UWB-based Wireless Body Area Networks Channel Modeling and Performance Evaluation

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***Abstract*—In the Wireless Body Area Network (WBAN), the wireless channel is complex and distinctive because of the irregular shape of human body. The channel modeling methods and results are different from those in traditional narrow-band communication environments. In this paper, we present channel models for WBAN in Ultra wideband (UWB) frequency range 3-9 GHz. The channels are modeled statistically and the channel model parameters are derived from actual measured data in an office environment. An interesting common result is that different shape people have significantly differences in multipath parameters. Taking into account the characteristics of body shape, we provide a new classified small-scale channel model which has three kind of channel models: sparse, medium and dense multipath channel models. These models can be applied to different scenarios and improve the system design. We evaluated these models by delays and average number of multipaths with the measured data. Results prove the effectiveness of our models.**

***Index Terms*—Channel Modeling, Wireless body area network(WBAN), Ultra wideband(UWB).**

I. Introduction

As is a kind of wireless area network around human body, WBAN has been paid much attention in recent years. It has been considered as a main technology of human scale wireless sensor network, especially for health monitoring system in digital medical research [1], [2]. In 2007 the international community IEEE802.15 group established a working task group IEEE802.15.6TG, which focuses on WBAN applications and standardization.

UWB technology offers high data-rate, low-power communication means. It is suitable for the construction of short range, low cost wireless network, for example the WBAN [3], [4], [5]. Therefore, the use of UWB into WBAN has been studied. A statistical channel model of UWB-based WBAN is valuable in evaluating performance of related wireless communication systems.

From the point of view of modeling the WBAN UWB channel statistically, the model is divided into two components: the large-scale part and the small-scale one [6]. The large-scale model is very useful for link budget estimation in communication system design. And the small-scale model could give details on the multipath environment as a guide in communication receiver implementation.

UWB channel can effectively overcome the multipath effects, result that the traditional narrow-band model is no longer applicable. Many scholars have proposed a lot of new broadband in-door channel models, in which the S-V model is the most widely used [7]. In WBAN channel modeling field, a kind of modified S-V model which assumes there is only one cluster in the arrival sequences is also widely used [8].

In this paper, we build a frequency domain measurement system using the vector network analyzer (VNA). Then we obtain channel transfer function data from different shape human models and derive a statistical model from the measured data. We propose a classified model which could more accurately represent different WBAN UWB channels through carefully analysis of the measured data. In order to evaluate the accuracy of the models, we use average delay and average number of multipath as the basis rules. The evaluation result proves the effectiveness of the model.

The remainder of the paper is organized as follows: Section II describes the measurement setup. Section III describes how the large-scale model parameters are extracted from the data and discusses about the result. Section IV presents the large-scale model parameter estimation, discusses the results, and gives the classified model. Section V comes the conclusion.

TABLE I
Measurement Setup Table

Parameters	Values
VNA	Agilent N5242A
Frequency range	3-9GHz
Sweep Time	Auto
Calibration	Full-2-port (Tx power = 0 dBm)
Anntenna	Dedicated omnidirectional antenna from 18k-9GHz

II. Measurement Setup

This paper analyzes the data obtained by frequency domain measurement through a VNA. Equipments and other specifications in this measurement are listed in Table I. The measurement uses Agilent N5424B VNA, which could analysis signals from 10MHz to 26.5GHz. Antenna used in the measurement is a kind of special wide-band antenna which could work from 1MHz to 18GHz.

Fig.1 shows the measurement positions of the body and the layout of the measurement site.

The measurements were performed in an office environment with only the test equipments and the human model. The VNA

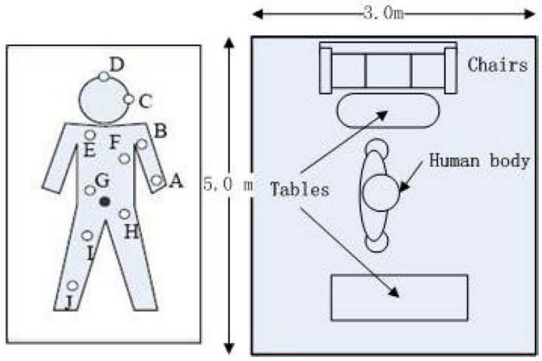

Fig. 1. Positions of the body region to measure channel transfer functions. layout of the measurement site, an small office.

