A Comparative Analysis of Propagation Models Suitable for Non-Line-of-Sight 5G Communication at 26 GHz

Pia Sarkar, Arijit Saha, and Amit Banerjee

Abstract The Non-Line-of-Sight (NLOS) communication in millimeter wave (mmWave) experiences high path loss in the urban region due to reflection, blockage etc. To design an efficient 5G system, the channel should be modelled such that data rate and capacity are high. This paper presents the close-in (CI) free space reference distance model, CI model whose path loss exponent is frequency weighted (CIF) and the alpha-beta-gamma (ABG) model for 26 GHz. The use of these models in 3rd Generation Partnership Project (3GPP) and Fifth Generation Wireless System design has drawn the attention of researchers to investigate more. As 26 GHz 5G band is commercially used for 5G communication in India, we have analyzed the path loss and capacity in this frequency taking different distances for Urban Macrocell (UMa), Urban Microcell (UMi) and input office scenario considering NLOS communication. The results show that path loss varies with variation of cell size.

Keywords UMa · UMi · Millimeter wave · 5G channel model

1 Introduction

To explore a 5G communication system it is important to model a channel such that it becomes reliable. In India many 5G bands are supported like n28, n78, n258 etc. It is found that n28 (700 MHz) and n78 (3300–3800 MHz) sub-6 GHz 5G bands are commonly used. In these bands the signal can cover long distances with a speed of 1 Gbps. To increase the data rate up to 10 Gbps mmWave frequency band n258

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(24.25–27.5 GHz) can be used. Certain models exist for below 6 GHz band. However, more researches are recently going on for the 6 GHz–100 GHz frequency range. Some projects like the 3rd Generation Partnership Project (3GPP) [1], Fifth Generation Channel Model (5GCM) [2], *Mobile and wireless communications Enablers for the Twenty-twenty Information Society* (METIS) [3], Millimetre-Wave Based Mobile Radio Access Network for Fifth Generation Integrated Communications (mmMAGIC) [4] are conducting research works on the propagation model in this high frequency range. Three models are frequently used, i.e. Close-In (CI) free space reference distance model, CI model whose path loss exponent is frequency weighted (CIF) and Alpha-Beta-Gamma (ABG) model. These models are used to calculate path loss and received power which are functions of distance and frequency.

Wang et al. [5] proposed a wideband channel model at 26 GHz applied for indoor Line-of-Sight (LOS) measurement. The bandwidth of this model was 1 GHz and the propagation distance was 2–67 m. Hur et al. [6] developed a channel sounder at 28 GHz valid for indoor communication like shopping mall. Al Samman et al. [7] presented channel characteristics for indoor at 6.5, 10.5, 15, 19, 28 and 38 GHz. Azar et al. [8] first presented the measurement at 28 GHz in New York city. The distance covered was 500 m. MacCartney et al. [9] suggested a 5G channel model for 28 GH and 38 GHz. The distance dependent path loss model was proposed for the outdoor scenario in an Urban Microcell. Sun et al. [10] investigated CI and ABG model at 28 GHz and 73 GHz where path loss was the function of the distance applicable for both indoor and outdoor scenarios. Close-in (CI) free space model gave satisfactory results than the Alpha-Beta-Gamma (ABG) model. Violette et al. [11] provided wideband measurement for the 28 GHz mmWave channel considering LOS and NLOS communication in a dense urban environment. Smulders et al. [12] overviewed a 60 GHz channel model considering ray tracing technique. Al Samman et al. [13] discussed the pathlosses of ABG, CI and CIF models for indoor communication at 3.5 GHz and 28 GHz. MacCartney et al. [14] presented the omnidirectional measurement of path loss at 28 GHz, 38 GHz and 73 GHz for 5G urban cellular technology. Samimi et al. [15] presented an outdoor channel model that can be implemented upto 100 GHz for Urban Macro cell (Uma) and Urban Microcell (UMi).

