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Abstract

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Measurement-Based Characterizations of On-body Channel in the Human Walking Scenario

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Abstract—In Wireless Body Area Networks (WBANs), on-body channels undergo temporal variations predominantly because of the body motion and shadowing of tissue. This paper focuses on a common human activity, walking, to explore the characteristics of the dynamic on-body propagation channel. A customized portable wireless sounder is built and utilized to collect the original on-body channel data both for the indoor and outdoor environments. We focus on exploring the second-order statistics of the channel gain variation during walking, including the temporal autocorrelation, the cross-correlation and the channel gain discrepancy between the two correlated links. This channel characterization facilitates more efficient designs and evaluations of WBAN systems, including more efficient network resource allocation and more efficient deployment of cooperative communication.

Index Terms—Wireless Body Area Networks, On-body Channel, Walking Scenario, Statistical Characterization

I. INTRODUCTION

Wireless body area networks (WBANs) are radio networks of sensors and/or actuators, placed on, in, around and/or near the human body, and represent the latest generation of personal area networks [2]. One of the principal application domains of WBANs is health-care, as well as other applications including consumer fitness, emergency services, and consumer entertainment. However, WBAN channels [3] contain a large number of factors contribute to the attenuation of the transmitted signal. These factors, including diffraction, reflection, energy absorption, antenna losses, etc., are particularly different from those in typical radio channels. The IEEE 802.15.6 standard [1] also indicate some unique technical requirements, such as specifications about packet error ratio (PER), radiated transmit (TX) power and transmission latency. Therefore, it is important to investigate the typical characteristics of WBAN channel to facilitate more efficient radio system design.

In the IEEE 802.15.6 BAN standard [1], three types of physical layer are defined, namely narrowband communications, ultra-wideband (UWB) communications and human body communications (HBC). Compared to UWB and HBC, narrowband communications is better suited to most WBAN applications, not only because of its mature technology but also resolvable multipath and inter-symbol interference (ISI) can be neglected [4], [5]. Besides, on-body channels are considered as the most prevalent channel for most WBAN

applications. Thus on-body channels in narrowband communications WBANs are the focus of this paper.

The small-scale fading models for fitting probability distributions to measured channel gain (i.e., the inverse of path loss), have been explored extensively in the literature [6]–[9]. In general, the best-fitting distributions to channel gain are lognormal, gamma and Weibull. The Rayleigh distribution is a poor choice for WBAN channels, though it is a good fit when various multipath in the radio channel are additive in the linear domain. For the walking scenario, the Weibull distribution is found to be the best-fit.

On the other hand, with respect to the large-scale fading models, the distance between two radio devices are utilized to model WBAN channels' channel gain [10]–[12]. However, as the WBAN is a short-range communication, for majority of scenarios, the signal attenuation is significantly affected by the shadowing of body tissues instead of the distance between two devices.

The complexity of human long-term activities (in terms of pattern, rate and frequency) and the placement of radio units result in the irregularity of channel state, which means that WBAN channels are not wide-sense-stationary (WSS) outside time frames of 500ms or less [13]. However, many existing channel models were proposed under the assumption of WSS, this implies that these channel models only provide limited descriptions of realistic on-body channels. Consequently, it is proposed to test the appropriateness and validity of various radio system designs using reliable empirical data, rather than long-term statistical modelling [14].

In this paper, we select walking scenario as an example to explore the dynamics of on-body channel, especially its second-order characteristics. Our previous work [18], proposed an aggregative transmission scheme combined with network coding, called A3NC, which took advantage of the negative correlation between the channels. However, this work was evaluated in a simulated walking scenario; therefore, another motivation of this paper is verifying the rationale of our proposed A3NC based on real channel dataset. Specifically, we have built customized wireless transceivers to measure actual empirical channel gain data in the walking scenario, in which two sensors are bound on two wrists and communicate with the hub (gateway) located on the torso.

