Indoor Mobile Network Planning by Utilizing B5G/6G mmWave and Sub-THz Bands

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[1]***Abstract*—Nowadays, there is a tremendous discussion of the B5G/6G air interface and its different propagation models that are suitable for the mid and high bands (mmWave) spectrum. The key RF characteristics and planning parameters are traffic types, propagation modeling, and techniques for estimating system throughput and capacity. The goal of this research is to describe initial planning and radio deployment perspectives for the implementation of B5G/6G new radio (NR) technology in indoor scenario. This scenario is suitable to predict and design the modern mobile networks inside administrative new capital known as "Knowledge City". In addition, This paper study and compare the path loss while using three different path loss propagation models close-in (CI), floating intercept (FI) and alpha-beta-gamma (ABG) model inside a building at different frequency bands 28 GHz, 73 GHz, and 300 GHz where the signal effected by distances, obstacles and surrounded environment. The case study is in indoor conference meeting room inside a building in one of the "Knowledge City in New Administrative Capital" that can accommodate up to 80 people, where the antennas can operate with each other directly line-of-sight (LOS) or are obstructed non-line-of-sight (NLOS). Also, antennas use matched polarization vertical to vertical direction (V-V). The paper also proposed coverage and capacity network planning model for indoor radio networks using high-frequency bands in the mmWave and sub-THz ranges.**

***Keywords*—B5G/6G Indoor Planning; Coverage Planning; Capacity Calculation; Throughput Estimation; Path loss propagation models.**

I. INTRODUCTION

Traditional cellular networks use frequencies ranging from 300MHz to 3GHz. Because signals have a higher wavelength, it could be delivered over distances of many kilometers without losing their strength. In mmWave and sub-THz bands, the penetration loss is low, and it is appropriate for enhanced interior coverage. However, due to the increased need for data, depending solely on the 3GHz spectrum, it is not possible to provide enhanced mobile broadband (eMBB) services, which require speeds of up to 10 Gbps. B5G/6G is looking at using higher frequency ranges (above 3 GHz) like mmWave (24 GHz to 86 GHz) and sub-THz (90 GHz -300GHz) to increase its capacity. These frequency communications can send gigabits of data rates per second very quickly because they have enormous bandwidth to carry the information [1]. If we use small cells that are 50 to 100 meters in radius, communication can still work well without causing any extra problems. To solve the problem of signal loss, there is another method called adaptive beam forming. This method uses a technology called massive multiple input, multiple output (MIMO). The way MIMO technology works is by using a group of antennas that are very good at sending signals in a specific direction or receiving signals from that same direction. This helps the signals move around obstacles and make up for any loss of quality along the way. Also, the huge MIMO technology offers greater capacity and reliability when compared to regular MIMO technology. So, B5G/6G technologies will work well in different types of networks and between different devices, like instance vehicle to vehicle or device to device (V2V/D2D) [2]. This include networks with moving devices or networks with connections through multiple devices.

B5G/6G offers fresh prospects and experiences for end to end E2E industry clients. To incorporate innovative technologies that should be considered: wider radio spectrum, massive MIMO antenna arrays, ultra-dense networking, new multiple accesses, software-defined networking (SDN), network function virtualization (NFV), edge computing, and network slicing. B5G/6G can provide an experienced rate of 1 Gbps in normal with rates greater than 10Gbps. Additionally, B5G/6G bolsters more than 1 million associations per square kilometer square, as well as less than 1ms of ultra-low air interface latency [3]. In addition to serving customers, it also offers a wide range of businesses, such as 4K live broadcasting, virtual reality (VR), augmented reality (AR), telemedicine, and high-definition (HD) video observation. Indoor hot spots such as stadiums, clinics, transport center points, and commercial buildings are becoming the scenarios of choice for operators and industry clients to use B5G/6G networks and develop their services. To be able to reach these prerequisites, diverse recurrence groups from 24GHz to 86GHz in the mmWave band and from 90GHz to 300GHz in sub-THz are characterized for B5G/6G communication frameworks by the International Telecommunication Union (ITU) in World Radio Communications Conference (WRC) in 2019 [4]. For the improvement of the B5G/6G frameworks to function in frequency bands up to 100 GHz, there's a need to utilize appropriate radio propagation models for these bands, which are not addressed by existing channel models created for bands underneath 6 GHz.

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A. B5G/6G Three Use Cases

As the research develops, the global mobile communications industry has come to an agreement on B5G/6G application scenarios. ITU-R, the radio communication sector of the International Telecommunication Union, identified three main categories of B5G/6G use cases:

- Enhanced Mobile Broadband (eMBB): is an improved sort of mobile broadband (MBB) benefit to provide superior execution and better performance for the user experience in situations like live HD video, virtual reality, and augmented reality.
- Ultra-Reliable and Low-Latency Communications (URLLC): this technology is primarily employed in applications like the Internet of Vehicles (IoV) and smart factories where ultra-low latency and ultra-high reliability are required.
- Massive Machine Type Communications (mMTC): is primarily utilized in the Internet of Things (IoT) to enhance connectivity between humans and machines or between machines, as well as to greatly increase network capacity and connection density.

These three new use case categories have different bandwidth, latency, mobility, connection density, and data rate requirements, particularly for indoor services where network requirements differ from service to service. Therefore, operators must be flexible in setting up the best indoor network deployment targets to suit each individual application scenario. The following Table (1) lists the indoor requirements for B5G/6G networks [5].

Table.1: Indoor requirements for 5G network

Cell edge rate	Downlink : ≥ 100 Mbps Uplink: ≥ 10 Mbps
Traffic density	2.5 Mbps/m^2 (densely-populated indoor scenarios) 0.5 Mbps/m^2 (general indoor scenarios)
Connection density	1 connection/m^2 (1 million connections/km^2)
Latency	1 ms
Positioning accuracy	1 m to 3 m
Reliability	99.999%

The scenario of an indoor enhanced mobile broadband (eMBB) hotspot provides a logical case study for indoor mmWave mobile networks. The key purpose of this scenario is to arrange small-cell coverage with high data rates and capacity for users within a restricted range [6]. Ordinary illustrations for this sort of situation include an open office, airplane terminal corridor, or shopping center. For such a setup, one would be curious about understanding the necessary access point density, deployment sites, and efficient network configurations. Understanding these framework plan perspectives is required to conduct an adequate system-level assessment, which essentially includes a representation of the mmWave channel [7].

