Experimental Correlation of Path Loss with System Performance in WBAN for Healthcare Applications

Terence S. P. See, Yu Ge, Tat Meng Chiam, Jeng Wai Kwan, Chee Wee Kim
Institute for Infocomm Research, Singapore
Email: [spsee, geyu, tmchiam, jwkwan, cwkim]@i2r.a-star.edu.sg

Abstract— **This paper presents the experimental characterization of the static on-body channel for healthcare applications at 2.48 GHz. The measurements are conducted in the anechoic chamber and laboratory. The link quality is measured by either using a vector network analyzer, where the path loss is averaged over a period of time or calculated from the received signal strength indicator (RSSI), which can be calculated from the receive sensor module. A correlation between the path loss and the packet delivery ratio (PDR) will be made via the probability distribution of the RSSI for a given transmit power. In addition, the optimal transmit power at the different body locations can be obtained, which will be useful to conserve the battery energy.**

Index Terms— **Wireless body area networks, channel characterization, on-body propagation, wireless communication systems, path loss**

I. INTRODUCTION

Body centric communications have shown a significant increase in interest over recent years due to the potential applications in healthcare, military, sports and entertainment. In medical services, wireless connections between the wearable devices are preferred for the ease of usage as well as the comfort and mobility of the users. In wireless body area network (WBAN) for medical applications, the quality-of-service, reliability and conservation of battery power are critical concerns. In order to facilitate the design of WBAN systems, it is necessary to characterize and model the various propagation channels on the human body so as to understand the effect of the unique properties of the body as well as the reflections due to the body in addition to the interference due to the multi-path and out-of-band signals from the existing operating systems and surroundings. On-body propagation channels have been widely studied using different existing and forthcoming communication standards such as UWB, Bluetooth, ZigBee, etc. and environments [1–4]. Although the distance for the on-body links are short, the transmission performance in WBAN systems are often unsatisfactory due to the reduced antenna performance near the body surface, blockage and absorption by the human body as well as the limited transmit power due to energy efficiency considerations and regulatory limitations.

The characterization of the on-body communication channel can be performed by using a vector network analyzer (VNA), where the path loss or S_{21} reading is recorded by connecting the transmit and receive antennas directly to the two ports of the VNA. Alternatively, a measurement test-bed can be constructed, which consists of several wireless sensors mounted directly on the body. The received signal strength indicator (RSSI) readings are then calculated from the individual sensors. With a certain value of the RSSI, the reliability of the WBAN system can be quantified by the packet delivery ratio (PDR) [5–6].

This paper presents the experimental characterization of the static on-body channel in the anechoic chamber and laboratory environment for healthcare applications. The link quality is determined from the vector network analyzer and the receive sensor module. An RSSI probability distribution for the different PDRs will be derived in order to correlate the path loss to the PDR. In addition, the optimal transmit power at the different locations of the body can also be obtained, which will be useful to conserve the battery power.

II. MEASUREMENT SETUP

A series of on-body measurements were performed in the anechoic chamber and in the laboratory with two different setups. In the first setup, the transmit and receive antennas are directly connected to the Agilent N5230A vector network analyzer. Fig. 1 shows the locations of the transmit and receive antennas on the body. The receive antenna is placed on the right waist and about 10 mm away from the body. The transmit antenna is placed at 17 locations on the head (right and left side), right and left hand (arm/elbow/wrist), chest center, right and left leg (thigh/knee/ankle), left waist and back. In the measurements, the power level of the VNA is set at 5 dBm and the continuous wave (CW) signal at 2.48 GHz is sent over a period of 8 s with a sampling rate of 0.5 ms. The transmission loss S_{21}, which can considered as the path loss including the antenna effects is recorded. The various sensor locations have been chosen which are useful for medical applications in the areas of patient monitoring, treatment and rehabilitation. In the second setup, the wireless MICAz transmitter and receiver modules are attached onto the body by using velcros. The antenna on the transmitter is separated by 10 mm from the body in order to reduce the effects of the body on the antenna. The RSSI level and the PDR at each transmitter location is then calculated for a given transmit power. The MICAz module measures 57 mm (length) × 33 mm (width) × 10 mm (thickness). The antenna is printed on a PCB and has a size of 33 mm × 6 mm × 1.6 mm. It is attached to the end of the module via an MMCX connector and is parallel to its width as shown in Fig. 2.

