Master's Thesis
석사 학위논문

Wireless Body Area Channel Measurement and Modeling

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Department of Information and Communication Engineering
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Advisor : Professor Ji-Woong Choi
Co-advisor : Professor Won-Seok Kang

By

Chanho Jin
Department of Information and Communication Engineering
DGIST

A thesis submitted to the faculty of DGIST in partial fulfillment of the requirements for the degree of Master of Science in the Department of Information and Communication Engineering. The study was conducted in accordance with Code of Research Ethics[1]

Dec. 14. 2014

Approved by

Professor Ji-Woong Choi (Signature)
(Advisor)

Professor Won-Seok Kang (Signature)
(Co-Advisor)

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[1] Declaration of Ethical Conduct in Research: we, as a graduate student of DGIST, hereby declare that we have not committed any acts that may damage the credibility of my research. These include, but are not limited to: falsification, thesis written by someone else, distortion of research findings or plagiarism. We affirm that my thesis contains honest conclusions based on my own careful research under the guidance of my thesis advisor.

Wireless Body Area Channel Measurement and Modeling

Chanho Jin

Accepted in partial fulfillment of the requirements for the degree of Master of Science

Dec. 14. 2014

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Abstract

Attention about the wireless body area networks (WBAN) system which based on IEEE802.15.6 for implantable medical device or wearable equipment has been increasing. While key devices, such as wearable device, medical device, demonstrate the potential for key technology of future. There are utilized in smart-watch to provide a variety of functions by interlocking smartphones, activity tracker to record user daily workouts or exercise information, u-healthcare to record biometric information such as blood glucose, blood pressure, heart rate, etc. Channel modeling is required in order to design and test the WBAN system. For the wearable devices, the positions of the device is changed according to the human movement. The state of the channel is changed by the position or velocity of the body. For the channel model considering the static situation, it is not appropriate to model the time varying channel according to the changes of human body posture. In addition, channel modeling through a body is quite difficult unlike that in the air since. It can be affected the channel characteristic such as propagation speed, channel gain, absorption depends on the permittivity values of the propagation medium. Therefore, communication channel should be considered the implantable cases. In this paper, our goal is to implement the channel modelling through practical experiment that can reflect time changes due to movement of the body. I analyzed the channel characteristics such as multipath, Doppler effect, Shadowing through practical experiment through time variation according to the human moves. I determined the human body channel according to the changes in the changes of posture or the implants in the human body.

Keywords: WBAN; channel modeling; channel measurement

Contents

I. INTRODUCTION

Attention about the wireless body area networks (WBAN) system which is based on IEEE 802.15.6 [1] for implantable medical device or wearable equipment has been increasing. Wearable device is a fascinating area of IT innovation. There are utilized in smart-watch to provide a variety of functions by interlocking smartphones, activity tracker to record user daily workouts or exercise information, u-healthcare to record biometric information such as blood glucose, blood pressure, heart rate, etc.

In the case of medical devices, it is smaller and can be implanted in the human body. It can be used conveniently to solve the problems, such as discomfort, risk of infection in use.

WBAN is divided into three parts, the in-body, on-body in accordance with the position of the device. It can be up to few hundred kbps data that is transferred between the communication device inside the human body and the outside. WBAN is the same as the conventional wireless communication system that the information is transmitted wirelessly. However, implantable WBAN system is different to use the human body as a communication channel for the medium. The human body has a different permittivity and conductivity value with the air. Channel modeling through a body is quite difficult unlike that in the air since.

While key devices, such as Nike’s Fuel Band, demonstrate the potential for wearable devices to change how we utilize the physical information on a daily. For the Samsung Galaxy Gear, Google Glass that is attached to the human body, devices are mainly worn on the wrist or head. In this case, the positions of the device is changed according to the human movement. The state of the channel is changed by the position or velocity of the body. Therefore, channel modelling is required in order to design and test the WBAN system.

In the existing WBAN standard, performance evaluation was conducted with respect to the AWGN channel [1]. When design WBAN System it required the analysis of the human channel characteristic caused by attenuation, diffraction, reflection, scattering of electromagnetic waves and studies on the interaction between the human body and the wireless radio propagation. The WBAN system and channel model is being conducted to satisfy the demand for multimedia data transmission [2].

There have been studies on channel modelling of WBAN system [3, 4, 5, 6, 7, 8]. [3] considers the channel modeling for in-body communication system and the human exposure. The path-loss model is performed by the commercial tool based on the FDTD(Finite Difference Time Domain) Simulation tool. [4] constructed an immersive visualization environment to conduct research in order to characterize RF propagation from medical implants. Extensive simulations have been performed to obtain a statistical path loss model for MICS channels. The authors recognize the fact that the extracted parameters for the statistical model are based on the simulation data. [5] assumed the path loss and absorption of an in-to-out body radio frequency (RF) wireless link between an endoscopy capsule and a receiver outside the body are numerically investigated. The path loss is investigated for three different tissues using the 3D FDTD solver SEMCAD-X at 402 MHz. In the case of existing channel modeling study was achieved through simulation value. It takes a long time to simulate a given fixed environment. And there should be further validated by measurement data from physical experiments. [6] obtained the measurements to estimate the impulse response needed to build models that can be used in WBAN medical applications. It is considered on-to-on body channel to determine propagation link. [7] introduced numerical and experimental investigations of biotelemetry radio channels and wave attenuation in human subjects with ingested wireless implants. Numerical electromagnetic analysis is applied to model in to on-body radio propagation channels using phantom model. Path loss models of the biotelemetry radio links were derived. [8] provided a channel model for the dynamic channel around the human body. The channel are analyzed and a statistical model of the dynamic channel based on the measured data is provided.

Existing studies considered simulation results for the in-body channel modeling. They did not consider the actual parameter values except the path-loss such as multipath, Doppler effect in the implantable case. Therefore, communication channel should be considered the implantable cases through practical experiment. For the channel model considering the static situation, it is not appropriate to model the time varying channel according to the changes of human body posture. Because the channel state is changed by the position or velocity of the body. Channel model requires that changes according to the time.

In this paper, our goal is to implement the channel modelling through practical experiment that can reflect time changes due to movement of the body. For an optimized system design WBAN system, we need to understand the channel characteristics such as multipath, Doppler effect, Shadowing through practical experiment through time variation of the channel characteristics. I will determine the human body channel through experiments. I will determine the channel model of human movement with time-varying situation.

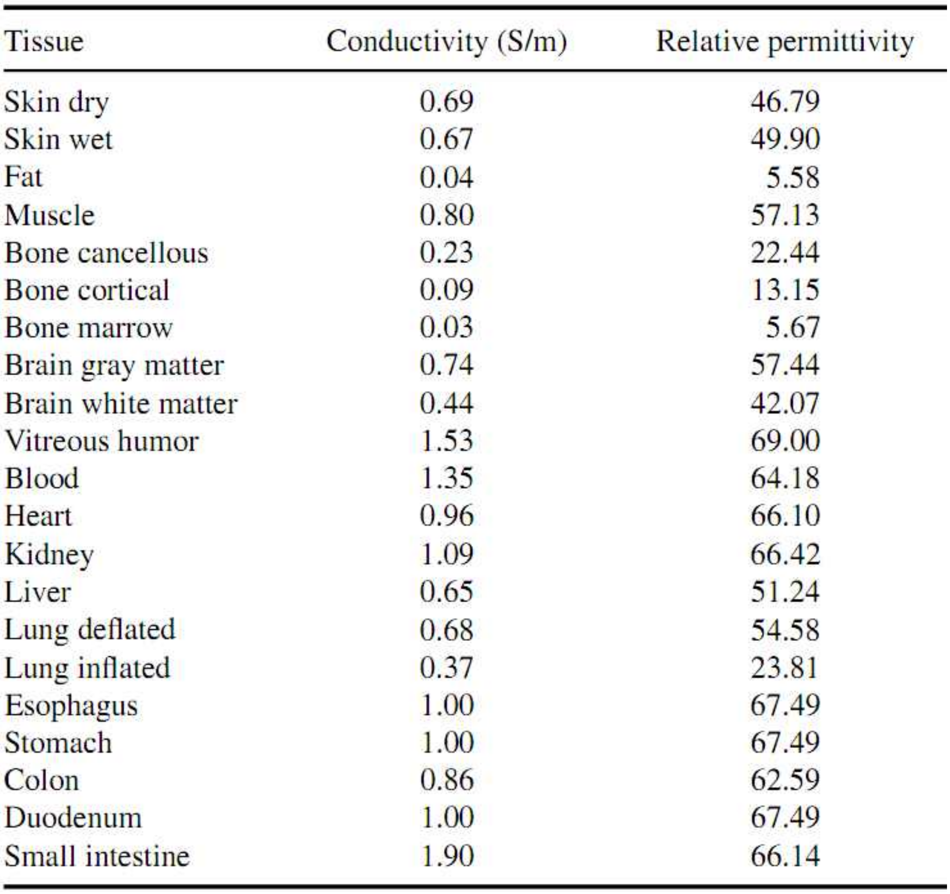
The rest of paper is described as follows. In section 2, I will explain the general propagation model. The proposed channel measurement method for body channel is presented in Section 3. Measurement setting and numerical results and channel modeling for environment is given in Section 4. Finally, I conclude the article in the Section 5.

II. PROPAGATION MODEL

2.1 Electromagnetic Characteristics of the Human Body

Channel modeling through a body is quite difficult unlike in the air since. It is different channel with human body and air due to different permittivity and conductivity value. It can be reduced the propagation speed when the permittivity getting larger. The part of electromagnetic waves reflected when the electromagnetic waves encounter an impedance discontinuity at the boundary of two medium with different characteristic impedance. We should consider the characteristic of human body with anatomically accurate at the tissue and organ levels in body area communications. Current high resolution computer models of the human body are based on medical imaging data. The level of detail is such that over 30 tissue types are used, and the resolution is of the order of several millimeters. The application of such models requires the dielectric properties to be allocated to various tissues and organs at the considered frequencies so that the electromagnetic fields can be analyzed. An analytic expression for the dielectric properties, that is, the complex permittivity as a function of frequency, is therefore highly useful in body area communications. The database on the dielectric properties of biological tissue is mainly based on Gabriel's measurement data [8].The dielectric measurements were performed in the frequency range from 1 MHz to 20 GHz for over 20 tissue types.

Tables 1 shows the conductivity values, relative permittivity values at 400MHz, respectively, for some main tissues and organs of the human body. This frequency covers main candidate bands for body area communications, and the dielectric properties play a dominant role in characterizing the body area channels. The reflectivity of the radio wave can be generated between the permittivity of the two medium. It can be occur Doppler effect, multipath fading because of the differences with two medium. This is an important factor when modelling the human body channel.



Tissue	Conductivity (S/m)	Relative permittivity
Skin dry	0.69	46.79
Skin wet	0.67	49.90
Fat	0.04	5.58
Muscle	0.80	57.13
Bone cancellous	0.23	22.44
Bone cortical	0.09	13.15
Bone marrow	0.03	5.67
Brain gray matter	0.74	57.44
Brain white matter	0.44	42.07
Vitreous humor	1.53	69.00
Blood	1.35	64.18
Heart	0.96	66.10
Kidney	1.09	66.42
Liver	0.65	51.24
Lung deflated	0.68	54.58
Lung inflated	0.37	23.81
Esophagus	1.00	67.49
Stomach	1.00	67.49
Colon	0.86	62.59
Duodenum	1.00	67.49
Small intestine	1.90	66.14

Table.1 Dielectric properties of some main tissues and organ at 400MHz.

2.2 Multipath Channel

In the case of implantable WBAN system, it is different to use the human body as a communication channel for the medium. Therefore, channel modeling is required in order to design and test the WBAN system. When we consider that receiving antenna (Rx) is inserted into the heart, and transmitting antenna (Tx) is placed on the wrist, multipath is occurred due to various reflection according to the motion, human body, difference in refractive index between air and medium of the body. Environment in which the body is located (Example: auditorium, office). The radio channel characteristics has a number of reflected waves. It consists of a number of plane wave having amplitude and phase. A fading component is also present which is mainly caused by the reflection of the signal from objects around the human body and human. The overlap occurs between the digital received symbols as interference due to multipath fading. Multipath model of the wireless communication environment was studied in terms of the field strength. Assuming that m of the reflected wave is received, the received signal $x(t)$ can be expressed by the following equation [9]:

$$x(t)=\sum_{n}a_{n}(t)s(t-\tau_{n}(t)) \tag{1}$$

Where $s(t)$ is the transmitted signal, $a_n(t)$ is the attenuation factor for the signal received on the n^{th} path and $\tau_n(t)$ is the propagation delay for the nth path. $s(t)$ can be expressed as

$$s(t)=\mathrm{Re}[s_{l}(t)e^{j2\pi f_{c}t}] \tag{2}$$

Where $s_l(t)$ is the equivalent baseband signal of transmitted signals. Substitute (2) into (1) yields the result

$$x(t)=\mathrm{Re}\left\{\left[\sum_{n}a_{n}(t)e^{-j2\pi f_{c}\tau_{n}(t)}s_{l}(t-\tau_{n}(t))\right]e^{j2\pi f_{c}t}\right\} \tag{3}$$

It is apparent from (3) that the equivalent baseband received signal is

$$r_{l}(t)=\sum_{n}a_{n}(t)e^{-j2\pi f_{c}\tau_{n}(t)}s_{l}(t-\tau_{n}(t)) \tag{4}$$

It follows that the equivalent baseband channel is described by the time-variant impulse response

$$h(\tau;t)=\sum_{n}a_{n}(t)e^{-j2\pi f_{c}\tau_{n}(t)}\delta(t-\tau_{n}(t)) \tag{5}$$

$h(\tau;t)$ represents the response of the channel at time t due to an impulse applied at time $t-\tau$. The impulse response of the channel changes by the movement of the human body and the external environment, $h(\tau;t)$ has the amplitude of the various path and delay. Received waveform distortion occurred by transmission signal $s(t)$ passes through the channel with impulse response $h(\tau;t)$. This fading is called frequency selective fading because the differently affected depending on each frequency band by considering the frequency domain. In the selective fading case, the waveform occur distortion different with a uniform fading and reduce the BER and data rate of the system.

