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Study and Comparison of Channel Simulation Models for 5G Applications

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Abstract: One of the major problems associated with the development of the fifth generation in telecommunications systems is the development of radio propagation models operating in mm waves (the frequency spectrum beyond 6 GHz). In this study, different types of channels were studied and evaluated at different values of frequencies. The 3rd Generation Partnership Project (3GPP) TR 38.900 (Release 14) path loss model and Close-In (CI) path loss model, Stanford University Interim (SUI) path loss model are studied and compared both LOS and NLOS environment are investigated to analyze. These results were based on large-scale results and beam tracking across multiple frequencies ranging from 0-100 GHz. This document describes the different channel models including) typical microcell and macrocell propagation scenarios for urban areas) a basic model for integrating path loss, shadow fading for the typical scenarios. This research demonstrates that the 3GPP Model is accurate and stable for the NLOS state and it is independent of the frequencies beyond the first meter of propagation to the LOS environment. SUI Model found to be more accurate and relevant to the LOS environment, followed it CI Model.

Key words: 5G channel model, UMI, UMA, outdoor, indoor, millimeterwave

INTRODUCTION

The rapid growth of personal communication devices such as smart phones and tablets and the growing demand for data everywhere have prompted telecommunications networks to work on providing data with higher quality. Innovative technologies and new frequency bands such as millimeter waves are needed to meet this demand, leading to the development of the so-called 5th-Generation wireless communications (5G) (Tikhomirov *et al*., 2018).

The emerging 5G communications systems are expected to introduce revolutionary technologies with the use of new concepts and new possible architectural styles (Rappaport *et al*., 2013). It is therefore, important to develop new channel standards and models to assist engineers in designing the system. The channel characterization was done on the wavelength frequencies by two previous researchers.

In downtown Denver, non-line-of-sight broadband channels were examined at 9.6, 28.8 and 57.6 GHz by Haneda *et al*. (2016). Samsung has been dynamic in measuring and modeling millimeter channels for modern mobile communications (Rappaport *et al*., 2017). In the band 81-86 GHz Aalto conducted measurements of point-to-point communication on a road in Helsinki, Finland (Roh *et al*., 2014). In 28, 38 and 73 GHz, broadband measurements were carried out in UMI, UMA and/or internal scenarios (Rappaport *et al*., 2015a, b). At 28 and 73 GHz, spatial and temporal measurements were obtained in conjunction with beam tracing the omnidirectional path loss models were explored in dense urban situations (Thomas *et al*., 2016).

There are many current and ongoing campaign endeavors around the world focusing on the 5G measurement. They include METIS 2020 (Anonymous, 2015), COST 2100/COST (Anonymous, 2015), IC 1004 (Rappaport *et al*., 2013), ETSI mm wave (Rappaport *et al*., 2015a, b), NIST 5G mm wave Channel Model Alliance (Sun and Rappaport, 2017), MiWEBA (Maccartney *et al*., 2015), mmMAGIC (Sun *et al*., 2016) and NYU Wireless (Sakaguchi *et al*., 2015). METIS 2020, extensive studies across a wide range of frequency bands (up to 86 GHz) and a very large bandwidth (100 MHz) contributed extensive studies in channel modeling, 3D polarization modeling, spherical and high spatial resolution. METIS channels consist of a map-based model, a random model and a hybrid model. The COST2100 channel model can be an engineering-based randomized Channel Model (GSCM) where it can reproduce the random characteristics of

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Multiple Input Output (MIMO) channels over time, frequency and space. The (New York University) NYU Wireless conducted and distributed large-scale urban propagation measurements at 28, 38, 60 and 73 GHz for both external and internal channels and provided large-scale and small-scale channel models (Rappaport *et al*., 2013).

This study presents the path loss models 3GPP TR 38.900 (Maccartney *et al*., 2015), Close In (CI) free space reference distance (Sun *et al*., 2016) and Stanford University Interim (SUI) (Sakaguchi *et al*., 2015). Using some sets of measurement data or monitoring of mm wave frequencies contributed by New York University (NYU), Nokia, University of Alburg (AAU), Qualcomm and Altoff University, the parameters in these three models were compared in both the UMI and UMA.

5G system requirements: The standard 5G mobile communication is also referred to as IMT-2020, aimed at improving the parameters of previous generation systems including the latest modification of the fourth generation or IMT-Advanced (Anonymous, 2016). The basic parameters of the 5G mobile communication system can be divided into three parts (Anonymous, 2016):

- enhanced Mobile BroadBand (eMBB) used for broadband internet access for resource intensive applications
- massive Machine Type Communications (mMTC) used for large-scale applications for internet of things
- Ultra-Reliable and Low Latency Communications (URLLC) for applications such as self-control vehicles

The 5G requirements are superior to 4G system parameters. Based on the applications and requirements of each sector with different priorities, so, the requirements in Table 1 do not necessarily represent the exact maximum values of fifth generation networks in general. For mMTC, the highest priority is communication density while spectrum efficiency and peak data rate are not important. For URLLCs, the highest priority is mobility and delay parameters for eMBB, area traffic capacity user data rate, mobility and peak data rate, although, communication density and latency are also important. So, the eMBB chip has the highest requirements and the most difficult to develop. General 5G prerequisites decide system parameters such as parameters of the physical layer including frequency band and bandwidth.

