# On Body Characterization for On-Body Radio Propagation Channel using Wearable Textile Monopole Antenna

Hasliza A Rahim[1], Fareq Malek[2], Ping Jack Soh[3], Nurbaizatul Hisham[1], Asmi Romli[1], Khatijjahhusna Abd Rani[4], Che Muhammad Nor Che Isa[1] and Fairul Afza[1] Ahmad Fuad[5]

[1]*Bioelectromagnetics Research Group, School of Computer and Communication, Universiti Malaysia Perlis, Kampus Pauh Tetap, Perlis, Malaysia.*

[2]*Department of Engineering and Information Science, University of Wollongong in Dubai, Dubai, UAE.*

[3]*The Advanced Communication Engineering Centre (ACE), School of Computer and Communication, Universiti Malaysia Perlis, Kangar, Perlis, Malaysia.*

[4]*School of Electrical System Engineering, Universiti Malaysia Perlis, Kampus Pauh Tetap, Arau, Perlis, Malaysia.*

[5]*Faculty of Engineering Technology, Universiti Malaysia Perlis, Kampus UniCITI Alam, Sungai Chuchuh, Padang Besar, Perlis, Malaysia.*

*haslizarahim@unimap.edu.my*

***Abstract*—This paper presents the experimental investigation of the characterization of the narrowband on-body radio propagation channel at 2.45 GHz. Wearable planar textile monopole antennas (TM) were used in this measurement campaign. The measurements were conducted in the RF-shielded room environment, considering eight on-body radio links. A statistical analysis was conducted on the spectral parameters of the channel to enable the prediction and modeling of dynamic on-body radio propagation characteristics. The empirical data were fitted to several well-known statistical models to determine the model that provided the best fit for the data. The results showed that the path loss exponent was consistent with the results of previous studies. The results also demonstrated that lognormal distribution was found to be the best fit for path loss in dynamic on-body radio propagation channel.**

***Index Terms*—On-Body Radio Propagation Channel; Textile Antenna; Narrowband; Statistical Model.**

## I. INTRODUCTION

The miniaturization of wearable hardware, embedded software, and digital signal processing has made body-centric wireless communication (BCWC) possible to integrate onto the human body. BCWC has been expanding in a wide range of fields, e.g., medical monitoring and sensing, emergency response, military, sports and in the multimedia field. In biomedical applications, for example, previous researchers have employed wearable health monitoring systems, such as VTAM (Clothes for Tele assistance in Medicine Project), the European Wearable Healthcare System (WEALTHY), LifeShirt [1], and Smart Shirt [2].

In recent years, the development of WBAN has been centered around channel characterization. In this complex scenario, the signal could arrive at its destination through several mechanisms, including penetration inside the body, diffraction, and scattering from body parts and local scatters. The movement of the human body makes this radio channel even more difficult to characterize. Much research has been devoted to characterizing the narrow-band on-body propagation channel [3-13]. In the earlier work, a channel model was derived for body area networks at 400, 900, and 2400 MHz from numerical simulation [3]. The authors reported that the propagation mechanism was dominated by the creeping waves around the human body as opposed to penetration through the body. The results showed that the penetration through the body underwent higher loss. Investigations of the on-body channel for both large-scale and small-scale fadings have been conducted [4-5, 11]. Thus, this paper aims to address the effect of changes in static postures and dynamics on the channel parameters using wearable textile monopole antennas, featuring omni-directional pattern. The findings focused the significance of the effects of body movement when designing the BCWC system due to the unstable of power level of the system [14].

## II. EXPERIMENTAL

A narrowband on-body measurement campaign was performed in an RF shielded room lined with microwave absorbing sheets in the Electromagnetic Hyper Sensitivity (EHS) Laboratory at Politeknik Syed Sirajuddin, Perlis, Malaysia. The dimensions of this RF-shielded room are 4 x 3 x 2.5 $m^3$. The room was furnished with a wooden table, a flat touchscreen monitor, and an arm chair. This measurement campaign was aimed at investigating the effect of metal on the radio propagation channel for on-body scenarios. A 2-port PNA (Agilent PNA E8362B) was used to determine the $S_{21}$ of a link with transmitting (*Tx*)-receiving (*Rx*) antennas placed on the body, as shown in Figure 1. This PNA was consistently calibrated. In these tests, a continuous wave (CW) signal at 2.45 GHz, with a sampling time of 0.5 ms, producing a total of $N$ = 1601 sampled points per acquisition was used. Two four-meter, low-loss, semi-flexible Huber Suhner coaxial cables were used. These cables were wrapped with microwave absorbing foam (Eccosorb Flexible Broadband Urethane Absorber number FGM-U-20-SA) to minimize the spurious radiation from and coupling between the coaxial cable. This measurement setup followed the standard procedure reported in [14-15].

