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Original Article

Estimation of Loss Probability and Path Loss for 5G Millimeter-Wave Communication using 5G NR Path Loss Model

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Abstract *- The performance characteristics of the 5G wireless communication system, which is recently undergoing more extensive development in the mmWave frequency range, are summarized in the research. The earliest research results with fundamental concepts of networks in networks are presented here, together with an account of the international efforts undertaken to mimic the channels for applications that are licensed and those that are not. Path Loss and LOS probability for several standards bodies, including (LOS), which represents line-of-sight, and NLOS, which represents non-line-of-sight probabilities, have been compared for a 28 GHz frequency range. For the 3GPP model Umi LOS Scenario, the path loss obtained is 105 dB and 70 dB for 200m with ABG and 5G NR model. The path losses obtained for the 3GPP Umi NLOS Scenario are 138 dB and 120 dB for 200m with ABG and 5G NR model. So, path loss for both scenarios is better with the 5GNR model. The LoS probability obtained for the 3GPP Umi loss Scenario is 0.093622 and 0.093518 for 200m with ABG and 5G NR model. For the 3GPP Umi NLOS Scenario, the improvability in loss probability obtained is 0.133333 and 0.128048 for 200m with the ABG and 5G NR models. So, the loss probability for both scenarios is enhanced with the 5GNR model.*

Keywords *- LOS probability, Reference channel models, Millimeter wave, Delay, 5GNR, 3GPP, Fifth generation (5G), Path loss.*

1. Introduction

At each point in the communication route, the quality of the signal received is determined by the amount of attenuation and losses experienced during its travel. The leading models are inappropriate for propagating a 5G network because of signal loss rate and high channel interference related to the millimeter wave (mmWave) band. Our ability to interact and communicate has changed dramatically as a result of the development of mobile communication networks. Each generation of technology—from the first generation (1G) analog systems to the digital advancements of 2G and 3G—has gradually improved network stability and data transmission speeds. The arrival of 4G technology resulted in a significant boost in mobile broadband capacities, opening up a plethora of applications that completely changed the digital world. As 5G technology becomes more widely used in industry, so does the need for wireless communication and wireless channel expertise. Thus, accurate propagation channel models are required. Reliability and skill in channel modeling techniques are key to overcoming the challenges presented by spectrum scarcity. The huge bandwidths available in the frequency bands beyond 6 GHz make them desirable for use both inside and outside the network in 5G. MIMO design is a technique that helps wireless systems communicate as effectively as feasible. MIMO methods can boost capacity by utilizing the angular and delay domains [5]. It is expected that millimeter-wave (mmWave) and 24 to 86 GHz frequency bands would be used by 5G wireless networks. Recent engineers utilize models like radio propagation for their own implementation design techniques and installation and for analysing possible wireless technologies. These models significantly impact choices about almost all facets of wireless communications. In a New Radio (NR) fifth-generation network, Path Loss (PL) and interference in signal issues need to be taken into particular account [4]. Long-term coexistence of the LTE network in fourth generation and 5G NR networks on a similar framework is predicted. The well-designed model is essential to minimize the co-channel interference and signal attenuation that accompany the initiation of deployment in the 5G NR network. Models are designed to determine the comparative analysis to existing models that most closely approximate the measured value. After 1G was released in the early 1980s, there was a decline in the advancement of mobile wireless communication. More connections are needed to support more users, necessitating the rapid evolution of mobile communication networks. Wireless technology has been evolving constantly since the introduction of first-generation mobile networks in order to satisfy increasing demand and stricter specifications. As a result, the telecom industry now faces a variety of new difficulties pertaining to technology, efficient use of spectrum, and, above all, end-user security. It is anticipated that mobile networks will offer very fast network speeds, feature-rich packets, and security with fast changes in the generation of wireless communication.

