

Experimental Investigation of On-Body Channel Modelling at 2.45 GHz

Hasliza A. Rahim, Fareq Malek, Nur A. M. Affendi, Azuwa Ali, Norshafinash Saudin, Latifah Mohamed

Abstract—This paper presents the experimental investigation of on-body channel fading at 2.45 GHz considering two effects of the user body movement; stationary and mobile. A pair of body-worn antennas was utilized in this measurement campaign. A statistical analysis was performed by comparing the measured on-body path loss to five well-known distributions; lognormal, normal, Nakagami, Weibull and Rayleigh. The results showed that the average path loss of moving arm varied higher than the path loss in sitting position for upper-arm-to-left-chest link, up to 3.5 dB. The analysis also concluded that the Nakagami distribution provided the best fit for most of on-body static link path loss in standing still and sitting position, while the arm movement can be best described by log-normal distribution.

Keywords—On-Body channel communications, fading characteristics, statistical model.

I. INTRODUCTION

BODY-CENTRIC Wireless Communications (BCWC) has received a growing attention due to promising new applications in home/health care, medical, military, sports, multimedia and other areas [1]-[6]. The miniaturization of wearable hardware, embedded software, digital signal processing and biomedical engineering development has turned human to human networking integrated with wearable sensors into reality [7]. Generally, BCWC includes number of wireless sensors placed on the human body where other on-body units, external base stations or wireless implants are made available to communication with these sensors.

In the open literature, many statistical analyses for the fading characteristics of on-body radio channel have been reported at 2.45 GHz [1], [8]-[10]. In [8], the authors reported that Nakagami- m distribution described well for the on-body mobile channel. Lognormal distribution was found to be best fit for fast fading in most of on-body channels in anechoic chamber [1], [10] and indoor environment [1]. However, Nakagami or Rician distribution was the best distribution to describe fast fading in a scattering environment, i.e. office [9].

The aim of this study was to experimentally investigate the fading characteristics for on-body radio channel. This work

H. A. Rahim is with the Embedded Computing Research Cluster, School of Computer and Communication Engineering, Universiti Malaysia Perlis, P. O. Box, Perlis, Malaysia (e-mail: haslizarahim@unimap.edu.my).

F. Malek, A. Sahadah, I. Adam, and N. B. M. Hashim are with the Embedded Computing Research Cluster, School of Computer and Communication Engineering, Universiti Malaysia Perlis, P. O. Box, Perlis, Malaysia (e-mail: mfareq@unimap.edu.my).

N. A. M. Affendi, A. Ali, N. Saudin, and L. Mohamed are with School of Electrical System Engineering, Universiti Malaysia Perlis, P. O. Box, Perlis, Malaysia (e-mail: nuradyani@unimap.edu.my).

highlights on a fast fading due to the effect of several human body postures and arm movement.

The paper is organized as follows. Section II describes the setup to perform the on-body measurement. Section III presents a brief background of statistical parameters and goodness of fit technique, Akaike Information Criteria. Section IV presents the results and analysis of the measured data. Finally, Section V provides a concluding remark of this work.

II. ON-BODY CHANNEL MEASUREMENT SETUP

The measurement campaign was performed in an anechoic chamber, located at Electromagnetic Hypersensitivity (EHS) Laboratory, Politeknik Tuanku Syed Sirajuddin, Perlis, Malaysia. In this work, we focused in investigating the influence of human body effect considering different body postures and arm movement on the channel fading characteristics. A vector network analyzer (VNA) was utilized in this measurement campaign to measure the frequency response, S_{21} parameter. Two omni-directional planar textile monopole antennas, resonating at 2.45 GHz Industrial, Scientific and Medical (ISM) band, with excellent impedance matching were used in the campaign, as analyzed in [11], [12]. Two low loss Huber Suhner coaxial cables of 5 meters were used to connect two antennas to two ports of VNA.

