Effect of Spacing and Radiation Pattern of Antenna Elements on Capacity in Near-field MIMO System

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1. Introduction

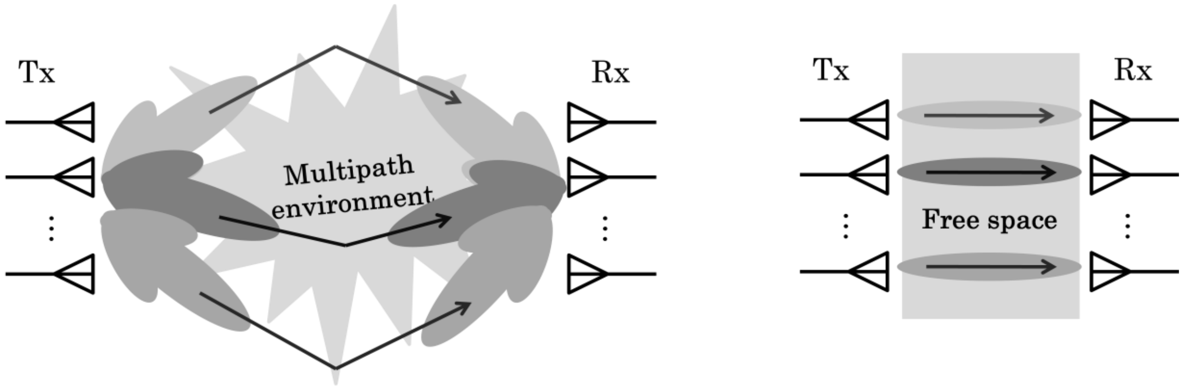
Multiple-Input-Multiple-Output (MIMO) transmission system, which uses plural antennas at both the transmitter and receiver, is an extremely spectrum-efficient technology. MIMO technology constitutes a breakthrough in wireless communication system design. The technology offers a number of benefits that help meet the challenges posed by both the impairments in the wireless channel as well as resource constraints. In addition to the time and frequency dimensions that are exploited in conventional Single-Input-Single-Output (SISO) transmission systems, the leverages of MIMO are realized by exploiting the spatial dimension [1]. Near Field Communication (NFC) is a short-range wireless connectivity technology [2] which enables the exchange of data between devices over a range of about 10 cm. Compared to the SISO system, using MIMO system will increase in data rate, which is realized for no additional power or bandwidth expenditure. However, the presence of a strong line-of-sight (LOS) component in a near field communication system, is viewed as a degradation in a conventional MIMO system [3].

This paper focuses on the element spacing, arrangement and radiation pattern of antenna elements in Near-field MIMO communication system. We try to find out the optimum parameters of the transmission array. In Sec.2, the analysis models of Near-field MIMO system with two types of arrangement are described. In Sec.3, the dual-dipole-element array is used to estimate the effect of the Half-Power Beam Width (HPBW) of radiation pattern on channel capacity, and the correlation among antenna elements is also discussed in detail in the section. The final conclusion is provided in Sec.4.

2. Analysis Model of Near-field MIMO System

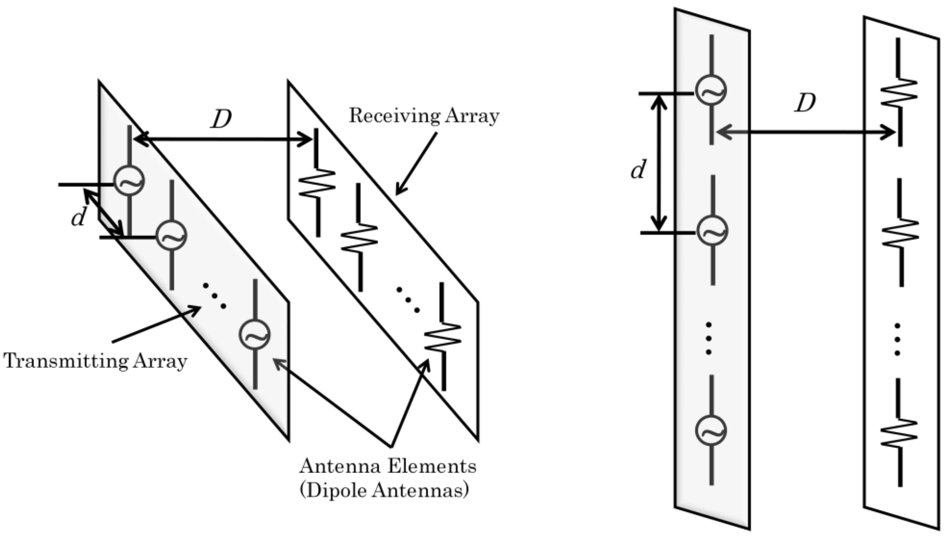
The Near-field MIMO communication system transfers data in a very short range, compared to the conventional MIMO system, it is supposed to work in the free space [4]. The difference between them is shown in Fig.1. The conventional MIMO works in the multipath-rich propagation environment, as shown in Fig.1(a), and it is expected to realize high channel capacity by utilizing the multipath components. However, the Near-field MIMO shown in Fig.1(b), can transfer data directly from the transmitter to receiver, without any fading caused by multipath components. The LOS paths are the major components, since the transmission antennas are placed in such a short distance.

