TCP/IP Body Area Network in intra-body transmission using OFDM-based wideband modulation

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Abstract

Intra-body transmission, which uses human body as part of the transmission medium is one of the promising data transmission methods for constructing Personal Area Network (PAN) or Body Area Network (BAN). Since signal propagates mainly through the human body, power consumption is smaller and transmission is less susceptive to eavesdropping.

One of the difficulties in intra-body transmission is that the transmission characteristics vary among individuals and change by surrounding environment. Even the posture of the user may affect the transmission characteristics. These variations make it difficult to construct IP networks using protocols such as TCP/IP.

We have investigated transmission characteristics of intra-body transmission system in frequency range from 300 kHz to 1 GHz. The transmission efficiency through the human body showed a peak at around frequency of 1 MHz, and was better than that through the air at all frequency less than 80 MHz. The difference was 20 dB or more at frequency less than 55 MHz.

To achieve IP network using TCP/IP protocol, we focused on Orthogonal Frequency-Division Multiplexing (OFDM) method, which is tolerant to the frequency transmission characteristic variations. We used frequency range from 2 to 28 MHz and investigated the feasibility of TCP/IP communication in intra-body transmission.

We evaluated characteristics of TCP/IP-based intra-body transmission using OFDM communication system on an experimental basis. Throughput of 53.5 Mbps on UDP and 15.2 Mbps on TCP were achieved between the transmitting and receiving electrodes gripped by right and left palms, and throughput of 68.1 Mbps on UDP and 16.8 Mbps on TCP were achieved between an electrode gripped by one hand and an electrode put on the wrist. We confirmed that the TCP/IP-based high-speed communication in intra-body transmission was achievable using OFDM modulation with 2 – 28 MHz.

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Keywords

Human body, Intra-body transmission, Body area network, Wearable, OFDM

1. INTRODUCTION

As electronic devices become smaller, people may begin to "wear" electronic devices instead of carrying them [1]. A communication method which uses human body as part of the transmission medium, which will be called "intra-body transmission" hereafter, may become a new Man-Machine interface because transmission path is established only when the user touches another device [2]. Studies on intra-body transmission originated from Zimmerman's pioneering work on intra-body transmission were carried out at MIT in 1995 [3]. And intra-body transmission is one of the promising data transmission methods for constructing Personal Area Network (PAN) or Body Area Network (BAN). Since signal propagates mainly through the human body, power consumption is smaller and transmission is less susceptive to eavesdropping [4]-[6].

One of the difficulties in intra-body transmission is that the transmission characteristics vary among individuals and change by surrounding environment. Even the posture of the user may affect the transmission characteristics. These variations make it difficult to construct IP networks using protocols such as TCP/IP.

In this paper, we focused on Orthogonal Frequency-Division Multiplexing (OFDM) communication, which is tolerant to the frequency transmission characteristic variations, using wider frequency range from 2 to 28 MHz, and investigated the communication on TCP/IP protocol using the OFDM modulation in intra-body transmission.

2. FREQUENCY CHARACTERISTICS OF HUMAN BODY

Fig. 1 shows a measurement system that we fabricated to measure intra-body transmission characteristics of a human subject by letting the subject hold the electrode in each hand. The transmission path will be from the left hand, passing through left arm, torso, right arm, and to the right hand. Transmission characteristics were measured by connecting a network analyzer to the electrodes. The blue solid line in Fig. 2 shows the transmission characteristics through the human body. The red

