# Throughput Improvement by Transmit 3D Beamforming and MCS Incorporating 1024-QAM

Kentaro Yoda, Takumi Yasaka, and Hiroyuki Otsuka

Department of Information and Communications Engineering, Kogakuin University,
1-24-2, Shinjuku-ku, Tokyo, 163-8677 Japan
Email: otsuka@cc.kogakuin.ac.jp

***Abstract*—Three-dimensional beamforming (3D-BF) is a promising technique to improve user throughput and/or extend cell coverage in fifth-generation mobile systems. One of key technology for increasing data rates is the use of higher-order modulation such as 1024-quadrature amplitude modulation (QAM). In this paper, we evaluate the transmission performance of mobile networks that use a modulation and coding scheme (MCS) incorporating 1024-QAM and transmit 3D-BF. The average and 5-percentile user throughput are clarified as a function of the number of transmit (Tx) beams up to 24, using system-level computer simulations. From these results, we confirm that 3D-BF with 24 Tx beams can improve the average user throughput by 2.2 times compared with those of non-BF, however, the improvement effect exhibited a smaller increase in user throughput than the use of 16 Tx beams. We also confirm that 3D-BF with 24 Tx beams can increase the use rate of 1024-QAM in MCS by 17% when compared with non-BF. This work provides an effective solution for designing mobile systems using 1024-QAM and 3D-BF.**

***Keywords—Mobile communication, 3D beamforming, Beam based transmission, 1024-QAM, User throughput***

## I. Introduction

Increasing system capacity and data rates is one of the objectives of fifth-generation (5G) mobile systems. The use of a massive multiple-input and multiple-output (MIMO) antenna is taken for granted in 5G and can fundamentally increase system capacity and data rates by its spatial multiplexing effects [1]-[4].

Massive MIMO antenna architectures also make it possible to realize three-dimensional beamforming (3D-BF), in which antenna beams can be individually tailored to each user equipment (UE) in horizontal and vertical planes. Downlink 3D-BF enables directs signal transmission toward a target UE, potentially increasing the received signal-to-interference plus noise ratio (SINR) while reducing the interference directed to adjacent cells and other UE [5]-[8]. Additionally, large propagation loss in high-carrier frequency bands is addressed by the use of 3D-BF [9], [10].

The use of higher-order modulation methods can increase the data rates within a limited bandwidth. The Third Generation Partnership Project (3GPP) Release 15 has introduced the incorporation of 1024-quadrature amplitude modulation (QAM) into a modulation and coding scheme (MCS), although its application areas and/or conditions are currently very limited [11]-[15].

Thus far, the performance evaluation using 3D-BF and MCS that incorporates 1024-QAM has not been sufficiently evaluated [16]. Therefore, we show the improvement effects of downlink 3D-BF as a function of the number of transmit (Tx) beams using an MCS incorporating 1024-QAM. We investigate the average and 5-percentile user throughput as a function of the number of Tx beams using system-level computer simulations.

Section II introduces the features of downlink 3D-BF using a beam-based transmission. This section also describes the beam management procedure for 3D-BF. Section III describes system-level computer simulation conditions and their results such as average and 5-percentile user throughput. This section also includes the analysis for the use rate of 1024-QAM when 3D-BF is used. Finally, Section IV summarizes the conclusions.

## II. 3D-BF using Beam-based Transmission

A large number of antenna elements can create 3D-BF which includes horizontal (azimuth-plane) and vertical (elevation-plane) beams. Figure 1 illustrates the concept of downlink 3D-BF using beam-based transmission which forms a grid of $M \times N$ beams using a Tx MIMO antenna, where $M$ and $N$ are the number of vertical beams in the elevation-plane, and horizontal beams in the azimuth-plane, respectively. The receiver of UE is assumed to be an omni antenna. Figure 2 shows the fundamental beam management procedure between evolved Node B (eNB) and UE. The eNB sweeps reference signal beams and UE measures the received SINR of each reference signal beam, and then reports the results to the eNB. Subsequently, the eNB decides the best Tx beam among $M \times N$ beams and optimal MCS index as a downlink adaptation [16].