In this work, the antennas were considered to be part of the on-body radio propagation channel. A pair of identical planar TM was utilized. The antenna was horizontally polarized, and the top radiator element was positioned parallel to the subject's body. The placement of the antennas in this work was similar to that in [16-18], i.e., antenna was used that had an omni-directional pattern in which the main radiating elements were parallel to the human body, featuring horizontal polarization. Both the transmitter and the receiver had the same polarization and orientation when mounted on the subject's body. Measurements were performed on two candidates of the average weigh 63 kg and height 1.58 m. This study is limited to the subject of same body mass index (BMI) since the human body channel is subject-specific [15]. The *Tx* (connected to port 1) was fixed at the right side of the upper arm (RUA), near the shoulder. The *Tx* placement was mounted on the RUA because this location was more realistic for the BCWC application; also, it did not limit regular movements of the user.

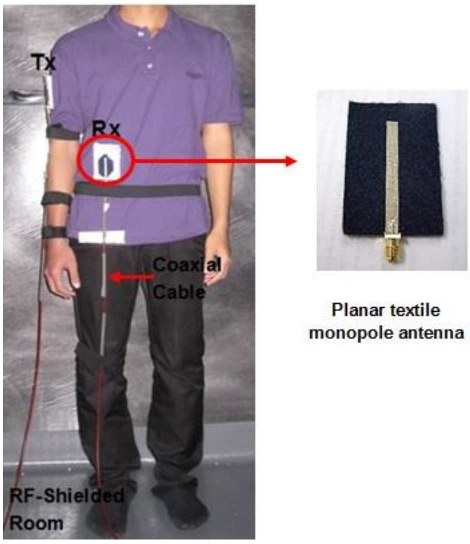


Figure 1: Measurement setup for narrowband on-body characterization investigations with Tx and Rx locations on-body

The *Rx* (connected to port 2) was mounted on eight different locations, i.e., right chest (*RC*), left chest (*LC*), right waist (*RW*), left waist (*LW*), right thigh (*RT*), left thigh (*LT*), right ankle (*RA*), and left ankle (*LA*). Two sets of measurements were performed. In the first experiment, the subjects were in a standing position with their arms stretched alongside the body, and they were two meters away from the semi-metallic RF tower. In the second set of measurements, the subjects were moving in various positions for each on-body channel. Several daily routine movements were performed, including bending, leaning forward, walking, running, rotation of the torso and arms. It was assumed that the subjects were moving at the speed of 2 m/s [19] for movements of the body, which changed at every 20 s. The sampling time was within the coherence time, $T_c$ = 10 ms. The coherence time, $T_c$, for the channels can be estimated from the maximum Doppler shift, $f_m = v/\lambda$, as [19]

$$T_c = \sqrt{\left(9/\left(16\pi f_m^2\right)\right)} \tag{3}$$

Several daily routine movements were performed, including bending, leaning forward, walking, running, and rotation of the torso and arms. For a single measurement, 20 sweeps were captured for each location and movement scenario, and analyzed as data samples, resulting in a total of 1280 sweeps.

## III. Result and Discussion

### A. Stationary On-body Radio Propagation Channels

The on-body channel variation caused by respiration was negligible when the subjects were stationary, since the dominant component of the creeping wave had greater influence than respiration on the variation of the on-body path loss [11]. The mean path loss characterizations were derived based on the empirical logarithmic distance path loss model, as the following:

$$PL_{dB} = PL_{dB}\left(d_0\right) + 10\gamma \log\left(d/d_0\right) + X\sigma \tag{1}$$

A least squares (*LS*) fit method was applied on the measured data. Table 1 gives the path loss exponent, the standard deviation of shadowing, and the average path loss. The results that were obtained in this study were in good agreement with the results reported in [13][15]. Further, the values of $\gamma$ presented in this work agreed with those presented in [16] using similar antenna characteristics (tapered slot antenna) and placement setup, where it was found that $\gamma$ = 3.0 in free space with the absence of ground plane, mounted very close to the body (3 mm).

