Location Dependent Channel Characteristics for Implantable Devices

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***Abstract* – This paper presents an impact on an *in-vivo* channel with respect to the position of *ex-vivo* antenna placement and its location. The paper also shows how the location of the antenna is impacting the channel. Three different parts are considered for the simulations using measured data for 500 MHz bandwidth. The results in the paper present the high location dependent characteristics of the *in-vivo* channel in the context of changing the position of the *ex-vivo* antenna. These findings can help in the system design for the future of the implantable devices design to be placed inside the human body.**

***Keywords* – Channel characteristics, channel response, ex-vivo antenna, in-vivo communication, implants.**

I. Introduction

Body-centric wireless networks are one of the most emerging areas under research by the scientists [1]. It is expected to be surprisingly impacting the medical world in the near future with its state of the art implantable devices and their communication with the outside world. The research will directly affect the doctors and patients and will help them with better and on time medical treatments. Those networks will be based on devices implanted inside the human body called *in-vivo* devices and devices outside the human body called *ex-vivo* devices. Currently the communication between *in*-vivo and *ex*-vivo devices are under intensive research. The first of its kind experimental analysis using a human cadaver are presented in [2] at 915 MHz, where they presented the path loss observed during experiments along with the depth of *in-vivo* antenna. The statistical path loss model is introduced in [3] at 915 MHz and 2.4 GHz. It is found that the mean path loss exhibits a linear decaying characteristics inside the body.

The critical and hard part to predict is the *in-vivo* channel. Due to the dense structure of the human body there is a serious path loss and signal attenuation problem due to the multipath characteristics of the channel. There are some models presented for *in-vivo* channel as in [4]. The experimental studies using Ultra-wideband (UWB) between 3.01 GHz – 10.6 GHz is presented in [5]. The channel response of the experimental data with respect to the *in-vivo* antennas placement are presented by the authors, where they show that the channel is highly location dependent and even with a slight change in position of the antenna is highly impacting the channel. Those characteristics pivot a way showing the complexity of the *in-vivo* channel and its location dependent characteristics. The mathematical analysis was carried out for the channel in [6] presenting an efficient mathematical model for the *in-vivo* channel and testing it with blind testing by using a new channel data which was not previously used by the model. The results show a reasonable Root Mean Square Error (RMSE) for both the modeled channel and the blind testing. Furthermore, the Bit Error Rate (BER) performance is evaluated in [7]. Equalizers are used to improve the performance of the *in*-vivo BER. UWB *in-vivo* channel modeling is presented with respect to the position of *ex-vivo* antenna in [8].

In this paper we are presenting the analysis of *in*-vivo channel and its locations dependent characteristics by placing the antennas in different parts of the male torso with respect to the changing position of the *ex*-vivo antenna. This study is presenting novel details regarding the channel properties of the channel which is not only dependent on the *in-vivo* antenna location but also introducing distortion in the channel if we change the position of the *ex-vivo* antenna.

II. Ex-vivo Antenna Placement

The experiment setup is explained in detailed in [5] along with the placement of the *in-vivo* antenna in different parts of the male torso including heart, stomach and intestine. The placement of the *ex-vivo* antennas are mainly in two different areas, the right lateral as shown in Fig. 1 (a) and the left lateral in Fig. 1 (b).

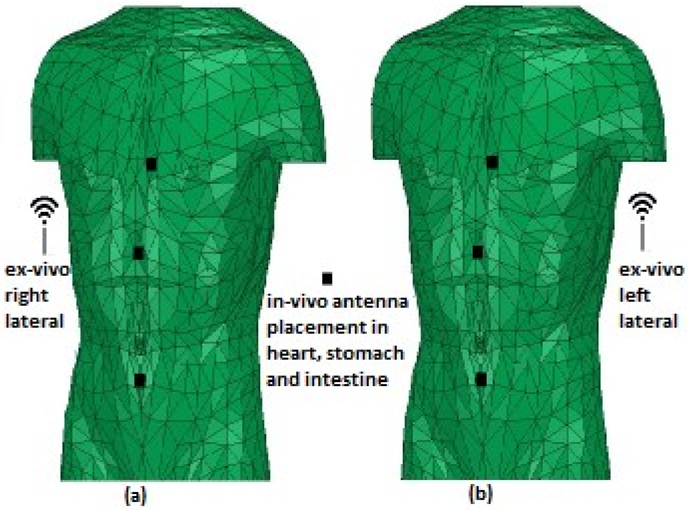


Fig. 1. Placement of the *ex-vivo* antenna (a) right lateral (b) left lateral.