Future mobile communications systems are anticipated to diverge significantly from current ones because of innovative service brought about by growing data traffic demand, increasing computational smart devices with power systems, and innovative, cutting-edge utilizations.[2]. Up to 10 (ten) Gbps of data transfer speed, 100 (hundred) Mbps of cell edge rates, and less than one millisecond of latency are all possible with 5G standards. Many sectors seek a unique frequency band that can accommodate the 5G requirements by offering wide channel bandwidth and 100 GHz spectrum to meet the latest 5G specifications. Precise radio measurements are necessary to facilitate the development of the upcoming 5G system. Research is conducted in the frequency range of 100 GHz [11]. Thus, results show short wavelengths and the propagation models are highly responsive to the scale of surroundings. It shows specific frequency dependence on path loss and the rising frequency of blockage. Furthermore, the penetration loss improves with frequency range largely material-dependent. The small-scale channel parameters, which include angle spread, multipath richness, and delay (jitter) spread, are reassuringly consistent across a variety of frequencies. When using the wide specific range of frequencies with the current 3GPP innovative model. This page describes the initial steps that will form the basis for those models, although further effort is needed to complete this model.

Models have characterised path loss as the signal degradation among BT and UT as a function of delay in propagation and additional parameters. A portion of the transmitter's power dissipation factor and the effects of the propagation channel contribute to the signal attenuation factors. Physics states that wireless communications propagate greatly in space. When an electromagnetic Radio Frequency (RF) signal passes through a medium, it could lose its route. When the signal comes into contact with objects, it is scattered, unshattered, refracted, and reflected due to the cumulative impact, which induces the signal to be absorbed. Transit via several paths and its frequency is shifted as the Doppler effect on the relative velocity. The signal changes substantially depending on the source and objects. The definition of an RF signal is specified as a space-time frequency signal that unquestionably has certain characteristics [7].

The interior scene includes a few examples of both closed and open businesses, like retail malls and office hallways. An office layout consisting of open areas as cubicle structures, some walled offices, open areas, hallways, and so on. Each partition wall is constructed from a different material, such as sheetrock, cinder block, glass, or poured concrete. In a work environment, APs are often positioned two to three meters away from one another, either on the ceiling walls are positioned one to two meters away from one another. A retail center typically has an open area in the middle known as an "atrium" and is two to five stories tall. In a shopping center, APs are often positioned roughly 3 meters above the walls or ceilings of the entryway and stores.

In contrast, UEs are positioned at a specific height of 1.2 to 1.5 meters. The floor, walls, and ceiling reflect light differently, making it difficult to navigate in low-light situations [10]. Measurements in office areas and mall settings show exponents with root loss, which depend on a 1 metre reference distance from free area space, with less than 2 meters under LOS settings, leading to a greater favorable route loss than anticipated by Friis' path loss estimate for free space. The exponent associated with loss in route appears to progressively improve frequency, most likely due to the correlation between surface roughness and wavelength, and the degree of wave guiding effect varies. Channels with small-scale integration measurements, likely angular spread and delay (jitter) spread, have shown the same remark, which can be calculated throughout channels over a very wide frequency range. With a few small amplitude variations, the main multipath components are available with all frequencies. According to recent studies, the polarization process for discrimination in indoor millimeter wave channels ranges from 15dB to 25 dB, with 73 GHz having higher polarization discrimination than the 28 GHz frequency range [6,9].

Realistic testing and comparison of the performance of novel wireless communication systems is made feasible by Reference Channel Models (RCM). Among other things, new requirements require that interfaces in MIMO have mobility be included in the model. Modulation techniques are used to serve as a test and authentication ground for new radio generations. With innovative applications, diverse antenna designs, etc., RCM aims to replicate typical radio environment features [12].

Examples of using the models in various applications are provided to show the broad range with some parametric range value. The different models for the channel are then differentiated using effective hybrid beam-forming methods, like coordinated multipoint transmission. A number of 5G proposed bands were approved by the 2018 IEEE World Radio Conference (WRC-15). Only academic uses are permitted for content mining and translation. Approval of IEEE is required for distribution and republication, even in cases where special usage is allowed. 24.25–27.5, 31.8–33.4, 37–43.5, 45.5–50.2, 50.4-52.6, 66–76, and 81–86 GHz are the bands. WRC-19 will approve the final list of bands with the spectrum and range in the 60 GHz frequency band also utilized [4].