Therefore, time variation of the channel characteristics should be considered in the body channel model.

2.3 Parameters for Multipath Model

The impulse response of the receiving point shown be delay spread in the radio channel. The multipath propagation characteristics can estimate the intersymbol interference and can determine the BER(Bits error rate) by analyzing the power delay profile. This is a parameter which is an index of the performance of digital communication. A power delay profile $p(\tau)$ is a statistical representation of the channel characteristics. This represents the received power per unit time by the multi-path. Typical parameters of the time dispersive multipath channel that may derive from the power delay profile are mean excess delay and RMS delay spread, coherence bandwidth.

2.3.1 Average excess delay

For one delay profile $h(\tau)$, power delay profile value $p(\tau)$ is as follows:

$$p(\tau) = \left|h(\tau)\right|^2 \tag{6}$$

The time dispersion characteristics, mean excess delay, of the multipath channel is the average value of the power delay profile. This is primary moment. It is defined by the following equation:

$$\bar{\tau} = \frac{\sum_k P(\tau_k)\tau_k}{\sum_k P(\tau_k)} \tag{7}$$

P is a k^{th} power of a multipath component, τ is the delay time of the k^{th} multipath component, $\sum_k P(\tau_k)$ is power received from the power delay profile.

2.3.2 RMS(Root mean square) delay spread

The RMS delay spread of the channel is evaluated for the characteristics of the channel time dispersion characteristics. This is defined as the secondary center moment of power delay profile.

$$\sigma_\tau = \sqrt{\tau^2 - \overline{\tau^2}} \tag{8}$$

Where τ^2 is the square of the mean excess delay.

$$\tau^2 = \frac{\sum_k P(\tau_k)^2 {\tau_k}^2}{\sum_k P(\tau_k)} \tag{9}$$

It means a value representing the time delay spread of the multipath channel. It indicates that the spread of the energy of the signal propagating. The RMS delay spread is an important parameter which determining the bandwidth capacity of the radio channel.

2.3.3 Coherence bandwidth

The frequency correlation function value $R_T(f)$ of the multipath channel is the Fourier transform of the normalized power delay profile. Coherence bandwidth is inversely related to the RMS delay spread σ_τ. If the coherence bandwidth is defined as a bandwidth spanning at least 0.9 of the frequency correlation function, coherence bandwidth B_{coh} is approximately as follows.

$$B_{coh} \approx \frac{1}{50\sigma_\tau} \tag{10}$$

If the coherence bandwidth is defined as a bandwidth spanning at least 0.5 of the frequency correlation function, coherence bandwidth B_{coh} is approximately as follows.

$$B_{coh} \approx \frac{1}{5\sigma_\tau} \tag{11}$$

This correlation bandwidth is shown in the figure 1.

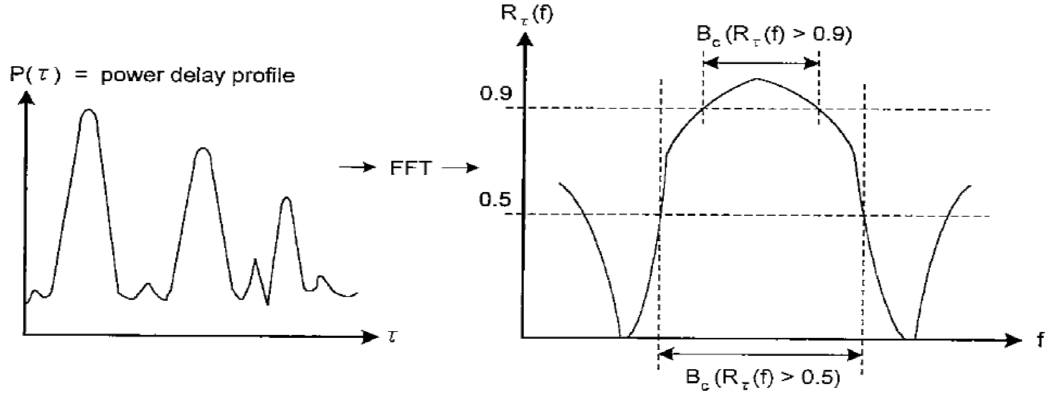


Figure 1. Interaction between coherence bandwidth and a power delay profile

The coherence bandwidth is small as the RMS diffusion increases. Therefore, the reliability of the data rate to be sent over the channel is reduced since the coherence bandwidth is small. Therefore, a signal larger than coherence bandwidth experiences intersymbol interference. This intersymbol interference increases BER. Data rate for bandwidth is limited by the Shannon capacity equation. In the case of digital transmission, data rate should satisfy as following condition to gain the low BER

$$R_b < \frac{1}{\tau_{\max}} \tag{12}$$

2.4 Doppler Channel

This experiment is to see the characteristic variation of the transmitter and receiver time variation according to the body movement. It is known that an apparent change of frequency will occur if there is a relative motion between the transmitter and the receiver such as wearable devices that can be worn on the wrist. Let $\{V\}$ is the propagation velocity of the wave vector $\{V\}$ of the medium (I.e., in the propagation speed of the wave in the medium, $c \approx 3\times10^{8} m/s$), f_0 is the frequency of the wave when signal when stopped, T_0 is the period of the signal, λ_0 is the wavelength.

If the transmitter is moving toward the observer at a rate of V_S, the interval λ between wave front is smaller than the wavelength of λ_0 when the transceiver is stopped. Since signal occurs one wave front during this period T_0, signal is also moved to propagation direction of the waves as much as $V_S \cdot T_0$. The interval between the new wave front and wave front occurred at an earlier time of T_0 is $\lambda_0 - (V_S \cdot T_0)$. The observed wavelength λ is as follows:

$$\lambda = \lambda_0 - v_s T_0 = \lambda_0 - \frac{v_s}{f_0} = \frac{V - v_s}{f_0} \tag{13}$$

Here, it can apply the relationship of the equation by using the wave propagation speed V in the medium, the wave frequency f_0 by the transmitter, the wavelength λ_0 of the radio waves that occur when the transmitter is to be stopped.

$$V = \lambda_0 f_0 \Rightarrow \lambda_0 = \frac{V}{f_0} \tag{14}$$

The observed frequency f, wavelength λ, propagation speed V at stopped receiver is as follows:

$$V = \lambda f \Rightarrow \lambda = \frac{V}{f} \tag{15}$$

The equation applying the above formula to the observed frequency f is as follows:

$$\frac{V}{f} = \frac{V - v_s}{f_0} \tag{16}$$

$$\therefore f = f_0 \frac{V}{V - v_s} \tag{17}$$

If the transmitter is far from the observer at a rate of V_S, the interval λ between wave front is larger than the wavelength of λ_0 when the transceiver is stopped. Because signal occurs one wave front during this period T_0, signal is moved to the opposite propagation direction of the waves as much as $V_S \cdot T_0$. The interval between the new wave front and wave front occurred at an earlier time of T_0 is $\lambda_0 + (V_S \cdot T_0)$.

The relationship between λ_0, f_0, V and λ, f, V are as follows.

$$V = \lambda_0 f_0 \Rightarrow \lambda_0 = \frac{V}{f_0}$$

$$V = \lambda f \Rightarrow \lambda = \frac{V}{f} \tag{18}$$

Applying the above equation, observed frequency f and wavelength λ are as follows:

$$\lambda = \lambda_0 + v_s T_0 = \lambda_0 + \frac{v_s}{f_0} = \frac{V + v_s}{f_0}$$

$$\Rightarrow \frac{V}{f} = \frac{V + v_s}{f_0} \tag{19}$$

$$\therefore f = f_0 \frac{V}{V + v_s} \tag{20}$$

The Doppler effect occur since of the propagation distance changes as occurrence point and any one point as the movement.

2.5 Parameters for Doppler Model

2.5.1 Doppler spectrum

The movement of body parts create time-varying channel conditions. Characterization of the Doppler spectrum is important for the determination of the time variance of the human channel. It is known that an apparent change of frequency will occur if there is a relative motion between the transmitter and the receiver. On one hand, whenever the source waves move towards the receiver, the receiver will detect a higher frequency sound, which is an upward shift in frequency because the receiver receives more waveforms per second and considered this observation as a higher frequency. If the receiver will perceive a lower frequency sound when either the transmitter or receiver moves away from each other, the receiver will detect a less number of waveforms. It will result in a downward shift in frequency. Time-varying channel impulse response is generally expressed by

$h(\tau,t)$. The frequency response of the channel in the frequency domain by Fourier transform $h(\tau,t)$ is $H(f,t)$.

$$h(\tau,t)=\sum_n a_n(t)e^{-j2\pi f_c\tau_n(t)}\delta(\tau-\tau_n(t))=a(\tau,t)e^{-j2\pi f_c\tau} \tag{21}$$

$$H(\tau,t)=\int_{-\infty}^{\infty} h(\tau,t)e^{-j2\pi f_c\tau}dt \tag{22}$$

In order to find the spectrum we first derive the autocorrelation $R_H(\Delta t)$, which is the inverse Fourier transform of the spectrum. The equation can be expressed as [10]:

$$\begin{aligned}&R_H(\Delta t)=E[H^*(f;t)H(f;t+\Delta t)]=R_H(\Delta f=0;\Delta t)\\&S(\lambda)=\int_{-\infty}^{\infty} R_H(\Delta t)e^{-2\pi\lambda\Delta t}d\Delta t=S_H(\Delta f=0;\lambda)\\&=\int_{-\infty}^{\infty} S_h(\tau,\lambda)d\tau\end{aligned} \tag{23}$$

The function $S(\lambda)$ is a power spectrum that gives the signal intensity as a function of the Doppler frequency λ .Characterization of the Doppler channels are available from the frequency domain and it can obtain by the Doppler power spectrum.

2.5.2 Doppler spread

The Doppler shift f_D is that how far from the signal is away from the center frequency. It is the first moment of the Doppler power spectrum.

$$f_D=E\left[S(\lambda)\right] \tag{24}$$

Doppler spread (Doppler spread) is indicating that how spread of the Doppler power spectrum. This is obtained by the square root of the second central moment of the Doppler power spectrum.

$$\sigma_D=rms\left[S(\lambda)\right] \tag{25}$$

2.5.3 Coherence time

Looking at the relationship between the typical coherence time T_{coh} and Doppler spread are as follows:

$$T_{coh}\approx\frac{1}{\sigma_D} \tag{26}$$

Coherence time represents the time distribution characteristics of the fading channel in the time domain. It also means that the Doppler spread in the frequency domain. Coherence time is also the period of time that can be thought that the channel is invariant. It occurs the distortion of the signal if the bandwidth of the signal is larger than the inverse of the coherence time in the baseband transmission. If signal has the symbol interval T, the required bandwidth of the signal is about $1/T$. Correlation process of this signal should be constant during the complex gain is at least one signal period. This condition is satisfied below formula.

$$T \ll \frac{1}{\sigma_D} \tag{27}$$

This channel is referred to as slow fading channel. To be non-selective fading, Symbol interval T is much greater than the multipath spread T_m and satisfies the following equation.

$$T_m \ll T \ll \frac{1}{\sigma_D} \tag{28}$$

2.6 Shadowing Channel

Transmitted signals are lost or delayed due to the absorption, reflection, and diffraction by the presence of obstacles. This is called shadowing causes by overlapping signals of the different size and phase. The movements of the body parts cause time-varying shadowing effects on the received signal. This is mainly due to the obstruction of the LOS path by the body parts.

Fig. 2 shows a wireless communication device attached on the wrist. If Tx is worn on the heart or the opposite wrist, the dispersion of the average value of the time-varying path loss has the potential to occur largely. For example, the overall vibration exercise such as arm is shown in Fig. 2. If Rx located at B, the signal attenuation will appear stronger than C and A because of the human body acts as an obstacle by the direction of radio wave.

