Geometry Performance for 5G mmWave Cellular Networks

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Abstract – **The fifth-generation (5G) mobile communication systems will benefit immensely with the extension of their operation to mmWave bands. To this end, understanding the system-level performance of mmWave cellular networks carries critical importance. In this paper, we investigate the average signal-to-interference plus noise ratio (SINR) distribution (geometry) performance for indoor and outdoor mobile stations (MSs) in mmWave cellular networks using 3GPP system-level simulations. We consider urban micro (UMi) and urban macro (UMa) environments for our evaluations. Simulation results show that, when operating at 60 GHz or higher frequencies, almost all the indoor MSs and more than 35% (65%) of outdoor MSs experience geometry performance less than 0 dB, in UMi (UMa) environments.**

***Index Terms* — 5G, mmWave, Path loss, UMa, UMi.**

1. Introduction

Achieving higher system capacity and higher data rates are two major goals in fifth-generation (5G) mobile communication systems. Hence, extending the operation of 5G systems to millimeter-wave (mmWave) bands is critical due to the availability of large amount of bandwidth. However, before extending 5G systems to mmWave bands, it is important to develop accurate mmWave propagation models, and evaluate them in realistic network scenarios.

There are several recent studies in the literature on mmWave channel modeling. In [1], a mmWave channel model is developed based on extensive channel measurements in 28 GHz, 38 GHz, 60 GHz, and 73 GHz mmWave bands. In [2], a measurement based path loss (PL) model is presented along with a distance dependent line-of-sight (LoS) probability model. Three mmWave PL models are developed in [3]: 1) close-in (CI) free space reference distance model, 2) alpha-beta-gamma (ABG) model, and 3) CI free space reference distance model with frequency dependent PL exponent (CIF), based on extensive channel measurement campaigns and ray tracing simulations.

It is generally known that higher frequencies lead to larger degradation of coverage. In this paper, we quantitatively analyze achievable performance at mmWave frequencies using propagation models proposed in [3] which are also the candidate propagation models for 3GPP [4, 5]. In particular, we focus on geometry performance and analyze how mmWave transmission performs in multi-cell environments.

2. Propagation Modeling for mmWave Transmission

We consider two particular environments for our analysis: 1) Urban micro (UMi), and 2) Urban macro (UMa). As the outdoor PL models, we consider CI model for LoS PL model as proposed in [4] whereas for NLoS PL model, ABG NLoS PL model is considered. However, CI NLoS PL model is yet another available option for NLoS PL with almost similar performance [6]. For indoor mobile stations (MSs), outdoor-to-indoor penetration loss (L_{O2I}, $L_{O2I} = L_{tw}(f_c) + L_{in} + x_{O2I}$ [4]) is added on top of the outdoor PL, where $L_{tw}(f_c)$, L_{in}, and x_{O2I} are the frequency dependent building penetration loss, loss due to signal travelling inside the building, and a random loss. In [4], models for frequency dependent penetration loss are provided for standard multi-pane glass, IRR glass and concrete. Oxygen absorption (OA) loss, $L_{OA} = \eta(f_c) \times d$, where $\eta(f_c)$ (dB/Hz) is a frequency dependent loss factor based on distance d, is considered as proposed in [4].

3. Investigation of Geometry Performance with 3GPP System-Level Simulations

Simulation parameters are summarized in Table I. We consider 3-tier cell layout with 19 cells each with 3 sectors (all together 57 sectors). MSs are dropped uniformly and randomly within the given area. The base station (BS) is equipped with a uniform linear antenna array (ULA) having 10 antenna elements and generates a vertical beam with a 10.2 degree half power beamwidth, and 17.6 dB maximum gain. The beam is electrically down tilted by 102 degrees (elevation angle) for transmission. Major propagation characteristics such as shadow fading, LoS probability and small-scale gain are also taken into consideration in the analysis. Oxygen absorption loss is considered only for 60 GHz, since it is negligible for all the other f_c values [4].

TABLE I
System-level simulator configurations

Parameters	Value
Deployment scenario	3D-UMi and 3D-UMa Hexagonal grid with wrap around (19 cells, 3 sectors/cell)
ISD	200 m (3D-UMi), 500 m (3D-UMa)
BS antenna height	10 m (3D-UMi), 25 m (3D-UMa)
MS distribution	Outdoor only and indoor only
Noise level / Noise figure	-174 dBm/Hz / 9 dB
f_c (GHz) (BW (MHz))	2 (20), 10 (300), 30 (500), 60 (1000), 100 (2000)
Tx power	41 dBm (3D-UMi), 46 dBm (3D-UMa)

(1) Geometry Performance for outdoor MSs

Geometry distribution captures the statistics of the average signal-to-interference-plus-noise ratio (SINR) in the area. The geometry for the considered scenario can be written as:

$$\text{Geometry} = P_{\text{Rx, Des}} / \left(\text{N}_0 + \sum_{i=1,\, i\neq \text{Des}}^{C} P_{\text{Rx, }i}\right)\,, \qquad (1)$$

where, $P_{\text{Rx,Des}}$, N_0 and $P_{\text{Rx, }i}$ are the received signal power from the serving cell, noise power, and received power from the ith interfering cell, respectively, and C is the number of cells in the layout, i.e., 57 in this evaluation.

