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Statistical characterization of the dynamic human body communication channel at 45MHz*

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Abstract—**the dynamic human body communication (HBC) propagation channel at 45 MHz was statistical characterized in this paper. A large amount of measurement data has been gathered in practical environment with real activities –treadmill running at different speeds in a lab room. The received power between two lower legs was acquired from three volunteers, with more than 60,000 snap shot of data in total. The statistical analyses confirmed that the HBC propagation channel at 45MHz followed the Gamma and Lognormal distributions at the slower (2 km/h and 4 km/h) and faster (6 km/h and 8 km/h) running activities, respectively. The channel is insensitive to body motion with the maximum average fade duration is 0.0413s and the most averaging bad channel duration time being less than 60 ms with the percentage of the bad channel duration time being less than 4.35%.**

I. INTRODUCTION

The increasing use of wireless networks and the constant miniaturization of electrical devices provide unprecedented opportunity for ubiquitous real-time healthcare monitoring without constraining the activities of the user[1]. A wireless Body Sensor Network (BSN) or body Area Network (BAN) consists of small, intelligent devices attached on or implanted in the body which are capable of establishing a wireless communication link. These devices provide continuous health monitoring and real-time feedback to the user or medical personnel. Furthermore, the measurements can be recorded over a longer period of time, improving the quality of the measured data[2, 3].

In BSN/BAN, a reliable, low power, secure and body-proximal wireless communication links are major considerations for designing BSN system[4]. Typically, Bluetooth, Zigbee and other Industrial Scientific Medical (ISM) band-based communication protocols are widely employed. Recently, a novel near field communication technology - human body communication (HBC) or intra-body communication (IBC) , which uses the human body as propagation medium, shows its great potential for BSN/BAN applications[5]. In HBC, The frequency band was suggested to be below 100 MHz[6], the propagation channel was characterized by assuming the body was in still [7-9]. However, the propagation channel should be dynamic, i.e., the daily activities such as walking and running, and physiological activities such as the heartbeat and breathing. These activities might affect the wireless propagation channels dramatically.

In this paper, *in-situ* HBC propagation measurement results obtained by using battery supplied transceiver were introduced. The transceiver works at 45 MHz around CM3 channel (IEEE P802.15 Working Group for Wireless Personal Area Networks)[10]. The time series of the captured data were analyzed firstly, and then the variation was statistically tested by well-known distributions, the level crossing rate (LCR) and average fade duration (AFD) were presented to analyze the burst features of HBC propagation channel.

II. EXPERIMENTAL SETUP

A. Transceiver

The power-supplied instruments (such as the vector network analyzer) were usually adopted to characterize the ISM bands channels, which created additional signal return path conducted by the ground of the main power in HBC [11] . Moreover, the long RF cables are inconvenient and easily generate the troublesome fluctuant signals during the moving. Therefore, a battery-powered transceiver was prototyped specifically for this study. Fig. 1 illustrated the transceiver with the affiliated single coupling electrode. The transmitter (TX) part incorporated a Direct Digital Synthesizer which is able to output a sine wave at 45 MHz, and the maximum output power is approximately 0 dBm, which is satisfactory to related safety standards[12]. In the receiver (RX) part, inputted power was amplified by a logarithmic amplifier, and then it was digitalized by AD converter in the Micro Control Unit (MCU), the digital data was also written to a SD card for the off-line analyses. Self-assembled electrodes were fabricated with nickel conductive cloth surrounded by electronic insulation tape, which connected to the transceiver through a short RF wire. This electrode was designed to test the electric coupling with human body, it does not need the direct body contact and could be easily integrated into clothes, shoes and etc, for BSN/BAN applications. The measurement system was finally packed by a wearable shield box that is suitable for measuring the dynamic propagation channel.

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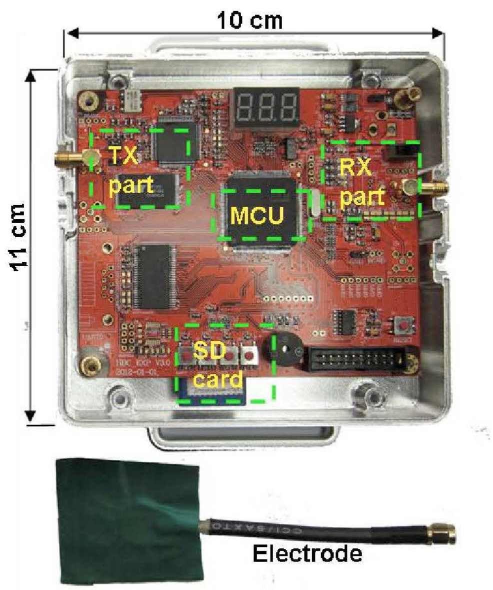

Figure 1. Transceiver and electrode for this study.