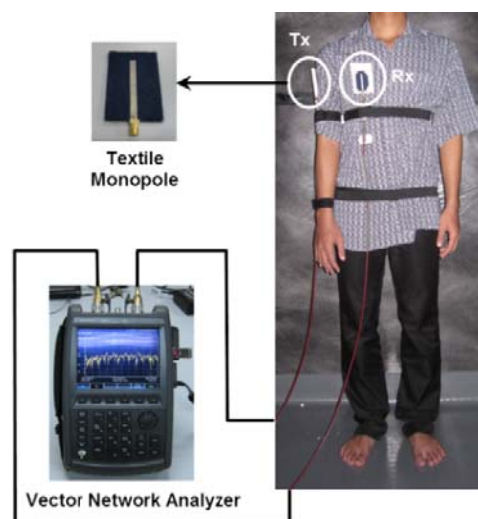


Fig. 1 Measurement setup in anechoic chamber using body-worn antennas

TABLE I
ON-BODY PATH LOSS

Scenarios	Locations	Lognormal		Normal		Nakagami		Weibull		Rayleigh	
		μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
Standing Still	Right chest	43.59	0.40	43.59	0.40	43.59	0.36	43.56	0.59	38.64	407.88
	Right waist	41.98	0.33	41.98	0.33	41.98	0.29	42.00	0.24	37.20	378.19
	Right thigh	48.80	0.71	48.80	0.71	48.80	0.64	48.80	0.69	43.25	511.16
	Left ankle	56.74	0.36	56.74	0.36	56.74	0.32	56.73	0.41	50.28	690.87
	Back	48.50	0.48	48.50	0.48	48.50	0.43	48.47	0.69	42.99	504.89
Sitting	Left chest	60.52	0.05	60.52	0.05	60.52	0.04	60.50	0.08	53.63	786.03
Arm Movement	Left chest	64.32	1.00	64.32	1.01	64.32	0.90	64.27	1.51	57.01	887.99

These coaxial cables were covered with microwave absorbing material to reduce the radiation of the cables. A sweep time of 4.25 s with a sampling time of 4.25 ms was configured, resulting a total number of sampled points per acquisition of $N=1001$. Six human subjects (three males and three females) were involved in this measurement in order to consider the variability of different physical bodies and genders on the channel fading characteristics. The transmitting antenna (Tx) was mounted on a fixed on-body location at right upper arm of the subject body. The receiving antenna (Rx) was mounted on the different on-body locations for standing still, sitting and arm movement:

- Five on-body locations, i.e., right chest (Rx1), right waist (Rx2), right thigh (Rx3), left ankle (Rx4) and on the centre of back (Rx5) while standing still;
- One on-body location, left chest (Rx6) while sitting on the chair;
- One on-body location, (Rx6) while performing random arm movement on sitting posture.

10mm of air-gap separation between antenna and the body was set. The average height and weight of all subjects were 161.1cm and 62.7kg, respectively. To exclude the cable losses, the VNA was consistently calibrated during the measurements. The input power of Tx was set at 0 dBm. Ten sweep durations were captured for each body posture and movement. Elastic bands were used to hold the coaxial cables, attaching to the body, from moving and bending throughout the measurement campaign. This measurement setup follows the standard procedure reported in [1], [10]-[13].

III. ON-BODY RADIO CHANNEL ANALYSIS

A. Statistical Parameters

The measured data is statistically analyzed by fitting the data to several well-known distribution functions namely: log-normal, normal, Nakagami, Weibull and Rayleigh. These statistical distributions were chosen as these distribution functions are extensively being applied to statistically model the on-body channel [10]. The estimated parameters are computed using maximum likelihood estimation for all distributions.