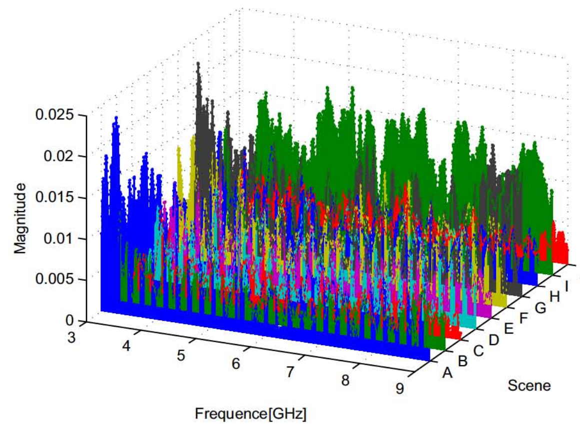

Fig. 2. Raw frequency data from vector network analyzer.

TABLE II
MEASUREMENT POSITION TABLE

scene	position
A	left hand
B	left upper arm
C	left ear
D	head
E	shoulder
F	chest
G	right rib
H	left waist
I	thigh
J	ankle

is controlled by a laptop which is connected through a ethernet twist cable to avoid interference. Before the measurement start, VNA is calibrated well with the radio cables.

The human model maintains the standing position during the measurements. Taking account of different WBAN applications, like Home Health Monitor System or Home Multimedia Entertainment Systems, the human model is divided into several regions for measurement, as is listed in Table II.

Receiving antenna is located in the front center of the body(solid circles), while transmitting antenna is located the A-J point (hollow circle) in the body surface.

In order to improve the accuracy of the model, we use people of different weight and shape as human model, whose information is listed in Table III. We obtain ten samples from the VNA at each position. Fig. 2 shows the raw data got from VNA.

We could roughly estimate the channel is a kind of frequency selective fading channel from the figure .

TABLE III
MODEL INFORMATION

Model No.	1	2	3
Height(cm)	162	172	170
Weight(kg)	44	60	90
Gender	Female	Male	Male
Shape	Thin	Normal	Fat

III. LARGE-SCALE MODEL

A. Data Process

Raw data from VNA(the S_{21} parameter) is in frequency domain and needs to be transformed into time domain for channel modeling.

Hamming window is used first to avoid time aliasing of inverse Fourier transform. Then the windowed signal is transformed to time domain by real pass-band inverse fourier transform (RP-IFFT).

Since the frequency domain windowing reduces time resolution, so time resolution adjust process is needed to adjust the time resolution of the corresponding time impulse response. To get the power delay profile (PDP) data, the first path of each time response is normalized to one and its arrival time is removed.

B. Path loss model

The path loss and mean excess delay are calculated from the measurement results. The path loss is obtained as mean path gain over the measured frequency band, as is shown in Eq.(1).

$$PL\left(d\right) = a \bullet \log_{10} d + b + X_{\sigma} \tag{1}$$

where $PL\left(d\right)$ follows zero mean log-normal random variables, d is the distance between the center (mm), a is the fading coefficient from the correlation, b is the reference point decline and X_{σ} is the variance of the shadow effects.

Each scenario is measured 10 times, use Eq.(2) to calculate the path loss. Then obtain the fading coefficient through least square method of the data and distance.

$$PL\left(d\left(p\right)\right) = -20 \bullet \log_{10}\left\{\frac{1}{10}\frac{1}{N_f}\sum_{j=1}^{10}\sum_{n=1}^{N_f}\left|H_j^p\left(n\right)\right|\right\} \tag{2}$$

where $PL\left(d\left(p\right)\right)$ is the path loss of position p, $H_j^p\left(n\right)$ is the measured S_{21} at position p. N_f is the VNA measurement sample point.