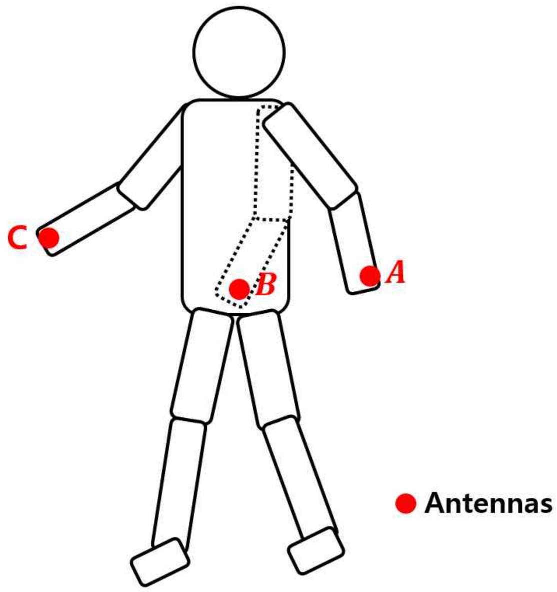


Figure. 2. Overall vibration exercise of arm shaking

Shadowing should be considered both characteristic in a stationary position and time-varying characteristic according to movement of the human body. The path-loss equation according to distance between the transceiver antennas based on Friss equation represents the propagation characteristics of the free-space.

$$PL(d) = PL(d_0) + 10n\log_{10}\left(\frac{d}{d_0}\right) \text{ [dB]} \tag{29}$$

Where d_0 denotes a reference distance, d is the distance between the two antennas. n is the path loss exponent. The equation can be expressed by considering the characteristics of the shadowing as follows [4].

$$PL(d) = PL(d_0) + 10n\log_{10}\left(\frac{d}{d_0}\right) + X_\sigma \text{ [dB]} \tag{30}$$

Where X_σ is a parameter value related to the Shadowing.

2.7 Measurement Method

I mentioned about typical channel characteristics such as path loss, multipath, Doppler effect, Shadowing in the above article. In order to determine the channel characteristics through practical experiment, I will describe the actual experimental method to determine the channel parameter value.

2.7.1 Measurement method for multipath channel

This experiment studies multipath characteristic of the transmission and reception device according to the movement of the human body, characteristics of changes in human position, and characteristics of human medium. The radio channel characteristics consists of a number of plane wave having amplitude and phase. A multipath component is also present which is mainly caused by the reflection of the signal from human body posture. In addition, the part of electromagnetic waves reflect when the electromagnetic waves encounter an impedance discontinuity at the boundary of human mediums.

Measuring the multipath uses PN sequence method and Impulse method to measure the time delay and multipath according to the movement of the body and to identify the characteristics of the communication channel while the communication device is placed in the human body.

2.7.1.2 Impulse method

Impulse method use approximation of impulse signal at the transmission side. This method can be measured magnitude and phase. Received signal is in itself the impulse response of the channel. It can be implemented simply. Therefore, this method has a short measurement time. However, it has a disadvantage of requiring high-speed sampling. If the distance between the transmitter and receiver moved away, the intensity of the signal is getting weaker and susceptible to noise. It is also difficult to generate the impulse signal. This method use close signal to the impulse instead of the impulse signal. The specific experimental settings and processing software approach is shows in Fig. 3 and Fig. 4.

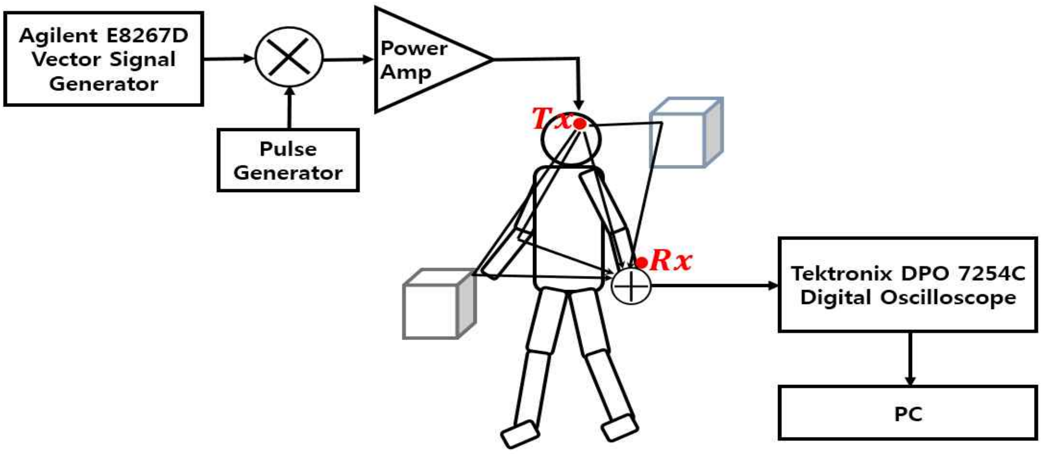


Figure 3. Measurement setting using impulse method

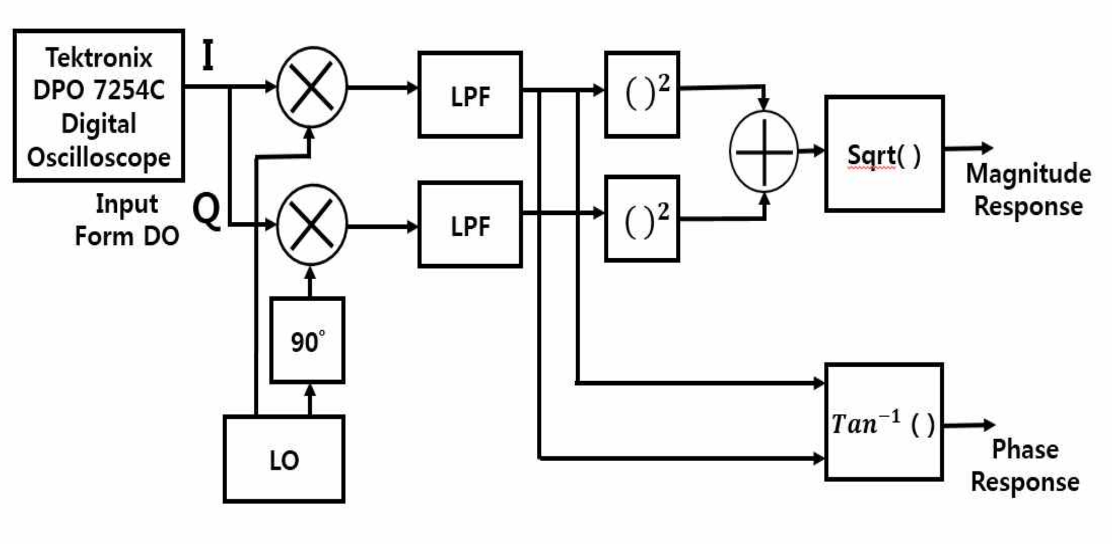


Figure 4. Post processing system architecture using impulse method

2.7.1.1 PN sequence method

To measure channel characteristics while the communication device is inserted in the body or placed on the wrist, it is required the impulse response. However, it is difficult to generate the impulse signal. So, I introduce the method for measuring the multipath has a using PN sequence method [11]. The PN sequence method is obtain the impulse response through correlation with sequences as an alternative to the problem of impulse method. It is better autocorrelation characteristics to increase the length of the PN sequence. However, if channel is changing very fast, it is difficult to use because of the processing time. It is important to use as appropriate by using the impulse method and PN sequence method.

The system for the experiment by using PN sequence is shown in Fig. 5.

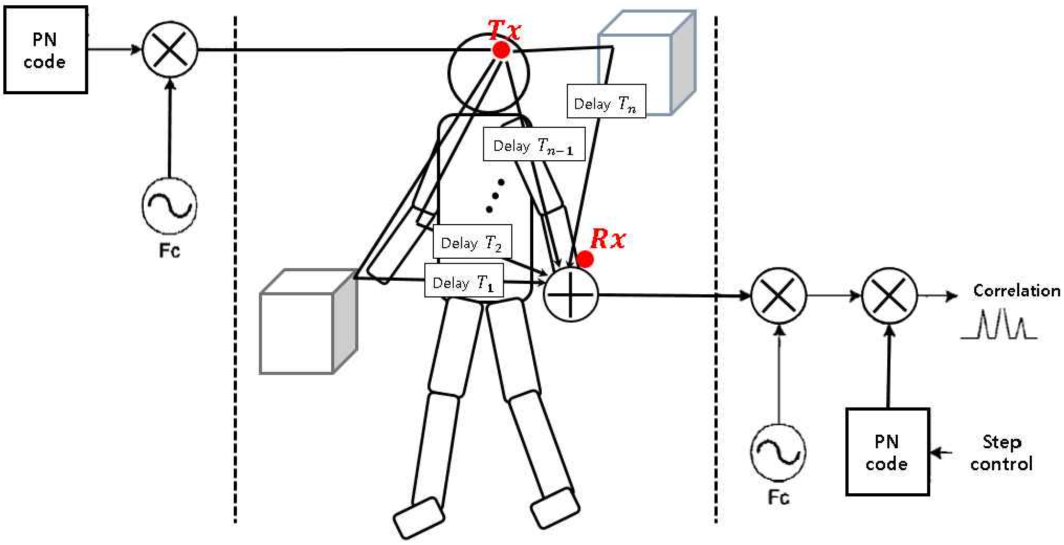


Figure 5. System architecture using PN sequence method

The autocorrelation function of the PN sequence has characteristic which periodic and a maximum value. Given a binary sequence P_n, the auto-correlation function is defined as:

$$R_c(R) = \frac{1}{N}\sum_{n=1}^{N} P_n P_{n-k} \tag{31}$$

Where n is the period of the PN sequence. k is an arbitrary natural number. To summarize, this is as follows:

$$R_c(k) = \begin{cases} 1, & k = lN \\ -\frac{1}{N} & k \neq lN \end{cases} \tag{32}$$

$R_c(k)$ is a periodic function. When N is an infinite length, $R_c(k)$ is a random binary signal. Auto-correlation function which convert to a continuous variable with respect to discrete k is as follows:

$$R_c(\tau) = -\frac{1}{T}\int_0^T P(t)P(t-\tau)dt, \qquad -\infty < \tau < \infty \tag{33}$$

This is shown as follows Fig. 6.

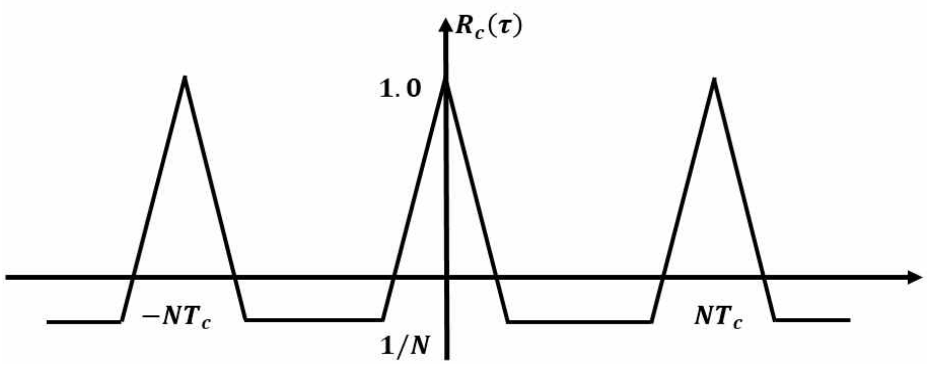


Figure 6. Auto-correlation of PN sequence

Channel can be estimated by using this characteristic. In order to measure the channel model of the human body, experimental method is detailed in Fig. 7.

