EFFECTIVENESS OF TERMINAL ANTENNA EMPLOYING ORTHOGONAL POLARIZATIONS AND PATTERNS IN OUTDOOR MULTIUSER MIMO SYSTEM

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ABSTRACT

This report presents experimental results on a Multi-User Multi-Input Multi-Output (MU-MIMO) channel of an antenna with orthogonal patterns and polarizations in an outdoor urban area. The antenna configuration employing orthogonal patterns and polarizations is useful in achieving a small terminal antenna since many antennas can be placed in the same location. The properties of this antenna are compared to an antenna array that has only vertical or horizontal polarization in this environment. The measurement results indicate that the antenna with orthogonal polarizations and patterns can always provide fairly high Signal to Noise Ratio (SNR) properties when two in three antennas are chosen. We verified the MU-MIMO transmission properties and found that the antenna with only a single polarization causes serious capacity deterioration when the antenna is inclined horizontally. On the contrary, the antenna in which each element has a polarization or pattern that is different to the others can provide a high channel capacity consistently even when the antenna is placed in any direction. The measured results indicate the effectiveness of the combination of the antenna selection and the use of the orthogonal antennas, which can enhance the channel capacity by up to 50%.

1. INTRODUCTION

Multi-Input Multi-Output (MIMO) technology, which employs several antennas, enhances wireless data transmission even with a limited bandwidth [1]. Considering a multiuser environment, the spatial multiplexing of several users, which is called multiuser MIMO (MU-MIMO), is more effective in enhancing the total data transmission ratio than single user MIMO [2], [3].

Various types of MIMO antennas have been studied and, in particular, small MIMO antennas and their downsizing techniques have been investigated for application to portable terminals [4], [5]. Combining antennas that employ orthogonal polarizations and patterns is an important means to configure MIMO antennas into a compact configuration since this method provides a low level of antenna coupling even with a narrow antenna spacing [6] - [8]. The authors proposed a six-port compact MIMO antenna, and this antenna can be actualized within the size of a PC card by means of combining the antennas with orthogonal polarizations and patterns [9]. It was shown that the MIMO performance of the antenna is almost the same as that of the three orthogonal dipoles, in which the size reduction of the dipole elements is not considered.

On the other hand, the number of transmitters or receivers in mobile terminals is restricted in terms of battery power and hardware complexity. The antenna selection in MIMO systems is effective in extending the channel capacity without increasing the number of transmitters or receivers [10] - [12]. The use of both the combination of the orthogonal antennas and antenna selection is the key toward achieving a compact MIMO terminal with high data transmission performance even when the power consumption and size of the terminal are limited.

The polarization selection method for Space Division Multiple Access (SDMA) was investigated and verified under outdoor environment conditions [13], however, the size restrictions and coupling effect of the small antennas must be taken into account. We need to extend this consideration to multi-antenna cooperative systems with practical small antenna configurations in order to consider the MU-MIMO performance.

In this report, we describe the experimental results of MU-MIMO channel properties in an urban microcell environment and show the effectiveness of the antenna selection when the orthogonal antennas are employed in the user terminal. As a terminal antenna, three orthogonal dipoles with narrow antenna spacing are used and compared to a vertically polarized compact dipole array. The multiaccess channel (MAC) capacity is estimated and shown under optimum antenna selection conditions.

In 2, the antenna geometry and antenna selection method are described. In 3, the measurement environment and the

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method for evaluating the channel properties are described. The measured MAC capacity is shown and the effect on the capacity enhancement by using orthogonal antennas and antenna selection is discussed in 4.

2. ANTENNA GEOMETRY AND PROPOSED ANTENNA SELECTION METHOD

2.1. Terminal Antenna Geometry

In the measurement of the MU-MIMO characteristics using an actual small antenna, not only the antenna coupling, but also the radiation pattern distortion and cross polarization components, which are generated by its geometries, could affect the channel properties [8], [9].

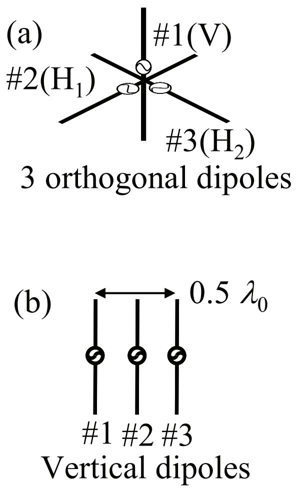


Fig. 1. Electrical design of terminal antenna.