## III. Simulation Conditions and Results

The primary simulation parameters are listed in Table I which includes the beam parameters used in 3D-BF. The carrier frequency and signal bandwidth are 2 GHz and 10 MHz per macro-sector, respectively. In each macro-sector, the number of UE installations is set to 30. Twenty-five different MCS indexes are used, where five types of modulation methods are adopted: quadrature phase shift keying (QPSK), 16-QAM, 64-QAM, 256-QAM, and 1024-QAM [16].

In the azimuth-plane at the eNB Tx MIMO antenna, the number of horizontal beams is fixed to 8 with the 3 dB beamwidth of 8.8 degrees. In the elevation-plane, the number of vertical beams is varied from one to three with the 3 dB beamwidth of 10, 5, and 3.3 degrees, respectively. The Tx antenna gain $G$ of each beam is set to 23, 26, or 27.8 dBi according to the total number of beams $M \times N$, as listed in Table I. These values are based on non-BF parameters, that is, the antenna gain is 14 dBi and 3 dB beamwidth is 70 degrees. The antenna gain $G$ of each beams is obtained by the combination of the number of $M$ and $N$, as follows:

$$G(dBi) = 10 \cdot log(M \times N) + 14$$

Tx antenna downtilt of eNB is fixed to 15 degrees. UE is distributed uniformly within each macro sector in the simulations. The path-loss model is obtained from [17].

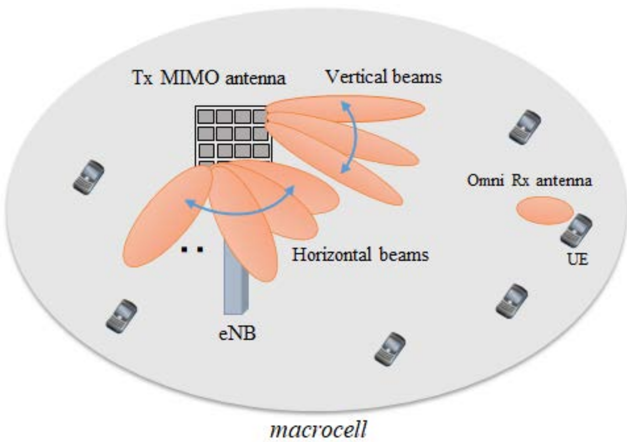


Fig. 1. Configuration of downlink 3D-BF using beam-based transmission.

Figure 3 shows the average and 5-percentile user throughput for the number of Tx beams: 8, 16, and 24 beams. The average and 5-percentile user throughput increase as the number of Tx beams increases. For example, 3D-BF with 16 Tx beams can improve the average and 5-percentile user throughput by approximately 2.0 and 1.7 times compared with those of non-BF, respectively. 3D-BF with 24 Tx beams can improve the average and 5-percentile user throughput by approximately 2.2 and 1.8 times compared with those of non-BF, respectively.

However, 3D-BF with 24 beams exhibits a smaller increase in user throughput than that with 16 beams. The use of excessive beams does not offer an attractive solution because the user throughput does not increase significantly, and they require a considerably greater number of antenna elements.

Figure 4 is an analysis of the use rate of each modulation method in downlink MCS versus the number of Tx beams. In the case of non-BF, the use rate of higher-order modulation methods is low: specifically, the use rate of 1024-QAM is negligible. Nevertheless, the use rate of 1024-QAM increases as the number of Tx beams increases, although the use rate of QPSK decreases. The use of 16 and 24 Tx beams can increase the use rate of 1024-QAM by 12% and 17%, respectively.

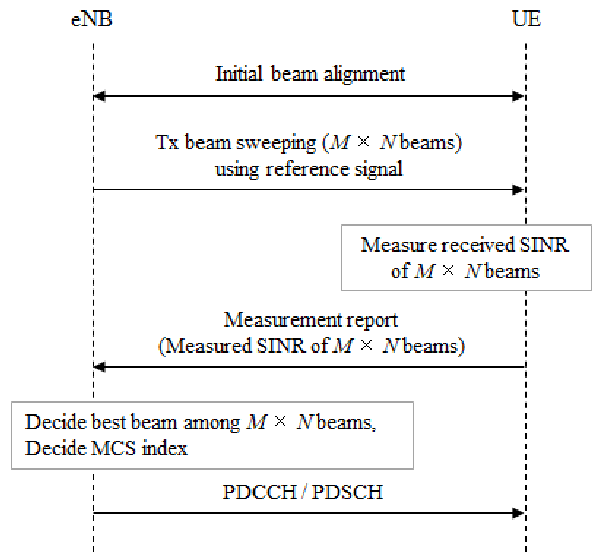


Fig. 2. Beam management procedure between eNB and UE.