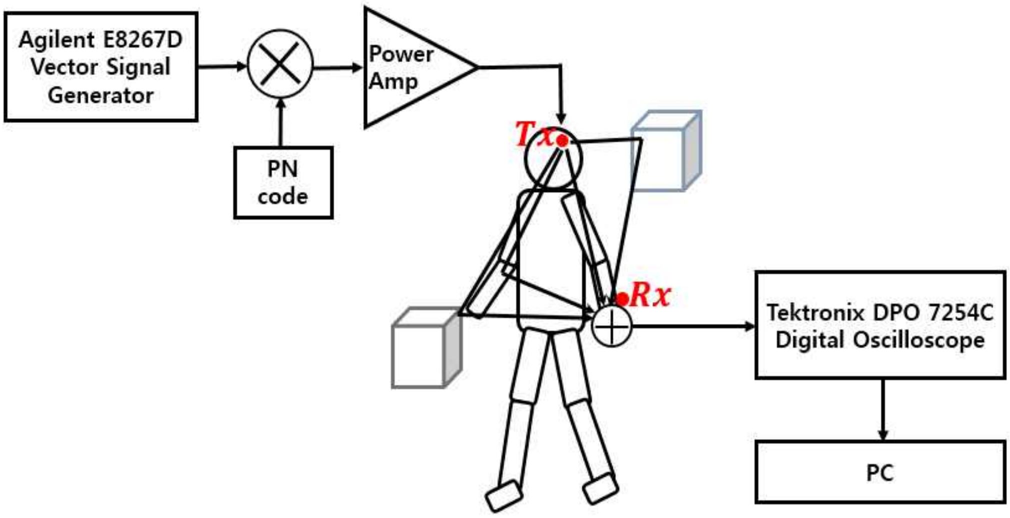


Figure 7. Measurement setting using PN sequence method

PN sequence is generated from Agilent's E8267D vector signal generator. After then, PN sequence is modulated by the carrier frequency. It is amplified via a power amplifier (Power Amp.) and radiated through the antenna. A power amplifier used in this method because of the attenuation of the signal power. When the experiment represented by the formula, an input $x(t)$, the output $y(t)$ is represented by the convolution integral as:

$$\begin{aligned} y(t) &= x(t) * h(t) \\ &= \int_{-\infty}^{+\infty} x(t-\lambda)h(\lambda)d\lambda \end{aligned} \tag{34}$$

To obtain the impulse response of the system, we define two correlation functions: the autocorrelation function of a signal $x(t)$ and the cross correlation function of a signal $x(t)$ with $y(t)$:

Autocorrelation function is follow as:

$$\begin{aligned} \varphi_{xx}(\tau) &= x(t) \otimes x(t) \\ &= \int_{-\infty}^{+\infty} x(t)x(t+\tau)dt \end{aligned} \tag{35}$$

Crosscorrelation function is follow as:

$$\begin{aligned} \varphi_{xy}(\tau) &= x(t) \otimes y(t) \\ &= \int_{-\infty}^{+\infty} x(t)y(t+\tau)dt \end{aligned} \tag{36}$$

Where τ is the time delay between the signal $x(t)$ and a delayed version of either $x(t)$ or $y(t)$ respectively. At zero time delay shift, the autocorrelation function has its maximum value, which is equal to the energy E in the signal as given by:

$$\varphi_{xx}(0) = \int_{-\infty}^{+\infty} |x(t)|^2 \, dt = E \tag{37}$$

Taking the cross correlation between the input $x(t)$ and the received signal $y(t)$ gives:

$$\begin{aligned} \varphi_{xy}(\tau) &= x(t) \otimes y(t) \\ &= \int_{-\infty}^{+\infty} x(t)y(t+\tau)dt \\ &= \int_{-\infty}^{+\infty} x(t)\int_{-\infty}^{+\infty} x(t+\tau-\lambda)h(\lambda)d\lambda dt \\ &= \int_{-\infty}^{+\infty} h(\lambda)\int_{-\infty}^{+\infty} x(t)x(t+\tau-\lambda)dtd\lambda \\ &= \int_{-\infty}^{+\infty} \varphi_{xx}(t-\lambda)h(\lambda)d\lambda \\ &= h(\tau) * \varphi_{xx}(\tau) = h(\tau) * k\delta(\tau) \end{aligned} \tag{38}$$

The inner integral in Equation (38) is the autocorrelation function $\varphi_{xx}(t-\lambda)$ of the signal $x(t)$ as a function of the time delay or time shift variable $(t-\lambda)$. Any waveform with an impulse autocorrelation function can be used to find the impulse response of the system by taking the cross correlation of the output of the system with a replica of the waveform at its input. Signal is passed through the channel signals. Signal is stored in the PC collected by Tektronix, Inc. DPO 7254C digital oscilloscope. The software processor pictures are shown in Fig. 8.

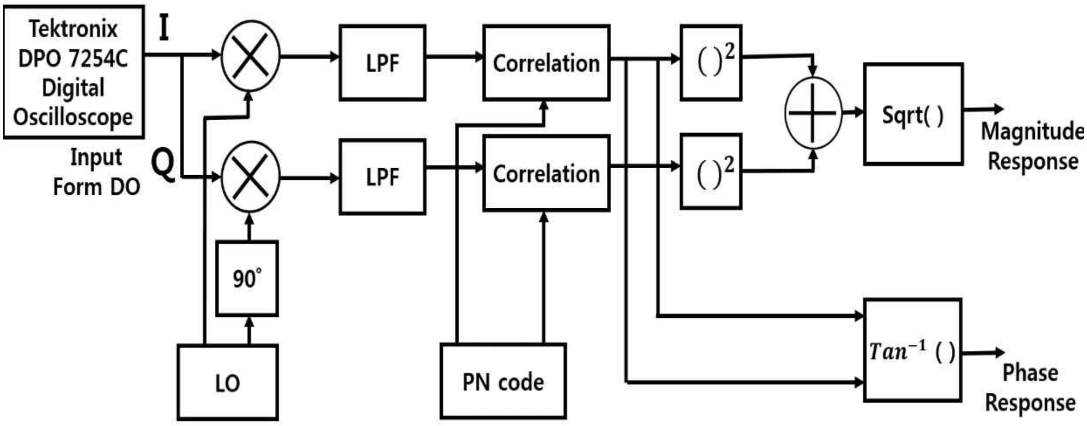


Figure 8. Post processing system architecture using PN sequence method

2.7.2 Measurement Method for Doppler Channel

Doppler shift is caused by the combined noise and interference such as different signal level, frequency shift, the time delay. We should identify the characteristics of the communication channel, Doppler shift characteristics and Doppler frequency by the movement of the human body through experiment. Characterization of the Doppler channels are available from the frequency domain and it can obtain by the Doppler power spectrum. This measurement setting to measure the Doppler shift and the Doppler frequency characteristics of human body channel and changing position of the transceiver is shown in Fig. 9.

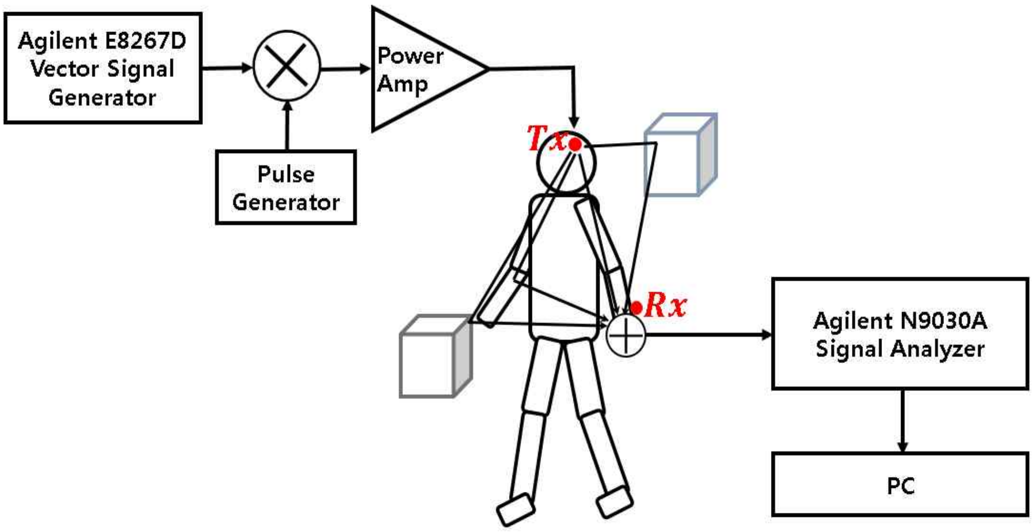


Figure 9. Measurement method for Doppler effect

The measurement equipment used in the experiment is Agilent's N9030A signal analyzer (SA) and signal generator. A signal analyzer measures the magnitude of an input signal versus frequency within the full frequency range of the instrument. The primary use is to measure the power of the spectrum of signals. We can easily determine the frequency characteristics by using signal analyzer.

Constant signal is modulated by a carrier frequency. And it is amplified via a power amplifier (Power Amp.) and radiated through the antenna. Transmission power is generated by the frequency of 403 Mhz with 0 dBm transmitted power. Signal has passed through the channel signals. And we can check the spectrum characteristic by using the signal analyzer. The results is stored in the PC collected by signal analyzer.

2.7.3 Measurement Method for Shadowing Channel

The fading component is basically caused by shadows or movement state of the human body. If there are not movement of the human body, fading is very slow. This state is different according to the angular position of the body. Areas such as the wrist is a possibility that variation of the attenuation is large because of a large portion of shadowing by the body. The experiment should be conducted in an ideal situation to find out the attenuation of time variation by the position change of the arm. Experimental setting is shown in Fig. 10.

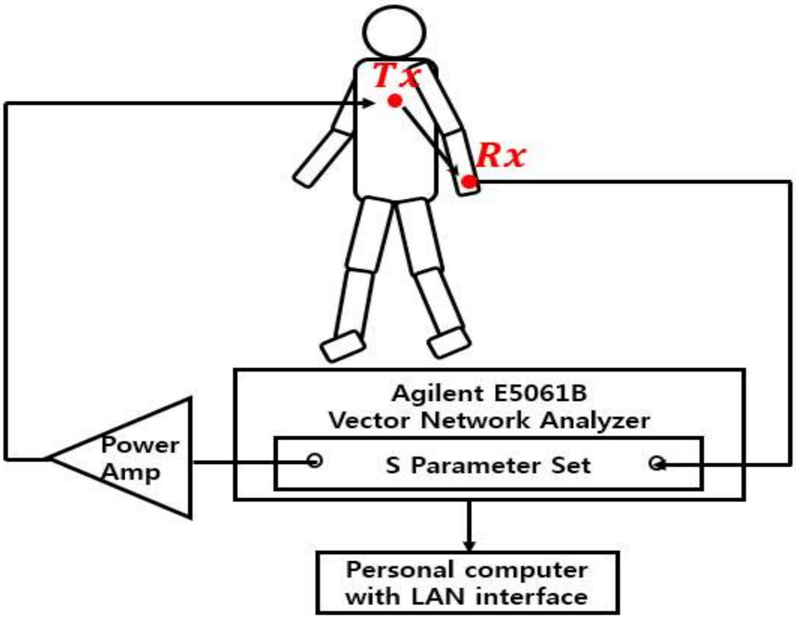


Figure 10. Measurement method for Shadowing

The measurement equipment used in the experiment is Agilent's E5061B Vector network analyzer (VNA). Network analyzer is used as an instrument that measures the network parameters of electrical signals. It commonly measure s–parameters because reflection and transmission of electrical signal are easy to measure. Transmission power is generated by the frequency of 403 Mhz and 0 dBm transmitted power. port1 from the VNA is radiated to port2. Signal has passed through the channel signals. And S-parameter is stored in the PC collected by network analyzer.

III.MEASUREMENT SETUP AND SCENARIO

In this section, Measurement setting and the scenario are given. In the existing WBAN standard, performance evaluation was conducted with respect to the AWGN channel. Existing channel modeling study was achieved through simulation value in the implantable case. It is, however, not appropriate to model the time varying channel according to the changes of posture or the implants in human body. In order to obtain a reliable channel, it is necessary to measure the value of a variable such as the Multipath, Doppler frequency, Shadowing by practical experiment. Also, we should be considered the dynamic situation according to the movement of the body. I set the experimental setup and scenario by considering the static conditions and dynamic conditions.

3.1 Design Implantable Antenna

The conductivity and permittivity values are changing when propagation pass through the human to air. The dielectrics have permittivity values which a characteristic value that represents the electrical characteristics of the medium. When you measure to channel characteristics using antenna, it affects the resonance frequency of the antenna and the propagation depends on the permittivity values of the propagation medium. Therefore, the implementation of the antenna is required considering the dielectric properties of the human body. In order to design the antenna properly, it was simulated using HFSS Simulation Tool [12]. HFSS is a commercial finite element method solver for electromagnetic structures from ANSYS. The acronym originally stood for high frequency structural simulator. It is one of several commercial tools used for antenna design, and the design of complex RF electronic circuit elements including filters, transmission lines, and packaging.

Designed antenna is shown in Fig. 11. The operating frequency is 403.5 MHz for Medical Implanted Communication Service (MICS).

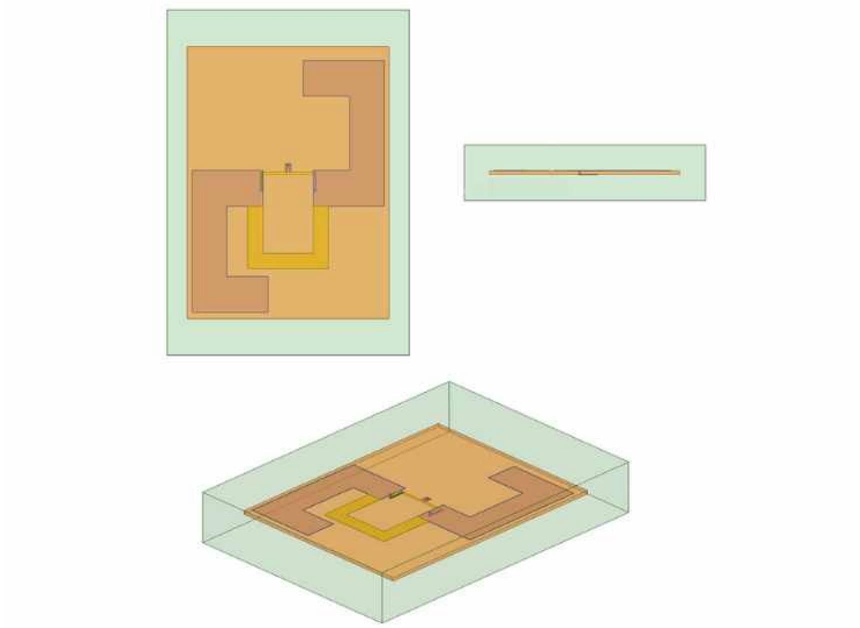


Figure 11. Design for implantable antenna for MICS band.