B. B5G/6G Frequency Bands

Development techniques for indoor B5G/6G systems have to consider primary key enabling technologies, which are various level organizing of mmWave and sub-THz frequencies for bigger capacity and utilizing MIMO innovation to deliver on what B5G/6G guarantees indoors, namely high data rate and low latency are the core of the B5G/6G network services [8]. mmWave and sub-THz have lower radio propagation and penetration losses than mid and low bands. Otherwise, mmWave and sub-THz have a broad range but limited coverage capability. Continuous coverage requires head ends with great density, and network development costs are frequently very high. In indoor places where the mid-band and low-band range assets cannot meet benefit prerequisites, mmWave and sub-THz should be superimposed onto these systems to meet the necessities of ultra-large capacity and low latency. In order to offer continuous coverage for B5G/6G basic coverage and capacity layer indoors, mid and low bands are used. This is done by taking into account spectrum resources, radio propagation characteristics, and network development costs. However, mmWave and sub-THz bands are used for traffic absorption in hotspot locations. It will be possible for B5G/6G connectivity to function in a variety of frequency bands [9]. This includes current frequency bands in 1GHz range, 3.5GHZ -6GHZ mid-band range, and 28GHZ - 100GHZ millimeter-wave range, as well as new frequencies in the 7-15 GHz cent metric range and 90-300 GHz sub-THz range in the W and D bands [10]. The ITU-R allocations in these bands are depicted in the fig (1) below.

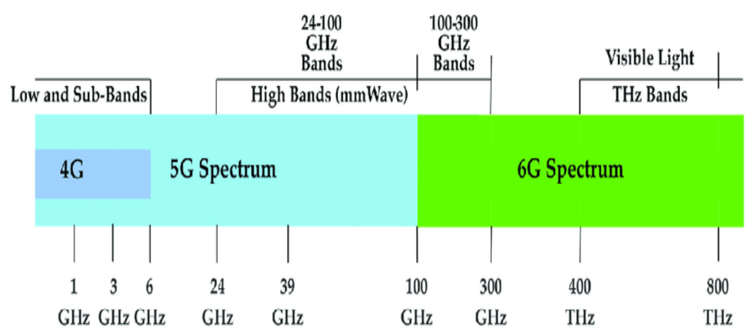

Fig.1: B5G/6G Spectrum

The present paper proceeds as following: Section II shows model verification according to related previous studies. Section III expounds on the planning model of B5G/6G, specifying its purpose, indicating exigency, and highlighting the primary features of radio planning. Section IV of the paper clarifies the proposed propagation models. Section V presents discussion and evaluation of obtained results from the tool developed for diverse applications. The final section (Section VI) of this study presents the concluding remarks and outlines potential avenues for further research.

II. Model Verification

Previous studies focused on the effectiveness of mmWaves for indoor communication at frequencies between 28 GHz and 73 GHz. Take into consideration whether there is a direct line of sight between the transmitter and receiver (LOS) or if non-line of sight (NLOS) where there are obstacles in between. Also looked at the impact of factors like buildings, antenna strength, frequency and the distance between the transmitter and receiver. A lot of research has been done on how wireless signals move and behave in indoors for frequencies below 6 GHz. This helps improve 4G services. Additionally, there has been interest in using very high frequencies, called sub-THz (between 90GHz and 300GHz) for 5G applications. Table (2) displays path loss parameters from previous studies for indoor propagation channel modeling at mmWave and sub-THz frequency bands. In order to validate the presented models, we use the different parameters that have been published in previous work such as [11, 12, 13]. So that figs (2) and (3) show the CI, FI and ABG path loss models LOS and NLOS at frequencies 28GHz and 73GHz respectively and fig (4) shows CI, FI and ABG path loss models LOS at frequencies 300GHz.

In accordance with previous published work and due to (according to the best of our knowledge) the shortage of researchers to investigate such a use case of indoor path loss models NLOS at 300GHz. Otherwise, these results have been investigated and revised to match previous work in spite of different frequency ranges and different distances for providing some sort of verification which presented models that can be tolerated or used for different frequencies as well as different operational conditions.

Table.2: Path loss Parameters

LOS communication scenario									
Frequency	CI		FI			ABG			
	PLE (n)	σ (dB)	α (dB)	β	σ (dB)	α (dB)	β	γ	σ (dB)
28	1.73	2.49	56.8	2.15	2.38	2.03	29.5	1.94	3.18
73	1.95	3.2	63.6	2.52	3.1	2.03	29.5	1.94	3.18
300	1.97	0.08	62.08	1.941	0.028	17.01	2.005	1.815	0.628
NLOS communication scenario									
Frequency	CI		FI			ABG			
	PLE (n)	σ (dB)	α (dB)	β	σ (dB)	α (dB)	β	γ	σ (dB)
28	2.64	3.14	65.4	2.24	3.12	2.13	28.4	2.91	5.3
73	4.06	3.15	79.5	3.12	3	2.13	28.4	2.91	5.3

