Basic Performance of Massive MIMO in Indoor Scenario At 20-GHz Band

Ryochi Kataoka, Kentaro Nishimori, Ngochao Tran* and Tetsuro Imai*
Graduate School of Science and Technology, Niigata University
8050, Ikarashi 2-nocho, Nishi-ku, Niigata-shi, Niigata, 950-2181, Japan
*Research Laboratories, NTT DOCOMO INC.
3-5, Hikari-no-oka, Yokosuka-shi, Kanagawa, 239-8536, Japan
Email : r.kataoka@m.ieice.org, nishimori@ie.niigata-u.ac.jp

***Abstract*—Massive multiple input multiple output (MIMO) enables the improvement on the transmission rate without increasing the burden on the signal processing by employing a large number of antennas at a base station. It was reported an effect of applying a massive MIMO to small cell at the 2-GHz band. However, main target of the massive MIMO will be the small cells at the high-frequency band, because the antenna size is very large when considering the massive MIMO in macro frequency band. In this paper, real propagation channels are measured by using a wideband channel sounder with horn antenna in 20-GHz band in an actual indoor propagation environment. Moreover, the performance of the interference rejection is evaluated when *virtual* circular array antenna with 24 elements is assumed.**

***Index Terms*—Massive MIMO, indoor propagation characteristics, 20-GHz band, circular array, maximum ratio combining, zero forcing**

I. Introduction

Multiuser MIMO (MU-MIMO) improves the system channel capacity by employing a transmission rate between a base station (BS) and multiple user equipment (UE) with a small number of antennas at the UE. In order to achieve the further improvement on the frequency utilization in future wireless systems with MU-MIMO transmission, the concept of *massive MIMO* has been recently proposed [1]. In the massive MIMO systems, the number of antennas at the BS (N_{BS}) is much larger than the number of antennas at the UE and the number of UEs. The massive MIMO enables the low-complexity signal processing, because the inter-user interference is easily mitigated by the high beamforming resolution [2].

Representative studies on massive MIMO systems have focused on a theoretical study on the channel capacity [2], a computer simulation using maximum ratio combining (MRC) and zero forcing (ZF) as the linear control method [3], and measurement of the actual propagation characteristics using a 128-elements channel sounder [1]. Although a linear or planer array in the horizontal and vertical planes is used in these evaluation, in order to realize high beamforming resolution [4], such array configurations cannot create the service area for all the directions. To solve this issue, the usage of a circular array or cylindrical array is one of the solutions. Therefore, we also previously reported the performance of the interference rejection by cylindrical array using an actual propagation channel in the outdoor at 2-GHz band [5][6]. However, main target of the massive MIMO will be the small cells at the high-frequency band [7], because the antenna size is very large when considering the massive MIMO in macro frequency band.

In this paper, we conducted measurements to obtain the

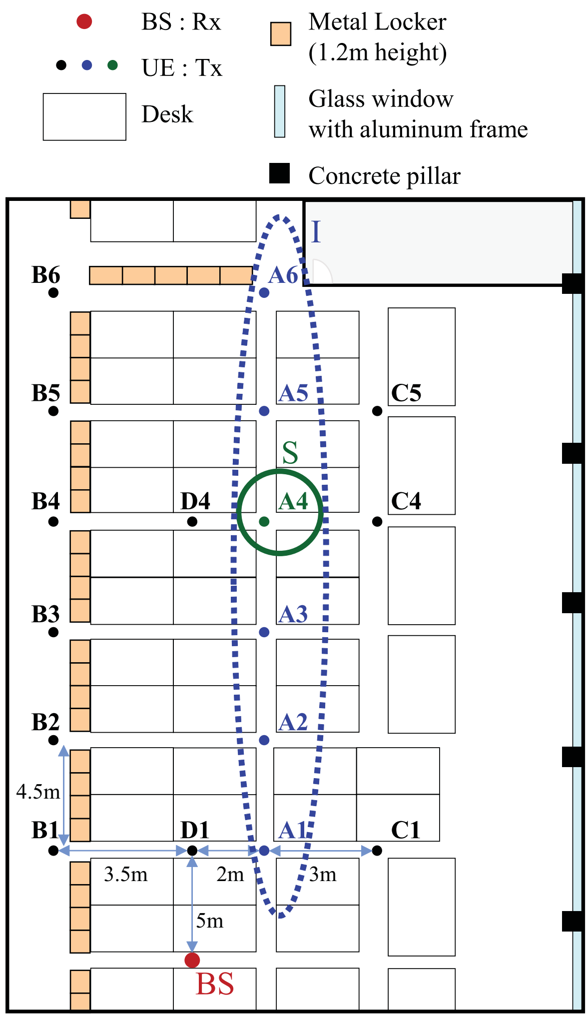

Fig. 1. Measurement environment.