It is a dipole type antenna. In order to reduce the size of the antenna, it is used as a substrate having a high dielectric constant value. The substrate used Rogers 3210 by Rogers Corporation. Permittivity value is 10.2. Antenna materials are used copper. The housing material is silicon. This is prevention for short phenomenon due to the water or phantom liquid. The antenna substrate size is satisfied with 4cm X 5cm X 1cm (width, length, height). The housing material size is satisfied with 5cm X 6cm X 1.5cm (width, length, height). The fabricated antenna is shown in Fig. 12.

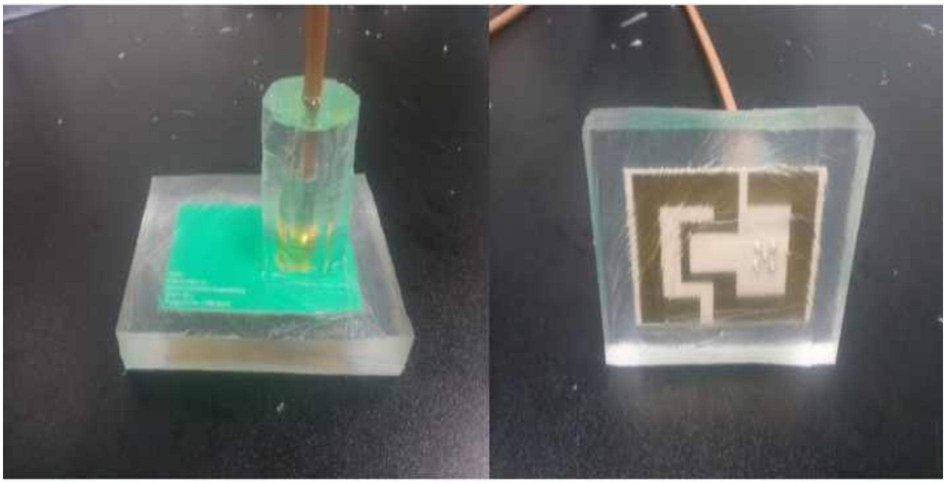


Figure 12. Implantable antenna for MICS band.

In order to measure the channel model of the human body, simulation results and experimental results must be the same for additional experiments on the human body. So, we need the verification of experimental environment for channel measurement. I build a real environment similar to HFSS environment, and directly measure the path-loss of the channel. After that, I compare with the HFSS result value and the actual measured value. Through this process, I make that the actual measurement environment and HFSS measurement environment be the same.

After ensuring the reliability of the actual measurement, I will build a time-varying channel model which similar environment with water. Fig. 13 shown the measurement setting for verification. In the environment that full of water in the box, I measured S-parameter through measurement and simulation using HFSS.

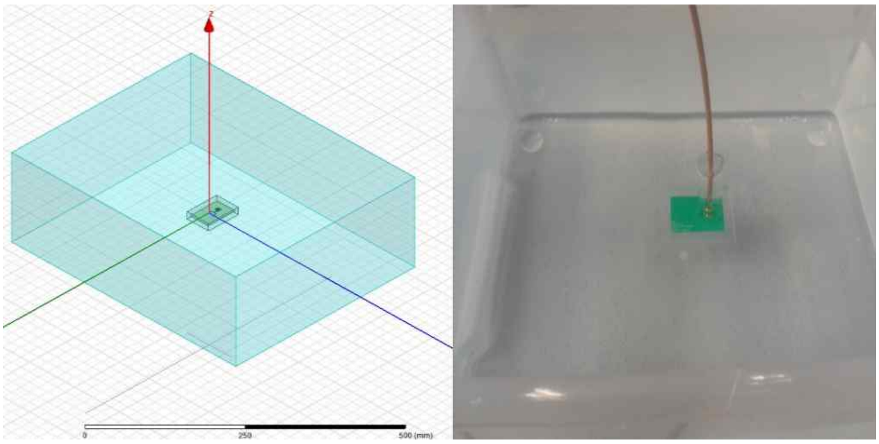


Figure 13. Measurement setting for verification.

The glass box size is satisfied with 30cm X 41cm X 40cm (width, length, height). The implantable antenna used during the measurement. I can be seen the simulation results and experimental results are well matched in Fig. 14. Hence, I can ensure the reliability of the actual measurement.

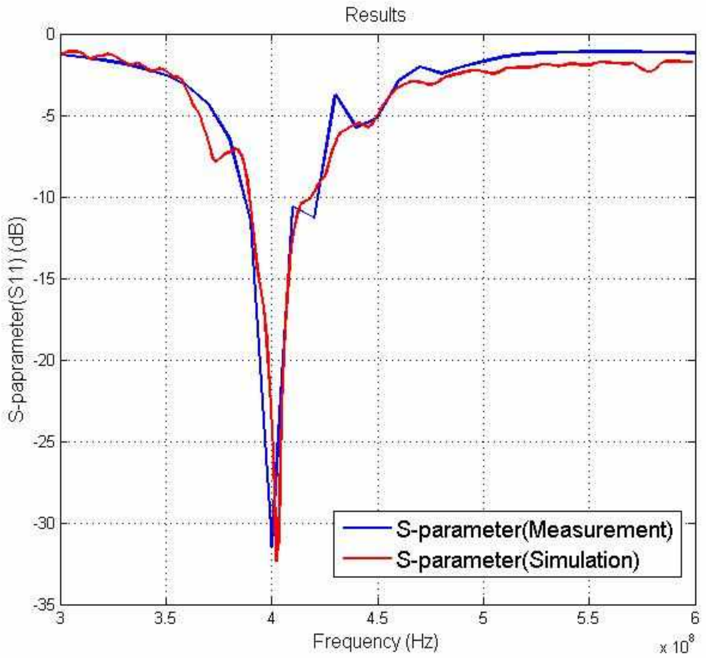


Figure 14. Measurement result for verification of antenna.

3.2 Measurement Setup and Scenario for Multipath Channel

I need the actual experiment scenario for channel characteristics for human implantable devices and time variation of channel characterization according to the movement of the body. In order to derive the scenario, it should know that the parameters that changes depending on human body. The variables influence the multipath according to the human body can be summarized as follows.

a. The location change of the transceiver according to the body movement.
b. Propagation speed changes according to the medium of the body.

The scenario for the location of the transmitting and receiving antennas and the measured parameter values were derived. Scenario is composed of a scenario for the measured parameter values for the multipath. The scenario was created with the consideration of variables such as body movements, antenna location. The purpose of the experiment is the impulse response measurement about body position changes according to the movement of the human body.

For accurate measurement of the human body channel characteristics, I should be measured using a human model and phantom liquid similar to the actual human body. However, it did not manufacture phantom liquid and human phantom model in this research. Before I proceed the measurement for human body channel characteristics, I used the water in test as a similar environment since the configuration of the human body is 70% water. It means that the water is more dominant than the other organs. And permittivity of water is the highest value among the body constituent. Water that a high dielectric constant value has the highest reflectivity from the body structure body. Propagation speed of electromagnetic waves within a particular medium can be expressed by the following equation:

$$V_p = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{c_0}{\sqrt{\mu_r \varepsilon_r}} \tag{39}$$

Where c_0 represents speed of light in the air. μ_r is the relative permeability in a particular medium. ε_r is the relative permittivity. It can be seen that the propagation speed is reduced when the permittivity getting larger. The part of electromagnetic waves reflected when the electromagnetic waves encounter an impedance discontinuity at the boundary of two medium with different characteristic impedance. Reflectance is defined as the ratio of reflected electric field and Incident electric field of the electromagnetic wave. It can be expressed by the following equation:

$$R = (\Gamma)^2 = \left(\frac{\eta_2 - \eta_1}{\eta_2 + \eta_1} \right)^2 \tag{40}$$

Where Γ represents reflection coefficient. η_1 is the refractive index of the transmission area. η_2 is the refractive index of the incident area. The changes in the speed of light and reflection between air and the human body medium. Propagation velocity and reflectivity according to body characteristic are shown in the table 2.

Medium`	**Speed of light(m/s)**	**Refractive index**	**Reflectance with air(%)**
Air	3	1	0
Water	0.333	9.124	64.3
Skin	0.438	6.849	55.5
Fat	1.270	2.362	16.4
Muscle	0.396	7.575	58.7
Bone cortical	0.827	3.627	32.2
Bone marrow	1.259	2.382	16.6
Brain gray matter	0.395	7.594	58.8
Brain white matter	0.462	6.493	52.3
Vitreous humor	0.361	8.310	61.6
Blood	0.374	8.021	60.5
Heart	0.368	8.152	61.0
Liver	0.419	7.159	56.9
Lung inflated	0.614	4.885	43.5
Esophagus	0.365	8.219	61.3
Duodenum	0.365	8.219	61.3

Table.2. Speed of light and reflectance characteristic according to human medium.

As shown in table 2, the speed and the reflectance of the light becomes different. The reflectivity of the radio wave can be also generated between the permittivity of the two medium. If the difference of refractive index is small between the two medium, it means that the reflectance is small. In contrast, if the difference of refractive index is large between the two medium, it means that the reflectance is large. Reflectance affects as the loss in the actual channel modeling. The loss affects path-loss exponent value.

To get the channel characteristic which multipath of the signal by the human body, I measured the channel by a similar scenario. I are created the experimental setup and scenario by considering the static conditions. The scenario for measuring the channel is shown in table 3.

Situations are selected the on-body to in-body, on-body to on-body cases which typical communication channels in the body area. The case of the on-body to on-body case, scenario prepared that transmitting antenna (Tx) is placed on the wrist, and receiving antenna (Rx) is also placed on the wrist. The case of the on-body to in-body case, scenario prepared that transmitting antenna (Tx) is placed on the wrist, and receiving antenna (Rx) is inserted into the water box. Tests for heart position is replaced by a water box. The water box size is satisfied with 30cm X 41cm X 40cm (width, length, height). I can check the presence or absence of human internal reflection due to the reflection of radio wave from the body inside to the outside.

Scenario	**Mode**	**Equipment**	**Tx**	**Rx**	**Area**	**Parameter**
1	On-body to in-body	Signal generator, oscilloscope	Wrist	Heart	Chamber Room	Impulse response
2	On-body to on-body		Wrist	Wrist		

Table. 3. Measurement scenario for multipath channel

3.3 Measurement Setup and Scenario for Dopper Channel

In order to measure the Doppler channel, I should be considered the dynamic situation according to the movement of the body. I set the experimental setup and scenario by considering dynamic conditions. Variable for measuring the Doppler effect according to the human movement can be summarized as follows.

a. The location change of the transceiver according to the body movement

The Doppler effect occur because of the propagation distance changes as occurrence point and any one point as the movement. Doppler shift is caused by the combined noise and interference such as different signal level, frequency shift, the time delay.

In this scenario, the purpose is to find the Doppler characteristic while changing in the position of transceiver. The scenario for measuring the channel is shown in table 4. Situations are selected the on-body to in-body, on-body to on-body cases. Scenario is configured the parameter which relative speed of the Rx and Tx According to the wrist movements with Tx is attached to the wrist, Rx is attached to the heart, head, wrist. It will appears the Doppler characteristics according to the variation of speed of the two devices according to the human movement.

Scenario	Mode1	Mode2	Equipment	Tx	Rx	Area	Parameter
1	Stop	On-body to on-body	Signal generator, spectrum analyzer	Wrist	Wrist	Chamber Room	Doppler frequency
	Run						
2	Stop			Wrist	Head		
	Run						
3	Stop	On-body to in-body		Wrist	Heart		
	Run						

Table. 4. Measurement scenario for Doppler channel

3.4 Measurement Setup and Scenario for Shadowing Channel

The power received at the receiving point can be different from the average value due to the change of body motion. Shadowing represents the dispersion around the mean value of the Path-loss. The purpose of this scenario is the measurements for the time variation of attenuation by shadowing according to the wrist motion when the Tx is located at wrist and the Rx is located at head or the opposite wrist.

a. The location change of the transceiver according to the body movement

The scenario for measuring the Shadowing channel is shown in table 5.The scenario is composed of the shadowing parameter value. Scenario are considered the parameters such as the position of the wrist (-45 to 45) and antenna position.

Scenario	**Mode**	**Equipment**	**Tx**	**Rx**	**Area**	**Parameter**
1	On-body to on-body	Vector Network analyzer	Head	Wrist(Left)	Chamber Room	S-parameter (S21)
2			Head	Wrist(Right)		

Table. 5. Measurement scenario for Shadowing channel

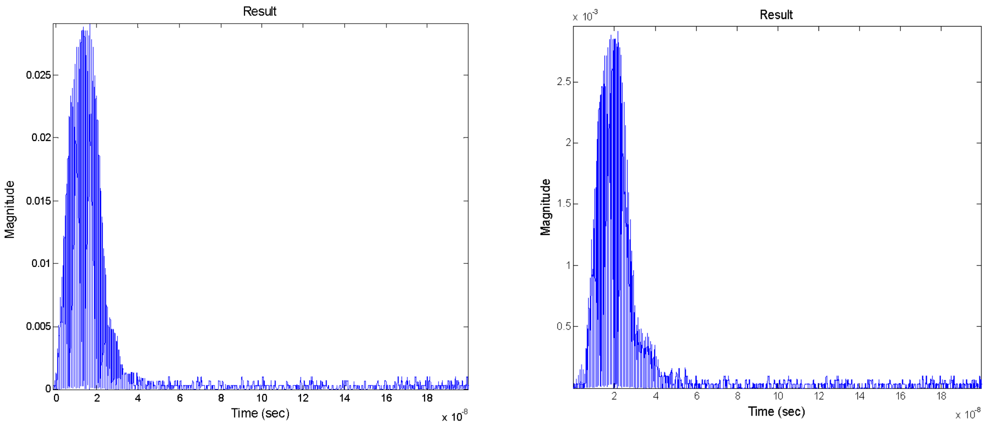
IV.MEASUREMET RESULTS

In this section, Measurement setting and numerical results and discussions are given. In the existing WBAN standard, performance evaluation was conducted with respect to the AWGN channel. Existing channel modeling study was achieved through simulation value in the case of implant. It is not appropriate to model the time varying channel according to the changes in the relative position of the environment or the changes of posture or the implants in human body.

