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Radio Channel Measurements in Off-Body Communications in a Ferry Passenger Cabin

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Abstract

This paper presents an off-body radio channel measurements in a ferry passenger cabin at 2.45 GHz band, for static sleeping scenarios with different body orientation and on-body antennas placements, and also for upper and lower sleeping berths. The measurements have been performed with two types of on-body wearable receiving antennas: FlexPIFA (flexible planar inverted F antenna), and FlexNotch (flexible adhesive-backed notch antenna) and one patch off-body transmitting antenna. The measurement equipment, measurement environment and investigated scenarios are described. A preliminary analysis of the results – the mean value (μ) and standard deviation (σ) – is presented. In general, the propagation path loss mainly depends on the type and location of the receiving antennas, and also on the body orientation during sleeping and surrounding elements of environment. The lowest mean path loss values (both below 56 dB) were obtained for upper sleeping berth and scenario, where receiving FlexPIFA antennas were mounted on chest and back during lying on the left side. In contrast, the highest values (both over 70 dB) were obtained for upper sleeping berth and scenario, where FlexNotch antennas were mounted on chest and right wrist during lying on the left side. Moreover, the standard deviation varies in a range from 3.7 dB up to 8.0 dB for all cases.

1. Introduction

Nowadays, the increasing use of wireless networks technology, continuous progress of electronic devices miniaturization, as well as the increasing demand for monitoring of the human body functions, aroused interest of researchers, system designers, and application developers, and allowed to develop the new radio network concept – Wireless Body Area Networks (WBANs). WBANs generally consist of a group of small, lightweight, ultra-low-power and short-range radios devices (i.e., sensors, actuators), which can be placed in, on, or around the body and they can monitor different vital functions, exchange them between each other and send to an external device (e.g., medical server) [1].

One of the main direction on the development of WBANs is the ability to use them in medical applications, where small, intelligent devices are capable of establishing a wireless communication link and could provide continuous health monitoring in real-time in hospitals, aged-care facilities and nursing homes [2]. For each wireless system, during its design and implementation phases, the propagation properties of the radio channel have to be known. There have been various studies on propagation characteristics for WBANs [3-5], especially for medical applications [6]. Most of the available works describe WBAN measurements in typical, easily accessible, indoor environments such as rooms [7, 8], corridors, hospital rooms, laboratories, or even in an anechoic chamber. There is a lack of work on radio channel measurements in real, unusual, harsh environments, e.g. sea ships or ferries, where the environment construction and elements have a significant impact on radio wave propagation. The increasing popularity and multiplicity of applications of WBANs requires to perform radio channel measurements in these environments. Doubtless, an example of such harsh environment is a hospital ship (i.e., this is the ship designated for primary function as a floating medical treatment facility or hospital and operated by the military forces of various countries), in which all walls, floors and ceilings are made of metallic materials.

One of the most popular activities in hospitals and medical treatment facilities is monitoring human body functions during rest or sleep. Some work on analysis and propagation characterization of radio channels for on- and off-body communications for sleeping scenarios has been done in [9], but there is no influence analysis on propagation conditions depending on the different body orientations, types of wearable antennas and their different placements. Additionally, the studies have been done for typical, easily accessible environment, which was the room of one of the authors.

Taking the above into consideration, there is the need to perform radio channel measurements and analysis in off-body communications in harsh environment, like a ferry passenger cabin, by including realistic sleeping static scenarios with different body orientations, different receiving antennas placements and types, and different heights of sleeping berth.

This paper is composed of five sections. In Section 2, the measurement equipment is described, while the investigated scenarios and environment are characterized in Section 3. Section 4 contains preliminary results and their analysis. The paper is summarized in Section 5, where future work is presented as well.

2. Measurement Equipment

The designed measurement unit includes the devices that implement the transmitting (Tx) and receiving (Rx) sections of the radio communications system. The measurement stand was developed at Gdansk University of Technology. In Fig. 1, the block diagram of the equipment set of the Tx and Rx sections used in the channel measurements is presented.

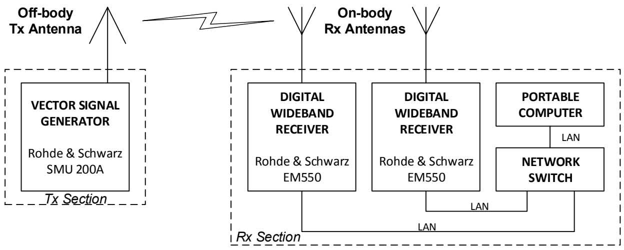

Figure 1. Block diagram of measurement stand.

