On The Optimum Data Carrier for Intra-body Communication Applications

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ABSTRACT

This paper provides a comparative study between the different available mediums, to be used as data carriers, for intra-body communications. Properties of these data carriers experienced while propagating through the body tissues are calculated using sets of experimental data available in literature and then compared to show which carrier has higher potential to meet the intra-body communication requirements. A simple accurate model is then presented for the signal transmission through the body. Parameters studied are the attenuation and delay while factoring the effect of biological differences due to age, gender etc.

Categories and Subject Descriptors

• Networks~Wireless personal area networks; • Applied computing~Biological networks

Keywords

Body area networks; intra-body communications; channel modeling.

1. INTRODUCTION

Mobile health has recently expanded to include wearable devices as a part of the vision of a holistic approach to wellness in general and health care services in particular. Once wearables become ubiquitous, they can provide healthy users, patients and doctors with an accurate reflection of the state of their body. This information will ultimately lead to better preventative medical practices and a truly personalized medical approach. Driven by the vision of a cable-free biomedical monitoring system, new wireless technologies that focus on sensor applications have been promoted as the next biomedical revolution, promising a significant improvement in the quality of health-care services. However, a major barrier to adoption of wearable technologies is the size and power requirements of wireless sensors which are typically dominated by the RF section of the associated transceivers. This leads to centralized solutions that share a transceiver (e.g. smart watches) that are localized to one part of the body and hence cannot perform distributed measurements. Due to their centralized nature, these types of sensors are known to be highly inaccurate in collecting information about various vital signs such as temperature, perspiration, respiration rate, due to their confinement to a single location on the human body. There is a need to have a new class of devices that are wirelessly networked, small in area and exhibit ultra-low power consumption, thus having the ability to perform distributed monitoring in a seamless manner. An attractive solution to such emerging vision is the use of intra-body communication systems where data transmission is achieved through the *skin*, rather than through air. Sensors and actuators can then inter-communicate through skin and be relayed to a centralized wireless hub that could be a smart watch for instance. This technique would ultimately lead to body area networks (BANs) that operate at extremely low power, with minimal foot print by replacing expensive, power consuming Radio Frequency (RF) front ends, for each individual node with simpler interfaces. Furthermore, while the skin operates as an interference channel for the communicating nodes, it is relatively protected from the higher levels of interference expected when broadcasting via the air.

This paper presents a comparison of the main potential means of data carriers for intra-body communications, namely using electro-magnetic waves, ultrasonic waves and magnetic coupling. We discuss the pros and cons of each approach and quantitatively discuss the frequency response of different body tissues to these modalities. We then present a model for intra-body communications, using the galvanic coupling technique, in case electromagnetic waves are being adopted as the appropriate data carrier for this emerging technology. In the proposed model, biological parameters of the human body are accurately modeled, as well as assumed to be variable, taking into consideration the impact of important factors; such as age and weight, on these parameters and thus on the overall attenuation profile.

2. Body Area Networks Approach

The concept of communication through the human body was first introduced in late 1990s using near field coupling [1-2], where different approaches were investigated to study the use of data carriers that best suit the nature of the human body in a quest for minimizing power, size, system complexity and health hazards.

2.1 Electromagnetic (EM) Waves

The first and most traditional approach for data transmission is EM waves. Use of EM waves in intra-body communications can be categorized into two main types; capacitive coupling (near field coupling method) and galvanic coupling. In capacitive coupling, only the signal electrodes of the transmitter and the receiver are attached to the body while the ground (GND) electrodes are left floating in the air. The conductive body forms the forward path while the signal loop is closed through the capacitive return path between the transmitter and the receiver

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GND electrodes. The second approach, which depends on the galvanic coupling principle, uses a pair of electrodes for both the transmitter and the receiver to propagate the electromagnetic wave. The signal is applied over two coupler electrodes and received by two detector electrodes. An attractive feature of the galvanic coupling approach is that the signal is totally confined to the body, unlike capacitive coupling where the signal return path is established through the air. Galvanic coupled signals experience minimal interference from other electronic devices, enabling robust and secure data exchanges.