Table 1: The fourth and fifth generation features

Requirements	4G (IMT-Advance)	5G (IMT-2020)
Area traffic capacity (Mbps/m^2)	0.1	10
Peak data rate (Gpbs)	1	20
User experienced data rate (Mbps)	10	100
Spectrum efficiency (bps/Hz)	×1	×3
Mobility (km/h)	350	500
Latency (msec)	10	1
Connection density (dev/km)	10^5	10^6

5G system parameters

Communication range: To know the cell range of the fifth-generation mobile phone network, the BS antenna connection parameters should be used. By Thomas *et al*. (2016) it is proposed to use three antennas with the main beam of 120°. Therefore, if one antenna efficiently transmits the maximum spectrum, the cell range can reach a value of 44 m. Given that the amplitude of the area motion should not necessarily have the maximum value at each point and that the close closure of Base Stations (BS) adds significantly to the cost of telecommunications services, it can be suggested that the cell range for eMBB can be greater. Furthermore, the draft ITU-R Report of October 2017 on IMT-2020 proposes different scenarios for 5G mobile networks in the eMBB section (Thomas *et al*., 2016). A desktop scenario or a high-end shopping center for User Equipment (UE) or an internal hotspot (eMBB). Can be fixed or moving slowly (speed does not exceed 10 km/h).

Data rates must reach maximum values suggesting that BS should be placed close to each other a distance of 20 m. Dense Urban-eMBB. This scenario for an urban area where users do not move faster than 30 km/h as the network structure can be divided into BS level at the macro level and and micro-level for access points. Rural-eMBB. Under this situation, the rural environment at a user speed of up to 500 km/h this value corresponds to high-speed rail traffic. For 5G systems, many design objectives can be distinguished:

- Capacity of downlink enhancement up to 20 Gbps latency reduction to 1 msec
- Mobility of user increases to 500 km/h
- 1 m devices per km^2 can be connected to the network

Propagation of radio-wave: Radio frequency propagation effects vary according to signal frequency as shown Maccartney *et al*. (2015) UHF (300 MHz-3 the UHF (includes the bands 790-794 MHz and 2.5 GHz. It is called a decimetric waves. Used for location, television, cell phone, relay, mobile and fixed communications. The decimeter radio waves propagate basically flat and suffer from reflections of smooth obstacles that meet the Rayleigh standard. SHF (3-30 GHz) includes the bands 3.4-3.8, 5.9, 25.5-27 GHz. These waves are commonly called centimeter waves and are mostly used in sequential and satellite communications. SHF signals indicate absorption of an experiment in air and air gases (mainly in oxygen and water vapor). SHF waves are widely used in mobile communications.

EHF (30-300 GHz), called millimeter waves and are afterward presented into radio communications. The millimeter waves are propagated by geometric optics and are characterized by a refraction within the ambiguity of the environment and critical absorption in atmospheric dust and gases. However, the most advantage of mmW waves is the ability to assign broad frequency bands that give target values for a radio link capacitance, rather than specifying that the EHF radio spectrum does not operate intensively. In this study, path loss channels simulation are tested under three values of the carrier frequency (700 MHz) in UHF bands (3.6 GHz) in SHF bands and (26 GHz) in EHF bands. These values are widely used by many researchs.

Channel simulation models

Line-of-sight probability: The status of the LOS is determined through a map-based approach, for example, through the placement of transmitters Access Point (AP) and receivers (UE) User devices and whether any buildings or walls prevent the direct path between AP and UE. The effects of objects not represented on the map such as trees, cars, furniture, etc. are calculated independently by using shading/blocking terms. The first model is the 3D 3GPP channel model in the UMA high-end User Equipment (UE) scenario for a height of 1.5 m (Anonymous, 2016):

$$P(d) = \min\left(\frac{18}{d},1\right)\left(1-e^{-d/63}\right)+e^{-d/63} \qquad (1)$$

where, d is the distance in m. Second model is the d_1/d_2 model:

$$P(d) = \min\left(\frac{d_1}{d}-1\right)\left(1-e^{-d/d_2}\right)+e^{-d/d_2} \qquad (2)$$

where, d_1 and d_2 are parameters are estimated to optimized P(d): New York University (NYU) suggested the third model is which is basically a 3G PP presentation of d_1/d_2 but with a square term for the LOS probability.

