Comprehensive Study of On-Body Radio Channels at 2.45 GHz for Different Human Test Subjects

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***Abstract*—The effects of eight different human body sizes and shapes on the narrowband (2.45 GHz) on-body radio propagation channels are investigated in this paper. Eight different real human body shapes and sizes are investigated. Experimental investigation is performed using a pair of Printed Monopole antennas in the indoor environment. The path loss was modeled as a function of distance for 34 different receiver locations for propagation along the front part of the body. Results and analysis show that due to eight different types of human body shapes and sizes maximum of 21 % variation in path loss exponent is observed. Variation of path loss for eight different narrowband on-body radio propagation channels of eight different human test subjects is also investigated.**

Keywords— narrowband; printed monopole antenna; on-body radio channel; body size effects; path loss; body-centric wireless communications.

I. INTRODUCTION

The rapid development of biosensors and wireless communication devices brings new opportunities for Body-Centric Wireless Networks (BCWN) which has recently received increasing attention due to their promising applications in medical sensor systems and personal entertainment technologies. Body-centric wireless communications (BCWCs) is a central point in the development of fourth generation mobile communications. In body-centric wireless networks, various units/sensors are scattered on/around the human body to measure specified physiological data, as in patient monitoring for healthcare applications. A body-worn base station will receive the medical data measured by the sensors located on/around the human body [1-7].

The human body is considered an uninviting and even hostile environment for a wireless signal. The diffraction and scattering from the body parts, in addition to the tissue losses, lead to strong attenuation and distortion of the signal [1]. In order to design power-efficient on-body communication systems, accurate understanding of the wave propagation, the radio channel characteristics and attenuation around the human body is extremely important. In the past few years, researchers have been thoroughly investigating narrow band and ultra wideband on-body radio channels. In [8-14], on-body radio channel characterisation was presented at the unlicensed frequency band of 2.45 GHz. In [3, 15-20] ultra wideband (UWB) on body propagation channels have been characterised and their behaviour has been investigated in indoor and chamber for stand-still, various postures and dynamic human body. It was noted that for different types of antennas, the path loss for on-body radio channels varies greatly. It was also noticed that due to the different postures and movements of the human body, the path loss for on-body radio channels varies. However, the sizes and shapes of the human body will also affect the propagation path and cause large variations in path loss for on-body radio links, and hence lead to different system performances.

Potential body-centric wireless networks need to provide efficient and reliable communication channels. Critical issues remain with regard to the human body effect, shape and sizes of the body, indoor propagations and radio channel characterization, which all must be addressed before the concept can be deployed for commercial applications. In this paper, the effects of eight different real human body sizes and shapes on the narrowband (2.45 GHz) on-body radio propagation channels have been studied. An experimental investigation was made in the indoor environment using a pair of Printed Monopole antennas. A frequency domain measurement set up was applied for narrowband on-body radio channel measurement.

The rest of the paper is organized as follows; section II illustrates the measurement setup, section III presents measurement results, radio channel parameters and modelling aspects, and finally section IV draws the conclusion of the study.

II. MEASURMEENT SETTINGS

In this study, eight real human test subjects with different body sizes, shapes and height were used in this measurement campaign (as shown in Fig. 1). Table I shows the dimensions of three different subjects used in this measurement (Male 1, Male 2, Male 3, Male 4, Male 5, Male 6, Male 7, Male 8). In this study, a pair of Printed Monopole antennas was used; as shown in Figure 2) [21]. The radiating element of the Printed

Monopole antenna was designed on the FR4 board with $\varepsilon_r = 4.6$ and thickness of 1.6 mm. There is a partial ground plane at the back side of the Printed Monopole antenna. The radiation pattern of the antenna becomes directive when it is placed on the human body. A HP8720ES vector network analyser (VNA) was used to measure the transmission response (S21) between two Printed Monopole antennas placed on the body. During the measurements, the transmitter antenna connecting with the cable was placed on the left waist, while the receiver antenna connecting with the cable was successively placed on 34 different locations on the front part of the standing human body; as shown in Fig. 3. The antennas were oriented with radiating elements parallel to the body and facing outward.

During the measurement, both transmitter and receiver antennas were placed on the cloths of all test subjects. The clothing was consistent between the test subjects used in this experiment. All the test subjects used in this experiment wearied a T-shirt and Jeans pant during the measurements. The test subjects were standing still during the measurements and, for each receiver location and measurement scenario, 10 sweeps were considered. The effects of the cable were calibrated out.

