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COMPARISON OF TWO MEASUREMENT TECHNIQUES FOR UWB OFF-BODY RADIO CHANNEL CHARACTERISATION

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Abstract—This paper presents comparison of two measurement techniques for ultra wideband (UWB) off-body radio channel characterization. A measurement campaign was performed in indoor environment using UWB wireless active tags and reader installed with the tag antenna and same set of measurement was repeated in the frequency domain using Vector Network Analyser (VNA) and cable connecting two standalone tag antennas for comparison/with a view to finding out the cable effects. Nine different off-body radio channels were experimentally investigated. Comparison of path loss parameters and path loss model for nine different off-body radio channels for the propagation in indoor environment both measurement cases are shown and analyzed. Results show that measurement taken by VNA connecting two standalone antennas through cables experiences lower path loss value for all nine different off-body channels. Least square fit technique is obtained to extract the path loss exponent. Increase of 12.96% path loss exponent is noticed when measurements are made using UWB tags and reader, i.e., without cable measurement scenario.

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1. INTRODUCTION

UWB communication is an exciting and innovative technology which can carry signals through many obstacles that usually reflect signals at more limited bandwidth and higher power. It is a low-power, high data rate technology that provides immunity to multipath interference and has robustness to jamming because of its low probability of detection. Its low power requirement due to control over duty cycle allows longer battery life which makes it suitable for body-centric applications [1, 2].

Recently there have been increasing interests in research and development devoted to short-range wireless systems for personal and body area networks [1–16]. In [4] UWB off-body communication channels measurement results in an anechoic chamber has been presented. The effects of the indoor environment on the UWB body area channel are investigated and shown in [5]. In addition, UWB on-body radio channel characterization and system level modeling for body-centric wireless network have been presented extensively in the open literature [6–16]. Potential UWB body-centric wireless network needs to be integrated with compact sensors and provides efficient and reliable communication channels. Critical issues remain with regards to indoor propagations, radio channel characterization and human body effect which need to be addressed before the concept can be deployed for commercial applications. In [6–16] UWB on body propagation channels have been characterized and their behavior have been investigated in indoor and chamber for stand-still, various postured and dynamic human body based on different antennas. In these cases [4–16] measurement campaigns were performed in the frequency domain using a VNA and cables connecting two standalone antennas. Cable effects haven't been considered.

In this paper, measurement campaigns were performed in the indoor environment using commercially available UWB wireless tags and reader installed with tag antenna provided by Time Domain PLUS$^{\text{TM}}$ [17]. The tags operate at the frequency band of $5.9 \sim 7.25\,\text{GHz}$ with a centre frequency 6.6 GHz. Same set of measurement was repeated in the frequency range of $5.9 \sim 7.25\,\text{GHz}$ using a VNA and cables connecting two standalone tag antennas. The aim of this study is to find out the effects of the cables on UWB off-body radio channels/radio channels in body-centric wireless communications. Nine different off-body radio channels are experimentally investigated for both measurement setups. Comparison of path loss for both measurements cases are shown and analysed.

The rest of the paper is organized as follows; Section 2 illustrates the measurement set up, Section 3 presents measurement results and radio channel parameters and modelling aspects, and finally Section 4 draws the conclusion of the presented work.

2. MEASUREMENT SETTINGS

In this study two sets of measurements were performed. For the first measurement a UWB reader installed with tag antenna was placed on the ceiling as shown in Fig. 1(b). A real human subject was used for this measurement purpose. The test subject was an adult male of mass 90 kg, height 1.68 m and chest circumference 114 cm. Nine UWB active tags were attached on different locations of the body including; right/left chest, right/left waist, right/left wrist, right ear and right/left ankle as shown in Fig. 1(a). Measurement was performed with the subject wearing 9 transmitter tags standing at 6 different locations with the interval of 1 metre in the sensor laboratory as shown in Fig. 1(b). During measurement, the subject was standing still for a period of 30 seconds at each location and the data were saved for that period using location based software. For all measurement scenarios, the subject was standing still facing toward the reader. The tag's transmit power is −13.01 dBm which is around 40 dB less than mobile phone transmit power. The transmitter tags are battery powered and the duration of the battery life is four years since the tags only transmit UWB pulses every one second. Second set of measurements were performed in the frequency domain using Vector Network Analyser (Hewlett Packard 8720ES-VNA) and two cables connecting two standalone tag antennas to measure the transmission response (S_{21}) in the frequency range of 5.9–7.25 GHz. Two coaxial cables have been used which are 4 metres (cable 1) and 8 metres long (cable 2). One end of the cable 1 was connected to the port 2 of the VNA and the other end was connected with the receiver antenna. For the second cable, one end was connected with the port 1 of the VNA and the other end was connected with the transmitter antenna. In this case, the receiver standalone tag antenna is placed on the same location where the reader installed with the tag antenna was placed for the first measurement and the transmitter standalone tag antenna is placed on the 9 different locations of the body where the transmitter tags were placed for the first measurement Figs. 1(a) and 1(b). The power of the network analyser was set to −13.01 dBm. The frequency range was set to 5.9–7.25 GHz at a sampling rate of 1601 with sweep time 800 ms subsequently. For each transmitter location and measurement scenario 30 sweeps were taken. Both measurements were performed in the body-centric wireless sensor laboratory at Queen Mary, University of London. The total area of the laboratory is 45 m^2 which includes a

