Short Paper: Experimental Characterization of *In Vivo* Wireless Communication Channels

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Abstract — *In vivo* wireless medical devices have a critical role in healthcare technologies due to their continuous health monitoring and noninvasive surgery capabilities. In order to fully exploit the potential of such devices, it is necessary to characterize the *in vivo* wireless communication channel which will help to build reliable and high-performance communication systems. This paper presents preliminary results of experimental characterization for this fascinating communications medium on a human cadaver and compares the results with numerical studies.

Index Terms — *In vivo* channel characterization, in/on-body communication, wireless body area networks (WBAN), wireless implantable medical devices.

I. INTRODUCTION

In vivo wireless medical devices have the potential to play a vital role in future healthcare technologies. Such technologies include, but are not limited to pacemakers, implantable cardiac defibrillators (ICDs), internal drug delivery devices, neurostimulators, and wireless capsule endoscopes (WCEs). These devices provide continuous health monitoring and reduce invasiveness of surgery with the integration of wearable devices. In order to fully exploit the capabilities of such devices, it is necessary to characterize and model the *in vivo* wireless communication channel (implant to implant and implant to external device).

There exists a tremendous ongoing research on *in vivo* channel characterization in recent years. It is known that this medium's characteristics are subject-specific and strongly dependent on antenna location and frequency of operation. Although, numerical characterization of *in vivo* wireless communication channel is being investigated intensely, there are relatively few studies for experimental characterization in the literature. This paper presents an experimental characterization of the *in vivo* wireless communication channel on human cadaver at 915 MHz. The preliminary results are presented and compared with our numerical study [1].

II. EXPERIMENTAL SETUP

The ethical approval for this study is obtained from Istanbul Medipol University. In order to validate the simulation results [1], the experiment is conducted on human cadaver with a similar setup. The human male torso area is investigated at 915 MHz by measuring channel response through a vector network analyzer (VNA), while using two antennas, one (*in vivo*) [2], and other a dipole antenna (*ex vivo*) as illustrated in Fig. 1. The *in vivo* antenna is placed at six locations inside the body around heart, stomach and intestine by a physician. The antennas are located in the same orientation and all return loss values are less than -7dB.
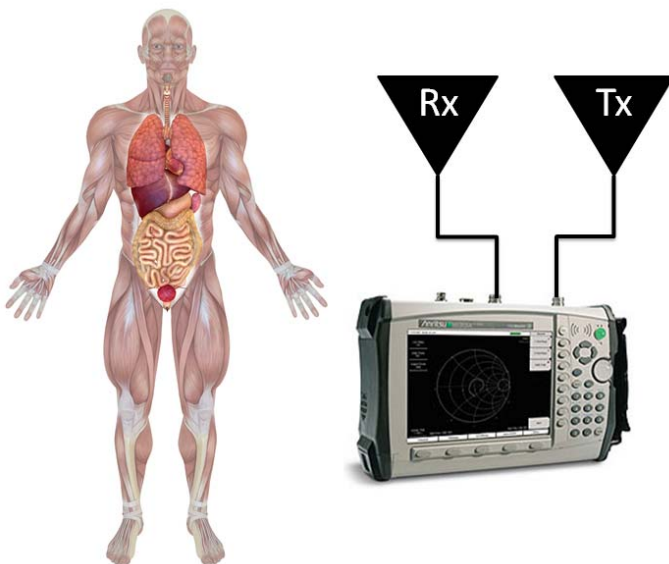

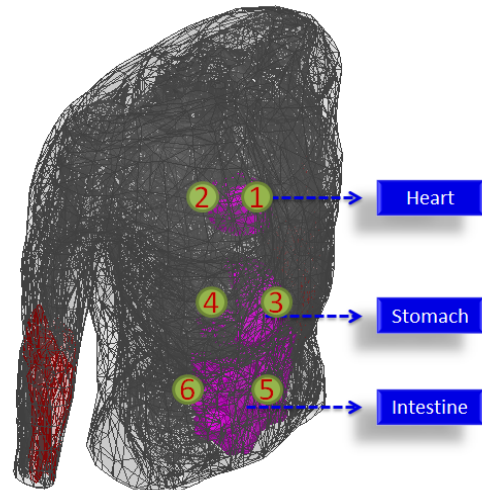Fig. 1: Experiment setup for *in vivo* channel.

