Performance Comparison of Antenna Deployment Cases and Precoding Schemes in an Ultra-Dense Scenario for High SHF Wide-band Massive MIMO in 5G

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Abstract:
Multiuser multiple-input multiple-output (MU-MIMO) downlink technology over massive MIMO is a key enabler for 5G systems and beyond. However, its performance may deteriorate when users are spatially correlated. Distributed antenna deployment (DAD) and nonlinear precoding (NLP) have been studied as countermeasures for this issue. In this paper, through simulations of 28 GHz-band massive MIMO downlink transmission in an ultra-dense urban scenario, it is revealed that, rather than DAD, concentrated antenna deployment (CAD) is more robust against channel transition issues up to walking speed. It is also found that combining CAD with NLP provided the best throughput performance in the evaluated scenario.

Keywords: Massive MIMO, MU-MIMO, high SHF band, ultra-dense urban scenario, antenna deployment, precoding

Classification: Wireless communication technologies

References
[1] E.G. Larsson, O. Edfors, F. Tufvesson, and T.L. Marzetta, “Massive MIMO for next generation wireless systems,” IEEE Commun. Mag., vol. 52, no.2, pp.186–195, Feb. 2014. DOI:10.1109/MCOM.2014.6736761
[2] T. Okuyama, S. Suyama, J. Mashino, and Y. Okumura, “5G distributed massive MIMO with ultra-high density antenna deployment in low SHF bands,” IEICE Trans. Commun., vol. E100-B, no.10, pp.1921–1927, Oct. 2017. DOI:10.1587/transcom.2017EBP3040
[3] H. Nishimoto, A. Taira, S. Uchida, A. Okazaki, and A. Okamura, “Mobility evaluation of massive MIMO with linear / nonlinear precoding based on SINR heatmap in a serving cell,” IEICE Tech. Rep., vol. 117, no.352, RCS2017-267, pp.95–100, Dec. 2017 (in Japanese).
1 Introduction

In the move towards the further refinement of spatial utilization in fifth generation mobile communications (5G) and beyond, multiuser multiple-input multiple-output (MU-MIMO) downlink technology over massive MIMO has been actively studied [1]. In 5G systems and beyond, the exploitation of higher frequency bands such as high super high frequency (SHF) and extremely high frequency (EHF) is a promising approach to accommodating the forthcoming huge traffic demands. In such bands, small-cellularization is envisioned for serving high capacity. One applicable use is in a dense urban scenario where many active users are closely located, causing high inter-user interference (IUI) among users in close proximity. MU-MIMO may not work well when users are spatially correlated like this.

A distributed antenna system is one approach to mitigating the high IUI issue. Wide antenna separation can reduce channel correlation. Its effectiveness has been reported through studies targeting low SHF bands below 6 GHz [2]. On the other hand, in the high SHF and EHF bands an increase in antenna panel separation may reduce the ability to handle user mobility because the beams from the overall antenna array become excessively narrow [3]. Another approach to densely populated cases is nonlinear precoding (NLP), with which in principle we can achieve IUI-free downlink transmission by canceling the IUI observed at the user ends in advance at the base stations (BSs). It has been reported that, compared with linear precoding (LP), NLP can significantly improve the system throughput, especially in a highly-correlated situation [4]. However, in general NLP is thought to be poor at handling mobility due to the inevitable constraints on IUI precancellation [5].

Based on the above background, in this paper the authors evaluate the performance of high-SHF-band massive MIMO downlink transmission in an ultra-dense urban scenario, in order to compare two cases of antenna deployment, concentrated antenna deployment (CAD) and distributed antenna deployment (DAD), and two precoding schemes, LP and NLP.

2 Evaluation scenario

Fig. 1 illustrates the scenarios evaluated in this paper. Targeting a scramble crossing with thousands of pedestrians such as Shibuya scramble crossing in Japan, in the simulation it was assumed that there were 1,600 users in total in a 70 m × 70 m evaluation area, and that 25% of the users, namely 400 users, were active. The
radio frequency was set at 28 GHz (wavelength, $\lambda = 10.7$ mm), and four carrier components (CCs) were used for downlink transmission, where one CC consisted of 1,584 subcarriers at 60 kHz spacing (bandwidth of 95 MHz). The remaining simulation parameters for modulation and demodulation were the same as those in [4]. Under the simulation conditions, the maximum sum-rate system throughput reached 32.8 Gbps.