The measurement campaigns were performed in the Body-Centric Wireless Sensor Laboratory at Queen Mary, University of London [22]. The total area of the lab is 45 m^2 which includes a meeting area, treadmill machine, workstations and a hospital bed for healthcare applications.

Male 1 Male 2 Male 3

Male 4 Male 5 Male 6

Male 7 Male 8

Fig. 1. Photographs of the eight test male subjects used for ultra wideband on-body radio propagation channel measurement (dimensions are shown in Table I).

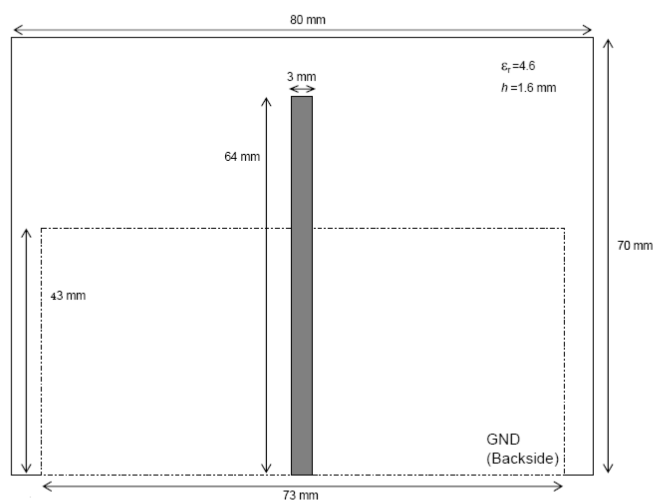

Fig. 2. Schematic diagram of Printed Monopole antenna used in this experiment [21].

TABLE I: THE DIMENSIONS OF EIGHT REAL TEST SUBJECTS USED IN THIS EXPERIMENT

Dimensions	Male 1	Male 2	Male 3	Male 4	Male 5	Male 6	Male 7	Male 8
Height (cm)	182	181	186	178	169	168	188	180
Weight (kg)	70	73	74	78	68	91	120	128
Chest Circumference (cm)	87	91	92	93	94	114	124	136
Waist Circumference (cm)	79	81	82	86	89	96	130	140

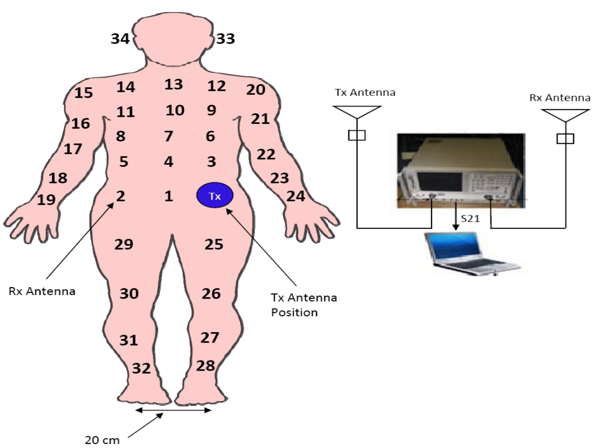

Fig. 3. Narrowband on-body radio propagation measurement settings showing the transmitter antenna is on the left waist while the receiver antenna is on 34 different locations of the body.

III. ON-BODY PARAMETERS FOR EIGHT DIFFERENT HUMAN BODY SHAPES

The path loss for the different receiver locations was calculated directly from the measurement data of S21 (10 sweeps) averaging at 2.45 GHz. It is well known that the average received signal decreases logarithmically with distance for both indoor and outdoor environments as explained in [23].

$$PL_{dB}(d) = PL_{dB}(d_0) + 10\gamma \log(\frac{d}{d_0}) + X_\sigma \qquad (1)$$

where d is the distance between transmitter and receiver, d_0 is a reference distance set in measurement (in this study it is set to 10 cm), $PL_{dB}(d_0)$ is the path loss value at the reference distance, and X_σ is the shadowing fading. The parameter γ is the path loss exponent that indicates the rate at which the path loss increases with distance.

