Experimental Study of On-Body Radio Channel Performance of a Compact Ultra Wideband Antenna

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Abstract

In this paper, on-body radio channel performance of a compact ultra wideband (UWB) antenna is investigated for body-centric wireless communications. Measurement campaigns were first done in the chamber and then repeated in an indoor environment for comparison. The path loss parameter for eight different on-body radio channels has been characterized and analyzed. In addition, 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, compared with anechoic chamber, a reduction of 16.34% path loss exponent is noticed in indoor environment. The antenna shows very good on-body radio channel performance and will be a suitable candidate for future efficient and reliable body-centric wireless communications.

Keywords

1. Introduction

Ultra wideband communication is an exciting and innovative technology which has become a very promising candidate for future short-range indoor high-speed data communication [1]. The UWB technology offers high

data rate communication links and low power emission level, in addition to less complex system designs which make it a promising technology for wireless body area networks (WBANs). Its low power requirement due to control over duty cycle allows longer battery life and also introduces green radio system. 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 [1]-[3]. A body-worn base station will receive the medical data measured by the sensors located on/around the human body. Antenna plays a vital role in body-centric wireless communications. Body-centric wireless networks have a range of applications, from monitoring of patients with chronic diseases and care for the elderly, to general well-being monitoring and performance evaluation in sports [1]-[7].

The human body is a hostile environment from a radio propagation perspective and it is therefore important to understand and characterize the effects of the human body on the radio channel parameters. The human body tissue is a lossy medium; hence, the wave propagating within the WBAN faces large attenuation before reaching the specified receiver. The design of a power-efficient and reliable on-body communication system requires suitable antennas which therefore require accurate understanding of the human body effects on the antenna performance parameters and radio propagation channels [8]. Researchers have been comprehensively investigating narrow band and ultra wideband on-body radio channels in the past few years. In [9]-[16], on-body radio channel characterization was presented at the unlicensed frequency band of 2.45 GHz. In [3] [17]-[22], ultra wideband (UWB) on-body propagation channels have been characterized and their behavior has been investigated in indoor and chamber for stand-still, various postures and dynamic human body. In previous studies, it is shown that different antennas have different on-body radio channel performances. However, the antennas presented and used in previous studies were large in physical size. In this paper measurement campaigns were performed in the chamber and indoor environment using a compact printed quasi-self-complementary ultra wideband (UWB) antenna. The major plan of this study is to investigate and analyze the on-body radio channels performance of the abovementioned compact UWB antenna. The path loss parameter has been characterized and analyzed for eight different on-body radio channels. In addition, the path loss exponent has been extracted for thirty-four different receiver locations on the front part of the human body using least square fit method.

The rest of the paper is organized as follows: Section 2 illustrates the measurement setup and the antenna used for this study; Section 3 presents measurement results, radio channel parameters and modelling aspects; and finally Section 4 draws the main conclusion.

2. Measurement Setup

In this study, the on-body radio channel performance of the compact quasi-self-complementary UWB antenna has been experimentally investigated. The S21 measurement campaigns of the compact UWB antenna were performed first in an anechoic chamber and then repeated in the indoor environment. In this experiment, an average-sized real male test subject, with a height of 1.74 m and a weight of 80 kg was used. A pair of compact quasi-self-complementary UWB antennas was used. A HP8720ES vector network analyzer (VNA) was used to measure the transmission response (S21) in the frequency range of 3 - 10 GHz between two antennas of the same type placed on the body. The frequency range was set to 3 - 10 GHz, with 1601 points and with a sweep time of 800 ms. **Table 1** shows the network analyzer settings. During the measurement, the transmitter quasi-self-complementary UWB antenna connecting with the cable was placed on the left waist and the receiver quasi-self-complementary UWB antenna was sequentially attached on 8 different locations on the front part of the body as shown in **Figure 1**. 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-Cen-

Table 1. Network analyzer settings.