Well investigation on path loss models have been done in 28, 38, 60 and 73 GHz frequency. Limited work has been carried on the 26 GHz channel model applicable for LOS scenario in indoor environment. Operators are interested to deploy 5G cellular technology in the urban area and 26 GHz is a commercial band used for 5G communication in India. This fact motivates us to analyze different path loss models at 26 GHz. In case of indoor scenario the chances of NLOS communication is more. Propagation models with NLOS possibilities have been studied in this work. Different cell sizes have been introduced in 5G cellular technology to enhance data rate and capacity. We have carried out our work considering different path lengths for macro, micro cell and indoor office location.

Previous research works have already been done with CI, CIF and ABG models at 26 GHz for LOS possibility in indoor location. We have analyzed the application of the commercial band 26 GHz for NLOS possibility in both outdoor and indoor office environment. We have investigated the received signal power and compared the capacity for these three models in UMa, UMi-SC and UMi-OS environment. The Novelty of the work lies here.

The organizations of the paper are as follows. Different path loss models have been described in Sect. 2. Free Space Path Loss model (FSPL), single and multiple frequency path loss models have been discussed in this section. Analysis of simulated results are presented in Sect. 3. Path loss, signal strength at receiver and channel capacity have been compared in this section. Conclusion of this work has been given in Sect. 4.

2 Path Loss Models

2.1 Free Space Path Loss Models

Path loss is given by

$$PL = P_t + g_t + g_r - P_r - Other\,Loss \tag{1}$$

$$\text{Free Space Path Loss(FSPL)[dB]} = 20log_{10}\left(\frac{4\pi df}{c}\right) \tag{2}$$

where, P_t, g_t, g_r, P_r, and d are transmitted power, transmitting antenna gain, receiving antenna gain, received power, and transmission distance respectively. Here f is frequency, and c is the velocity of light.

2.2 Single Frequency Propagation Model

2.2.1 CI Model

The path loss of CI model is represented as

$$PL^{CI}(f, d)[dB] = FSPL(f, 1m) + 10nlog_{10}\left(\frac{d}{1m}\right) + X_\sigma^{CI} for\, d \geq 1m \tag{3}$$

where, f is the frequency in Hz, d is the distance covered in m. FSPL is Free Space Path Loss calculated for 1m distance at frequency f, n is the Path Loss Exponent (PLE). If standard deviation σ reduces, path loss reduces, PLE optimizes.

X_σ^{CI} is the zero mean Gaussian random Variable with standard deviation σ in dB. It comes from large-scale path loss due to shadowing effect.

$$X_\sigma^{CI} = PL^{CI}(f, d)[dB] - FSPL(f, 1m) - 10nlog_{10}\left(\frac{d}{1m}\right) for\, d \geq 1m \tag{4}$$

2.3 Multiple Frequency Propagation Model

2.3.1 CIF Model

The path loss of the CIF model can be written as

$$\begin{aligned} PL^{CIF}\ (f, d)[dB] =& FSPL(f, 1m) + 10n\left(1 + b\left(\frac{f - f_0}{f_0}\right)\right)log_{10}\left(\frac{d}{1m}\right) \\ & + X_\sigma^{CIF}\ \ for\ d \geq 1m \end{aligned} \tag{5}$$

where, n is Path Loss Exponent (PLE), f and d denote frequency and distance respectively, b presents how path loss depends on weighted average frequency.

$$f_0 = \frac{\sum_{k=1}^{K} f_k N_k}{N_k} \tag{6}$$

where, f_0 is the reference frequency calculated from some measured data points. K is the number of frequencies. N_k is the number of path loss measured values. X_σ^{CIF} is the zero mean Gaussian random variable expressing shadowing.

In case of single frequency when f_0 will be same as f and $b = 0$, then the multi frequency CIF model turns into a single frequency CI model.

2.3.2 ABG Model

Path loss of the ABG model is expressed as:

$$PL^{ABG}(f, d)[dB] = 10\alpha log_{10}(d) + \beta + 10\gamma log_{10}(\mathrm{f}) + X_\sigma^{ABG} \tag{7}$$

where, α and γ are path loss varying factors with distance and frequency. d and f are distance and frequency respectively, β (in dB) is the floating offset. X_σ^{ABG} is the zero mean Gaussian random variable with standard deviation σ in dB.