Because of the recent technology utilized, the diverse requirements, particularly for different wide intensive wireless communication technology with wireless networks, have experienced a substantial transition over the past ten years. As a result, the Utilization of aggressive propagation channels has been necessary to reach the minimum quality of service restriction.

In wireless communication systems, having Spectral Efficiency (SE) parameters is a key determinant of the system's performance [1]. Using many inputs and numerous outputs, the MIMO technique is a key technology for greatly improving SE. There are generally three primary models for MIMO channels: the physical, analytical, and standardized models. In the physical models, physical parameters characterize the MIMO channel. The statistical properties of the MIMO channel are shown in the analytical models with respect to the moderated data. Modern radio propagation architecture, advanced signal processing, and numerous access techniques can all be built on top of the standardized models [3].

2. The Urban Micro and Urban Macro Scenarios

The transmitter's height is limited to fewer than 25 meters in the Umi Channel characteristics. Researchers' investigation indicates that Friis' free space path loss modeling in various frequencies over 6 GHz appears to be reasonably similar to LOS route loss. NLOS scenarios exhibit a steeper route loss slope, much like lower bands. Thus, the highest range allowed and the greater loss in some rays of trace and shadow are dimed for measurements comparable with lower frequency bands; however, the shadow fade in tracing rays is significantly high (> 10 dB) with actual measurements. It is standard practice to estimate the RMS of azimuth angle spread of departure (from the AP position) to roughly equal 10-to-30-degree rotation and the RMS of delay spread between 50 and 500 ns period.

Furthermore, more absorptions with omnidirectional antennas and millimeter wave technology with the channel have a directional nature. Thus, frequency shuts off in non-LOS scenarios with a frequency range less than 6.0 GHz, which means a range exceeding 6 GHz has minimal range.