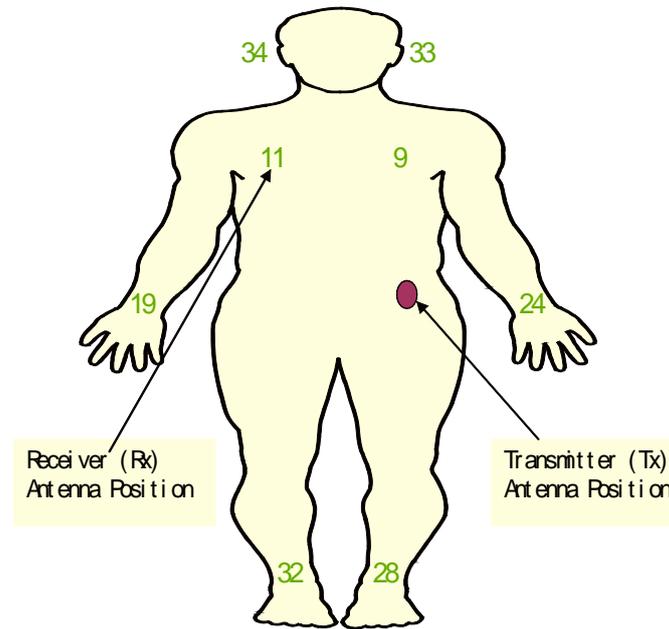|	
Frequency Band	3 to 10 GHz
Frequency Points	1601
Sweep Time	800 ms
Number of Sweep	10
VNA Transmit Power	0 dBm

Figure 1. On-body measurement settings showing the transmitter antenna is on the left waist while the receiver antenna is on 8 different locations of the body.

tric Wireless Sensor Laboratory at Queen Mary, University of London. 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. The dimension and geometry of the Body-Centric Wireless Sensor Laboratory are shown in **Figure 2**.

Antenna Parameters

The dimensions and geometry of the compact quasi-self-complementary ultra wideband antenna used for this measurement are shown in **Figure 3**. A half-circular disk with a radius of 6 mm and its complementary magnetic counterpart are printed on the different side of the dielectric substrate. The small printed quasi-self-complementary antenna is fed by a microstrip line. The antenna is fabricated on FR4 substrate with thickness of $h = 1.6$ mm and relative permittivity of $\varepsilon_r = 3$. The length and the width of the substrate for this antenna are 25 and 16 mm, respectively. The total size of the antenna is 25 × 16 mm^2 which is around $0.25\lambda_0 \times 0.16\lambda_0$ in electrical length, where, λ_0 is the free space wavelength at 3 GHz. The antenna size is not only physically small, but also electrically small. A triangular slot is cut on the ground plane in order to improve the impedance matching of the antenna. There is a partial ground plane at the back of the self complementary compact ultra wideband antenna [23]. The S11 measurement campaigns of the proposed UWB antenna were performed in an anechoic chamber. The return loss was first measured in free space and then the antenna was placed directly on the body (left side of the waist), and at 1, 4, 8 and 16 mm away from the body. **Figure 4** shows the free space and on-body return loss responses of the used compact UWB antenna when placed at various distances away from the human body. The figure illustrates that the antenna has excellent impedance matching across the UWB band, with return loss less than −10 dB. This antenna shows very good radiation patterns, radiation efficiency and gain when placed on the human body as reported in [24]. More detail analysis about antenna return loss, radiation pattern, efficiency and gain can be found in [24].