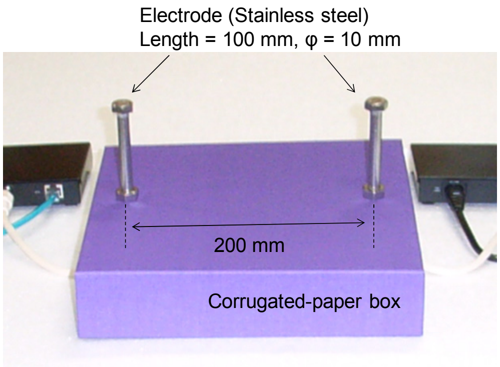


Fig. 1 Measurement system for intra-body transmission characteristics

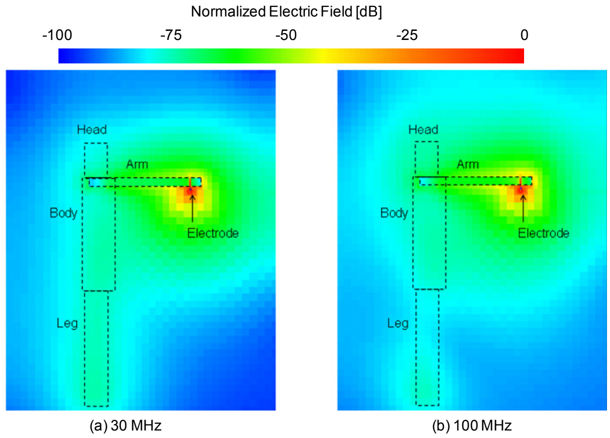


Fig. 3 Normalized Electric field distributions (RMS values)

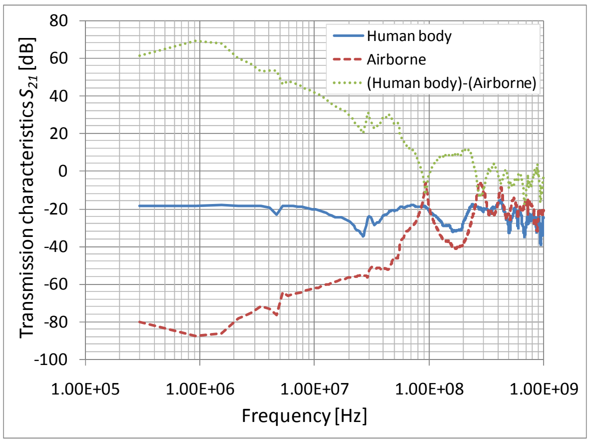


Fig. 2 Frequency transmission characteristics through the human body and the air

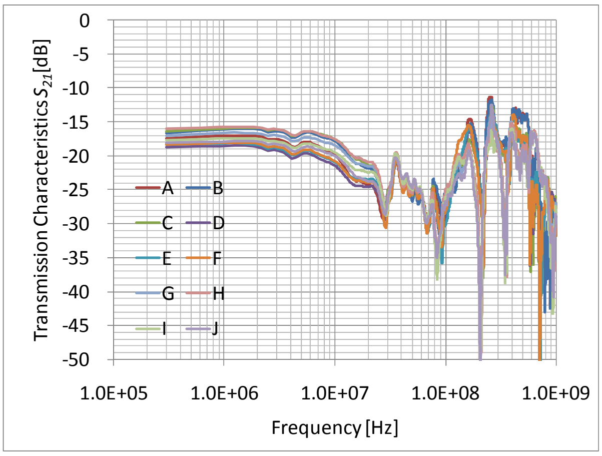


Fig. 4 Transmission characteristics through the human body of 10 people consisting of men and women between the ages of twenties and sixties

broken line shows transmission characteristic when the subject was not holding the electrodes. This corresponds to the transmission characteristic of air borne transmission. The green dotted line shows the difference between the two. As shown in Fig. 2, the transmission characteristic through the human body is larger than that of airborne transmission from the frequency range from 300 kHz to 80 MHz, and has difference of 20 dB or more below 55 MHz. The maximum is at around frequency of 1 MHz.

Fig. 3 shows the electric field distributions when human grips electrodes with their hands and the electrode transmit the signal of frequencies at 30 MHz and 100 MHz. The elliptic-cylindrical human body model used for electromagnetic field analyses is considered as an average human body size of a Japanese adult male [7], [8]. As shown in Fig. 3, although it is almost the same electric field distributions around arm and electrode at the frequencies between 30 MHz and 100 MHz, it is confirmed that radiation to the air increases as the frequency increases. This is because the transmission through the air becomes dominant over that through the human body as the frequency increased.