2.2 Magnetic Human Body Communications

A new approach was recently proposed in [3] where resonant magnetic coupling was suggested to be used as an alternative physical layer for BAN. In this approach, coils wrapped around anatomy (arm, leg, head ...etc.) are used to generate and receive magnetic based signals. The main motivation is that the permeability of human tissues is similar to air which enables the magnetic fields to travel more freely through the human body. This approach suffers from some drawbacks. The fact that the permeability of human tissues are similar to air makes it more difficult to confine the signal within the human body, thus part of the signal will be lost in the air. Moreover, it is not possible to separate the electric and magnetic fields for an EM wave as long as the displacement current ratio to the conduction one is considerable. The ratio is plotted for different body tissues, as shown in Figure 1. , showing that in the Mega-Hertz frequency range it is not possible to assume that both fields are independent. Such results imply that data transmission cannot be attributed to the magnetic field only, but to the electric field as well since they cannot be separated at the frequencies of interest while propagating through human tissue. Moreover, the need to wrap a coil around the body wherever we need to setup a communication node limits the use of such approach, making it inconvenient especially if multiple nodes are considered.

2.3 Ultrasonic Waves

Acoustic waves are mostly used for underwater communications since they possess better propagation properties in water as compared to RF waves. Since more than 65% of the human body consists of water, ultrasonic waves (acoustic waves at the non-audible frequency range; above 20 KHz) was thought to have good potential as a means of communication for BAN. Research then followed [4-5] to investigate the efficiency of using ultrasonic waves in BANs, mainly to communicate between implantable devices, since ultrasonic waves propagate very poorly through air. This approach suffered from some drawbacks as well. A major drawback is the acoustic bio-effects, among which are heating and cavitation [6]. As ultrasonic waves propagate through the body tissues, a portion of the wave energy is absorbed and converted to heat, leading to an increase of these tissues' temperature, especially when wave intensity is increased, leading to undesirable biological effect. The other serious biological effect is cavitation. Ultrasonic waves are associated with pressure variations, causing bubbles in the propagation medium, body tissues in our case, to expand and contract. As this pressure variation activity increases, bubbles may collapse leading to tissue damage, a concern that has to be seriously considered when dealing with ultrasonic waves' propagation on a periodic, repeated manner. However, the impact of these two bio-effects can still be minimized through techniques of impulsive transmissions with low power and pressure levels, as ways of keeping the acoustic intensities to which the tissues are exposed to within the safety limits [7].

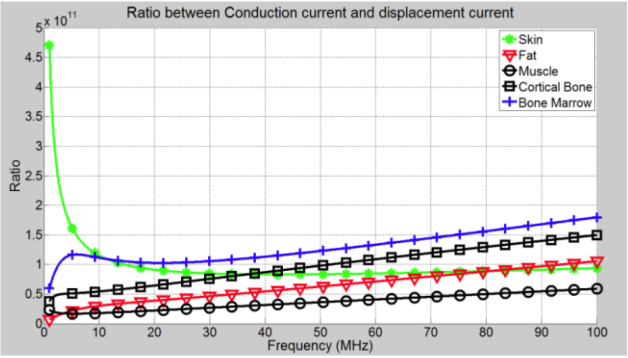


Figure 1. Ratio between displacement and conduction currents in different body tissues, showing that the displacement current values are large enough thus electric and magnetic fields cannot be assumed to be independent of each other in this frequency range.

3. Electromagnetic V.S. Ultrasonic Waves

From the discussion in previous section, it is concluded that electromagnetic waves and ultrasonic waves are more convenient as data carriers for BANs. In this section, more in depth comparison will be shown between the two mediums, taking into consideration the biological properties of the human body, within the frequency range for intra-body communications; from low KHz up to 100 MHz's. The main to consider, being key factors for any system design, are attenuation (gain) and the delay profiles

3.1 Attenuation

Human tissue is considered to be a lossy medium where ultrasonic waves are dissipated in the form of heat. Attenuation of acoustic waves is caused mainly due to the absorption of the pressure energy by the medium in which the wave is propagating. Such attenuation is dependent on the type of the tissue as well as the frequency of operation. In general, attenuation for acoustic waves follows the relation:

$$\alpha = \alpha f^{b} \qquad (1)$$

Where α is the attenuation in (Decibels/ (centimeter*Mega-hertz)), f is the frequency, a and b are constants that depend on the acoustic properties of each tissue.