$$P(d) = \left(\min\left(\frac{d_1}{d}-1\right)\left(1-e^{-d/d_2}\right)+e^{-d/d_2}\right)^2 \qquad (3)$$

Table 2: Cell types parameters of cell types based on their bandwidth (Anonymous, 2015)

Cell types	Pt (W)	Cell range (km)	Applications
Mac-cell	10-50	8-30	Outdoor
Mic-cell	1-10	0.2-2	Outdoor/indoor
Pico-cell	0.25-1	0.1-0.2	Outdoor/indoor
Femto-cell	0.001-0.25	0.01-0.1	Indoor

Table 3: Comparison of the three LOS probability models for UMA situation

Types of models	d_1	d_2	Mean Square Error (MSE)
3GPP Model	19	62	0.0210
d_1/d_2 Model	21	65	0.0171
NYU Model	21	161	0.0140

Table 4: Comparison of the three LOS probability models for UMI situation

Types of model	d_1	d_2	Mean Square Error (MSE)
3GPP UMA	19	62	0.0204
d_1/d_2 Model	21	65	0.0135
NYU (squared)	21	161	0.0103

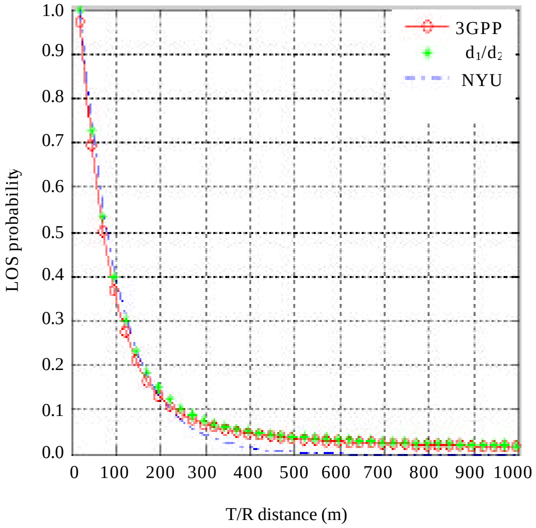


Fig. 1: UMA LOS probability for the three models considered

Table 2 and 3 summarizes the results and compares the three models with the data in Fig. 1. In terms of the average Square Error (MSE) between the LOS probability of data and models, the NYU Model was lower than the MSE but the difference was small. Given that the current 3GPP UMA Model conforms to reasonable data and includes 3D Mode support for UEs, it is recommended to use the current 3GPP LOS Model for UMA for frequencies above 6.0 GHz. For the UMI scenario, Table 4 summarizes the comparison of the three models with the data in Fig. 2. In terms of average Square Error (MSE) between the LOS probability of data and models, the NYU (square) model was the lowest MSE but the distinction was small.

Path loss models

Closed-In (CI) path loss model: The equation for the CI Model is givin by Eq. (4) (Anonymous, 2016):

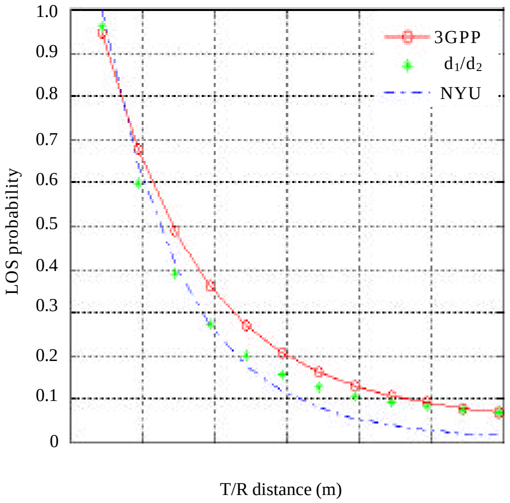


Fig. 2: UMI LOS probability for the three models considered

$$PL^{CI}(f,d) = FSPL(f,1)[dB]+10n\log\left(\frac{d}{1m}\right) \quad (4)$$

Where:

$PL^{CI}(f, d)$ = The mean Path Loss
n = The Path Loss Exponent (PLE)
d = The separation distance between both transmitter and receiver
FSPL (f, 1 m) = The Free Space path loss in dB at a T-R separation distance of 1 m at the carrier frequency f by Eq. 5

$$FSPL(F,1m) = 20\log_{10}\left(\frac{4\pi f}{c}\right) \quad (5)$$

where, c is the speed of light. The CI Model is based on the basic principles of wireless propagation and dating to Friis and Bullington, PLE where the value is 2 in the free space as shown by Friis and the value 4 for the model of the terrestrial X-ray diffraction propagation model. Use d_0 = 1 m in mmWave path loss models because base stations will be shorter or mounted indoors and closer to obstacles (Anonymous, 2016).

