실외환경에서 밀리미터파 소형 셀의 커버리지 측정

Thanh Ngoc Nguyen, 전태현* 정회원

Coverage Evaluation of mmWave Small Cell in Outdoor Environment

Thanh Ngoc Nguyen, Taehyun Jeon* *Regular Member*

요 약

최근 데이터 처리용량 증대에 대한 수요를 만족시키기 위해서, 전파 자원을 효율적으로 사용하고 네트워크 용량을 증대시키는 연구가 진행되고 있다. 현재 차세대 5G 이동통신망의 핵심적인 기술로서 소형 셀 네트워크, 밀리미터파대역 그리고 빔포밍이 존재한다. 그러나 밀리미터파대역의 전파특성이 기존에 사용되고 있는 대역의 것과 상이하기 때문에, 기존 대역을 사용하는 무선통신시스템이 재설계되어야 할 필요가 있다. 본 연구에서는 실외환경에서 60GHz의 셀 네트워크에 대한 3D 시뮬레이션 모델을 논의한다. 거리협곡 시뮬레이션 환경 등을 포함한 일반적인 도심 환경에서 소형 셀 시스템에 대한 커버리지와 시스템 성능을 분석한다. 또한, 데이터 처리용량의 개선을 분석하기 위해 빔포밍의 적용을 고려하였다. 시뮬레이션 결과, 밀리미터파 소형 셀 기반의 시스템이 데이터 전송속도 측면에서 5G의 요구사항을 충족시킬 수 있는 주요 후보 기술 중의 하나가 될 것으로 기대된다.

Key Words : Small cell, mmWave, Beamforming, Throughput, Coverage analysis

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 bandwidth becomes cramped for the massive number of user. One promising solution is to move to higher frequencies (millimeter wave band), where there is a huge free spectrum. In mmWave frequencies, the bandwidths 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 adopt 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

※이 연구는 서울과학기술대학교 교내연구비의 지원으로 수행되었습니다.
*서울과학기술대학교 전기정보공학과, 교신저자: 전태현 (thjeon@seoultech.ac.kr)
접수일자 : 2017년 12월 16일, 수정완료일자 : 2017년 12월 26일, 최종게재확정일자 : 2017년 12월 27

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.

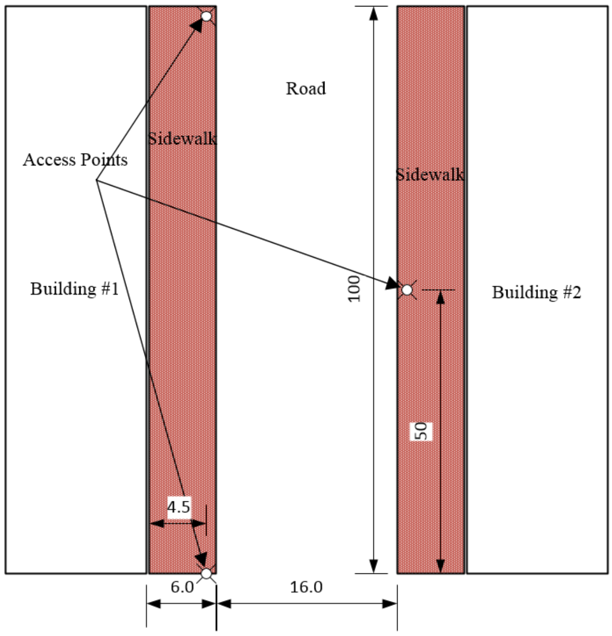

Fig. 1. Street canyon scenario.

The propagation channel is modeled with the Quasi-Deterministic approach [1, 2]. The methodology for the simulation is summarize 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 is specified in Table 1.

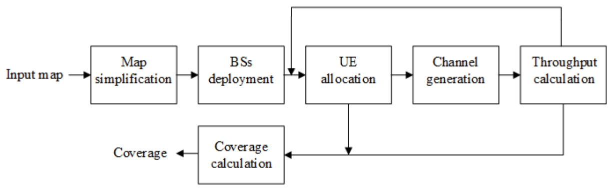

Fig. 2. Flow chart of simulation procedure.

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:

$$SNR_{LOS}(dB) = P_{rx} - N = P_{tx} + G_{tx} + G_{rx} - 20\log\left(\frac{4\pi f}{c}d\right) + O(d) - N \quad (1)$$

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

Table 1. Simulation parameters.

Parameter	Value
AP position	[x_{tx}, y_{tx}, 6] m
User position	[x_{rx}, y_{rx}, 1.5] m
Street dimensions (L×W×H)	100×28×8 m
Transmit power	43 dBm
Frequency carrier	60 GHz
Bandwidth	1 GHz
Oxygen absorption	15 dB/km
User antenna	Single omni antenna
BS antenna	Omni antenna, Full adaptive antenna array with 16 elements

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 (5.6 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.