Fig. 4 shows the transmission characteristics through the human body of 10 people consisting of men and women between ages of twenties and sixties. As shown in Fig. 4, the transmission characteristics among individuals in the frequency range from less than 30 MHz were similar. The difference was only in the transmission gain which varied by 4 dB. In the frequency range above 30 MHz, the variation becomes smaller because the transmission through the air becomes dominant over that through the human body.

Fig. 5 shows the transmission characteristics between two hands for various arm postures. Variation is less than 3 dB in the frequency range below 30 MHz, and increases as the frequency increases. In this measurement, the two electrodes were removed from the box shown in Fig. 2 and the electrode was held in each hand. The distance between the two electrodes varied from 0.2 m to 1.5 m. Since transmission loss is given by the formula $L = 10 \log_{10} (4\pi d/\lambda)^2$ (d: distance, λ: wavelength), transmission loss at frequency of 1 GHz at distances of 0.2 m and 1.5 m are 18.5 dB and 36.0 dB respectively [9]. The difference is approximately 20 dB, which is in accord with the measured

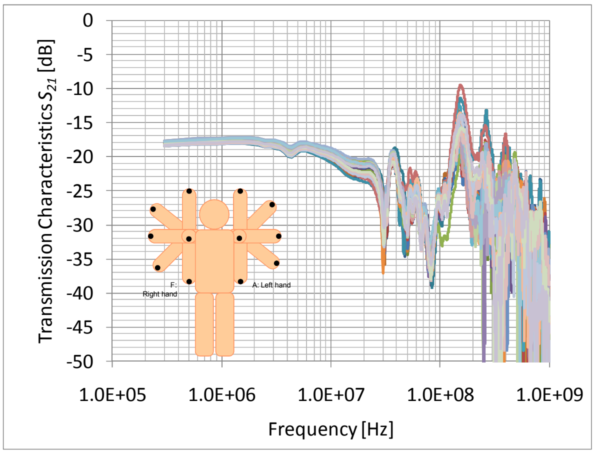


Fig. 5 Transmission characteristics between two hands for various arm postures

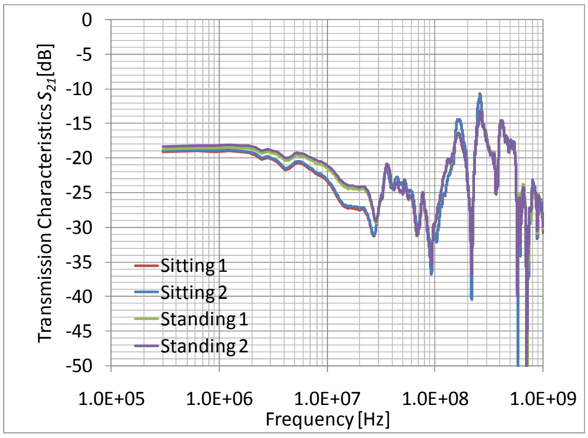


Fig. 6 Transmission characteristics for standing and sitting postures

transmission loss shown in Fig. 5. This suggests that transmission through the air is dominant in the frequency range around 1 GHz.

Fig. 6 shows the transmission characteristics for standing and sitting postures. The physical difference between these two postures is the relation with the surrounding environment which causes transmission characteristics difference in frequency range from 1 MHz to 30 MHz. At frequency greater than 30MHz, the difference becomes smaller because transmission through the air becomes more dominant.

Results shown in Fig. 2 through 6 indicate that the presence of human body contributes to transmission characteristics in frequency lower than 80 MHz. At frequency higher than 80 MHz, transmission through the air becomes dominant. This suggests that frequency range below 80 MHz should be selected for applications in order to exploit merits of intra-body transmission.

3. TRANSCEIVER SPECIFICATIONS

Design of intra-body communication for high-speed IP network will be discussed in this section.

Using higher frequency and wider frequency band are common methods to increase the speed of communication and transmission efficiency. Since transmission through human body is better than that through the air by 20 dB or more in the frequency range below 55MHz, we focused on Orthogonal Frequency-Division Multiplexing (OFDM) communication. This method uses wide frequency range from 2 to 28 MHz, and has high tolerance to variation in frequency transmission characteristic.

OFDM method is commonly known as the communication method which is tolerant to the frequency transmission characteristic variations of transmission path caused by multiple paths [10].

