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Evaluation of Distributed MIMO Antennas for Mobile Terminal

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1. Introduction

Over the past ten years, MIMO transmission, which improves the communication quality and enhances the system capacity within a limited frequency band, has attracted much attention [1, 2]. In utilizing multiple antennas for small mobile terminals, the space arranging the multiple antennas are limited and the distance between them is compelled to be short. Hence, the radiation efficiency and antenna correlation are degraded by the effect of mutual coupling, and the MIMO channel capacity cannot be ideally obtained [3]. In addition, the performance of the antenna is degraded by the effect of the human body in the usage environment of such the terminal [4, 5].

For arranging the multiple antennas with higher efficiency and lower correlation, we have proposed a novel architecture, that the antennas are implemented onto the multiple distributed terminals deployed in a near field and then the signals received by the distributed antennas are consolidated to a specific main-terminal through the wireless communication links between them. As one utility scenario of this architecture, deployment of the two terminals (main and sub-terminal) around a user (human body) can be considered. In this paper, we evaluate the antenna performance with the distributed terminals in the scenario, as well as in the free space, in order to show the effectiveness of the distributed MIMO antenna architecture through the comparison to a single terminal by the computer simulation. Concretely, main and sub terminals, respectively with two antennas, and single terminal with four antennas and human body phantom are modeled and their efficiency, antenna correlation, and MIMO channel capacity are evaluated with the FDTD (Finite Difference Time Domain) calculation.

2. System and calculation model

The basic concept of the distributed MIMO antenna system for mobile terminal is shown in Figure 1. The base station with four transmit antennas communicates with main terminal through MIMO propagation channel. Meanwhile, the main and sub terminal receive the transmitted signal with two receive antennas, respectively, and the sub-terminal transmits the received signals to the main terminal through the wireless link between the terminals at the same time. With an assumption that the link between terminals are ideally established and then the main terminal can deal with the synchronized received signals of the four distributed antennas, the MIMO channel capacity can be calculated as the following equation,

$$C = \log_2 \det\left(\frac{\gamma}{N_T}\mathbf{H}\mathbf{H}^{\mathrm{H}} + \mathbf{I}\right) \quad (1)$$

$\mathbf{H} = [\mathbf{H}_{\text{BS-MT}}^{\mathrm{H}}\mathbf{H}_{\text{BS-ST}}^{\mathrm{H}}]^{\mathrm{H}}$ is a 4x4 MIMO channel matrix, where $\mathbf{H}_{\text{BS-MT}}$ and $\mathbf{H}_{\text{BS-ST}}$ are 4x2 channel matrix between the base station and main terminal, and base station and sub-terminal, respectively. For calculating (1), the channel response, which is the element of the matrix, is calculated with the radiation pattern of the following terminal antennas with or without human body and uniformly distributed component waves of multipath channel.

The configuration of the antenna model that arranges the four planar inverted F antennas (PIFAs) in a single terminal model is shown in Figure 2. The antenna model that arranges the two antennas in each main-terminal and sub-terminal (Distributed model) is configured such that PIFA#3 and PIFA#4 of the single terminal model are removed. The feeding point of the distributed model's antenna is that the main-terminal mounted PIFA#1 and PIFA#2, and the sub-terminal mount PIFA#3 and PIFA#4. The PIFA are designed to resonate at 1.5 GHz. The four PIFAs with the same size (18 × 37.4 mm^2) are mounted on the ground plane of size 100 × 50 mm^2. The distance between the shorting and feeding pins is 2.35 mm and the height of the antenna is 4 mm. The feeding point was adjusted appropriately in order to match the input impedance to 50Ω. Figure 3 shows the configuration of the human model. In our study, we use the two-thirds muscle-equivalent phantom at 1.5 GHz. Its relative permittivity and conductivity are equivalent to two-thirds times that of human muscle (ε_r = 36.0, σ = 0.9 S/m) [6]. According to the average height of Japanese people, we assumed the height of the human model to be 1660 mm. However, in order to reduce the calculation time, we shorten the leg length to 450 mm because the influence is negligible. In our calculation model, the single terminal model is that the MIMO terminal loads the four array antennas is held in the right hand. While, the distributed model is that the main MIMO terminal loads the two antennas is held in right hand and another terminal (sub-terminal) that loads the two antennas is placed in the pocket near the chest (Chest model) or the waist (Waist model). In all calculation models with the human model, the distance between terminals and human is 5 mm taking into the consideration the terminal. In addition, the ground plane of the terminal is placed in the nearer side towards the human body.