Fig. 1. Hardware design diagram

II. MEASUREMENT SETUP

Many current works utilize the vector signal analyser (VSA) as the testbed to capture the on-body channel information in dynamic motion scenarios. However, due to the size and power requirements of VSA, it is impractical to capture real channel state information in a dynamic mobile scenario. For example, some existing works adopted walking or running on the spot, some performed the measurement on a treadmill, and the majority was carried out indoors. Given this limitation, we have built a portable wireless transceiver to collect the real on-body channel information in movement scenario, which is self-powered and capable to collect real-time channel gain data.

A. Transceiver Implementation

Inspired by the testbed design in [15], we construct our new wireless transceiver from easy-assembled and widely available commercial hardware modules. As illustrated in Fig. 1, each wireless transceiver consists of one radio module, one micro-controller, one MicroSD card and two AAA batteries. The microcontroller controls all other components; the batteries supply power; the radio module is in charge of broadcasting and receiving wireless signals, and the MicroSD card stores the information of wireless channels. The main function of these devices is to transmit and receive continuous data packets from each other, thus facilitating the analysis of channel gains.

Based on the hardware design in Fig. 1, all the components are chosen from the mature commercial products.

- **Radio Module:** The XBee series1 is utilized as the RF front end, which works within the 2.4GHz ISM band. When in operation, the XBee's output power is set to $0dBm$.

- **Microcontroller:** the Arduino OUN is utilized as the logical controller board. Both the XBee module and MicroSD card shield module are plugged into the control board. The Arduino OUN not only controls the sending and receiving of data from radio module, but also writes the channel information to the MicroSD card. When the testbed is in operation, one packet will be broadcast at the data rate of 250kbps every 5ms.

- **MicroSD card:** The MicroSD card is used to record the channel information by receiving data from the radio. More specifically, the receivers write the receiving time, packet ID and the real-time received signal strength indicator (RSSI) value to the MicroSD card. Note that since the XBee's

Fig. 2. Components of radio device and the deployment on subject's body

Fig. 3. Typical indoor and outdoor environment

transmission power is $0dBm$, the RSSI value is actually equal to the channel gain and is the inverse of the path loss.

- **Battery:** A power shield with two AAA batteries is plugged into the control board to supply the power.

As shown in Fig. 2, the wireless transceiver looks like a "sandwich" with three PCBs overlying each other to make the system self-contained.

B. Measurement environment and procedure

In our experiment, the measurements were conducted in both indoor and outdoor environments. As shown in Fig. 3, the outdoor environment was an open oval field of about 13000 square meters. The indoor environment is a hallway inside a building.

As the swinging motion of human arms is a unique feature in the human walking scenario, in this paper, we mainly consider the network deployment in Fig. 4 with two sensors bound on the wrists.

As shown in Fig. 4, we consider two locations for the hub (coordinator or gateway), i.e. on the abdomen (attached to the belt) and on the back collar, where a subject could comfortably wear the hub that is expected to be larger than a sensor node. Two sensors (SN_1 and SN_2) are attached to the wrists. Moreover, to explore the effect of the antenna direction and the wrist's shadowing, the XBee module is also rolled around the wrist in four directions: 0° , 90° , 180° and 270° ,

Fig. 4. Deployment of the sensors and the hub

Fig. 5. Four directions of the testbed on the wrist

as depicted in the Fig. 5. Consequently, there are 16 individual experimental setups ($2 \times 2 \times 4$) in total.

Concerning each measurement setup, the hub node is configured to broadcast packets to two sensors continuously with the frequency of 200Hz (200 sample per second). In other words, the time resolution is 5ms, considered to be sufficient to capture the time variation of the on-body channels. On the other hand, when the XBee modules on the wrists receive the packets, the microcontroller extracts the RSSI and writes it to the MicroSD card together with the system time and the packet sequence. As each setup lasts for about 1 minute (walking one minute) and there are 16 setups, 16-minutes channel gain data, containing about 192000 samples, is recorded.

In addition, it is necessary to explain why the downlinks (from the hub to the sensors) are utilized to capture the channel gain, instead of the uplinks (from the sensors to the hub). As demonstrated in [15] and [16], in the narrowband communication environments the on-body channels show prominent reciprocity, which means the channel profiles of downlink and uplink are the same. Moreover, as the two sensors record the corresponding RSSI almost simultaneously, the downlinks are a better choice for the cross-correlation analysis.