A least-square fit method is applied on the measured path loss data for 34 different receiver locations (Fig. 3) to extract the path loss exponent for eight test subjects, as shown in Fig. 4. Table II lists the values of path loss exponent (γ), path loss at the reference distance d_0, obtained for the eight different test subjects. It can be noted that the path loss is affected by the body size. Due to different body sizes and shapes, the path loss exponent γ and the mean path loss $PL_{dB}(d_0)$ at the reference distance vary for the eight different human bodies. Maximum of 21 % variation in path loss exponent is noticed for the eight different body shapes, sizes and height. Results show that the path loss exponent increases with the body size. It is noted that the path loss exponent is subject-specific. In the case of subjects with the low value of body chest and waist circumference such as male 1, the path loss exponent is lower and with the high value of chest and waist circumference for male 8, the path loss exponent is higher. In this case for thinner subject (male 1), the propagation between the transmitter and receiver is more line of sight (LOS) than the body with higher volume of the chest and waist circumference leads to lower value of path loss exponent (γ=3.20). For subject with higher curvature radius trunk such as (male 8), the wave reaches the receiver through creeping wave propagation, which has higher signal attenuation, thus leading to higher value of exponent (γ=4.05). For the subject with higher volume of chest and waist circumferences, the communications for some of the receiver locations is heavily blocked by the different body parts, compared to the subject with lower value of chest and waist circumferences. In addition, the body tissues are also different for various subjects which also contribute for the variation of the path loss. For the on-body radio channel, the propagation is mainly through creeping wave, free space and guided wave. Different shapes and sizes of the test subjects affect the propagation mode for on-body propagation links.

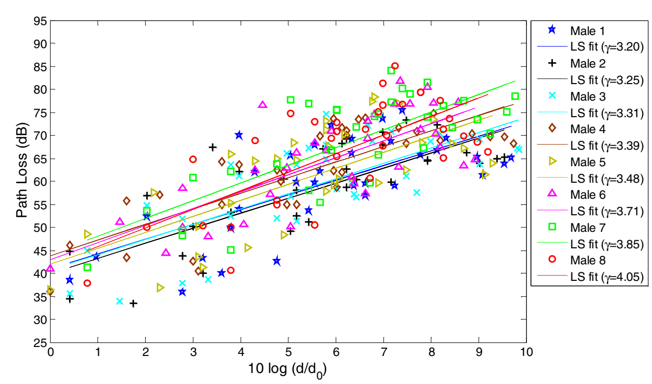

Fig. 4. Measured and modelled path loss for narrowband on-body channels versus logarithmic Tx-Rx separation distance of eight different human bodies (Male 01-Male 08).

TABLE II. NARROWBAND ON-BODY PATH LOSS PARAMETERS FOR EIGHT DIFFERENT TEST SUBJECTS. THE PARAMETER γ IS THE PATH LOSS EXPONENT, $PL_{dB}(d_0)$ IS THE PATH LOSS AT THE REFERENCE DISTANCE, AND σ IS THE STANDARD DEVIATION OF THE NORMALLY DISTRIBUTED SHADOWING FACTOR.

Path loss parameters	**Male 01**	**Male 02**	**Male 03**	**Male 04**	**Male 05**	**Male 06**	**Male 07**	**Male 08**
γ	3.20	3.25	3.31	3.39	3.48	3.71	3.85	4.05
$PL_{dB}(d_0)$	41.0	40.8	40.7	43.8	42.0	42.8	44.2	41.7
σ	7.62	6.80	7.12	6.31	8.01	7.09	7.17	8.12

X_σ is a zero mean, normal distributed statistical variable, and is introduced to consider the deviation of the measurements from the calculated average path loss. Fig. 5 shows the deviation of measurements from the average path fitted to a normal distribution for eight different test subjects' cases. Table II lists the values of standard deviation of the shadowing factor obtained for three different test subjects. The standard deviation σ of the normal distribution was found to be the highest for male 05 and male 08, whereas the lowest is noticed for the male 02 and male 04. Results indicate that the standard deviation value σ varies for different test subjects.

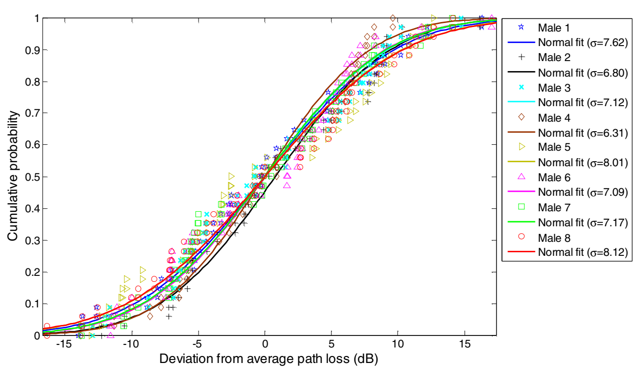

Fig. 5. Deviation of the measurements from the average path loss for eight different real human test subjects.