B. Scenario configurations

In order to mimic the real BSN/BAN application scenarios, the measurement was conducted in our BSN lab room, which is 6×8 m^2, has one glass wall and several electrical instruments are powered on. Three young volunteers were selected, the body weight of the volunteers varied from 60 to 80 kg, and body height varied from 160 to 180 cm with the average age of 25 years old. All subjects were informed the study contents prior to the experiments and all of them signed the consent form. Fig. 2 shows the experimental setup scenario, the electrodes were fastened at the lower legs of the volunteer for this channel is common used in body activity monitoring [13].

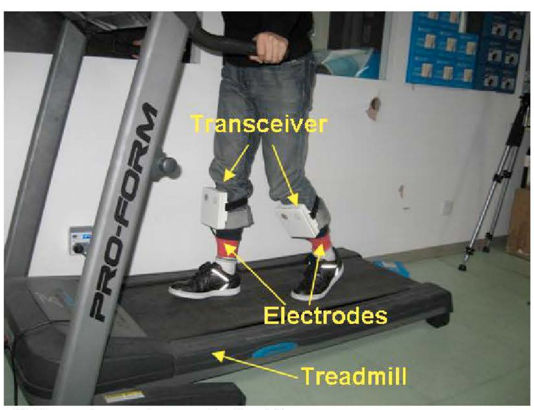

Figure 2. Experimental setup in the lab room.

Volunteers are requested to run on the treadmill with different speeds at 0 km/h (stand still), 2 km/h, 4 km/h, 6 km/h and 8 km/h. In each measurement, 200 seconds data with 100 Hz sample rate were acquired, and approximately 60,000 snapshots of channel response were captured during each measurement configuration.

III. Measurement Results And Analyses

A. Normalized received power and time series.

In order to focus on characterizing the dynamic propagation channel, the received power was normalized by the mean of stand still configuration scenario. Fig. 3 depicts the time series of normalized received power (RP) within 10s. The signals fluctuated in a regular base along with the repetitive actions were observed in each configuration, the fading times seems to have the relationship with the running speed. Compared to Fig. 3(a), larger number of fading times was founded in Fig. 3(d). Moreover, the maximum fading depth is approximately -20 dB with most fading depths below -15 dB could also be examined from Fig. 3. These observations indicated that the propagation channel also suffered the body movement. Considering the coupling mechanism of HBC[7], this fading may result from the variation distances of on-body signal coupling path and ambient ground signal return path. In order to quantitatively analyze this dynamic characteristic, the first and second order statistical analysis was conducted.

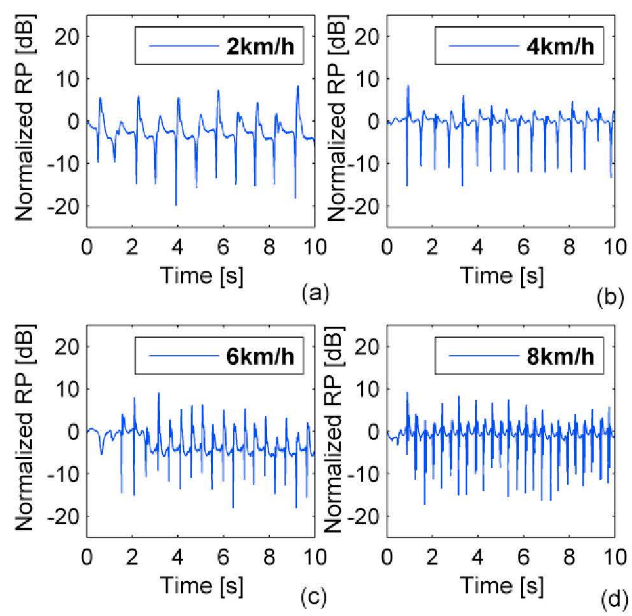

Figure 3. Time-varying series of normalized received power at each configuration within 10 s.

