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Experimental Analysis of Ultra Wideband *In Vivo* Radio Channel

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***Abstract*—In this paper, we present the experimental analysis of *in vivo* wireless channel response on Ultra-Wideband (UWB) with the frequencies between 3.1 – 10.6 GHz. The analysis proves the location dependent based characteristics of *in vivo* channel. The results clearly show the highly multipath scenario. It can also be observed that the multipath effect of the channel is much higher in the denser areas, i.e. an antenna placed within the intestine area or inside the stomach. Results prove that *in vivo* channel is different from a conventional communication channel and therefore extensive studies need to be done to understand the channel.**

Keywords—channel response; in vivo communication; wireless body area networks (WBAN).

I. INTRODUCTION

In vivo communication [1] is one of the most emerging technology under research. It helps us understand the communication between implantable devices [2] placed inside the human body with external conventional communication devices using Universal Mobile Telecommunication System (UMTS), Long Term Evolution (LTE), Wireless Fidelity (Wi-Fi) or possibly Fifth Generation (5G) technologies in the near future. There are several devices under research to be implanted in a human body to wirelessly send data to the server or doctor in case of a patient with the implant. The hurdles in developing those devices are their size, which is expected to be possible on a micro or nanoscale [3], battery life, circuit design and antenna for communication. Besides all those challenges the most critical part is to extensively study and understand the channel for *in vivo* communication.

Wireless channel [4] is always hard to predict and analyze; it can quickly change according to the environment and position of the antennas especially in non-line of sight scenarios. We can consider a channel as a black box where we only know the input and what we received at the output. Although there are different channel models presented by the researchers for different types of wireless scenarios, for conventional communication [5] and non-conventional communication, i.e. *in-vivo* communication channel model [6].

The mobile wireless communication channel varies over time and frequency. This variation can be mainly divided into two types, large-scale fading [7] and small-scale fading [8]. Large-scale fading is the function of distance and shadowing by large objects such as buildings while on the other hand, small-scale fading occurs due to the constructive and destructive interference of a multipath signal. In order to design an efficient system, it is essential to measure the channel extensively. The knowledge of the channel response allows us to build propagation models [9] and get the maximum out of the system.

This paper presents an experimental analysis of Ultra-Wideband (UWB) *in vivo* channel response. Simulations are presented for three different regions of the human body including heart, stomach and intestine in six different places.

II. SIMULATION SETUP AND RESULTS

To get a real channel response, extensive experiments were performed using a human cadaver. Three locations were selected for the experiments. The heart area, stomach area and intestine. These locations were subdivided according to the requirements of the test by placing the antennas below, on top and inside the organs. To make it near to the real scenario, fresh animal organs were selected to be placed in the human cadaver. Two different types of antennas were used for those experiments, an *ex vivo* antenna and an *in vivo* antenna, both the antennas fully protected and covered to avoid any contact with organs. The *in vivo* antenna were placed inside the cadaver in different locations to get the readings while the *ex vivo* antenna position was fixed for all those experiments. The depths, angles and losses for those experiments are presented in [10]. Demir *et al.* [11] presented a statistical path loss model and *in vivo* channel characteristics for a male torso, power delay profile of each anatomical direction is also simulated to understand the power losses.

The channel response for the experiments were saved using a Vector Network Analyzer (VNA). Both the antennas were connected with the VNA. Simulations were carried out in Matrix Laboratory (MATLAB). Simulation parameters are shown in Table I. The *in vivo* antenna was placed on top, below and inside the stomach. While for heart and intestine the antennas were only placed on top and below the heart and intestine. The data collected was normalized using (1).

$$N_i = \frac{x_i - min(x)}{max(x) - min(x)} \quad (1)$$

Where $x = (x_1, \ldots, x_n)$ and N_i is our i^{th} normalized data.

$min(x)$ is the minimum value of variable *x*.

$max(x)$ is the maximum value of variable *x*.

TABLE I. SIMULATION PARAMETERS

Parameters	**Values/units**
Frequency to Time domain	IFFT
Bandwidth	50MHz
Central Frequency	6.75GHz
S-parameters	S_{21}
Time	μsec
Channel Response	Normalized (0-1)

The original data saved through VNA was in the frequency domain (2) which has been converted to time domain (3) using Inverse Fast Fourier Transform (IFFT). As we know that multiplication in frequency domain is equivalent to convolution in time domain. The data was collected at UWB frequencies (3.1 – 10.6 GHz), but for simulation, only 50 MHz bandwidth was selected, the central frequency for this UWB is 6.75GHz. Data was normalized between (0-1). The normalized channel response for stomach is shown in Fig. 1. Fig 1 is showing readings in three different locations including below, on top of and inside the stomach. Fig. 2 presents channel response for heart presenting readings in two different positions including below and on top of the heart. While Fig. 3 confers the channel response for intestine conferring readings on top of and below intestine.

$$y(f) = H(f)x(f) \tag{2}$$

$$y(n) = H(n) \otimes x(n) \tag{3}$$

Here $H(f/n)$ is channel response, x y H are all functions of signal frequency *f/n*.