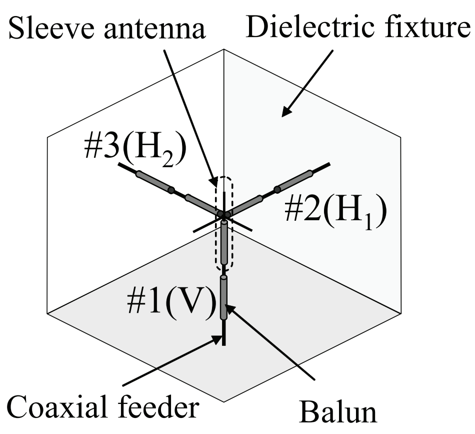


Fig. 2. Actual geometry of three orthogonal dipoles for measurement.

In this study, to verify the true effect of the use of orthogonal antennas, three orthogonal dipoles, shown in Fig. 1 (a), are chosen as the simplest antenna configuration that has orthogonal patterns and polarizations. It comprises one vertical and two horizontal dipoles, and their axes are orthogonal to each other. The other reason for using this antenna is that it covers any direction isotropically and the MIMO performance can be recognized to be independent from the user antenna direction. For comparison, a single polarization dipole array, shown in Fig. 1 (b), is measured as well. The array length is set to half a wavelength, since the antenna width of three orthogonal dipoles can be defined as the antenna length of the half wavelength dipole in Fig. 1 (a).

The actual geometry of the three orthogonal dipoles for this experiment is shown in Fig. 2. The sleeve antennas are employed as dipole elements, and placed into a right angle to each other.

2.2. Antenna Selection

At the mobile terminal, two of the three antennas are supposed to be used. The best antenna combination, which gives the highest capacity, is chosen. For a multi-user environment, all possible antenna combinations at each user are considered. In this measurement, the channel of all three ports is measured, and the MU-MIMO characteristics with the antenna selection are estimated after the measurement.

3. MEASUREMENT ENVIRONMENT AND EVALUATION OF MULTI-USER PROPERTIES

3.1. Base Station Antenna and Measurement Environment

Figure 3(a) shows the configuration of the base station antenna. It consists of four dual-polarization (0 / 90 degrees) subarray antennas. The subarray spacing is one wavelength in the horizontal direction. The geometry of the dual polarized subarray is shown in Fig. 3(b). Eight vertical and horizontal dipoles are arranged vertically. Each polarization array has an individual RF feeder. The actual gain of the subarray antenna is 14.5 dBi for both polarizations. As described above, this base station antenna array has eight ports and all ports are connected to the receivers. As shown in Fig. 4, the antenna is placed on an antenna tower at the height of approximately 50 m.

The terminal antenna placed on the roof of a vehicle transmits a 4.85-GHz OFDM signal, which has a 20-MHz bandwidth and consists of 104 subcarriers. Figure 5 shows the measured urban environment. The terminal antenna is placed at five positions on the street, indicated as Points A to E in the figure.

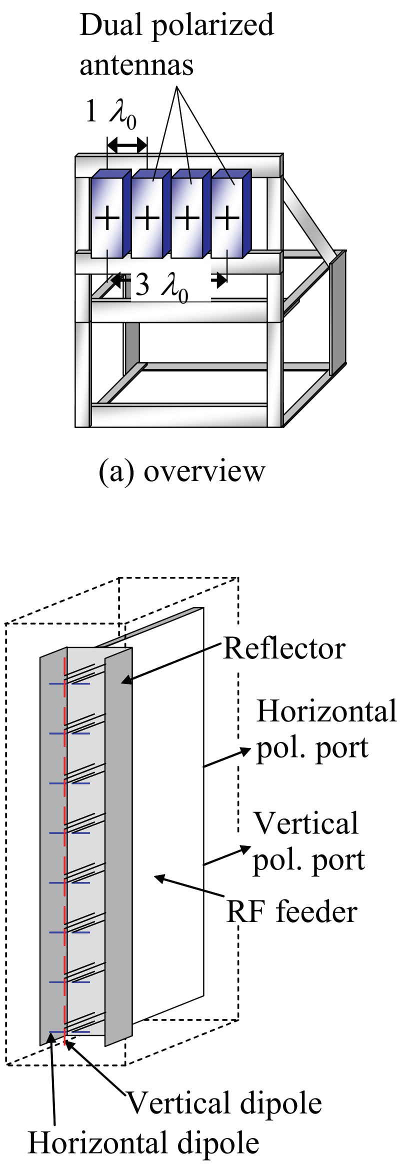


Fig. 3. Geometry of base station antenna.