3GPP path loss model: The 3GPP path loss model UMA LOS consists of two sections separated by a breakpoint distance where the attenuation attenuation increases beyond the cutoff distance as shown in Table 5-7 (MacCartney and Rappaport, 2017):

$$PL_{UMALOS} = \begin{cases} PL_1 = 32.4+20\log_{10}(d_{3D})+20\log_{10}(fc) \\ 10m \le d_{2D} \le d_{BP} \\ PL_2 = 32.4+20\log_{10}(d_{3D})+20\log_{10}(fc)\text{-}10\log_{10} \\ \left((d_{BP})^2+(h_{BS}\text{-}H_{UT})^2\right), d_{BP} \le d_{2D} \le 5km \end{cases} \quad (6)$$

Table 5: Gives the values of CI parameters used in this research

Scenario/Enviornment	Models	Freq. (GHz)	Distance (m)	PLE (n)
UMI				
LOS	CI	0.7, 3.6, 26	1-1000	2.0
NLOS				3.1
UMA				
LOS	CI	0.7, 3.6, 26	1-5000	2.0
NLOS				3.3

Table 6: Gives the values of 3GPP parameters used in this research

Sce.	Models/Env.	Parameters
UMI	**3GPP**	
	LOS	$h_{UT} = 1.5$ m , $h_{BS} = 10$ m
	NLOS	
UMA	**3GPP**	
	LOS	$h_{UT} = 1.5$ m , $h_{BS} = 25$ m
	NLOS	

Table 7: Gives the values of SUI parameters used in this research

Sce./Env.	Parameters
UMI	
LOS	$h_{UT} = 1.5$ m, $h_{BS} = 10$ m, n = 1.9, sf = 6.5
NLOS	
UMA	
LOS	$h_{UT} = 1.5$ m, $h_{BS} = 25$ m, n = 4.5, sf = 6.5
NLOS	

$$d_{3D} = \sqrt{d_{2D}{}^2+h_{UT}{}^2}$$

Breakpoint distance d_{BP} = 4hBShUTfc/c where, fc is the middle frequency in Hz, c = 3.0×108 m/sec is the propagation velocity in free space and h_{BS} and h_{UT} are the compelling antenna heights at the BS and the UT, respectively. The UMA NLOS path loss model in 3GPP (Rappaport *et al*., 2015) is taken directly from ITU-R (MacCartney and Rappaport, 2017):

$$PL_{UMA\text{-}NLOS} = \max(PL_{UMA\text{-}LOS}, PL_{UMA\text{-}NLOS})\text{for}10m \le d_{2D} \le 5km,\ PL_{UMA\text{-}NLOS} = 13.54+39.08\log_{10}(d_{3D})+ 20\log_{10}(fc)\text{-}0.6(h_{UT}\text{-}1.5) \quad (7)$$

The UMI-LOS path loss model in 3GPP is:

$$PL_{UMI\text{-}LOS} = \begin{cases} PL_1 = 32.4+21\log_{10}(d_{3D})+20\log_{10}(fc), \\ 10m \le d_{2D} \le d_{BP} \\ PL_2 = 32.4+40\log_{10}(d_{3D})+20\log_{10}(d_{BP})^2 \\ +(h_{BS})\text{-}H_{UT}{}^2 d_{BP} \le d_{2D} \le 5km \end{cases} \quad (8)$$

$$d_{3D} = \sqrt{d_{2D}{}^2+h_{UT}{}^2}$$

$$PL_{UMI\text{-}NLOS} = \max\left(PL_{UMA\text{-}LOS}, PL_{UMA\text{-}NLOS}\right) \quad \text{for } 10\,m \leq d_{2D} \leq 5\,km \tag{9}$$

Stanford University Interim (SUI) Model: SUI path loss model for UHF/microwave band from the SUI Model for fc 2 GHz (Anonymous, 2017):

$$PL_{SUI}(d) = PL(d_o) + 10n\log10\left(\frac{d}{d_o}\right) + X_{fc} + X_{RX} + X_{\sigma} \tag{10}$$

$$PL(d_o) = 20.\log_{10}\left(\frac{4\pi d_o}{\lambda}\right) \tag{11}$$

$$n = a\text{-}b.h_{TX} + \frac{c}{h_{TX}} \tag{12}$$

$$X_{fc} = 6.\log_{10}\left(\frac{f_{MHz}}{2000}\right).fc>2GHz \tag{13}$$

$$X_{RX} = -10.8\log_{10}\left(\frac{h_{RX}}{2}\right) \tag{14}$$

where, • wavelength in meters, $PL(d_0)$ in Eq. 10 shows the loss of free space in dB at a close reference distance d0 X_{fc} and X_{RX} in Eq. 11 and 12 indicate the correction factors for the frequency and receiver heights, respectively and Eq. 10 is the typical random random shading variable with an average of 0 dB and the standard deviation [dB] such as 8.2<10.6 dB. The fMHz in Eq. 11 is the frequency of the carrier (fc) in MHz h_{TX} and h_{RX} indicate the height of the Transmitting antenna (TX) and the Receiver (RX) in meters, respectively. Parameters a-c in Eq. 12 are constants used to model the types of terrain encountered in the service area (Anonymous, 2017).