III. RESULTS AND ANALYSIS

A. Shadowing Effect in Signal Attenuation

We first analyze the path loss variation for the hub placing on different locations, i.e. on the abdomen and on the back collar, and explore the insight of the body's shadowing effect. Since the influence from reflection can be neglected in the outdoor environment, the outdoor cases are chosen for this purpose. Besides, to focus on the torso's shadowing, the 0° cases are selected. Fig. 6 shows the plots of a typical time

Fig. 6. Time variation of the RSSI

Fig. 7. RSSI variation and corresponding walking phase when the hub is deployed on the abdomen

Fig. 8. RSSI variation and corresponding walking phase when the hub is deployed on the back collar

variation of RSSI for the link from one sensor to the hub in the outdoor environment.

As shown in Fig. 6, the path loss exhibit sharp fluctuations either for the “abdomen” case and “back collar” case. To deepen understanding of the shadowing effect from body parts in the human walking scenario, Figs. 7 and 8 illustrate the trend of RSSI variation and corresponding walking phases.

As shown in Fig. 8, when the hub is placed on the back collar, the distance from the wrists to the hub nearly remains the same. However, the path loss curve still exhibits sharp fluctuation when the person walks. Further, the signal attenuation is highly relevant to the “extent” of the body part that shadows the direct link between the transmitter and receiver. The “extent” here refers to the volume and depth of

Fig. 9. Autocorrelation vs. Time interval

the impeding body part. On the other hand, if the shadowing from body parts can be neglected, the path loss is also affected by the distance between them, but causing a much smaller impact compared to the body's shadowing. Considering the process in Fig. 7 as an example, when moving from P_1 to P_3 , the links remains in line-of-sight (LOS); consequently, the path loss diminishes with the decrease of the distance between the two radios. Conversely, when the arm swings behind the torso (P_3 to P_5), the channel gain suffers a steep drop. In other words, the absolute value of the curve's gradient for P_3 - P_5 is much bigger than that for P_1 - P_3 , which confirms the body shadowing as the predominant factor to the signal attenuation.

B. Autocorrelation and Periodicity

In this subsection, we will explore the periodicity of channel gains by exploring more insight behind the temporal autocorrelation of channel gains. Intuitively, the periodicity results from walking cycles, and as seen from Fig. 6, the periodic trend in the channel gain variation can be clearly observed, for both "abdomen cases" and "collar cases". Whereas the periodicity seems to not be straightforward, when the experiment is performed in the indoor environment or the transceiver is rolled around the wrist (the RSSI plots for these cases are not shown due to the limited space). To deepen the insight behind the periodicity, we utilize Pearson product-moment correlation coefficient (PCC) [17] to present the temporal autocorrelation of channel gain.

$$\rho_a(\tau) = \frac{\sum_{n=1}^{N-\tau} (x(n) - \bar{x})(x(n+\tau) - \bar{x})}{\sqrt{\sum_{n=1}^{N-\tau} (x(n) - \bar{x})^2} \sqrt{\sum_{n=1}^{N-\tau} (x(n+\tau) - \bar{x})^2}} \quad (1)$$

where $\bar{x}$ is the mean of the RSSI in dBm , τ is the time delay and $N=12000$ is the length of each measurement.

Taking the channel SN_1 -hub as an example, Fig. 9 shows the autocorrelation coefficients for different setups. From Fig. 9, the PCC exhibits a clear periodicity and it is easy to extract the cycle period to be around 1050ms. In the indoor scenarios, there are more reflections from surrounding objects; hence the

TABLE I
CROSS-CORRELATION BETWEEN TWO LINKS

	Indoor		Outdoor	
	Abdomen	Collar	Abdomen	Collar
0°	-0.70	0.09	-0.68	0.24
90°	-0.37	0.02	-0.45	0.37
180°	0.00	0.06	-0.30	0.32
270°	-0.59	-0.31	-0.73	-0.67

curves experience more small deviations and the amplitude of PCC is relatively smaller. Moreover, when the radio device rolls around the wrist, i.e. 0° , 90° , 180° and 270° , the PCC is affected. The differences mainly result from the change of antenna's direction and the change of shadowing from the arms. Especially for the case of 180° , since the transceivers are bound on the top of wrists and is shadowed further by the wrist itself, the PCC for these cases still exhibit the periodicity but with smaller amplitudes.

