Observations from Ultra Wideband On-Body Radio Channel Measurements

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Abstract

This paper reports the highlights from the recent ultra wideband (UWB) radio channel measurement activities carried out by the Centre for Wireless Communication (CWC), University of Oulu, Finland. The experimental work was targeted to create data for measurement based radio channel modelling. Models are to be used in on-body and on-off body UWB wireless body area network (WBAN) transceiver performance studies. The channel measurements were carried out in a frequency domain using volunteer humans to create a propagation medium of interest. The experiments were done in an anechoic chamber which, at the end, result reference UWB WBAN channel models for future measurements. They will take place in expected WBAN utilization areas, such as hospitals or elderly care or residential homes. The results pointed out interesting features in channel characteristics when cardiac implant is involved.

1. Introduction

Wireless sensor networks (WSN), including its sub-section wireless body area network (WBAN), are coming to increase greatly the number of existing radio transceiver embedded devices in the world during the next few years. Without touching the Internet of Things (IoT) topic in general, more specific application fields for sensor networks can be found from medical, health and wellbeing sectors. To utilize radio spectrum as efficiently as possible, all the communicating radio systems should be designed considering all the information available describing the targeted signal propagation characteristics. This makes it possible to better optimize the receiver for different environments.

The IEEE Std. 802.15.6-2012 [1] defines the signal structure for ultra wideband (UWB) WBAN communications, leaving the receiver architecture and implementation issues open. This enables uninterrupted transceiver research and development work, which still requires accurate models to be used to describe how radio signal propagates in the close vicinity of a human body. In addition to [1], the IEEE Std. 802.15.4-2011 [2] is utilizing UWB waveforms. During the standardization processes of IEEE Std. 802.15.6-2012 and 802.15.4-2011, related study groups defined WBAN channel models for different frequency ranges as reported in [3] and [4]. In addition to UWB, those documents describe reference channel models also for narrowband communication in several center frequencies.

Centre for Wireless Communications (CWC) has a long history in measurement based radio channel modeling since the first results especially for WBAN use in hospital environment were published already in 2009 in [5], and later on, in [6-7]. A comparative analysis using the standard channel model from [3] and the model from [5] was reported in [8]. Later on, the WBAN channel measurements at CWC were focused on describing deeply the static situation when a human under study was not moving. However, pseudo-dynamic cases were also covered. The restrictions for movement during the frequency domain measurements are based on the channel's coherence time compared to the frequency response's measurement time. The environment needs to be unchanged during the sweep time to guarantee that all the recorded frequency samples are taken from the same posture. By decreasing the sweeping time, immobility requirement can be loosed. On the other hand, the selected sweep time reflects to inter-frequency channel bandwidth and the number of measured frequency points, which have an impact on the achieved accuracy.

The rest of the paper is focused on the recent experiments which were done in an anechoic chamber to reduce the impact of environment on the WBAN channel models. Thus the presented results are illustrating the signal propagation characteristics in the situation when only human's impact is taken into account.

2. Measurement system and procedure

The main target was to produce channel models that can be used to validate the correct operation of the measurement system used, and to create reference models for the corresponding measurements carried out in environments where the WBAN is typically used. On the other hand, in WBAN applications, the most significant

978-1-4673-5225-3/14/$31.00 ©2014 IEEE

contribution to the received signal energy is provided by the first propagation paths which are typically the signal components traveling along a body or through the air.

The measurements were carried out using a four-port vector network analyzer (VNA), Rohde & Schwarz ZVA8 [9], which enabled the measurement of six different links at one installation plus other six corresponding reverse links between the four antennas attached to VNA. For post processing, one setting provided thus 12 individual links for six link combinations. Two different types of non-commercial antennas, dipole and double loop, which were designed for on-body communication, were used during the measurements [10]. Each measurement setting includes four similar antennas. In addition, in some measurements there was also commercial antenna involved, namely Skycross SMT-3TO10M-A [11]. The antennas were attached to a human body using a piece of Rohacell (20 mm thick) between the antenna and skin to improve the antenna's radiation efficiency.