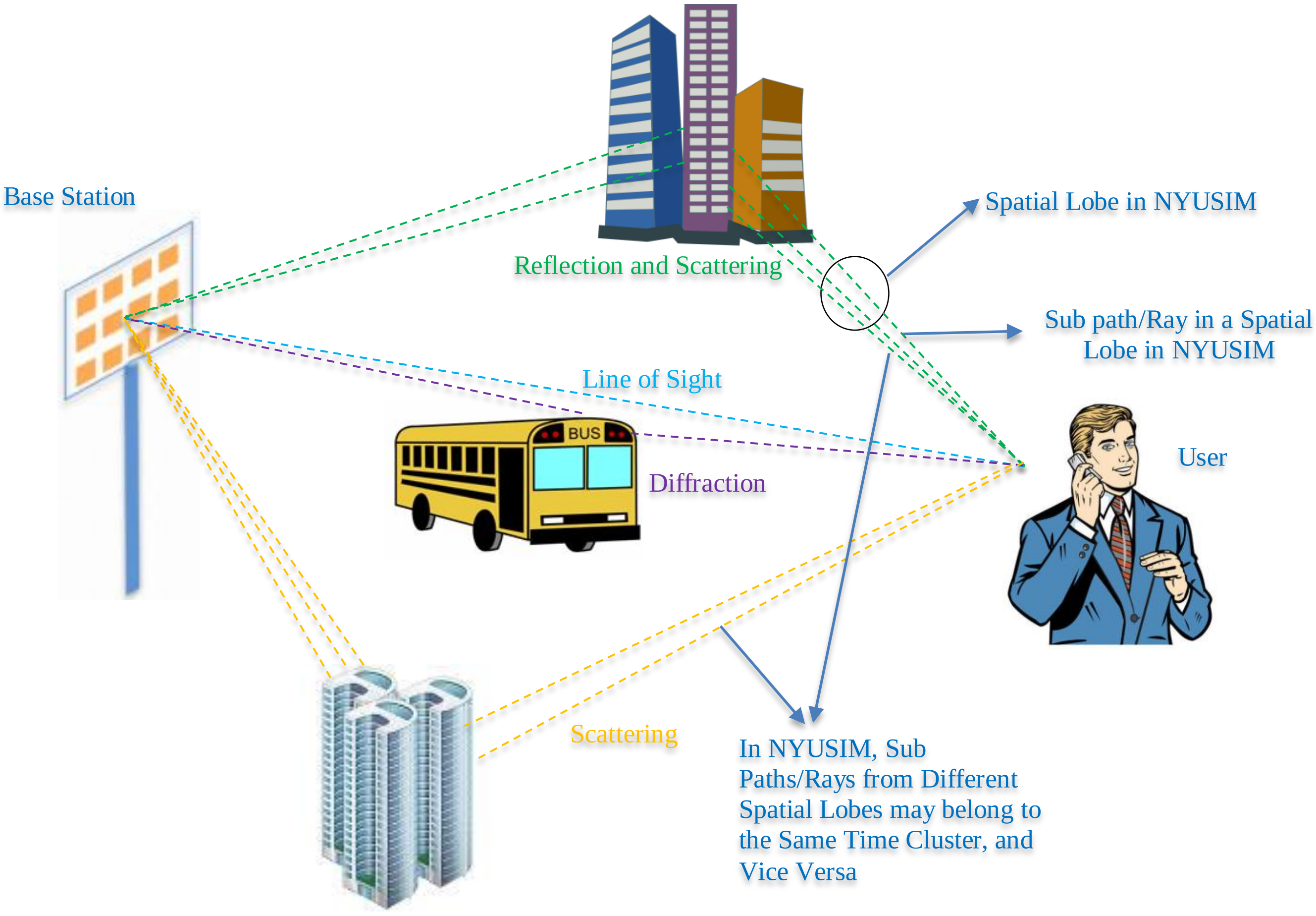

Fig. 1 The NYUSIM model [4]

In Umi Channel features, the transmitter is maintained at a height higher than 25 meters. Thus, the way the path loss functions in LOS is probably the same as in a free area with free space path loss, which is similar to the Umi scenario.

Different patterns over frequency for NLOS path loss models are typically somewhat unclear over a wide frequency range.

The rate of increase of the loss with frequency looks nonlinear, as it is slightly high in a range of spectra. This is because the frequency-dependent propagation process known as diffraction is more prevalent at lower frequencies. At the highest frequency, reflection and dispersion could be highly relative.

On the other hand, the data's reduced dynamic range at higher frequencies may distort the patterns. Additional measurements will be taken to understand the Umi channel fully.

Based on initial ray-tracing tests, the angle and the delay channel spreads are only somewhat frequency dependent and usually 2-3 times smaller than in.

Ray tracing proceeds over with a cross-polar scattering path due to diffuse scattering, resulting in a reduced XPR [11].

3. Different Path Loss Models

For 5G wireless communications channels, Alpha-Beta-gamma (ABG) and Close In (CI) with free space reference distance modeling are two viable multi-frequency large-scale path loss modeling techniques [4]. The ABG model's corresponding equation is given by [4]

$$U1 = 10 * \text{€} * log(\frac{d}{1m}) + \delta + 10 * \text{¥} * log(\frac{f}{1GHz}) + \sigma$$

Where, U1 is the function of frequency and distance defines the path loss in terms of decibels (db) € and ¥ are coefficients illustrating the reliance of U1 on frequency and distance.

δ represents an extreme value of offset, σ represents the Gaussian random variable with zero mean.

The CI model is specified by [4]

$$U2 = \upsilon + 10 * \upsilon 1 * log(, d/\text{б}) + \psi$$

Where, U2 is the function of frequency, and distance denotes the path loss for the CI model in decibels. $\upsilon 1$ is used for the path loss exponent, ψ representing the Gaussian process with zero mean. б is the reference distance in close free space.

$$\upsilon = 20 * log\left(\frac{(4 * \Pi * f * \text{б} * 10^{-9})}{c}\right)$$

ϒ represents free space path loss at transmitter and receiver distance of d_{cf} at carrier frequency f.

4. Channel Model Structure

4.1. Path Loss

In radio waves, the route loss parameter is defined as the ratio of transmitted power to received power in a wireless communication system. Path loss is measured in db.