3.2. MAC Capacity with Antenna Selection

In this study, the channel matrix is measured at each point, and the MAC capacity for MU-MIMO is calculated by combining several of the channel matrices of the different points.

For example, the channel matrix at Point A is defined as

$$\boldsymbol{H_A} = \begin{pmatrix} h_{A11} & h_{A12} & \cdots & h_{A1M_T} \\ h_{A21} & h_{A22} & \cdots & h_{A2M_T} \\ \vdots & \ddots & & \vdots \\ h_{AM_R,1} & h_{AM_R,2} & \cdots & h_{AM_R,M_T} \end{pmatrix} \quad (1)$$

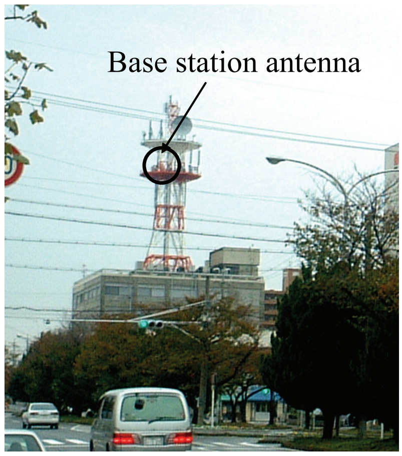


Fig. 4. Base station antenna at an antenna tower.

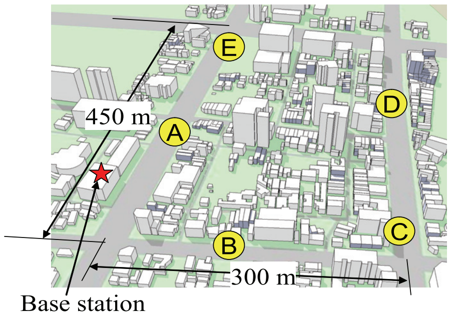


Fig. 5. Urban environment and measured points.

where M_T is the number of the terminal antennas and M_R is the number of base station antennas. When the users at A to C are spatially multiplexed, the combined channel matrix is written as

$$\boldsymbol{H_{multi}} = \begin{pmatrix} h_{A11} & \cdots & h_{A1M_T} & h_{B11} & \cdots & h_{B1M_T} & h_{C11} & \cdots & h_{C1M_T} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ h_{AM_R,1} & \cdots & h_{AM_R,M_T} & h_{BM_R,1} & \cdots & h_{BM_R,M_T} & h_{CM_R,1} & \cdots & h_{CM_R,M_T} \end{pmatrix}. \quad (2)$$

Since two of three antennas are chosen at each terminal, one column for each point is removed from (2). Therefore, three columns are removed in this case because three channel matrices are combined. Now, this matrix is defined as H'_{multi}, and the MAC capacity is obtained from the following formula.

$$C_{multi} = \log_2 \det \left(\boldsymbol{I} + \frac{\gamma_0}{M'_T} \boldsymbol{H'_{multi}} \boldsymbol{H'_{multi}}^H \right) \quad (3)$$

Here, $\boldsymbol{I}$ is a unit matrix, M_T' is the number of the selected transmitting antennas at each terminal, and γ_0 is the signal-to-noise ratio (SNR). The optimum antenna combination, for which (3) gives the highest capacity, is searched using the procedure described here.

In the actual measurement, since the number of the base station antennas is $M_R = 8$, and the number of the terminal antennas is $M_T = 3$, 8×3 MIMO channels are measured. After the measurement, the MAC capacity, in which the number of selected transmitting antennas is set to $M_T' = 2$, is calculated.

