Simulation for Blockage Sensitivity Evaluation of Millimeter Wave Cellular in Urban Scenarios

Thanh Ngoc Nguyen, Taehyun Jeon

Abstract— The advantage of the millimeter wave and highly directional antenna array have been proved to be possible to achieve the requirement of the 5G in satisfying the high data rate and massive connection with ultra low latency. However, the commercialization of the 5G network requires a deep understanding of the channel behavior of the wireless link in the millimeter wave band. In this paper, system level simulation is developed for the millimeter wave communications system which emulates the physical channel of 60 GHz radio wave based on quasi-deterministic method. In the simulation, in order to compensate the propagation path loss found in this band, the base station and the users are supposed to be equipped with 2D array antenna which forms 3D beam pattern. The simulation helps to evaluate the effect of the beamforming of the quality of the connection and effect of the blockage caused by obstacles like foliage, humans, vehicles, etc. Using numerical simulation results, we validate and demonstrate how beam directionality and random blockage impact the throughput of arbitrary located users in a mmWave network.

Index Terms: Beam pattern, Blockage, Millimeter wave band, System level simulation, Urban scenario.

I. INTRODUCTION

In this decade, we have been entering the era of multi-media communication via the personal mobile device. There has been an enormous increase in data demand through cellular network services. The number of mobile devices connecting to wireless networks is increasing exponentially. As a consequence, a large pressure is put on the researchers and mobile manufacturers to find out the new technologies and solutions for the next generation wireless communication systems. Even though the 5G network is in the initial stage, there are several techniques which are considered as the candidates for the network. Among them, the millimeter wave is the most promising solution. With the gigahertz of underutilized bandwidth [1], millimeter wave wireless communication systems are expected to address the bandwidth shortage of the current wireless system which operates in the under 6 GHz band. However, propagation properties of these bands are extremely different from those in the current wireless technologies which have already been elaborately studied with many well investigated propagation models, e.g., 3GPP/3GPP2 and WINNER channel model. In order to design the suitable hardware and the efficient protocol for the millimeter wave, the knowledge about the characteristics of millimeter wave propagation is needed.

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One of the major obstacles of millimeter wave implementation is the high path loss in propagation suffered in these frequency bands. The measurements at the 28 GHz band found that the losses were about 12 dB and 30 dB higher than at 2.55 GHz for Line-of-Sight (LOS) and Non-Line-of-Sight (NLOS), respectively [2]. In addition, in the millimeter wave frequency band, the oxygen absorption is very high with 98 percent of the transmitted energy absorbed [3]. This nature severely limits the range of the wireless system operating in millimeter wave bands. Fortunately, the advantage of large antenna arrays and beamforming techniques are propounded to combat this high path loss. Due to the shorter wavelength of the millimeter wave, the space required by each antenna element is reduced. By allowing to integrate a larger number of antenna element in the same assigned volume, the directivity and the achieve gain of the antenna array are enhanced. The quality of the wireless link is improved as well. Moreover, the quasi-optical propagation property of the millimeter wave encourages the transmission to direct the signal energy and focus on an aimed user. On the other hand, the highly directional beam formed by antenna array narrows down the radiation and reduces the interference to other users. From the above reasons, consideration of beamforming and its effects are essentially required for designing and implementation of millimeter wave communication systems.

There are a lot of studies which had been done in both academia and industry to evaluate the millimeter wave communication systems. The group of authors in [3] carried out a measurement of outdoor millimeter wave channel and proposed a 3D channel model. The capacity of the measured channel is evaluated and compared to the 3GPP cellular models. Another work on 3D simulation study of the outdoor millimeter wave systems based on ray tracing technique is done in [4]. In this study, the authors focus on the reconstruction of the environment around the system but neglect the consideration of 3D beamforming. In [5], a simulation framework was proposed with mmTrace [6] to predict channel characteristics with multiple transceivers in specified environments. The proposed simulator applied the 2D image based raytracing approach to consider three well known problems in wireless network including: hidden node, concurrent transmission and nomadic eavesdropping in various environments with arbitrary obstacles. So far, there are not many works focusing on the evaluation of the beamforming supported millimeter wave system in 3D geometry.