The transmitting section consists of a vector signal generator SMU 200A, and a patch off-body Tx antenna, operating in the license-free band centered at 2.45 GHz. The antenna has linear polarization, 3 dBi gain, and half-power beamwidth of 115° in the H-plane and 140° in the E-plane. The Tx signal, at 2.45 GHz with BPSK (Binary Phase Shift Keying) modulation, is pseudo-random bit sequence with a length of 23 bits and 3 kb/s bit rate. Power calibration of the Tx section was done via the power sensor Agilent U2000A, with a 40 dB attenuator MiniCircuits BW-40N100W, and a computer with the N1918A power analysis manager. After calibration, the signal power at the input of the off-body Tx antenna was -2 dBm.

The RX section consists of two digital wideband receivers R&S EM550, respectively for both Rx antennas, and controlled via a network switch by a portable computer, which is also responsible for measurement data storage and preliminary calculations using dedicated software. In the presented solution, the average sampling period of the receivers was 3 ms, while each single scenario lasted 60 s. The radio signal bandwidth was set to 12 kHz. The measurements have been performed with two types of on-body Rx antennas, operating at 2.45 GHz as well. The first type is the wearable flexible planar inverted F antenna (FlexPIFA), with linear polarization, 2 dBi gain and ability to be flexed in convex and concave positions. The second one is the wearable flexible adhesive-backed notch antenna (FlexNotch), also with linear polarization, 2 dBi gain and ability to be flexed in convex and concave positions.

The connections between signal generator or wideband receivers, and Tx or Rx antennas were realized with a 3 m long Sucoflex 104 cables. The attenuation of these cables at 2.45 GHz is 1 dB, being taken into account during the calibration process.

3. Description of Measurements

The measurements were carried out in a cabin located on deck number 7 on the passenger ferry M/F Wawel [10]. The measurement campaign was made during one of the cruises, when the ferry was on the open sea. This allowed to ensure maximally realistic measurement conditions. The selected measurement location is an internal cabin (without windows), and arranged to accommodate up to four persons. There are two rooms inside the cabin: the main space with four sleeping berths, and the bathroom. The plan view of the cabin and the measurement area (the red outline) is presented in Fig. 2. All walls, ceiling, and floor of the investigated cabin are made of metallic materials.

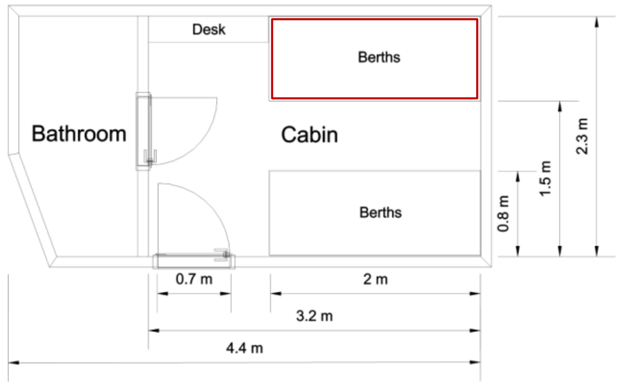

Figure 2. Plan view of the investigated cabin.

The height of the cabin is 2.1 m, which corresponds to the height of the Tx antenna, placed in the central part of the cabin on the ceiling. The measurements have been performed on two sleeping berths, on two different heights, respectively 0.4 m for the lower sleeping berth and 1.35 m for the upper one. The distance between Tx antenna and berths was 1.2 m and 2 m, respectively for upper and lower berths. The berths were made of metallic material, which had a crucial impact on the obtained path loss values. The others furniture and objects, like desk and chair, are made of wood or plastic. Additionally, during measurements, two persons were present in cabin, the operator of measurement stand and a person performing the measurement laying scenarios. The height and weight of the investigated body is 1.72 m and 60 kg, respectively.

In a typical application of WBANs in off-body communications (e.g., health-care, military, emergency services or fitness applications), there are multiple locations where the antennas can be placed. To perform the radio channel measurements for static scenarios during sleep in a cabin ferry, the three Rx antennas placements were took into account – chest, back and right wrist.

For each scenario, two Rx antennas have been mounted simultaneously, in the following configurations: configuration 1 (C1) – chest and back, and configuration 2 (C2) – chest and right wrist.