In order to compare the path loss of eight different human bodies, 8 different on-body channels have been chosen (Fig. 6). Fig. 7 shows variation in path loss for 8 different on-body links of eight different human bodies. Due to different shapes and sizes of the human body, the path loss varies for each different receiver location on the body. For the considered 8 different on-body links due to different human body sizes and shapes, maximum of 13.02 dB variation of path loss of an on-body link is occurred. It was noted for the transmitter to right wrist link (Rx 19) of male 01 and male 08, where the variation of path loss for this link of eight different subjects is mainly due to different trunk size of the different subjects. In the case of male 01, the trunk size is much smaller than the trunk of male 08, which creates less NLOS and less blocked communication, resulting in a lower path loss value for this link of the male 1. In particular, subjects with higher chest and waist circumferences (male 06, male 07, male 08) show higher path loss value for the wrist links, compared with the subjects with smaller chest and waist sizes (male 01, male 02, male 03). For different subjects, the higher path loss variation is noticed for the receivers on the wrists and on the ankles, while the lowest path loss variation is noticed for the ear and chest links.

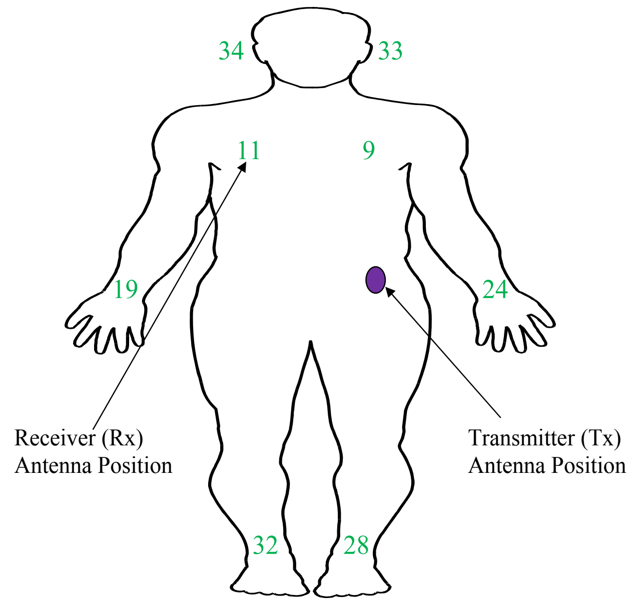

Fig. 6. Considered 8 different on-body links chosen for path loss comparison of eight different human test subjects.

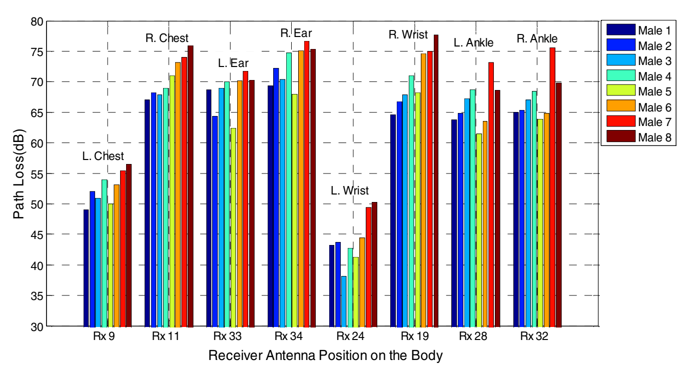

Fig. 7. Variation of path loss for 8 different on-body radio propagation channels of eight different real human test subjects.

IV. CONCLUSION

In this paper, narrowband on-body radio propagation study at 2.45 GHz was performed by characterizing the path loss for eight different real human subjects of different sizes and shapes. Measurement campaigns were performed in an indoor environment using a pair of Printed Monopole antennas. Results and analysis showed that due to the eight different body sizes and shapes a maximum variation of 21 % in path loss exponent occurred. The effect of the eight different human body sizes and shapes variations on the 8 different narrowband on-body radio channels was studied where results demonstrated that, for certain on-body links (e.g. waist to right wrist) the changes in body size and shape can lead to a significant variation (up to 13.02 dB) in path loss. The path loss exponent generally increases with the body size. Results indicate that, for different subjects, the path loss varies maximum for the wrist and ankle channels and minimum for the ear and chest links.

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