TABLE IV
PATH LOSS TABLE

parameter	Thin	Normal	Fat	Total
a	25.87	20.50	20.87	23.39
b	-21.68	-6.84	-6.26	-14.20
n	2.587	2.05	2.087	2.339
σ_N	4.24	3.58	4.18	4.18

Excess delay and Root-Mean-Square (RMS) delay are got from the transformed time data, as is shown in Eq.(3) and Eq.(4).

$$\tau_m\left(d\left(p\right)\right)=\sqrt{\frac{\sum\limits_{j=1}^{10}\sum\limits_{n=1}^{N_f}t(n)^2\bullet\left|h_j^p\left(n\right)\right|^2}{\sum\limits_{j=1}^{10}\sum\limits_{n=1}^{N_f}\left|h_j^p\left(n\right)\right|^2}} \tag{3}$$

$$\tau_{RMS}\left(d\left(p\right)\right)=\sqrt{\frac{\sum\limits_{j=1}^{10}\sum\limits_{n=1}^{N_f}\left\{t\left(n\right)-\tau_m\left(d\left(p\right)\right)\right\}^2\bullet\left|h_j^p\left(n\right)\right|^2}{\sum\limits_{j=1}^{10}\sum\limits_{n=1}^{N_f}\left|h_j^p\left(n\right)\right|^2}} \tag{4}$$

Where $\tau_m\left(d\left(p\right)\right)$ is mean excess delay of position p, $\tau_{RMS}\left(d\left(p\right)\right)$ is r.m.s. delay of positon p, $h_j^p\left(n\right)$ is the jth time response of position p.

C. Result analysis

Table IV is the parameters got from the measured data which is measurement results from three type of bodys. The model parameters indicate that only a small part of the energy absorbed by the body, most of the energy is scattered around the human body. Taking into account the human body between the attenuation coefficient n between 5-7, the obtained attenuation coefficients from the measured data show that the coefficient in front of the body is near 3.

Fig. 3 shows the fitted path loss model versus the measurement data, scenes A-J are the points marked with A-J letters each. Squares markers represent the measured result of thin body while circles represent the normal size, triangular represent the fat body.

It can be seen from the figure that different shape models have a larger path loss distinction, up to 6dB. Futhermore, all is greater than the loss of free space.

The shadow effects in WBAN UWB channel is very complicated than those analysis in wireless communications, but many scholars find that most of the multipath components is generated by the scattering effects around the body. so in modeling it log-normal distribution is much superior than other distributions [9], [10], [11].

Fig. 4 shows the excess delay and RMS delay maps. As we can see from the figure, the RMS delay under the two environments are less than 30ns.

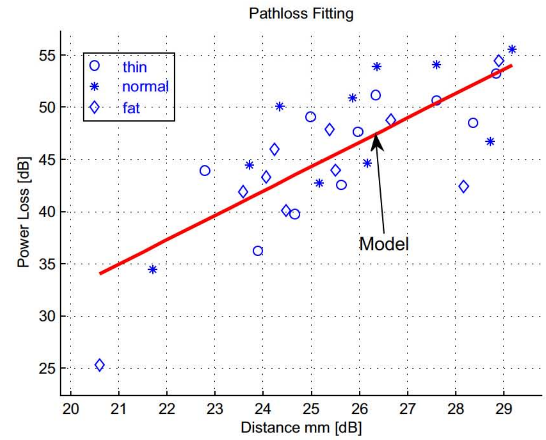

Fig. 3. Path loss calculated from the measured data.

