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Experimental evaluation of MIMO transmission on between human bodies communication

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Abstract: In this paper, we propose multi-input multi-output (MIMO) transmission using human bodies. The proposed scheme is experimentally evaluated using test subjects, whose bodies are located at different positions. A high channel capacity was achieved by using MIMO transmission. The channel capacity obtained for 2×2 MIMO in body-to-body communication is approximately 1.6 times higher than that obtained when using single-input single-output transmission. The experimental results indicate the success of the proposed method in increasing channel capacity using MIMO. The presented research is relatively unique, and the results would therefore be a valuable contribution to this field of research.

Keywords: MIMO, body-to-body communication, channel capacity
Classification: Wireless Communication Technologies

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1 Introduction

Today's consumers are surrounded by a wide range of mobile communication devices, such as smart phones, laptop PCs, mobile game consoles, and so on. In the future, a unified communication method will likely be required to link these diverse mobile terminals. One solution that was proposed by Zimmerman is the concept of using the human body as a communication path to link mobile terminals [1]. This type of communication, called intra-body communication, would offer a benefit of communication without constraint of physical cabling on account of the body being occupied as a communication medium.

We apply intra-body communication technology in this study and focus on the transmission of signal between two human bodies. The transmission scheme is herein referred to as body-to-body communication. Unlike intra-body communication, body-to-body communication involves intermediary technology between wired and wireless communication. Therefore, it has the same advantages of intra-body communication, while eliminating the need for antennas and device of wireless communication systems. In related studies, body-to-body communication results have been minimally obtained through a focus on intra-body communication [2]. Consequently, addressing network configuration and basic evaluation experiments for body-to-body communication is important.

In this paper, we present our experimental evaluations of body-to-body communication. Multiple-input multiple-output (MIMO) transmission [3] is introduced to increase a channel capacity. The channel capacity by MIMO transmission is compared with that by single-input single-output (SISO) transmission.

2 Experimental methodology of intra-body communication and body-to-body communication

In Sect. 3, we compare respective electric power (the received power) in SISO by inter-body communication and body-to-body communication. An electrode is required to respective communications. Therefore, body-to-body communication is confirmed by prototype electrode. In addition, body-to-body communication in SISO is evaluated to verify that an input signal is transmitted to different bodies via a radio medium. The transmission of electric power is additionally confirmed in the experiment and results are compared. In Sect. 4, an experimental by body-to-body communication using MIMO transmission is employed in order to increase the channel capacity. Low frequencies, those below the microwave, are sufficiently effective to enable signals to be transmitted in the human body [4]. However, when low frequencies are used, it is difficult to obtain wideband performance by small

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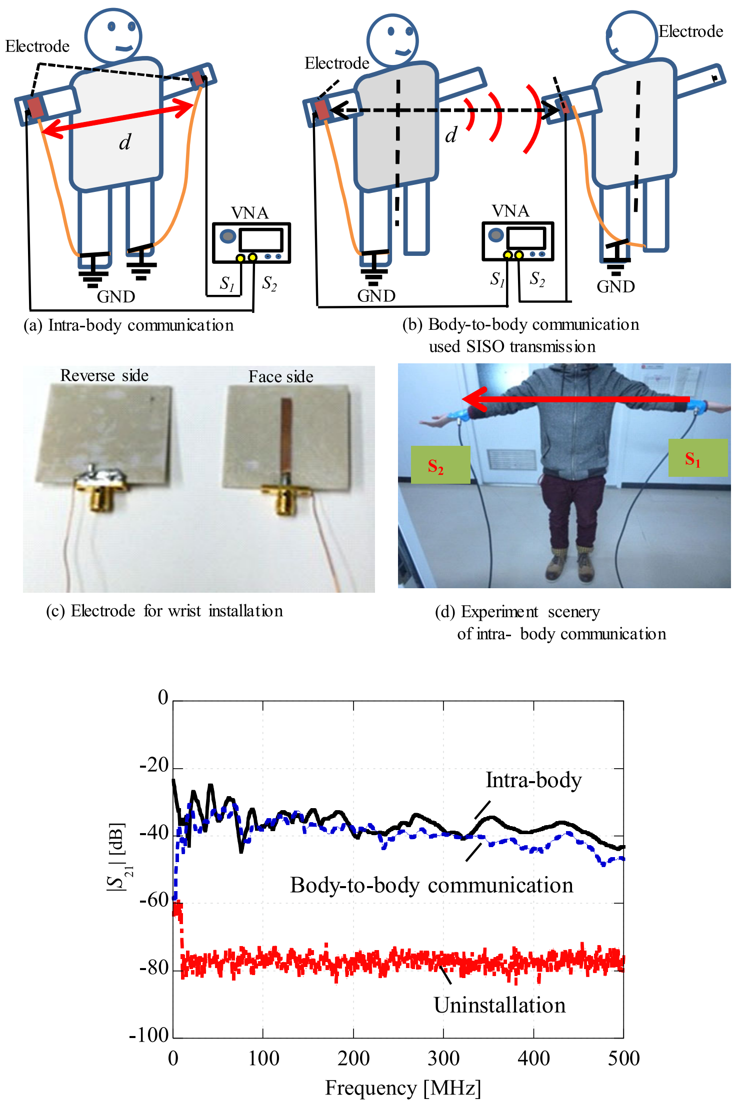
antennas. If SISO transmission is used, a high transmission rate may not be obtained. In this study, this issue is solved by using a 2×2 MIMO transmission. The channel capacity by MIMO and SISO transmissions are evaluated in terms of body-to-body communication.



