Coverage Evaluation of mmWave Small Cell in Outdoor Environment

Thanh Ngoc Nguyen, Taehyun Jeon*

Abstract

In an effort to compensate the rising of the data throughput demand nowadays, there have been many research works to optimize the radio resource and increase the capacity of the network. At the present, small cell network, mmWave band and beamforming technology are leading the trend and becoming the core solutions of the fifth generation (5G) cellular networks. Since the propagation characteristics of radio wave in the mmWave band is quite different from the conventional bands, the communication systems which work in these bands have to be redesigned. In this paper, a 3D simulation model is discussed for cellular network at 60 GHz in outdoor environments. Coverage analysis and system performance is carried out for a small cell system in the typical urban environment including street canyon simulation scenario. In addition, the beamforming technique is considered to evaluate the throughput improvement. Simulation results show that the mmWave small cell systems is expected to be one of the major candidate technologies to satisfy the requirements of 5G in terms of data rate.

I. Introduction

The demand for cellular data is expected to rise exponentially every year. Even though the current techniques such as OFDM and other MIMO techniques provide a huge improvement, the conventional frequency band becomes cramped for the massive number of users. One promising solution is to move to higher frequencies (millimeter wave band), where there is a huge free spectrum. In mmWave frequencies, the bandwidth for user is 1-7 GHz where a very high data rate can be achieved. In addition, due to the small wavelength, entering the mmWave band also enables the implementation of massive MIMO antenna arrays and beamforming (BF) techniques.

The architecture of the system in the cellular network should be changed to adapt the difference of the propagation characteristics between the mmWave and the conventional bands. The most noticeable feature of the mmWave bands is the high free-space attenuation. Moreover, the penetration loss through building materials is significantly higher than lower bands. Even though high directivity antenna arrays and beamforming (BF) techniques can help to compensate the high path loss, the
coverage of the mmWave communication is limited. Typically, the range of mmWave applications is in the order of several hundreds meter. In this scenario, high density cell deployment is considered as a promising solution for next generation cellular network with mmWave bands.

In this paper, we focus on small cell networks in mmWave outdoor environment. In detail, we analyze the coverage and the system performance of a small cell system in the typical urban environment. A system level simulator for the beamforming supporting mmWave system is built based on the assumptions and the initial parameters are provided by [1]. The main goal of this research work is to develop the essential tools for designing and evaluating the small cell network which is emerging as a promising solution to realize the 5G mobile network.

The remaining of this paper is structured as follows. In section 2, the basic properties of a small cell system is briefly outlined. The description of the simulation methodology and scenario are informed in this part as well. Next, in section 3, simulation results are provided along with the analysis of the coverage and the throughput performance. Finally, in section 4, conclusion is given to close our work.

II. Simulation Methodology

As discussed earlier in the previous section, in recent years, mmWave technology is one of the main research trends for 5G mobile network. This frequency band is expected to provide greater capacity due to the massive amount of free spectrum. However, the range of the wireless communication applications in this frequency band is limited due to the high path-loss and atmospheric absorption. In order to provide a high data rate to mobile users in a continuous and stable way, a dense deployment of wireless small cells is required.

In this paper, we consider a general outdoor environment which was described in [1]. In detail, the street canyon scenario is utilized as a simulation assumption. A typical street canyon is illustrated in Fig. 1 which includes streets and pedestrian sidewalks along the buildings. To simplify the simulation, we investigate only the downlink system between the access points on the lampposts and the mobile users which are assumed to be the handheld devices.

![Fig. 1. Street canyon scenario.](image)

The propagation channel is modeled with the Quasi-Deterministic approach [1, 2]. The methodology for the simulation is summarized in Fig. 2. When the geometric information is acquired, each building is represented by a simple polygon. Moreover, the adjacent buildings are merged together and the inside areas are removed. The deployment of the access point is supposed to be fixed as shown in Fig. 1. The placement of the mobile users is randomly generated in the sidewalk and the road area. The position of the access points and mobile users are used to calculate the deterministic components in the channel model. After that, the appearance of obstacles and reflection objects such as trees, lampposts, cars, bus stops, etc are added in to the channel generation process as random components. The simulation parameters are specified in Table 1.