During measurements, the eight sleeping static scenarios have been realized: lying on the back with hands along the body (L1), lying on the back with hands under the head (L2), lying on the front with hands are along the body (L3), lying on the front with hands under the head (L4), lying on the left side with right hand on the bed (L5), lying on the left side with right hand under the head (L6), lying on the right side with right hand on the bed (L7), lying on the right side with right hand under the head (L8). Of course, each scenario has been analyzed for lower and upper sleeping berths. These scenarios, being the most often sleeping positions, allow to investigate the influence of body orientation, height of sleeping berth, type of wearable antennas and their placement on propagation conditions, i.e., Line of Sight (LoS), Quasi LoS (QLoS), and Non LoS (NLoS). The propagation conditions for all scenarios, configurations and berths are presented in Table 1.

Table 1. The propagation conditions in ferry cabin.

	Scenario	C1		C2	
		Chest	Back	Chest	Right Wrist
		Rx 1	Rx 2	Rx 1	Rx 2
UPPER BERTH	L1	LoS	NLoS	LoS	LoS
	L2	LoS	NLoS	LoS	NLoS
	L3	NLoS	LoS	NLoS	NLoS
	L4	NLoS	LoS	NLoS	NLoS
	L5	LoS	NLoS	LoS	LoS
	L6	LoS	NLoS	LoS	NLoS
	L7	NLoS	LoS	NLoS	NLoS
	L8	NLoS	LoS	NLoS	NLoS
LOWER BERTH	L1	QLoS	NLoS	QLoS	NLoS
	L2	QLoS	NLoS	QLoS	NLoS
	L3	NLoS	QLoS	NLoS	NLoS
	L4	NLoS	QLoS	NLoS	NLoS
	L5	QLoS	NLoS	QLoS	QLoS
	L6	QLoS	NLoS	QLoS	NLoS
	L7	NLoS	QLoS	NLoS	NLoS
	L8	NLoS	QLoS	NLoS	NLoS

4. Analysis of the Preliminary Results

During the measurement campaign in the ferry passenger cabin, over 2 million power values were collected, which means about 32 000 data for each analyzed scenario. This significant number of measurement results allowed to prepare a valuable statistical analysis of propagation path loss. At this stage of research, the mean value (μ) and the standard deviation (σ) was calculated and analyzed for each scenario. The results are divided into types of Rx antennas, and are presented in Tables 2 and 3.

Considering all measurement results, the better choice for WBANs in off-body communications for sleeping scenarios in ferry passenger cabin is the FlexPIFA antenna type, because the mean value and standard deviation of all path loss results is lower than for FlexNotch antennas (the mean values are 57.1 dB and 68.3 dB, and the standard deviation values are 6.9 dB and 10.6 dB, respectively).

Table 2. The results of statistical analysis for FlexPIFA.

	Scenario		C1		C2		Total for scenario
			Chest	Back	Chest	Right Wrist	
			Rx 1	Rx 2	Rx 1	Rx 2	
UPPER BERTH	L1	μ / σ [dB]	58.7 / 4.7	61.6 / 4.9	50.8 / 4.0	59.1 / 4.5	57.6 / 6.1
	L2	μ / σ [dB]	52.3 / 4.2	58.9 / 4.7	63.6 / 4.6	65.9 / 4.0	60.2 / 6.8
	L3	μ / σ [dB]	53.3 / 4.3	52.9 / 4.9	66.6 / 4.7	59.4 / 4.0	58.1 / 7.1
	L4	μ / σ [dB]	61.4 / 4.7	51.4 / 5.0	53.4 / 4.1	60.1 / 4.0	56.6 / 6.2
	L5	μ / σ [dB]	52.6 / 4.3	56.1 / 4.7	53.7 / 4.2	52.3 / 3.8	53.7 / 4.5
	L6	μ / σ [dB]	46.8 / 4.3	55.2 / 4.9	55.7 / 4.1	64.1 / 3.8	55.5 / 7.5
	L7	μ / σ [dB]	60.9 / 7.4	54.0 / 5.2	49.7 / 4.1	64.4 / 5.5	57.2 / 8.1
	L8	μ / σ [dB]	66.5 / 4.7	55.7 / 5.6	57.2 / 4.4	57.4 / 4.4	59.2 / 6.4
Total for configuration μ / σ [dB]			56.6 / 7.7	55.7 / 5.8	56.3 / 7.1	60.3 / 6	
LOWER BERTH	L1	μ / σ [dB]	62.5 / 6.6	54.3 / 5.1	50.4 / 4.2	52.9 / 3.9	55.1 / 6.8
	L2	μ / σ [dB]	63.7 / 5.2	55.1 / 5.0	50.7 / 4.0	57.3 / 4.5	56.8 / 6.7
	L3	μ / σ [dB]	61.7 / 4.3	50.3 / 4.7	55.6 / 4.1	61.6 / 5.0	57.3 / 6.6
	L4	μ / σ [dB]	58.5 / 4.3	52.4 / 5.1	63.4 / 4.2	64.9 / 7.7	59.7 / 7.4
	L5	μ / σ [dB]	57.7 / 4.7	49.9 / 5.1	74.4 / 8.0	60.5 / 4.3	60.5 / 10
	L6	μ / σ [dB]	57.2 / 4.8	61.5 / 5.7	49.3 / 4.1	62.9 / 4.3	57.8 / 7.1
	L7	μ / σ [dB]	46.9 / 4.3	59.9 / 6.0	51.1 / 4.4	57.4 / 4.4	53.8 / 7.1
	L8	μ / σ [dB]	50.1 / 4.3	60.3 / 5.6	52.0 / 4.1	53.6 / 4	54.0 / 6.0
Total for configuration μ / σ [dB]			57.3 / 7.4	55.5 / 6.8	55.9 / 9.5	58.9 / 6.4	