In intra-body transmission, frequency transmission characteristic variations of human body and the surroundings can be caused by individual difference, surrounding environment and postures of human body as shown in Fig. 4, 5 and 6. Therefore OFDM method can be useful for stable communication.

Fig. 7 shows the function block diagram of the transceiver we built for evaluation of OFDM modulation to intra-body transmission using frequency range from 2 to 28 MHz.

As shown in Fig. 7, we used a standard OFDM modulation with slight modification. Frequency range from 2 to 28 MHz was used, and the numbers of subcarriers were 917. Subcarrier modulation mapping can be changed appropriately from Binary phase shift keying (BPSK) to 1024 Quadrature amplitude modulation (QAM) depending on the condition of transmission path. We adopted turbo encoding for error-correcting, which is commonly used for Third-Generation (3G) cell phone. Cyclic prefix was used for guard intervals.

Transmission and reception processes of OFDM are as follows.

First, about transmitting process, the baseband data inputted to the OFDM transmitter, which goes through the scrambler, the turbo encoder, the inter-leaver and the subcarrier mapper, are converted from frequency domain to time domain using Inverse Fast Fourier Transformation (IFFT). And frequency up converting can be done after inserting preamble and guard interval. Finally, OFDM modulation signal can be gained after Digital to Analog converting (D/A), and the gained OFDM signal goes to the electrode. The transmitted signal from transmitting electrode goes

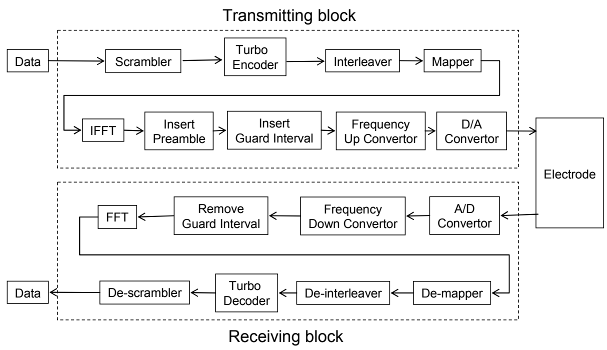
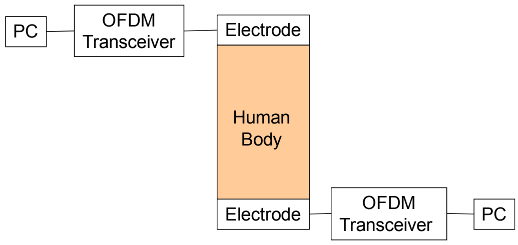
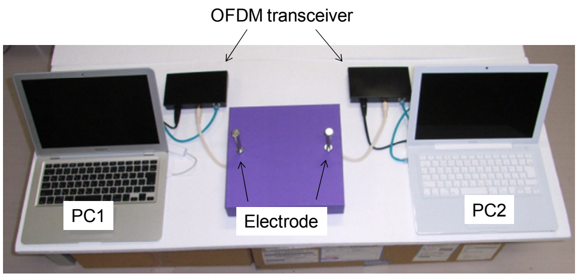


Fig. 7 Block diagram of OFDM transceiver



(a) Block diagram of OFDM communication system for intra-body transmission



(b) Appearance of OFDM communication system for intra-body transmission

Fig. 8 OFDM communication system for intra-body transmission on an experimental basis

through a human body as a transmission medium and reaches the receiving electrode.

Next, about receiving process, when transmitted OFDM modulation signal from through human body reaches the receiving electrodes, frequency down conversion is done after Analog to Digital conversion (A/D). And remaining signal processing goes through by synchronous control using preamble signals of receiving signal. After removing guard intervals and conversion from frequency domain to time domain using Fast Fourier Transformation (FFT), subcarrier de-modulation finally finishes at the de-mapper. The baseband data output is gained after going through the de-inter leaver, the turbo decoder and the de-scrambler.

Fig. 8 shows (a) the block diagram of the OFDM transceiver system and (b) the appearance of OFDM transceiver system for intra-body transmission.

