Statistical Characterization of Multiple Antennas Dynamic Body-to-body Radio Propagation Channel

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Abstract— This paper presents the multiple antennas dynamic body-to-body channel in an indoor environment by utilizing quarter-wave planar textile monopole (TM) antennas at 2.45 GHz. The single input and multiple output (SIMO) measurement system uses a signal generator and two spectrum analyzers, to generate (transmit) continuous wave and measure (receive) the S_{21} parameters. During each measurement, two users are positioned at a 1 m distance where several body movements are performed, such as walking, sitting, running, jumping, bending and rotation of arms. The measured body-to-body path loss is evaluated and characterized by fitting to five well-known statistical distributions. The results exhibit that the Lognormal distribution provided the best fit for most of multiple antenna body-to-body dynamic link path loss in most of body movements performed in the experiment.

1. INTRODUCTION

Body-centric wireless communication systems (BCWC) are key components of future wireless communication systems, e.g., fourth generation (4G). A BCWC connects various devices around human bodies, such as body sensors, body monitors and wearable electronic devices. With respect to communication range, the BWCS are categorized as "off-body", e.g., links between a person and a local access point (AP) or between two persons, and "on-body" systems, e.g., connections between devices mounted/worn on the same person [1, 2]. Body-to-body radio channel differs from the body-to-AP channels in antenna heights and types, communication range, device types and the device on-body locations which are not limited to belts or pockets. Knowledge on the body-to-body radio propagation channel is limited in the open literature, e.g., [1–3]. Thus, the aim of this study is to investigate the channel characteristics of dynamic body-to-body communications, highlighting on human body's movement effects for SIMO system.

2. MEASUREMENT SETUP

The experiment is carried out in a strictly controlled indoor environment at Embedded, Computing Research Cluster, Universiti Malaysia Perlis to investigate effects of multipath propagation environment on body-to-body radio propagation channel. The dimension of the room is $7\,\mathrm{m} \times 5\,\mathrm{m}$. No other people are presented when the measurement is performed except two subjects and data collectors. Two light weight and simple structures of planar quarter wavelength textile monopole (TM) antenna (total dimension: $40 \times 60\,\mathrm{mm}^2$) are utilized in the measurement (see Figure 2) [4]. A TM is placed on right upper arm and two TM receivers are spaced, ℓ at $\ell \gg \lambda/2$ in order to avoid mutual coupling. SIMO measurement system uses a Rohde & Schwarz signal generator (model SMBV100A) and two spectrum analyzers, Rohde & Schwarz (model FHS4 Handheld) and AdvanTest (model R1313A). Signal generator (SG) works in Continuous Wave at carrier frequency $f_o = 2.45\,\mathrm{GHz}$. The spectrum analyzers are set at span $= 20\,\mathrm{MHz}$, sweep time $= 20\,\mathrm{s}$, reference level $= 10\,\mathrm{dBm}$ and attenuation $= 40\,\mathrm{dB}$. The average height and weight of a pair of gender subjects is 172 cm and 55 kg. The placement of transmitter (Tx) is fixed at the right side of upper arm on the Body 1 (SA) and the placement of receivers (Rx) are fixed on four pairs of second human body (SB); right chest-left upper arm (RC-LU), right chest-left waist (RC-LW), right chest-ankle (RC-A) and left upper arm-back (LU-B) (see Figure 1). Tx is connected to SG and the two Rxs are connected to the each port of Spectrum Analyzers. During each measurement, two users are positioned at a 1 m distance. The SA is static and SB is in dynamic movement where several body movements are performed, including walking, sitting, running, jumping bending and rotation of arms. An antenna-body separation of 10 mm is applied by putting foam with $e_r \approx 1$. A 10 meter low loss semi-rigid and two 4 meter flexible (Multiflex-141) coaxial cables are used in the measurement campaign, manufactured by Huber-Suhner. Cables are wrapped with Eccosorb Flexible Broadband Urethane Absorber model: FGM-U-20-SA microwave absorbing foams. The SG is calibrated before the measurements to ensure that the RF input power supplied to textile monopole (TM) is 0 dBm by setting frequency offset $= -7.8$ dB. Both of the spectrum analyzers are also calibrated by measuring standing still position (static movement) and in walking movement. The S_{21} parameter is captured simultaneously using these two spectrum analyzers. The difference of S_{21} value (from both spectrum analyzers) is subtracted from S_{21} value of AdvanTest spectrum analyzer.