The Near-field MIMO analysis models used in this paper are shown in Fig.2. Two linear arrays consisting of identical half-wavelength dipole antennas are placed parallel face-to-face as the transmitter and receiver, respectively. The number of antenna elements in both ends are set the same as $M_T=M_R=M$. The distance between two adjacent antenna elements is denoted as element spacing d, and the distance between the transmitter and the receiver is defined as antenna distance D. Considering that the dipole antenna has an omni-distributional radiation pattern rather than an isotropic pattern, the array antennas are arranged in two types, horizontal and vertical as shown in Fig.2. At the transmitting array, the equal transmitting power is fed on each antenna element, respectively.



(a) Conventional MIMO System (b) Near-field MIMO System

Figure 1: Conceptual Configurations of Conventional and Near-field MIMO System



(a) Horizontal Linear Arrangement (b) Vertical Linear Arrangement

Figure 2: Analysis Models of Near-field MIMO System

3. Channel Characteristics of Near-field MIMO System

3.1 Channel Capacity Evaluation of MIMO System

To evaluate the performance of the Near-field MIMO system, the channel capacity C is used as the performance index. The generalized capacity formula for the general (M_T, M_R) case is given as follow [5]

$$C = \log_2 \det\left[I_{M_R} + (\rho/M_T)\cdot \boldsymbol{H}\boldsymbol{H}^{\dagger}\right] \text{ [bps/Hz]} \quad (1)$$

In this equation, 'det' means determinant, I_{M_R} is the $M_R \times M_R$ identity matrix, ρ is the average SNR at each receiver branch, $\boldsymbol{H}$ is the normalized MIMO complex channel matrix and '$\boldsymbol{H}^{\dagger}$' stands for the complex conjugate transpose of the matrix.

All the results in this paper are calculated by using Method of Moments (EEM-MOM).

3.2 Optimal Element Spacing

In a Near-field MIMO system, the spatial correlation and SNR play significant roles in channel capacity performance. Furthermore, the spatial correlation and SNR are both conditioned strongly by the element spacing d, so the element spacing d need to be discussed carefully in antenna designing of Near-field MIMO system. N. Honma mentioned that, there was an optimal element spacing with certain antenna distance and certain number of the antenna elements, and the situation of using two facing squarely arranged dipole array was analysed in detail [4].

In this subsection, the two type arranged linear dipole arrays with antenna element number $M_T=M_R=4$ are simulated. The antenna distance D normalized by λ_0 (λ_0 is the wavelength in free space) is changed, and the optimal element spacing d_{opt} (d_{opt} is defined as the element spacing that derive the highest channel capacity at a certain D) and the channel capacity approached at d_{opt} are plotted in Fig.3. Figure 3 indicates that we obtain almost the same trend of d_{opt} as squarely arranged arrays in [4], that is, d_{opt} increases with D. However, the linearly arranged arrays can obtain smaller d_{opt} than the squarely arranged ones, especially the horizontal type array. It also can be seen in Fig.3 that, the horizontal linear array can obtain higher channel capacity than vertical one at the same spacing.

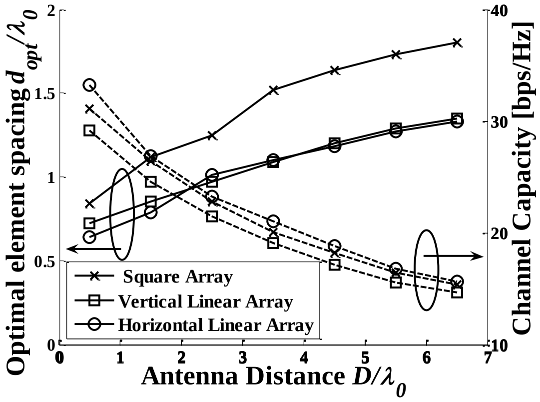
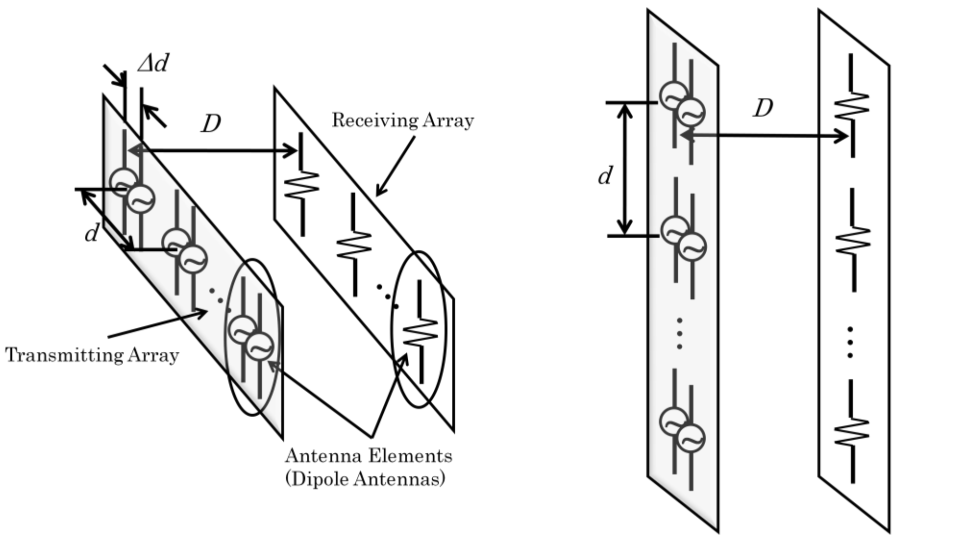