3. Ultra Wideband On-Body Radio Channel Parameters

3.1. On-Body Radio Channel Characterisation

The path loss for each receiver location is directly calculated from the measurement, averaging over the frequency band of 3 - 10 GHz. In this study, the path loss for eight different on-body radio channels has been characterised and investigated (see **Figure 1**). A comparison of path loss for eight different on-body radio channels
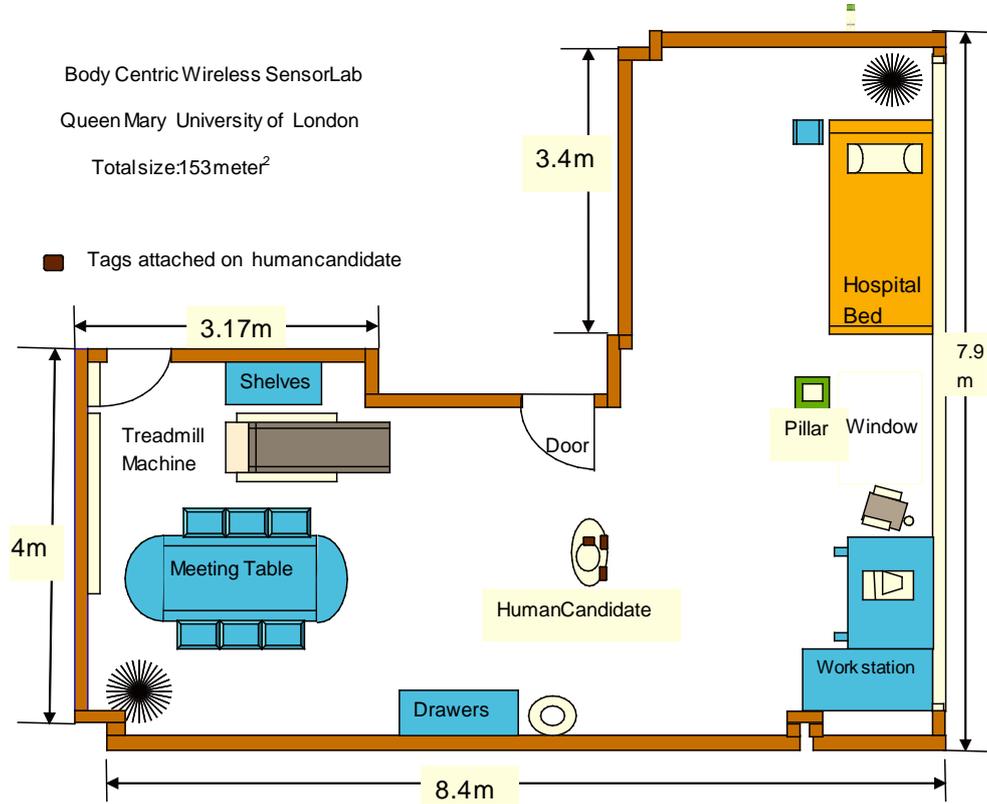
Figure 2. Dimension and geometry of the body-centric wireless sensor laboratory where the indoor on-body radio propagation measurements for the presented study is performed.
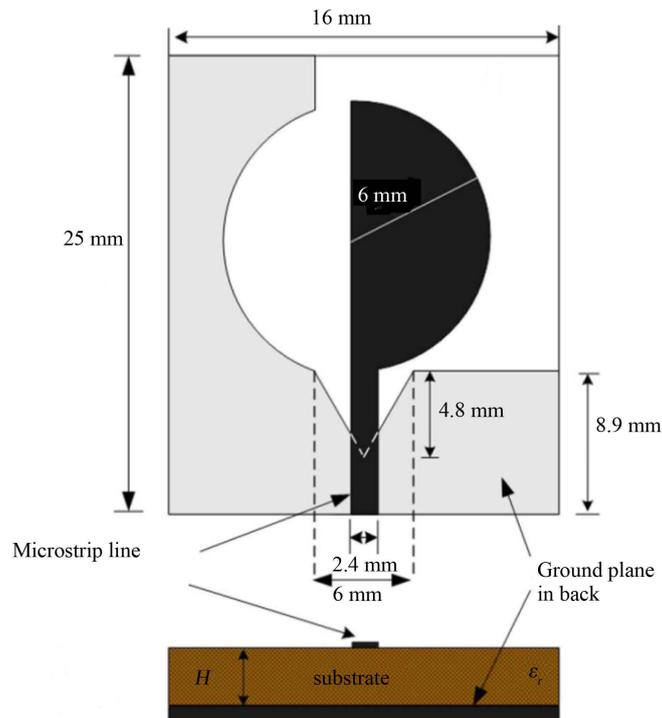