P_L [dB] = 10*log(Transmitted Power / Received Power)

P_T denotes transmitted power, and P_R denotes received power. In free space, according to Friis' law, PR (received power) is dependent on the distance, wavelength, and frequency, as defined by,

$$\Phi h = P_T * G_{T.} * G_R * (\lambda/4\Pi\Theta k)^2$$

Where, λ represents wavelength, $\Theta k$is the spatial difference between the transmitter and receiver, G_T and G_R is the gain of the transmitter and receiver antenna. On the other hand, path loss is more severe in real environments due to the abundance of conducting and dielectric materials with obstacles.

These are the reasons behind the increased interest in field measurement conduction and path loss modelling parameters. Many observational route loss models have found widespread application at frequencies lower than 6 GHz.

The path loss (dB) is computed using the following specifications. 28 GHz is maintained as the carrier frequency. The transmitter antenna's base station height is maintained at ten meters. The base station's entire allotted greed and all of its antennas receive 46 dB of power.

The receiving antenna has a height of 1.5 meters and a noise figure of 9 dB; the receiver's antenna temperature is maintained at 290 Kelvin. According to the path loss model, the split between the transmission and reception is between 10 meters and 300 meters. Thus, the 3GPP model is implemented using the 5G-NR route loss model.

The scenario of path loss of urban macrocells is selected. The environment's average height is maintained at five meters. The NLOS channel and the LOS channel are the two main channels that exist in the environment. Thus, the Uma scenario is chosen here to use the 3GPP model.

Umi and Uma are the two distinct situations selected for the computation of the LOS probability. The LOS probability is calculated for both scenarios in this research.

4.2. Path Loss Model [8]

4.2.1. Uma LOS Scenario

$$\theta\theta = \begin{Bmatrix} \mathit{\Gamma}_1 10m \leq \partial \leq \mu \\ \mathit{\Gamma}_2 \mu \leq \partial \leq 5km \end{Bmatrix}$$

$$\mathit{\Gamma}_1 = 28.0 + 22 * log(\mathit{\Theta}) + 20 * log(\kappa)$$

$$\mathit{\Gamma}_2 = 28.0 + 40 * log(\mathit{\Theta}) + 20\, log(\kappa) - 9$$

$$* log((\mu)^2 + (\mathit{\Lambda}t - \mathit{\Lambda}t1)^2)$$

Where, $\mathit{\Theta}$ denotes the 3D distance between transmitter and receiver, κ denotes carrier frequency, μ denotes breakpoint distance, and the height of the base station and UT $t, \mathit{\Lambda}t1$, respectively.

4.2.2. Uma NLOS Scenario

$$\zeta = max\,i\,mum(\text{Ʊ}, \text{Ʊ}')$$

$$for 10m \leq \partial \leq 5km$$

$$\text{Ʊ}' = 13.540 + 39.080 * log(\rho) +$$

$$20\, log_{10}(\kappa) - 0.6(\mathit{\Lambda}t1 - 1.5)$$

Break point distance is given by μ = 2*$\mathit{\Lambda}t$ *$\mathit{\Lambda}t1$ *(κ /c), where c = 3.0 10^8 m/s in free-space propagating velocity and the BS antenna and UT antenna are specified by the h_{BS} and h_{UT}, respectively.

4.2.3. The 5G NR Path Loss Model

LOS Scenario

$$\hbar = \begin{cases} PL_1 10m \leq \partial \leq \text{ƛ} \\ PL_2 \text{ƛ} \leq \partial \leq 10Km \end{cases}$$

$$\mathit{\Gamma}_1 = 20 * log(40\pi * \rho * \kappa/3) +$$

$$min\,i\,mum(0.03 * h^{1.72}, 10)\, log(\rho) -$$

$$min\,i\,mum(0.044 * h^{1.72}, 14.77) +$$

$$0.002\, log_{10}(h) * \rho$$

$$\mathit{\Gamma}_2 = \mathit{\Gamma}(\text{ƛ}) + 40 * log(\frac{\rho}{\text{ƛ}})$$