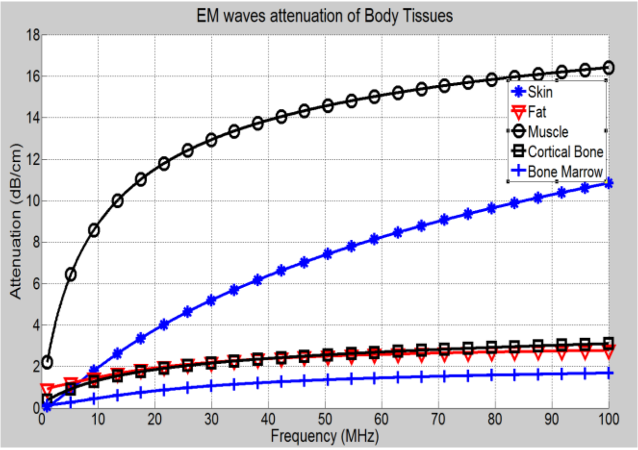
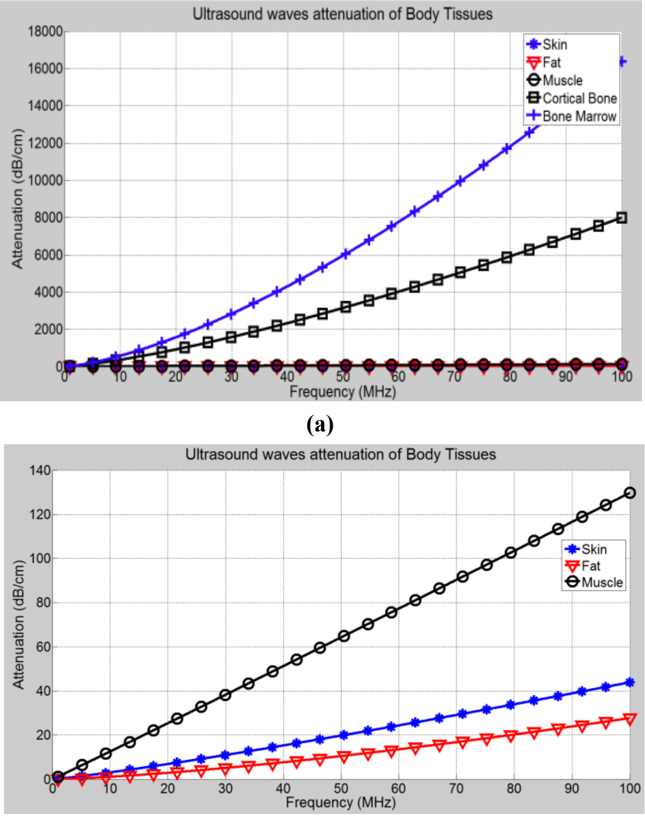


Figure 2. Attenuation that EM waves experience when propagating through each of the main five tissues of the human body.



(a)

(b)

Figure 3. (a)Attenuation that Ultrasonic waves experience when propagating through each of the main five tissues of the human body, (b) zoomed in version to show attenuation for skin, fat and muscle tissues.

Figures 2 & 3 clarify the attenuation properties of the main human tissue types (skin, fat, muscle, cortical bone and bone marrow) to the propagation of both ultrasonic and EM waves. For ultrasound attenuation profiles versus frequency, the constants a and b are calculated from previous work in literature [8-10] using curve fitting techniques. As for EM attenuation, it was calculated according to the following equation:

$$\alpha = \frac{w}{2}\sqrt{\mu\,\varepsilon(w)}\,\tan\left(\delta(w)\right) \qquad (2)$$

Where α is the attenuation (dB/cm), w frequency (rad/s), μ permeability, ε(w) frequency dependant permittivity and tan (δ(w)) is the loss tangent, and these electrical properties were all calculated for each tissue [11]. It can be shown that according to the attenuation profiles for the human body tissues, ultrasonic waves experience more attenuation, in the form of heat dissipation, compared with EM waves within the targeted frequency range for BAN.

3.2 Delay

Another important aspect is the propagation delay, i.e. how fast these waves can travel through the body tissues. Ultrasonic waves are known to travel at very low speeds in the human body [12]; ranging between 1450 m/s in fat to 4080 m/s in bone. Such low speed introduces a significant delay at the receiver node which is directly translated into severe multi-path reflection problems. That drawback requires complicated system topologies and extra hardware at each node, leading to more complicated power hungry systems.