TABLE I. PRIMARY SIMULATION PARAMETERS

| Parameter | | Assumption | | |
|---|---|---|---|---|
| Cell layout | | 19 cell sites, 3 sectors per site | | |
| Cell radius (m) | | 289 (ISD = 500) | | |
| Carrier frequency (GHz) | | 2.0 | | |
| System bandwidth (MHz) | | 10 | | |
| eNB Tx power (dBm) | | 46 | | |
| eNB Tx antenna downtilt (deg.) | | 15 | | |
| eNB antenna height (m) | | 32 | | |
| UE distribution | | Uniform distribution, 30 UEs per sector | | |
| UE Rx antenna height (m) | | 1.5 | | |
| Link adaptation | | 25 MCS indexes (QPSK to 1024-QAM) | | |
| 3D-BF in downlink | | | | |
| Elevation plane | Number of vertical beams $M$ | 1 | 2 | 3 |
| | 3 dB beamwidth (deg.) | 10 | 5 | 3.3 |
| Azimuth plane | Number of horizontal beams $N$ | 8 | | |
| | 3 dB beamwidth (deg.) | 8.8 ( =70/8) | | |
| Total number of beams $M \times N$ | | 8 | 16 | 24 |
| Antenna gain $G$ of each beam (dBi) | | 23 | 26 | 27.8 |

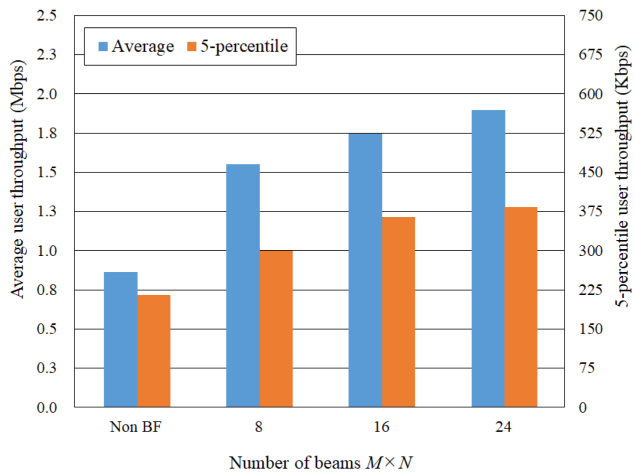


Fig. 3. Average and 5-percentile user throughput versus the number of Tx beams.

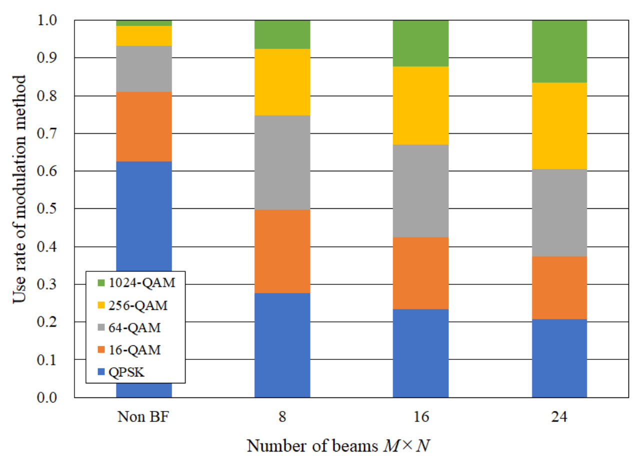


Fig. 4. Use rate of each modulation method in downlink MCS versus the number of Tx beams.

## IV. Conclusion

This paper presented the throughput improvement by downlink Tx 3D-BF and an MCS incorporating 1024-QAM as a function of the number of Tx beams up to 24. We investigated the average and 5-percentile user throughput as a function of the number of Tx beams using system-level computer simulations. We clarified that 24 Tx beams can improve the average and 5-percentile user throughput by approximately 2.2 and 1.8 times compared with those of non-BF, respectively. However, the improvement effect exhibited a smaller increase in user throughput than the use of 16 Tx beams. We also confirmed that the use rate of 1024-QAM in MCS increases as the number of Tx beams increases, e.g., the number of 24 Tx beams can increase the use rate of 1024-QAM by 17% compared with that of non-BF.