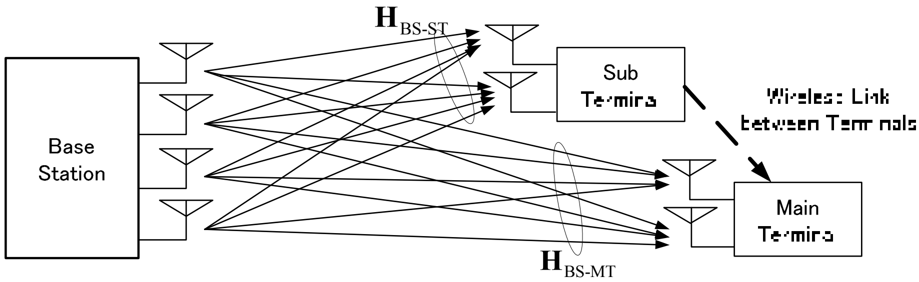
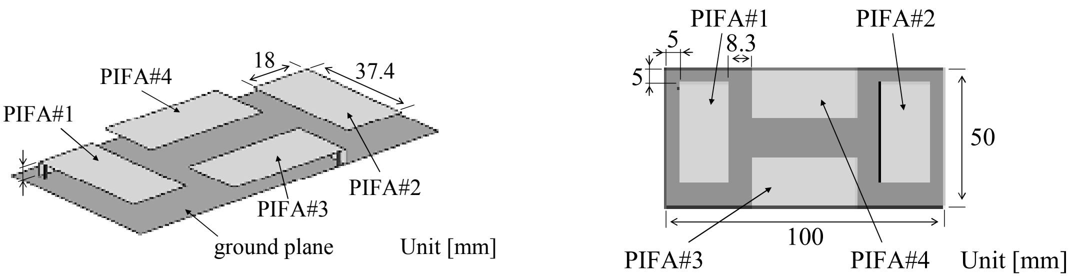
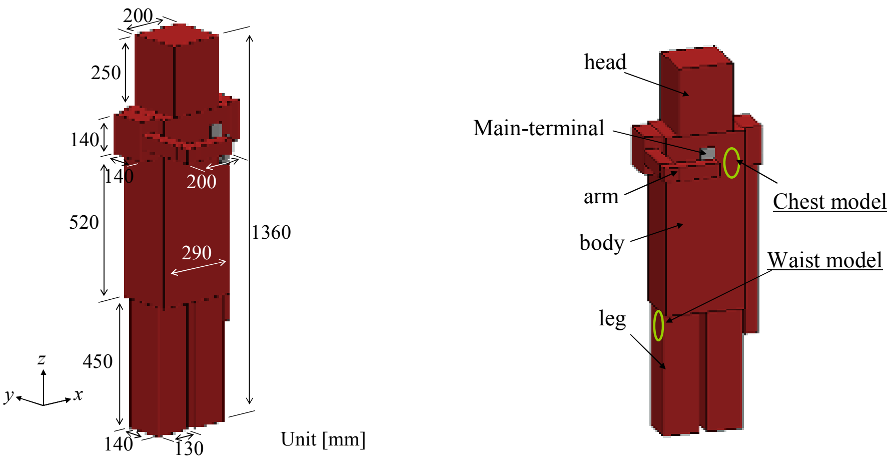


Figure 1: Basic concept of the distributed MIMO antenna system for terminal



(a) over view (b) location of arranging PIFA plates

Figure 2: Structure of the MIMO terminal



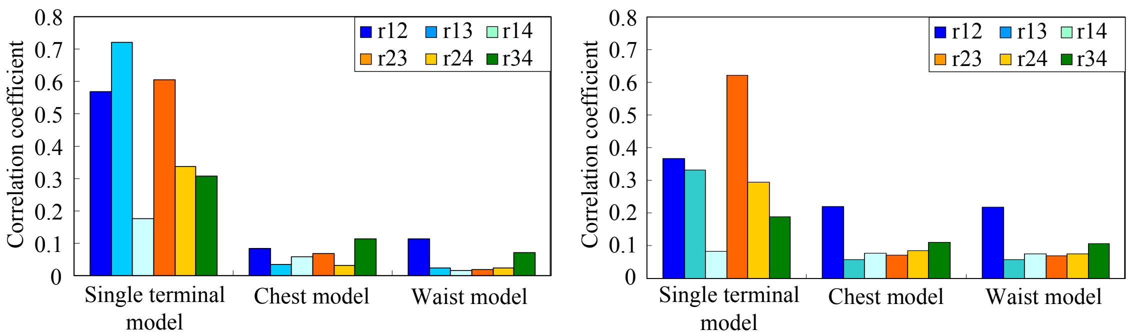
(a) human model (b) position of the sub-terminal

Figure 3: Human model and calculation model

3. Calculation results

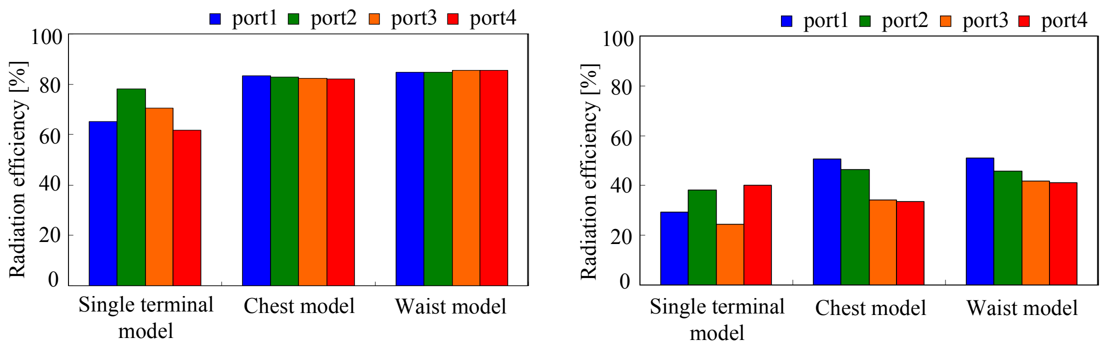
3.1 Radiation efficiency and Antenna correlation