Figure 3. Dimension and geometry of the quasi-self-complementary ultra wideband antenna used for this experiment [22].
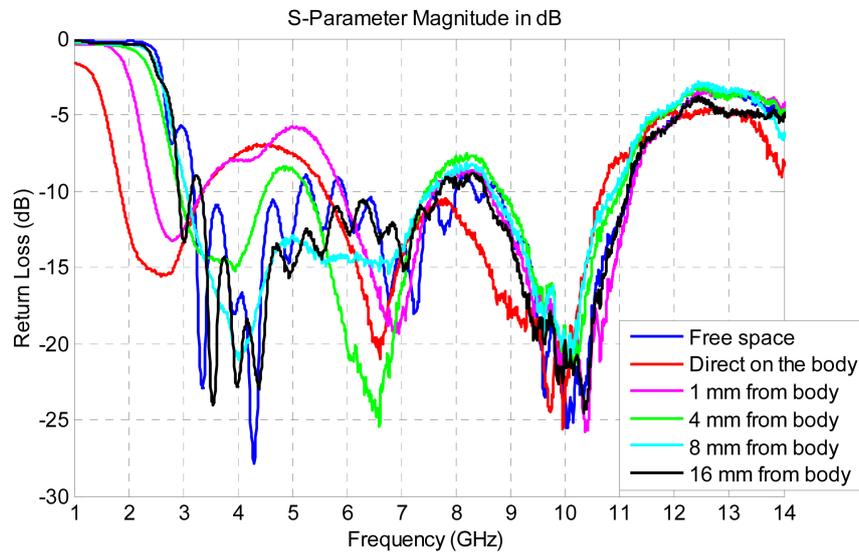
Figure 4. Return loss responses of the tested compact UWB antenna when placed at various distances away from the human body (left side of the waist).

measured in the anechoic chamber and in an indoor environment using compact quasi-self-complementary ultra wideband antenna is shown in **Figure 5**. Both in the chamber and in an indoor, the highest path loss is noticed for the transmitter to right-wrist link, while the lowest is noticed for the transmitter to left-chest and left-ankle links. In this case, for the transmitter to right-wrist wrist link, the communication distance between the receiver antenna and the transmitter antenna is larger; in addition, there is a presence of non-line-of-sight (NLOS) communications, which cause the highest path loss value for this channel. For the left waist to right-wrist link, the propagation mechanism is mainly creeping waves, which experience higher signal attenuation, resulting in higher path loss value. On the other hand, for the left ankle and left-chest links, there is a clear line-of-sight (LOS) communication which causes the lowest path loss values for these two channels. Although the communication distance for the transmitter to the left ankle link is large, the path loss value is low which can be due to the contribution of ground reflection from the indoor environment. Due to the non-reflecting environment, most of the on-body channels experience higher path loss value when measurements are made in the chamber. In the indoor environment due to reflecting area and contributions of multipath reflection most of the on-body channels experience lower path loss value compared with chamber. The average path loss of all eight on-body radio channels in the chamber is 65.72 dB whereas 63.71 dB is found in the indoor environment. Although the size of this antenna is compact, it shows very good on-body radio channels behavior/performance.

3.2. Path Loss vs. Distance

In this section, the path loss was modeled as a function of distance for 34 different receiver locations for propagation along the front part of the body. During this measurement, the compact transmitter UWB antenna was placed on the left waist and the receiver antenna was attached on 34 different locations on the front part of the body as shown in **Figure 6**. It is well known that the average received signal decreases logarithmically with distance for both indoor and outdoor environments as explained in [25].

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

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.