If $\alpha = 20log\frac{4\pi}{c}$, β becomes equal with Path Loss Exponent (PLE) and γ is equal to 2, and the ABG model transforms into the CI model.

3 Results

We have analyzed the path loss, signal strength at receiver and capacity considering three channel models i.e., CI, CIF and ABG models at 26 GHz for NLOS communication in Macrocell, Urban Microcell and indoor office scenario. Simulation Parameters are listed below in Tables 1 and 2.

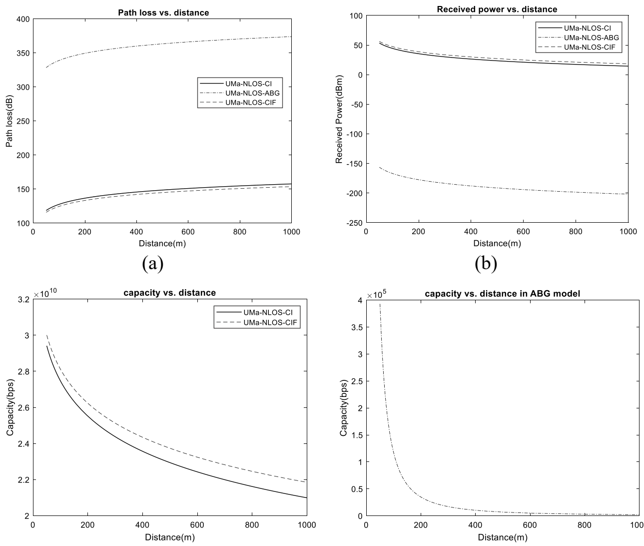
For the UMa environment distance is taken from 0 m to 1000 m. For CI, CIF and ABG models path loss at 1000 m are shown in Fig. 1a as 157.5, 153.5 and 373.78 dB respectively. In Fig. 1b the received power at 1000 m distance are 14.47, 18.48 and −201.75 dBm for CI, CIF and ABG models respectively. As in the ABG model thr signal experiences more path loss, received power decreases rapidly. Received power becomes negative in dBm as thr received power is less than 1milliWatt (mW). In Fig. 1c the capacity at 1000 m distance in the CI model is 21 Gbps and in the CIF model 21.86 Gbps. In Fig. 1d the capacity at 1000 m distance in the ABG model is 0.021 Gbps.

Table 1 Simulation parameters

Parameter	Value
Carrier frequency (f)	26 GHz
Bandwidth (B)	1.3 GHz
Transmitting antenna gain in dBi (g_t)	20
Receiving antenna gain in dBi (g_r)	2
Transmitted power (P_t) in dBm	150
Distance taken for UMa scenario	0–1000 m
Distance taken for UMi-SC and UMi-OS scenario	50–100 m
Distance taken for indoor office scenario	4–20 m

Table 2 Model parameters for UMa, UMi and indoor office scenario in NLOS communication (* S.C.- Street Canyon, O.S.-Open Square, SF-Shadow Fading)

Model	Scenario	Model parameters
ABG	UMa	$\alpha = 3.5$, $\beta = 13.6$, $\gamma = 2.4$, SF = 5.3 dB
	UMi-SC	$\alpha = 3.48$, $\beta = 21.02$, $\gamma = 2.34$, SF = 7.8 dB
	UMi-OS	$\alpha = 4.14$, $\beta = 3.66$, $\gamma = 2.43$, SF = 7 dB
	Indoor office	$\alpha = 3.1$, $\beta = 1.3$, $\gamma = 3.8$, SF = 10.3 dB
CI	UMa	n = 3, SF = 6.8dB
	UMi-SC	n = 3.19, SF = 8.2 dB
	UMi-OS	n = 2.89, SF = 7.1 dB
	Indoor office	n = 2.9, SF = 10.9 dB
CIF	UMa	n = 2.9, b = −0.002, SF = 5.7 dB
	UMi-SC	n = 3.2, b = 0.076, SF = 7.1 dB
	Indoor office	n = 3, b = 0.21, SF = 10.4 dB