In this paper, the channel model of beamforming millimeter wave communication systems is explained and demonstrated which is based on both specified geometric information of the environment and the random location of the user as wells the unpredictable objects. The propagation paths including LOS and the single bounce path are mathematically analyzed and simulated. The random factors including the reflection of the unpredicted objects and the appearance of the random obstacles are also incorporated in the simulation [7]. In addition, a low-complexity simulation to evaluate the blockage sensitivity of millimeter wave systems is conducted. The remainder of this paper is arranged as follows: section 2 provides the geometric assumption of the network, the channel model and the beamforming structure. In section 3, simulation methodology is described and some results are given to evaluate the performance of the system and the effect of beamforming. Finally, section 4 is the conclusion summarizing this work.

II. SYSTEM MODEL

A. Network Geometry

In this paper, we consider a millimeter wave communication system in general outdoor environment described in [7]. To make the simulation more practical, the urban street canyon scenario is used which includes mobile users, cars, trees, lampposts, streets and pedestrian sidewalks along the buildings. In order to reduce the complexity of the simulation, we consider only the downlink between the base station and the mobile users which are assumed to carry the handheld devices. The base station is located on the lamppost which is 6 meter in height. The base station is equipped with 3 antenna arrays to cover 360 degrees in the azimuth plane and each sector configures a uniform rectangular array (URA) with dimension of $N_{tx} \times N_{ty}$. Similarly, the mobile user is equipped with a $N_{rx} \times N_{ry}$ URA with $N_{tx} > N_{rx}$ and $N_{ty} > N_{ry}$ due to the cost and energy limitation. The obstacles and reflecting objects are added in the environment. The trees and the lampposts are fixed on the pavements. The cars and pedestrians randomly appear on the street and potentially block the aligned beam between the base station and mobile users. Table 1 summarizes the parameters of the assuming urban street scenario.

TABLE I STREET CANYON SCENARIO

Parameter	Value
BS height, Htx	6 m
UE height, Hrx	1.5m
Distance from BS to the nearest wall	4.5 m
Sidewalk width	6 m
Road width	16 m
Street length	100 m
Road and sidewalk material	Asphalt
Building walls material	Concrete

B. Ray Tracing and Channel Reconstruction Modelling

As discussed above, the propagation characteristics of millimeter wave are different from the microwave. Due to the quasi-optical nature of the millimeter wave, the signal power is transmitted mainly via the LoS path, single-bounce and double-bounce rays [7]. In the ray tracer, based on the geometric information of the network, these paths are collected and the corresponding power, angle of arrival and the angle of departure are calculated. Only these paths are considered to contribute to the channel while other paths such as diffraction and higher-order reflections are neglected in our model. Fig. 1 illustrates an example of the ray tracing in our urban street scenario.

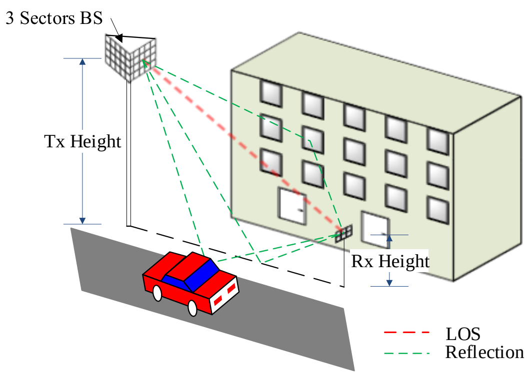

Fig. 1 Urban street scenario.

The calculated information from network geometry is used to construct the channel matrix. The first parameter considered is the ray power which is calculated by:

$$P_r = P_t + G_t(\theta_l^t, \phi_l^t) + G_r(\theta_l^r, \phi_l^r) - PL_l - RL_l \quad (1)$$

where P_t, P_r are transmitted and received power, respectively. $G_t(\theta_l^t, \phi_{cl}^t)$ and $G_r(\theta_l^r, \phi_l^r)$ are the beam gains in dB corresponding to the indexed l-th ray at elevation angle θ and azimuth angle ϕ of transmit and receive antenna, respectively. The PL_l is the free space propagation loss and RL_l is reflection loss which is defined by the material of the reflectors. In this paper, we refer to the measurement result in [7] which specifies the reflection factor of common materials.
The channel matrix is considered as an accumulation of all independent rays which is represented as follows:

$$H = \sqrt{\frac{N_{tx}N_{ty}N_{rx}N_{ry}}{\sum_{l=1}^{L} L_c}} \sum_{l=1}^{L} \sqrt{P_l} e^{-j\psi_l} e_r(\theta_l^r, \phi_l^r) e_t^*(\theta_l^t, \phi_l^t)$$