The experimental system consists of two OFDM transceivers and two laptop PCs. Each transceiver is connected to an electrode by coaxial cable as shown in Fig. 8 (a). The laptop PC and the transceiver are connected by Local Area Network (LAN) cable and communicate by TCP/IP protocol. The laptop PC and the OFDM transceivers are all battery powered and have no common power source which may become a stray path between the transceivers.

Fig. 9 shows the spectrum mapping of OFDM transceiver for intra-body transmission on an experimental basis. Fig. 9 shows that the output signal consisted of wideband signal in the frequency range from 2 to 28 MHz. The output power level was -25 dBm/10 kHz in the frequency range from 2 to 15 MHz and

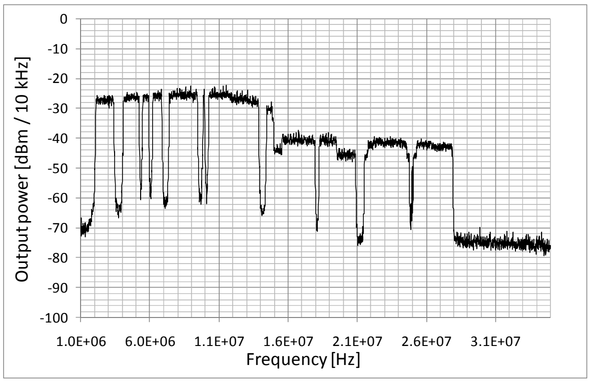


Fig. 9 OFDM spectrum mapping

was -42 dBm/10 kHz in the frequency range from 15 to 28 MHz with dips at several frequencies. Although this power spectrum was slightly different from standard OFDM signals, which was due to the specification of the modulation device we used, we assumed that the difference will not affect the evaluation of OFDM for intra-body transmission.

4. TRANSMISSION CHARACTERISTICS

We investigate the transmission characteristics through a human body as a transmission medium using OFDM transceiver system on an experimental basis as shown in Fig. 8 in chapter 3.

Fig. 10 shows the electrode placement on a human body and Fig. 11 shows how the electrodes were attached to the body. We used cloth bands to attach the electrodes.

Fig. 12 shows the transmission characteristics S_{21} in the frequency range from 1 MHz to 1 GHz for electrode placements shown in Fig. 10. The measurements were carried out by using battery-powered signal generator and spectrum analyzer.

Table 1 shows the throughput on IP protocol, TCP and UDP, for the electrode placements shown in Fig. 10. The measured throughput data on TCP and UDP protocol shown in Table 2 are the average transmission speed during 10 second period. The

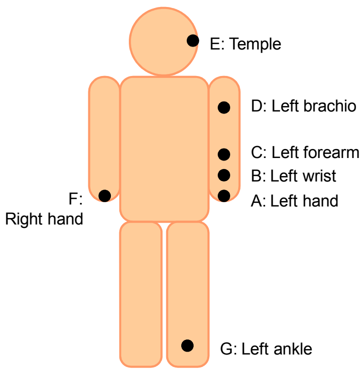


Fig. 10 Electrode placements on a human body for investigation of transmission characteristics using OFDM transceiver system

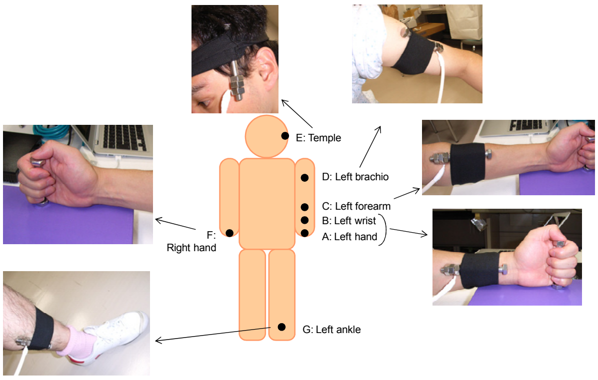


Fig. 11 How to install and put on electrode on a human body for investigation of transmission characteristics

Table 1 Throughput and average transmission characteristics between Transceivers in the frequency range from 2 to 28 MHz