Table 3. The results of statistical analysis for FlexNotch.

	Scenario		C1		C2		Total for scenario
			Chest	Back	Chest	Right Wrist	
			Rx 1	Rx 2	Rx 1	Rx 2	
UPPER BERTH	L1	μ / σ [dB]	51.4 / 4.1	83.3 / 6.0	62.4 / 3.8	74.8 / 4.8	68 / 12.9
	L2	μ / σ [dB]	55.6 / 4.2	85.6 / 6.0	66.7 / 3.8	74.6 / 4.8	70.6 / 12
	L3	μ / σ [dB]	78.3 / 4.5	69.8 / 4.0	72.6 / 4.0	79.6 / 6.1	75.1 / 6.2
	L4	μ / σ [dB]	71.1 / 4.1	67.8 / 3.9	78.4 / 4.0	74.6 / 4.6	72.5 / 5.4
	L5	μ / σ [dB]	60.7 / 4.7	89.4 / 4.2	61.6 / 4.1	60.5 / 4.3	62.0 / 6.8
	L6	μ / σ [dB]	53.7 / 4.2	75.3 / 4.3	71.8 / 4.8	83.3 / 5.0	70.9 / 12.
	L7	μ / σ [dB]	76.2 / 4.1	71.5 / 6.7	68.7 / 3.9	72.8 / 4.5	72.3 / 5.6
	L8	μ / σ [dB]	66.3 / 4.1	53.5 / 4.2	62.4 / 4.5	74.6 / 4.8	64.1 / 8.8
Total for configuration μ / σ [dB]			64.3 / 11	75.5 / 15	67.9 / 6.8	74.2 / 7.8	
LOWER BERTH	L1	μ / σ [dB]	51.8 / 3.9	89.7 / 7.2	65.1 / 5.4	70.6 / 5.3	69.3 / 15
	L2	μ / σ [dB]	57.0 / 5.1	83.2 / 5.2	54.2 / 5.2	69.6 / 5.4	66.1 / 13
	L3	μ / σ [dB]	85.0 / 4.6	58.4 / 4.8	80.1 / 5.0	72.7 / 5.2	74.1 / 11
	L4	μ / σ [dB]	86.7 / 6.3	45.2 / 4.5	64.4 / 5.2	79.7 / 6.0	69.1 / 17.
	L5	μ / σ [dB]	63.9 / 5.6	56.7 / 7.1	57.6 / 5.4	66.3 / 5.8	61.1 / 7.2
	L6	μ / σ [dB]	74.9 / 4.0	53.8 / 6.1	60.0 / 5.1	85.3 / 6.1	68.5 / 14
	L7	μ / σ [dB]	63.4 / 3.7	45.8 / 4.9	57.2 / 5.8	73.0 / 5.3	59.8 / 11
	L8	μ / σ [dB]	57.9 / 3.7	46.4 / 4.7	74.5 / 5.9	76.3 / 6.2	63.7 / 13
Total for configuration μ / σ [dB]			67.5 / 13	60.2 / 17	64.1 / 10	74.2 / 7.9	

Considering only the body placements for FlexPIFA, the lowest values of propagation path loss were obtained for C1, when the antennas were mounted on chest and back. The mean values in total for the placement on the upper sleeping berth are 56.6 dB (chest) and 55.7 dB (back), and on the lower one, the mean values for chest and back are 57.3 dB and 55.5 dB, respectively. Considering the best sleeping static scenario, the lowest values were obtained for lying on the left side with right hand on the bed (L5): 53.7 dB (for upper sleeping berth), and during lying on the right side and when the right hand was also on the bed (L7): 53.8 dB (for lower sleeping berth). For all cases, the lowest mean values of path loss were obtained for the upper sleeping berth, for C1 (chest and back), during lying on the left side: 46.8 dB and 55.2 dB, whereas the highest for the lower one, for C2 (chest and right wrist), during lying on the left side with right hand on the bed: 74.4 dB and 60.5 dB.