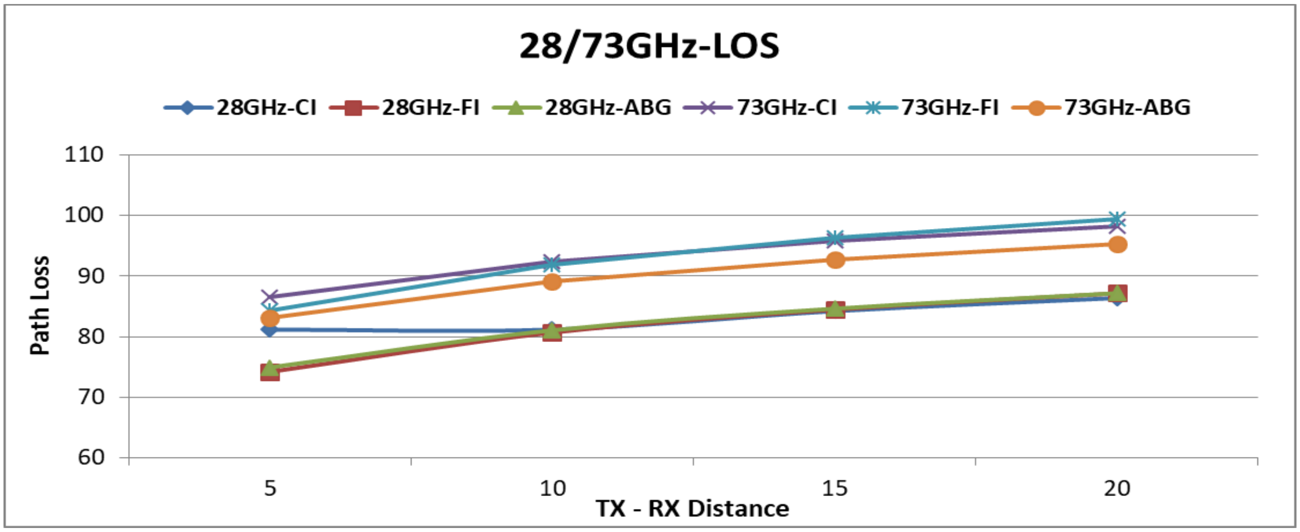

Fig. 2: Path Loss verses distance at 28,73GHz LOS

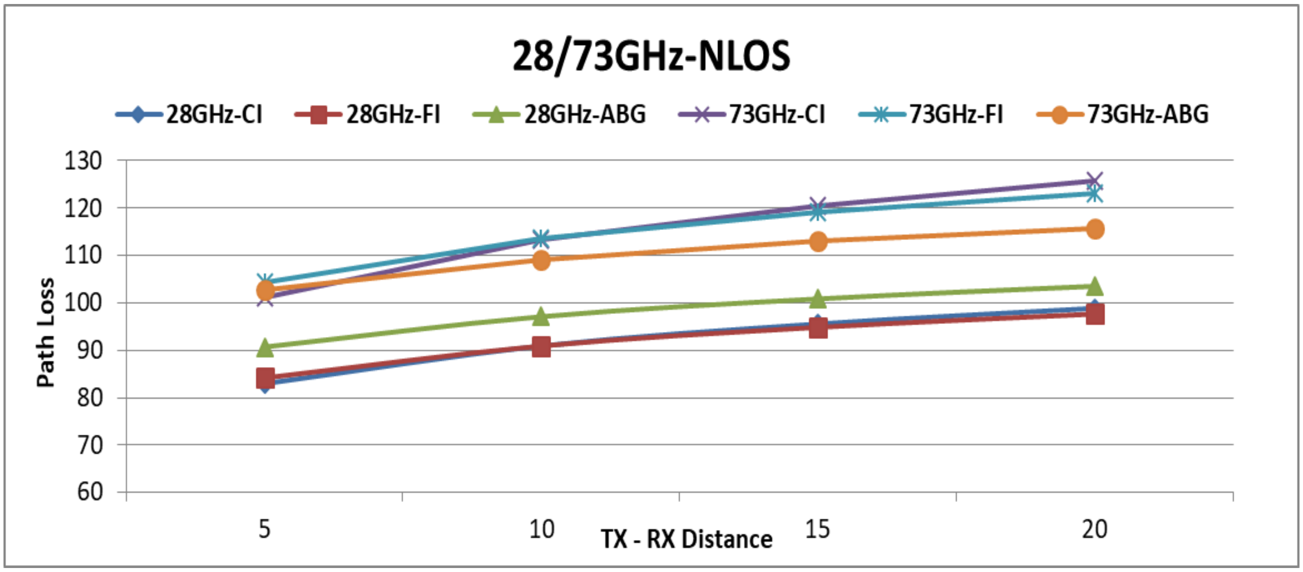

Fig.3: Path Loss verses distance at 28,73GHz NLOS

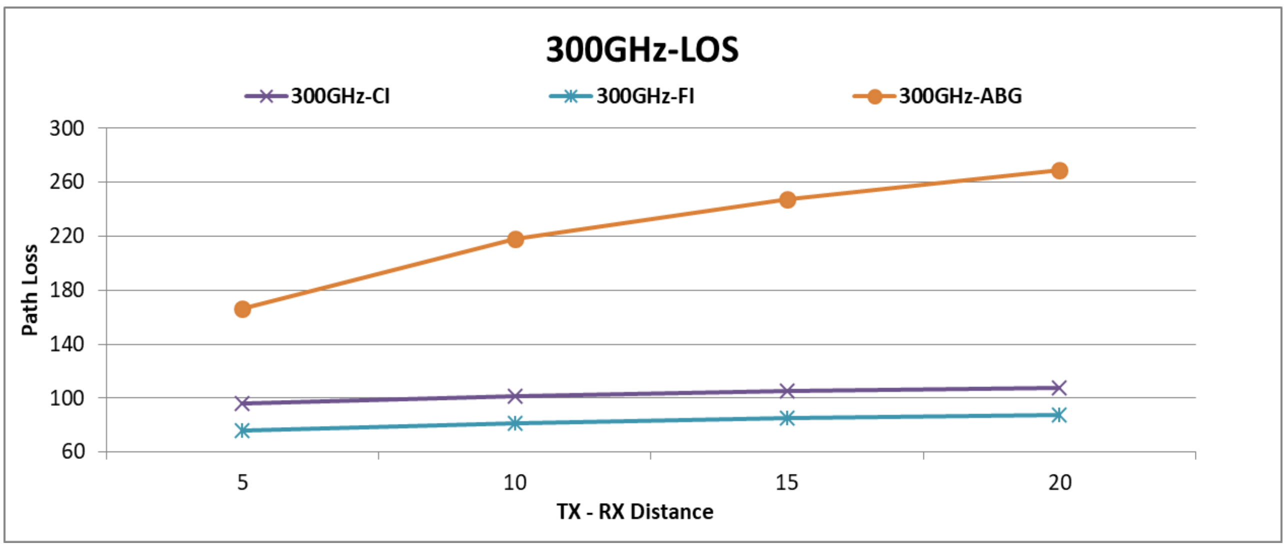

Fig.4: Path Loss verses distance at 300GHz LOS

III. Proposed Planning Model

This study's goal is to carry out the B5G/6G new radio network planning in an interior conference meeting room in the "Knowledge City of New Administration Capital." The current planning proposes use of mmWave and sub-THz bands of the frequency spectrum that apply to 28GHz, 73GHz, and 300GHz as radio frequency bands under test in the execution of International Mobile Telecommunications-2020 (IMT-2020) for 5G technology.

A. Research Methodology

This research was conducted in an indoor conference meeting room with dimensions up to $100m^2$ at the "Knowledge City of the New Administration Capital," which can accommodate up to 80 people with a transmit (TX) antenna height of 2.5m and an receive (RX) antenna height of 1.6m. The data sources were divided into primary and secondary data. Primary data are facts discovered through on-site surveys. Secondary data flow as in fig (5) that supported the analysis during the research was gathered from the literature with references to the internet, journals, publications, and web searches. The introductory step taken is to decide the parameters to be utilized during the analysis, such as frequency, fade margin, sensitivity, received signal strength, transmitted signal strength, sending antenna gain, receiving antenna gain, wavelength, and shadowing loss. Following, calculate path loss using various propagation models, SINR, and aggregated throughput.