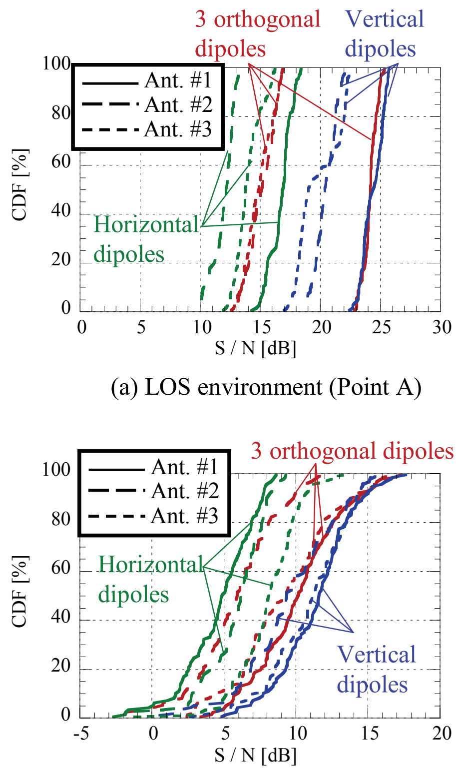
4. RESULTS

Figures 6(a) and 6(b) show the cumulative distribution function (CDF) of the SNR. Here, the graph in Fig. 6 (a) is the result when the terminal is placed at Point A (LOS environment), and the graph in Fig. 6 (b) is the result when the terminal is placed at Point B (NLOS environment). The results of the three orthogonal dipoles show that the highest SNR is observed at the vertical antenna, #1, for both locations. One of the horizontally polarized dipoles shows the lowest SNR in the three orthogonal dipoles. This is caused by the matching of the radiation pattern and propagation environment. This corresponds to the tendency that a high SNR is observed at all antennas of the vertical dipole array. In the vertical dipole array, the SNR of Antenna #2 is lower than that of the others. This is because the center antenna couples with the two neighboring antennas and the radiation efficiency of #2 is seriously deteriorated. On the contrary, Antennas #1 in the vertical dipole array yields a higher SNR than Antenna #1 in the three orthogonal dipole. The reason why the end elements in the vertical dipole array yield a high SNR even with the coupling loss among the neighboring elements is that the vertical dipole array functions as a Yagi-Uda array and the antenna gain in the horizontal plane is enhanced. Based on this consideration, we estimate that most of the propagation paths are distributed in the horizontal direction from the terminal antenna.

On the other hand, the terminal antenna with only a horizontally polarized dipole array yields a low SNR. This tendency is observed at the other measurement points. This means that the antenna with only a single polarization is susceptible to SNR deterioration because the mobile terminal direction could be randomly set by user. On the contrary, the three orthogonal antennas would provide a stable high SNR because we can choose the two best antennas from the three differently directed antennas.

The MU-MIMO MAC capacity, which is defined as the total achievable bit rate at the base station, is verified by combining the measured channel information at Points A to E. Figure 7 shows the mean MAC channel capacity versus the number of users where the transmitted power and antenna geometry of the user terminals are uniform. At each terminal antenna, the best antenna combination is chosen to optimize the MAC capacity. The values in the graph indicate the average capacity of all the possible combinations of the users. From these results, we find that the three orthogonal dipoles yield the highest MAC capacity. On the contrary, the horizontally polarized array exhibits the lowest MAC capacity and this is because of the low SNR of the horizontally polarized antenna as shown in Fig. 6. The vertical dipole array exhibits a MAC capacity as high as that for the three orthogonal dipoles. These results mean that the performance of the single polarized terminal antenna fluctuates between the vertical and horizontal polarizations. Nevertheless, three orthogonal dipoles stably maintain the highest channel capacity for various numbers of spatially multiplexed users, and the improvement in the capacity compared to the worst case of a single polarized array, where the antenna is inclined horizontally, is up to 50 %.

Figure 8 indicates the averaged spatial correlation versus the number of users. This result shows that the spatial correlation can be decreased by an increase in the number of multiplexed users. Since the spatial correlation between the users at the different locations is much lower than that among the antennas of the same terminal, the averaged spatial correlation of MU-MIMO can be lowered. The horizontal dipole array has the lowest spatial correlation, and the three orthogonal



(a) LOS environment (Point A)

(b) NLOS environment (Point B)

Fig. 6. Cumulative distribution function of SNR.

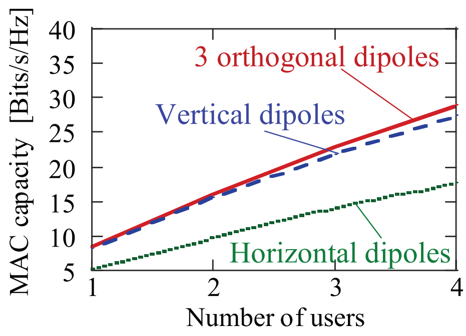


Fig. 7. Mac capacity versus the number of users.