C. Cross-correlation and Channel Gain Difference

The cross-correlation between different links is instructive for network resource allocation and the schedule of cooperative communication. Similar to the above autocorrelation analysis, the PCC is used to evaluate the cross-correlation between two channels from sensors to the hub.

$$\rho_c = \frac{\sum_{n=1}^N (x(n) - \bar{x})(y(n) - \bar{y})}{\sqrt{\sum_{n=1}^N (x(n) - \bar{x})^2} \sqrt{\sum_{n=1}^N (y(n) - \bar{y})^2}} \quad (2)$$

where $\bar{x}$ is the mean of the RSSI of link from SN_1 to the hub in dBm , and $\bar{y}$ is the mean RSSI of the link from SN_2 to the hub.

Table I presents the correlation coefficient for different experimental setups. The walking scenario exhibits relatively low spatial cross-correlation coefficients, as spatial cross-correlation is generally considered to be significant for values of 0.7 or greater. This result is also confirmed by the work in [15]. Further, the cross-correlations vary dramatically with the network deployment, including the placement of the hub and sensors, surrounding environment and transceiver's direction. Interestingly, compared to the cases of 0° , 90° , and 270° , the case for 180° exhibits the lowest cross-correlation. The reason is similar to the explanation for temporal autocorrelation, i.e., the shadowing of the wrist and the arm.

The PCC provides the correlation and periodicity between channels. However, a low absolute value of PCC does not necessarily mean that two links are completely independent; for example, it does not reflect the actual difference between the two channel gains. In this paper, we introduce another new, simple but important parameter, namely the channel gain (or RSSI) discrepancy (in dB) to reflect the actual difference between two channel gains. We denote the discrepancy as CGD, The CGD is crucial for estimation of SINR (signal to interference plus noise ratio) in contention-based network

Fig. 10. The distribution of the CGDs

resource management, and may provide new potential to design more efficient transmission schemes.

As shown in Fig. 10, the probability distributions of the CGD are different in different the experimental setups, but they all show a high proportion for the case when the CGD being greater than 5dB . Besides, the CGD medians for four experimental setups from (a) to (d) are 15dB , 7dB , 21dB and 11dB respectively. Obviously, in the outdoor environment the CGD tends to be greater than that in the indoor environment. The main reason is that the reflections from surrounding objects in the indoor environment narrow the gap between two RSSI. Besides, the “abdomen cases” experience a bigger CGD than the “collar cases”, mainly because the shadowing effect is stronger for the “collar cases” in comparison with the “abdomen cases”.

Further, if two sensors broadcast the packet simultaneously, the gap between two channel gains is the major constituent of the overall SINR, assuming that the environmental noise is relatively low. The relationship between SINR and BER has been investigated intensively in the literature, which indicates that $\text{SINR} > 5\text{dB}$ can achieve a reasonable low BER for most low-order modulation schemes. Accordingly, if two sensors located on the wrists concurrently broadcast packets to the hub on the torso in walking scenarios, the hub can restore at least one signal with a high probability. This preliminary qualitative result explains the rationale of our proposed aggregative allocation scheme [18], plus it may provide a new perspective to optimize the WBAN transmission systems.

IV. CONCLUSION

In this paper, we have detailed our customized portable wireless transceiver for collecting realistic WBAN channel gain data in walking scenarios. The measurement results confirm that body shadowing is a predominant factor for signal attenuation in the 2.4GHz ISM band. Besides, a detail illustration of the variation of the channel gain and some second-order characteristics (autocorrelation, cross-correlation and channel gain discrepancy) have also been deprived. Strong periodicity is observed due to the cycle of up limb swing. Interestingly, although the cross-correlation between on-body

channels is not significant, the channel gain discrepancy tends to remain large in a large proportion of time. These novel channel characteristics may facilitate more efficient system design and system evaluation schemes, including but not being limited to efficient network resource management and efficient cross-layer cooperative communication protocols.