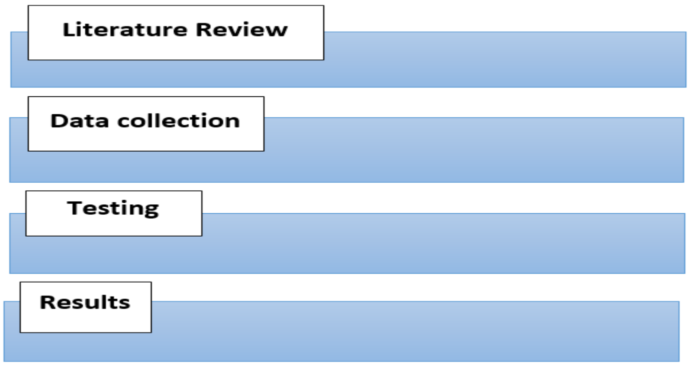

Fig.5: Work Flow

IV. Path loss for Indoor Channel Characteristics

Path loss is an example of the essential parameters that define the wireless propagation channel and affect any communication system's performance. It is utilized to characterize the power decay of wireless channels with respect to the TX-RX separation distance. Numerous studies have been conducted to examine the indoor path loss for mmWave and sub-THz propagation models. Diverse way path loss models have been proposed and explored for the indoor channels at diverse mmWave bands, including the close-in free space reference distance (CI) model, the 3GPP floating intercept (FI) model, and the alpha-beta-gamma ABG model [14]. For both line-of-sight (LOS) and non-line-of-sight (NLOS) channels, the path loss model calculates the amount of signal deterioration along the propagation path over a given distance. In this paper, we will utilize three path-loss models: The primary is the single-frequency close-in (CI) free space, the single-frequency floating-intercept (FI), and the alpha-beta-gamma (ABG) [11].
The first is the single-frequency close-in (CI) free space reference distance model, which is defined as in equation (1).

$$PL^{CI}(f,d)[dB] = FSPL(f,d_0) + 10\beta log_{10}\left(\frac{d}{d_0}\right) + X_\sigma^{CI} \quad where\ d \geq d_0 \qquad (1)$$

Where $FSPL(f,d_0) = 20log_{10}\left(\frac{4\pi f d_0}{c}\right)$ is the free space path loss at carrier frequency f with $d_0 = 10$cm and c as the speed of light, β represents the PLE, and X_σ^{CI} represents the large scale shadow fading.
The second model is the single-frequency floating-intercept (FI) model defined as in equation (2)

$$PL^{FI}(d)[dB] = \alpha + 10\beta log_{10}\left(\frac{d}{d_0}\right) + X_\sigma^{FI} \quad where\ d \geq d_0 \qquad (2)$$

where $PL^{FI}(d)$ is the path loss in dB as a function of d, α is a floating intercept in dB that represents the free-space path loss at $d_0 = 10$cm, d_0 is a reference distance, β is the path-loss exponent (PLE) that characterizes the dependence of path loss on d, and X_σ^{FI} is the large-scale shadow fading with standard deviation σ (in dB) [15]. The third model is the alpha-beta-gamma (ABG) model is a common multi-frequency model that uses a frequency dependent and distance-dependent term to estimate path loss is defined in equation (3)

$$PL^{ABG}(f,d)[dB] = 10\alpha log_{10}\left(\frac{d}{d_0}\right) + \beta + 10\gamma log_{10}\left(\frac{f}{1\ GHz}\right) + X_\sigma^{ABG} \quad where\ d_0 = 1m \qquad (3)$$

Where α the distance dependence factor on path loss, β is an optimized offset, γ is the frequency dependence factor and X_σ^{ABG} is the shadow fading term [16].
Here, referring to measured path loss$PL(f,d)$, the transmit powerP_t, transmit and receive antenna gains G_t and G_r respectively and the received power P_r which is as equation (4).

$$P_r = P_t + G_t + G_r - PL(f,d) \qquad (4)$$

Throughput is a metric that quantifies the speed of access to data by multiple users through successful data transfer between nodes over a specified unit of time, typically expressed in seconds. In this paper the approximate data transfer rate in B5G/6G indoor at mmWave and sub-THz bands calculated according to equation (5) where B is the bandwidth (Hz) , SINR is signal to noise ratio at receiver.

$$Throughput = Blog_2(1 + \text{SINR}) \qquad (5)$$

V. Numerical Results and Discussion

This segment describes the discussion of findings from path loss models LOS and NLOS analyses and evaluations of the model's variables performance. The path loss mostly depends on the operating frequency, TX-RX separation distance, environment influences represented in the propagation path loss (PLE) and shadowing effects, according to all path loss models discussed in section IV. Table (3) presents the path loss parameters of the CI, FI and ABG based on various measurements studies in indoor environment for LOS and NLOS situations using different frequencies such as 28GHz, 73GHz, and 300GHz [17].

A. Coverage Estimation

This experiment investigated three frequency bands (28 GHz, 73 GHz, and 300 GHz) at directional antenna polarizations (V-V), exposing the results and enabling a comparison between path loss propagation models (CI, FI, and ABG) in accordance with previous published work [10, 11, 12] and the presented parameters at Table (3) that will be used in this investigation of the different parameters effects for different frequency bands based on the presented proposed propagation models. Figures (6), (7), and (8) show the path loss models at 28, 73, and 300 GHz in the LOS environments, respectively. Figures (9) and (10) show the path loss models at 28 and 73 GHz in the NLOS environments, respectively.
We noticed that the CI, FI, and ABG path loss model curves overlapped with each other at using the same frequency band

such as 28 GHz and 73 GHz in LOS. Otherwise, at sub-THz frequency 300 GHz, ABG path loss increased with distance increasing compared to the CI and FI path loss models. Also, in NLOS path loss results of the three models have very similar performance. However, variation increased with TX-RX distance increasing, and obstacles exist in the indoor environment. Demonstrating that the indoor mmWave and sub-THz Propagation channel constructive interference of ground and ceiling bounce reflections and a wave guide effect down halls and corridors with a NLOS-directional that is not frequency-dependent.