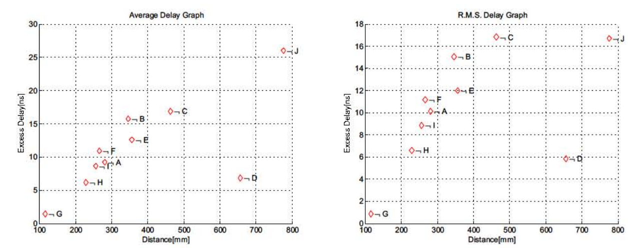

Fig. 4. Average delay and r.m.s. delay calculated from the measured data

IV. SMALL-SCALE MODEL

A. Power delay profile model

The power delay profile model is a kind of statistical approximation of the small scale effects by the human body scattering. It plays an important role in the design of the multipath environment receiver. Recently many scholars model small scale fading phenomena from two perspectives, Poisson model [8] and transmission filter model [12]. Taking into account the test environment of multipath sparsity, Poisson model is widely used in modeling the path arrival of the channel.

This model is given by a single cluster and exponential decay. Eq.(5) express the model expression of the channel.

$$h(t)=\sum_{l=0}^{L-1}a_l\exp(j\phi_l)\delta(t-t_l) \tag{5}$$

where a_l represents for the amplitude, t_l represents the arrival time, and ϕ_l is the phase.

The amplitude is modeled with a Rice decline distribution. The phase is modeled with a uniform distribution of $[0,2\pi]$. The arrival time and arrival rate of multiple paths is modeled by a poisson process.

To provide a statistical model on the amplitude a_l, its first path is normalized into one and the time of arrival on the first

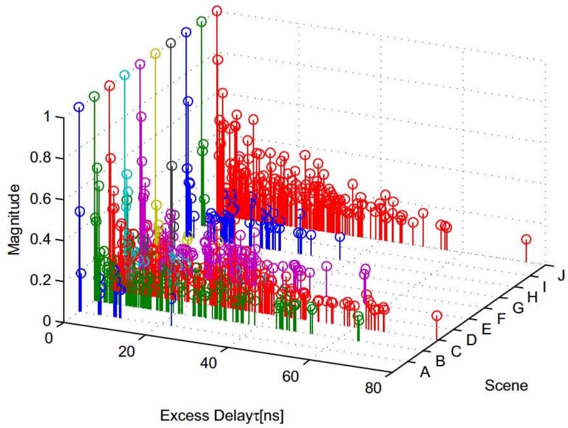

Fig. 5. PDP data of different scene.

path is removed. Eq.(6) is the formula for the amplitude fit.

$$10_l \log 10|a_l|^2 = \begin{cases} 0, l = 0 \\ \gamma_0 + 10\log 10(\exp(-\frac{t_l}{\Gamma})) + S, l \neq 0 \end{cases} \tag{6}$$

where S is the standard deviation of the zero-mean log-normal distribution. The model is equivalent to a single cluster model with Rice and exponential decay model.

Eq.(7) is the formula for the Poisson model,

$$p(t_l|t_{l-1}) = \lambda \bullet \exp(-\lambda(t_l - t_{l-1})) \tag{7}$$

where t_l is the path to reach.

The average number of paths is obtained from a Poisson process, as described in the following equation

$$\bar{L} = \frac{\bar{L}^L \exp(\bar{L})}{L!} \tag{8}$$

Where $\bar{L}$ is the average number of multipath arrived.

B. Result analysis

1) PDP model parameters: Fig. 5 shows the PDP data of the measured scenes. In the figure, each signal sequence is one of the 10 measured samples of the scene. It shows that PDP data attenuate is a kind of single cluster decay trend.

Table V shows the model parameters. To illustrate the differences of different human body model fitting, each human body is modeled alone, and the parameters are listed at the first 3 columns. The table shows the total PDP model parameters exact from the total measured data in the last columns. To evaluate the fitness of the model parameters, we use the estimated models to generate channel data, and compare the delay and multipath number with the measured data. $\bar{\tau}$, $\bar{\tau}_{rms}$, NP_{20dB} represent the delay and path number generated from the measured data, while $\bar{\tau}_{sim}$, $\bar{\tau}_{rmssim}$, $NP_{20dBsim}$ represent the delay and path number got from the simulated channel data.

Fig. 6 is the fitting diagram of the exponential decay PDP amplitude. Fig. 7 is the pdf and cdf of the fitting error, it is a log-normal distribution.