(a) Intra-body communication
(b) Body-to-body communication used SISO transmission
(c) Electrode for wrist installation
(d) Experiment scenery of intra- body communication
(e) S_{21} of received power via human body (s)

Fig. 1. Human body(s) communication configuration and evaluation results.

3 Evaluation of intra-body communication and the body-to-body communication with SISO

In our initial tests, we evaluated whether signal could be transmitted within the body of test subject, as shown in Fig. 1(a), in order to confirm the received power of intra-body communication. Fig. 1(c) shows electrodes of the prototype. The electrodes are probe type. The electrode surface was in contact with the wrist. For the experiments on intra-body communication, we applied the electrodes directly to both wrists of test subject, as shown in Fig. 1(d). We used a vector network analyzer (VNA) to measure the received power of transmitted signals. The

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measurement was performed with subject's electrode-fitted arms which are horizontally extended and maintained in a static state. The electrodes and ground cables were attached to both wrists and ankles of the subject and held in place with masking tape. The received power was measured at a frequency band of 500 KHz–500 MHz. Ground terminals were wound around subject's ankles and connected with cables to place them at a sufficient distance from the electrodes.

Fig. 1(b) illustrates the experimental method used for body-to-body communication. Like intra-body communication experiments, body-to-body communication is also evaluated by measuring the received power when signals are transmitted from S_1 to S_2 by VNA. The signals by SISO transmission were transmitted between two bodies of test subjects. The electrode was used for the wrist of each subject in order to confirm whether signals were transmitted between their bodies. As shown in Fig. 1(b), transmit distance, d between test subjects was set to be 1 m.

Fig. 1(e) shows the received power measured for intra-body and body-to-body communications. These results are compared to the received power when electrodes were not attached. The frequency is shown on the horizontal axis, and $|S_{21}|$ as the received amplitude is depicted on the vertical axis. The range of frequency is from 500 kHz to 500 MHz. The noise level is indicated at approximately -80 dB when electrodes are not attached (uninstalled). Intra-body communication shows a high received power level of -40 to -30 dB in all the frequency band, while body-to-body communication shows a received power level of -45 to -30 dB: these power levels are much higher than the noise power level. These results confirm that signals can be transmitted by both intra-body and body-to-body communications.

4 Comparison of channel capacity in body-to-body communication using MIMO and SISO

In Sect. 3, body-to-body communication using SISO transmission was confirmed by $|S_{21}|$. In this section, the channel capacity of body-to-body communication by using MIMO transmission is experimentally evaluated. The purpose of this experiment is to confirm whether MIMO transmission can be utilized to improve the channel capacity in terms of body-to-body communication. In this experiment, we used a four-port VNA for MIMO transmission. Fig. 2(a) illustrates an experimental configuration used for body-to-body communication by MIMO transmission. As shown in Fig. 2(a), electrodes are applied to both wrists of each test subject. It is verified whether signals were transmitted between their bodies, which are separated by the distance of $d = 1$ m. Therefore, unlike SISO measurements, four electrodes were used and 2×2 MIMO transmissions were considered.

To reduce errors caused by the differences between individual test subjects, three pairs of test subjects are evaluated (test subjects A, B, and C). We evaluated three different test subject pairs: A–B, B–C, and C–A. Fig. 2(b) shows the propagation path of the 2×2 MIMO transmission. The right wrists were connected to VNA ports S_1 and S_3; the left wrists were connected to S_2 and S_4. Fig. 2(c) illustrates an experimental scene of body-to-body communication using MIMO transmission. The measurement was performed with two subjects facing each other while their arms were horizontally extended. Electrodes were attached to both arms.

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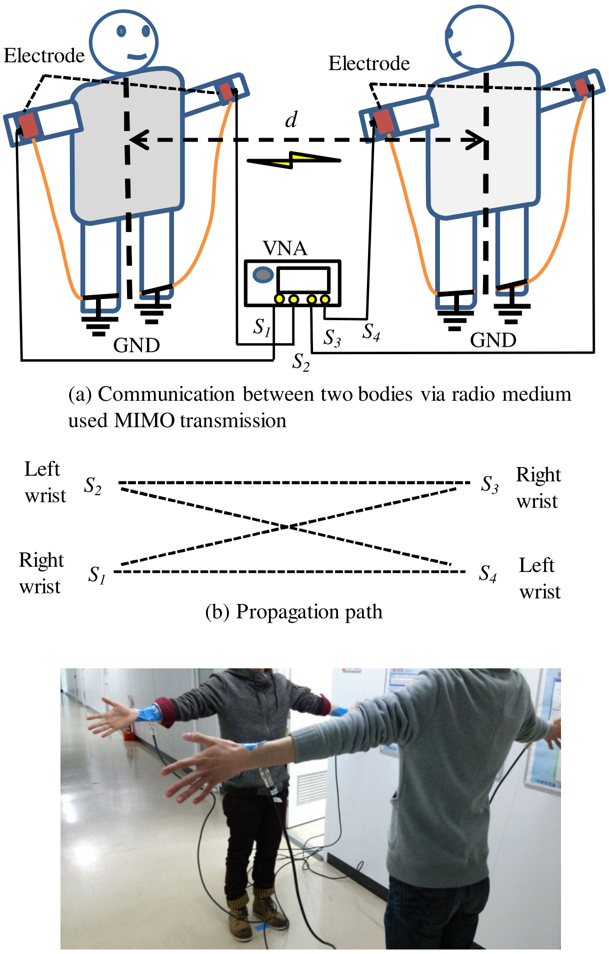