In order to obtain a reliable channel, it is necessary to measure the value of a variable such as the Multipath, Doppler frequency, Shadowing by practical experiment. Also, I should be considered the dynamic situation according to the movement of the body. I created the experimental setup and scenario by considering the static conditions and dynamic conditions.

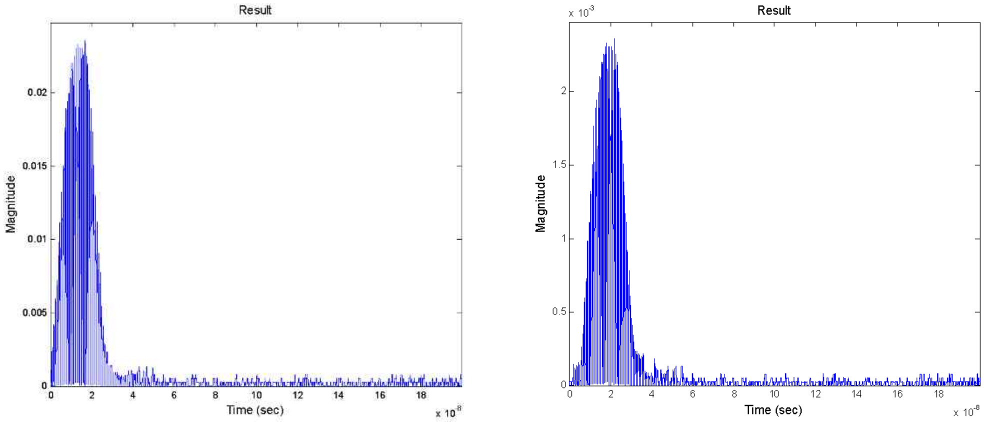
4.1 Measurement Results for Multipath Channel

I measured channel impulse response by using impulse method. Fig. 15 and Fig. 16 show transmitted signal and received signal by using signal generator and oscilloscope in scenario 1 and scenario 2. To generate an impulse-like signal, the minimum length of the signal was generated by the signal generator. The impulse signal characterized through the carrier frequency with 403 MHz as center frequency.



(a) (b)

Figure 15. Transmitted signal (a) and received signal (b) in scenario 1.



(a) (b)

Figure 16. . Transmitted signal (a) and received signal (b) in scenario 2.

In the case of scenario 1, it can be seen that the 4~5 nano second propagation delay occurred. By comparing transmitted signal and received signal, it can't verify the additional multi-path. In the case of scenario 2, it can be also seen that the 4~5 nano second propagation delay occurred. It also does not verify the additional multi-path.

The channel state can be also determined by coherence bandwidth. If coherence bandwidth is small in comparison to the bandwidth of the transmitted signal, the channel is said to be frequency-selective. In this case, the signal is severely distorted by the channel. On the other hand, if coherence bandwidth is large in comparison with the bandwidth of the transmitted signal, the channel is said to be frequency-nonselective. Coherence bandwidth in Hz is given approximately by the equation:

$$B_c = \frac{1}{D} \tag{41}$$

Where D is a delay spread. WBAN system is a specification for using 3MHz frequency band. It can be seen the frequency side of the measurement results in Fig. 17 and Fig. 18.

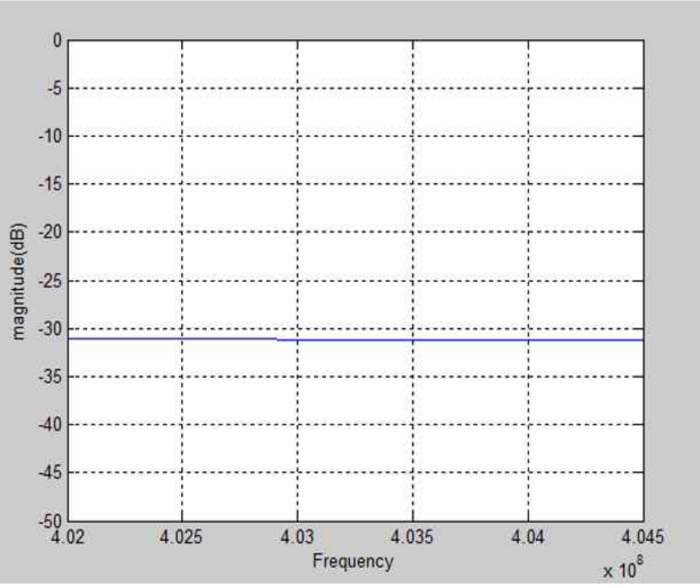


Figure 17. Frequency characteristic of the measurement results in scenario 1.

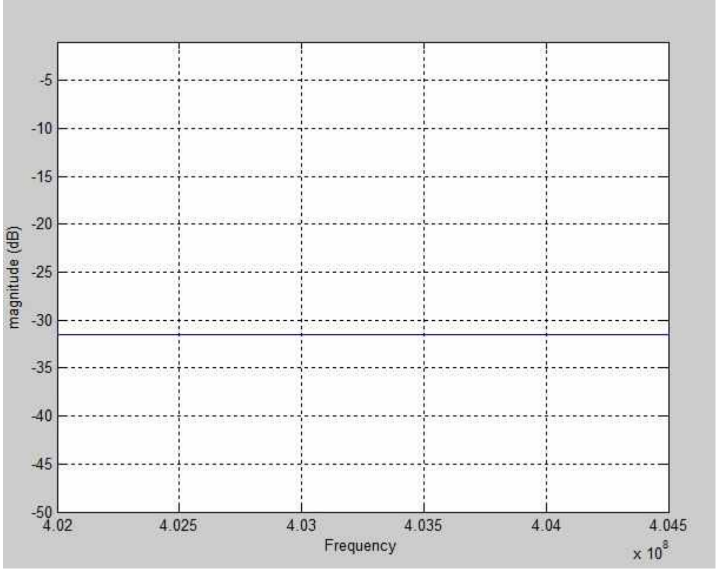
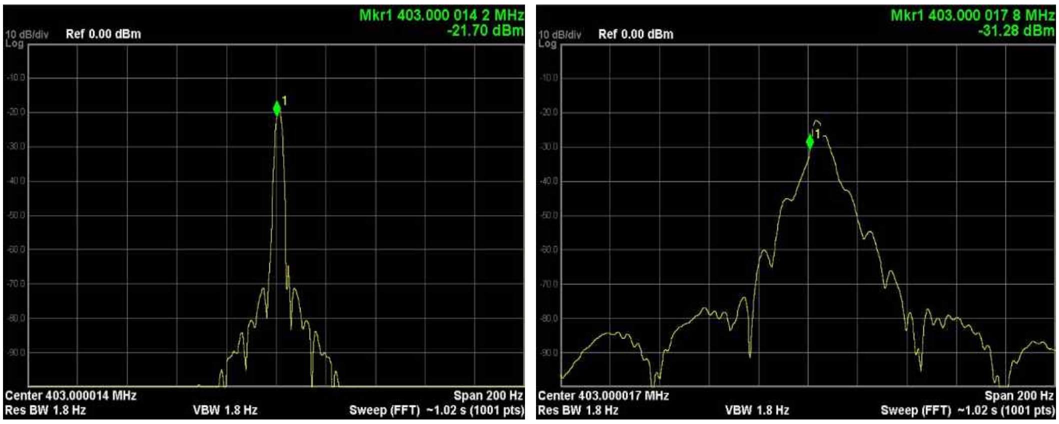


Figure 18. Frequency characteristic of the measurement results in scenario 2.

Delay spread means that the delay difference between the first and the last path of the multi-path. In the case of scenario 1, the delay spread D over the channel is about 0 sec because there is no multipath. From the channel measurement values, the channel characteristics is flat. In the case of scenario 2, the delay spread D over the channel is same as scenario 1. It can be reasonably assumed that the channel is flat in Fig. 17and Fig. 18.

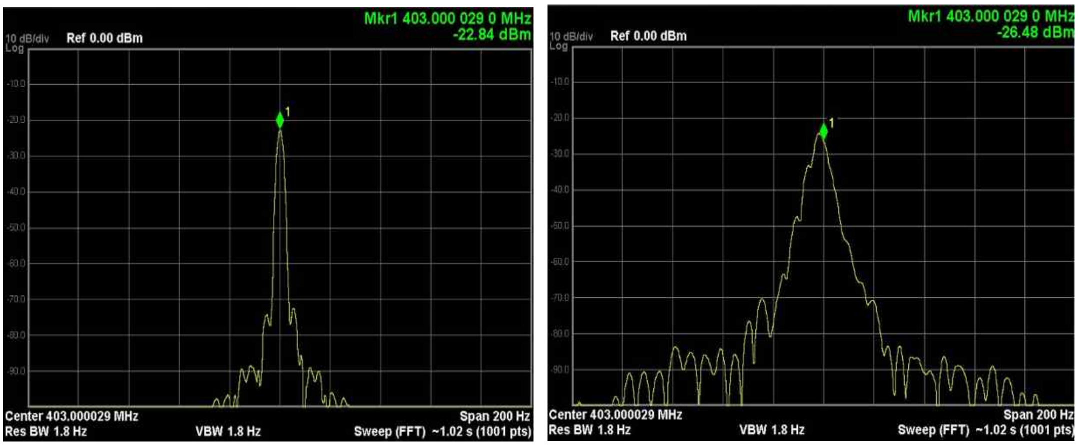
4.2 Measurement Results for Doppler Channel

I measured Doppler frequency for scenario 1, 2 and 3. Fig. 19, Fig. 20, and Fig. 21 show frequency characteristic when stopping and when moving by using signal generator and spectrum analyzer. The transmitted signal characterized through the carrier frequency with 403 MHz as center frequency. I observed the spectral characteristics of center frequency when human does not move. The Doppler frequency can be seen when running for all scenarios.



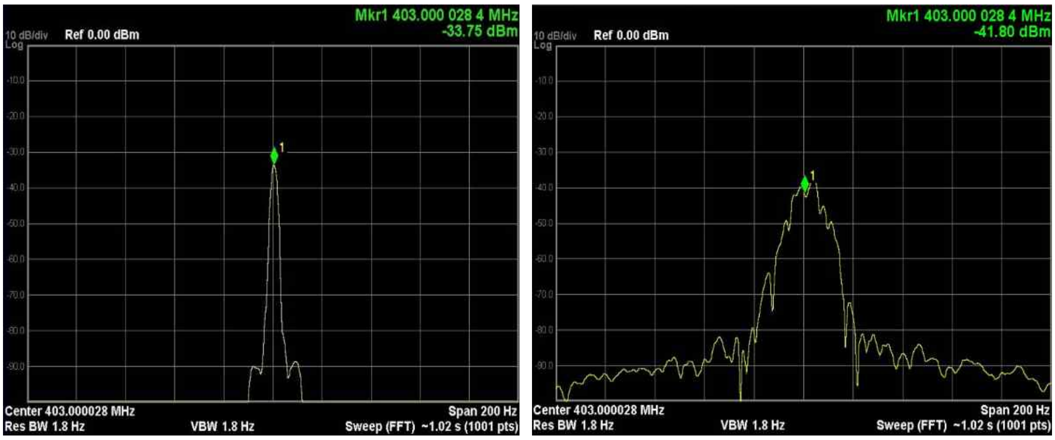
(a) (b)

Figure 19. Doppler characteristic when stop(a) and run(b) in scenario 1.



(a) (b)

Figure 20. Doppler characteristic when stop(a) and run(b) in scenario 2.



(a) (b)

Figure 21. Doppler characteristic when stop(a) and run(b) in scenario 3.

When we define a value below -10 dB in the measured Doppler frequency, it can be seen that about 20Hz Doppler frequency occurred for scenario 1, 15Hz Doppler frequency occurred for scenario 2, 20Hz Doppler frequency occurred for scenario 3.

As a result of the Doppler frequency values, the channel state can be determined by coherence time. Coherence time is the time duration over which the channel impulse response is considered not to be not varying. Coherence time is the time distribution of the fading channel characteristics in the time domain. In addition, it also means that the Doppler spread in the frequency domain.

