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Radio Channel Measurements in 868 MHz Off-Body Communications in a Ferry Environment

Krzysztof K. Cwalina*[(1)], Slawomir J. Ambroziak[(1)], Piotr Rajchowski[(1)], and Luis M. Correia[(2)]
(1) Fac. of Electronics, Telecommunications and Informatics, Gdansk University of Technology, Gdansk, Poland
(2) INESC-ID / Instituto Superior Técnico, University of Lisbon, Lisbon, Portugal

Abstract

In the paper, a characterization of the 868 MHz off-body radio channel in BANs is presented. Measurements were carried out in a ferry environment using a specific set-up. A method for path loss using radio distance measurements (RDMs) was developed. It allows to automate the measurements process and make it independent from the variable speed of a moving person. Based on the observed path loss as a function of distance, the obtained values are divided into Line-of-Sight (LOS) and Non-Line-of-Sight (NLOS) conditions. The results show that, in LOS, the smallest path loss mean value (67.79 dB) and standard deviation (3.87 dB) were obtained for the placement of the mobile node (MN) on the chest (TO_F) of a moving person in an approaching scenario (APR). In NLOS, the lowest path loss mean value (71.57 dB) was also obtained for the same scenario. In other scenarios, more than approximately 5 dB higher path loss mean value was obtained.

1. Introduction

A growing number of wearable devices to monitor health parameters or to record parameters of the movement contributed to dynamic development of the Wireless Body Area Networks (WBANs) operating within the human body. The nodes are placed directly on or inside the human body, thus its influence on the radio link cannot be ignored. Body position changes significantly affect radio channel parameters, including path loss attenuation, signal fading, and impulse response [1].

In the IEEE 802.15.6 standard, ranges of frequency bands for WBANs in different regions of the world [2] have been indicated. The selected European unlicensed 868 MHz band is generally intended for use in telemetry systems. Currently, measurement and simulation research focus, among others, on the analysis of radio channels, and in particular on propagation attenuation modeling for different environments, including harsh environments in terms of radio wave propagation. In this paper, an example of a ferry environment is analyzed, which should not be regarded as a typical indoor environment, due to its metal structure [3, 4, 5, 6, 7, 8].

The few publications in the literature that take a ship environment into account aimed to characterize ultra-wideband (UWB) channels operating in [6, 9] GHz and narrowband channels operating in the 2.4 GHz band. Considering the limited number of publications dealing with the path loss modeling in a passenger ferry environment, there is the need to develop a universal propagation model for WBANs for *off-body* communication in 868 MHz band [3, 4, 7]. The results will allow to develop a model that will facilitate the radio link design for WBANs, which can be very important from both the users multimedia services point of view and their safety. The research originality presented in this paper, apart from the obtained path loss measurements in untypical environment, is the use of a new measurement method using radio distance measurements (RDMs).

This paper is composed of four more sections. In Section 2, the mobile measurement equipment, consisting of WBANs devices, is described. Section 3 describes measured passenger ferry environment and investigated scenarios. In Section 4 preliminary results of obtained path loss, and corresponding radio distance estimation, values are shown. Section 5 summarizes current state of work, and indicates future course of research.

2. Measurement equipment

Measurements were made by use of a mobile measurement equipment including hardware and software developed WBAN nodes and data acquisition server (DAS). Three types of devices were used:

- reference node (RN) with dimensions of $130 \times 35 \times 31\text{mm}^3$ and connected via a wired RS232 interface to the DAS;
- mobile nodes (MN) with dimensions of $58 \times 16 \times 35\text{mm}^3$ and attached to the human body;
- computer with dedicated software is used as DAS, which (beside saving data to files) monitors measurement equipment by displaying information, among others, number of devices in network, operation mode, the actual distances between the nodes, and so on.

The hardware and software implementation of the developed measurement method, using RDMs time-synchronized with path loss measurements in the selected frequency band, required improvement in relation to the already found in the literature measurement equipment with another radio interface [4, 6, 7, 9]. Each node consists of two parallel working radio interfaces:

- narrowband radio module CC1120 produced by Texas Instruments company, working in the 868 MHz band, used to determine the propagation attenuation,
- ultra-wideband (UWB) radio module DWM1000 produced by DecaWave company, working in the 6 489 MHz band, used to perform the radio distance measurements,

Both radio interfaces operate in accordance with the IEEE 802.15.4 standard, which is indicated as a possibility to use in WBANs [1, 10]. WBANs protocol solutions using both radio interfaces, their self-organization methods, data exchange, time division multiple access (TDMA) and description of the implemented physical layer based on microcontrollers are described in more details in [11].

