

Study on Channel Capacity in Near-field MIMO System when Using Dual-dipole Array

[#]Dalin Zhang, Toshikazu Hori, Mitoshi Fujimoto
Graduate School of Engineering, University of Fukui
3-9-1 Bunkyo, Fukui, Japan. 910-8507
zhang@wireless.fuis.u-fukui.ac.jp

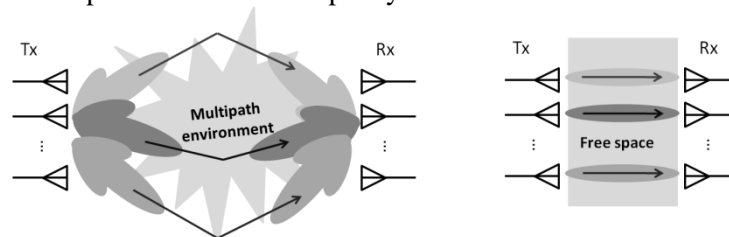
Abstract

This paper introduces the dual-dipole array into the near-field MIMO communication system. Comparing with the conventional single-dipole array, the proposed array possesses very huge dominance in channel capacity. The optimal HPBW of the radiation pattern of the dual-dipole element is found at about 50° . The deterioration of channel capacity caused by antenna location errors is also clarified in detail.

Keywords : MIMO Near-field Communication Channel Capacity Dual-dipole

1. Introduction

Near field communication (NFC) is a short-range wireless connectivity technology [1] which enables the exchange of data between devices over a range of about 10 cm. The future near-field communication systems will require more channel capacity than current ones like WLAN or Bluetooth. Therefore, the Multiple-Input-Multiple-Output (MIMO) [2], which has a wider bandwidth, multi-value modulation system, and spatial multiplex scheme, is proposed to use in the high-speed NFC systems. Compared to the Single-Input-Single-Output (SISO) system, using MIMO system will increase in data rate, which is realized for no additional power or bandwidth expenditure. 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 [3]. 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. Since the transmission antennas are placed in such a short distance, the line-of-sight (LOS) paths are the major components. This paper introduces the dual-dipole array into the near-field MIMO system to improve the channel capacity.

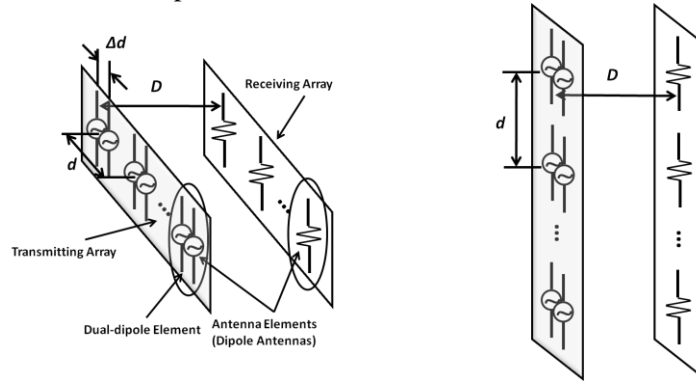


(a) Conventional MIMO System (b) Near-field MIMO System
Figure 1: Conceptual Configurations of Conventional and Near-field MIMO System.

This paper focuses on the element spacing, radiation pattern of antenna elements and antennas' location errors 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 dual-dipole arrays are described. Section 3 discusses the effect on channel capacity of array parameters including half power beamwidth (HPBW), element spacing and antenna distance, and the channel capacity deterioration occurred by antennas' location errors is also clarified in this section. The final conclusion is provided in Sec.4.

2. Analysis Model and Evaluation

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. Since the transmission antennas are placed in a very short distance, the shape of radiation pattern is the significant component to affect the channel capacity. The conventional single-dipole array has an omni-directional radiation pattern. It wastes most transmitting power on the other directions. Therefore, we set two dipoles on the transmitting end as one element. We call the new element as dual-dipole element, which can make the pattern more orientational than the conventional array. 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 , and the distance between the two dipole antennas in one transmitting element is defined as Δd . The array antennas are arranged in two types, horizontal and vertical as shown in Fig.2. In addition, 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 2: Analysis Models of Dual-dipole Arrays in Near-field MIMO.

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 [4]

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

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, \mathbf{H} is the normalized MIMO complex channel matrix and ‘ \mathbf{H}^\dagger ’ stands for the complex conjugate transpose of the matrix. The adaptive control for the weight coefficients is optimized by the eigenmode beamforming algorithm.

