Proceedings of ISAP2016, Okinawa, Japan

Ray-tracing Based Performance Evaluation of 5G mmWave Massive MIMO in Hotspots

Chenwei Wang†, Haralabos Papadopoulos†, Koshiro Kitao††, and Tetsuro Imai††
† DOCOMO Innovations, Inc., Palo Alto, CA 94304, USA
†† NTT DOCOMO, INC. Yokosuka, Kanagawa, 239-8536, Japan
Email: †{cwang, hpapadopoulos}@docomoinnovations.com, ††{kitao, imaite}@nttdocomo.com

***Abstract* – We evaluate the user rate performance of massive MIMO small cells in hot-spot areas. In particular, with the use of the 28GHz millimeter wave band ray-tracing channel data generated according to the realistic map in Shinjuku, Tokyo, Japan, we investigate the user-specific rates in an area of 150m×120m. The results show promising rate performances with the use of a variety of beamforming schemes in both cellular and distributed manners.**

***Index Terms* — Massive MIMO, small cells, millimeter wave, beamforming**

1. Introduction

Massive Multiple-Input Multiple-Output (MIMO) small cells are emerging as an attractive option for coping with the predicted explosive growth in wireless data traffic, as they have the potential to provide vast throughputs per unit area. Small cells 0 enable dense spatial resource reuse on the same time-frequency transmission resources. Massive MIMO on the other hand is made possible by using massive antenna arrays at each base station (BS). It allows spatially multiplexing many users on the same channel resource [2], [3] and providing high-rate transmission to each of these users. In theory, the combination of small cells with massive MIMO transmission has the potential to provide 100-fold or higher increases in throughput per unit area and bandwidth with respect to existing systems.

While there have been abundant amount of literature on massive MIMO small cells on the LTE low frequency bands, recently massive MIMO has attracted much attention at higher frequency bands, including millimeter wave (mmWave) bands, due to the fact that massive MIMO is viewed as an promising technology at higher frequency bands. The large antenna array can allow higher power directivity and can compensate for the harsh propagation conditions at these frequency bands. Hence, it is of interest to investigate a scenario involving massive MIMO, small cells and high frequency bands such as mmWave bands.

One scenario of immediate interest for the deployment of massive MIMO small cells involves serving geographical hot-spot areas. In this paper, we consider one of the densest environment Shinjuku, Tokyo, Japan, with the area shown in Fig. 1. Specifically, the scenario we investigate, shown in the region bounded by the black lines, involves the use of 12 BS sites, indicated by black dots, to serve the potentially massive data traffic demands, i.e., a total of 13609 outdoor user spots on a 1m × 1m square grid. Since it is difficult to collect the exactly realistic data at the current stage, we employ the ray-tracing channel data which is generated according to real propagation environment. Although the ray-tracing data is not as accurate as the realistic data, it provides at least an avenue to learn what we can harvest by using the new technologies. In our recent work [4], we had already used the same map to study the cellular network throughput performance based on 3.5 GHZ ray-tracing data. In contrast, in this paper, we are primarily interested in the network throughput performance by using 28GHz ray-tracing data based on a variety of beamforming schemes.

Fig. 1. Shinjuku, Tokyo, Japan (The region for study is 150m × 120m, bounded by the longitude interval [139.7039, 139.7056] and the latitude interval [35.6880, 35.6894])

2. Downlink (DL) Transmission Schemes

We assume TDD-OFDMA based transmission at 28GHz, single antenna at each user terminal, and channel training based on UL/DL radio channel reciprocity.

Our evaluations include both single-point and multi-point transmission schemes. In single-point transmission, each BS serves K users terminals within each resource element, independently (and simultaneously with the transmissions) of all other BSs across Shinjuku, using conjugate beamforming (CBF) or zero-forcing beamforming (ZFBF). As a reference, we also consider schemes serving a single user terminal per BS and per transmission resource element from single-antenna BSs (SISO) and from M-antenna BSs via beamforming (SUBF). Single-point transmission is also referred to as cellular transmission since the data required by each user is sent from one BS only.

We are also interested in the multiple-point transmission scheme where each user (being served within a given resource element) receives its coded data on a beam formed across C BSs for some number $C > 1$. Furthermore, any given BS performs ZFBF across all the C×K users it serves in each resource block (each user is served in a C-cluster transmission). Hence, each BS chooses the beams for the users it serves locally and independently of all the other BSs. Thus, the multi-point transmission is also referred to as distributed MIMO (DMIMO). Note that for one user, when the same data stream shared among multiple BS sites via backhaul is transmitted from those C BSs and finally coherently added up at that user, the user can harvest the cluster beamforming gain over multiple BSs, besides the local beamforming gain over massive antenna arrays.

The DL transmission schemes above are summarized in Table I by highlighting their characterizations. Also, we assume equal power allocation over the multiple user streams at each BS for simplicity.