TABLE I
MEASUREMENT SPECIFICATIONS.

Radio frequency	19.85 GHz
Bandwidth	50 MHz
Number of FFT points	1024
Transmit signal	OFDM-QPSK
Number of subcarriers	449
Transmission power	1 W
Type of antenna (UE)	Sleeve antenna
Antenna height (UE)	1.5 m
Type of antenna elements (BS)	Horn antenna
Antenna height (BS)	2.3 m
Distance from BS to UE	5.4∼27.6 m

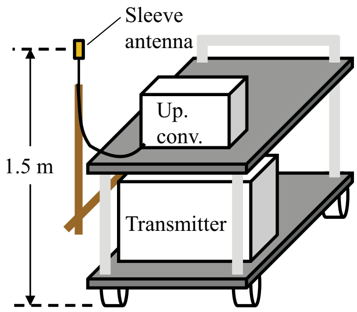

Fig. 2. Configuration of the UE.

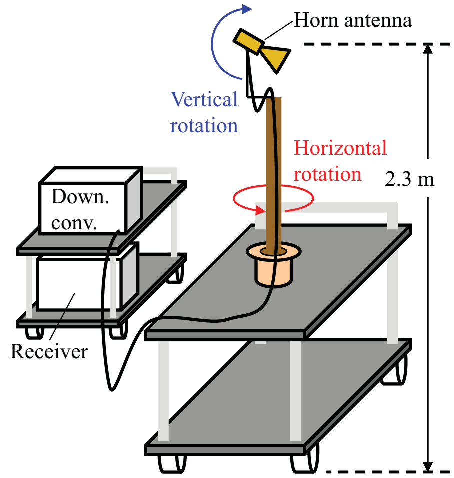

Fig. 3. Configuration of the BS.

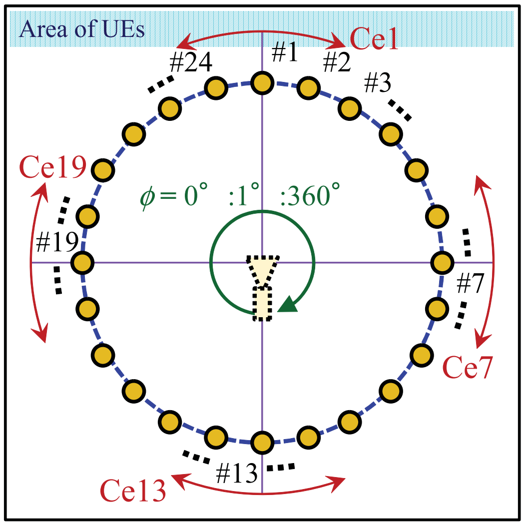

Fig. 4. Virtual circular array with 24-element.

basic performance of massive MIMO when considering the high-frequency band in small cell environment. An actual channel state information (CSI) was measured by using a wideband channel sounder with horn antenna in 20-GHz band at the indoor environment. First, the characteristics of the interference rejection of MRC and ZF in a real environment are evaluated when the *virtual* circular array antenna with 24 elements is assumed. We verify that the ZF is essential for reducing the interference when considering the circular array even at the 20-GHz band. Moreover, the characteristics with the smaller number of antennas in the horizontal planes is verified, in order to simplify the burden of signal processing for the ZF algorithm.

The remainder of this paper is organized as follows. Section II shows the measurement environment and the configuration of virtual circular array. Section III shows the characteristics of the interference rejection in real propagation channel.

II. MEASUREMENT AND EVALUATION ENVIRONMENT

Fig. 1 shows the measurement environment. We conducted the measurement when considering an office in indoor scenario (office in the DOCOMO R&D Center, Kanagawa, Japan). The real CSI was measured by using a wideband channel sounder in 20-GHz band.