B. First-order statistics

Five well-known probability density functions (PDF) such as Lognormal, Gamma, Rayleigh, Nakagami and Weibull distributions were adopted to find the besting fitting distributions for the normalized received power. All distribution parameters in each configuration were obtained by using the maximum likelihood estimation (MLE), and then the best distribution model was selected by the Akaike information criterion (AIC) which has been discussed in detail in[14].

Tab. 1 summarized the best fitting distribution functions and the estimated parameters by AIC and MLE, respectively. In order to find whether alternative distributions existed, the ΔAIC that the difference of AIC between the best-fitting and the next best-fitting model in each configuration was also illustrated.

TABLE I
STATISTICS FOR MEASUREMENT DATA

Items	2 km/h	4 km/h	6 km/h	8 km/h
Best fitting	Gamma	Gamma	Lognormal	Lognormal
a/mu(db)	2.69	2.54	-0.72	-0.81
b/sigma(db)	0.24	0.22	0.68	0.85
ΔAIC	2109.4	4045.8	883.8	10081.6
*LCR(Hz)**	0.49	1.02	1.20	2.74
AFD(s) *	0.0413	0.0266	0.0159	0.0159
*PFD (%)**	2.01	2.70	1.91	4.35

** Threshold θ=-10dB*

As reported in existing literatures, at the GHz ISM bands, Lognormal was usually adopted to describe the static on-body channel [15, 16] ,while Nakagami and Weibull characterized the dynamic on-body channel well[15-17]. However ,in our investigation, it was observed from Tab. 1 that the Gamma distributions was found to be the best fitting distribution function for the running speeds at 2 km/h and 4 km/h, whereas the Lognormal distribution was observed to fit well with running speed at 6 km/h and 8 km/h. Moreover, by suggested in [14] ,when the AIC difference ΔAIC>10, the alternative models have either essentially no support, and might be omitted from further consideration, or at least those models fail to explain some substantial explainable variation in the data. So we considered here that no alternative model would be chosen for none of ΔAIC ≤ 10 in each configuration.

C. Level crossing rate and average fade duration

Two important second order statistical parameters: level crossing rate (LCR) and average fade duration (AFD), which help in the selection of the most suitable error protection coding scheme and interleaving algorithm in wireless communication, were investigated in this paper.

Fig. 4 plots the level crossing rate that the average number of times the signal positively crosses a given threshold, θ, within a given observation period, T=600s. The LCR value with threshold θ=-10 dB is also listed in Tab. 1. It was noteworthy that the LCR depended on the running speeds, the faster running results in the higher LCR, for example, the LCR is only 0.49 Hz at the 2 km/h running speed while 2.74 Hz at the 8 km/h running speed.

The average fade duration is the ratio between the total time the received signal is below a reference threshold, θ, and the total number of fades. It helps determine the most likely number of bits that may be lost during a fade. Fig. 5 displays the AFD at different running speeds and the AFD value for a given threshold θ=-10 dB is also showed in Tab. 1. It was observed that AFD is independent on the running speed. compared to the dynamic on-body channel investigation at 2.45GHz[18], HBC achieved lower AFD values.

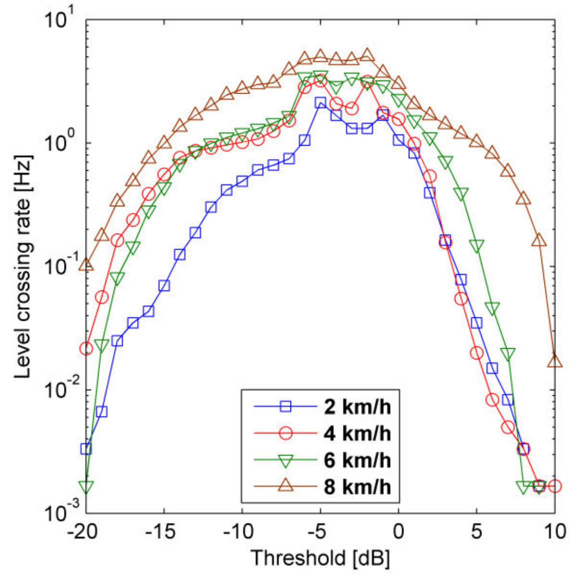

Figure 4. Level crossing rate at different running speeds.