Figure 4 shows the antenna correlation of each MIMO terminal in free space and with the human model. The correlation of the distributed terminals model can be reduced from the Single terminal model by taking the distances of antennas in free space and with human body. It is noteworthy that the differences by the position of the sub-terminal in this evaluation, e.g. chest and waist model, is little. The radiation efficiency of each model in free space and with the human model is shown in Figure 5. The radiation efficiency is wholly high in free space and, it can be confirmed that the efficiency is affected when the terminal is near the human body. This can be explained that the radio wave is absorbed by human body and the performance of the antenna is affected. The average radiation efficiencies of four antennas in the distributed model (chest and waist) is improved from those of the single terminal model in free space and with human model. It can be considered that the improvement comes from the reduction of the mutual coupling by taking the antenna distances.



(a) No human model (in free space)　　(b) With human model

Figure 4: Antenna correlation

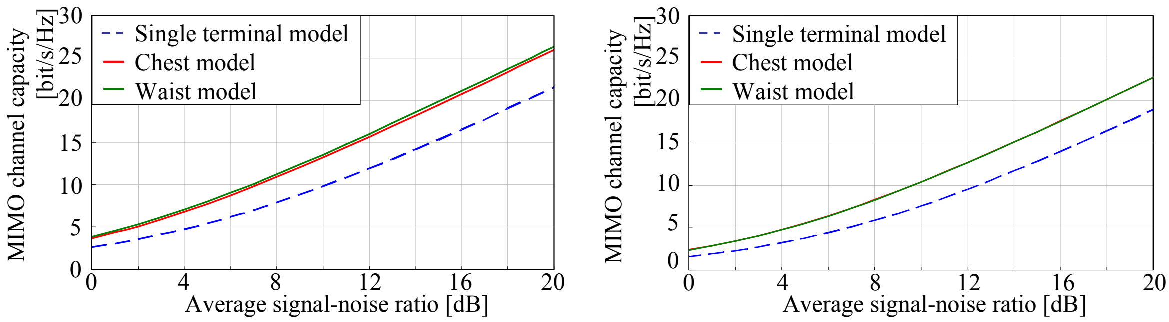


(a) No human model (in free space)　　(b) With human model

Figure 5: Radiation efficiency

3.2 MIMO channel capacity

For further showing the effectiveness with MIMO channel capacity, Ergodic MIMO channel capacity is calculated. The channel response between each transmit and receive antenna is calculated by the weight sum of the 3D radiation pattern corresponding to the direction of arrivals of component waves, that are uniformly distributed. Figure 6 shows the MIMO channel capacity of each MIMO terminal with human model and in free space. Fig.6 (a) shows results in free space. From the figure, the MIMO channel capacity can be improved by distributing the antennas from the Single terminal model because of the aforementioned improvements of antenna correlation and radiation efficiency. Concretely, when the average signal-noise ratio is 20, the MIMO channel capacity of Single terminal model is approximately 21.5 bit/s/Hz. In contrast, the MIMO channel capacity of chest model is about 26.0 bit/s/Hz and that of waist model is 26.3 bit/s/Hz. As the results, the MIMO channel capacity is improved about 22 percent by distributing the antennas in free space. Fig.6 (b) shows the results with human body. The results shows the improvement by distributing the antennas and that is not depend on the position of the sub-terminal. When the average signal-noise ratio is 20, the MIMO channel capacity of chest and waist model is approximately 22.7 bit/s/Hz whereas that of the Single terminal model is approximately 18.9 bit/s/Hz. As the results, the MIMO channel capacity is improved about 20 percent by distributing the antennas with the human body. Furthermore, the results in both figures show that the degradation of MIMO channel capacity by the absorption loss are almost the same in Single terminal model and distributed terminal model.



(a) No human model (in free space) (b) With human model

Figure 6: MIMO channel capacity

4. Conclusion

In this paper, we evaluate the performance of the antennas distributed around near field through the comparison to that with totally same numbers of antennas on a single terminal in order to verify the effectiveness of the distribution deployment. The antenna correlation and the radiation efficiency can be improved by distributing and arranging the multiple antennas to terminals. As the results, the MIMO channel capacity is improved about 20 percent by the distribution. Furthermore, human body can absorb the electromagnetic wave and influence to the performance of MIMO antennas.

As a further study, the high accuracy human model will be used in calculation in order to confirm the suitability of simplified human model, and dependency of performance on the position of the sub-terminal will be evaluated with including the quality of wireless link between terminals.

References

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