Table I lists the measurement specifications. Fig. 2 and Fig. 3 show the configuration of the UE and BS, respectively. We measured the uplink CSI of Single Input Single Output (SISO) from the UE to the BS. As can be seen in Fig. 2, sleeve antenna with a vertical polarization is used at the UE. The UE transmits a signal at 17 points of A1∼D4 in Fig. 1. As can be seen in Fig. 3, horn antenna is used at the BS. Here, the horn antenna (3 dB beam width is 20°) at the BS receives a signal while rotating its antenna in the horizontal plane. The step of rotating angle is 1 degree.

Fig. 4 shows the evaluation configuration of this paper. In this study, the characteristics of the interference rejection are evaluated by using a *virtual* circular array antenna with 24 elements by selecting 24 points with 15 degree interval in the horizontal plane. As can be seen in Fig. 4, UEs are present in the direction of $\phi = 180°$. Moreover, the element numbers (#) of the virtual circular array are 1 to 24 from the direction of $\phi = 180°$ in a clockwise.

III. CHARACTERISTICS OF THE INTERFERENCE REJECTION IN REAL PROPAGATION CHANNEL

In this paper, we assumed that there are one desired user (S) and one interference user (I). The signal-to-interference-plus-noise power ratio (SINR) characteristics are evaluated by using MRC and ZF. The weights of MRC and ZF were calculated

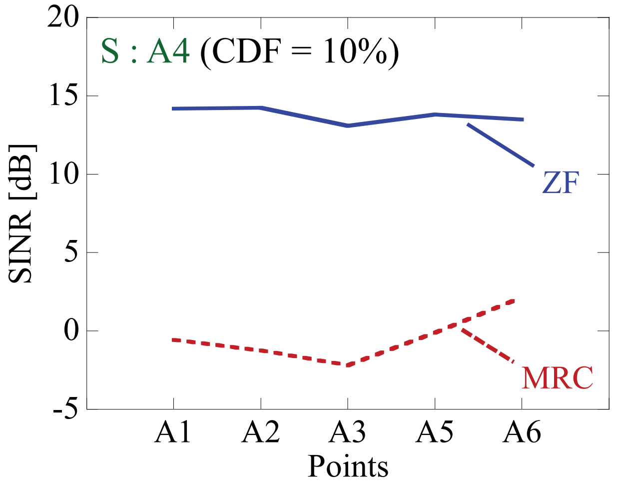

Fig. 5. SINR with CDF=10 % that are calculated by using the MRC and ZF.

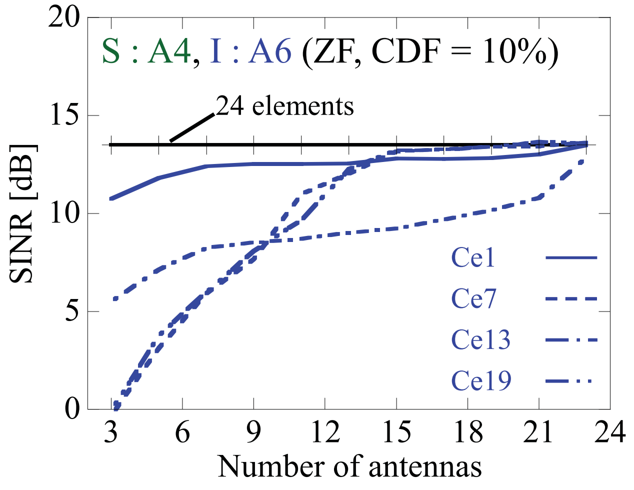

Fig. 6. SINR with CDF=10 % by ZF versus the number of antennas in the horizontal plane.

for each subcarrier. Moreover, the thermal noise is artificially added. The average signal-to-noise power ratio (SNR) among subcarriers is 30 dB at the reference antenna. Here, the reference antenna is selected as the average received power among subcarriers of the desired user is maximized. In this paper, the evaluation was performed in 5 ways : the desired user is located at a fixed point (A4), and the interference user is located at A1, A2, A3, A5 and A6, respectively. Furthermore, five time slots are used for each measurement point.

