Demo Paper: An Ultrasonic Intra Body Area Network for E-Health Applications

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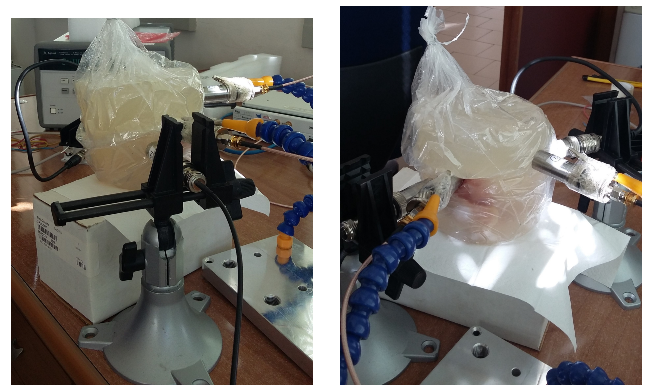
***Abstract*—Nowadays Intra Body Area Networks (I-BAN) are still a scarcely explored area because of the difficulties and risks in successfully propagating signals inside the body where sensor devices employing RF waves cannot be used. In this demo we will prove the feasibility of setting up an ultrasonic I-BAN employing non ionizing radiations to perform multihop communications. We will identify critical features for the propagation and show that intra-body networking is possible.**

I. Introduction

In next generation Body Area Networks it is envisaged to have implanted or ingested pill-sized sensor devices deployed inside the body to perform continuous monitoring and periodically communicating with a remote medical center by way of a gateway node located on the body (e.g. a smart watch or phone [1]). Apart for the issues related to compatibility of materials to be used in devices deployed inside human organs and tissues, a relevant communication problem is posed either in terms of waves being used for communications, or support of multihop communications from a device to the gateway node. In fact, the human body is composed for more than 65% by water, a fluid through which RF waves scarcely propagate because of the high attenuation [2]. Moreover, traditional ionizing RF waves can cause overheating of tissues and consequent degeneration and damage of cells [3]. In the last 10 years body-coupled communications based on galvanic or capacitive coupling have been introduced [4] along with ultrasonic communications [5]. In the past [6] we have shown that in principle the use of ultrasonic waves is feasible and secure but we still did not prove that multihopping is possible. Accordingly, in this demonstration, we will both show that transmission is feasible and that multihop can be proficuously employed to reduce the ultrasonic transmission power needed and increase the potential monitoring range in implanted I-BAN. To this purpose we will use a real testbed developed using USRPs [7] and appropriate ultrasonic transducers, switches and LNAs. We will consider a transmission channel obtained by employing real organic tissues embedded inside a ballistic gel, mimicking human body tissues.

II. Demo description

In this demo we will experiment different scenarios to both prove the feasibility of ultrasonic transmission inside the body and to estimate to which extent it is possible to support communications. The system for the demo consists of 2 parts: the *transmission medium* and the *HW/SW system* itself. The transmission medium consists of a cylinder of ballistic gel, 8 cm of height and 78.5 cm^2 of section, which allows us to mimic the human body as the transmission medium. Ballistic gel is a solution consisting of gelatin powder in water. It simulates the density and viscosity on human muscle tissues and was developed by Martin Fackler in the field of wound ballistics [12]. In order to test a realistic scenario we also enhanced the ballistic gel by encapsulating inside commercially available organic tissues consisting of animals bones, muscles, skin and fat (see Figure 1). The HW/SW system consists of 4 Olympus V326-SU ultrasonic transducers. Transducers operate around 6 MHz with a -6 dB bandwidth of about 4 MHz. Each transducer is connected to a single node in the network. The amplification and filtering devices, similarly to [8], are two Mini-Circuits Pulse Amplifier (PA) ZPUL-30P to amplify the signal in transmission, and two Low Noise Amplifiers (LNA) ZFL-1000LN+ to filter and amplify the received signal, respectively. The A/D and D/A conversions are performed by two USRP N210 from Ettus Research [7], each of them incorporating a dual 100 MSPS 14-bit ADC and a dual 400 MSPS 16- bit DAC, and an FPGA unit (Spartan 3A-DSP 3400). Each USRP is equipped with two daughterboards (LFTX and LFRX) that operate from DC to 30 MHz. Observe that each daughterboard can work either as a receiver (LFRX) or as a transmitter (LFTX) only; therefore to use each transducer in both directions, we use four Minicircuit switches ZX80-DR230+ USRP driven, that alternatively connect the transducer to the appropriate daughterboard. The physical



(a) (b)

Fig. 1. a) Testbed configuration when using pure ballistic gel b) or ballistic gel with organic tissues.