TABLE I
Characterizations of DL Transmission Schemes

	(K, M, C) range	**BF Gain**	**ZF Interference**	**BS Process.**
SISO	K=1, M=1, C=1	No	No	Local
SUBF	K=1, M>>1, C=1	Local BF (intra-cell)	No	Local
CBF	K>1, M>>1, C=1	Local BF (intra-cell)	No	Local
ZFBF	K>1, M>>1, C=1	Local BF (intra-cell)	Local ZF (intra-cell)	Local
DMIMO	K>1, M>>1, C>1	Local & Cluster BF (inter & intra-cell)	Local & Cluster ZF (inter & intra-cell)	Local

3. Ray-tracing Based Simulation Results

We consider sample simulations to evaluate the DL performance of the transmission schemes introduced in prior section in Shinjuku, assuming large patch antenna arrays at each BS. We assume TDD-OFDMA based transmission at 28GHz and channel training based on UL/DL radio channel reciprocity. The system parameters include: bandwidth 20MHz, sampling frequency 30.72MHz, rollover coefficient 0.5, subcarrier bandwidth 15kHz, number of subcarriers 1200, and FFT size 2048. Note that although the bandwidth on 28GHz mmWave bands can be much wider than 20MHz as in LTE, we still use LTE system parameters here, because not only we intend to fairly compare the performances with [4], but also the system parameters for mmWave communication have not been well established. In addition, we assume ideal training, ideal relative RF calibration, and ideal carrier/timing/ sampling offset synchronization.

Prior to running cellular transmission where each BS serves a subset of users, we need to first associate users with BSs. For this, we assume what is commonly referred to as received signal-strength indicator based user/BS association, which in massive MIMO implies that each user chooses the serving BS from which it receives the largest nominal (average) received signal strength. Similarly, in the distributed MIMO case, where a user receives its data from C nearby BSs, the cluster of C nearby BSs are chosen as the serving BSs from which the user receives C largest nominal signal strength. In the cellular transmission methods, we consider M = 25 antennas at each BS and K = 4 multiuser (MU) transmission, which corresponds to 4 users per BS sending UL pilots (a total of 48 users over the 12 BSs in Shinjuku) over any given scheduling block of transmission. The same total number of user pilots over Shinjuku enable C-cluster distributed MIMO with C = 2, whereby each BS can transmits data to (up to) 2×4=8 users.

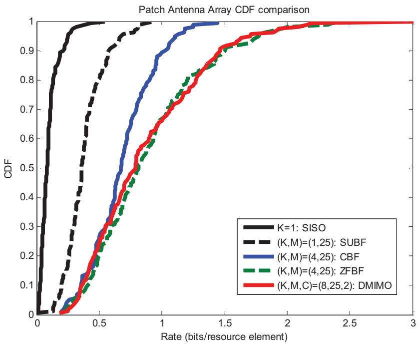

Fig. 2. Network throughput performance

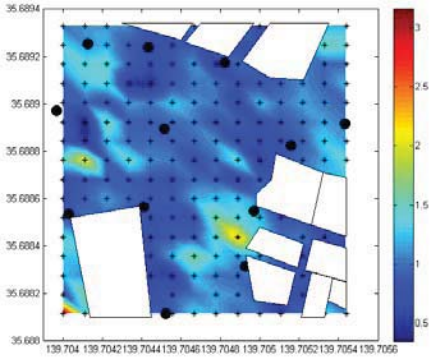

Fig. 3. Heat map of the user spot-specific rate ratio between DMIMO and ZFBF (DMIMO is better if the user-specific value is larger than one, and otherwise ZFBF is better.)

The CDFs of user-specific rate performances regarding the DL transmission schemes are shown in Fig. 2. It can be easily seen that the rate performance increases from SISO to SUBF owing to beamforming gain over massive antenna arrays. The rate increases from SUBF to CBF and ZFBF is contributed by multiuser beamforming, and ZFBF is better than CBF in terms of the user rates since ZFBF eliminates the intra-cell interference. In addition, the DMIMO curve seems to be similar to ZFBF, but by comparing the rate performances for every user spot, Fig. 3 suggests that while ZFBF performs better in the user spots near to BSs, DMIMO outperforms ZFBF in those spots in the cell edge area. This is because across the BSs to form a cluster to serve a cell-edge user, the user is able to harvest cluster beamforming gain and inter-cell interference level diminishes.

References

[1] V. Chandrasekhar, J. Andrews, and A. Gatherer, “Femtocell networks: A survey,” IEEE Communications Magazine, vol. 46, no. 9, pp. 59 – 67, Sep. 2008.

[2] T. Marzetta, “Noncooperative cellular wireless with unlimited numbers of base station antennas,” IEEE Transactions on Wireless Communications, vol. 9, no. 11, pp. 3590 –3600, Nov. 2010.

[3] H. Huh, G. Caire, H. Papadopoulos, and S. Ramprashad, “Achieving massive MIMO spectral efficiency with a not-so-large number of antennas,” IEEE Transactions on Wireless Communications, vol. 11, no. 9, pp. 3226–3239, Sep. 2012.

[4] Hiroyuki Ishii, et al., “5G Key Technology: Massive MIMO”, Nikkei Electronics, pp. 73-82, Nov 2014.