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Experimental Implant Communication of High Data Rate Video Using an Ultra Wideband Radio Link

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Abstract—**Ultra wideband (UWB) is one of the radio technologies adopted by the IEEE 802.15.6$^{\text{TM}}$-2012 standard for on-body communication in body area networks (BANs). However, a number of simulation-based studies suggest the feasibility of using UWB for high data rate implant communication too. This paper presents an experimental verification of said predictions. We carried out radio transmissions of H.264/1280×720 pixels video at 80 Mbps through a UWB multiband orthogonal frequency division multiplexing (MB-OFDM) interface in a porcine chirurgical model. The results demonstrated successful transmission up to a maximum depth of 30 mm in the abdomen and 33 mm in the thorax within the 4.2–4.8 GHz frequency band.**

I. INTRODUCTION

The IEEE 802.15.6$^{\text{TM}}$-2012 standard [1] specifies the characteristics of the physical (PHY) and medium access control (MAC) layers for the implementation of body area networks (BANs). This standard considers several radio interfaces for low power devices operating on, in, or around the human body to serve a variety of low-data-rate applications including medical sensing and monitoring. Novel medical applications such as implanted automatic drug-delivery devices [2], high-resolution capsule endoscopes [3], and micro robots for in-body biopsy and therapeutic procedures [4], require high data rate implantable transceivers built with the simplest and least power-consuming electronic circuits.

It has been demonstrated through computer simulations that ultra wideband (UWB) technology has the potential to enable high data rate transmissions from/to implantable devices [5], [6]. In addition, impulse radio (IR) UWB transceivers can have simple structures [7] that facilitate their miniaturization [8]. However, the strong attenuation that UWB signals within 3.1–10.6 GHz suffer when propagating through human tissues [9]–[16] imposes the need for experimental verification of the feasibility of using UWB interfaces for high data rate implant communication. The human body is a very complex propagation medium that is difficult to model accurately; hence, computer simulations do not capture all the effects observed in real experiment [17] and can lead to discrepancies between simulation-based and experimental evaluation of implant UWB communication links.

In order to corroborate the feasibility of high data rate communication between implanted and on-body transceivers through a UWB link, on October 10, 2011, we carried out an experiment using a living porcine model in an operating room (OR) at the Oslo University Hospital, Norway. We transmitted H.264/1280×720 pixels video from a wireless USB hub located on top of the porcine model's body to a USB host implanted in the animal. These communication devices used the multiband orthogonal frequency division multiplexing (MB-OFDM) UWB transmission mode. We implanted the wireless host at different depths inside the animal body and evaluated the quality of the video transmission subjectively. Successful transmission was observed up to a maximum depth of 30 mm in the abdomen and 33 mm in the thorax within the 4.2–4.8 GHz frequency band. These results demonstrated the feasibility of high data rate transmission for implant communication in the abdominal and thoracic areas.

The rest of the paper is organized as follows: Section II describes the characteristics of the transceivers and the animal model used in the experiment; in Section III the results of the experiment are presented and discussed. Finally, Section IV summarizes our conclusions.

II. EXPERIMENT MATERIALS

A. Transceivers and Communication Setup

The UWB communication link used in the experiment consisted of a 4-port USB hub and a wireless USB host compliant with the ECMA-368 standard [18]. The host was connected to the USB port of a PC and a wireless link with the devices connected to the hub was established with the aid of dedicated control software installed in the PC (Fig. 1).

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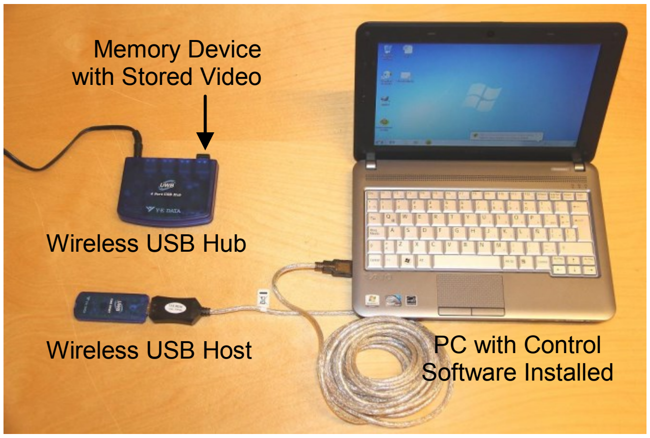
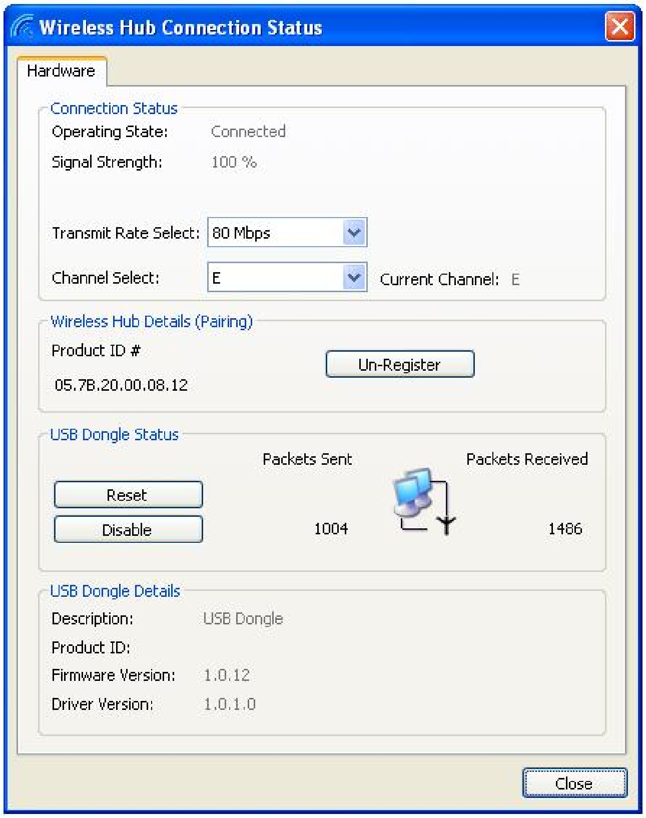