In order to modify the SUI path loss model using measurements of 3.6 and 26 GHz NLOS, we simply find a slope correction factor such as Eq. 10 agree to the free-path loss model in free-reference space (Rappaport *et al*., 2013) which uses PLEs as shown in Table 7. In order to modify the SUI path loss model using measurements of 3.6 and 26 GHz NLOS, we simply find a slope correction factor such as Eq. 10 agree with the free path loss model in free reference space (Rappaport *et al*., 2013) which uses PLEs as shown in Table 7 that the SUI Model contains more parameters that allow for frequency and elevation modulation. Thus, the SUI Model is more general and fully appropriate.

Modified SUI path loss model: The modified SUI Model for mmWave in NLOS environments (Anonymous, 2017):

$$PL_{SUI,\ Mod}[dB](d) = \alpha NLOS\times(PLSUI(d)\text{-}PLSUI(d_0))+PL(d_0)+X_{\sigma}$$

where, • NLOS is the mean slope correction factor (unitless) obtained directly from the NLOS mpirical results. For the LOS environment, the Friis FS path loss formula was used and the • LOS regression correction factor was found as follows:

$$PL_{FS,\ Mod}[dB](d) = \alpha LOS\times(PLFS(d)\text{-}PLFS(d_0))+PL(d_0)+X_{\sigma}$$

RESULTS AND DISCUSSION

Using the five large-scale propagation path loss models presented in section 5 and the outdoor measurement data at both 700 MHz and 3.6 and 26 GHz, path loss parameters are analyzed and compared.

Comparison between different models

UMI-(LOS and NLOS): From Fig. 3, we note that the 3GPP Model is worst one because it is not affected by changing

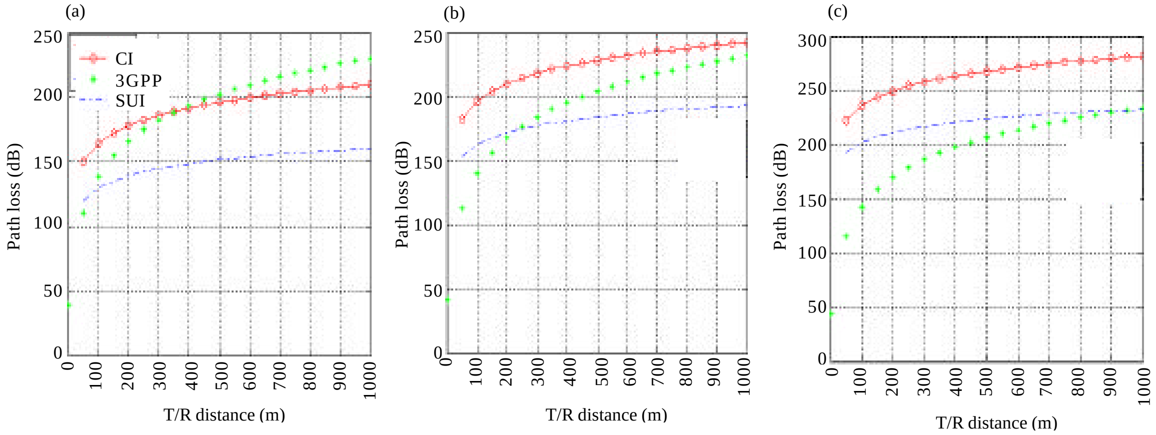
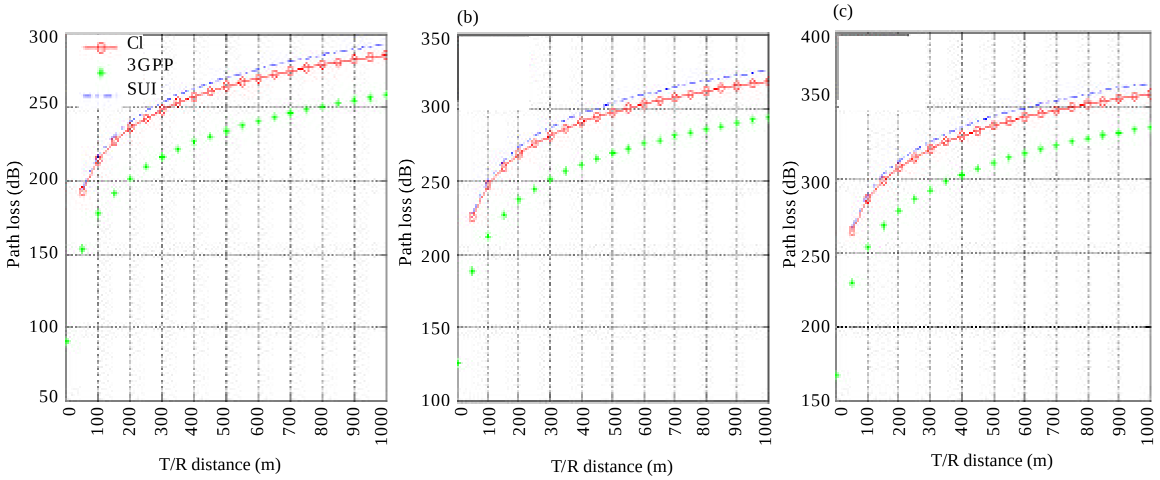