B. Akaike Information Criteria

To select the best model among several models of fading, Akaike Information Criterion (AIC) is used [8], [11]. In [14], it reported a detailed description of the usage of AIC's and its drawback in determining the fading models for body-centric

channels. The second order AIC, normally expressed as AIC_c , written as

$$AIC_c = -2 \log_e(L) + 2K + \frac{2K(K+1)}{n-K-1} \quad (1)$$

where L is the maximized log likelihood, model K is the number approximation parameters in the selected model and n is the sample size. The log likelihood is available in the Maximum Likelihood (ML) estimator and thus (1) can be directly computed. Meanwhile, the second part of (1) restricts additional parameters so as to guarantee that best fits the data with the least of parameters. In determining the models rank from the best to worst and to show strong proof that one model is better than another, the relative values of AIC_c is utilized. The expression for relative values of AIC_c is

$$\Delta i = AIC_{c,i} - \min(AIC_c) \quad (2)$$

where, AIC_c is the AIC value for model index i . From (2), the best model among the set of models is determined when $\Delta i = 0$. In general, $\Delta i < 2$ refers to significant evidence for model and if values are between 3-7, it implies that the model has less satisfactory level. However, if values are greater than 10, it suggests that the model is impossible to happen.

IV. RESULTS AND DISCUSSION

A. On-Body Path Loss Statistics

In anechoic chamber where the effect of multipath fading is minimized, the path loss of on-body radio channel is mainly due to the lossy human tissues, leading to high attenuation, and the movement of the human body. In this work, two scenarios are considered: stationary and body movement. As known, a larger signal variation occurs when the transmitter moves with respect to the receiver than when the transmitter is in stationary position. Table I presented the average value (μ) and standard deviation, (σ) of path loss statistical models.

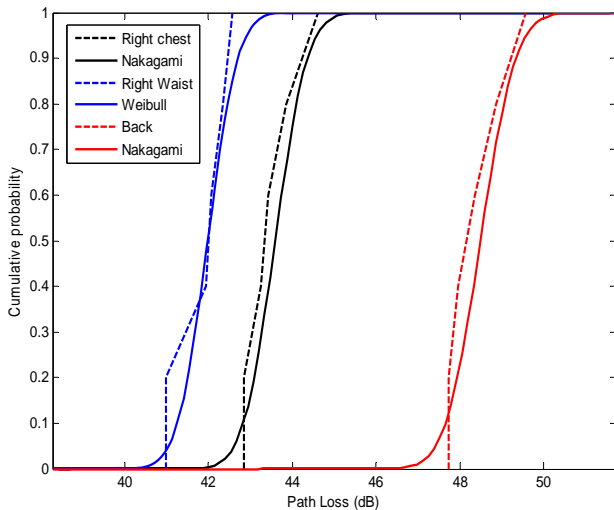


Fig. 2 Cumulative distribution of the path loss fitted to the best statistical model for standing still in right chest, right waist and back positions

For standing still posture, as expected, the highest average path loss occurred on the upper-arm-to-left-ankle link as the communication distance between Tx and Rx4 is the furthest. The smallest value of average path loss was obtained by fitting the measured data to Weibull distribution. Meanwhile, the lowest average path loss was observed by the upper-arm-to-right-waist link that obtained high similarity in statistical fit to all distributions, except Rayleigh. The least spread of data, indicating by the smallest value of σ in upper-arm-to-right-waist link case for most distributions showed a high accuracy of statistical fit. The results also showed that the average path loss of moving arm varied higher than the path loss in sitting position, up to 3.5 dB. This confirms that upper-arm-to-left-chest was more affected by the movement of arm. Higher value of σ for Rayleigh distribution in all on-body links of all cases showed the worst statistical model compared to other distributions.

B. Statistical Analysis

The measured data was statistically analyzed by applying the second-order AIC to determine the best fit model for all cases. The estimated parameters were computed based on 95% confidence interval utilizing dfit tool in the Matlab statistical toolbox. In stationary case, the on-body receivers were located at different elevations and positions, from upper-arm-to-left chest to upper-arm-to-left-ankle link.

