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Proposal of Antenna Selection Method for Terminal Antenna with Orthogonal Polarizations and Patterns for Outdoor Multiuser MIMO System

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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].

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 [3]. 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 [4]. 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 [5]. It was shown that the MIMO performance of the antenna is almost the same as that for 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 [6]. 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 [7], 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 propose an antenna selection method suitable for MU-MIMO terminals with orthogonal polarization and patterns. Two of three orthogonal antennas are selected based on only the signal-to-noise ratio (SNR) information. From the results of the measured channel properties in an urban microcell environment, the multiaccess channel (MAC) capacity is estimated and shown under the proposed antenna selection conditions, and the effectiveness of the proposed method is discussed.

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, can affect the channel properties [4], [5].

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

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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).

2.2 Proposed Antenna Selection Method

At the mobile terminal, two of three antennas are supposed to be used in this scenario. In our method, two antennas with the highest SNR are chosen from the three antennas at each terminal. This antenna selection method is effective in alleviating the calculation load since the SNR of each antenna at the terminal is simply obtained from the channel matrix. Furthermore, our selection method is intended to be used for the antennas with orthogonal polarization and patterns. Since some antenna combinations, chosen by our method, affect the spatial correlation between users, there would be some capacity deterioration compared to that given by the ideal antenna combination, which would give the highest channel capacity. However, very slight deterioration is expected in this case since the spatial correlation can always be lowered by using orthogonal antennas. Another point of interest is the relationship between the bandwidth and capacity. Since the optimum antenna combination would depend on the frequency, the effect of the antenna selection for the actual bandwidth of the wireless communication must be clarified.

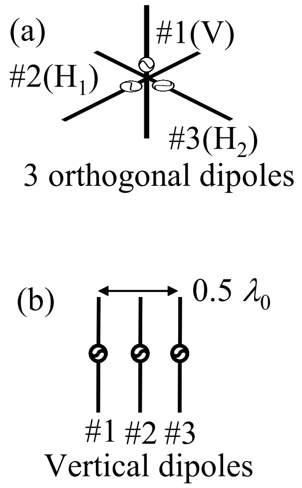

Figure 1: Electrical design of terminal antenna.

3. Measurement Environment and Evaluation of Multi-user Properties

Figure 2 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 actual gain of the subarray antenna is 14.5 dBi for both polarizations. This base station antenna array has eight ports and all ports are connected to the receivers. The base station 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 3 shows the measured urban environment. The terminal antenna is placed at five locations on the street, indicated as Points A to E in the figure.

In this study, the channel matrix is measured at each point, and the MAC capacity for MU-MIMO is calculated by combining several numbers of channel matrices at different points. When the matrices, $\boldsymbol{H}_A$, $\boldsymbol{H}_A$, and $\boldsymbol{H}_A$ represent the channel information for Users A, B, and C respectively, the MU-MIMO channel for the three users can be expressed as $\boldsymbol{H}_{multi} = [\boldsymbol{H}_A, \boldsymbol{H}_B, \boldsymbol{H}_C]$. Since two of three antennas are chosen at each terminal, one column for each point is removed from the combined matrix. Therefore, three columns are removed in this case because three channel matrices are combined. Now, this matrix is defined as $\boldsymbol{H}'_{multi}$, and the MAC capacity is obtained from the following formula.

$$C_{multi} = \log_2 \det \left(\boldsymbol{I} + \frac{\gamma_0}{M'_T} \boldsymbol{H}'_{\boldsymbol{multi}} \boldsymbol{H}'_{\boldsymbol{multi}}{}^H \right) \qquad (1)$$

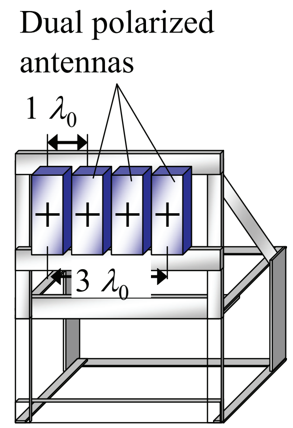

Figure 2: Geometry of base station antenna.

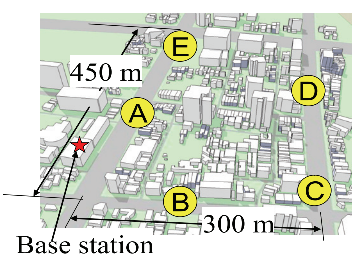

Figure 3: Urban environment and measurement points.

Here, $\boldsymbol{I}$ is the unit matrix, M'_T is the number of selected transmitter antennas at each terminal, and γ_0 is the SNR. The optimum antenna combination, for which (1) gives the highest capacity, is searched using the procedure described here.