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

3. Channel Capacity of Near-field MIMO with Dual-dipole Array

3.1 Effect of Element Beamwidth of Dual-dipole Element

Figure 3 plots the relationship of HPBW versus channel capacity. In this simulation, the influence of the correlation among the elements is included. In Fig.3, 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 $\text{HPBW} = 180^\circ$.

Figure 3 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 MIMO system indicates a higher channel capacity than a single-dipole 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° . The corresponding Δd of the optimal HPBW is about $0.55\lambda_0$.

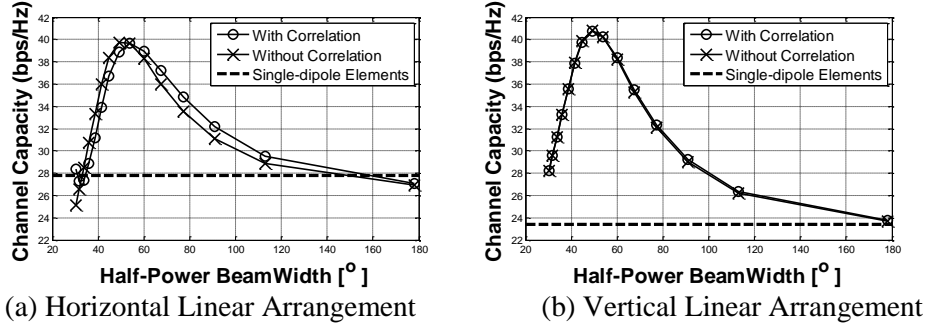


Figure 3: Effect of the Antenna Element's Beamwidth.

3.2 Effect of Antenna Distance and Element Spacing

In a near-field MIMO system, the antenna distance D and element spacing d play significant roles in channel capacity performance. Furthermore, the spatial correlation and SNR are both conditioned strongly by the element spacing d [3], so the element spacing d needs to be discussed carefully in antenna designing of near-field MIMO system. In our former paper [5], we have proved that there was an optimal element spacing with a certain antenna distance when using a conventional single-dipole array.

In this subsection, the two type arranged linear dual-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) changes from $0.4\lambda_0$ to $1.6\lambda_0$, the element spacing d varies from $0.6\lambda_0$ to $2\lambda_0$, and Δd is fixed at $0.5\lambda_0$. The channel capacity approached at each condition is plotted in Fig.4. Figure 4 indicates that the channel capacity of the system will decrease as either the antenna distance D or element spacing d increases. However, it is obvious that D affects the channel capacity more significantly, since the channel capacity changes very flatly as the d varies, especially when D is small, the effect of element spacing on channel capacity can be ignored. In addition, the curves of horizontal type array are more fluctuant than the vertical ones.

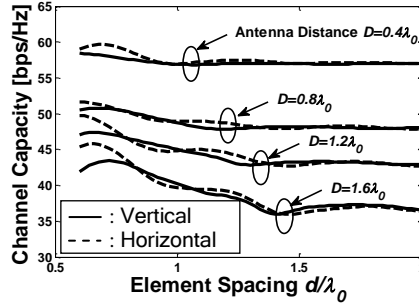


Figure 4: Effect of Antenna Distance and Element Spacing.

3.3 Effect of Antenna Location Errors

In the former discusses, the effects of the basic characteristics of dual-dipole array are clarified. In those cases, the transmission antennas are considered placing face to face. However, in practical application the opposing antennas can't be placed in the ideal position. Therefore, the channel capacity deterioration caused by the antenna location errors will be discussed in this subsection.

The antenna location errors include offset error and rotational error. In this simulation, as shown in Fig.5, the vertical arranged arrays are simulated to clarify the channel capacity deterioration. The element spacing d is fixed at λ_0 , and the distance between two dipoles in one element Δd is fixed at $0.55\lambda_0$. In the offset error model, the offsets of the receiving antenna on both y and z directions are considered, and the offset errors are shifted by Δy and Δz , respectively, as shown in Fig.5(a). In the offset error model, the antenna distance D is fixed at $1.6\lambda_0$. The rotational error is only considered that the receiving antenna rotates around x axis by θ_x , as shown in Fig.5(b). In the rotational error model, the antenna distance D is also discussed from $0.4\lambda_0$ to $3.2\lambda_0$.