Where μ represents breakpoint distance is given by,

$$\text{ƛ} = (2 * \prod * \mathit{\Lambda}t * \mathit{\Lambda}t1 * \kappa/c)$$

NLOS Scenario

$$\psi = max\,i\,mum(\psi, \psi')$$

$$for 10m \leq \partial \leq 5Km$$

$$\psi = 161.04 - 7.1 * log(W_t) + 7.5 * log(h) -$$

$$(24.37 - 3.7 * (\frac{h}{ht_i})^2)$$

$$* log(ht_i) +$$

$$(43.42 - (3.1 * log(ht_i)^2))$$

$$* (log(\rho) - 3) + 20$$

$$* (log(\kappa)) -$$

$$(3.2 * (log(11.75 * ht_o))^2 - 4.97)$$

4.3. LoS Probability Model [8]

4.3.1. Umi Scenario

$$P_{LOS} = \begin{Bmatrix} \frac{18}{\partial} + exp(-\frac{\partial}{36})(1 - \frac{18}{\partial}) \end{Bmatrix}, \partial \leq 18m$$

4.3.2. Uma Scenario

$$P_{LOS} = \begin{Bmatrix} \left[\frac{18}{\partial} + exp(-\frac{\partial}{36})(1 - \frac{18}{\partial})\right] * \\ \left[1 + \mathit{\Phi}'(\boldsymbol{ht_o})\frac{5}{4}(\frac{\partial}{100})^3 exp(-\frac{\partial}{150})\right] \end{Bmatrix}, 18m \prec \partial$$

$$W\boldsymbol{h}ere$$

$$\mathit{\Phi}'(\boldsymbol{ht_o}) = \begin{cases} 0\boldsymbol{ht_o} \leq 13m \\ (\frac{\boldsymbol{ht_o} - 13}{10})^{1.5} 13m \prec ht_o \leq 23m \end{cases}$$

5. Flow Chart for Calculating Path Loss

In the 5GNR path loss model, path loss can be obtained using the following flowchart. There are fourteen steps in all. The first step is to use the rician factor "K" to calculate the loss between the transmitter and the receiver. The second step is to determine the sample size and FFT size. Finding the fading channel's maximum delay is the third step. The path loss calculation is the fourth step. The creation of auxiliary variables and measurement initialization comprise the fifth stage. The sixth stage involves sending a CP-OFDM waveform through the channel and measuring with SNR at each path loss value distance between the transmission and the reception. Create an OFDM sequence grid assign a QPSK signal in seventh stepwise denotation. The next action is modulating using CP-OFDM. Applicability of path loss to signal is the eighth step. Apply the route loss signal and create the AWGN signal in steps nine and 10. Perform demodulation at the receiver end now, and in the eleventh step, demodulate the received signal and noise using CP-OFDM. Measure the received power, noise, and overall power of the received signal is occur step twelve. Thus, overall SNR is computed in steps thirteen and fourteen, and then the outcome can be processed.

