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Performance Analysis of Macro-Cellular Propagations Corresponding to the Urban and Rural Environment Based on Their Power Delay Profile in LOS Communication for Millimeter Wave 5G Cellular Network

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Abstract: This paper is based on the propagation scenario of Urban and Rural communication generally known as Urban Macrocell (UMa) and Rural Macorcell (RMa) propagation for the next generation 5G cellular network. The overall comparison of two scenario is done based on their Power Delay Profile (PDP) for some specific Millimeter-Wave frequency bands like 16, 20, 28, 37, 48, 56, 60, 71, 82GHz as they exist in the proposed frequency band list of International Telecommunication Union (ITU) for the upcoming 5G cellular network. The propagation was directional and Line of Sight (LOS) in this particular aspect of judgement. The study and simulation procedure has been performed in NYUSIM software developed by New-York University (NYU) USA and it uses the MATLAB environment in the backend to perform the "Monte Carlo" simulation. Some specific parameters like the Pathloss, Pathloss exponent, and Received power has been taken as the key parameters to measure the performance. The characteristics curve has been generated for every specific frequency bands in order to observe the variations of performance. Then the outcome has been compared with each other in respect of Urban Macrocell (UMa) and Rural Macrocell (RMa) propagation in 5G cellular network to make a proper judgement on the appropriate selection of frequency bands in that particular environment. The analysis shows that 60GHz frequency band provides the higher measurements of Pathloss, Pathloss Exponent and Lower measurements of Received power compared to the other frequency bands due to its higher rate of atmospheric absorption.

Keywords: *Rural Macrocell (RMa); Urban Macrocell (UMa); Millimeter Wave (mmWave); LOS Communication; Power Delay Profile (PDP).*

Introduction: From the perspectives of the recent statistics, it can be said that the amount of smart communicating devices like Mobile phones, Tablets, Computers, Smart gadgets are increasing so rapidly and therefore, communication has become the fastest growing sector [1]. Now the main aspect of contribution is to ensure the better Quality of Services (QoS) for wireless communication. The network researchers are always very busy in search of meeting those demands. Therefore, the future network's architecture and its some parameters like the network speed, data traffic, communication protocols are some experimental issues. The spectrum from 0.5GHz to 100GHz are now the most significant area where a vast number of researches are performing [2]. 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. Millimeter wave (mm Wave) is optimal for its high frequency and speed of data transmission. But the performance can be hampered due to high attenuation, Humidity, Rain rate, Transmission power etc [3].

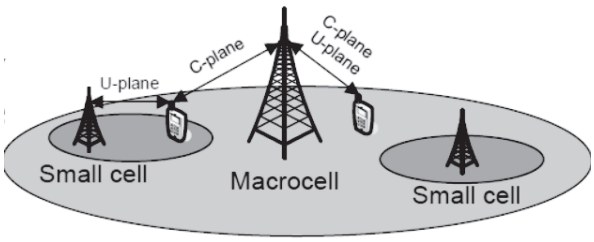

Fig -01: Macro-cell Propagation

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Therefore, the power delay profile of millimeter wave frequency bands consists some important parameters which can be used to compare the performance of different frequencies as well as their characteristics. Millimeter wave 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 [8-9]. 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]. Macrocell is a cell in telecommunication network that provides radio coverage with larger cellular area and often operated with higher power where the microcell is just the opposite of it. 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 [4-9]. 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.

Literature Review: The path loss model for long distance in rural area like Rural Macrocell 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 communication. The pathloss model for the 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 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]. 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.

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. But there is a lack of study of millimeter wave frequency bands and their performances corresponding to their Directional Power Delay profile 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 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.

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 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.

The main change of the value of parameters are applied in “Channel 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]. 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 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. 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-

$$G(\theta, \emptyset) = \max\left(G_0 e^{-\alpha\theta^2-\beta\emptyset^2}, \frac{G_0}{100}\right) \quad \text{eq. 1}$$

$$\alpha = \frac{4ln\ (2)}{\theta^2{}_{3dB}}, \beta = \frac{4ln\ (2)}{\emptyset^2{}_{3dB}}, G_0 = \frac{4123\eta}{\theta_{3dB\emptyset3dB}} \quad \text{eq. 2}$$

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]

Results and Discussion: The International Telecommunications Union (ITU) has proposed the list of frequency bands for the next generation of mobile and wireless communication system in World Radiocommunication Conference (WRC-2019). Where the frequency bands from 7GHz to 100GHz are selected as the millimeter wave for the standardization of 5G cellular network [17].