![Fig. 2. Flow chart of simulation procedure.](image)

In this simulation, the signal power of the LOS component is the calculated as a reference to infer the power of other components including the reflection from
the ground, the building wall and random objects [3]. From the SNR, throughput is figured out by the Shannon’s capacity equation. Finally, the combination of the user position and the throughput gives the coverage of the considered cell. The signal to noise ratio can be calculated from the following equation:

\[ SNR_{cell}(dB) = P_{tx} - N - P_{ir} + G_{rx} + G_{tx} - 20\log_{10}\left(\frac{4\pi d}{c}\right) + O(d) - N \]  

(1)

where \( P_{tx} \) is a transmitted power, \( G_{tx} \) and \( G_{rx} \) are a transmitter and receiver antenna gains in dBk, respectively. \( d \) is a distance between the access point and the mobile user and \( O(d) \) is an oxygen absorption in 60 GHz (dB/km).

Table 1. Simulation parameters,

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP position</td>
<td>([x_a, y_a, 5]) m</td>
</tr>
<tr>
<td>User position</td>
<td>([x_u, y_u, 1.5]) m</td>
</tr>
<tr>
<td>Street dimensions</td>
<td>([L, W, H]) m</td>
</tr>
<tr>
<td>Transmit power</td>
<td>43 dBm</td>
</tr>
<tr>
<td>Frequency carrier</td>
<td>60 GHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>1 GHz</td>
</tr>
<tr>
<td>Oxygen absorption</td>
<td>15 dB/km</td>
</tr>
<tr>
<td>User antenna</td>
<td>Omni antenna, Full adaptive antenna array with 16 elements</td>
</tr>
<tr>
<td>BS antenna</td>
<td>Omni antenna, Full adaptive antenna array with 16 elements</td>
</tr>
</tbody>
</table>

III. Simulation results

In this section, the coverage performance of a typical mmWave small cell is analysed. Fig. 3 shows the average throughput of mobile user with 1 GHz bandwidth with heat map illustration. For the simulation scenario, two scenarios with the different number of APs (1 and 3 APs) are considered. In these scenarios, the inter-cell interference is not taken into account and each AP works in a different frequency. In Fig. 3 (a), the throughput of all the user positions within a radius of 100 m around AP is higher than 2 Gbps. On the other hand, the lowest data rate (3.6 Gbps) is achieved in case that 3 APs are deployed as shown in Fig. 3 (b). These results demonstrate that the mmWave small cell systems have the ability to meet the requirements of 5G which have to ensure the minimum data rate of 1 Gbps [4]. The peak data rate of approximately 11.2 Gbps is achieved at the area nearby the APs. Within the distance of 10 m from the APs, the throughput is certainly higher than 10 Gbps. The average throughput of all the user positions is 7.29 Gbps and 4.45 Gbps in the 1 and 3 APs deployment cases, respectively.

![Fig. 3. Heat map of throughput with (a) 1 access point and (b) 3 access points in 100×28 area (m²).](image)

As mentioned earlier, the beamforming and the smart antenna techniques are promising solutions to compensate a very high propagation attenuation in mmWave bands. In this part, we examine the effect of the adaptive antenna array at the transmitter side. Two types of transmits antenna are studied: an omni antenna and a full adaptive antenna array with 16 elements. In both simulation cases, the transmit power is constant (43 dBm). We adopt the fully adaptive beamforming technique which adjust the radiation pattern of the 12 dBi antenna array (16 elements) [5]. By increasing the directivity, the SNR of the receiver is improved and the data rate is enhanced. Fig. 4 and Fig. 5 clearly show the benefit of the beamforming implementation. The coverage of the system is expanded significantly from 25 m to 90 m while the data rate of 6 Gbps can be maintained as shown in Fig. 4. The cumulative distribution functions (CDFs) of throughput for two types of BS are illustrated in Fig. 5. From the simulation results, the beamforming array shows clear throughput gain compared to the omni directional ones.

IV. Conclusion

In this paper, we evaluate the system performance of
mmWave small cell in a general outdoor environment in terms of the coverage and the throughput. Simulation procedures are discussed including the outdoor channel modeling and the calculation of the throughput and the coverage. From the simulation results, the beamforming and the smart antenna techniques can be applied to achieve the further improvement regarding the coverage and the throughput performance of the system. This result also shows that the mmWave small cell systems is expected to satisfy the requirements of 5G in terms of data rate and coverage.

![Fig. 4. Throughput vs. distance for users located around the base station](image)

![Fig. 5. CDF of throughput with different types of transmit antenna at the base station](image)

References


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