Performance evaluation of distributed antenna in uplink MU-MIMO using amplitude information and many-to-one switch

Soichi Ito1a), Sho Yoshida1, Kentaro Nishimori1, Tomoki Murakami2, Koichi Ishihara2, and Yasushi Takatori2

1 Graduate School of Science and Technology, Niigata University, 8050 2-no-cho Ikarashi, Nishi-ku, Niigata 950–2181, Japan
2 Nippon Telegraph and Telephone Corporation, NTT Access Network Service Systems Laboratories, 239–0847, Japan

a) ito@gis.ie.niigata-u.ac.jp

Abstract: This paper proposes a hardware configuration for uplink multi-user multiple-input multiple-output (MU-MIMO) transmissions with distributed antenna systems (DASs) in real indoor environments. Beam-forming (BF) technology is used in the DAS with massive MIMO. In massive MIMO transmission, signal processing becomes complicated because of the massive antennas. Therefore, in general, a technique known as digital beamforming (DBF) is adopted, in which the weight values are calculated through digital signal processing. Massive MIMO systems applying DBF, which requires receivers for all massive antennas, have problems related to power consumption and cost because the access point becomes large.

We propose an analog–digital hybrid configuration, which selects antennas using a many-to-one switch connected to the antenna. In the proposed configuration, it is possible to reduce the number of receivers required, by grouping antennas using many-to-one switches. In this paper, we evaluate the effect of the proposed configuration through computer simulations using the propagation channels obtained from experiments conducted in real indoor environments. The effectiveness of the proposed configuration is demonstrated by comparing the basic characteristics, when antennas are selected according to the conventional full-digital configuration and the proposed analog–digital hybrid configuration.

Keywords: multiuser MIMO, distributed antenna system, antenna selection, channel capacity, zero-forcing

Classification: Antennas and Propagation

References

1 Introduction

Multiuser multiple-input multiple-output (MU-MIMO) transmissions have been attracting much attention, as a technique for improving the channel capacity of the entire system by generating a large virtual channel between the access point (AP) and multiple user terminals (UTs) [1, 2, 3].

Downlink MU-MIMO transmissions have been introduced as one of the main technologies in the LTE and IEEE 802.11ac standards. Uplink MU-MIMO transmission is currently being standardized under LTE-advanced [4]. In IEEE 802.11ax [5], the standardization of uplink MU-MIMO and orthogonal frequency division multiple access (OFDMA) has been decided, and it is expected that their importance will increase in the future.

Massive MIMO transmissions have been attracting much attention in 5th generation mobile communication systems (5G) and IEEE 802.11ay, in order to improve the performance of MU-MIMO transmissions [6, 7, 8, 9].

In massive MIMO transmission, the antenna configuration used for communication is usually selected by the digital part is adopted. The signal processing becomes complicated because of the presence of many antennas. In this configuration, when massive MIMO transmission is assumed, the scale of the access point becomes large, as receivers are required for all antennas. The increase in the access point size is problematic in terms of power consumption and cost.
In this paper, we propose a hardware configuration for uplink MU-MIMO transmission, to solve this problem. In the proposed configuration, the distributed antennas are first divided into multiple groups. Then, the antennas with the highest received powers are selected using amplitude detectors. Finally, the antennas are selected using many-to-one switches. This configuration is named the analog–digital hybrid configuration. The proposed configuration is suitable for implementation in massive MIMO transmission. In order to clarify the effectiveness of the proposed configuration, we performed computer simulations using the propagation channels obtained through experiments conducted in real indoor environments.

The remainder of this paper is organized as follows. Section 2 describes the conventional and proposed configurations and explains the advantages of the proposed configuration. Section 3 shows the measurement environment and measurement parameters. In Section 4, the effectiveness of the proposed configuration is demonstrated by comparing the basic characteristics when antennas are selected according to the conventional full-digital configuration and the proposed analog–digital hybrid configuration. The paper is concluded in Section 5.

2 Conventional configuration and proposed configuration

Fig. 1(a) shows the conventional access point (AP) configuration of the DAS in uplink MU-MIMO. In the conventional configuration, the antennas used for communication are selected through digital signal processing. Down converters and analog-to-digital (A/D) converters are necessary for the receivers, and receivers are connected to all antennas. In the case of massive MIMO, the required number of receivers increases as the number of antennas increases, and the hardware is scaled up.

Fig. 1(b) shows the proposed analog–digital hybrid configuration. The proposed configuration uses many-to-one switches and amplitude detectors. The $N$ antennas are divided into $N_S$ groups. $N_L$ represents the number of antennas in each group. All antennas in a group are connected to one many-to-one switch. Therefore, in the proposed configuration, one antenna is selected by each switch. The received signal of each group is input to the amplitude detector via the directional coupler.
The amplitude information is measured by the amplitude detectors, and the antenna with the maximum amplitude is selected by each many-to-one switch. In this configuration, one receiver is connected to one many-to-one switch. Therefore, the required number of receivers is reduced from $N$ to $N_S$, when compared to the conventional AP configuration, and the hardware scale is reduced. Compared to the conventional configuration in which the antenna is selected in the digital part, in the proposed configuration, the antenna is selected in the analog part by the many-to-one switch, and thus, the antenna selection process becomes simple.