The studied frequency range was 2 – 8 GHz; the upper limit is due to the VNA limitations. The transmit power used at the measurements was +10 dBm, number of measured frequency points per sweep 1601 and VNA IF bandwidth 100 kHz. This provides 288.14 ms sweep time. Each link was measured 100 times consecutive to increase the statistical reliability.

During the measurement campaign, two different sets of measurements were executed. Most of the studied cases were following the antenna placements presented in Figure 1a. The other setting was used with two persons in which the other person had titanium alloy aortic valve implant and the reference person has not. In that case, several antenna positions in two rows in both sides of the body were studied, as showed in Figure 1b. The other side of the body had symmetrical arrangement for the 12 antenna sites shown in Figure 1b. The antenna positions in the arms are common resulting totally 28 antenna locations. In both cases, there were also two antennas having a fixed location presented in green star in Figure 1b. The grey stars represent the changing antenna positions.

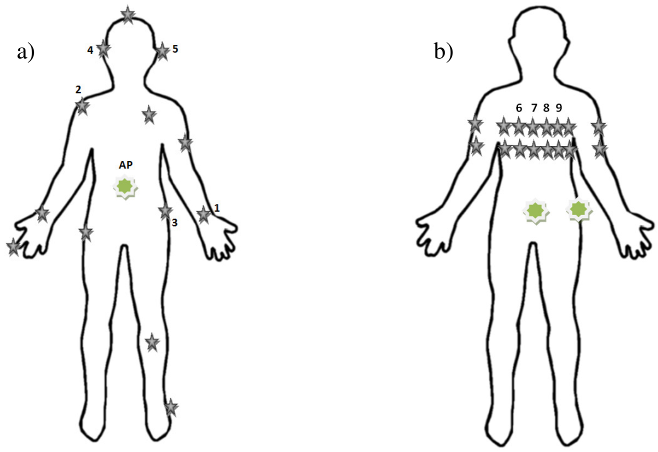


Figure 1. Antenna placements during the measurements: a) typical setting, b) with a person having an implant.

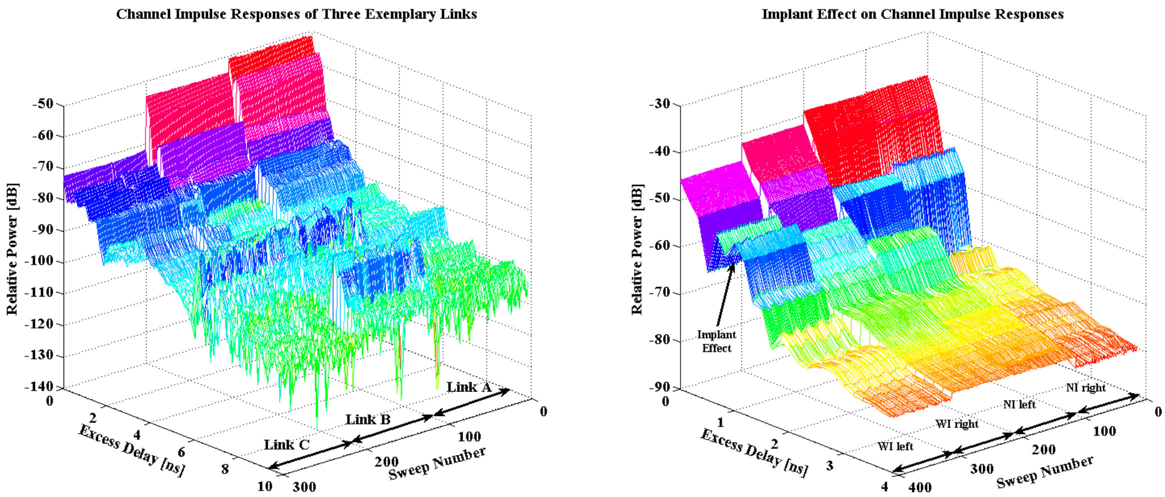
As already mentioned, the four-port VNA was able to measure in succession all the different links between the antennas connected to VNA, producing 12 individual scattering parameter sets. During the data post-processing, the s-parameters s_{12} and s_{21} from each measured antenna pair were analyzed. These s-parameters were corresponding to the frequency response of the channel. The remaining s_{11} and s_{22} were indicating the goodness of the antenna-skin matching. In the post-processing, an inverse fast Fourier transform (IFFT) was used to convert the frequency domain channel characteristics into the delay domain ones. The data analysis was performed in Matlab^{TM}.