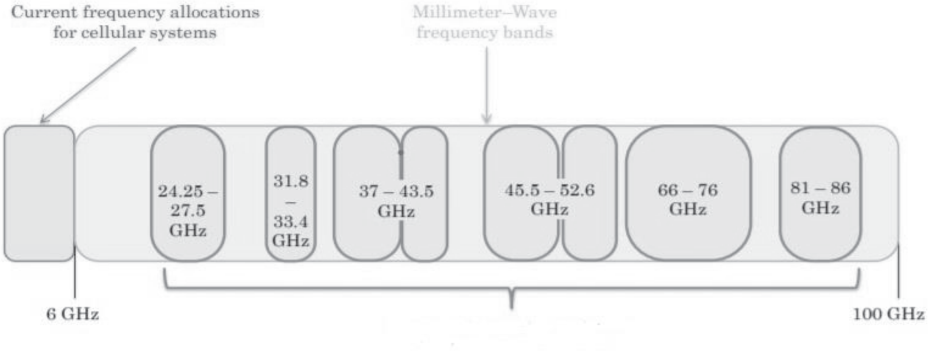

Fig - 02: Frequency bands proposed by ITU at WRC-2019.

Therefore, the frequency bands like 16, 20, 28, 37, 48, 56, 60, 71 and 82 GHz are taken for the study purpose and the simulation procedure has been performed on each of the following frequency bands described above to measure the performance.

The total outcome of the simulation process is 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.

A. 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 – 03. 16GHz frequency has the lower pathloss both for UMa (122.7 dB) and RMa (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.

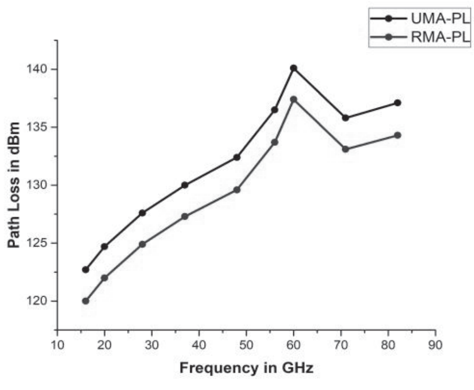

Fig-3: Path Loss at 16, 20, 28, 37, 48, 56, 60, 71 and 82 GHz frequency for UMa and RMa propagation in Line-of-Sight communication.

B. Path Loss Exponent: Figure-4 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).

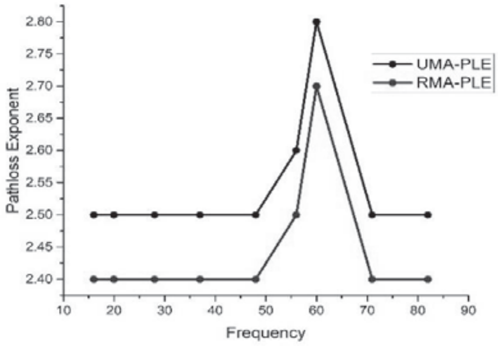

Fig-4: Path Loss Exponent at 16, 20, 28, 37, 48, 56, 60, 71 and 82 GHz frequency for UMa and RMa propagation in Line-of-Sight communication.

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. 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.

C. Received Power: Figure-5 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 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).

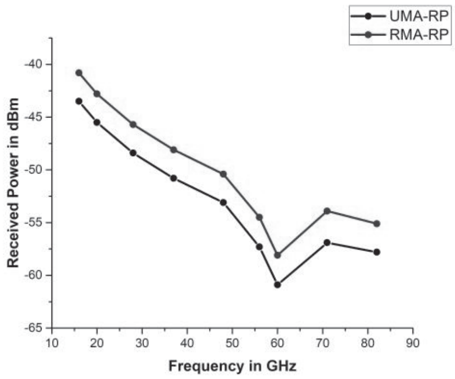

Fig-5: Calculated Received Power at 16, 20, 28, 37, 48, 56, 60, 71 and 82 GHz frequency for UMa and RMa propagation in Line-of-Sight communication.

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.

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 UMa and RMa Propagation.

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. 60GHz frequency band faces the maximum amount of atmospheric absorption. The existing Oxygen molecules and water vapor in the higher atmosphere absorbs the Electro-Magnetic (EM) energy of 60GHz band [18]. Therefore, the 60GHz band consist the higher Pathloss, Pathloss-Exponent and the lower Received Power at the receiver end.

So, the application of 60 GHz frequency will not be efficient for millimeter wave 5G cellular network as it will be extremely attenuated in the outdoor atmosphere. This issue related with 60GHz frequency, can be mitigated with the application of short link communication. It can be deployed for very short distance applications like indoor environment in future 5G cellular network. New wireless standards like IEEE 802.15.3c and IEEE 802.11ad can be far more developed focusing on the application of 60GHz frequency band as it provides large bandwidth.

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.

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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