It should be also noted that the estimated value of the received signal power was obtained with a resolution of 1 dB, being the mean values of several consecutively received symbols. The measurement research has shown that the five consecutively received symbols give satisfactory results with a standard deviation that does not exceed unity at a relatively short time of the ability to read next value, i.e. approximately 270 μs with a deviation of ±5 μs. Selected parameters of the 868 MHz module used for measurements should be mentioned: center frequency 868.3 MHz, frequency deviation 50 kHz, 5 dBm signal power, 2-GFSK (Gaussian Frequency Shift Keying) modulation, 50 kbps bitrate, 67 B data length with data whitening included. Additionally, the interface uses a compact ceramic antenna ANT1204F007R0870A produced by Yageo company, characterized by the following parameters: 1.67 dBi gain, 870 MHz resonance frequency and -28 dB return loss (RL). The biggest impact for the choice of antenna was the physical dimension and the possibility of use it in miniaturized wearable devices [1].

Usually, in WBAN measurements, the distance between successive path loss measurement samples is determined basing on the average speed with which a person moves during the measurement [9, 12]. This requires constant surveillance and performing the manual determination of the beginning and the end of data recording. Radio distance measurements allow to automate the measurement process. Time synchronization of both radio interfaces, using a dedicated signal line, allows to obtain information about the path attenuation and the corresponding distance between the transmitter and receiver at once. All measured data can be recorded and analyzed independently of the person's speed in different scenarios.

To estimate the distance between two nodes, UWB interface and the method of Symmetric Double-Sided Two-Way Ranging (SDS-TWR) which minimizes local oscillators drift and increase accuracy through the exchange of three measurement packets were used.

3. Investigated Scenarios

The measurements were carried out on a passenger ferry MF WAWEL in May 2016, during mooring, when only the crew was present on the ferry. Construction elements (i.e. walls, ceiling, floor, doors and handrails) are made of steel with different thicknesses [8]. Fig. 1 shows a three-dimensional plan of part of the deck, in which measurements were made.

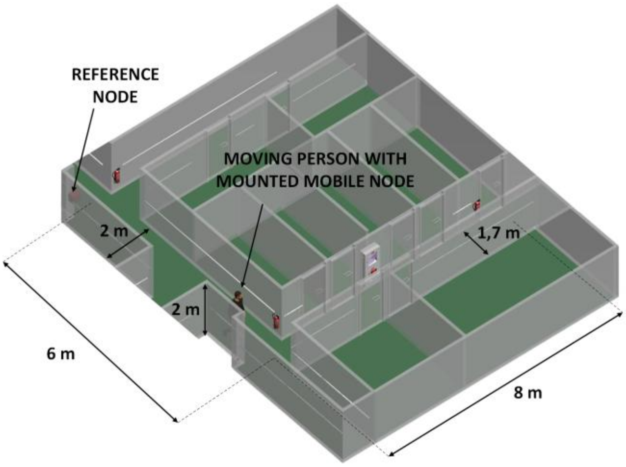

Figure 1. Three-dimensional plan of part of the deck.

All *off-body* measurement scenarios were realized by attaching a stationary RN to the wall at a height of 1.2 m on the seventh passenger deck. A single MN was placed on the person moving along the axis of a narrow corridor. The separation between human skin and radiating elements was about 1 cm. The measurements were carried out by one person: a man with 1.72 m height, 60 kg weight and 20.3 body mass index (BMI).

From the many typically selected montage locations of wearable devices, three were selected as representative for applications in WBAN, e.g., smartwatches, pulsometers, multimedia glasses and so on [1, 9, 13, 14]:

- right side of head (HE_R), height h_{HE_R}= 1.65 m,
- chest (TO_F), height h_{TO_F} = 1.35 m,
- left wrist (AB_L), height h_{AB_L}= 0.9 m.

Measurements were carried out for two dynamic scenarios, i.e. approaching (APR) and departing (DEP) with relation to RN. These are two scenarios that match the typical human behavior in a closed environment, being widely used in *off-body* BAN research [9, 15]. In the DEP scenario, a person starts in a distance of 2 m from the RN with Line-of-Sight (LOS) towards the end point of the “L” shape path. However after about 6.5 m, the Non-Line-of-Sight (NLOS) conditions can be distinguished. The walk ended after 14 m path. Authors distinguish LOS and NLOS conditions by the presence of metal obstacles in the propagation path.

The approaching scenario is reversed with respect to departing scenario in terms of the direction of movement and the start and end points of the route. For each scenario and the MN montage location measurements were made 20 times. Measurements were not affected by third parties, and in passenger cabins occurring on the propagation path there were not any people.

4. Analysis of the Preliminary Results

During the measurements, 43 626 measured path loss values, with 40 ms sampling rate, for both scenarios and three mounting locations of MN and the corresponding RDMs were obtained. Fig. 2 shows the path loss as a function of distance for one of the scenarios.

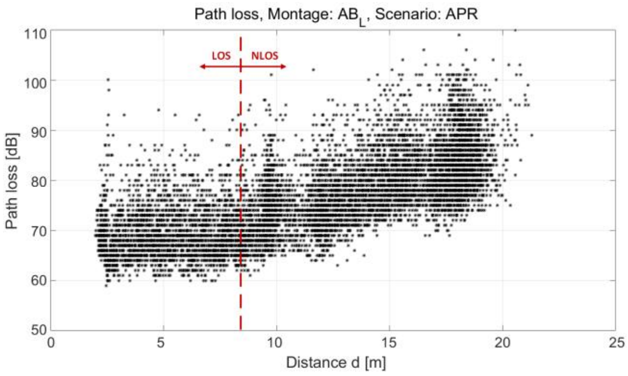

Figure 2. Path loss as a function of distance for the antenna montage on the wrist and approaching (APR) scenario.