(a) Communication between two bodies via radio medium used MIMO transmission

(b) Propagation path

(c) Experiment scenery of body to body communication used MIMO transmission

Fig. 2. Body-to-body communication configuration using MIMO transmission

Body-to-body communication using SISO transmission was performed using the same configuration described in Sect. 3 and S_1 and S_4 were used in Fig. 2(b). In addition, electrodes were in contact with the wrists. The copper wires connected to the ground terminals were placed at an adequate distance from the wrist electrodes by winding them around the ankles and connecting them with cables to eliminate any potential difference. The measurement time was 60 s per measurement. The measurement was performed ten times, and the average value of those ten measurements was obtained. The channel capacity by SISO and MIMO transmission was obtained when the frequency bandwidth was changed.

Using Shannon capacity formula [5], Shannon capacity in SISO channel is expressed as

$$C_{SISO} = \log_2(1 + \gamma) \text{ [bits/s/Hz]}. \tag{1}$$

Shannon capacity in MIMO channel is expressed as

$$C_{MIMO} = \log_2 det\left(I + \frac{\gamma}{M}\boldsymbol{HH}^H\right) \text{ [bits/s/Hz]}, \tag{2}$$

$$\boldsymbol{HH}^H = \begin{pmatrix} |h_{11}|^2 + |h_{12}|^2 & h_{11}h_{21}^* + h_{12}h_{22}^* \\ h_{21}h_{11}^* + h_{22}h_{12}^* & |h_{21}|^2 + |h_{22}|^2 \end{pmatrix},$$

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where h_{ij} denotes the channel response for j-th and i-th transmitter and receiver. γ is the signal-to-noise ratio (SNR), I is an identity matrix, and M is the number of antennas (electrodes). Because our experiment was employed by 2×2 MIMO, $M = 2$ and $\boldsymbol{HH}^H$ is a 2×2 channel matrix.

In these evaluations, the frequency range was 500 kHz to 500 MHz. The measurement results of SISO and 2×2 MIMO transmission were compared, as shown in Fig. 3. The channel capacity in SISO channel is obtained by using the channel between S_1 and S_4 in Fig. 2. The SNR is 20 dB. The measurement results are shown when the distance between test subjects is fixed at $d = 1$ m. For three pairs of test subjects, the channel capacity is obtained at approximately 12 bits/s/Hz when using SISO transmission. For the MIMO transmission, the channel capacity of approximately 20 bits/s/Hz is obtained. The channel capacity obtained for 2×2 MIMO is approximately 1.6 times higher than that obtained when using SISO. These results show that the channel capacity is increased by 2×2 MIMO transmission, even for body-to-body communication.

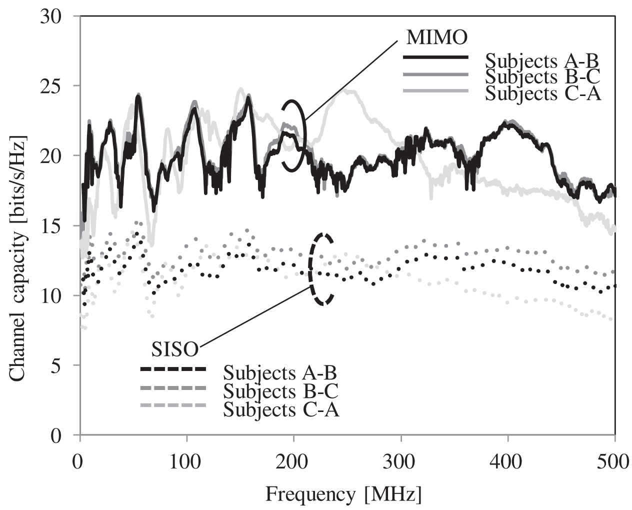

Fig. 3. Channel capacity using SISO and MIMO in the body-to-body communication

5 Conclusion

In this paper, body-to-body communication was evaluated using 2×2 MIMO channel. The experimental results indicate that MIMO transmission can provide a channel capacity at approximately 1.6 times higher than that of SISO transmission. Therefore, it is confirmed that MIMO transmission is effective for transmission rate improvement, even when using the human body communication.

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