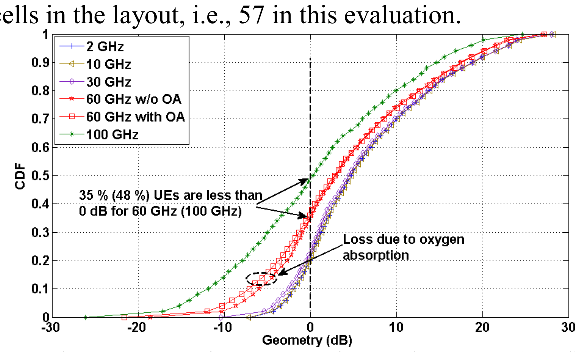

Fig. 1. CDFs of Geometry for outdoor MSs (UMi).

Fig. 1 and Fig. 2 show the geometry distribution of outdoor MSs in UMi and UMa environments. As can be observed from Fig. 1, up to a central frequency of 30 GHz, difference in geometry performance is not significant. This is because, for these frequencies, the interference power is dominant compared to noise power in the denominator of (1) (system is interference limited), and both the interference power and the signal power decrease without significantly impacting the geometry performance.

On the other hand, for 60 GHz and 100 GHz, there is a clear degradation in geometry. This is because, the noise becomes dominant factor in the denominator of (1), i.e., system is noise limited, as a result of smaller interference power due to high frequency-dependent path loss. Hence, the decreasing signal power (while noise power is constant) results in the degradation of geometry performance. Similar observation can be made for UMa outdoor MSs also (Fig. 2) but with further geometry degradation at all frequencies. This is because, UMa is in a more severe noise limited situation due to larger inter-site-distance (ISD).

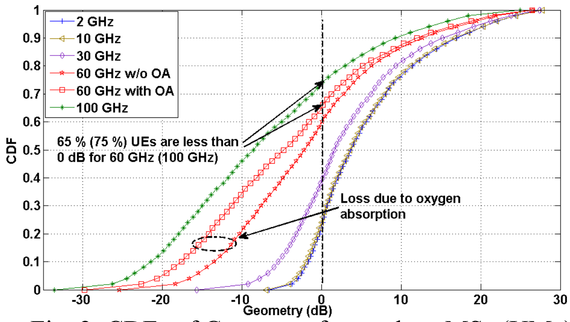

Fig. 2. CDFs of Geometry for outdoor MSs (UMa).

Further, at f_c = 60 GHz, there is a considerable OA loss and MSs in both UMi and UMa suffer from this. However, as can be observed from Fig. 1 and Fig. 2, when the system is interference limited, OA loss is not that significant. We can observe this more clearly from Fig. 1.

(2) Geometry Performance for Indoor MSs

Fig. 3 and Fig. 4 capture the geometry distribution of indoor MSs in UMi and UMa environments. As can be seen, geometry performance is severely degraded for indoor MSs in mmWave frequencies. For outdoor MSs in UMi environment, at 2 GHz, 10 GHz and 30 GHz, only 20% of MSs experience geometry performance less than 0 dB whereas for indoor UMi MSs, similar geometry performance can be achieved only at 2 GHz. This is because, compared to 2 GHz, indoor MSs operating at 10 GHz and 30 GHz experience on average, additional penetration loss of 10 dB and 16 dB, respectively.

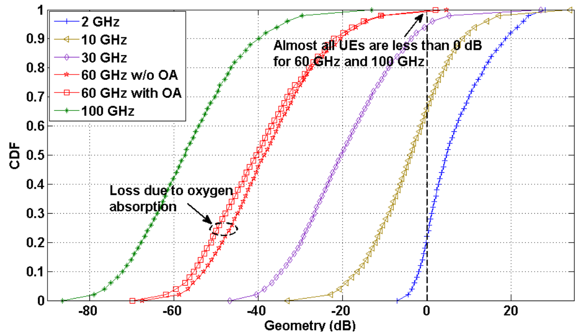

Fig. 3. CDFs of Geometry for indoor MSs (UMi).

As observed for outdoor MSs, geometry performance degradation can be observed at 60 GHz for indoor MSs also due to OA. However, unlike in outdoor case, now OA loss at 60 GHz contributes for geometry degradation as the system is more in noise limited situation.

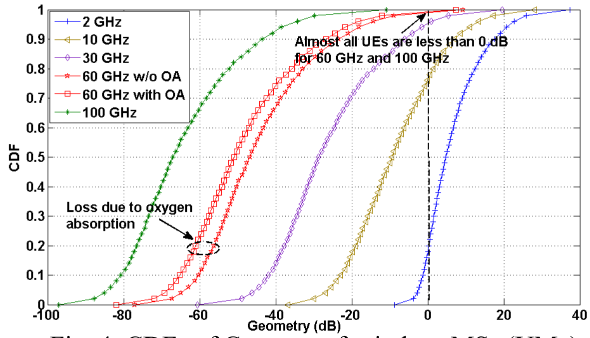

Fig. 4. CDFs of Geometry for indoor MSs (UMa).

4. Conclusion

In this paper, we evaluated geometry performance of indoor / outdoor MSs in UMa / UMi environments with mmWave propagation models using 3GPP system-level simulations. At higher frequencies, outdoor MSs experience geometry less than 0 dB for 35% (48%) at 60 (100) GHz in UMi, and 65% (75%) at 60 (100) GHz in UMa environments. Almost all indoor MSs experience geometry less than 0 dB in both environments, at higher frequencies.

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