Table 1
Path loss characteristics of on-body radio propagation channel

| Parameter | Present Study | Ref [13] | Ref [16] | Ref [18] |
|---|---|---|---|---|
| $P(d_0)$(dB) | 35.6 | - | - | 45.0 |
| $d_0$ (m) | 0.1 | 0.1 | 0.1 | 0.1 |
| $\gamma$ | 3.0 | 3.5 | 3.0 | 3.0 |

### B. Dynamic On-body Radio Propagation Channels

To model fading channels for dynamic on-body radio propagation channel, the average path loss was compared to several well-known distributions that are used frequently in wireless communications, such as normal, lognormal, Nakagami, Weibull, and Rician. The estimated parameters of the statistical fit were computed based on a 95% confidence interval utilizing *dfittool* in the statistical toolbox of MATLAB. The best model among the chosen fading models was selected by using the Akaike Information Criterion (AIC) [11][15] to evaluate the goodness of fit of these statistical models. The second order AIC is normally expressed as $AIC_c$, written as:

$$AIC_C = -2\log_e\left(L\right) + 2K + \left(2K\left(K+1\right)\right)/\left(n-K-1\right) \tag{2}$$

Figure 2 shows the cumulative distribution of the path loss fitted to log-normal distribution on several on-body radio links based on Akaike criterion in body movement scenario. Table 2 summarizes the average value ($\mu$) and standard deviation ($\sigma$) of $AIC_c$ of the modeled path loss, lognormal distribution, in each scenario for all subjects considering the effects of body and arm movements. The highest standard deviation ($\sigma$) was observed at left waist position. The subjects had the highest variation of path loss, as represented by $\sigma$. This implied that a higher relative change in distance occured between *Tx* and *Rx* when the transmitter was on the subjects' limbs, leading to the changes in the path loss values. Also This may have been caused by shorter distance of *Tx*-*Rx* at left waist in one of the subjects when the subject was moving rapidly, resulting in higher variation of the path loss.

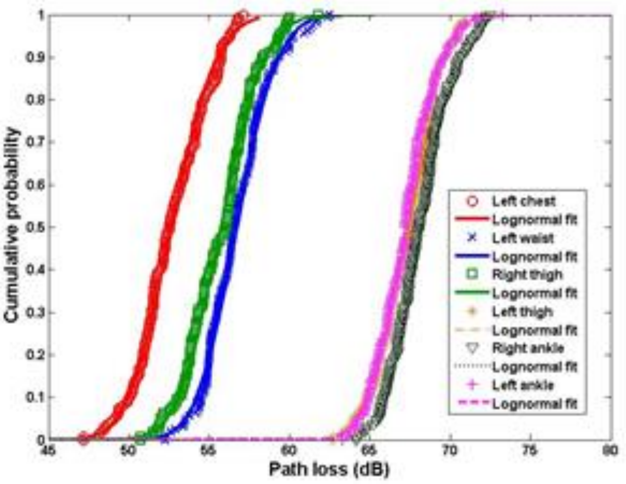


Figure 2: Cumulative distribution of the path loss fitted to lognormal distribution for subjects on on-body links

Table 2
Cumulative distribution of the measured path loss fitted to a lognormal distribution

| Rx Position | Path loss (dB) | |
|---|---|---|
| | $\mu$ | $\sigma$ |
| RC | 46.15 | 1.71 |
| LC | 53.03 | 1.81 |
| RW | 48.49 | 1.72 |
| LW | 54.26 | 2.97 |
| RT | 56.76 | 1.84 |
| LT | 61.05 | 1.84 |
| RA | 64.75 | 1.76 |

## IV. Conclusion

In this paper, the characteristics of the narrowband on-body radio propagation channel at 2.45 GHz using wearable planar textile monopole antennas were experimentally investigated. The measurements were conducted in the RF-shielded room environment. A statistical analysis was conducted on the spectral parameters of the channel to enable the prediction and modeling of dynamic on-body radio propagation characteristics. The empirical data were fitted to several well-known statistical models by applying Akaike criterion to determine the model that provided the best fit for the data. The results demonstrated that lognormal distribution was found to be the best fit for path loss in dynamic on-body radio propagation channel. The highest standard deviation (σ) was observed at left waist position, indicating that the channel is predominantly affected by changes in distance between transmitter and receiver.

## Acknowledgment

The authors thank all volunteers for participating in the experiment. We also thank Surentiren Padmanathan for his technical assistance in conducting the experiment. We also appreciate the financial support provided by grants from UniMAP, KPT (9001-00016) and SKMM (9002-00028).

## References

[1] Axisa, F., Schmitt, P. M., Gehin, C., Delhomme, G., McAdams, E., & Dittmar, A. "Flexible technologies and smart clothing for citizen medicine, home healthcare, and disease prevention, " *IEEE Transactions on Information Technology in Biomedicine*, vol. 9, no. 3, pp. 325–336, 2005.

[2] Neitz, M. and Neitz, J. "Molecular Genetics of Color Vision and Color Vision Defects, " *Archieves of Ophthalmology*, vol. 63, no. 2, pp. 232–237, 2000.