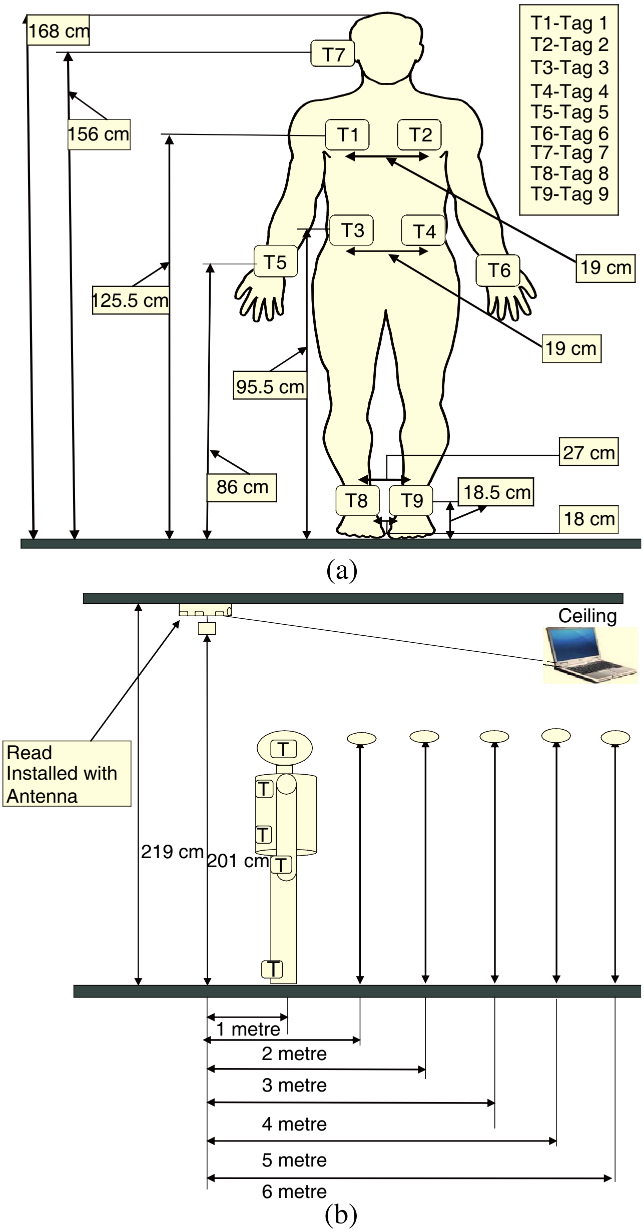


Figure 1. Measurement set up of UWB reader and active transmitter tags. (a) Front view of subject wearing 9 active UWB transmitter tags on the body as standing. (b) Measurement scenario and side view at 1–6 meter locations.

meeting area, treadmill machine, work stations and a hospital bed for health care applications [16].

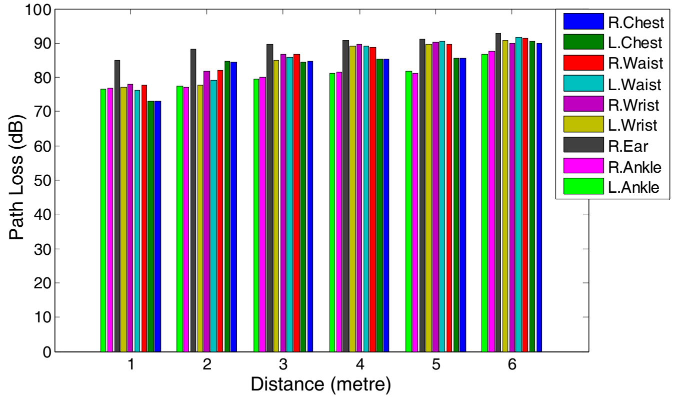
3. UWB OFF-BODY RADIO CHANNEL PARAMETERS