Figure 3: Optimal Element Spacing at Certain Antenna Distance

3.3 Effect of Element Beamwidth on Channel Capacity

In the former discussion, the antenna element is a single dipole antenna with an omni-directional radiation pattern. To investigate the effect of the radiation pattern, one dual-dipole array is used as one element of the transmitting array. The analysis models are shown in Fig.4. The distance between the two dipole antennas in one antenna element is defined as Δd. Once the Δd varies, the Half-Power Beam Width (HPBW) of the radiation pattern will changed. Therefore, we can investigate the effect of beamwidth of antenna element on channel capacity via altering the Δd. In this simulation, two type arranged linear array are considered, and the element number is still set as $M_T=M_R=4$, antenna distance $D = 1.6\lambda_0$, element spacing $d = \lambda_0$. And the transmitting power of each dual-dipole element is constrained as the same as single-dipole element.

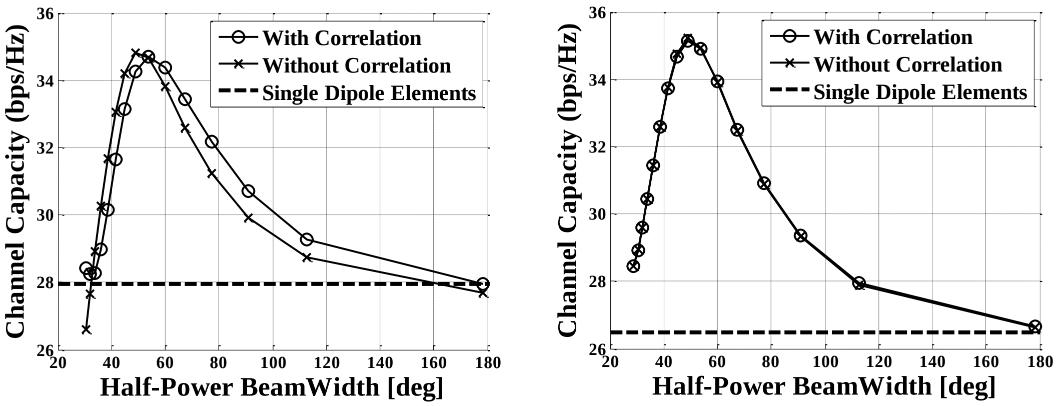


(a) Horizontal Linear Arrangement (b) Vertical Linear Arrangement

Figure 4: Analysis Models of Dual-dipole-element Arrays in Near-field MIMO

Figure 5 plots the relationship of HPBW versus channel capacity. In this simulation, the influence of the correlation among the elements is included. In Fig.5, the curve with circle indicates the correlation among the elements is considered, and the curve with cross indicates the correlation is not considered. The dashed line indicates the channel capacity of a single-dipole model at the same situation. Here, the condition when the HPBW couldn't be measured, in other words, when the radiation pattern has no obvious main beam, is defined as HPBW = 180 °.

Figure 5 indicates that the beamwidth of radiation pattern of antenna elements has a great impact on the channel capacity. We can find that, when the HPBW is smaller than 180 °, the dual-dipole-element MIMO system indicates a higher channel capacity than a single-dipole-element one. As the HPBW changes, the channel capacity will achieve a peak point. And the highest channel capacity can be obtained when HPBW is around 50 °. It is illustrated that the correlation affects the optimal HPBW on a horizontal linear array as shown in Fig.5(a) On the other hand, the effect of correlation can be ignored in a vertical linear array as shown in Fig.5(b).



(a) Horizontal Linear Arrangement (b) Vertical Linear Arrangement

Figure 5: Effect of the Antenna element's Beamwidth

4. Conclusion

This paper focused on the optimal antenna design in Near-field MIMO communication. The element spacing and antenna arrangement were considered to play significant roles in the channel capacity performance of the Near-field MIMO. There was an optimal element spacing at a certain antenna distance in either horizontal or vertical linear array antennas. As the antenna distance enlarged, the optimal element spacing increased. A dual-dipole-element array was utilized to investigate the effect of HPBW in the Near-field MIMO. Adjusting the beamwidth of antenna element, the channel capacity could be improved obviously from a single-dipole-element array. The optimal HPBW was found at about 50 ° .

References

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