(a) (b)

(c) (d)

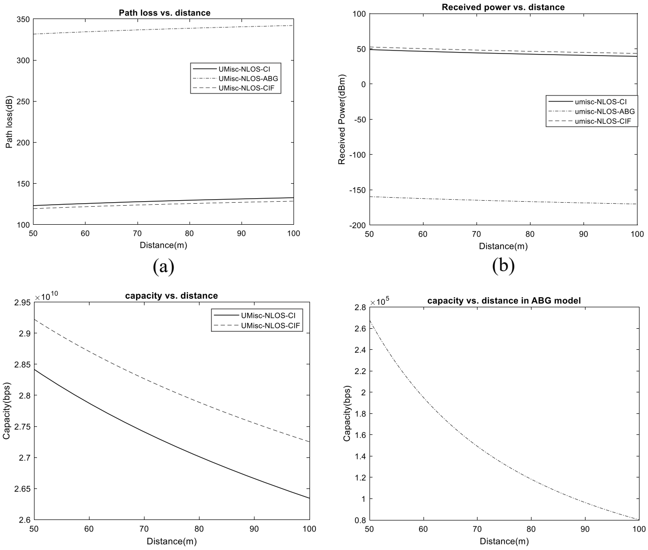
Fig. 1 **a** Path loss versus transmission distance, **b** Received power versus distance, **c** Capacity versus distance of CI and CIF model, **d** Capacity versus distance of ABG model in urban Macrocell environment

For the UMi-SC environment distance is taken from 50 m to 100 m. For CI, CIF and ABG models path loss at 100 m are shown in Fig. 2a as 132.7, 128.5 and 342.09 dB. In Fig. 2b the received power at 100 m distance are 39.28, 43.47 and −170.1 dBm for CI, CIF and ABG modelS respectively. In Fig. 2c the capacity at 100 m distance in the CI model is 26.35 Gbps and in the CIF model 27.25 Gbps. In Fig. 2d the capacity at 100 m distance in the ABG model is 0.81 Gbps.

For the UMi-OS environment distance is taken from 50 m to 100 m. For CI and ABG models at 100 m distance path losses are shown in Fig. 3a as 125.6 dB and 346.5 dB. In Fig. 3b received power which is 46.38 and −174.5 dBm for CI and ABG model, respectively. In Fig. 3c the capacity at 100 m distance in the CI model is 27.9 Gbps. In Fig. 3d the capacity in the ABG model is 0.485 Gbps.

For Indoor office environment distance is taken from 4 m to 20 m. For CIF and CI model path loss at 20 m are shown in Fig. 4a as 104.579 and 109.295 dB. In Fig. 4b the received power at 20 m distance are 67.45 and 62.66 dBm for CIF and CI models respectively. In Fig. 4c the capacity at 20 m distance in the CIF model is 32.43 Gbps. In Fig. 4d the capacity in the CI model is 31.41 Gbps.

For the CI and CIF propagation model, more path loss occurs in UMa scenario than UMa-SC, UMa-OS and minimum path loss occurs in the Indoor office scenario. These models provide minimum capacity for UMa case and maximum capacity in the Indoor Office environment. UMi-SC case produces more pathloss than UMi-OS environment.

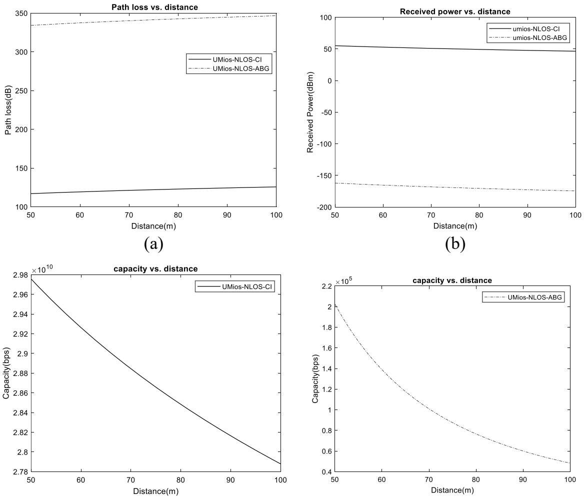


(a) (b)