Fig. 2: Measurement locations on human cadaver.

III. Radio Channel Characterization

EM wave propagation inside the body is strongly related to the location of the antenna. Therefore, *in vivo* wireless channel characterization is mostly investigated for a specific part of the human body. Fig. 2 shows the antenna locations inside the body and Table I summarizes path loss values for these locations. The signal propagates through different organs and tissues that the path loss changes significantly for the locations at similar depth from body surface.

Table I: Path loss values for selected *in vivo* locations.

Location	*In Vivo* Depth	Path Loss
01) Above Heart	3 cm	45.32 dB
02) Below Heart	8 cm	55.61 dB
03) Above Stomach	5 cm	48.19 dB
04) Inside Stomach	9 cm	50.80 dB
05) Above Intestine	2 cm	29.95 dB
06) Below Intestine	10 cm	50.47 dB

The channel modeling subgroup (Task Group 15.6), which worked on developing of the IEEE 802.15.6 standard, submitted their final report on body area network (BAN) channel models in November 2010 [3]. In this report, it is determined that Friis transmission equation can be used for in vivo scenarios by adding a random variation. In our previous study [1], the path loss is modeled as a function of depth by the following equation in dB:

$$PL\ (d) = PL_0 + m\ (d\ /\ d_0) + S \qquad (d \geq d_0)$$

where d stands for the depth from body surface in millimeters, d_0 denotes the reference depth (i.e. 10mm), PL_0 represents the intersection term in dB, m is the decay rate of received power, and S is the random shadowing parameter in dB, which presents a normal distribution for a fixed distance. The parameters for each anatomical body part are listed in the previous study. Table II compares the parameters which are obtained by numerical and experimental methods. The

Table II: Parameters for the statistical path loss model.

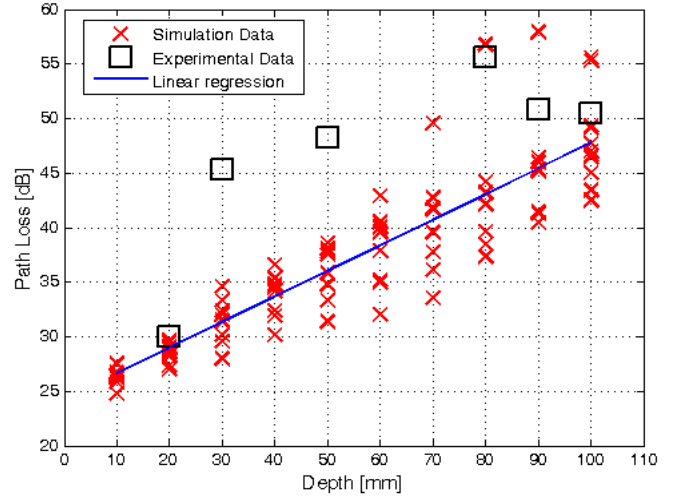| Environment	PL_0[dB]	m
Simulation	23.04	2.28
Experimental	33.81	2.09

Fig. 4: Path loss versus depth from body surface.

discrepancies should have occurred due to additional losses which does not considered in the simulation.

IV. Conclusion

To the best of our knowledge, this is the first study that experimentally investigates the *in vivo* wireless communication channel on human cadaver. Numerical and experimental characterizations of the *in vivo* channel at 915 MHz are compared and preliminary results are presented. The results emphasize the importance of the antenna location. However, further research need to be performed for more *in vivo* locations, operational frequencies and well-designed *in vivo* antennas.

References

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