TABLE V
PDP MODEL PARAMETERS

–	thin	normal	fat	total
γ_0	-11.4353	-12.6473	-12.5327	-12.297
Γ	29.1193	32.3326	33.864	31.9654
σ_s	4.6479	4.2659	3.7599	4.1444
λ_0	1.1432	1.1794	1.4286	1.2758
NP_{20dB}	25.06	36.07	53.95	38.36
$\bar{\tau}$	11.4162	14.4671	16.6356	16.6356
$\bar{\tau}_{rms}$	10.3846	12.5252	13.4458	13.4458
NP_{20dB}	25.06	36.07	53.95	38.36
$\bar{\tau}_{sim}$	9.5526	13.0549	16.0354	12.9924
$\bar{\tau}_{rmssim}$	7.827	10.7692	12.6534	10.6052
$NP_{20dBsim}$	25.05	36.09	53.75	39.65

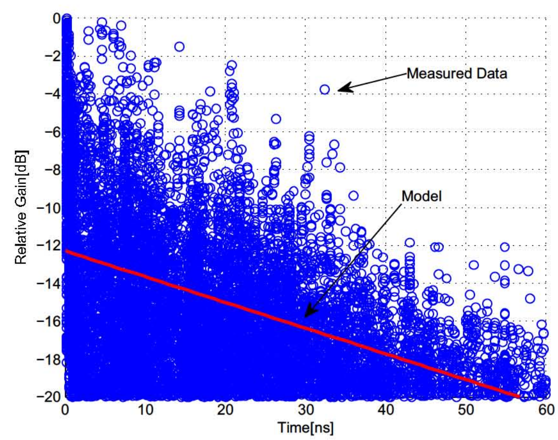

Fig. 6. Exponential decay factor Γ and rice factor γ_0

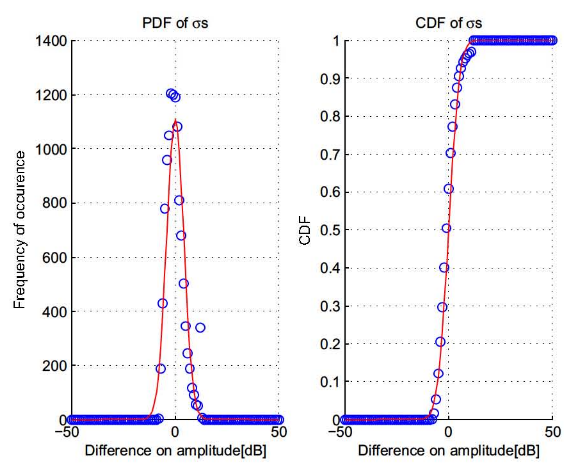

Fig. 7. Normal distribution on the difference of amplitude σ_s.

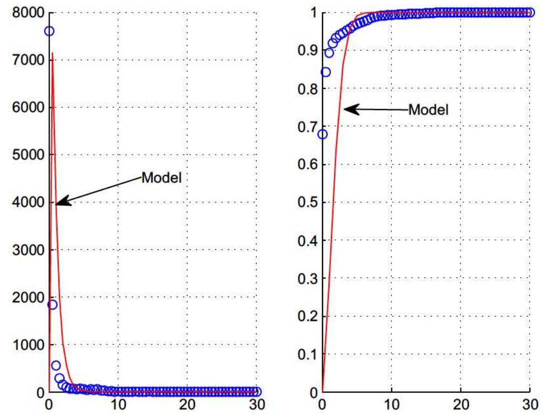

Fig. 8. Poisson distribution on the differential path-arrival time.