Fig. 3: UMI-LOS (CI, 3GPP and SUI) received power for carrier frequency models vs. Tx/Rx distance: a) f = 700 MHz; b) f = 3.6 GHz and c) f = 26 GHz



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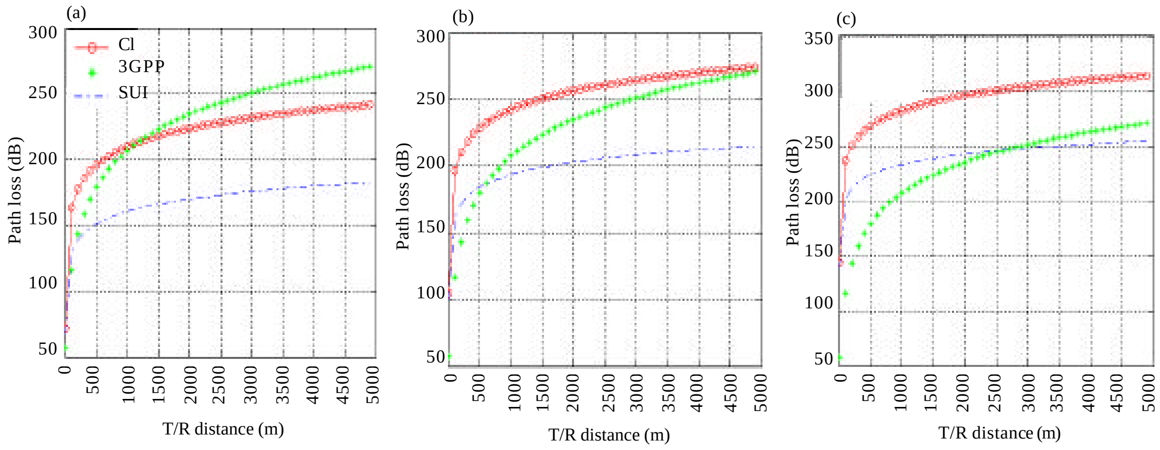


Fig. 5: UMI-LOS (CI, 3G PP and SUI) path loss for carrier frequency models vs. Tx/Rx distance: a) f = 700 MHz; b) f = 3.6 GHz and c) f = 26 GHz

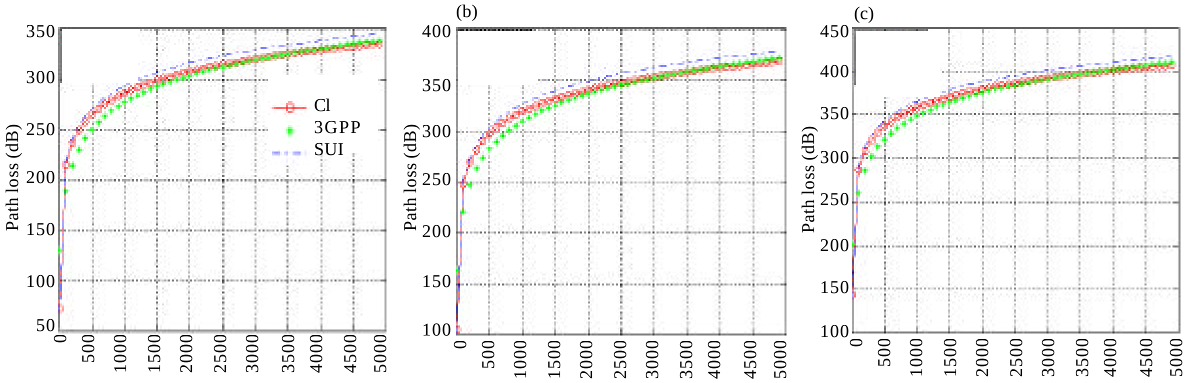
the frequency range, therefore, we conclude SUI is the best one of the different values of frequency and then CI (Fig. 4). We note that the performance of 3GPP is the best one and then CI but SUI is the worst case for the three ranges of frequencies. Finally, for the case UMI scenario 3GPP unsuccessful for the case of LOS but in case of NLOS, it is best performed with respect of frequency.