3.1. Off-body Radio Channel Characterisation

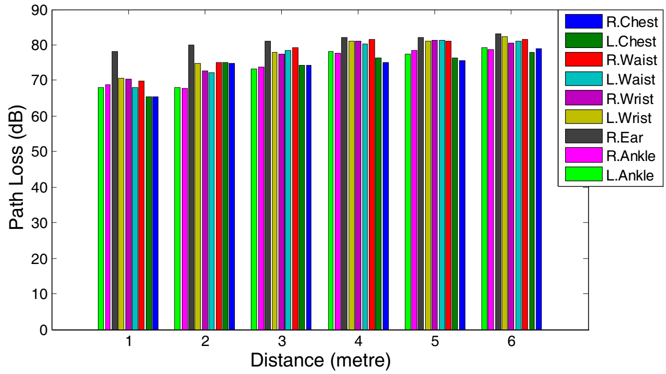
For the first set of measurements, tags-reader case, the measured Received Signal Strength Indicator (RSSI) level for each transmission tag is recorded over the measurement duration of 30 seconds for each different location (1–6 metre). The path loss for nine different off-body channels was calculated from the measured RSSI for each transmitter tag and is averaged over the measurement durations of 30 seconds. But for the second set of measurements (i.e., two stand alone tag antennas connected to VNA through cables), the path loss is directly calculated from the measurement averaging over the frequency band of $5.9 \sim 7.25\,\text{GHz}$.

Figures 2(a) and 2(b) show comparison of measured average path loss for nine different off-body links for both measurement scenarios respectively. Results show that in comparison with two measurement techniques all nine different off-body channels experience higher path loss value when measurements are made using wireless tags and the reader. This can happen due to the effects of the cables. It is assumed that when cables are connected to the small antennas, they may radiate which causes the increase of signal strength and results in less signal attenuation and lower path loss value for the measurement case taken by VNA connecting two standalone antennas. It is also assumed that for the first measurement case the tag antenna is integrated with the system where there can be effects due to the circuit which may result in higher path loss value for the first measurement case. One other cause for the difference of path loss might be the different models used for the evaluation of the path loss in the two measurement methods.

Figure 3 shows comparison of average path loss for both measurement cases when subject was standing at 1 meter distance location. The average of nine different off-body channel's path loss when subject was standing at one metre distance location is 77.00 dB for tag and reader case while 69.54 dB is noticed for two standalone antennas and cable case. Results show that an average of 7.46 dB lower path loss value is noticed when measurements are made using two standalone antennas connecting to VNA through cables. When subject was standing at 1, 2, 3, 4, 5, 6 metre distance locations, the average path loss of nine off-body channels for cableless measurement case is 77.00 dB, 81.40 dB, 84.74 dB, 86.81 dB, 87.29 dB, 90.20 dB while for two standalone antennas with cable case they are 69.54 dB, 73.39 dB,



(a) Tags-Reader (without cable)



(b) Tag antenna-Tag antenna (with cable)

Figure 2. Comparison of average path loss for nine different off-body channels when measurements are made (a) tags and reader (b) two standalone antennas connecting with VNA through cable.

76.58 dB, 79.27 dB, 79.44 dB, 80.34 dB respectively. The total average path loss of all nine off-body channel's at (1 $\sim$ 6 metre) for the first measurement case is 84.57 dB while 76.42 dB is noticed for the second measurement case.

In comparison with two measurement cases (cable and cable-less) the lowest variation of average path loss of 6.48, 6.55 dB is noticed for both ankle links when measurements are made standing subject at 1 $\sim$ 6 metre distance. For both measurement cases the path loss is noticed higher for the reader to right ear link in comparison with other off-body channels when subject was standing at 1 $\sim$ 6 metre distance locations as shown in Figs. 2(a), (b). This happened so due

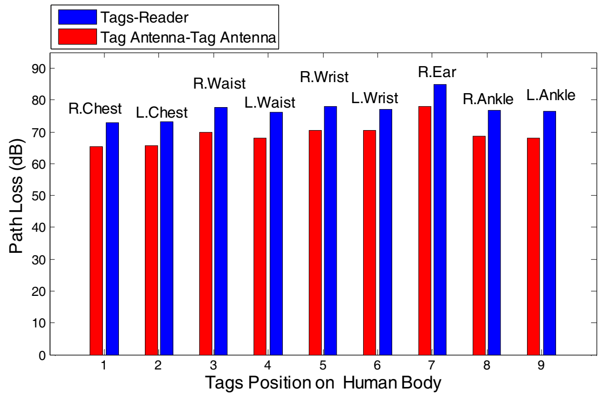


Figure 3. Comparison of average path loss for nine different off-body channels in both measurement cases when subject was standing at 1 metre distance.

to different orientation of the tag/tag antenna in relative to the receiver antenna located on the right ear. Since the subject was standing still facing toward the reader for all measurement scenarios, there was line of sight communication between most of the tags located on the body (except right ear) and the reader but for the right ear case the relative position of the tag in relative to the reader changed and there was not direct communication path from the tag to the reader which result in higher path loss. In both cases as the distance between the transmitter and receiver increases the increase of path loss is found to be the lowest for the reader to right ear link.