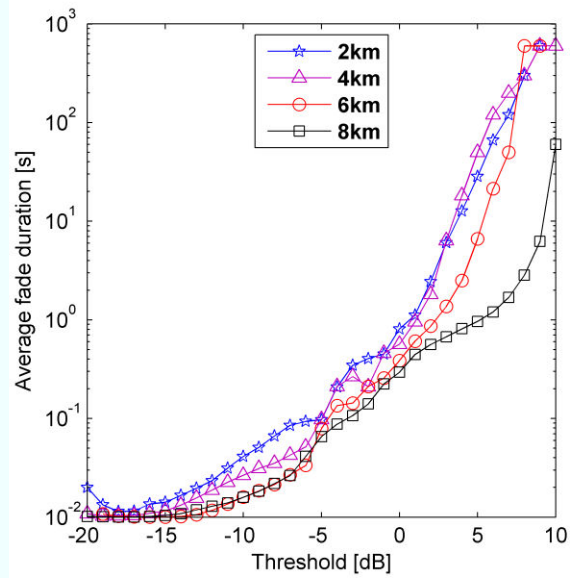

Figure 5. Average fade duration at different running speeds.

The empirical cumulative distribution function (ECDF) of fading duration which is the total time for the received power is lower than a given threshold θ=-10dB was drawn, as the Fig. 6 shows. The channel is bad when the received power drops below the threshold θ, otherwise, the channel is termed good. We observed that the fading duration (time of bad channel occupied) is dependent on the running speed. Most of the fading time (for the CDF is nearly 0.9) is below 60ms at 2km/h, whereas below 30 ms at the higher speeds. Meanwhile, no fading duration time excesses 200 ms. The percentage of the fading duration (PFD) for each configuration or the percentage of the time when the channel is bad is summarized in Tab. 1, we noted that the percentage values have no obvious regularity with the running speed, while at 8 km/h has the maximum value of 4.35%. we compared this parameters to the UWB communication that has been investigated in [15], the bad channel occupied a relative smaller percentage in HBC was observed.

The best distribution fitting and estimated parameters for the ECDF of fading duration are also illustrated in Fig. 6. The Gamma distribution fitted well at the 2 km/h and 4 km/h running speeds while Lognormal distribution behaved well at 6 km/h and 8km/h running scenarios.

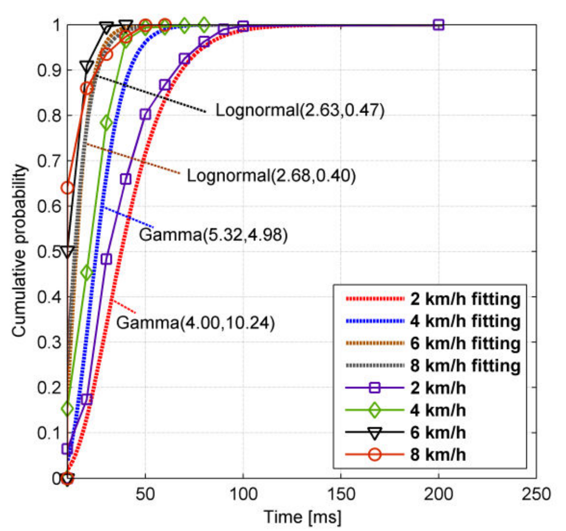

Figure 6. ECDF and the fitting of bad channel duration time.

IV. Conclusion

In this paper, a wearable self-assembled measurement system that at a real HBC application scenario was adopted to perform the dynamic HBC channel measurement with three volunteers in a lab room, and the statistical characterization of the running activities with different speeds on the treadmill were presented. The time series of the measured data was observed by the amplitude fluctuation in a regular base along with the running actions. By using the MLE and AIC, Gamma and Lognormal distribution were found to be the best fitting distributions for the slow (2 km/h and 4km/h) and fast (6 km/h and 8 km/h) running configurations, respectively. The LCR is dependent on the running speeds while AFD is not. Given a threshold θ=-10dB,the maximum LCR is 2.74 Hz at the 8 km/h running speed and the AFD value ranges from 0.0159 s to 0.0413 s. The fading duration is dependent on the running speed, most of the fading duration time is below 60 ms while no fading duration time excesses 200 ms, the maximum calculated percentage of bad channel duration is 4.35%. According to the observation from the time-vary characteristics and the statistical analyses, it was conclude that HBC channel suffered but insensitive to body motion with it has lower AFD and the less percentage of the bad channel duration time, which preliminarily showed the great promise in BSN/BAN applications.