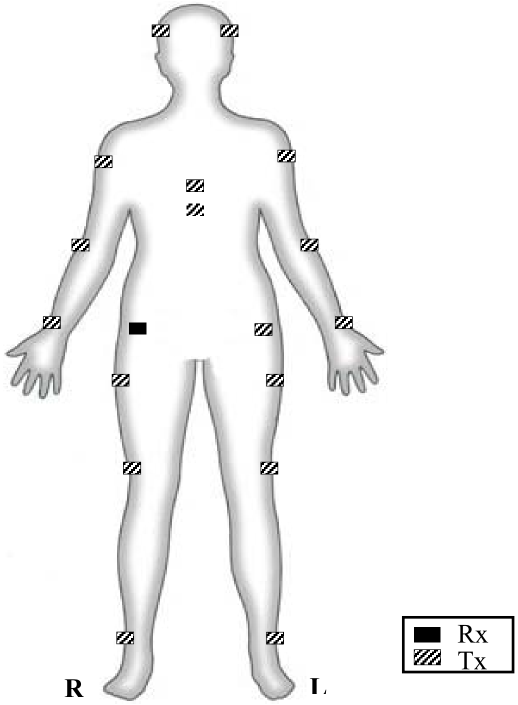

Fig. 1 Locations of transmitter and receiver on the body.

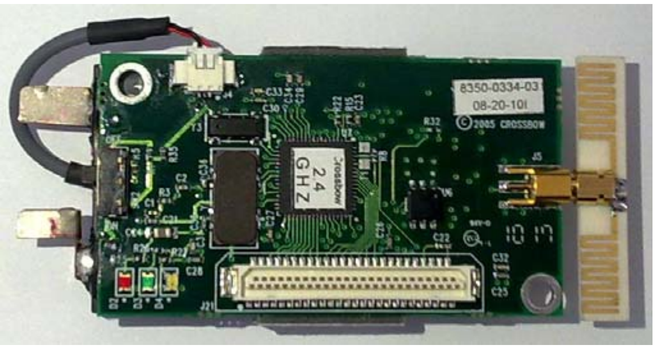

Fig. 2 Photo of MICAz module with antenna.

III. RESULTS AND DISCUSSIONS

The S_{21} parameter, which corresponds to the path loss, is recorded from the VNA over a period of 8 s and averaged. The human subject under test is stationary and stands in an upright manner. Table I shows the average $|S_{21}|$ for the different locations of the transmitter at the anechoic chamber and laboratory.

Table I: Average $|S_{21}|$ at various transmitter locations in the anechoic chamber and laboratory

Tx location	**Average $|S_{21}|$ (dB)**	
	Anechoic chamber	**Laboratory**
Right Arm	-57	-55
Right Elbow	-39	-41
Right Wrist	-34	-36
Left Arm	-83	-60
Left Elbow	-64	-58
Left Wrist	-76	-67
Chest	-68	-66
Right Thigh	-55	-63
Right Knee	-58	-55
Right Ankle	-60	-47
Left Thigh	-76	-63
Left Knee	-78	-55
Left Ankle	-78	-53
Right Head	-63	-47
Left Head	-77	-59
Back	-83	-57
Left Waist	-63	-53

From the table, it can be seen that in the anechoic chamber, the path loss is lower when the transmitter was placed on the right side of the body. The right elbow and wrist experience a low path loss due to the closer proximity to the receiver that was located on the right waist. The right thigh has a higher loss due to some blockage by the hand. However, when the transmitter was located on the left side of the body, the higher path loss is due to the non line-of-sight between the transmit and receive antennas caused by the different extent of blockage by the body.