Table.3: Path Loss Measurement Parameters

LOS communication scenario									
Frequency	CI		FI			ABG			
	PLE (n)	σ (dB)	α (dB)	β	σ (dB)	α (dB)	β	γ	σ (dB)
28	2.254	1.77	58.8294	2.1537	1.7431	2.03	29.5	1.94	3.18
73	1.6	3.2	79.8	0.7	2.3	2.03	29.5	1.94	3.18
300	1.97	0.08	62.08	1.941	0.028	17.01	2.005	1.815	0.628
NLOS communication scenario									
Frequency	CI		FI			ABG			
	PLE (n)	σ (dB)	α (dB)	β	σ (dB)	α (dB)	β	γ	σ (dB)
28	2.8815	8.1287	81.847	1.0558	0.7872	2.13	28.4	2.91	5.3
73	5.3	8.94	79.5	3.12	3	2.13	28.4	2.91	5.3

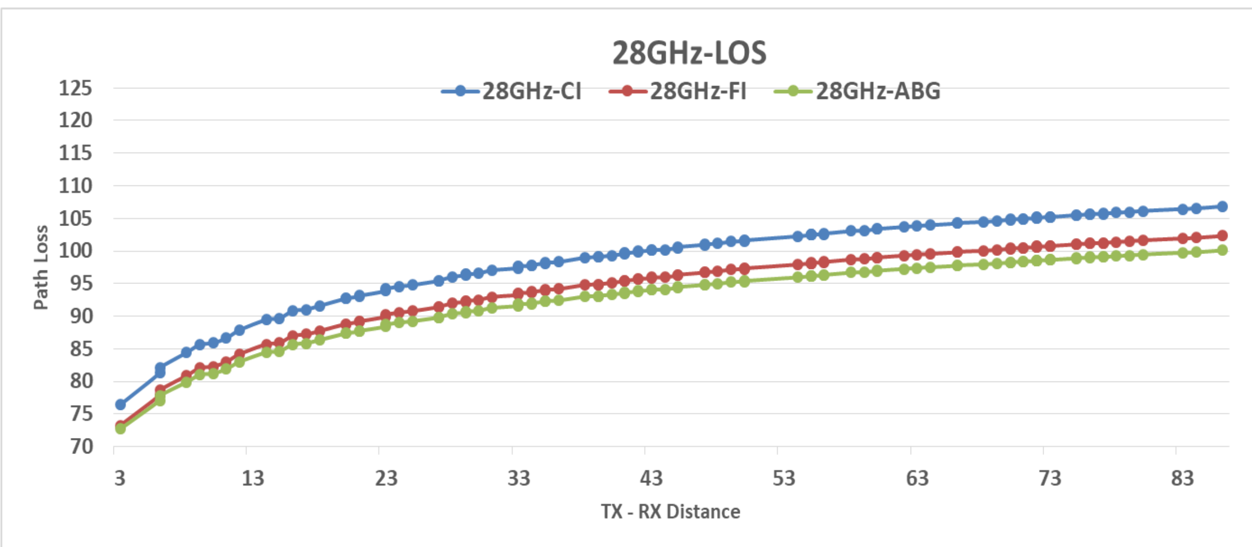

Fig.6: Path Loss verses distance at 28GHz LOS

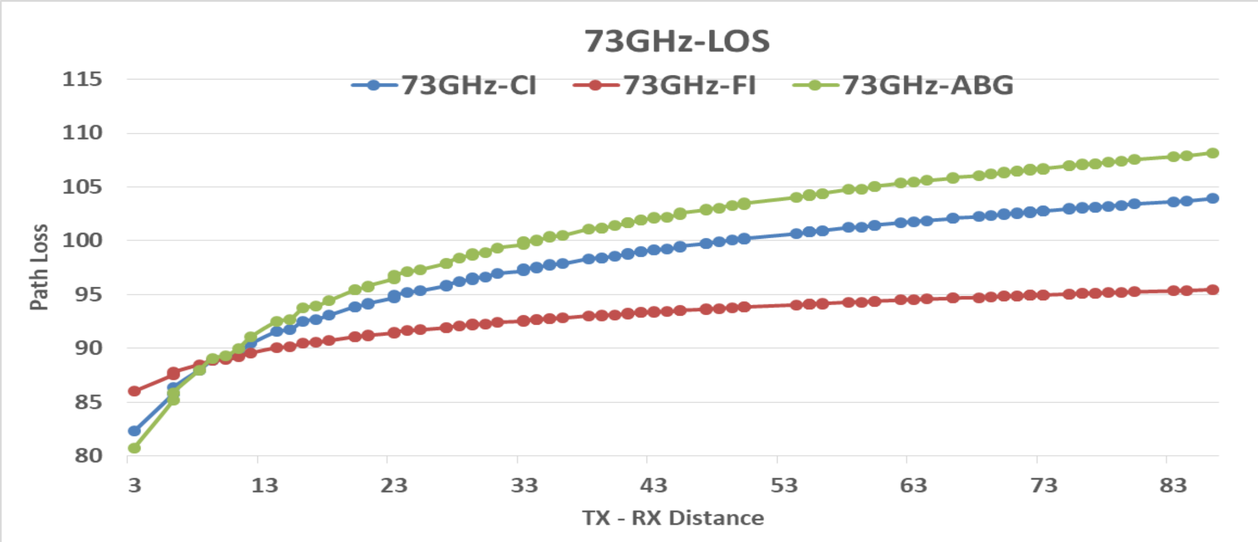

Fig.7: Path Loss verses distance at 73GHz LOS

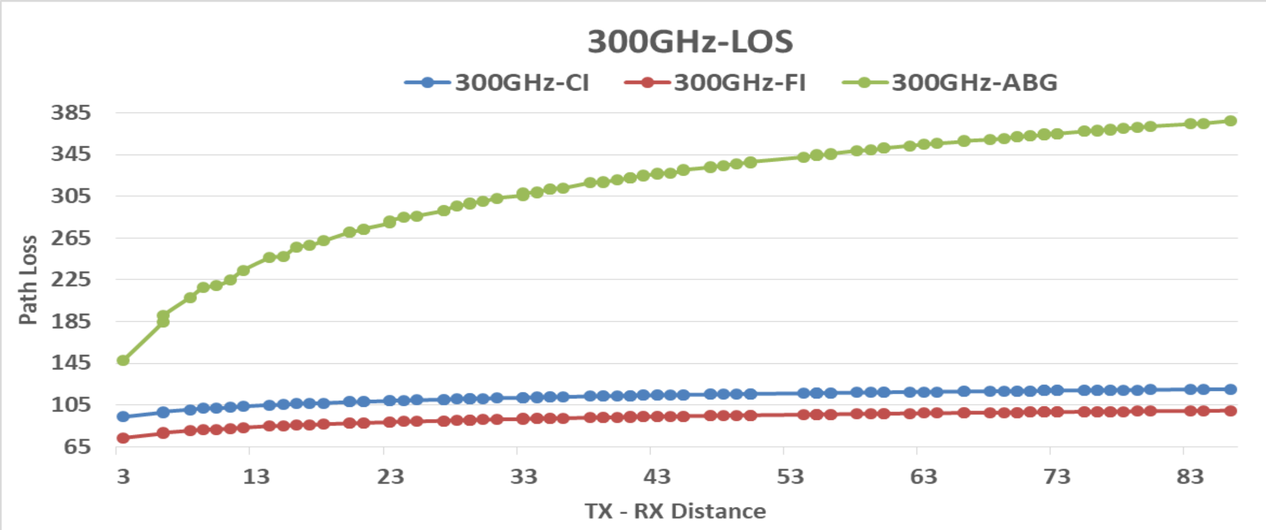

Fig.8: Path Loss verses distance at 300GHz LOS

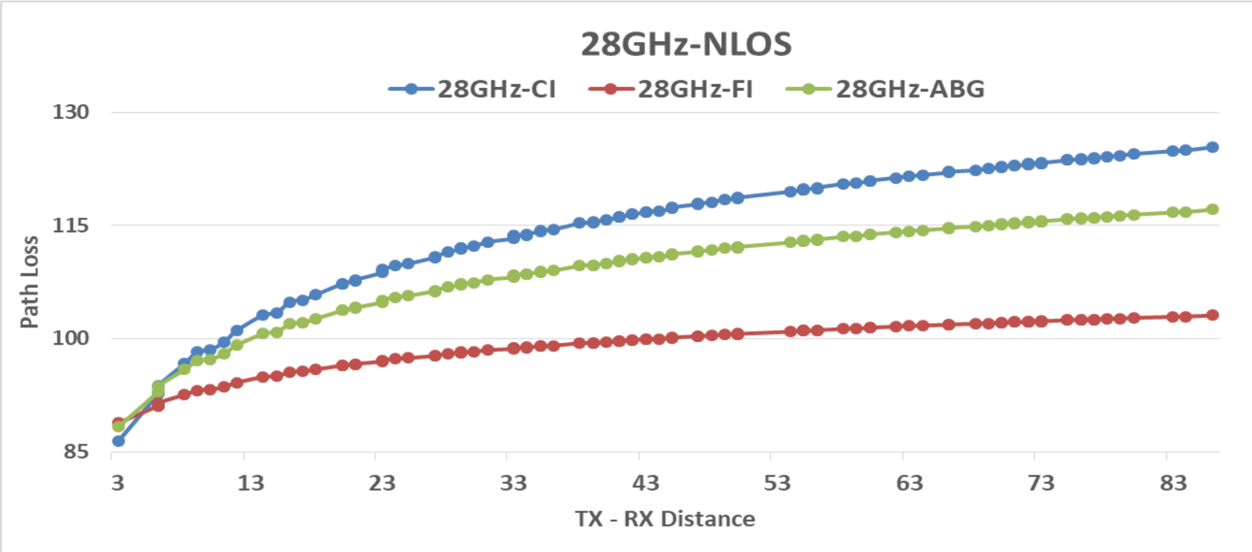

Fig. 9: Path Loss verses distance at 28GHz NLOS

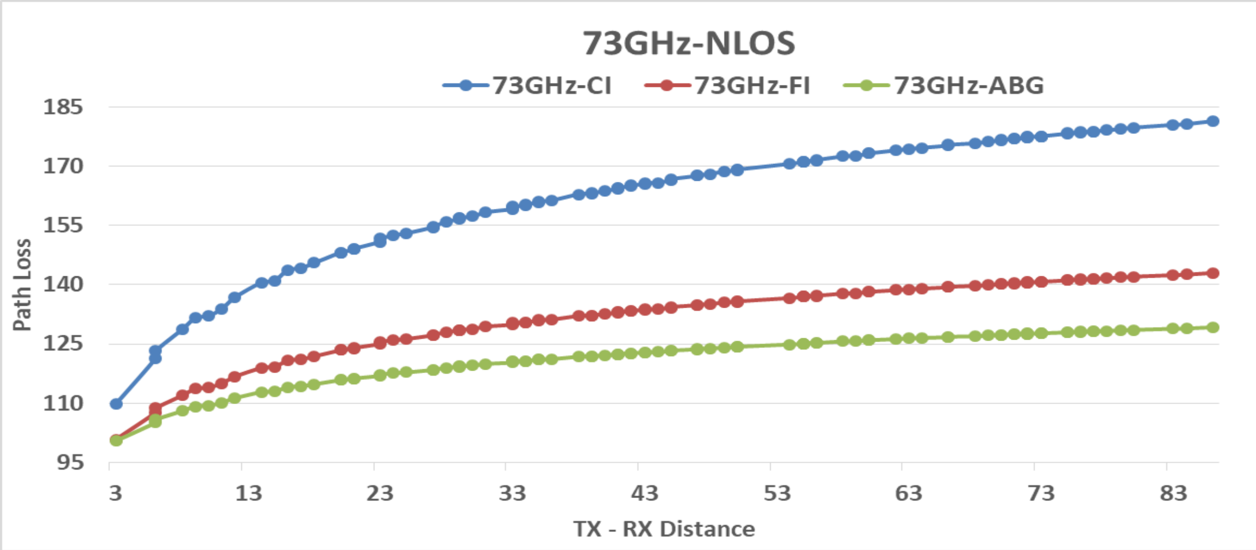

Fig.10: Path Loss verses distance at 73GHz NLOS

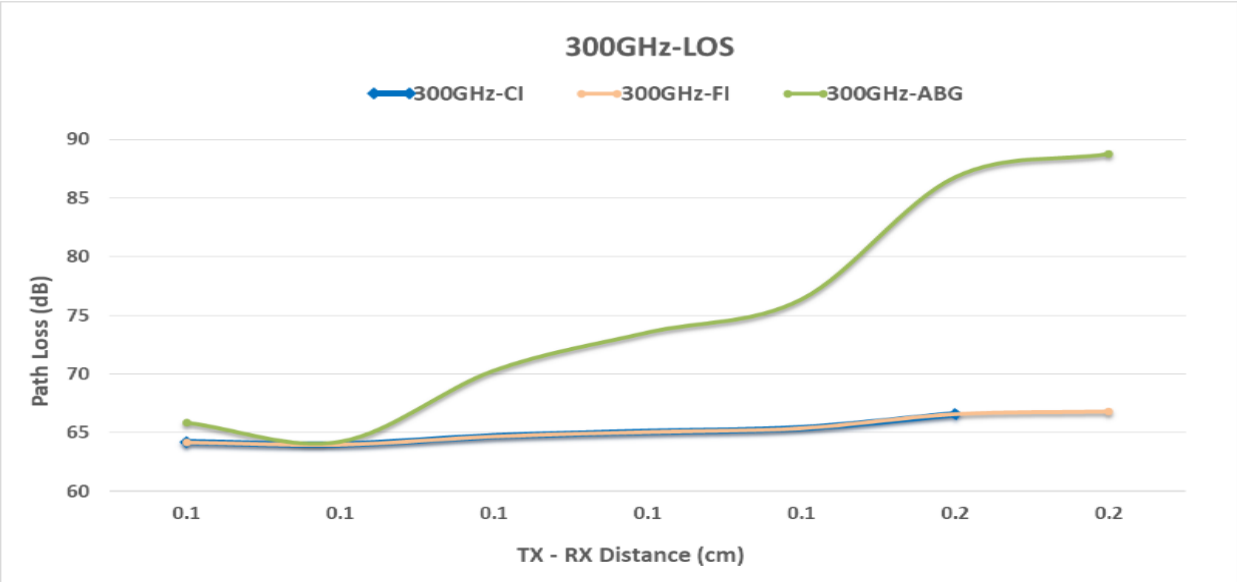

Fig.11: Path Loss verses distance less than 1m at 300GHz

Expected from section V that the different path loss models are monotonically the same except for sub-THz models ,as in sub-THz the effect of frequency will take a big difference between ABG model verses other path loss models as shown in fig (11), so the ABG model is most useful for higher frequencies but in the literature such as the other researchers [16] present this model for very short distance may be less than 1 m but in our case we