In order to extract the path loss exponent a least-square fit technique was performed on the measured path loss for the 34 different receiver locations (**Figure 6**). **Figure 7** shows the measured value and modelled path loss
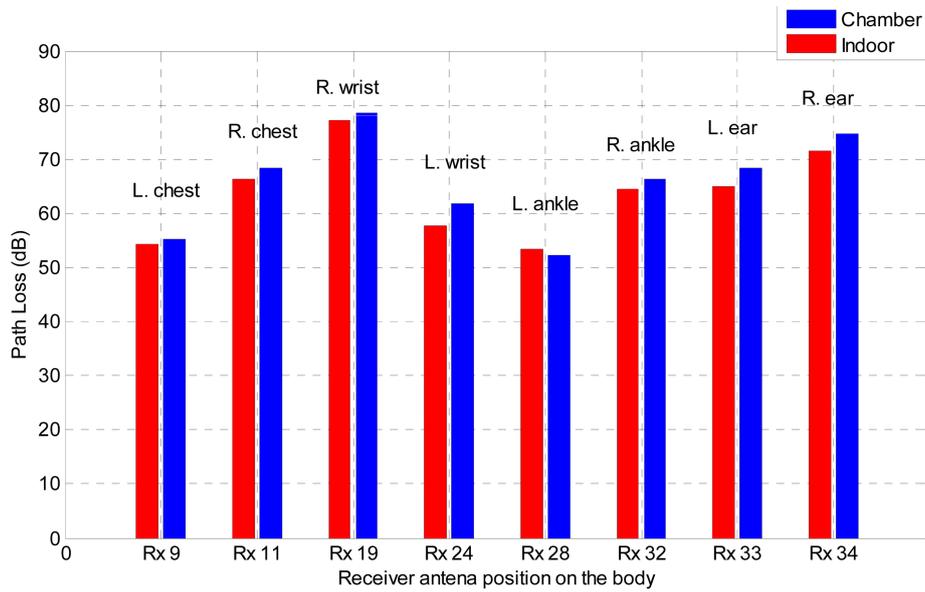
Figure 5. Comparison of path loss for eight different on-body radio channels measured in the chamber and in an indoor environment for the tested compact UWB antenna used in this study.
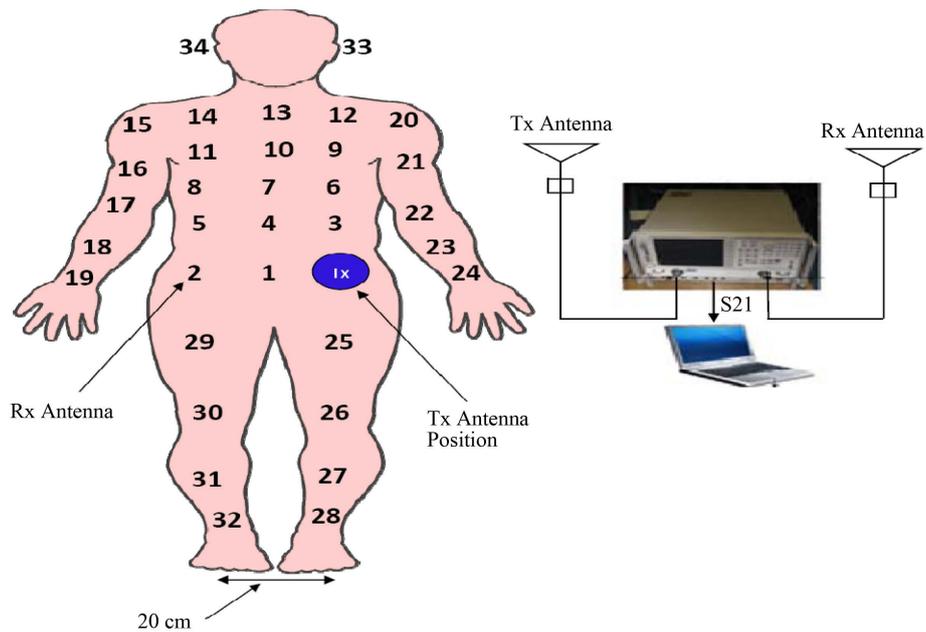

Figure 6. UWB on-body measurement settings showing the transmitter antenna is on the left waist while the receiver antenna is on 34 different locations of the body.

for on-body channels versus logarithmic Tx-Rx separation distance. In this study, the path loss exponent was found to be 2.57 in the chamber and 2.15 in indoor (**Table 2**). In the indoor environment, the path loss exponent was found to be lower compared to chamber. When measurements are performed indoor, the reflections from surroundings scatters increase the received power, causing reduction in the path loss exponent. A reduction of 16.34% was noticed in indoor compared to the chamber in this case.