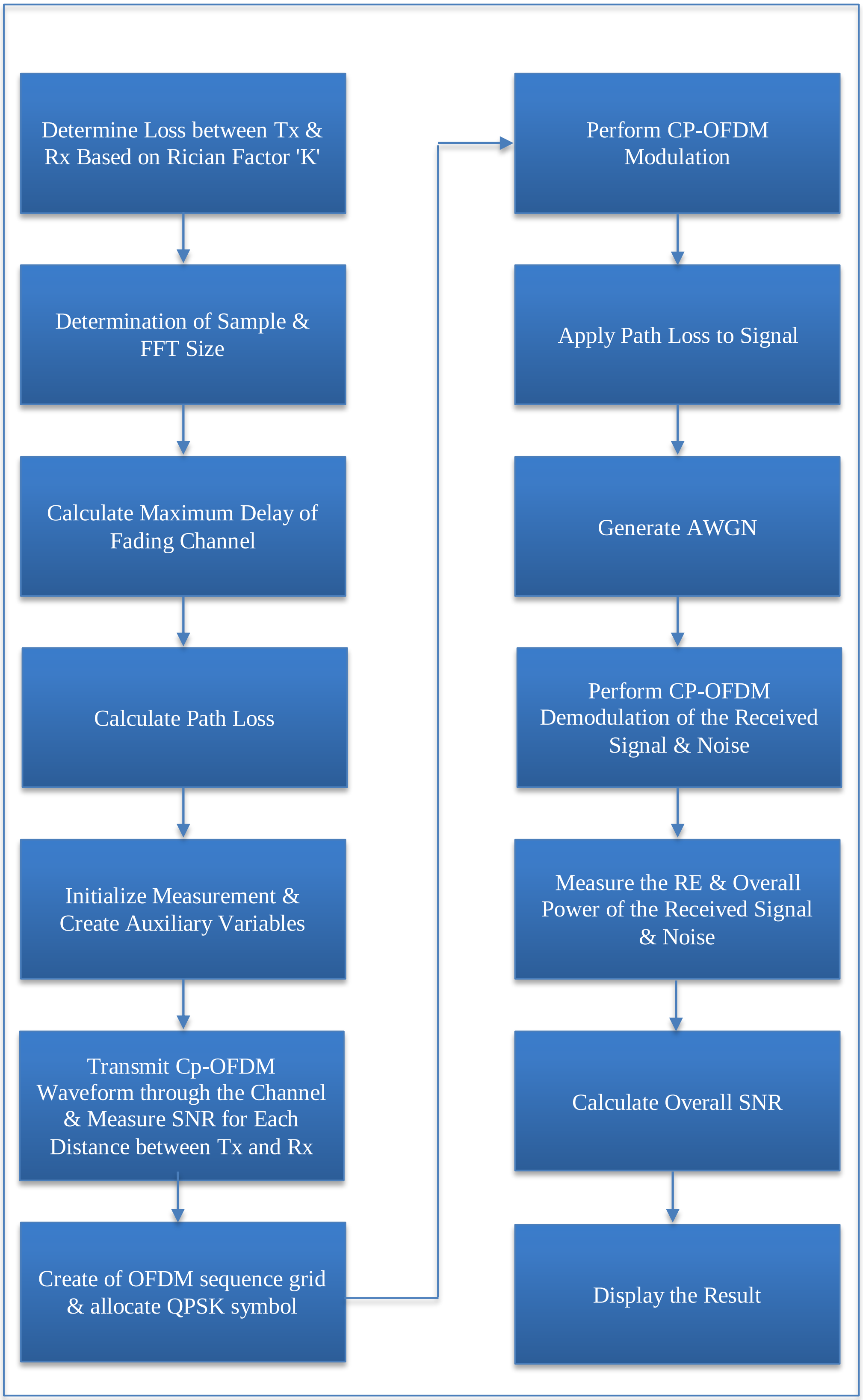

Fig. 2 Flow chart for getting path loss

6. Result

Path loss basically described the strength of the signal. In the milli meter wave communication the strength of the signal gets reduced as the distance increases. Due to which many antennas are required for good communication in 5G. The distance between two antenna are kept as minimum as possible to get good signal strength. The path loss graph basically described the impact of signal strength over the distance. The path loss is very less for shorter distance as shown in Figure 3. The path loss is 40 dB for 50 meter for the 3GPP Umi Line of Sight scenario. If Non Line of Sight communication is considered then it comes out to be 100 dB for the same 50 meter range. So from the path loss graph it can be concluded that for fruitful communication in 5G the distance between the two antennas should be reduced.

To optimize the system performance the LoS probability plays a vital role. The LoS probability should approach zero ideally. The los probability for Umi and Uma scenarios is mentioned in the graph. The los probability is less Umi scenario as compared to Uma scenario. The LoS probability value is a little bit high for the short distance as shown in Figure 4. For the 50 meter range the value of LoS probability comes out to be 0.523 for Umi scenario and for Uma scenario it is 0.649. The los probability is exponentially decreased for larger distance.