3 Antenna selection methods and measurement environment

Fig. 2(a) show the real indoor measurement environment. In Fig. 2(a), the blue circles are the UTs, and the AP antennas are represented by the colors A, B, C, and D. Each color indicates one group of AP antennas. The number of AP antennas is 32 and the number of UTs is 32. From 32 users, four users are selected for each trial. A total of 35,960 trials are conducted for different UT combinations. At this time, the numbers 1~4 are assigned to the UTs. Then, #UT 1~4 are paired with groups A~D. A single antenna with the highest signal-to-noise ratio (SNR) is selected from each group (A, B, C, and D at the AP in Fig. 2(a)): four AP antennas are selected in total in Fig. 2(a). The resulting $4 \times 4$ uplink MU-MIMO transmission is evaluated in Fig. 2(a).

Fig. 2(b) shows our measurement parameters. The carrier frequency and bandwidth are 2.425 GHz and 20 MHz, respectively. The transmission signal is an orthogonal frequency division multiplexed (OFDM) signal. The transmission power is 0 dBm. The transmitters and receivers are connected with the UTs and AP antennas, respectively, and the uplink channel state information (CSI) between the UTs and AP antennas is measured. The heights of the AP and UT antennas are 2.3 and 0.7 m, respectively. Patch and sleeve antennas are used for the AP and UT antennas, respectively. The thermal noise power is determined so that the average received power versus the thermal noise power, i.e., SNR, is 20 dB when considering all the antennas and UTs.

We now evaluate the Shannon capacity and achievable bit rate using zero forcing (ZF) while considering the actual propagation channel. The Shannon capacity in the uplink channel $C_s$ can be written as:
\[ C_s = \sum_{k=1}^{4} \log_2 \left( 1 + \frac{P}{4\sigma^2 \lambda_k} \right), \]

where \( \lambda_k \) is the \( k \)-th eigenvalue, and \( P \) and \( \sigma^2 \) are the transmit power and noise power, respectively. The achievable bit rate using ZF \( C_{ZF} \) can be written as:

\[ C_{ZF} = \frac{1}{4} \sum_{k=1}^{4} \log_2 \left( 1 + \frac{\text{SNR}_{ZF,k}}{4} \right), \]

where \( \text{SNR}_{ZF,k} \) is the \( k \)-th SNR obtained from the interference cancellation due to the ZF for the \( k \)-th user.

In the proposed configuration, the antennas are selected in the analog section. Using the signal sent to the amplitude detector via the directional coupler, the antenna with the highest SNR is selected. The selected antennas are switched using the many-to-one switch. This is named DASH.

In the conventional configuration, the antennas are selected in the digital part. Therefore, the antennas with the highest SNR are selected from each group (A, B, C, and D) at each subcarrier of OFDM, similar to DASH. This is named DASH (sub).

### 4 Comparison of channel capacity

Fig. 3 shows the transmission rates and channel capacities of DASH and DASH (sub). The solid line represents the transmission rate when ZF is applied to DASH (sub) and DASH, and the dashed line represents the channel capacity when applying the Shannon limit to DASH (sub) and DASH.

In the conventional configuration DASH (sub), antennas are selected in the digital part; therefore, antennas can be selected for each subcarrier of OFDM. It is thus possible to select a more optimal antenna, when compared to the proposed configuration that selects the antenna in the analog part. The transmission rate is also high, accordingly. This difference can also be confirmed from the graph. However, since the difference is very small, the performance degradation of DASH is also small, when compared to that of DASH (sub).

![Fig. 3. Achievable bit rate (DASH and DASH (sub))](image-url)
Antenna selection in the conventional configuration is a very complicated process, and the scale of the base station increases on the hardware side. On the other hand, the antenna selection process by the proposed configuration is relatively simple. Furthermore, in the proposed configuration, the scale of the AP can be reduced by using many-to-one switches. From this, it can be confirmed that the proposed configuration is very effective as a realistic hardware configuration in which the performance hardly deteriorates.

5 Conclusion

In this paper, we proposed an analog–digital hybrid hardware configuration using amplitude detectors and many-to-one switches for uplink MU-MIMO transmission with DAS.

In the proposed configuration, the distributed antennas were divided into multiple groups. Each group of antennas were connected to a many-to-one switch, and an amplitude detector selected the antenna with the highest received power in the group. The selected antennas were switched by each many-to-one switch.

Compared to the conventional full-digital hardware configuration, the proposed configuration could reduce the size of the AP by using many-to-one switches. In the conventional configuration, the processing becomes complicated as many antennas are used for communication. On the other hand, in the proposed configuration, the antennas can be selected through relatively simple processing.

In this study, we experimented in real indoor environments assuming DAS and acquired the propagation channel. From the obtained propagation channel, the performance was evaluated by comparing the conventional configuration and the proposed configuration, in terms of the transmission rate and channel capacity. From the results, it was confirmed that the performance degradation in the proposed configuration was small, when compared with the conventional configuration selecting antennas for each subcarrier. It was shown that the proposed configuration was effective as it could be realized through simple calculations and the sizes of AP devices could be reduced.

Acknowledgments

We would like to thank the members of the Nishimori Laboratories and NTT Access Network Service Systems Laboratories for their assistance in the indoor measurements. Part of this work was supported by KAKENHI, Grant-in-Aid for Scientific Research (B) (17H03262).