References

[1] B. Latre, B. Braem, I. Moerman, C. Blondia, and P. Demeester, "A survey on wireless body area networks," *Wireless Networks,* vol. 17, pp. 1-18, Jan 2011.

[2] H. F. Rashvand, V. T. Salcedo, E. M. Sanchez, and D. Iliescu, "Ubiquitous wireless telemedicine," *Communications, IET,* vol. 2, pp. 237-254, 2008.

[3] Y. Guang-Zhong, *Body Sensor Networks*. London: Springer, 2006.

[4] M. Patel and W. Jianfeng, "Applications, challenges, and prospective in emerging body area networking technologies," *Wireless Communications, IEEE,* vol. 17, pp. 80-88, 2010.

[5] T. G. Zimmerman, "Personal Area Networks: Near-field intrabody communication," *IBM Systems Journal,* vol. 35, pp. 609-617, 1996.

[6] H. Baldus, S. Corroy, A. Fazzi, K. Klabunde, and T. Schenk, "Human-centric connectivity enabled by body-coupled communications," *Communications Magazine, IEEE,* vol. 47, pp. 172-178, 2009.

[7] R. Xu, H. Zhu, and J. Yuan, "Electric-Field Intrabody Communication Channel Modeling With Finite-Element Method," *Biomedical Engineering, IEEE Transactions on,* vol. 58, pp. 705-712, 2011.

[8] K. Fujii, M. Takahashi, and K. Ito, "Electric Field Distributions of Wearable Devices Using the Human Body as a Transmission Channel," *Antennas and Propagation, IEEE Transactions on,* vol. 55, pp. 2080-2087, 2007.

[9] M. S. Wegmueller, M. Oberle, N. Felber, N. Kuster, and W. Fichtner, "Signal Transmission by Galvanic Coupling Through the Human Body," *Instrumentation and Measurement, IEEE Transactions on,* vol. 59, pp. 963-969, 2010.

[10] K. Y. Yazdandoost and K. Sayrafian-Pour, "Channel Model for Body Area Network (BAN)," *IEEE P802.15-08-0780-12-0006,* 2010.

[11] N. Cho, J. Yoo, S. J. Song, J. Lee, S. Jeon, and H. J. Yoo, "The Human Body Characteristics as a Signal Transmission Medium for Intrabody Communication," *Microwave Theory and Techniques, IEEE Transactions on,* vol. 55, pp. 1080-1086, 2007.

[12] W. H. Organization. (1993). *Electromagnetic Fields (300 Hz to 300 GHz)*. Available: http://www.inchem.org/documents/ehc/ehc/ehc137.htm

[13] S. Patel, K. Lorincz, R. Hughes, N. Huggins, J. Growdon, D. Standaert, M. Akay, J. Dy, M. Welsh, and P. Bonato, "Monitoring Motor Fluctuations in Patients With Parkinson's Disease Using Wearable Sensors," *Information Technology in Biomedicine, IEEE Transactions on,* vol. 13, pp. 864-873, 2009.

[14] K. P. B. D. R. Anderson, *Model selection and multimodel inference : a practical information-theoretic approach*, 2nd ed. ed. New York,: Springer-Verlag New York, Inc., 2002.

[15] A. Taparugssanagorn, B. Zhen, R. Tesi, M. Hämäläinen, J. Iinatti, and R. Kohno, "A UWB WBAN channel model based on a pseudo-dynamic measurement," *Annals of Telecommunications,* vol. 66, pp. 177-185, 2011.

[16] K. Minseok and J. I. Takada, "Statistical Model for 4.5-GHz Narrowband On-Body Propagation Channel With Specific Actions," *Antennas and Wireless Propagation Letters, IEEE,* vol. 8, pp. 1250-1254, 2009.

[17] S. L. Cotton and W. G. Scanlon, "Characterization and Modeling of the Indoor Radio Channel at 868 MHz for a Mobile Bodyworn Wireless Personal Area Network," *Antennas and Wireless Propagation Letters, IEEE,* vol. 6, pp. 51-55, 2007.

[18] Z. H. Hu, Y. I. Nechayev, P. S. Hall, C. C. Constantinou, and H. Yang, "Measurements and Statistical Analysis of On-Body Channel Fading at 2.45 GHz," *Antennas and Wireless Propagation Letters, IEEE,* vol. 6, pp. 612-615, 2007.