On the other hand, in the laboratory environment, the path loss at most of the transmitter locations is reduced. This is due to the presence of strong multipath signals from the surroundings as well as reflections from the ground. The reduction in the path loss in the laboratory can be as much as more than 20 dB at some transmitter locations such as the back, left arm, left knee and left ankle, whereas there is only a slight reduction in the path loss at the chest. Only a very slight increase in path loss of about 2 dB can be observed at the right elbow and right wrist, while the path loss at the right thigh increased by about 8 dB. Also, the path loss at the ankle is lower as compared to the knee and thigh despite the longer distance to the receiver. This is due to the effect of the reflections from the ground which is more predominant. However, in the chamber environment where the multipath signals and ground reflections are absent, the path loss gradually increases from the thigh to the ankle, which is attributed to the increase in the distance between the transmitter and receiver.

With the transmit antenna attached directly to the MICAz module and placed on the body, the receiver MICAz module placed on the right waist is able to calculate the received signal strength indicator, which reflects the absolute received power for a given transmit power. The packet delivery ratio

(PDR), which reflects the overall system performance, can also be calculated. The PDR can be defined as the ratio of the number of data packets that are collected at the receiver to the number of data packets that are transmitted. Fig. 3 shows the probability distribution of the RSSI for the different PDR values at a transmit power of -25 dBm. The probability is calculated by dividing the number of occurrences of each RSSI value (every received packet has 1 RSSI value) by the total number of packets received and multiplied by the respective PDR. The RSSI can be adjusted by varying the distance between the transmitter and receiver. When the RSSI is above -88 dBm, the PDR is 1, which implies that all the packets are successfully received. In order to achieve the PDR of 0.992, the probability of RSSI = -88 dBm is 0.844 and 0.141 for the RSSI = -89 dBm. As the PDR is reduced to 0.746, the probability of the RSSI = -89 dBm is 0.318 and 0.387 for the RSSI = -90 dBm. When the PDR is lower than 0.5, most of the RSSI values are in the range of -90 to -92 dBm. Since the path loss can be calculated from the mean RSSI for a given transmit power level, the path loss can be correlated with the PDR from the RSSI probability distribution.

At each transmitter location on the body, the RSSI probability distribution profile at a given transmit power can be obtained. A suitable transmit power can be chosen based on the PDR and the profile of the probability distribution. It is desirable to achieve a high PDR of more than 0.9. For instance, Fig. 4(a) shows the probability distribution when the transmitter was placed at the right arm. The optimum transmit power of -10 dBm has been chosen in order to achieve a PDR of 0.968. Furthermore, it can be seen that the majority of the RSSI is concentrated at -89 dBm. In Fig. 4(b), when the transmitter was placed on the left side of the head, the PDR is only 0.288 and the majority of the RSSI values is at -90 dBm although the highest possible transmit power of 0 dBm is used.

The mean RSSI of the profile can be calculated at the various transmitter locations as shown in Table II. The corresponding transmit power is also given. It can be seen that different transmit power when the transmitter was placed at different locations on the body in order to achieve the desirable PDR of more than 0.9.

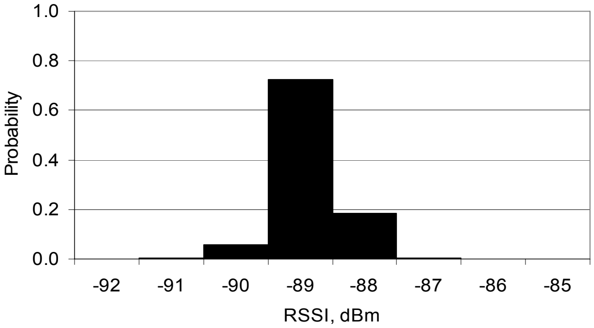

Fig. 4(a) RSSI probability distribution with the Tx placed on the right arm (Tx power = -10 dBm, PDR=0.968).