Fig. 5 shows the SINR with CDF=10 % that are calculated by using the MRC and ZF. All the elements (24 elements) are used to obtain the SINR in Fig. 5. As can be seen in Fig. 5, the SINR obtained by ZF is more than 13 dB. On the other hand, the SINR obtained by MRC is less than 2.2 dB. Moreover, the SINR obtained by ZF is approximately 10 dB higher than that by MRC. Therefore, even in the 20-GHz band, it is shown that the ZF is essential for reducing the interference when considering the circular array. Note that it is not possible to form a sufficiently narrow beam when applying MRC in a circular array as revealed by study in the 2-GHz band of the past [6].

Next, we clarify the SINR characteristics with the smaller number of antennas at the BS, in order to simplify the burden of signal processing for the ZF algorithm. Fig. 6 shows the SINR with CDF=10 % by ZF versus the number of antennas in the horizontal plane. Here, the desired user is A4 and interference user is A6. For simplification, evaluation is carried out at Ce1∼Ce19 shown in Fig. 4. The antennas for Ce1, 7, 13 and 19 are defined as the center elements. Then, two antennas are increased for both side from the center elements. For example in the case of Ce7, (#6, #7, #8), (#5, #6, #7, #8, #9) ... are selected according to increasing the number of antennas. As can be seen in Fig. 6, the SINR by Ce1 is higher than those by Ce7 and Ce19, when the number of antennas is less than twelve, and the SINR by Ce1 is higher than Ce13 regardless of the number of antennas. We can observe that the SINRs by Ce7 and Ce19 are almost same. On the other hand,

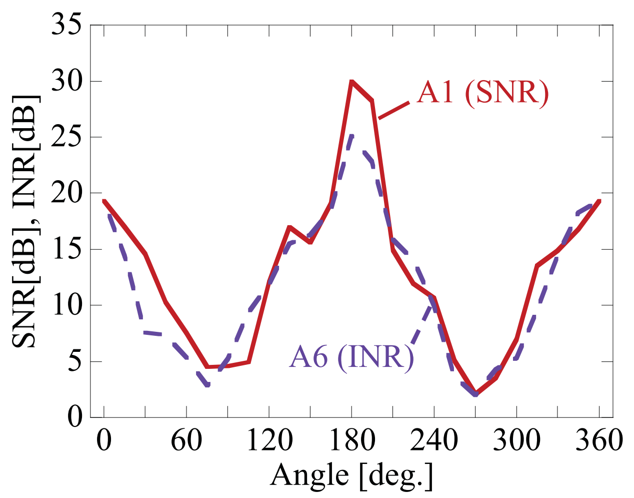

Fig. 7. SNR and INR for each element (S : A4, I : A6).

the SINRs by Ce7 and Ce19 is higher than the SINR by Ce13 when the number of antennas is greater than or equal to 11, and the SINRs by Ce7 and Ce19 is higher than the SINR by Ce1 when the number of antennas is greater than or equal to 13. From the observation in Fig. 6, it is shown that the antenna selection is very important for the usage in small number of antennas in massive MIMO system.

Fig. 7 shows the SNR and INR for each element. As can be seen in Fig. 7, the SNR and INR are almost same. In addition, the SNR and INR are smallest at 270°(#7) and 90°(#19) directions due to the lack of multi-path from the UEs. On the other hand, the SNR and INR at 180°(#1) are highest among all the elements. Therefore, the SINR becomes higher when the antennas near 180° directions.

From the above results, we clarified that the SINR characteristics obtained in about 13 antennas is almost same the SINR characteristics obtained in all 24 antennas, by preferentially selecting a high SNR antennas when using the ZF.

IV. Conclusion

In this paper, performance evaluation of massive MIMO using *virtual* circular array has been investigated in an actual indoor small cell environment. An actual propagation channel was measured by using a wideband channel sounder with horn antenna in 20-GHz band at the indoor environment. A sufficient interference reduction is obtained by ZF, whereas MRC cannot sufficiently reduce the interference when all antennas (24 elements) are used, even in the 20-GHz band. Moreover, it is shown that is important to select the efficient antennas with high SNR when all the antennas cannot be used by the hardware limitation and so on, because it is observed that the SNR is greatly changed according to the direction from the UE.

As a future work, the SINR characteristics by the MU-MIMO transmission should be evaluated, because massive MIMO enables the multi-user transmission with a large number of antennas.

Acknowledgments

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