(c) (d)

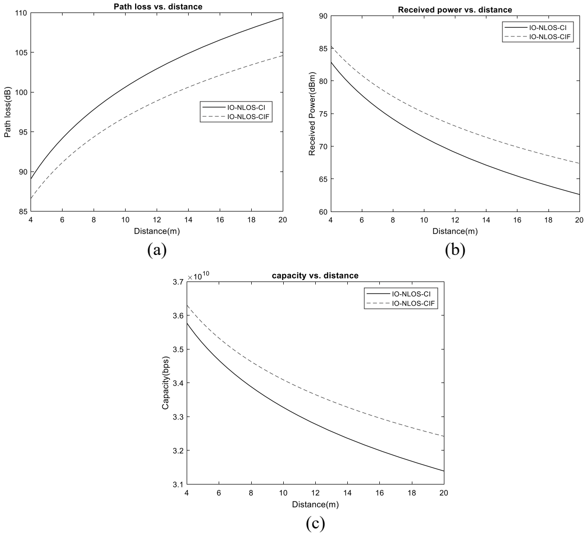
Fig. 2 **a** Path loss versus transmission distance, **b** Received power versus distance, **c** Capacity versus distance of CI and CIF model, **d** Capacity versus distance of ABG model in urban Microcell (UMi-SC) environment

Fig. 3 **a** Path loss versus transmission distance, **b** Received power versus distance of CI and ABG model, **c** Capacity versus distance of CI, **d** Capacity versus distance of ABG model in urban Microcell (UMi-OS) environment



(a) (b)

(c) (d)



(a) (b)

(c)

Fig. 4 **a** Path loss versus transmission distance, **b** Received power versus distance, **c** Capacity versus distance of CI and CIF model in input office environment

In the ABG model UMa environment offers maximum path loss and least capacity. UMi-SC scenario causes less path loss than UMi-OS and provides maximum capacity.

4 Conclusion

We have analyzed three propagation models to compare received signal power, path loss and capacity in 5G communication at the commercial band of 26 GHz for different cell sized urban scenario. ABG model is complex and difficult to implement, as three parameters have to be adjusted to minimize the standard deviation of the shadowing effect. In the ABG model α parameter denotes distance dependent path loss in the first one meter reference distance which is almost same as the physical based n parameter of CI model. The two optimization parameters α and β of the ABG model are non-physical and vary drastically with the variation of distance. If the distance is less than 30 m or more than several hundred meters ABG model shows more prediction error. ABG model causes more measurement error in case of low frequency.

The results show that path loss is less and the receiver signal strength and capacity increases in the CI model as compared to the ABG model. Whereas the CI model is simple, stable and practically realizable as only one parameter needs to be controlled for a lower value of standard deviation. The parameter of the CI model does not change so much as distance changes. The prediction is stable for all path lengths and frequencies. It can be said that the CI model is simple, accurate and robust as compared to the ABG model. With the modification of the ABG model, the CI model can be applied in 3GPP to predict path loss accurately.

In CI and CIF models path loss basically shows much dependency on frequency in 1 m close-in reference distance. The presence of frequency dependent b parameter CIF model can measure the path loss with more accuracy and it is suitable for indoor environment. Beyond 1 m distance path loss does not vary much with frequency. As frequency dependent b parameter sets to 0 value in CI model, it suits better for the outdoor environment.

The parameter values proposed here can be used for further development of 5G technology and beyond at a higher frequency. The hybrid channel model can also be implemented.

Declarations **Conflict of Interest** The authors declare that they have no conflicts of interest.

Author's Contribution All authors contributed equally in the preparation of the manuscript.

Ethical Approval Not applicable.

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Availability of Data and Materials Not applicable.

Competing Interests The authors declare no competing interests.

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