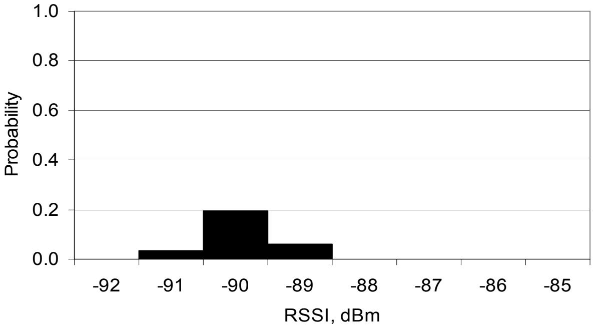

Fig. 4(b) RSSI probability distribution with the Tx placed on the head (left) (Tx power = 0 dBm, PDR=0.288).

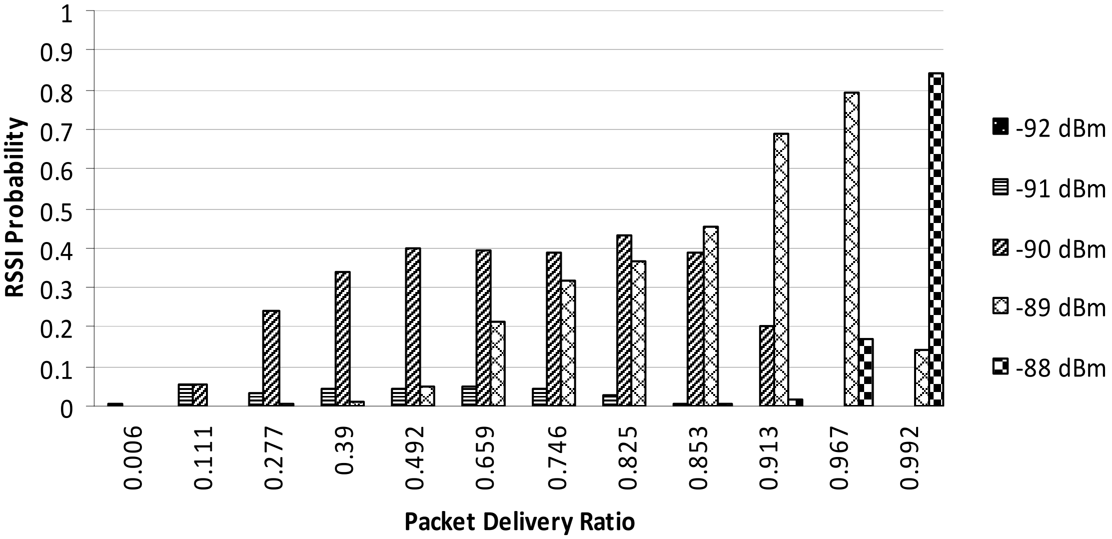

Fig. 3 RSSI probability distribution for the various PDRs.

Table II: Mean RSSI at the various locations of the transmitter

Tx location	Tx Power (dBm)	Mean RSSI (dBm)
Right Arm	-10	-88.9
Right Elbow	-25	-84.6
Right Wrist	-25	-62.5
Left Arm	0	-92.0
Left Elbow	-5	-86.5
Left Wrist	-10	-86.4
Chest	-7	-82.9
Right Thigh	-15	-80.7
Right Knee	-15	-84.3
Right Ankle	-15	-86.3
Left Thigh	0	-89.7
Left Knee	0	-89.2
Left Ankle	0	-87.3
Right Head	-7	-82.3
Left Head	0	-89.9
Back	-3	-88.0
Left Waist	-10	-88.5

From the table, since different transmit power levels are required for the different on-body links in order to achieve a good PDR, an optimum transmit power can be derived which will be useful to conserve the battery power. For instance, the PDR of 1.0 can be achieved at the right elbow even when the transmit power is only -25 dBm. Hence, it is not necessary to transmit at higher power levels. Furthermore, for the locations of the node where the low PDR is achieved despite the transmit power being at its maximum level of 0 dBm, this can possibly be resolved by using the nearby nodes that have a stronger RSSI as relays.