## Acknowledgments

This work was supported in part by JSPS KAKENHI Grant Number JP21K11874, Grant-in-Aid for Scientific Research (C). We would like to thank Mr. Yuji Omura who is graduates of Kogakuin University for his contributions to construct system-level computer simulations.


## References


[1] D. Soldani and A. Manzalini, “Horizon 2020 and beyond; On the 5G operating system for a truly digital society,” *IEEE Veh. Tech. Mag.*, vol. 10, no. 1, pp. 32-42, March 2015.

[2] T. Nakamura, A. Benjebbour, Y. Kishiyama, S. Suyama, and T. Imai, “5G radio access: Requirements, concept and experimental trials,” *IEICE Trans. on Commun.*, vol. E98-B, pp. 1397-1406, Aug. 2015.

[3] T. E. Bogale and L. B. Le, “Massive MIMO and mmWave for 5G wireless HetNet,” *IEEE Veh. Tech. Mag.*, vol. 11, no. 1, pp. 64-75, March 2016.

[4] 3GPP TS 38.101-4, “5G NR User equipment radio transmission and reception; Performance requirements,” Release 15, Sept. 2019.

[5] Y. Song, X. Yun, S. Nagata, and L. Chen, “Investigation on elevation beamforming for future LTE-Advanced,” in *Proc. ICC2013 Workshop Beyond LTE-A*, pp.106-110, June 2013.

[6] W. Lee, S-R. Lee, H-B. Kong, and I. Lee, “3D beamforming designs for single user MISO systems,” in *Proc.* GCOM2013, pp.3914-3919, Dec. 2013.

[7] Z. Hu, R. Liu, S. Kang, X. Su, and J. Xu, “3D beamforming methods with user-specific elevation beamforming,” in *Proc. CHINACOM2014*, pp.383-386, Aug. 2014.

[8] 3GPP TSG RAN WG1 #86, “Beam management procedure for NR MIMO,” Aug. 2016.

[9] M. Giordani, M. Polese, A. Roy, D. Castor, and M. Zorzi, “A Tutorial on beam management for 3GPP NR at mmWave frequencies,” *IEEE Communications Surveys & Tutorials*, vol. 21, no. 1, pp. 173-196, Sept. 2018.

[10] F. Kemmochi, Y. Omura, and H. Otsuka, “Throughput performance of multiband HetNets using sectorized picocells with 3D beamforming at 28 GHz band,” in *Proc. VTC2021-Spring*, MACC-VIII (virtual), April 2021.

[11] Q. Mu, L. Liu, L. Chen and Y. Jiang, “CQI table design to support 256 QAM in small cell environment,” in *Proc. WCSP2013*, pp.1-5, Oct. 2013.

[12] 3GPP TR 36.783, “Evolved Universal Terrestrial Radio Access (E-UTRA); Introduction of 1024 Quadrature Amplitude Modulation (QAM) in LTE downlink (Release 15),” April 2017.

[13] T. Ota, M. Nakamura and H. Otsuka, “Performance Evaluation of OFDM-based 256- and 1024-QAM in Multipath Fading Propagation Conditions,” in *Proc. ICUFN2017*, 7B-5, Aug. 2017.

[14] R. Tian, K. Senda, T. Ota, and H. Otsuka, “Transmission performance of OFDM-based 1024-QAM in multipath fading conditions,” *IEICE Communication Express*, vol. 7, no. 7, pp. 272-277, 2018.

[15] H.Otsuka, R. Tian, and K. Senda, “Transmission performance of an OFDM-based higher-order modulation scheme in multipath fading channels,” *Journal of Sensor and Actuator Networks (JSAN)*, vol. 8, no.2, pp. 1-15, March 2019.

[16] Y. Omura, F. Kemmochi, K. Fujisawa, and H. Otsuka, “Implementation of MCS incorporating 1024-QAM and beam-based transmission in 3D-BF,” in *Proc. VTC2020-Spring*, 1D-2 (virtual), May 2020.

[17] 3GPP TR 38.901 version 14.2.0 Release 14, “Study on channel model for frequencies from 0.5 to 100 GHz,” Oct. 2017.