UMA-(LOS and NLOS): From Fig. 5, we also note 3GPP Model is not affected by changing the frequency, therefore, SUI is the best path loss with respect to T/R distance for different frequency values. Then, CI on the other hand in Fig. 6, the 3GPP Model performance is the best one for the case of NLOS then CI and SUI is the last one (Fig. 6-10).

Received power for different models

UMI (LOS and NLOS): For LOS case (Fig. 7) the 3GPP Model is the worst one and SUI is the best then CI. but (Fig. 8) for the case of NLOS the 3GPP is best received power then CI and the last SUI.

UMA (LOS and NLOS): From Fig. 9, we also note 3GPP Model is not affected by changing the frequency, therefore, SUI is the best path loss with respect to T/R distance for different frequency values. Then CI on the other hand in Fig. 10 the 3GPP Model performance is the best one for the case of NLOS then CI and SUI is the last one.



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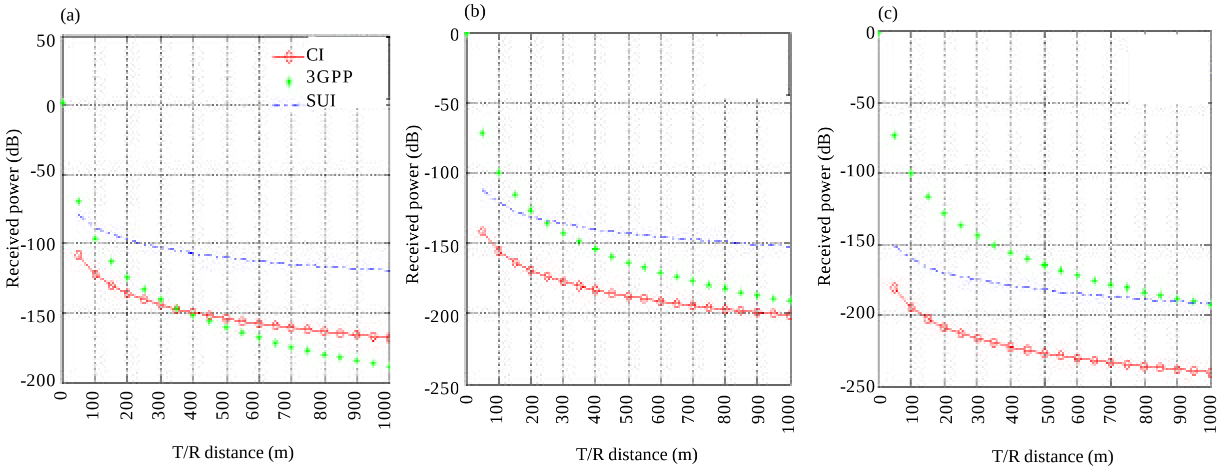

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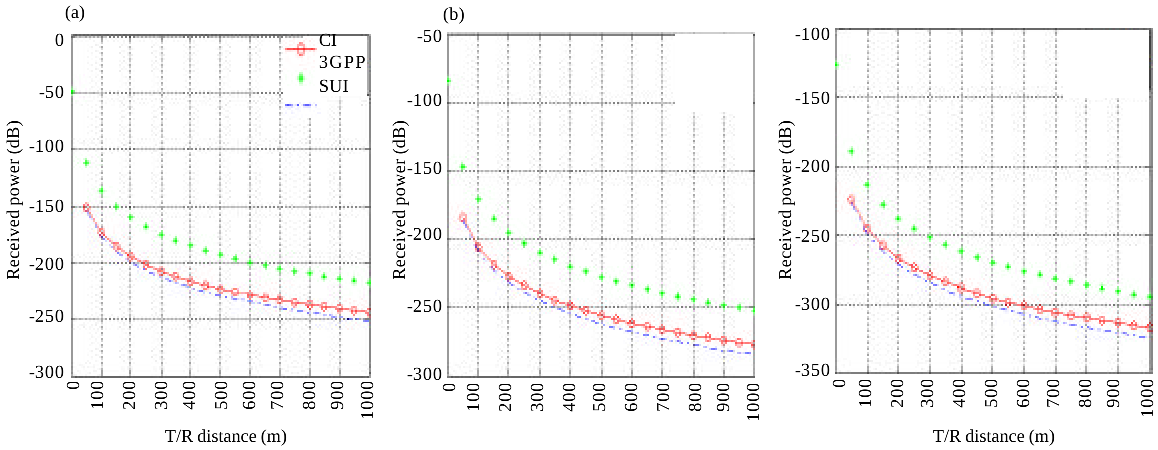