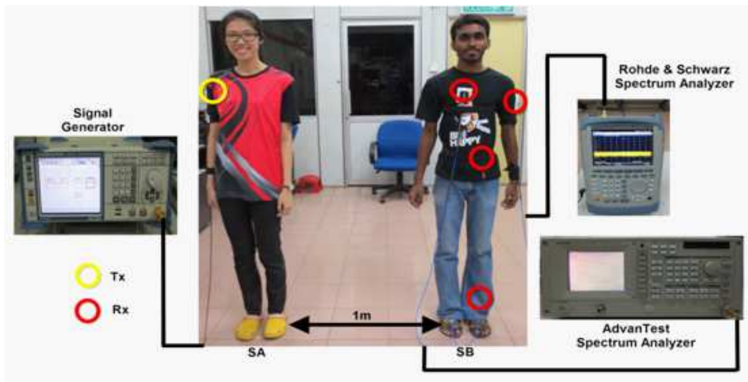
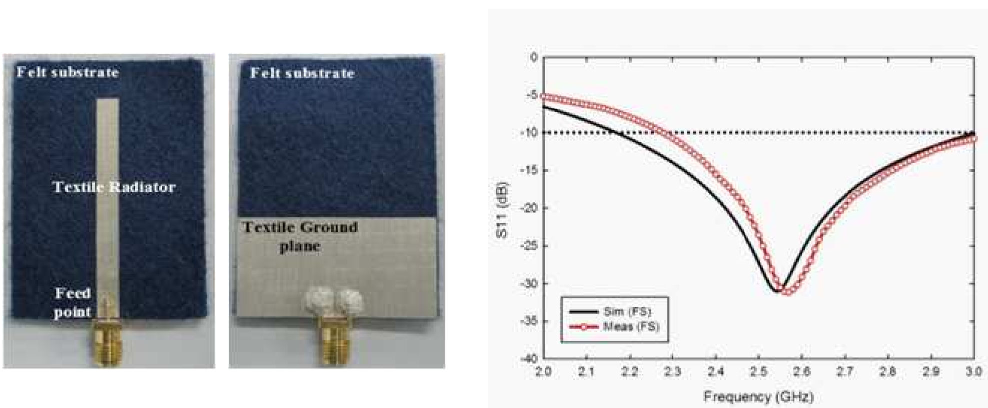


Figure 1: Body-to-body measurement setup in the laboratory environment.



(a) (b)

Figure 2: (a) Structure of planar TM and its fabrication prototype in front and back views. (b) Reflection coefficient of simulated and measured in free space (FS).

3. STATISTICAL ANALYSIS

To select the best model among several models of fading, Akaike Information Criterion (AIC) is used [8, 11]. The second order AIC, normally expressed as AIC_c, written as

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

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

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

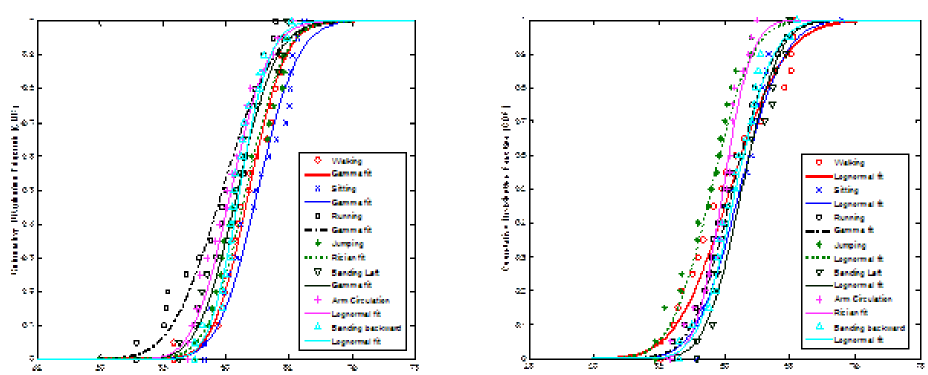
where AIC_c is the AIC value for model index i. From (2), the best model among the set of models is determined when $\Delta i = 0$. In general, $\Delta i < 2$ refers to significant evidence for model and if values are between 3–7, it implies that the model has less satisfactory level. However, if values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