For standing still scenario, it was found that Nakagami provided the best fit in most on-body links including right chest, left ankle and back positions with the remaining on-body link fitted to Weibull distribution. Fig. 2 shows the measured data with its best fit for standing still case in right chest, right waist and back positions. Furthermore, Nakagami also provided the best fit for sitting case in left chest position, as shown in Fig. 3.

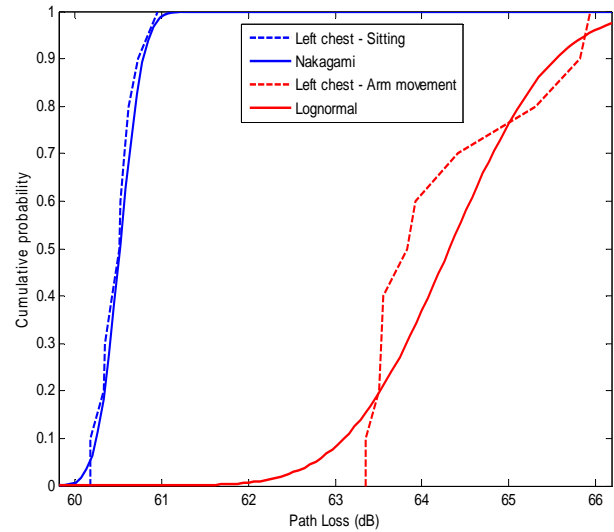


Fig. 3 Cumulative distribution of the path loss fitted to the best statistical model for sitting and arm movement in the left chest

When the user was in stationary regardless the body positions, it was observed that no dominant component was present as small multipath fading was experienced in this case, both for line-of-sight (LOS) and non-line-of-sight (NLOS).

On the other hand, for the arm movement case, the result showed that the lognormal distribution provided the best fit ($\mu = 4.14$, $\sigma = 0.004$). This explains that the moving arm contributed to the reflections and shadowing effects when the electromagnetic (EM) propagated across the human body surface. As the dominant of the received signals were the reflection and diffraction waves, this led to a lognormal distribution, as agreed in [10]. Meanwhile, the worst fit was given by Rayleigh distribution in both cases, stationary and mobile.

V. CONCLUSION

The experimental investigation and statistical analysis of on-body channel fading at 2.45 GHz has been performed in this work. The measurement was carried out in the anechoic chamber where two user state conditions were considered; stationary and mobile. For standing still case, various on-body links were performed. However, for sitting (static) and arm movement cases, only one on-body link was performed. In the future work, more on-body links with various body movements will be carried out in both anechoic and indoor environments to study the effects of human body movements on the on-body radio channel propagation. The results showed that the average path loss of moving arm varied higher than the path loss in sitting position for upper-arm-to-left-chest link, up to 3.5 dB. The analysis also concluded that the Nakagami distribution provided the best fit for most of on-body static link path loss in standing still and sitting positions (4 on-body links). The log-normal distribution provided the best fit for only one case, the arm movement, due to the effects of reflections, diffraction etc.

ACKNOWLEDGMENT

The authors would like to thank the subjects who involved in this measurement setup. This work is partially supported by the Short Term Grant scheme Universiti Malaysia Perlis, under grant 9001-00436, Knowledge Transfer Programme Grant (KTP), grant no. 9011-00009 under Ministry of Higher Education. The authors would also like to express their highest gratitude to Universiti Malaysia Perlis and Ministry of Higher Education.