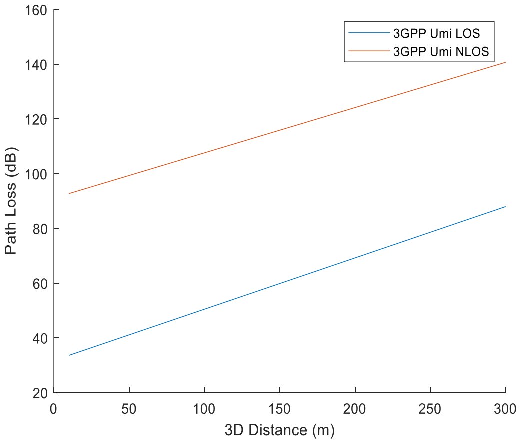

Fig. 3 Path Loss for different scenarios in 3GPP

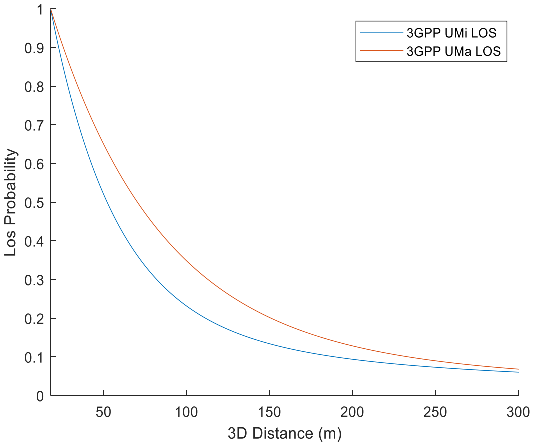

Fig. 4 LoS probability for different scenarios in 3GPP

7. Comparison

Table 1. Represents the parametric value of path loss for the ABG and 5G NR models

Channel Models in Mm Wave	Parametric Representation	ABG Model	5G NR Model
3GPP Umi LOS Scenarios	Path Loss	106 dB for 200m	71 dB for 200m
3GPP Umi NLOS Scenarios	Path Loss	139 dB for 200m	121 dB for 200m

Table 2. Represents values of LOS probability for the LOS probability model and 3GPP TR model

Channel Models in Mm Wave	Parametric Representation	ABG Model	5G NR Model
3GPP Umi LOS Scenarios	LoS Probability	0.09489 for 200 m	0.09397 for 200 m
3GPP Uma LOS Scenarios	LoS Probability	0.12222 for 200m	0.127025 for 200m

Table 3. Simulation settings for getting path loss and loss probability

Parameter	Specification
Carrier Frequency	28 GHz
The base Station Transmits Power	46 dBm
Receiver Noise Figure	10 dB
Height of Transmitter	10 m
Height of Receiver	1.5 m
Transmitter- Receiver Distance	10 to 300 m

8. Conclusion

This article examines the various channel modeling techniques utilized in the development of 5G radio communication channels, including both their general architecture and the key distinctions among mmWave and microwave channel models. Path loss is calculated using the 3GPP model with the 5gNR model, and it is compared to other models, such as the ABG model in the 28GHz frequency with NLOS and LOS scenarios. The LoS probability is also estimated for the Uma and Umi Scenarios at the 28 GHz frequency. The models' comparison leads to the conclusion that the 5GNR model improves path loss. For a 200-meter distance, the 3GPP Umi LOS and 3GPP Umi NLOS scenarios improve path LOS by 35 and 18 dB, respectively. Additionally, the 3GPP TR Model improves the LoS probability by 0.01% and 0.5% for the 3GPP Umi and 3GPP Uma scenarios, respectively. Prior research has mostly employed uniform path loss models, which may not fully capture the intricacies of urban environments. The proposed work, on the other hand, offers an enhanced path loss model that considers these factors and shows increased accuracy in signal degradation prediction in densely populated locations. Furthermore, we present a comparison analysis demonstrating that the proposed model achieves up to the 3GPP TR Model and improves the LoS probability by 0.01% and 0.5% for the 3GPP Umi and 3GPP Uma scenarios, respectively, with better predictive accuracy than conventional methods.

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