Assuming an analog-digital hybrid configuration with multiple subarrays for the massive MIMO [4], the antenna subarray associated with a TX digital port at the BS was a 64-element planar phased array. The antenna panel was composed of a pair of ideally-isolated cross-polarized subarrays, as shown in Fig. 5 in [4]. The BS had eight antenna panels, namely 16 subarrays. For CAD, as shown in the top figure in Fig. 1(a), all the BS antenna panels were placed on the roof of a building at one corner of the scramble crossing, where the panel orientation was two vertical and four horizontal. In contrast, for DAD, as shown in the top figure in Fig. 1(b), two panels were placed on the roof of each building at the four corners of the scramble crossing, where the panel orientation at each building was both horizontal. The spacing between adjacent panels was $8\lambda$ (85.7 mm) for both cases, and the spacing between adjacent buildings was 50 m for DAD. The BS antenna height was 21 m, and the vertical downtilt was 30°. Each user had one pair of ideally-isolated cross-polarized omnidirectional antennas, namely two RX ports. Both moving vehicles and walking pedestrians were considered as users. The user antenna height was set to 1.7 m and 1 m for vehicles and pedestrians, respectively.
For a fair comparison of the performance, random scheduling and a round-robin algorithm were employed. Every 20 ms, eight users out of the 400 active users were selected and transmitted to in turn to perform 16-stream MU-MIMO downlink transmission (two streams per user). Therefore all the active users were given fair transmission opportunities with an interval of one second. For the precoding, block diagonalization and Tomlinson-Harashima precoding were employed for the LP and NLP schemes, respectively.

In the evaluation scenario, the traffic signals for both vehicles and pedestrians were controlled just as in a real crossing as time passed (see the top figure in Fig. 2). The entire evaluation ran for 120 seconds. Pedestrians were walking across the crossing for the first 20 seconds and the last 20 seconds. In the remaining periods, excluding signal change intervals, vehicles were moving north and south, and then east and west. For the vehicles, the speed of movement was set to an average of 30 km per hour except for the periods allowed for speeding up and slowing down. For the pedestrians, the walking speed was set to an average of
3 km per hour, while in the periods when the signals were flashing and red it was about 6 km per hour and 1–2 km per hour, respectively.

3 Numerical results

Figs. 2 and 3 demonstrate the sum-rate throughput performance with elapsed time and its cumulative distributions, respectively. Here, the sum-rate throughput, which is a summation of the throughputs of eight users, is equivalent to the system throughput. Note that in Fig. 2 a simple moving average over 0.5 seconds is applied to each throughput curve for visibility, whereas in Fig. 3 the instantaneous throughputs are plotted cumulatively. We see that the throughput for CAD outperformed that for DAD when the pedestrians were walking across the scramble crossing. While DAD can mitigate IUI, it has already been reported in [3] that the ability of a more widely spaced antenna array to handle mobility tends to be worse because the resulting spot beam, while providing a high signal-to-interference-plus-noise power ratio (SINR), covers a smaller area, so a moving user rapidly moves out of the beam. Therefore CAD was more robust to channel variation up to walking speed. When the traffic signals for the pedestrians remained red, however, we had the situation that many users clustered closely together at the four corners of the scramble crossing. In that case, while the performance of CAD degraded, DAD saw a slightly improved throughput thanks to channel decorrelation due to its large antenna spacing, in addition to the benefits from reduced walking speed. It is noted that, although moving vehicles were randomly scheduled as receiving users as well as pedestrians in this period, their effect was negligible because the population of vehicles was much smaller than that of the pedestrians.

Also, when comparing the precoding schemes, we find that NLP produced higher throughput than LP, especially in high IUI conditions, typified by CAD and the period with red signals for the pedestrians. This phenomenon reflects
the reports in [3, 4]. Here note that, compared with DAD, CAD tends to cause high IUI due to beam overlapping while it has better ability to handle mobility. Hence, as a result, the combination of CAD with NLP provided the best overall throughput, exceeding 20 Gbps about 95% of the time.

4 Conclusions

In this paper, the authors numerically evaluated the system throughput performance of high-SHF-band massive MIMO downlink transmission in an ultra-dense urban scenario, to compare CAD and DAD configurations and LP and NLP schemes. Through the computer simulations, it was found that, in the evaluation scenario having many walking pedestrians in close proximity, CAD provided better throughput rather than DAD. Also, it was clarified that CAD with NLP showed the best performance when walking pedestrians dominated.

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