If the coherence time is larger than the symbol period, the channel is said to be a slow fading channel. On the other hand, if the coherence time is smaller than the symbol period, the channel is a fast fading channel. If B is defined as the signal bandwidth, the required symbol time is $1/B$. MICS band is a specification for using a frequency band between 402 and 405 MHz for WBAN system. The required symbol time of WBAN system is 0.3 μs. As a result of the channel measurement values for all scenario, Doppler spread is about 20Hz, 15Hz and 20Hz for scenario 1, 2 and 3 respectively. We can easily check the coherence time of channel is larger than symbol time of WBAN system. So, we can know the channel is a slow fading channel.

4.3 Measurement Results for Shadowing Channel

Fig. 22 shown the s-parameter values between Tx and Rx for scenario 1 and 2. It seems that periodic attenuation by wrist movement and additional shadowing between Rx and Tx for all scenario.

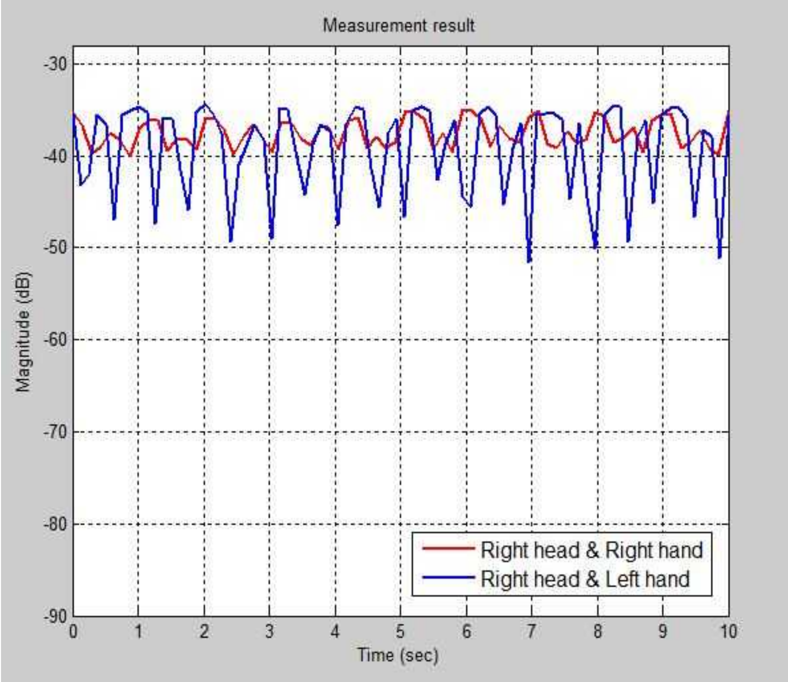
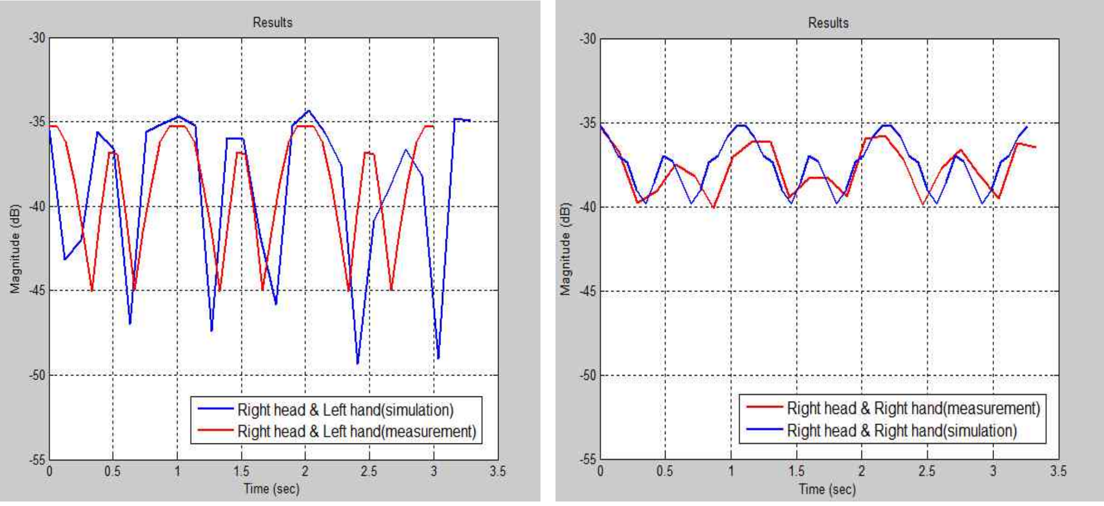


Figure 22. Shadowing characteristic for scenario 1, 2.

By comparing scenario 1 and scenario 2, it can be seen that the right head & left hand case has many attenuation compared to right head & right hand. It means that large variation of attenuation since right head & left hand case has large shadowing portion by the body when the wrist moves.

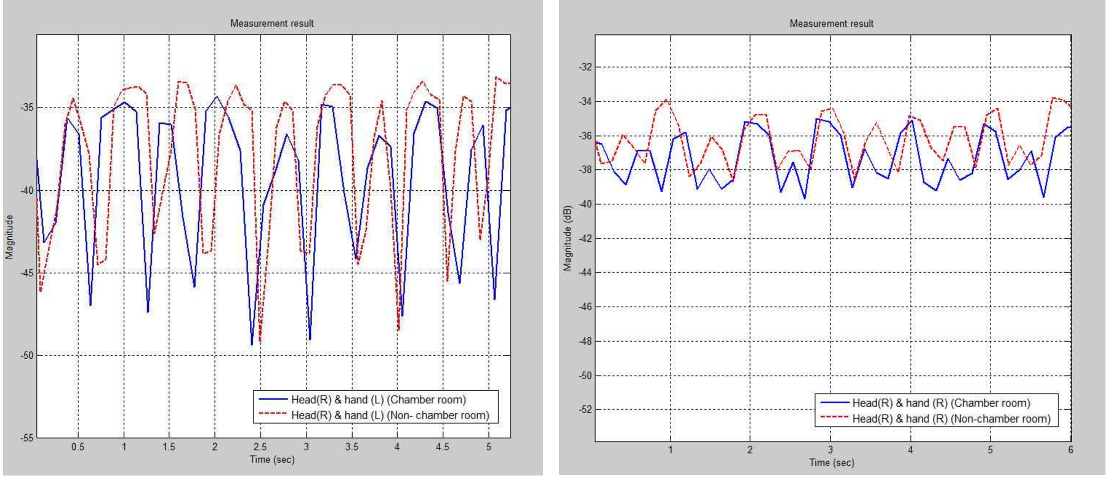
To determine the reliability of the experiments, we need the verification of experimental environment for channel measurement. I build a real environment similar to HFSS environment, and directly measure the path-loss according to the posture of the body. After that, I compared with the HFSS result value and the actual measured value. We can see that the actual measurement environment and HFSS measurement environment has a similar tendency in the Fig. 23.



(a) (b)

Figure 23. Comparison with simulation and measurement for scenario 1(a), 2(b).

Fig. 24 shows the comparison of the two conditions that the experimental data in the chamber room and office for the scenario 1. It can be seen the S-parameter values at the office are 1~2dB higher than chamber room. This is a possibility that noise or multipath coming from the office environment.



(a) (b)

Figure 24. Measurement values with chamber and non-chamber room for scenario 1(a), 2(b).

Fig. 25 shows the group delay for scenario 1 with respect to the frequency band. The frequency band is 400 to 403 MHz. The minimum value of the group delay is 0 seconds and the maximum is 15 nano seconds. As a result, 15nsec multipath delay was confirmed as the difference between the maximum and the minimum group delay.

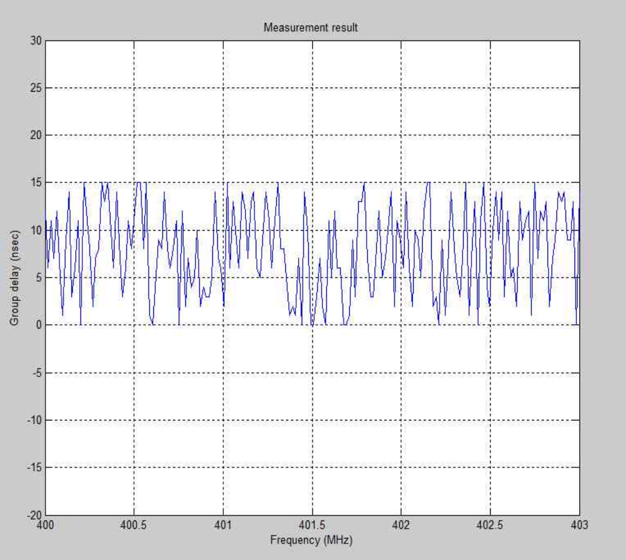


Figure 25. Group delay for scenario 1.

Therefore, the multipath components are present, but the delay of the multi-path is very short compared to the WBAN symbol time. It means that the deterministic channel modeling is possible because of the direct-path components is the dominant than multipath components.

4.4 Channel modeling

In order to determine the channel model, we should consider the human movement with time-varying situation. It seems that periodic movement by wrist and time interval between Rx and Tx in the Fig. 26.

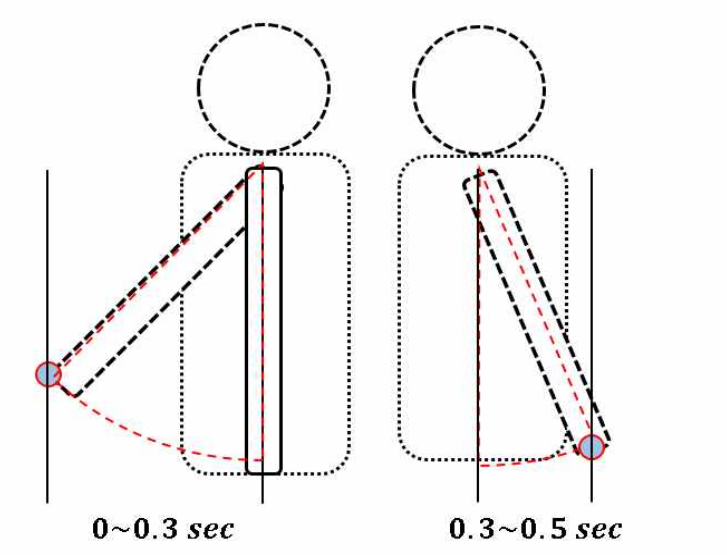


Figure 26. Time interval according to the arm movements.

The period of the motion is about 0.5 seconds. Attenuation tendency can be seen relative to the wrist motion with t sec intervals. It means that the state of the channel is changed by the position or velocity of the body. Therefore, we should consider the channel model of human movement with time-varying situation.

Fig. 27 and Fig. 28 show the change of the distance and the change of acceleration according to wrist movement. By using these parameters, I can create a channel model according to time variation.

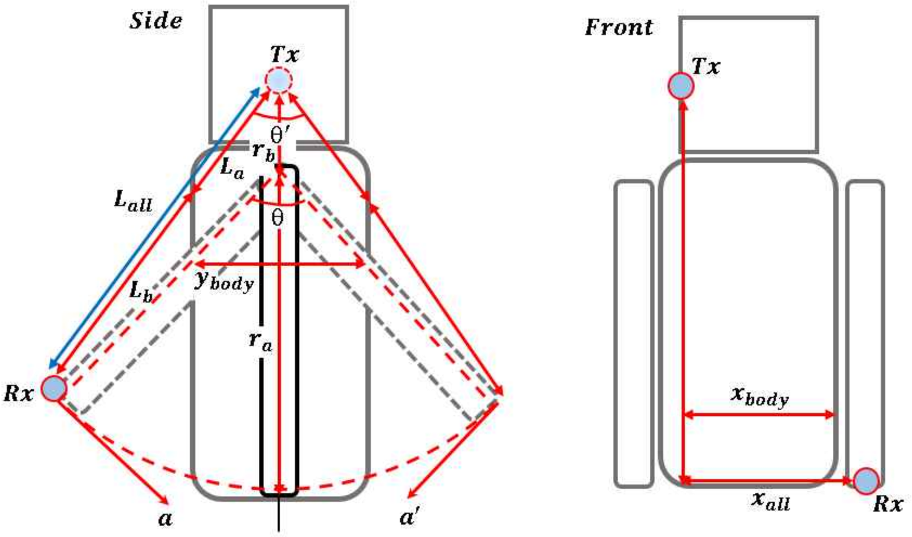


Figure 27. Arm movement architecture in side and front.

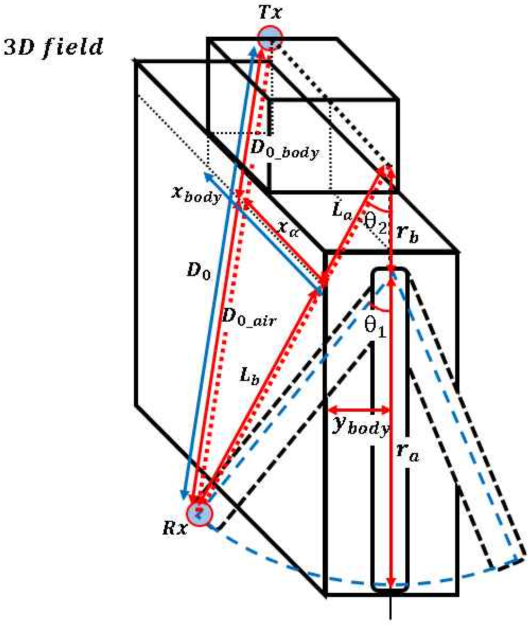


Figure 28. Arm movement architecture in 3D field.