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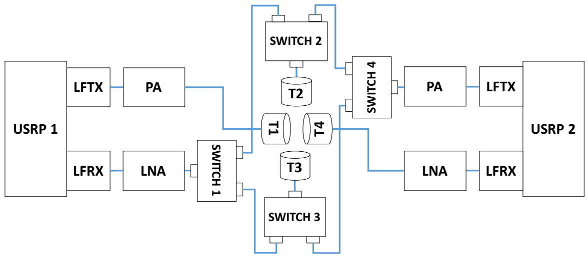

Fig. 2. System Overview.

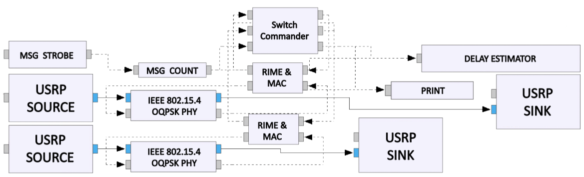

Fig. 3. Snapshot of GNU Radio modules in case of 2 hops transmission.

testbed is shown in Figure 2. Each USRP is connected, via Gigabit Ethernet, to a PC running Ubuntu and the GNU Radio software development environment [9]. Leveraging such approach, we based our work on the modules developed in [10] to recreate a communication stack based on RIME [11], and we added new modules to manage the single hop and multihop communication scenarios. The PHY layer of the proposed system consists of IEEE 802.15.4 modules working in the frequency range of a few MHz. In the current configuration we employ a QPSK modulation. The system is reported for 2 hops in Figure 3. The networking layer is provided by the RIME stack. Rime is a modular, lightweight networking stack, part of the Contiki operating system, that is designed for constrained devices. Our multihop management layer has been implemented on top of the described blocks and it allows to implement single hop and multihop communications. The demo will include 2 phases:

Phase 1: We send a message issued by the *Message Strobe* module that sends it to the Rime and MAC modules of the first node; then the message is passed at the PHY layer and finally it reaches the first USRP where it is transmitted by the transducer T1 (Figure 2). The message traverses the medium and is received by T4. At the receiver side the message traverses the communication stack up to the application layer. Finally, at the application layer, the message is received by the *Delay Estimator* block that logs the event. The Delay Estimator measures the transmission time of each message, by collecting two timestamps: one when the message is sent by the Message Strobe, and one when it is received by the Delay Estimator. In this phase we will show that the message can be correctly received and transmission is feasible.

Phase 2: Once observed that ultrasonic transmission across biological tissues is possible, we will perform 2 hops and 3 hops transmissions to investigate the extent to which this is possible. In particular we will both investigate on the impact of the number of nodes as well as their positions and transmission rate as well as interference among multiple flows and delay. In the 2 hops scenario a message sent by USRP1 through T1 and received by the transducer T4 is not forwarded to the Delay Estimator, but it is retransmitted using an echo block. This block sends back the message along the protocol stack to T2 for retransmission. T3 then receives the message which is finally recorded by the Delay estimator at USRP1. For the 3 hops scenario we share the USRP devices by employing four ZX80-DR230+ switches. Such system is controlled by the Switch Commander module that, on top of the communication stack, acts as a controller for the system, switching the connections according to the 3 hops scenario. In particular, the first hop occurs between Transducers T1 and T2, the second between Transducers T2 and T3, and the final hop between T3 and T4. In this scenario Transducers T2 and T3 have to alternatively send and receive, and it is the Switch Commander that, upon receiving from the RIME blocks all the messages sent over the network, acts on the switches, changing the boards Transducers are connected to.

III. Conclusions

In this demo we investigate the feasibility of using multihop communications in intra-body area networks. To this purpose we use ultrasonic transmissions to support implanted BANs and to this purpose we design and develop an experimental testbed including also a realistic transmission medium mimicking human body characteristics. We investigate both on the feasibility of transmission itself as well as on the possibility to support multihopping. In this way it will be possible to limit the amount of transmission power employed, so avoiding tissues overheating or the need for proximity between devices implanted inside the body and the gateway node used to communicate with the remote medical center.

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