Figure 1. MB-OFDM UWB communication setup used in the experiment.



Connection Status
Operating State: Connected
Signal Strength: 100 %
Transmit Rate Select: 80 Mbps
Channel Select: E
Current Channel: E

Wireless Hub Details (Pairing)
Product ID #
05.7B.20.00.08.12

USB Dongle Status
Packets Sent: 1004
Packets Received: 1486

USB Dongle Details
Description: USB Dongle
Product ID:
Firmware Version: 1.0.12
Driver Version: 1.0.1.0

Figure 2. User interface of the communication control software.

A H.264/1280×720 pixels video clip recorded at 30 frames/s was stored in a digital memory device, which was plugged to one of the ports of the wireless USB hub. The video clip was wirelessly accessed by the host and displayed on the PC screen. The dedicated control software indicated the signal strength in percentage, with 100 % being the best link condition (Fig. 2). This indicator was used as an approximate measurement of the link quality in our experiment.

The communication link supported transmission rates of 53.3, 80, 106.7, 160, 200, 320, 400, and 480 Mbps in free space. We set the system to 80 Mbps since this was the minimum value that covered the required transmission rate of 73.8 Mbps (640×480×24-bits×10-frames/s) for a capsule endoscope with VGA image capabilities [19]. The MB-OFDM UWB transceivers occupied 528 MHz of bandwidth with center frequency at 4488 MHz and power spectral density of –41.3 dBm/MHz. The wireless host was implanted in the body of the porcine model.

B. *The Porcine Model*

A Norwegian landrace pig (female, body weight 35 kg) was utilized. Permission for the experiment was obtained from the Research Animal Commission, Norway, and the animal was given humane treatment according to protocol. A porcine model was used due to the appropriate size and the laboratory's experience with this model. Laparotomy and thoraoctomy were performed in order to enable the implantation of the wireless host at various depths and angles in the abdominal and the thoracic cavity, respectively.

III. EXPERIMENTAL RESULTS

The experiment consisted in implanting the wireless host (protected by a plastic bag) inside the porcine model while the video transmission from the hub (located on top of the animal's body aligned vertically with the implanted host) was taking place (Fig. 3). The control software was used to approximately assess the link quality. Additionally, a subjective assessment of the video quality was done by observing the video clip on the PC screen. For this subjective assessment we assigned three different quality values to the video: Excellent, Good, and Poor. *Excellent* indicated a video quality in which practically no difference was noticed between the corresponding video transmissions in free space and inside the body. *Good* denoted sporadic video imperfections, e.g., momentary "freezing" of the video. *Poor* indicated continuous failure of the video transmission. Moreover, there were cases in which no transmission was possible at all due to extremely high attenuation and therefore no video for assessment was available.

The antennas of the transceivers were linearly polarized; hence, the operating surgeons were instructed to keep the relative alignment between the hub and the host that ensured the best link quality during the operation. The results for both the abdomen and thorax are summarized in Table I.

Additionally, the effect of angle mismatch on the quality of the transmission was assessed for the thoracic case. For this sake, the hub was located on the left side of the thorax at different inclination angles with respect to the zenithal point above the host. This was done while the host was implanted behind the sternum at a depth of 33 mm. These results are summarized in Table II.