Table III shows a comparison of the path loss obtained from the VNA and the mean RSSI. From Fig. 3, by taking the difference between the RSSI of -88 dBm and the transmit power of -25 dBm, it can be deduced that the threshold value for the path loss is around 63 dB in order to achieve the good PDR of more than 0.9. From the data collected via the VNA, it can be seen that the path loss has exceeded the threshold for the transmitter locations on the left thigh, left knee, left ankle, left arm, left elbow, and left head. This implies that a high transmit power may be necessary in order to achieve the desired PDR. However, when the transmitter was placed on the left side of the head or left arm, a low PDR has been achieved even when the transmit power is at its maximum level of 0 dBm. In this case, relays may be required in order to establish a reliable communication link. On the other hand, on the left wrist, back and chest, a good PDR has been obtained despite the large path loss that was measured by the VNA. This is probably because at these transmitter locations, the variation in the path loss is extremely sensitive to the relative position of the transmit and receive antennas as well as the separation between the antenna and the body. Hence, in order to conserve the transmit power and at the same time enhance the overall link reliability, relays via the neighboring nodes can be deployed.

Table III: Comparison of the path loss from the VNA and mean RSSI

Tx location	Path Loss from VNA (dB)	Path Loss from Mean RSSI (dB)	PDR
Right Arm	57	78.9	0.968
Right Elbow	39	59.6	1.000
Right Wrist	34	37.5	0.999
Left Arm	83	92.0	0
Left Elbow	64	81.5	0.994
Left Wrist	76	76.4	0.995
Chest	68	75.9	0.998
Right Thigh	55	65.7	0.999
Right Knee	58	69.3	0.998
Right Ankle	60	71.3	0.999
Left Thigh	76	89.7	0.052
Left Knee	78	89.2	0.895
Left Ankle	78	87.3	0.996
Right Head	63	82.3	0.999
Left Head	77	89.9	0.288
Back	83	85.0	0.988
Left Waist	63	78.5	0.991

IV. CONCLUSION

In this paper, an attempt to correlate the path loss and the system performance in terms of the packet delivery ratio (PDR) has been performed experimentally. The path loss can be measured from the VNA or calculated from the mean RSSI. The RSSI probability distribution can be used for the different on-body links and environment in order to predict the PDR from the path loss data. In addition, the optimal transmit power at different nodes can be obtained, which will be useful to conserve the battery energy.

REFERENCES

[1] P. S. Hall, M. Ricci, and T .M. Hee, “Characterization of on-body communication channels,” in *Proc. ICMMT 2002*, Aug. 17–19, 2002, pp. 770–772.

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

[3] Y. I. Nechayev, P. S. Hall, C. C. Constantinou, Y. Hao, A. Odawally, and C. Parini, “Path loss measurements of on-body communication channels,” *2004 International Symposium on Antennas and Propagation*, Aug. 17–21, 2004, pp. 745–748.

[4] A. Fort, C. Desset, J. Ryckaert, P. Doncker, L. Van Biesen, and P. Wambacq, “Characterization of the ultra wideband body area propagation channel,” *2005 IEEE International Conference on Ultra-Wideband*, 2005, pp. 6.

[5] S. Cotton and W. Scanlon, “A statistical analysis of indoor multipath fading for a narrowband wireless body area network,” *2006 IEEE 17th International Symposium on Personal, Indoor and Mobile Radio Communications*, 2006, pp. 1–5.

[6] S. Cotton, G. Conway, and W. Scanlon, “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, 943–955, Apr. 2009.