Where L_a, $L_a^{'}$ are distance of the shadowed part by the human body at the side. L_b, $L_b^{'}$ are distance of the part by the air at the side. r_a is the arm length. r_b is the distance between transmitter and shoulder. θ_1, θ_2 are angles of the arms according to the time variation. $\theta_1^{'}$, $\theta_2^{'}$ are angles relative to the motion of the transceiver. y_{body}, $y_{body}^{'}$ and x_{body} are the default value of y-axis and x-axis length of the human body. a is acceleration in $0 \sim 0.5$ sec intervals. $a^{'}$ is acceleration in $0.5 \sim 1$ sec intervals. To determine channel model $h(t)$, I define the parameters as follows

$$\alpha = \frac{a}{r_a} \tag{48}$$

$$w = \alpha t = \frac{a}{r_a} t \tag{49}$$

Where α, w are the angular acceleration and the angular velocity of the arm motion. In the case of rotational movement of the stationary shaft, the angle θ can define using the angular acceleration and the angular velocity as follows:

$$\theta(\deg) = \frac{180}{\pi} \cdot \theta(rad) = \frac{180}{\pi} \cdot \left\{ \theta_{t=0} + (w_{t=0} \cdot t) - \left(\frac{a \cdot t^2}{2r_a} \right) \right\} \tag{50}$$

Where θ is an angle of the arms according to the time variation. $\theta_{t=0}$ and $w_{t=0}$ are the angle and angular velocity at time $t = 0$. $\theta_{t=0}$ is 1.22 radian.

$$\begin{aligned} D_0 &= \sqrt{L_{all,\,\mathrm{t=0}}^2 + x_{all}^2} \\ &= \sqrt{r_a^2 + r_b^2 - 2 \cdot r_a \cdot r_b \cdot \cos\left(180 - 70\right) + x_{all}^2} \end{aligned} \tag{51}$$

$$\left[\begin{aligned} L_{all} &= \sqrt{r_a^2 + r_b^2 - 2 \cdot r_a \cdot r_b \cdot \cos\left(180 - \theta_1\right)} \\ &= \sqrt{r_a^2 + r_b^2 - 2 \cdot r_a \cdot r_b \cdot \cos\left[180 - \frac{1}{2}\frac{180}{\pi} \cdot \left\{ \theta_{t=0} - \left(\frac{a \cdot t^2}{2r_a} \right) \right\} \right]} \end{aligned} \right]$$

Where D_0 is the initial distance between transmitter and receiver. D_0 can determine by using law of cosines equation. The law of cosines is useful for computing the third side of a triangle when two sides and their enclosed angle are known, and in computing the angles of a triangle if all three sides are known.

$$\begin{aligned} D_{0\_body} &= \sqrt{L_{a,\,\mathrm{t=0}}^2 + (x_{body} - x_{\alpha})^2} \\ &= \sqrt{L_{a,\,\mathrm{t=0}}^2 + \left(x_{body} - \frac{L_{b,\,\mathrm{t=0}} \cdot x_{body}}{L_{all}} \right)^2} \\ &= \sqrt{L_{a,\,\mathrm{t=0}}^2 + \left[x_{body} - \frac{(L_{all} - L_{a,\,\mathrm{t=0}}) \cdot x_{body}}{L_{all}} \right]^2} \end{aligned} \tag{52}$$

$$[L_{a,\,\mathrm{t=0}} = \frac{y_{body}}{\sin\theta_{2,\,\mathrm{t=0}}},\quad \theta_{2,\,\mathrm{t=0}} = \cos^{-1}\left[\frac{2r_a^2\{1-\cos(\frac{180}{\pi}\cdot 0.5\cdot\theta_{t=0})\} - (r_a + r_b)^2}{2(r_a + r_b)L_{all}} \right]$$

$$D_{0\_air} = D_0 - D_{0\_body} \tag{53}$$

Where D_{0_body} is initial distance through the human body. D_{0_air} is initial distance through the air.

$$\begin{aligned} D_{all}(t) &= \sqrt{L_{all}^2 + x_{all}^2} \\ &= \sqrt{r_a^2 + r_b^2 - 2\cdot r_a \cdot r_b \cdot \cos\left[180 - \frac{180}{\pi} \cdot \left\{ 0.5 \cdot \theta_{t=0} - \left(\frac{a \cdot t^2}{4r_a} \right) \right\} \right] + x_{all}^2} \end{aligned} \tag{54}$$

$$\left[\begin{aligned} L_{all} &= \sqrt{r_a^2 + r_b^2 - 2\cdot r_a \cdot r_b \cdot \cos(180 - \theta_1)} \\ &= \sqrt{r_a^2 + r_b^2 - 2\cdot r_a \cdot r_b \cdot \cos\left[180 - \frac{1}{2}\frac{180}{\pi} \cdot \left\{ \theta_{t=0} - \left(\frac{a \cdot t^2}{2r_a} \right) \right\} \right]} \end{aligned} \right]$$

$$\begin{aligned} D_{body}(t) &= \sqrt{L_a^2 + (x_{body} - x_\alpha)^2} \\ &= \sqrt{L_a^2 + \left(x_{body} - \frac{L_b \cdot x_{body}}{L_{all}} \right)^2} \\ &= \sqrt{L_a^2 + \left[x_{body} - \frac{(L_{all} - L_a) \cdot x_{body}}{L_{all}} \right]^2} \end{aligned} \tag{55}$$

$$[L_a = \frac{y_{body}}{\sin\theta_2},\quad \theta_2 = \cos^{-1}\left[\frac{2r_a^2 \left\{ 1 - \cos\left(\frac{180}{\pi} \cdot \left(0.5 \cdot \theta_{t=0} - (a \cdot t^2 / 4r_a) \right) \right) \right\} - (r_a + r_b)^2}{2(r_a + r_b) L_{all}} \right]]$$

$$D_{air} = D_{all} - D_{body} \tag{56}$$

Where $D_{all}(t)$ is the distance according to the time variation between transmitter and receiver. $D_{body}(t)$ is the distance through human body according to time variation. Therefore, we can define the channel model $h(t)$ of human movement with time-varying situation by using path loss equation.

$$h(t) = PL(D_0) + 10n_1 \log_{10}\left(\frac{D_{body}(t)}{D_{0\_body}} \right) + 10n_2 \log_{10}\left(\frac{D_{air}(t)}{D_{0\_air}} \right) + X_\sigma \ \text{[dB]},\quad \mathrm{T} < \mathrm{t} < \mathrm{T}{+}0.5,\quad \mathrm{T} = 0, 0.5, 1, 1.5 \ldots \tag{58}$$

Where $PL(D_0)$ is the initial path loss value at the distance D_0. X_σ is the random variable of the channel. n_1 is the path-loss exponent of the body parts. n_2 is the path-loss exponent of the air. I was calculated the loss of air and water, respectively. Reflectance index between body water and air affects the initial path loss value $PL(D_0)$. Therefore, we can define the channel model $h(t)$ of human movement with time-varying situation. The parameter values to be used for the actual measurements are shown in table 8.

Parameter	**Value**
x_{body}	$26cm$
x_{al}	$33cm$
r_a	$61cm$
r_b	$25cm$
y_{body}	$14cm$
a	$16.55m/s^2$
$\theta_{t=0}$	$2.44rad$
$\theta_{1,\ t=0}$	$1.22rad$
n_1	8
n_2	2

Table. 8. Parameter setting values for human channel model

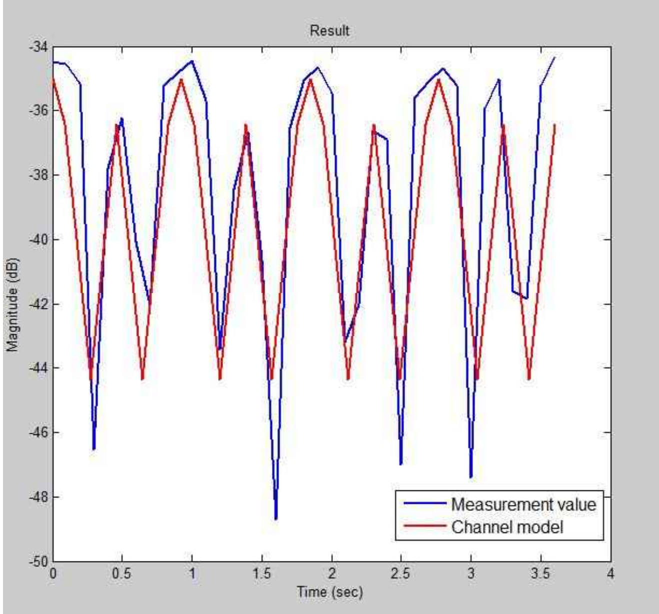


Figure 29. Verification of the channel model.

In order to verify the channel model of the human body, Fig. 29 shows the simulation result value and the actual measured value. I can be seen the channel model value and experimental value are well matched. Through this process, it can be seen that the model has a reliability.

Wearable devices such as smartphones or Google Glass has accelerometer and gyro sensor. We can be obtained acceleration, velocity, position information of the human motion by using the acceleration sensor and a gyro sensor. Therefore, time-varying human channel model is possible using the proposed channel model with these information. In the wearable device having a limited battery, we can share the wireless channel efficiently depending on the channel variation. The average battery lifetime can be extended by reducing the power consumption through adaptive power control according to the proposed channel model.

V. CONCLUSION

In this paper, I studied body area channel characteristics. I have measurement results of water. Instead of human body, thereby verifying the measurement environment. I measured multipath, Doppler, shadowing using the water in test as a similar environment with human case. As a result of multipath, Doppler and shadowing between water and wrist, I can get the coherence time and bandwidth. From this values, we can know the channel is a slow fading channel. I determined the human body channel according to the changes in the changes of posture or the implants in the human body. This is the intermediate step for measuring a time-varying body area channels. Therefore, we need to resolve the irregular feature through detailed measurements which similar to the human body.

For the future work, we can interpret these irregular characteristics and prove through detailed experiments. We can measure the channel characteristics depend on the speed and position change of transceiver according to the movement by using human phantom model. Throughout this study, we also can plan the detailed experiments and performance evaluation for WBAN system. After that, we can develop a time-varying channel model which low complexity and actual by utilizing the result. Also, we can make human channel model efficiently to design and test the WBAN system.

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요 약 문

무선 인체 영역 채널 측정 및 모델링

이식 형 의료기기 또는 웨어러블 디바이스 같은 IEEE 802.15.6 표준에 기초한 무선 인체 영역 네트워크(WBAN)시스템에 대한 관심이 증가하고 있다. 스마트폰과 연동되는 손목 시계, 사용자의 운동 정보나 생활 정보를 기록할 수 있는 Activity tracker, 혈당, 혈압, 심박수 등의 생체 정보를 기록하는 U-healthcare 등이 사용되고 있다. 이러한 WBAN 시스템의 중요성이 높아지고 있는 가운데 채널 모델링은 WBAN 시스템을 설계 및 테스트하기 위해 필요하다. 웨어러블 디바이스의 경우 디바이스의 위치는 인체의 움직임에 따라서 변화되고 채널의 상태 또한 몸의 위치 또는 속도에 의해 변화한다. 정적인 상황을 고려하여 채널 모델의 경우, 사람의 신체의 자세 변화에 따른 시간 변화적인 채널을 모델링하기 적절하지 않다. 또한, 신체를 통한 채널 모델링의 경우 인체의 유전율 값에 따라서 전파의 속도, 채널 이득, 흡수가 기존의 공기와는 다르기 때문에 WBAN에 대한 통신 채널은 통신 기기가 몸에 이식된 상황 또한 고려되어야 한다. 본 논문에서는 신체의 움직임으로 인해 시간 변화적인 채널을 반영할 수 있는 실질적인 실험을 통한 채널 모델링을 구현하였다. 사람의 움직임에 따른 시간 변화적인 상황에 대한 멀티패스, 도플러, 쉐도잉과 같은 채널 특성을 인체와 비슷한 특성을 가지는 물에 대한 실험을 통하여 측정하였다. 실험 결과 멀티패스, 도플러, 쉐도잉에 대한 파라미터 값을 얻을 수 있었고 확률적인 모델이 아닌 Deterministic한 채널을 모델링을 진행하였다. 사람이 움직일 때의 가속도, 속도, 위치 정보를 스마트폰이나 구글글라스 같은 웨어러블 디바이스에서 얻을 수 있고 이런 정보들과 제안된 채널 모델을 사용하여 시간 변화적인 채널모델링이 가능해 진다. 이를 통해 제한적인 배터리를 갖는 웨어러블 디바이스에서 채널 특성 변화량에 따라서 무선 채널을 효율적으로 공유할 수 있고, 어댑티브한 파워 컨트롤을 통하여 디바이스 노드의 파워 소모를 줄여 평균 배터리 수명을 연장시킬 수 있는 효과를 기대할 수 있다.

핵심어: WBAN, Channel modeling, Channel measurement