Here, ψ_l is the uniform random variable from 0 to 2π, $e_t(\theta_l^t, \phi_l^t)$ and $e_r(\theta_l^r, \phi_l^r)$ are array response vectors at the transmitter and receiver, respectively. The array

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response vector of an Nx×Ny array at elevation θ and azimuth ϕ are represented in (3) with $m \in \{0,1,\cdots,N_x-1\}$ and $n \in \{0,1,\cdots,N_y-1\}$. We assume $d=\lambda/2$, while λ and d denote the wavelength of the carrier frequency and the antenna spacing, respectively. The operation '*' denotes the conjugate transpose.

$$e(\theta,\phi) = \frac{1}{\sqrt{N_x N_y}}\begin{bmatrix} 1,\cdots,e^{\frac{j2\pi d}{\lambda}(m\sin\theta\cos\phi+n\sin\theta\cos\phi)}, \\ \cdots,e^{\frac{j2\pi d}{\lambda}\left((N_x-1)\sin\theta\cos\phi+(N_y-1)\sin\theta\cos\phi\right)}\end{bmatrix}^T \quad (3)$$

C. Codebook Based Beamforming

As mentioned before, high directivity antenna is essential for millimeter wave communications to overcome the severe path loss and provide reliable channel. However, the alignment of beams between base station and mobile user, which is called beamforming, requires considerable effort due to the limited feedback. Among a lot of research work on beam searching and beam alignment [8]-[10], in millimeter wave system, fixed beamforming or beam switching is preferred due to the low cost and complexity. The fixed beamforming applies one of a predefined set of weight vectors to the antenna elements. The IEEE 802.15.3c standard specifies the codebook given by the weights applied to the antenna elements which are represented as [5]:

$$W(n_x,n_y,k_x,k_y) = j^{\mathrm{fix}\left\{\frac{n_x\times \mathrm{mod}[k_x+(k_x/2),k_x]}{K_x/4}\right\}+\mathrm{fix}\left\{\frac{n_y\times \mathrm{mod}[k_y+(k_y/2),k_y]}{K_y/4}\right\}} \quad (4)$$

where n_x and n_y are the antenna indices corresponding to x and y-axis, respectively. While, k_x and k_y are the indices of the beams in $K_x \times K_y$ size codebook. The operation $\mathrm{fix}\{\cdot\}$ is rounding toward zero function.

In this paper, we adopted the multi-level codebook based beamforming proposed in [8] to reduce the overhead. This technique separates the beam searching process into two stages, the first stage searches the rough beam and the second one searches the fine beam inside of the first stage result beams. Due to the limitation, in this paper, we neglect the beam searching process and adopt the result from [8] to select the best beam alignment for both base station and mobile user.

III. SIMULATION RESULTS

A. Simulation Setup

Based on the network geometric assumption and the channel model discussed in previous section, we develop the simulation to evaluate the performance of the millimeter wave system in an urban street canyon scenario. Firstly, based on the network assumption described in section 2, the geometric information is acquired. Buildings are represented by a simple polygon, the adjacent buildings are merged together and the inside areas are removed. The location of the base station is supposed to be fixed as shown in Figure 1. The location of the mobile user is randomly generated in the sidewalk and the road area. The positions of the base station and mobile user are used to calculate the deterministic components in the channel model. Due to the limitation of this study, we consider single user case only. The inter-cell interference is ignored to reduce the complexity of the simulator. The system parameters used for the evaluation is specified in Table 2.

TABLE II SIMULATION PARAMETERS

Parameter	Value
Carrier frequency	60 GHz
BS antenna array dimension	$N_{tx} = N_{ty} = 8$
Maximal beam gain of BS	24.5 dB
Sector transmit power	43 dBm
UE antenna array dimension	$N_{rx} = N_{ry} = 4$
Maximal beam gain of BS	18.26 dB
Thermal noise density	-174 dBm/Hz
Bandwidth	2 GHz
Position distribution	Uniformly random

B. Effect of Beamforming

Fig. 2a and Fig. 2b compare the CIR before and after beamforming technique was exploited in both base station and mobile user side. The 2D antenna array with 8×8 elements is utilized at the base station and 4×4 elements ones at the mobile user. Through the beam alignment, we select the weight vector which could provide the maximum antenna gain to the spatial coordinates corresponding to the ray with the maximum power (MPR). The effect of beamforming is shown in Figure 2 (b), it works as a spatial filter to compress the undesired signal that has angle of arrival (AoA) different from AoA of MPR significantly. Consequently, the desired signal is enhanced and the multi-path interference is supressed. In time domain, the delay spread caused by the multipath is dramatically reduced and the system performance is improved. To further enhance the system capacity, the beamforming technique should be implemented in both transmitter and receiver.