Fig. 8: UMI-NLOS (CI, 3GPP and SUI) received power for carrier frequency models vs. Tx/Rx distance: a) f = 700 MHz; b) f = 3.6 GHz and c) f = 26 GHz

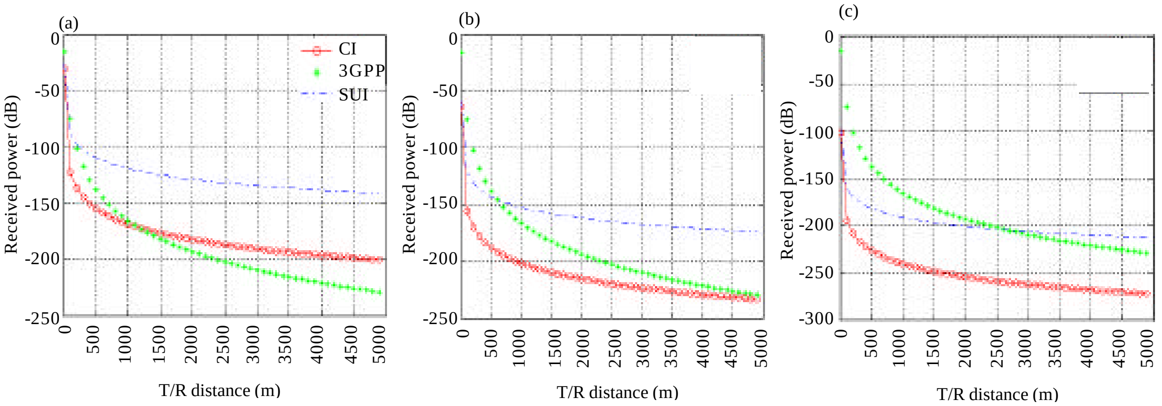

Fig. 9: UMA-LOS (CI, 3GPP and SUI) received power for carrier frequency models vs. Tx/Rx distance: a) f = 700 MHz; b) f = 3.6 GHz and c) f = 26 GHz

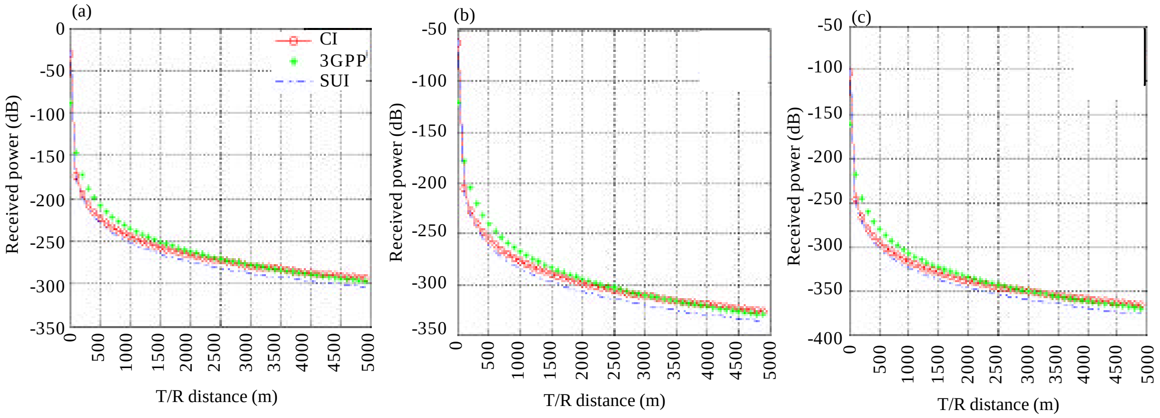

Fig. 10: UMA-NLoS (CI, 3GPP and SUI) path loss for carrier frequency models vs. Tx/Rx distance: a) f = 700 MHz; b) f = 3.6 GHz and c) f = 26 GHz

CONCLUSION

In this study, we given a comparison of the 3GPP, CI and SUI path loss models within the mmWave frequency bands, utilizing measured data and ray-tracing from 0.5-100 GHz gotten from diverse datasets from research groups over the world. The CI Model is physically tied to the transmitter power employing a close in free space reference and standardizes all measurements around an inherent 1 m free space reference distance that's physically based, hence, permitting simple utilize for changing distances without a calculator, through the utilize of just a single parameter (PLE or n).

An in-depth consider on the existing 3GPP (11) UMA/UMI LOS and NLOS path loss models for frequencies from 0.5-100 GHz and found that no considerable experimental prove exists to date to bolster selection of this model by ITU-R. Given that few work existed within the literature and the questionable parameters utilized in 3GPP and ITU standards. The LOS SUI path loss, a great match with the CI LOS Model in (1) which indicated a SF of 4-6 dB. Additionally, the NLOS 3GPP Model, resulted in good path loss compared to the CI and SUI.

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