.1
48	132.4	129.6	2.5	2.4	-53.1	-50.4
56	136.5	133.7	2.6	2.5	-57.3	-54.5
60	140.1	137.4	2.8	2.7	-60.9	-58.1
71	135.8	133.1	2.5	2.4	-56.6	-53.9
82	137.1	134.3	2.5	2.4	-57.8	-55.1

It can be easily observed from the table-2 that the 60 GHz frequency band has the maximum Pathloss, Pathloss Exponent and the minimum received power both for the Urban Macrocell (UMa) and Rural Macrocell (RMa) propagation in LOS environment. So the application of 60 GHz frequency will not be efficient for millimeter wave 5G cellular network. One more thing is noted that Urban Macrocell (UMa) propagation has higher pathloss and pathloss exponent compared to Rural Macrocell (RMa) propagation for all the frequencies described above. Therefore the Rural Macrocell (RMa) propagation consist higher received power compared to Urban Macrocell (UMa) propagation.

3. CONCLUSIONS

This paper represents the basic scenario of Urban Macrocell (UMa) and Rural Macrocell (RMa) propagation and their power delay profiles for 16, 20, 28, 37, 48, 56, 60, 71 and 82 GHz frequency bands in 5G cellular network for Line of Sight Communication. The channel characteristics like Path loss, Path loss exponent, and Received power are considered as main parameters to evaluate the performance respect to their UMa and RMa propagation. The maximum Path loss and Path loss exponent has been calculated for the 60 GHz frequency. Moreover the comparison showed that UMa propagation for will face much path loss and path loss exponent compared to the RMa propagation for every specific millimeter wave frequency band.

The future work will involve the measurement of the effects of rain rate, humidity, temperature and foliage loss over the millimeter wave propagation in different environmental scenarios. Future work will also conclude the performance observation of RMa and UMa propagation in Non Line of Sight environment.

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