4. RESULTS AND DISCUSSION

Table 1 presents the mean received power at Branch 1 (B1) and Branch 2 (B2) and power difference between two branches for four body-to-body channels at 2.45 GHz. The result shows that the maximum power difference between two branches is RC-A link for arm circulation movement. It is evident that the RC-A, with longer communication link, provides the maximum path loss variation between two branches of antennas. Meanwhile, the least power difference between two branches is seen on LU-B link for bending left motion. Although LU-B link is a non-line-of-sight (NLOS) scenario, it is observed that LU-B link obtains the minimum path loss variation of body-to-body channel in dynamic movement. This is due to the fact that bending left motion reduces the distance, and thus, more electromagnetic (EM) wave propagates in a direct path from Tx on SA to Rx(s) on SB. The measured data is statistically analyzed by applying the second-order AIC to determine the best fit model for all cases. The estimated parameters are computed based on 95% confidence interval utilizing dfittool in the Matlab statistical toolbox.

Table 1: Mean power difference for all body-to-body channels at 2.45 GHz.

Movement	LU-B			RC-A			RC-A			RC-LW		
	Mean Power (dB)		Power Difference (dB)	Mean Power (dB)		Power Difference (dB)	Mean Power (dB)		Power Difference (dB)	Mean Power (dB)		Power Difference (dB)
	B1	B2		B1	B2		B1	B2		B1	B2	
Walking	62.29	61.46	0.83	62.0	58.64	3.36	62.17	61.09	1.08	63.34	57.67	5.67
Sitting	63.54	61.58	1.96	62.61	62.06	0.55	60.45	62.03	1.58	62.54	59.93	2.61
Running	57.92	61.63	3.71	61.24	61.69	0.45	60.70	59.61	1.09	61.58	59.75	1.83
Jumping	62.38	60.81	1.57	61.76	60.29	1.47	61.05	59.01	2.04	59.37	58.6	0.77
Bending Left	60.86	61.07	0.21	55.64	60.63	4.99	60.97	60.83	0.14	61.7	61.04	0.66
Arm Circulation	61.21	59.72	1.49	56.64	64.04	7.40	60.65	61.24	0.59	59.07	60.76	1.69
Bending Backward	61.45	60.78	0.97	60.29	62.91	2.62	60.89	59.37	1.52	61.78	60.04	1.74



(a) (b)

Figure 3: CDF for body-to-body channel (a) LU-B link and (b) RC-LW link.

Table 2 summarizes the best fit model for all body-to-body channels in different movements. In LU-B link case, Gamma provides the best fit for walking, sitting, running and bending left movements (see Figure 3(a)). Since B1 and B2 are located on the opposite side of each other, this introduces NLOS scenario. From this result, it is shown that Gamma distribution is best described for NLOS case in dynamic movement. For RC-A and RC-LW links, the channel fading follows Lognormal distribution for all movements, except for sitting and arm circulation (RC-A case) and running and arm circulation (RC-LW case) respectively. As Lognormal distribution usually models the shadowing effect [1], the reflection and diffraction of signal from the surrounding and arms (reflection and shadowing) affects the path loss of RC-A and RC-LW links (see Figure 3(b)). Although both Rxs are mounted on the front side of body, the shadowing from arms dominates the EM propagation, and thereby resulting in Lognormal fitting. However, for RC-LU link, Rician dominates the best fit for most of the movements (walking, sitting, bending left, and arm circulation).

Table 2: Best fit model for all body-to-body channels.