It should be noticed that the path attenuation in LOS (i.e. to about 8.5m distance from RN) increases slightly with the increase in distance, which is caused by the metallic construction of the corridor and its dimension, which causes the waveguide effect for the measured frequency band. In the distance over 8.5 m, the relation between the path loss and distance between the MN and RN is more evident. Thus, it was decided that the analysis should take the estimation of path loss separately for LOS and NLOS into account. As expected, path loss exponents for both cases are significantly different.

There are a number of received signal power fading up to 40 dB which in real conditions network, compatible with the standard IEEE 802.15.6 designed for WBANs, a packet loss and the quality of service fall may occurred [2]. It is noteworthy that the amplitude of this fading does not depend on the distance so much and even when there is 2 m distance between RN and MN devices, but fading rate increases with the distance.

It is also noted that the path attenuation values were obtained at distances up to 22 m, which distance is greater than the maximum distance between nodes occurring during measurements. According to the described measurement scenarios, the actual distance in a straight line in the farthest measurement point is about 11.3 m. Because of the design of the deck and the waveguide nature of the propagation environment, the components of radio wave propagating only along the corridor are received. It results in the presented results of the RDMs.

It is known that RDMs are affected by a measurement error [16]. In the described ferry environment, increasing RDMs deviation with the increasing distance is visible. It occurs especially for NLOS. Thus, the distances to the farthest point of measurement are affected by the largest distance error estimate. In order to minimize it, the moving average filter (MAF) of the 10 samples involved is used. The person movement and propagation environment caused a loss of some RDMs during all measurement sessions. Lost measurements were approximated using the MAF.

The analysis of results was carried out separately for LOS and NLOS, which were distinguished on the basis of the distance estimate obtained by using the UWB interface. Tab. 1 shows the results of the mean value (μ) and standard deviation (σ) calculated separately for both scenarios and three MN montage locations.

Table 1. The results of the mean value μ and standard deviation σ of measurement data.

MONTAGE	SCENARIO	LOS/NLOS	μ [dB]	σ [dB]
HE$_R$	APR	LOS	74,24	5,83
		NLOS	77,28	5,63
	DEP	LOS	72,88	5,16
		NLOS	77,16	5,64
TO$_F$	APR	LOS	63,79	3,87
		NLOS	71,57	5,64
	DEP	LOS	72,15	4,98
		NLOS	75,93	5,81
AB$_L$	APR	LOS	68,95	4,83
		NLOS	76,35	5,64
	DEP	LOS	71,33	5,28
		NLOS	78,28	5,31

The smallest path loss mean value (67.79 dB) and standard deviation (3.87 dB) were obtained for the approaching scenario (APR) and montage of MN on the chest (TO$_F$). LOS, with no partial shadowing of MN antenna by the body and the height of its montage similar to the height of RN, were the basic determinants of the obtained values. For the same conditions, the highest mean value of path loss and its standard deviation were obtained for the MN mounted on the right side of the head (HE$_R$). This is due to the MN antenna partially shadowed by the body, and main direction of the MN antenna was orthogonal to the main direction of the RN antenna.

For NLOS, as expected, both the path attenuation average value and the standard deviation are greater than at LOS. The lowest mean value (71.57 dB) was also obtained for the antenna mounted on the chest (TO$_F$) and approaching scenario (APR). Further measurement scenarios obtained approximately 5 dB higher values, wherein the highest mean value obtained for the MN mounted on the left wrist

(AB_L) and departing (DEP) from the reference node. This is due to the specificity of the natural human gait and hand movement during which the antenna was shadowed by moving person torso. The standard deviation values for all montage placements are similar, which means that during the development of the propagation model it will be possible to describe fading by a one random variable independently from the location of the MN.

5. Conclusions

Part of the measurement research, presented in this paper, fits into the area of WBANs as an important direction of development of 5th generation modern radio networks.

The used measurement equipment including heterogeneous WBAN nodes and measurement method using time-synchronized radio distance measurements were described. Measurements of the 868 MHz *off-body* radio channel in a real ferry environment were made. Two realistic person movement scenarios with respect to stationary reference node scenarios, which were repeated for each of the three most popular WBANs node montage on the human body were performed.

The analysis of the preliminary results obtained in real environment determines the direction of future research work. There is a need to develop a new propagation model for unlicensed 868 MHz band, which can be widely used in both wireless sensor networks and wireless body area networks. Using the linear regression separately for LOS and NLOS, it will be possible to determine the path loss exponent as well as the path loss for a reference distance. In addition, probability density functions of random variables representing the impact of the shadow fading and multipath fading will be fitted [9].

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