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. **Figure 8** shows the deviation of measurements from the average path loss fitted to a normal distribution for both measurement cases. In this case, the standard deviation
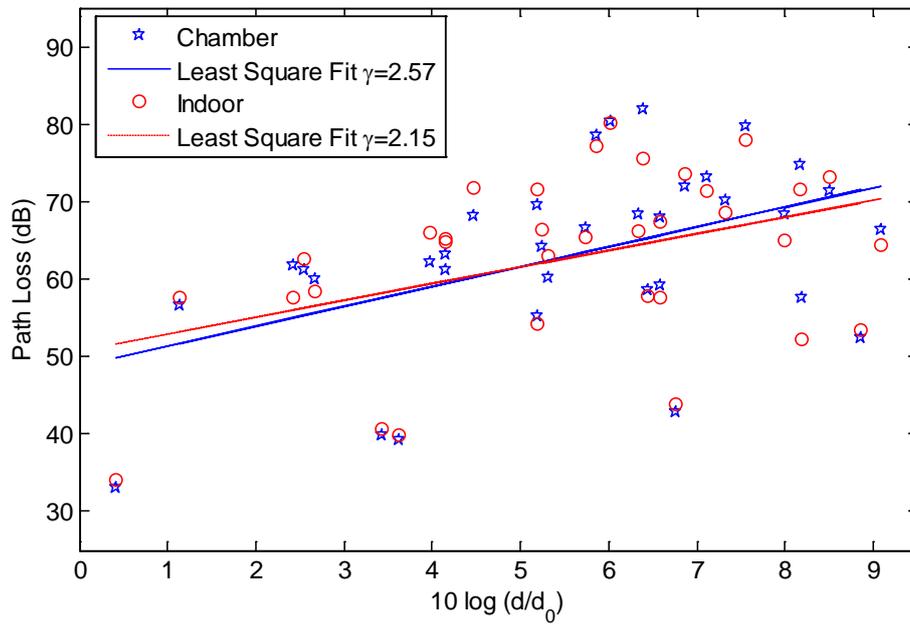
Figure 7. Measured and modelled path loss for on-body channel versus logarithmic (Tx) and receiver (Rx) separation distance for tested compact quasi-self-complementary UWB antenna.
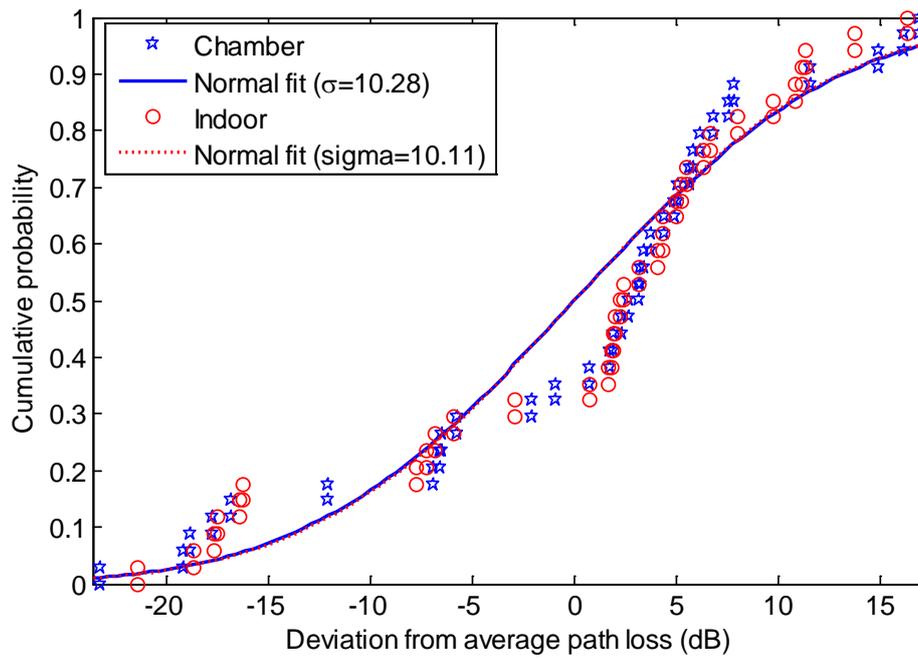

Figure 8. Deviation of the measurements from the average path loss (fitted to normal distribution) for the tested compact UWB antenna used in this experiment.

Table 2. Path loss parameters of the tested compact UWB antenna used in this experiment.

Path loss parameters	Chamber	Indoor
γ	2.57	2.15
$PL_{dB}(d_0)$ (dB)	49.0	50.8
σ (dB)	10.28	10.11

of the normal distribution is found to be slight lower in the indoor environment (Table 2).

4. Conclusion

In this paper, ultra wideband on-body radio propagation channel measurements were performed using compact quasi-self-complementary ultra wideband antenna in the chamber and indoor environment. Eight different on-body radio channels have been investigated and analyzed. Path loss parameters of this proposed antenna are investigated for both chamber and indoor environment cases. In this study, the highest path loss is noticed for the transmitter to right-wrist link, while the lowest is noticed for the transmitter to left-chest and left-ankle links. Due to its compact size and very good on-body radio channel performance, the printed quasi-self-complementary ultra wideband antenna will be a proper candidate for reliable and efficient communications in UWB wireless body area networks.

Acknowledgements

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