3.2. Path Loss vs. Distance

It is well known that the average received signal decreases logarithmically with distance (for both indoor and outdoor environments). The path loss can be modelled as a linear function of the logarithmic distance between transmitter and receiver as explained in [3],

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

where d is the distance between transmitter and receiver, d_0 is a reference distance set in measurement (set to 1 meter in this study), $PL_{\mathrm{dB}}(d_0)$ 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 technique is performed on measured path loss results for all 9 off-body channels (1–6 meter) at 54 different transmitter locations in indoor to extract the path loss exponent and the mean path loss at the reference distance for both measurement cases. Fig. 4 shows the measured value and modelled path loss for off-body channel versus logarithmic Tx-Rx separation distance showing path loss exponent for tags-reader (without cable) and two standalone antennas (with cable) measurement scenarios.

The path loss exponent values for tag-reader and two standalone antennas cases are different. For tags-reader case, it is found to be 1.83 while 1.62 is noticed when measurements are made with the two standalone antennas connecting with VNA through cable as shown in the Fig. 4 and Table 1. Results show that when measurements are made using the cable and two antennas, 0.21 lower path loss exponent and 7 dB lower path loss value at the reference distance is noticed in comparison with the measurement made using the tag and the reader (without cable). This happened so because when measurements are made using cable and Vector Network Analyser connecting two standalone small antennas, the cable and the connector may also radiate which increases the received signal strength for this case hence experiences less path loss exponent and less path loss value at the reference distance in comparison with the first measurement scenario made without cable.

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

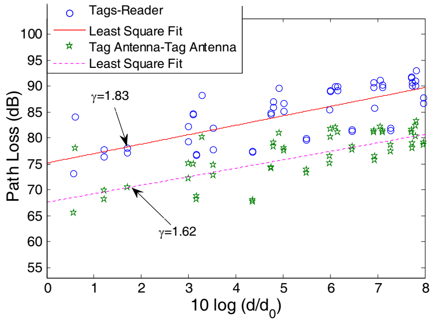


Figure 4. Measured and modeled path loss for off-body channels versus logarithmic Tx-Rx separation distance for both measurement cases.

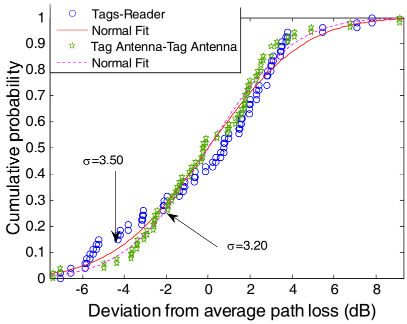


Figure 5. Deviation of the measurements from the average path loss fitted to normal distribution.

Table 1. Comparison of path loss parameters.

Scenarios	γ	$PL_{\mathrm{dB}}(d_0)$	σ
Tags-Reader	1.83	75	3.50
Standalone Antennas	1.62	68	3.20

measurements from the average path loss fitted to a normal distribution for both measurement cases. The standard deviation of the normal distribution for tags-reader (without cable) case is found to be $\sigma = 3.50$ while 3.20 is found for the stand alone antennas (with cable) case as shown in Table 1. The difference of the standard deviation value σ in between two measurement cases are very close to each other. In the indoor environment, shadowing and the reflections from surrounding environment scatters are the main contributors to the deviation from the average path loss.

4. CONCLUSION

In this paper experimental results of two measurement techniques for UWB off-body radio propagation channels are shown and analyzed. First measurement was performed using UWB transmitter tags and the reader (without cable) and second measurement was performed using two standalone antennas connecting to VNA through cable (with cable). Path loss of nine different off-body channels for both cable and cable less measurement scenarios are shown and investigated. Results and analysis show that in average of 7.46 dB lower path loss value is noticed when measurements are performed using two standalone antennas connecting to VNA through cable. Increase of 12.96% path loss exponent is noticed for the first measurement, i.e., tags-reader case. It is concluded that cable has some effects on the UWB off-body radio propagation channels/radio channels in body-centric wireless communications. There can be some effects from the circuits integrated with the antennas as well.

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