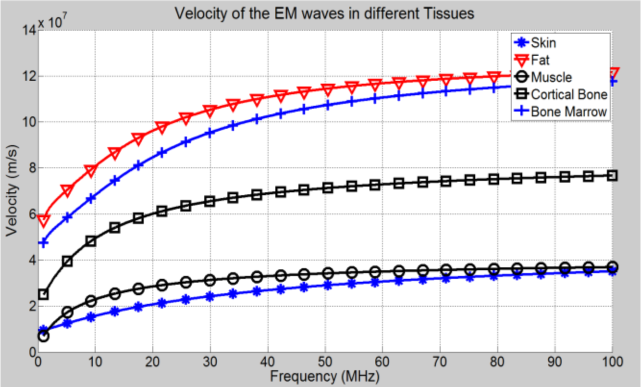


Figure 4. Propagation speed of EM waves in different body tissues.

Such a problem is much less pronounced in the case of EM waves' propagation. Velocity of EM waves' propagation within the different body tissues are shown in Figure 4. With such high propagation speeds, delay problems can be considered to be much less severe to deal with, especially with short distance communications as in the case of BANs, when EM waves are used as data carriers as opposed to Ultrasonic waves.

4. Channel Model

From the previous comparison, it was shown that EM waves are advantageous over other mediums for data transmission through the human body. Among the two available techniques, galvanic coupling is more attractive due to its immunity to interference and its potential for establishing a more secured closed loop network of sensors. To provide a reliable and flexible platform for smart bio-sensor networks, the intra-body channel model has to be well specified. Numerous research efforts exist that address modeling the body as a communication channel. Experimental trials were performed in [13-16]. Yet these models assumed constant parameters for the body's geometrical attributes. In our work [17], biological parameters are assumed to be variable, taking into consideration the impact of important factors; such as age and weight, on these parameters and thus on the overall attenuation profile. For the proof of concept, a model of the arm was considered, where simulation results are plotted and compared with published experimental results, showing high accuracy in identifying the optimum frequency for signal transmission for intra-body communications systems, as shown in Figure 5.

5. Conclusion

In this paper, possible mediums to be used as data carriers for intra-body communications were considered, namely; electromagnetic waves, pure magnetic waves and finally ultrasonic waves. Properties of each carrier were considered with respect to their propagation through the different body tissues. Then a more in depth comparison was shown between EM waves and ultrasonic waves concerning the attenuation and delay that each of them would experience when propagating through the human body, within the frequency range of interest for intra-body communications' applications. It was clearly shown that EM waves possess better properties, that can support BAN requirements, versus ultrasonic waves as EM waves experience much less attenuation and delay when traveling through the body. Such facts are crucial for system designers, as although ultrasonic circuits may appear simple in general, the hardware that would be required to compensate for the loss caused by ultrasonic waves' propagation in body tissues would add extra hardware and power compensation, making it a less attractive solution when compared

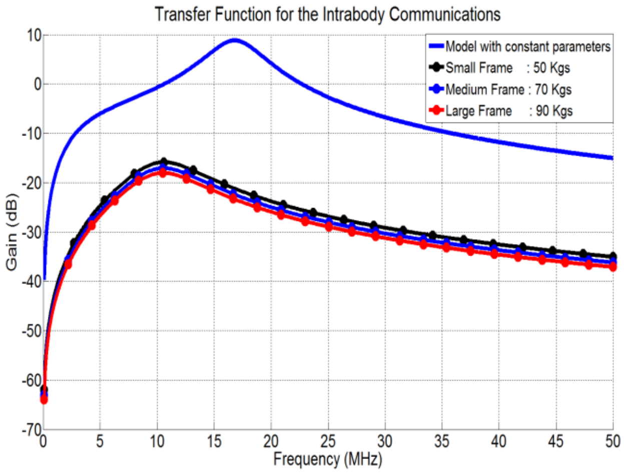


Figure 5. The proposed channel model frequency response, where simulation results show the gain in dB plotted from 100 KHz t0 50 MHz, considering different body frames; small, medium and large. The results from our model are compared to those obtained from circuit model in which the biological parameters are assumed to be constant. The proposed model succeeds in determining the optimum frequency -10.5 MHz- for data transmission.

with EM waves. Finally an accurate channel model for signal propagation (for EM waves using the galvanic techniques) is presented, showing the attenuation/gain profile for the human body over the frequency band of interest. Unlike in other intra-body communication research work where comparisons are shown between the main two techniques for EM signal transmission- capacitive and galvanic coupling, the novelty of this paper is that it takes one step back to provide a comparative study between the different data carriers that are used or proposed in the BAN field, where the electrical, acoustic and biological properties are discussed and thoroughly compared.

6. ACKNOWLEDGMENTS

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