The *in-vivo* and *ex-vivo* antennas were both connected to the Vector Network Analyzer (VNA) to capture the readings from the experiments by capturing the *s*-parameters consist of *S11, S12, S21* and *S22*. Those parameters are further analyzed in MATLAB©. In the previous experiments the position of the *ex-vivo* antennas was fixed but in the current research we are presenting the channel response simulations by placing the *ex-vivo* antenna towards the right lateral and placing the *in-vivo* antennas in multiple parts of the torso as explained in [5], after taking the readings the *ex-vivo* antennas was placed besides the left lateral of the torso and all the readings were taking again by changing the position of *in-vivo* antenna with in the human torso. All the experiments were performed using Ultra-Wideband (UWB) considering the high bandwidth characteristics of UWB.

III. Simulations and Results Discussion

All the simulations are performed using the real measurement data files captured during experiments using VNA. The channel response was captured in frequency domain which was further processed and converted to time domain. The parameters used in the simulations are shown in Table I.

TABLE I
SIMULATION PARAMETERS

Parameters	Values/Units
Frequency range	3.01 GHz to 10.6 GHz
Central frequency (*fc*)	6.75 GHz
Bandwidth	500 MHz
Channal response conversion	IFFT
S-parameters	S21
No of in-vivo antenna locations	7 different locations
No of ex-vivo antenna location	Near right and left lateral

The simulations are performed using 500 MHz bandwidth from the measured data. Fig. 2 presents the simulations for *in-vivo* antennas placed on top of heart and below heart, while the *ex-vivo* antennas was placed at the right lateral and the left lateral for each reading. The results in Fig. 2 (a) is presenting the simulations for the heart when the *ex-vivo* antenna was placed near right lateral and Fig. 2. (b) show the results for the heart when the *ex-vivo* antenna was placed near the left lateral. From the figures the difference between the channel response is not much noticeable. That can be because of the condition at the time of those experiments but that cannot always be the same. It can also be affected if the *ex-vivo* antenna can be placed in another location. The channel can also get impacted from the surrounding especially in an indoor scenario there can be considerably higher multipath effect. The rest of the simulations are consisting of two parts the intestine area and the stomach but the results in both Fig. 3 and Fig. 4 are noticeably different as compare to the results in Fig. 2. Which show us that the placement and location of both *in-vivo* and *ex-vivo* antennas must be kept in consideration while designing a new system.

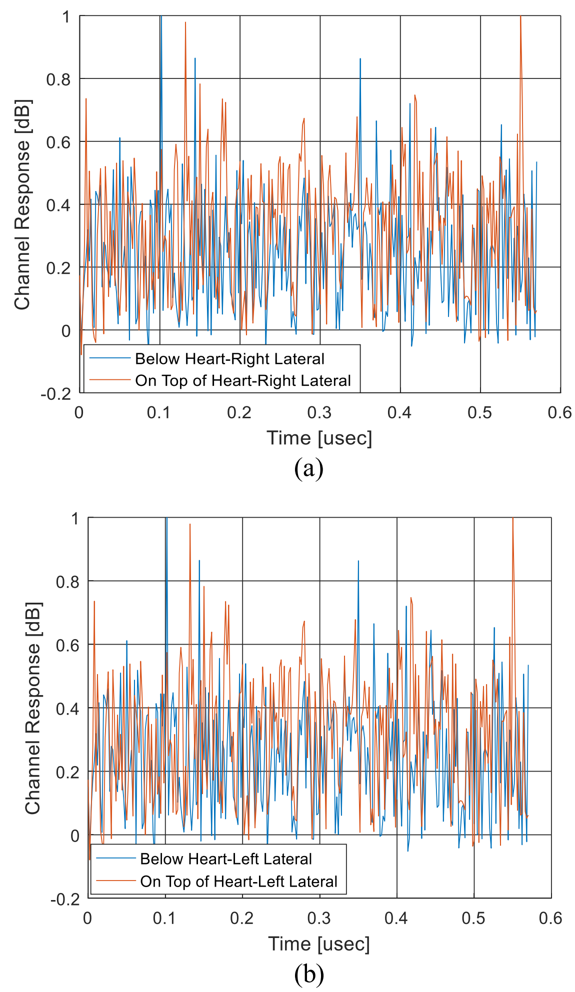
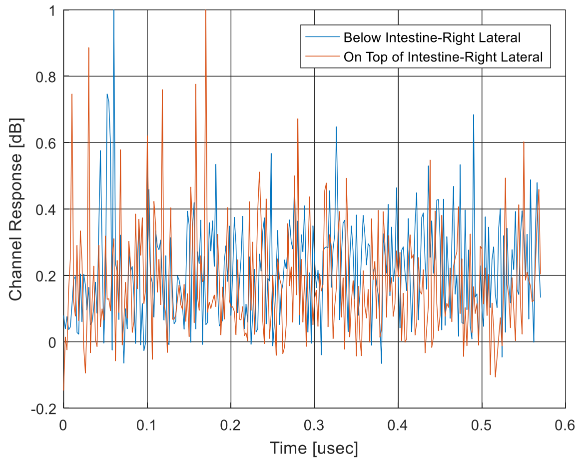
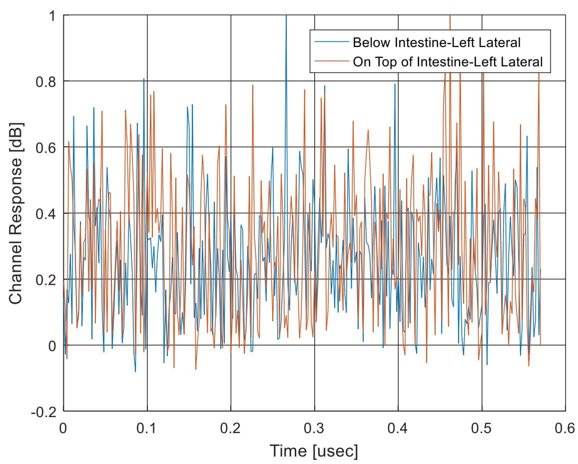