The simulation results shown in Fig.6 indicate that as the antenna location errors increase the channel capacity decreases very badly. It can be seen from Fig.6(a) that when Δy is less than

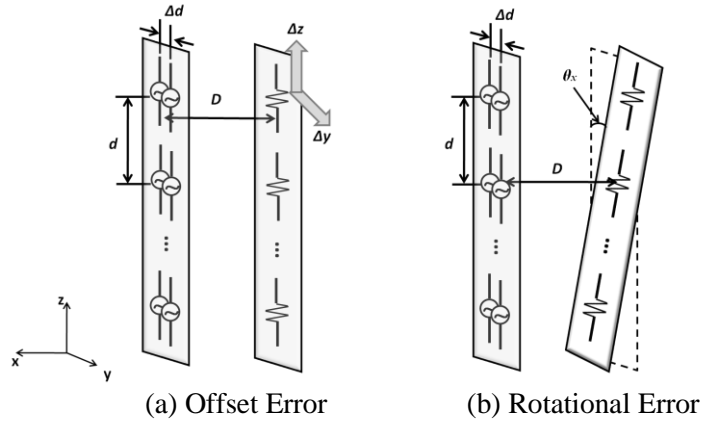


Figure 5: Models of Antenna Location Errors.

$0.8\lambda_0$ or Δz is less than $0.5\lambda_0$, the deterioration of channel capacity is less than 10%. In addition, the effect of the offset on z direction is larger than that on y direction. Figure 6(b) indicates that when D is small the channel capacity will deteriorate very steeply, and as the D increases the curves turn to more flat. That means the effect of rotational error will become smaller as D increases. In particular $D=1.6\lambda_0$, when the rotational error is less than 20° , the deterioration is less than 10%.

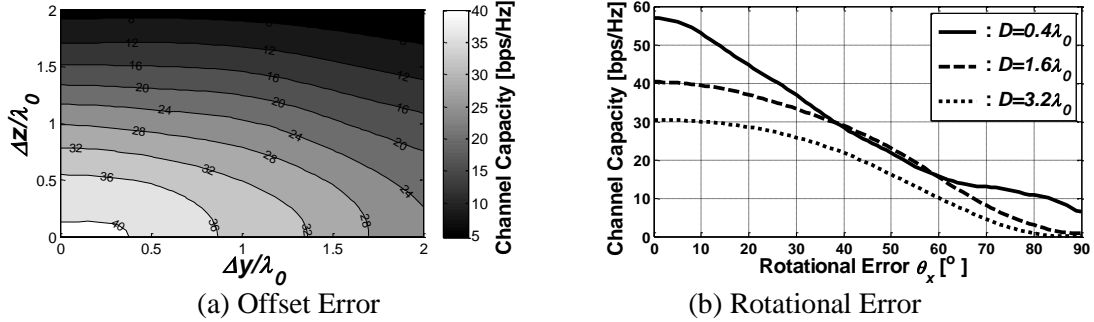


Figure 6: Effect of Antenna Location Errors on Channel Capacity Deterioration .

4. Conclusion

The channel capacity in near-field MIMO system with dual-dipole array was described. It was proved that a better channel capacity could be obtained by the dual-dipole array than the case of single-dipole array in near-field MIMO system. The basic characteristics of the array were discussed. The HPBW of dual-dipole element and the antenna distance were considered playing significant roles in the channel capacity performance rather than the element spacing. And the optimal HPBW was found at about 50° . The deterioration of channel capacity caused by antenna location errors was also clarified. When the deterioration was less than 10% (vertical array, $D=1.6\lambda_0$, $d=\lambda_0$, $\Delta d=0.55\lambda_0$), the offset errors on y and z directions should be less than $0.8\lambda_0$ and $0.5\lambda_0$, respectively, and the rotational error around x axis should be less than 20° .

References

- [1] G. Fettweis, E. Zimmermann, V. Jungnickel, E.A. Jorswieck, "Challenges in Future Short Range Wireless Systems," IEEE Vehicular Technology Magazine, vol.2, no.1, pp.24-31, Jun. 2006.
- [2] E. Biglieri, R. Calderbank, A. Constantinides, A. Goldsmith, A. Paulraj, H. V. Poor, MIMO Wireless Communications, 1st edition, Cambridge University Press, New York, 2007.
- [3] N. Honma, K. Nishimori, T. Seki, M. Mizoguchi, "Short range MIMO communication," Proc. of EuCAP2009, Berlin, Germany, pp.1763-1767, Mar. 2009.
- [4] G.J. Foschini, M.J. Gans, "On Limits of Wireless Communications in a Fading Environment when Using Multiple Antennas," Wireless Personal Communications, vol.6, no.3, pp.311-335, Mar. 1998.
- [5] D. Zhang, T. Hori, M. Fujimoto, "Effect of spacing and radiation pattern of antenna elements on capacity in near-field MIMO system," Proc. of ISAP2010, Macao, China, pp.179-182, Nov. 2010.