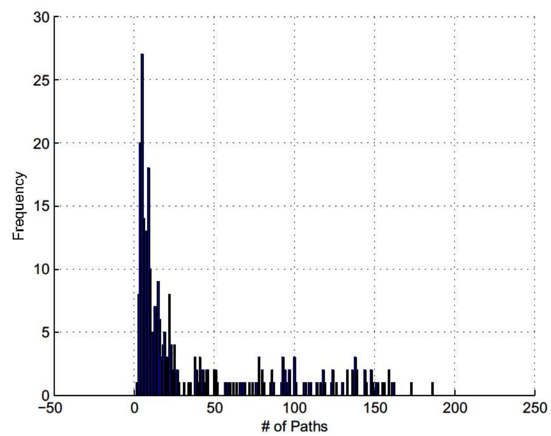

Fig. 9. Average number of arrival paths.

2) Classified PDP model: We found that the average paths of different shape body's scenes have a large disparity through detailed analysis of the measurement data.

As shown in Fig. 10, Fat body has more path numbers than the other two shapes. Thin body of people has less multipath phenomena, except the scene J (near ankle) which has a lot of multipath scatter from the ground, most of the scene arrive path is less than 30.

Since WBAN is a kind of low-power, intelligent network, how to use power efficiently is a key point. So more details of the channel information we get, we have more space to improve the system performance. From the every scene parameter analysis, we could divide the channel of WBAN to 3 categories: Sparse, Medium and Dense Multi-path channel. The sparse channel is a kind of channel which multipath number less than 10, while medium is between 10 and 50, dense is greater than 50.

Table VI shows the three models parameters exacted from special scenes. Table VII shows the evaluation of the three model with the measured data. It shows that the three model could fit the measued data very well.

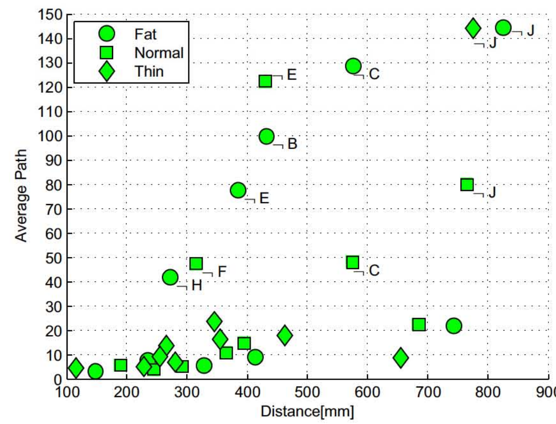

Fig. 10. Average path number of each scene from measured data.

TABLE VI
CLASSIFIED PDP MODEL PARAMETERS

—	Dense	Medium	Sparse
γ_0	-12.27	-11.97	-10.48
Γ	35.19	18.31	8.10
σ_s	3.59	4.27	5.76
λ_0	1.74	0.84	0.65
NP_{20dB}	113.8	29.95	7.64

V. CONCLUSION

We build a complete WBAN UWB channel measurement platform, to obtain the frequency domain channel data in an office environment. Then we use statistical parameter estimation method, to get the large-scale and small-scale channel model. The Path loss model shows that WBAN UWB channel has an attenuation factor near 2.5, which is much larger than the free space attenuation factor of 2 and smaller than the human body attenuation factor of $5 \sim 7$. The small-scale model is based on poisson process with exponential decay of amplitude. From the point of the fitted parameters, the WBAN UWB channel is a dense multipath, fast fading frequency selective channel.

It is important to choose a suitable criterion to evaluate the channel models. In this paper, we use the estimated models to generate channel data, then calculate the delay and average multipath number of the generated channel data, and compare them with those exacted from the measured data. This procedure can evaluate the channel models accurately and quickly . The classified small-scale model which include three kind of channel models for sparse, medium or dense

TABLE VII
CLASSIFIED PDP MODEL EVALUATION

	Dense		Medium		Sparse	
	Sim	Target	Sim	Target	Sim	Target
$\bar{\tau}$	26.24	25.97	11.38	15.04	3.65	8.15
$\bar{\tau}_{rms}$	19.73	16.68	10.38	14.60	3.71	8.37
NP_{20dB}	113.97	113.8	29.83	29.95	7.7	7.64

multipath WBAN UWB channels is based on the difference of body's shapes. Evaluation results show that the model fit the actual measured data very well.

ACKNOWLEDGMENT

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