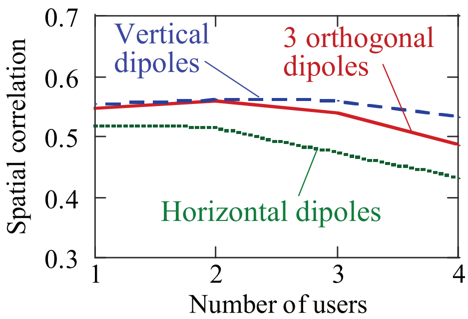


Fig. 8. Spatial correlation versus the number of users.

dipoles have nearly the middle spatial correlation among three antenna configurations. This is because there is much freedom in the allocation of the user polarization in MU-MIMO using three orthogonal dipoles, the spatial correlation is decreased, and its capacity is enhanced compared to that when using the vertical dipole array.

Figure 9 shows the average SNR versus the number of users. The SNR increases with the number of users. This is because the transmission power for each user is supposed to be same, and the increase of the number of users yields an enhancement in the total transmitting power. The SNR of the vertical dipole array is slightly higher than that of the three orthogonal dipoles. On the contrary, the SNR of the horizontal dipole array is much lower than that of the others. This means that the antenna selection among the three orthogonal dipoles is effective in enhancing the SNR even when the antenna is placed in any direction.

In order to verify the relationship between the spatial multiplexing effect and propagation environment, the MAC capacity for two users is investigated. Table 1 shows the MAC capacity for a LOS environment when two users exist at Point A and E. Where, the capacity gain is defined as

$$G_{capacity} = \frac{2C_{multi}|^{X,Y}}{(C_X + C_Y)}, \quad (4)$$

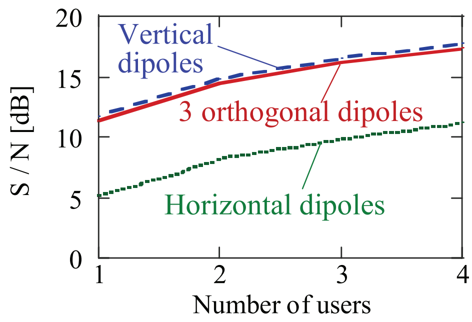


Fig. 9. Averaged SNR versus the number of users.

where 'X' and 'Y' represent the terminal position of two users. Terms C_X and C_Y are the single user MIMO capacity, and $C_{multi}|^{X,Y}$ is the MAC capacity for two spatially multiplexed users. It is seen that the difference in the capacity gain of three antennas is very slight. Furthermore, the capacity can be enhanced by approximately two fold even when two LOS users are multiplexed. We observe that the three orthogonal dipoles exhibit a fairly low spatial correlation compared to that for the vertical dipole array.

Table 1. MU-MIMO channel property at point A (LOS) and E (LOS)

Antenna	Spatial correlation	MAC capacity [bits/s/Hz]	Capacity gain
3 orthogonal dipoles	0.448	24.8	1.96
Vertical dipoles	0.523	24.6	1.96
Horizontal dipoles	0.418	17.2	1.98

Table 2. MU-MIMO channel property at point B (NLOS) and C (NLOS)

Antenna	Spatial correlation	MAC capacity [bits/s/Hz]	Capacity gain
3 orthogonal dipoles	0.360	11.2	1.81
Vertical dipoles	0.374	10.5	1.82
Horizontal dipoles	0.382	6.34	1.78

Table 3. MU-MIMO channel property at point D (NLOS) and E (LOS).

Antenna	Spatial correlation	MAC capacity [bits/s/Hz]	Capacity gain
3 orthogonal dipoles	0.694	16.7	1.93
Vertical dipoles	0.802	16.1	1.86
Horizontal dipoles	0.523	10.8	1.95

Table 2 gives the MAC capacity for a NLOS environment with users at B and C. We find a lower spatial correlation compared to that in the LOS environment is obtained for all antenna configurations. This is because there is no direct path between the terminal and the base station in this environment, and the paths are distributed almost homogeneously all around the terminal. On the other hand, the capacity gain is slightly lower than that of the LOS environment. This means that the spatial correlation reduction effect from spatial multiplexing is smaller than that for the LOS environment.

The MAC capacity when the LOS and NLOS users are multiplexed is shown in Table 3. From this result, we see that the spatial multiplexing effect with two users from different environments is still effective and is just between that with only LOS users and that with only NLOS users. We also find that the three orthogonal dipoles have the highest capacity in these three scenarios.

5. CONCLUSION

The MU-MIMO capacity when employing a terminal antenna with orthogonal patterns and polarizations was measured in an outdoor urban area. Based on a comparison with a single polarization array, we found that serious deterioration occurs when the vertical dipole array is inclined horizontally. It was shown that the selection of orthogonal antennas at the terminal is effective in enhancing the MU-MIMO capacity and improves the capacity by 50% compared to that using a horizontally polarized array antenna.

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