are investigating at planning implementation process for difference cell radiuses that extend from 3m up to 83m. We can conclude that sub-THz frequencies are not recommended to get the cell radius to be more than 5m in order to have same boundary level the same upper bound (110dB) to be looks like the other frequencies from different mmWave s so that the cell radius will not exceed 1m.

B. *Capacity (Throughput) Estimation*

By expanding the frequency and bandwidth as in Table (4), the specified throughput might be expanded to accommodate various user services in the same bandwidth. Figure (12) shows the average throughput per user. However, expanding the carrier Frequency will result in increased attenuation (path loss), and the signal will be affected by noise related to frequency increasing, which will lead to throughput decreasing.

Table.4: Max/Min Throughput Estimation

Frequency(GHz)	**28**	**73**	**300**
Bandwidth(MHz)	100	200	800
Antenna Gain(dBi)	2	2	2
Power TX(dBm)	23	23	23
Noise(dBm)	-93.992	-90.981	-84.961
Max Throughput(Gbps)	1.5	2.3	9.6
Min Throughput(Gbps)	0.4	0.5	0.1

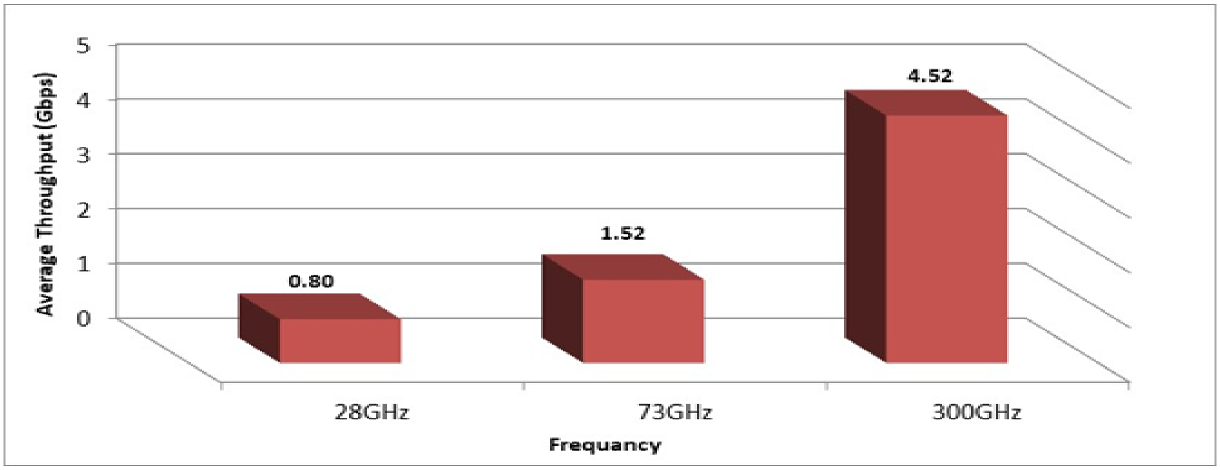

Fig.12: Average Throughput per user at 28, 73 and 300GHz

VI. Conclusions

This paper presents the mmWave and sub-THz path loss propagation models measurements (CI, FI and ABG) at 28 GHz, 73 GHz, and 300 GHz frequency bands in indoor LoS and NLOS environments. The results show that all three models have very similar performance and the model with the smallest number of