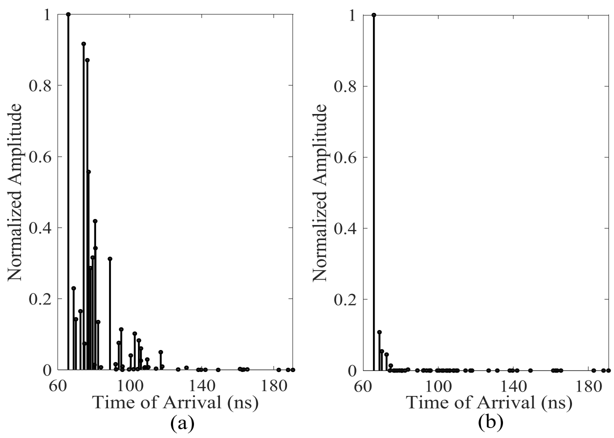

Fig. 2 A snapshot of channel impulse response, (a) without and (b) with effect of beamforming antenna array.

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C. Blockage Sensitivity Analysis

In this section, we present numerical results to evaluate the sensitivity of millimeter wave wireless communication system to the random blockage. In the simulation, we assume the mobile user is walking on the sidewalk with a speed of 3 km/h [11]. Two situations are considered. In the first case, mobile user is located at 19 meters from base station and 3 meters apart from the nearest wall. In the second case, the mobile user is located at 38 meters from the base station. In parallel, two configurations of antenna array at the base station are considered ($N_{tx} = N_{ty} = 8$ and $N_{tx} = N_{ty} = 16$).

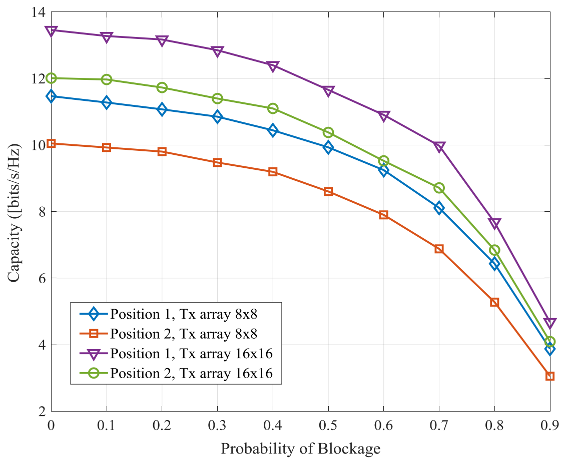

Fig. 3 Blockage sensitivity of millimeter wave wireless.

The obstacles randomly appear in the environment and block the wireless link between the base station and mobile user [12]. In this paper, we adopt the blockage modeling of human-body proposed in [13] and [14] to infer the blockage probability of rays in the channel model. The simulation results are presented in Fig. 3. The result shows the degradation of the throughput caused by the appearance of obstacles. The connection drops down when the blockage probability gets over 0.6. The result also shows that increasing the directivity of array antenna by expanding number of antenna element makes system robust to the blockage.

IV. CONCLUSION

Understanding the propagation characteristic of millimeter wave is necessary for design and implementation of the next generation wireless communication system. In this paper, we develop a simulation which is based on the quasi-deterministic approach to predict the propagation behavior of millimeter wave in an urban street canyons scenario. A 3D channel model comprises deterministic strong rays which are generated by ray-tracing from geometric information and number of relatively weak random rays based on results of experimental measurements. Through the simulation, we evaluate the performance of the millimeter wave cellular system, the effect of beamforming in compressing the multipath and enhancing the link quality. In addition, the effect of blockage caused by random obstacles was considered. The simulation provides a supportive tool for design and testing the millimeter wave system.

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