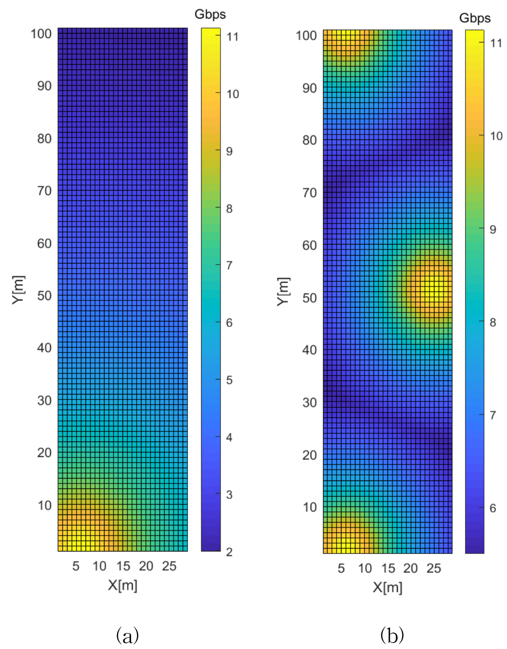

Fig. 3. Heat map of throughput with (a) 1 access point and (b) 3 access points in 100×28 area (m^2).

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 transmit 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.

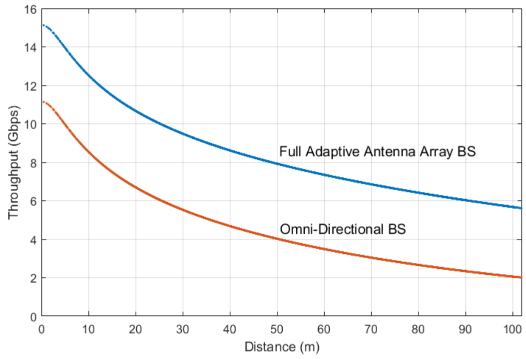

Fig. 4. Throughput vs. distance for users located around the base station

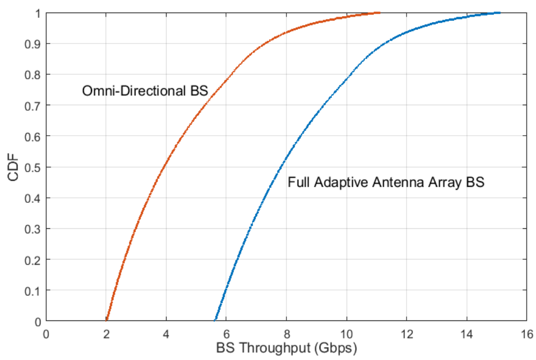

Fig. 5. CDF of throughput with different types of transmit antenna at the base station

References

[1] A. Maltsev, A. Lomayev, A. Pudeyev, I. Bolotin, and Y. Gagiev, Channel Models for IEEE 802.11ay, IEEE 802.11-15/1150r4, 2016.

[2] A. Maltsev, A. Pudeyev, I. Karls, I. Bolotin, G. Morozov, R. Weiler, and W. Keusgen, “Quasi-deterministic approach to mmWave channel modeling in a non-stationary environment,” IEEE Globecom Workshops, pp. 966-971, 2014.

[3] R. J. Weiler, M. Peter, W. Keusgen, A. Kortke, and M. Wisotzki, “Millimeter-wave channel sounding of outdoor ground reflections,” IEEE Radio and Wireless Symposium (RWS), 2015.

[4] S. Sun, T. S. Rappaport, R. W. Heath, A. Nix, and S. Rangan, “MIMO for Millimeter-Wave Wireless Communications: Beamforming, Spatial Multiplexing, or Both?,” IEEE Communications Magazine, vol. 52, no. 12, pp. 110-121, 2014.

[5] J. Mietzner, R. Schober, L. Lampe, W. H. Gerstacker, and P. A. Hoeher, “Multiple-antenna techniques for wireless communications-a comprehensive literature survey,” IEEE Communications Surveys & Tutorials, vol. 11, no. 2, pp. 87-105, 2009.

저자

응웬 딴(Thanh Ngoc Nguyen) **정회원**

- 2015년 : Hanoi University of Science and Technology, School of Electronics and Telecommunication, Department of Biomedical Engineering 졸업(학사)
- 2017년 : 서울과학기술대학교 전기정보공학과 졸업(석사)
- 2017년~현재 : 서울과학기술대학교 전기정보공학과 재학(박사)

<관심분야> : 빔포밍, 5G, 무선센서네트워크

전 태 현(Taehyun Jeon) **정회원**

- 1989년 : 연세대학교 전기공학과 졸업(학사)
- 1993년 : 미네소타대학교 전기공학과 대학원 졸업(석사)
- 1997년 : 미네소타대학교 전기공학과 대학원 졸업(박사)
- 1997년~1998년 : Motorola 연구원
- 1998년~2001년 : Texas Instruments 연구원
- 2002년~2005년 : 한국전자통신연구원(ETRI) 선임연구원
- 2005년~현재 : 서울과학기술대학교 전기정보공학과 교수

<관심분야> : 유무선 통신시스템, 근거리 무선통신, 이동통신