Fig. 2. Channel response for heart (a) right lateral (b) left lateral

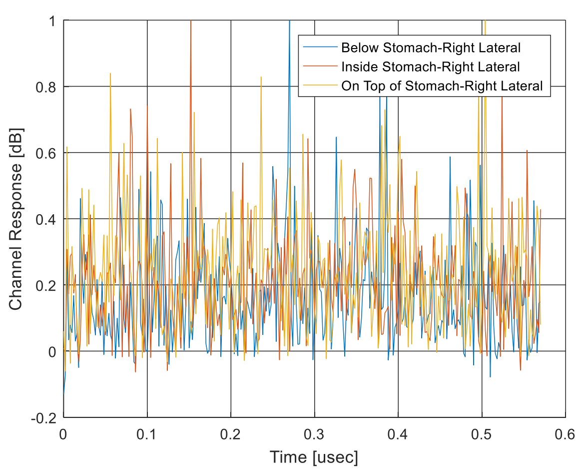


(a)

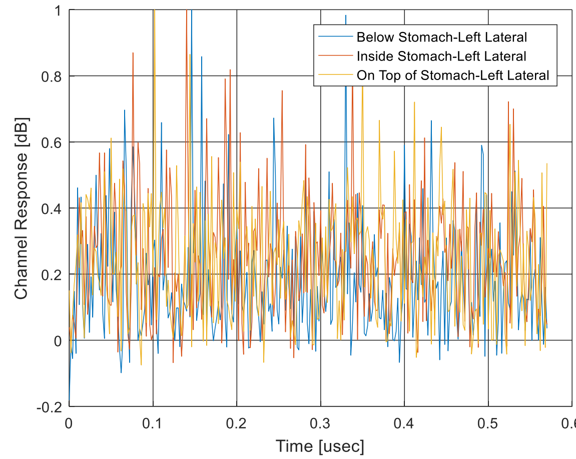


(b)

Fig. 3. Channel response for intestine (a) right lateral (b) left lateral



(a)



(b)

Fig. 4. Channel response for stomach (a) right lateral (b) left lateral

These finding can also pivot the road towards the real scenarios for *in-vivo* communication system. As by considering the future implants for humans they must be somehow communicating to the conventional communication devices placed outside the human body in form of Wi.Fi or cellular technologies. The scenarios can give us an overview that the channel models designed for the conventional communication systems for highly multipath environment can help us design the channel model for *in-vivo* communication systems. The only difference is we need to consider two channel models, for inside the human body and outside the human body then merge them together for a final channel model which can be used for effective and efficient *in-vivo* communication.

IV. Conclusion

This research present novel details regarding the channel characteristics of *in-vivo* communication with respect to the change in position of the *ex-vivo* antennas. We can conclude that for *in-vivo* communication we should not only consider the placement of antennas inside the human body but it is also important to consider the impact of antennas outside the human body. As we can see from the results that if we change the position of external antenna from right lateral to left lateral it is also impacting the channel response. Those results can help us design better communication systems for the upcoming *in-vivo* devices.

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