Rxs Location	**Movement**	**Best Fit Model**	**Estimated Parameter**	
LU-B	Walking	Gamma	$a = 743.56$	$b = 0.08$
	Sitting	Gamma	$a = 620.02$	$b = 0.10$
	Running	Gamma	$a = 348.65$	$b = 0.17$
	Jumping	Rician	$v = 0.29$	$\sigma = 0.14$
	Bending Left	Gamma	$a = 615.77$	$b = 0.10$
	Arm Circulation	Lognormal	$\mu = 4.10$	$\sigma = 0.04$
	Bending Backward	Lognormal	$\mu = 4.11$	$\sigma = 0.03$
RC-A	Walking	Lognormal	$\mu = 4.10$	$\sigma = 0.05$
	Sitting	Gamma	$a = 899.71$	$b = 0.07$
	Running	Lognormal	$\mu = 4.12$	$\sigma = 0.03$
	Jumping	Lognormal	$\mu = 4.11$	$\sigma = 0.04$
	Bending Left	Lognormal	$\mu = 4.06$	$\sigma = 0.06$
	Arm Circulation	Rician	$v = 0.80$	$\sigma = 0.40$
	Bending Backward	Lognormal	$\mu = 4.12$	$\sigma = 0.04$
RC-LU	Walking	Rician	$v = 0.19$	$\sigma = 0.10$
	Sitting	Rician	$v = 0.33$	$\sigma = 0.16$
	Running	Gamma	$a = 852.97$	$b = 0.07$
	Jumping	Lognormal	$\mu = 4.09$	$\sigma = 0.04$
	Bending Left	Rician	$v = 0.38$	$\sigma = 0.19$
	Arm Circulation	Rician	$v = 0.41$	$\sigma = 0.21$
	Bending Backward	Lognormal	$\mu = 4.11$	$\sigma = 0.05$
RC-LW	Walking	Lognormal	$\mu = 4.10$	$\sigma = 0.06$
	Sitting	Lognormal	$\mu = 4.11$	$\sigma = 0.04$
	Running	Gamma	$a = 580.73$	$b = 0.10$
	Jumping	Lognormal	$\mu = 4.08$	$\sigma = 0.04$
	Bending Left	Lognormal	$\mu = 4.12$	$\sigma = 0.04$
	Arm Circulation	Rician	$v = 0.14$	$\sigma = 0.07$
	Bending Backward	Lognormal	$\mu = 4.11$	$\sigma = 0.04$

5. CONCLUSIONS

In this work, we investigate the multiple antennas dynamic body-to-body channel modeling of radio propagation channel in an indoor environment at 2.45 GHz. Quarter-wave planar TM antennas are used in the measurement. The mean power difference between two Rxs for all pair locations is presented and analyzed. Besides, a statistical analysis is also performed to mean path loss of body-to-body by fitting to well-known statistical distribution. The results show that most of dynamic body-to-body channel in most of body movements can be best described by Lognormal distribution due to reflection, diffraction and shadowing effects. Our analysis clearly shows that body movements and positioning between two receive

REFERENCES

1. Michalopoulou, A., A. A. Alexandridis, K. Peppas, T.Zervos, F. Lazarakis, K. Dangakis, and D. I. Kaklamani, "On-body channel modelling: Measurement and statistical analysis," *2010 Loughborough Antennas and Propagation Conference (LAPC)*, 201–204, Loughborough, UK, Nov. 8–9, 2010.
2. Abbasi, Q. H., M. M. Khan, S. Liaqat, M. Kamran, A. Alomainy, and Y. Hao, "Experimental investigation of ultra wideband diversity techniques for on-body radio communications," *Progress In Electromagnetics Research C*, Vol. 34, 165–181, 2013.
3. Rosini, R., R. Errico, D. Errico, and R. Verdone, "Body-to-body communications: A measurement-based channel at 2.45 GHz," 1763–1768, Sydney, Australia, Sept. 9–12, 2012.
4. Rahim, H. A., M. F. B. A. Malek, I. Adam, S. Ahmad, N. B. M. Hashim, and P. S. Hall, "Design and simulation of a wearable textile monopole antenna for body centric wireless communications," *PIERS Proceedings*, 1381–1384, Moscow, Russia, Aug. 19–23, 2012.