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

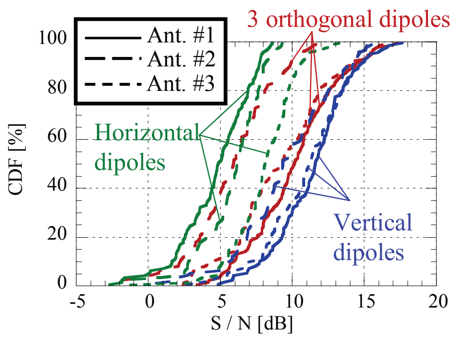

Figure 4: Cumulative distribution function of SNR.

4. Results

Figure 4 shows the cumulative distribution function (CDF) of the SNR at Point B. The results of the three orthogonal dipoles show that the highest SNR is observed at the vertical antenna, #1. One of the horizontally polarized dipoles exhibits the lowest SNR among 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 in the vertical dipole array. In the vertical dipole array, Antenna #1 yields a higher SNR than the vertical antenna, #1, of the three orthogonal dipoles. 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. This tendency is observed at the other measurement points. Based on this consideration, we estimate that most of the propagation paths are distributed in the horizontal direction from the terminal antenna.

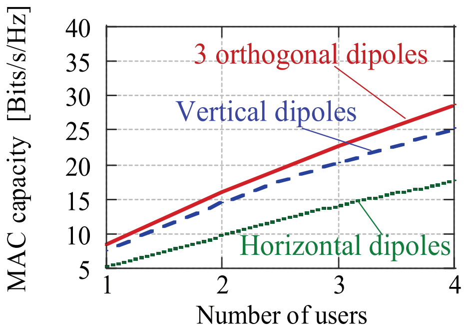

Figure 5: Mac capacity versus the number of users.

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 5 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 antenna is chosen based on the proposed antenna selection method. The values in the graph indicate the average capacity of all the possible combinations of the users, and are averaged through all frequency bands that we measured. 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. 4. The MAC capacity for the vertical dipole array is slightly lower than 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 %.

We investigated the effect of the bandwidth on the MAC capacity. Figure 6 indicates the deterioration bit rate versus the bandwidth. Here, n_u is the number of the multiplexed users. Since antennas would be selected by means of an RF switch, it is impossible to achieve the optimum antenna selection for an arbitrary frequency range. In this graph, the reference bit rate is set to the narrowest bandwidth in our measurement, which corresponds to the bandwidth of the subcarrier. For comparison, the ideal selection method, which gives the maximum capacity, is also indicated. These results show that the proposed selection method with the vertical dipoles yields high bit rate deterioration. On the contrary, the deterioration with the proposed method for three orthogonal dipoles is fairly low. The effectiveness of the proposed method for the three orthogonal dipoles in particular is enhanced when a wider bandwidth and many more user terminals are employed. The improvement of 0.7 bits/s/Hz in the MAC capacity is observed when n_u is 4, and the bandwidth is 16 MHz. Considering the slight difference in the proposed

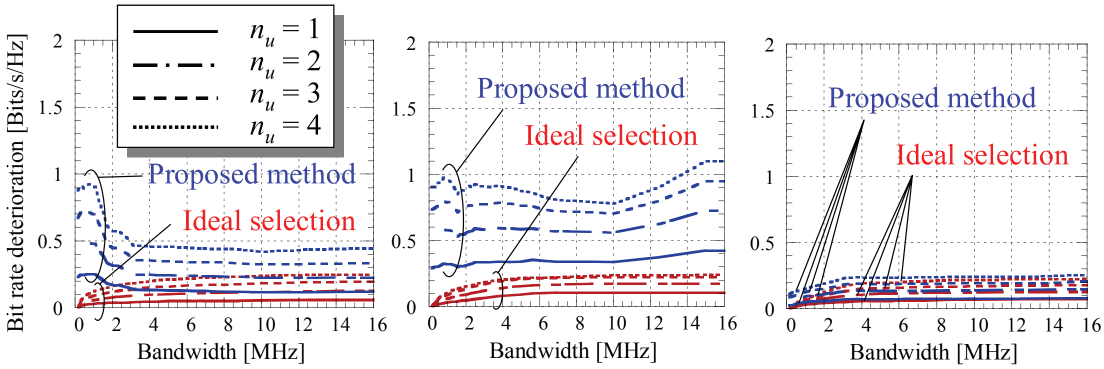

Figure 6: Bit rate deterioration versus bandwidth.

method and the ideal selection, we find that applying the proposed method to the orthogonal antennas is quite effective. On the other hand, the result of the horizontal dipoles shows very little deterioration, but only a low MAC capacity is expected from the graph shown in Fig. 4.

5. Conclusion

The antenna selection method suitable for MU-MIMO terminals with orthogonal patterns and polarizations has been proposed and verified based on outdoor measurements. Based on a comparison with a single polarization array, we found that the orthogonal antennas with the proposed antenna selection method, which can simplify the selection algorithm by utilizing only the SNR information, provided the highest channel capacity, and improved the capacity by 50% compared to that using a horizontally polarized array antenna. Furthermore, the proposed method with orthogonal antennas suppressed the bit rate deterioration even when the bandwidth and the number of the users are increased.

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