parameters would be the better choice. Noticed that the best models for path loss in the indoor environment at the mmWave and sub-THz bands are the CI and FI models for LOS channels and such as the FI and ABG models for NLOS .On the other hand The ABG model showed all frequency in LOS and NLOS that represent an amount of attenuation with increasing frequency especially at sub-THz as at 300 GHz. We can conclude that the difference between our model and previously presented models is about 5dB, in spite of its different parameters and operation conditions. Whereas our model can be used for different applications, models, and frequencies. We can present this model to be used in order to achieve the most suitable propagation model that may be used for both mmWave and sub-THz applications for different B5G/6G deployment scenarios. In other words, the main contribution of the presented work is to elaborate on and investigate the effect of the selection of a suitable propagation model as well as the expectation of the expected capacity (aggregated throughput) of the framework. Thus, the presented model may be used for the planning of B5G/6G from different capacity and coverage perspectives.

References

[1] Hesham. M. El-Badawy, H. A. Sayed Ahmed, S. H. Zainud-Deen and H. A. El-AzemMalhat, "B5G/6G Network Planning For Study Case In Knowledge City Area As Model For Smart Cities," 2023 40th National Radio Science Conference (NRSC), Giza, Egypt, 2023, pp. 191-200, doi: 10.1109/NRSC58893.2023.10152960.