Path	Throughput [Mbps]		Average transmission characteristics S_{21} [dB]
	TCP	UDP	
A–B	16.8	68.1	−9.12
A–C	16.3	65.5	−12.1
A–D	16.2	54.2	−14.7
A–E	15.0	53.2	−17.0
A–F	15.2	53.5	−20.3
A–G	14.8	53.7	−17.9
Coaxial cable	19.5	88.7	−0.21

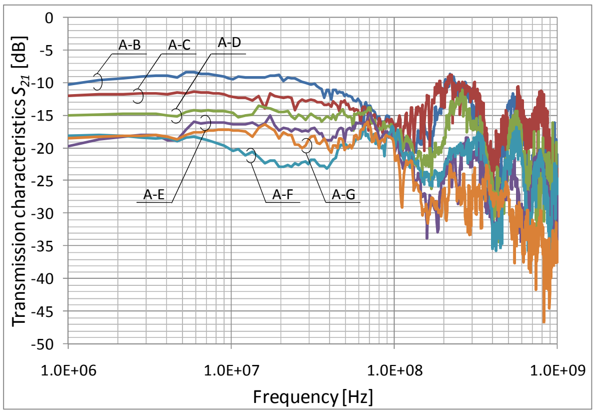


Fig. 12 Transmission characteristics S_{21} between transceivers

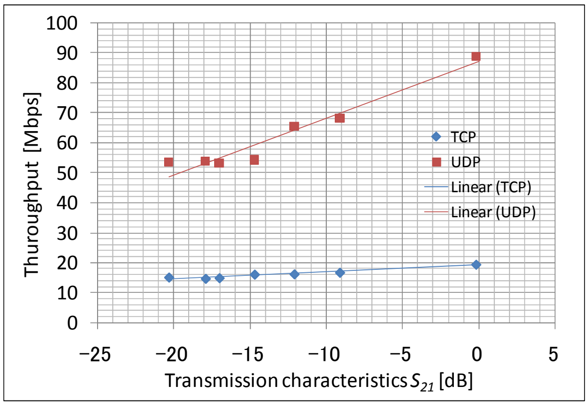


Fig. 13 Throughput as a function of average transmission characteristics S_{21}

average transmission characteristics between electrodes S_{21} in the frequency range from 2 to 28 MHz are also shown in Table 1. As shown in Table 1, when the electrodes were held in both hands (path A-F), the throughput were 15.2 Mbps on TCP protocol and 53.5 Mbps on UDP protocol. The throughput between the palm and wrist (path A-B) were 16.8 Mbps on TCP protocol and 68.1 Mbps on UDP protocol. This arrangement assumes a communication between a wristwatch-type device and an apparatus touched by the user. Throughput was 14.8 Mbps or more for all paths between a palm and other electrodes shown in Fig 10.

Although TCP adopts more complicated than UDP, such as retransmission, throughput of 14.8 Mbps was attained using OFDM for intra-body transmission. This throughput should be high enough for most application using IP communication in intra-body transmission.

Fig. 13 shows the relationship between average transmission characteristics and the attained throughput. The increase of throughput is linear, which suggests that we can estimate the throughput from the transmission characteristics S_{21}.

5. CONCLUSION

The transmission efficiency through the human body showed its peak at around frequency of 1 MHz, and was better than that through the air frequency from 300 kHz to 80 MHz. The efficiency was greater by 20 dB or more compared to transmission through the air at frequency less than 55 MHz.

Transmission characteristics of intra-body communication using Orthogonal Frequency-Division Multiplexing (OFDM) were evaluated in order to use this modulation method for constructing IP network on TCP/IP protocol.

Throughput between electrodes gripped by right and left palms were 53.5 Mbps on TCP protocol and 15.2 Mbps on UDP protocol, and throughput between an electrode gripped by one hand and an electrode put on the wrist were 16.8 Mbps on TCP protocol and 68.1 Mbps on UDP protocol. This throughput is sufficient for using TCP/IP for in intra-body transmission. The throughput had linear relationship with the average transmission characteristics S_{21} given in logarithmic scale. This suggests that the throughput can be estimated from the transmission characteristics.

6. ACKNOWLEDGMENTS

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