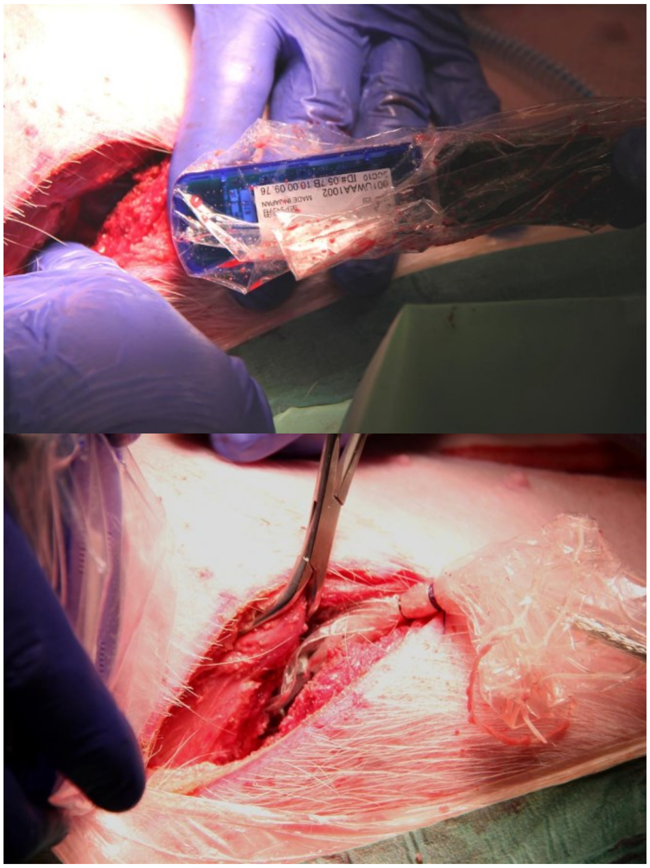


Figure 3. Implantation of the wireless host in the thorax of the animal model through a lateral thoracotomy.

TABLE I. RESULTS IN THE ABDOMEN AND THE THORAX

Location Inside the Body	Depth (mm)	Signal Strength (%)	Video Quality
ABDOMEN			
Left lower quadrant	20	30–60	Excellent
On top of the liver	30	20–30	Excellent
Between the liver lobes	45	0–10	Not Available
In front of the right kidney	80	0	Not Available
Behind the liver	95	0	Not Available
THORAX			
Behind the sternum	33	50–80	Excellent
Behind the rib cage in front of the lung	50	0–10	Not Available
Behind the right lung	75	0	Not Available

TABLE II. RESULTS FOR DIFFERENT ANGLES AROUND THE THORAX

Angle with Respect to the Top of the Thorax	Signal Strength (%)	Video Quality
0	50–80	Excellent
15	20	Good
30	10	Good
45	10	Poor

A. Discussion

As we see in Table I, the maximum depths that allowed proper high data rate transmission were 30 mm and 33 mm for the abdomen and thorax, respectively. If one assumes that the porcine model used in the experiment provides a fair representation of the dielectric properties of a human torso, then according to [13] and [15] the path loss attenuation at 30 mm and 33 mm inside the human abdomen and chest are approximately 20 dB and 25 dB, respectively. These attenuation values are caused by the propagation medium (i.e., biological tissues) only. It is important to notice that the implanted host used an antenna optimized for transmission in free space. The fact that this antenna was embedded in a different propagation medium added losses to the link budget. It is very likely that the replacement of the antenna in the host for a dedicated UWB implantable antenna (e.g., [20]) will improve the link quality thereby increasing the depth at which proper transmission is feasible. Moreover, choosing the most appropriate transmission frequency can also increase the transmission range [21]. Obviously, the use of lower data rate, e.g., 53.3 Mbps, can increase even more the transmission range.

From Table II, it is clear that the alignment between implanted and on-body transceivers played an important role in the quality of the transmission. In the case of the thorax, locating the hub at different angles caused an increase of propagation path length and depolarization of the antennas. Although the shortest Euclidian distance between transceivers does not necessarily ensure the lowest propagation loss in a highly inhomogeneous medium like biological tissues, it is recommended to always minimize the propagation path length. The antennas' relative polarizations must be accurately kept matched in all the cases.

This experiment demonstrated the feasibility of high data rate communication for superficially implanted devices despite the frequency-selective attenuation of the UWB implant channel [16]. For deeply implanted devices such as a capsule endoscope, further improvement of the link quality must be attained through the use of an adequate implantable antenna and lower transmission frequencies. Although MB-OFDM UWB transceivers were used here for experimentation, IR-UWB transceivers are recommended for the real implementation of implantable medical devices.

IV. CONCLUSION

To the best of our knowledge, this was the first experiment reported in the literature in which an ultra wideband transceiver was implanted in an animal model for high data rate communication. An in-vivo experiment was necessary to mimic more accurately the dielectric properties of a human torso. The objective of the experiment was to verify in a practical way the feasibility of high data rate transmission in living tissues using ultra wideband signals. As such, the experiment can be deemed successful since it demonstrated excellent video transmission for a transmission range up to 30 mm and 33 mm in the abdomen and thorax of a porcine model, respectively. Although these depths are relatively close to the skin, successful high data rate communication at deeper locations can be achieved through the use of a properly-designed implantable antenna; these experiments are underway.

The results of this experiment can be used as the basis for an IEEE 802.15.6^{TM}-2012 standard amendment to include ultra wideband as an optional radio interface for implantable devices in wireless body area networks. However, impulse radio must be favored for implant communication due to its relative simple implementation. Hence, similar experiments to the one previously described will be done with impulse radio ultra wideband prototype transceivers. Clearly, much remains to be done.

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