Simulations prove that even a slight change in the position of the *in vivo* antenna inside the human cadaver can affect the communication. It can also be observed that *in vivo* communication is highly location dependent and it is a highly multipath channel. As from the graphs, it is shown that channel response is highly unpredictable and can be easily changed with the movement of the antenna. As different places were selected inside the cadaver for the placement of the *in* vivo antenna, i.e. on top below and inside (in case of stomach only) to understand the *in vivo* channel.

The plots show that the multipath effects in the denser area are higher as compared to the comparatively non-denser areas. If we can observe the stomach plots the multipath effect and channel taps are much higher while the antenna is placed below or inside the stomach, as compared to the readings while the antenna was placed on top of the stomach. Those situations can also be observed in heart and intestine plots. The multipath effect is much higher while the antenna is placed below the heart. For intestine overall, the multipath effect is much higher as compared to the heart plot. As intestine itself creates a perfectly dense situation for the signal to travel, and high power is required to place an antenna inside or below the intestine as compared to the other parts. In all experiment, the skin of the human cadaver was kept closed while taking the readings which add another layer of protection for the signal.

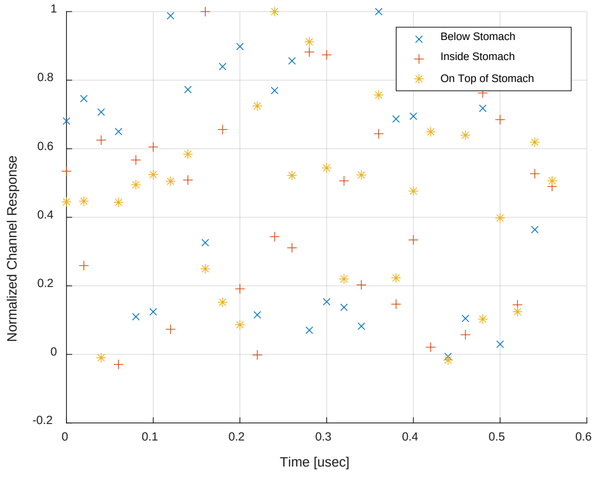

Fig. 1. Normalized channel response for the stomach.

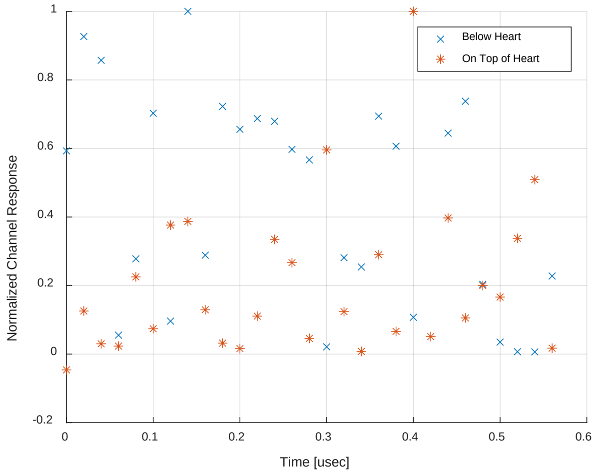

Fig. 2. Normalized channel response for heart.

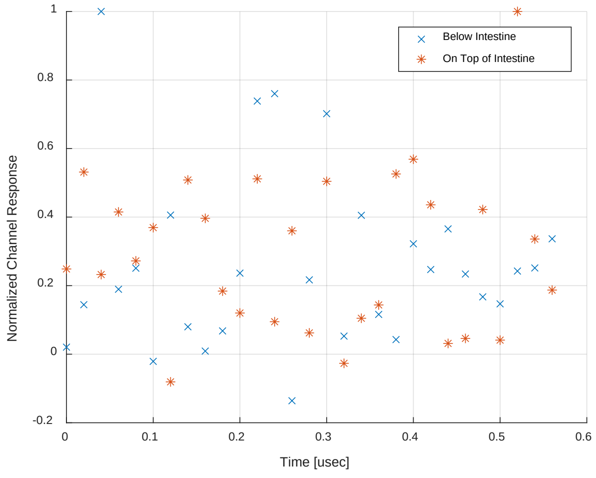

Fig. 3. Normalized channel response for intestine.

III. CONCLUSION

This paper present experimental channel response for *in vivo* communication. The simulations in this paper will help the researchers understand the real channel response and its effects on the communication. It is concluded that *in vivo* is a multipath channel and can be highly changeable with the change in position of the antenna even if it is at a small distance. The reported analysis highlights the challenges for modelling those types of channels and open a way for further studies in such environment.

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