REFERENCES

- [1] A. Alomainy et al., "Statistical analysis and performance evaluation for on body radio propagation with microstrip patch antenna," *IEEE Trans. on Antennas and Propagation*, vol. 55, no. 1, pp. 245-248, 2007.
- [2] E. Reusens et al., "Characterization of on-body communication channels and energy efficient topology design for wireless body area networks," *IEEE Trans. on Information Technology in Biomedicine*, vol. 13, no. 6, pp. 933-945, 2009.
- [3] H. B. Lim, D. Baumann and E-Ping Li, "A human body model for efficient numerical characterization of UWB signal propagation in wireless body area networks," *IEEE Trans. on Biomedical Engineering*, vol. 55, no. 3, pp. 689-697, 2011.
- [4] X. Chen, X. Lu, D. Jin, L. Su and L. Zeng, "Channel modeling of UWB-based wireless body area networks," in *Procs of 2011 IEEE International Conf. on Communications (ICC)*, June 2011, pp. 1-5.
- [5] Q. Wang, T. Tayamachi, I. Kimura and J. Wang, "An on-body channel model for UWB body area communications for various postures," in *IEEE Trans. on Antennas and Propagation*, vol. 57, no. 4, pp. 991-998, 2009.
- [6] G. A. Conway and W. G. Scanlon, "Antennas for over-body-surface communication at 2.45 GHz," *IEEE Trans. on Antennas and Propagation*, vol. 57, no. 4, pp. 844-855, 2009.
- [7] P. S. Hall and Y. Hao, "Antennas and propagation for body centric communications," in *Procs. of European Conference on Antennas and Propagation (EuCAP)*, Nov. 2006.
- [8] S. L. Cotton and W. G. Scanlon, "An experimental investigation into the influence of user state and body area networks at 2.45 GHz," *IEEE Trans. on Antennas and Propagation*, vol. 8, no. 1, pp. 6-12, 2009.
- [9] Y. I. Nechayev, P. S. Hall, I. Khan, and C. C. Constantinou, "Wireless channels and antennas for body-area networks," in *Procs of 2010 Seventh International Conference on Wireless On-demand Network Systems and Services (WONS)*, Feb. 2010, pp. 137-144.
- [10] A. Michalopoulou, A. A. Alexandridis, K. Peppas, T. Zervos, F. Lazarakis, K. Dangakis, and D. I. Kaklamani, "On-body channel modeling: Measurements and statistical analysis," in *Procs of 2010 Loughborough Antennas and Propagation Conference (LAPC)*, Nov. 2010, pp. 201-204.
- [11] H. A. Rahim, F. Malek, I. Adam, S. Ahmad, N. B. Hashim and P. S. Hall, "Design and Simulation of a Wearable Textile Monopole for Body Centric Wireless Communications," in *PIERS Proceedings*, Moscow, Russia, Aug 2012, pp. 1381-1384.
- [12] H. A. Rahim, F. Malek, N. Hisham and M. F. A. Malek, "Statistical analysis of on-body radio propagation channel for body-centric wireless communications," in *PIERS Proceedings*, Stockholm, Sweden, Aug. 2013, pp. 374-378.
- [13] Q. H. Abbasi, A. Sani, A. Alomainy and Y. Hao, "Experimental characterization and statistical analysis of the pseudo-dynamic ultrawideband on-body radio channel," *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 748-751, 2011.
- [14] A. Fort, C. Desset, P. De Doncker, P. Wambacq and L. Van Biesen, "An ultra-wideband body area propagation channel model-from statistics to implementation," *IEEE Trans. Microwave Theory Tech.*, vol.54, no. 4, pp. 1820-1826, 2006.



Hasliza A. Rahim received the B.Sc degree in electrical engineering from University of Southern California, Los Angeles, United State of America in 2003 and M.Sc. degree in electronic systems design engineering from Universiti Sains Malaysia, Penang, Malaysia in 2006. She is currently working toward the Ph.D degree at Universiti Malaysia Perlis, Perlis, Malaysia.

She is a Lecturer with the School of Computer and Communication Engineering, under Antennas, Microwave, Radio Propagation and Electromagnetics (AMREL) Research Group, Embedded Computing Research Cluster, Universiti Malaysia Perlis, Perlis, Malaysia. Her current research interests include wireless body area networks, radio propagation characterization and modeling, electromagnetics, microwave, bio-medical applications, embedded system, signal processing, and digital communication. She has authored or coauthored several technical papers in journals and conferences as well as reviewed articles in various international conferences proceedings.