[2] M. Alsabah, "6G Wireless Communications Networks: A Comprehensive Survey" IEEE Access, pp. 148191-148243, 2021.

[3] T. T. Oladimeji, P. Kumar, and M. K. Elmezughi, "Path Loss Measurements and Model Analysis in an Indoor Corridor Environment at 28 GHz and 38 GHz." Sensors, vol. 22, no. 19, p. 7642, 2022, doi: 10.3390/s22197642.

[4] *IEEE 5G World Forum (WF-5G) | 10–12 September 2020*, August 2020, [online] Available: https://ieee-wf-5g.org/ .

[5] September2018(Version2.0). https://carrier.huawei.com/minisite/Indoor-5G/pdf/Indoor-5G-Networks-White-Paper-V2.0-en.pdf

[6] J. Kibilda, "Indoor Millimeter-Wave Systems: Design and Performance Evaluation." *Proceedings of the IEEE*, vol. 108, no. 6, pp. 923-944, 2020, doi: 10.1109/jproc.2020.2989189.

[7] E. N. Ganesh, "Study and Analysis of 5G Research Activities," *Journal of Telecommunication, Switching Systems and Networks*, vol. 8, no. 3, pp. 18–27, 2021

[8] H. Halbauer and T. Wild, "Towards Power Efficient 6G Sub-THz Transmission" *2021 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit)*, 2021.

[9] N. Docomo NT. 5G Channel Model for bands up to100 GHz. Technical report; 2016 Oct

[10] S. Alraih, "Revolution or Evolution? Technical Requirements and Considerations towards 6G Mobile Communications" *Sensors*, p. 762, 2022.

[11] S. Salous, A. Al-Jzari, M. Abdulali, and J. Towers, "Multi-band measurements in indoor environments," in *2021 15th European Conference on Antennas and Propagation (EuCAP)*, IEEE, 2021, pp. 14.

[12] G. R. MacCartney, S. Deng, and T. S. Rappaport, "Indoor office plan environment and layout-based mmWave path loss models for 28 GHz and 73 GHz," in *2016 IEEE 83rd Vehicular Technology Conference (VTC Spring)*, 2016.

[13] C.-L. Cheng, S. Kim, and A. Zajic, "Comparison of path loss models for indoor 30 GHz, 140 GHz, and 300 GHz channels," in *2017 11th European Conference on Antennas and Propagation (EUCAP)*, 2017.

[14] 3GPP –ETSI TR 138 901 - V17.0.0 - 5G (220204) [Online]. Available: https://www.etsi.org/deliver/etsi_tr/138900_138999/138901/17.00.00_60/tr_138901v170000p.pdf.

[15] Ahmed Mohamed Anwar, Mohamed Shehata, Safa M. Gasser, &Hesham El Badawy. (2023). Handoff Scheme for 5G Mobile Networks Based on Markovian Queuing Model. Journal of Advanced Research in Applied Sciences and Engineering Technology, 30(3), 348–361. https://doi.org/10.37934/araset.30.3.348361

[16] A. Al-Saman, M. Cheffena, O. Elijah, Y. A. Al-Gumaei, S. K. Abdul Rahim, and T. Al-Hadhrami, "Survey of millimeter-wave propagation measurements and models in indoor environments," *Electronics (Basel)*, vol. 10, no. 14, p. 1653, 2021.

[17] T. S. Rappaport, G. R. MacCartney, M. K. Samimi, and S. Sun, "Wideband millimeter-wave propagation measurements and channel models for future wireless communication system design," *IEEE Trans. Commun.*, vol. 63, no. 9, pp. 3029–3056, 2015.

[18] Hesham M. El-Badawy, and Rowayda A. Sadek, "B5G/6G Service Planning Process for the Deployment of Smart Cities as a Model for Massive Urban Area Applications," 2022 39th National Radio Science

Conference (NRSC), Cairo, Egypt, 2022, pp. 332-341, doi: 10.1109/NRSC57219.2022.9971192.
[19] T. T. Oladimeji, P. Kumar, and M. K. Elmezughi, "Path loss measurements and model analysis in an indoor corridor environment at 28 GHz and 38 GHz," *Sensors (Basel)*, vol. 22, no. 19, p. 7642, 2022.

Abbreviation table

#	**Abbreviation**	**Meaning**
1	B5G/6G	Beyond Fifth-generation / Sixth-generation
2	mmwave	Millimetre Wave
3	NR	New Radio
4	CI	Close-In
5	FI	Floating-Intercept
6	ABG	Alpha-Beta-Gamma
7	GHz	Giga Hertz
8	LOS	Line of Site
9	NLOS	Non-line of sight
10	THz	Tera hertz
11	eMBB	Enhanced Mobile Broadband
12	Gbps	Giga bit per second
13	MIMO	Multi input multi output
14	V2V	Vehicle to Vehicle
15	D2D	Device to Device
16	E2E	End to End
17	SDN	Software defined network
18	NFV	Network function virtualization
19	4K	4 Kilo pixels
20	VR	Virtual reality
21	AR	Augmentation reality
22	HD	High definition
23	ITU	International Telecommunication Union
24	WRC	World Radio Communications Conference
25	eMBB	Enhanced Mobile broadband
26	URLLC	Ultra-Reliable Low Latency Communications
27	mMTC	Massive Machine-Type Communications
28	IOT	Internet of Things
29	Mbps	Megabits-per-second
30	Mbps/ms	Megabits-per-second / millisecond
31	ms	Millisecond
32	m	Meter
33	PLE	Propagation Path Loss
34	σ (dB)	Standard deviation
35	α (dB)	Floating intercept
36	B	Path-loss exponent
37	α	Distance dependence factor on path loss
38	β	Optimized offset
39	γ	Frequency dependence
40	IMT-2020	International Mobile Telecommunications-2020
41	TX	Transmit
42	RX	Receive
43	PL	path loss
44	FSPL	Free space path loss
45	F	Frequency
46	d	Distance
47	dB	Decibel
48	X_{σ}^{CI}	Shadow fading
49	c	Speed of light
50	X_{σ}^{FI}	Shadow fading
51	X_{σ}^{ABG}	Shadow fading
52	Pt	Transmit power
53	Gt	Transmit Antenna gains
54	Pr	Receive power
55	Gr	Receive Antenna gains
56	SINR	Signal to noise ratio
57	B	Bandwidth
58	dBm	Decibels relative to a mill watt
59	dBi	Decibels relative to isotropic