REFERENCES

- [1] “IEEE standard for local and metropolitan area networks: Part 15.6: wireless body area networks”, *IEEE submission*, Feb. 2012.
- [2] S. Movassaghi, M. Abolhasan, J. Lipman, D. Smith, and A. Jamalipour, “Wireless body area networks: A survey,” *IEEE Communications Surveys & Tutorials*, vol. 16, pp. 1658-1686, 2014.
- [3] K. Y. Yazdandoost and K. Sayrafi-Pour, “Channel Model for Body Area Network (BAN)” *Network*, pp.91, 2009.
- [4] A. Fort, J. Ryckaert, C. Desset, P. D. Doncker, P. Wambacq, and L. V. Biesen, “Ultra-wideband channel model for communication around the human body,” *IEEE Journal on Selected Areas in Communications*, vol. 24, pp. 927-933, 2006.
- [5] D. Smith, D. Miniutti, L. Hanlen, A. Zhang, D. Lewis, D. Rodda, et al., “Power delay profiles for dynamic narrowband body area network channels id: 15-09-0187-01-0006,” *IEEE Submission*, 2009.
- [6] S. L. Cotton and W. G. Scanlon, “A Statistical Analysis of Indoor Multipath Fading for a Narrowband Wireless Body Area Network,” in *IEEE 17th PIMRC*, 2006, pp. 1-5.
- [7] S. L. Cotton and W. G. Scanlon, “Higher-order statistics for $\kappa - \mu$ distribution,” *Electronics Letters*, vol. 43, p. 1, 2007.
- [8] A. Fort, C. Desset, P. Wambacq, and L. V. Biesen, “Indoor body-area channel model for narrowband communications,” *IET Microwaves, Antennas & Propagation*, vol. 1, pp. 1197-1203, 2007.
- [9] D. B. Smith, L. W. Hanlen, J. Zhang, D. Miniutti, D. Rodda, and B. Gilbert, “First- and second-order statistical characterizations of the dynamic body area propagation channel of various bandwidths,” *annals of telecommunications*, vol. 66, pp. 187-203, 2010.
- [10] A. Alomainy and Y. Hao, “Modeling and Characterization of Biotelemetric Radio Channel From Ingested Implants Considering Organ Contents,” *IEEE Transactions on Antennas and Propagation*, vol. 57, pp. 999-1005, 2009.
- [11] X. Chen, X. Lu, D. Jin, L. Su, and L. Zeng, “Channel Modeling of UWB-Based Wireless Body Area Networks,” in *2011 IEEE ICC*, 2011, pp. 1-5.
- [12] A. Fort, C. Desset, P. D. Doncker, P. Wambacq, and L. V. Biesen, “An ultra-wideband body area propagation channel Model-from statistics to implementation,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 54, pp. 1820-1826, 2006.
- [13] V. Chaganti, L. Hanlen, and D. Smith, “Are Narrowband Wireless On-Body Networks Wide-Sense Stationary?,” *IEEE Transactions on Wireless Communications*, vol. 13, pp. 2432-2442, 2014.
- [14] D. B. Smith and L. W. Hanlen, “Channel Modeling for Wireless Body Area Networks,” in *Ultra-Low-Power Short-Range Radios*, ed: Springer, 2015, pp. 25-55.
- [15] L. Hanlen, V. Chaganti, B. Gilbert, D. Rodda, T. Lamahewa, and D. Smith, “Open-source testbed for Body Area Networks: 200 sample/sec, 12 hrs continuous measurement,” in *IEEE 21st PIMRC Workshops*, 2010, pp. 66-71.
- [16] M. Lauzier, P. Ferrand, A. Fraboulet, H. Parvery, and J. M. Gorce, “Full mesh channel measurements on Body Area Networks under walking scenarios,” *7th EuCAP*, 2013, pp. 3508-3512.
- [17] K. Pearson, “Note on regression and inheritance in the case of two parents,” *Proceedings of the Royal Society of London*, vol. 58, pp. 240-242, 1895.
- [18] Z. Hongyun, F. Safaei, and T. Le Chung, “Joint analog network coding and channel allocation in the walking scenario for WBAN,” in *2016 ISCC*, 2016, pp. 604-609.