Similarly, for FlexNotch antennas, the first placement (C1) is better, because the mean values in total are lower than for the second placement (C2). For the upper sleeping berth they are 64.3 dB and 75.5 dB, and for the lower one 67.5 dB and 60.2 dB, respectively for chest and back placements. The same occurs for FlexPIFA antennas, in case of the best sleeping static scenario, the lowest values were obtained for L5: 62 dB (upper sleeping berth), and L7: 59.8 dB (lower sleeping berth). A different result was obtained when all cases are taken into account, the lowest mean values of path loss being measured for the lower sleeping berth, for C1, during lying on the right side (L8): 57.9 dB and 46.4 dB, and the highest for the upper sleeping berth, for C2, during lying on the left side with right hand under the head (L6) – 71.8 dB and 83.3 dB.

5. Conclusions

This paper presents off-body radio channel measurements during sleep in a ferry passenger cabin at 2.45 GHz band. Firstly, the measurement equipment and environment are described. The measurements have been performed with two types of on-body wearable Rx antennas. Then, the eight sleeping static scenarios with different body positions, different on-body antennas placements and for upper and lower sleeping berth situations are presented. Finally, the results of preliminary statistical analysis of measurements in case of each scenario are shown.

In general, the analysis shows that the mean and standard deviation values of propagation path loss strongly depend on the type and locations of receiving antennas, but also on the body position during sleeping and surrounding elements of the environment. The lowest mean path loss values were obtained for the upper sleeping berth and scenario, where receiving FlexPIFA antennas were mounted on chest and back during lying on the left side. In this situation, both antennas are in the best propagation conditions with no object in the direct visual line of sight (LoS). The highest values were obtained for the upper sleeping berth and scenario, where FlexNotch antennas were mounted on chest and right wrist during lying on front with hands under the head. In this scenario, for both antennas, the radiation pattern field was shadowed by the human body.

Future work will focus on the development of a new narrowband radio channel model in the 2.45 GHz band, for the investigated environment.

6. Acknowledgments

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7. References

1. A. Reichman, J. Takada, “Body communications”, *Pervasive Mobile & Ambient Wireless Communications*, Springer, London, U.K., 2012.

2. J. Y. Khan, M. Yuce, “Wireless Body Area Networks - Technology, Implementation, and Applications”, *Taylor & Francis Group,* Boca Raton, USA, 2012.

3. D. B. Smith, D. Miniutti, T. A. Lamahewa, L. W. Hanlen, “Propagation Models for Body Area Networks: A Survey and New Outlook”, *IEEE Antennas and Propagation Magazine*, vol. 55, no.5, 2014.

4. S. J. Ambroziak, L. M. Correia, R. J. Katulski, M. Mackowiak, “Measurements of Path Loss in Off-Body Channels in Indoor Environments”, *1st URSI Atlantic Radio Science Conference* (URSI AT-RASC), Gran Canaria, Spain, 2015.

5. S. J. Ambroziak, L. M. Correia, K. Turbic, “Radio Channel Measurements in Body-to-Body Communications in Different Scenarios”, *URSI Asia-Pacific Radio Science Conference* (URSI AP-RASC), Seoul, South Korea, 2016.

6. P. A. Catherwood, W. Scanlon, “Link Characteristics for an Off-Body UWB Transmitter in a Hospital Environment”, *Loughborough Antennas & Propagation Conference*, U.K., 2009.

7. L. Xia, S. Redfield, P. Chiang, “Experimental Characterization of a UWB Channel for Body Area Networks”, *EURASIP Journal on Wireless Communications and Networking*, USA, 2011.

8. S. J. Ambroziak, L. M. Correia, R. J. Katulski, M. Mackowiak, C. Oliveira, J. Sadowski, K. Turbic, “An Off-Body Channel Model for Body Area Networks in Indoor Environments”, *IEEE Transactions on Antennas and Propagation*, vol. 64, no 9, 2016.

9. D. B. Smith, D. Miniutti, L. Hanlen, “Characterization of the Body-Area Propagation Channel for Monitoring a Subject Sleeping”, *IEEE Transactions on Antennas and Propagation*, vol. 59, no. 11, 2011.

10. Polferries, *Passenger ferry M/F Wawel*, Jan. 2017 (http://www.polferries.com/ferries/wawel/description).