[3] Park, S., & Jayaraman, S. "Enhancing the quality of life through wearable technology, " *IEEE Engineering in Medicine and Biology Magazine*, vol. 22, no.3, pp. 41–48, 2003.

[4] Ryckaert, J., De Doncker, P., Meys, R., de Le Hoye, A., & Donnay, S. "Channel model for wireless communication around human body," *Electronics Letters*, vol. 40, no. 9, pp. 543–544, 2004.

[5] Alomainy, A., Hao, Y., Owadally, A., Parini, C. G., Nechayev, Y., Constantinou, C. C., & Hall, P. S. "Statistical analysis and performance evaluation for on-body radio propagation with microstrip patch antennas," *IEEE Transactions on Antennas and Propagation*, vol. 55, no. 1, pp. 245–248, 2007.

[6] Hu, Z. H., Nechayev, Y. I., Hall, P. S., Constantinou, C. C., & Hao, Y. "Measurements and statistical analysis of on-body channel fading at 2.45 GHz," *IEEE Antennas and Wireless Propagation Letters*. vol. 6, pp. 612–615, 2007.

[7] Alves, T., Poussot, B., & Laheurte, J. "Analytical propagation modeling of BAN channels based on the creeping-wave theory," *IEEE Transactions on Antennas and Propagation*, vol. 59, no. 4, pp. 1269–1274, 2011.

[8] Bringuier, J. N., & Mittra, R. "Electromagnetic wave propagation in body area networks using the finite-difference-time-domain method," *IEEE Sensors Journal*, vol. 12, no. 7, pp. 9862–9883, 2012.

[9] Chandra, R., & Johansson, A. J. "An analytical link-loss model for on-body propagation around the body based on elliptical approximation of the torso with arms' influence included," *IEEE Antennas and Wireless Propagation Letters*, vol. 12, pp. 528–531, 2013.

[10] Cheffena, M. "Performance evaluation of wireless body sensors in the presence of slow and fast fading effects," *IEEE Sensors Journal*, no. 99, pp. 1–1, 2015.

[11] Cotton, S. L., Conway, G. A., & Scanlon, W. G. "A time-domain approach to the analysis and modeling of on-body propagation characteristics using synchronized measurements at 2. 45 GHz," *IEEE Transactions on Antennas and Propagation*, vol. 57, no. 4, pp. 943–955, 2009.

[12] Cotton, S. L., & Scanlon, W. G. "An experimental investigation into the influence of user state and environment on fading characteristics in wireless body area networks at 2.45 GHz," *IEEE Transactions on Wireless Communications*, vol. 8, no. 1, pp. 6–12, 2009.

[13] Yang, X., Yang, S., Abbasi, Q. H., Zhang, Z., Ren, A., Zhao, W., & Alomainy, A."Sparsity-inspired nonparametric probability characterization for radio propagation in body area networks," *IEEE Journal of Biomedical and Health Informatics*, vol. 19, no. 3, pp. 858–865, 2015.

[14] Zhao, Y., & Hao, Y. "A subject-specificity analysis of radio channels in wireless body area networks," *Engineering Journal*, vol. 15, no. 3, pp. 39–47, 2011.

[15] Abbasi, Q. H., Sani, A., Alomainy, A., & Hao, Y. "On-body radio channel characterization and system-level modeling for multiband OFDM ultra-wideband body-centric wireless network," *IEEE Transactions on Microwave Theory and Techniques*, vol. 58, no. 12, pp. 3485–3492, 2010.

[16] Abbasi, Q. H., Sani, A., Alomainy, A., & Hao, Y. "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.

[17] Abbasi, Q. H., Sani, A., Alomainy, A., & Hao, Y. "Numerical characterization and modeling of subject-specific ultrawideband body-centric radio channels and systems for healthcare applications," *IEEE Transactions on Information Technology in Biomedicine*, vol. 16, no. 2, pp. 221–227, 2012.

[18] Liu, L., van Roy, S., Quitin, F., De Doncker, P., & Oestges, C. "Statistical characterization and modeling of doppler spectrum in dynamic on-body channels," *IEEE Antennas and Wireless Propagation Letters*, vol. 12, pp. 186–189, 2013.

[19] Sani, A., Alomainy, A., Palikaras, G., Nechayev, Y., Hao, Y., Parini, C., & Hall, P. S. "Experimental characterization of UWB on-body radio channel in indoor environment considering different antennas," *IEEE Transactions on Antennas and Propagation*, vol. 58, no. 1, pp. 238–241, 2010.

[20] Khan, I., Nechayev, Y. I., & Hall, P. S. "On-Body Diversity Channel Characterization," *IEEE Transactions on Antennas Propagation*, vol. 58, no. 2, pp. 573–580, 2010.