3. Results

In this chapter, the obtained results are shortly summarized. The data analysis produced statistical models for path loss and impulse response characteristics for different links that WBAN implementation can cover. The antenna settings used in the radio channel measurements are following possible node locations used, e.g., in monitoring Parkinson's disease symptoms [12] or electrocardiogram measurements, providing thus realistic results for signal propagation statistics for designing a real WBAN system. In this context, immobility requirement during the measurement was kept. Due to the space restrictions, this paper presents only sample results. More results related to these measurements can be found from [13-14].

Depending on the link under study, the received signal can vary significantly. Moreover, multipath propagation is changing the channel impulse response (CIR). Figure 2a highlights the differences in the channel responses when different types of links are studied. Using the antenna locations defined in Figure 1a, Link A represents the link between points AP-1, Link B is a link between points 2-3 and Link C is a link between points 4-5. The selected links are providing extremes of the CIRs; from line-of-sight through obstructed to fully inhibited links. The impulse responses, 100 consecutive CIRs per each link, using dipole antennas are shown. The selected links explicitly introduce the large dynamic scale of the received signal characteristics in WBAN environment. The power levels are not normalized, only the first arriving paths are synchronized to show commensurable excess delay caused by the channel. Most of the received signal energy will arrive within 1.3 ns excess delay. The strong reflections after around 4 ns excess delay are based on the movable structures used to reduce the space in the anechoic chamber. If the line-of-sight link can be obtained, the received signal quality is good compared to the case which is fully occupied even the link being short, like ear-to-ear link.

Figure 2b highlights the impulse responses measured with two test persons; a person with an implant (WI) and a reference person without an implant (NI). As an example of the impact of an implant on the channel impulse response, the links between points 6-7 and 8-9 from Figure 1b were presented for both persons. These links are symmetrical compared to the human body but the link 8-9 cross the heart. As can be seen from the CIRs, the link 6-7 for both persons is similar. However, in the case of link 8-9, there is a visible difference in the delayed signals when the implant is involved. The structural difference between the test persons has an impact on the measured channel impulse response but the impact of implant on the CIR is clear. The symmetrical links in NI case produce almost similar CIRs but in the case of WI, the amplitude of the main peak decreases and the longer excess delays are providing additional energy. The first observation is also reported in [15], where results were based on different data set. The impact of implant has also been perceived by computer simulations where similar implant and partly similar assumptions for signal characteristics were used [16].



a) b)

Figure 2. a) Measurement based impulse responses for different types of UWB links, b) Chest links with two persons, other has an implant (WI) and the other has not (NI).

5. Conclusion

In this paper, the observations from the recent WBAN on-body radio channel measurements by CWC, Oulu, Finland for UWB were reported. The results clearly show how the link geometry and blockage will change the behavior of channel impulse response. The dynamic range from the received first path signal power viewpoint can be more than 20 dB. Moreover, channel impulse responses include differently behaving multipath components. The variation is high but the typical excess delay is less than 1.3 ns. On the other hand, the reported results also verify that metallic implant has an impact on the signal propagating over it. Even though the link distance is short, a significant change in the measured impulse response was seen. The characteristics of the left side of chest's CIRs that cross the heart/implant are different between the persons who has and who has not an implant, thus the right side of chest's CIR are similar. The study to find reasons for that behavior is now ongoing.

6. Acknowledgments

This work is partially funded by the Finnish Funding Agency for Innovation (Tekes) via the projects Wireless Body Area Network for Health and Medical Care (WiBAN-HAM) and EWiHS (Enabling Future Wireless Healthcare Systems). In addition, this paper is also part of the EU COST IC1004 Action.

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