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Communication Performances of Intrabody Communication for WBAN

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***Abstract*—*In this paper, we provide a comprehensive study of Intrabody communication(IBC) for WBAN in terms of their implementation, modeling, and communication parameters. IBC is a method of transmitting an electrical signal, considering the human body as a transmission medium. Compared to other wireless technologies, IBC is more advantageous.IBC is implemented in mainly two ways – Electrostatic coupling and Galvanic Coupling. Signal propagation models in analytical and numerical methods for these two coupling methods have been studied. Communication parameters to increase the transceivers' efficiency to transmit and receive the digital data through the human body in terms of data rate and power consumptions have also been considered.*

Keywords*-*Intrabody Communication(IBC), WBAN, Modeling, Simulation, Communication Parameters

I. INTRODUCTION

Increasing needs in health monitoring in the present day have lead to the implantation of sensors on and in the body to monitor the physiological signals. These sensors communicate wirelessly using wireless technology like Zig-Bee, Bluetooth, ANT, but these technologies have disadvantages of power consumption and external interferences. Hence a new technology was prescribed where skin/tissue is used as a medium for signal transmission. This new wireless technology is termed as Intra-Body communication (IBC), which allows the exchange of information using the human body's dielectric properties. In comparison to other wireless technologies, IBC exhibits low power consumption and less susceptibility to external interferences.

Enormous development in the Body area network(BAN) due to the increase in the aging population led to remote patient monitoring. It gained importance due to the portability and flexibility provided for the user. BAN communicates among the sensors, collects the physiological data from the sensors, and sends it to the linked sensor, which later communicates to the remote station, a hospital.

The latest international standard for Wireless Body Area Network(WBAN) is IEEE 802.15.6. It provides an international standard for low power, short-range, and extremely reliable wireless communication within the human body's proximity, supporting a vast range of data rates for different applications. Short-range, wireless communication in the vicinity of, or inside, a human body (but not limited to humans) are specified in this standard. It uses existing industrial, scientific medical (ISM) bands and frequency bands approved by national medical and/or regulatory authorities. Support for quality of service (QoS), extremely low power, and data rates up to 10 Mbps is required while simultaneously complying with strict non-interference guidelines where needed.WBAN in comparison to other wireless networks such as Wireless Personal(WPAN), Wireless Local(WLAN), Wireless Metropolitan(WMAN), and Wide Area Network(WAN), as shown in figure1.

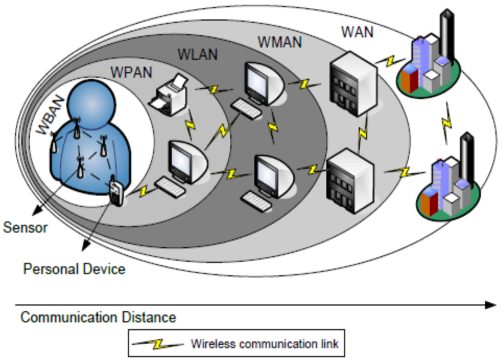

FIGURE 1. WBAN POSITIONED IN WIRELESS NETWORKS. COURTESY[2]

WBAN can communicate between few meters, whereas WPAN can communicate from one WBAN to another, enhancing communication further. This can later communicate through WLAN, WMAN, WAN to other networks. BAN using IBC finds diversified applications in the field of health care where vital body signals are sensed and transmitted to a monitoring device, defense, emotion, detection, sports, consumer electronics, and many more.

IBC was first proposed by Zimmerman [1] as a communication technology for WBAN. IBM first introduced IBC in 1996. IBC is a novel transmission technique using the human body as a transmission channel for electrical signal transfers [1]. IBC is one of the physical layers of BAN as defined by the IEEE 802.15.6 task group. IBC can be implemented in two ways, namely capacitive coupling and Galvanic coupling methods

II. METHODS OF IMPLEMENTATION

A. Capacitive Coupling:

Zimmerman[1] was the first to determine that placing a hand in the electric field attenuates the received signal. Based on this principle, he introduced the concept of Personal Area Network(PAN) that allows electronic devices on the body to communicate and exchange information without using any sophisticated antenna, only through electrodes that couple the electric signal to the human body. He developed a prototype of IBC for data transfer.

Capacitive coupling IBC also termed Electro-static Coupling IBC [3] and near-field coupling IBC[1][4]

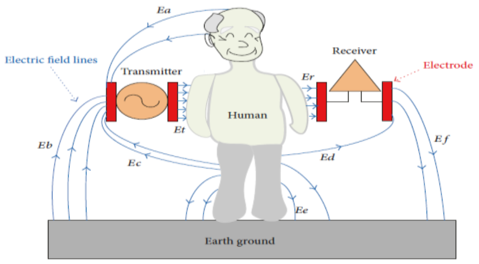

Figure2. Capacitive couplingCourtesy:[5]

The Signal electrodes of both transmitter and receiver electrodes are attached to the skin, whereas the ground electrodes are floating in the air. A large electric field is introduced into the body through the electrodes. The conductivity of the human body serves as a conducting plate that induces an electric field. The return path is formed through the environment or earth forms as an external ground [6]. The detected signal at the receiver is unstable due to the external environment's influence [1]. Capacitive couplings IBC are best suited for applications with longer range, maybe the whole body, and applications operating at higher frequencies [7].

B. Galvanic Coupling:

Handa et al. [8] first reported about Galvaniccoupling in 1997. The transmitting and the receiving electrode were in direct contact with a human body, thus forming the Galvanic coupling, as shown in figure 3.

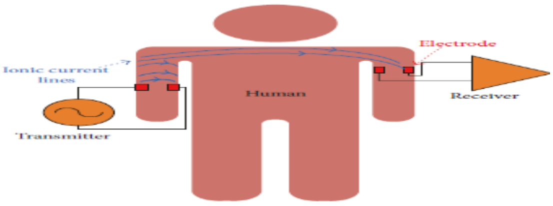

Figure 3. Galvanic Coupling principle Courtesy: [5]

The results showed that data transmission with lower power consumption is possible with Galvanic coupling IBC. Lindsey et al. in [9] tested Gal-IBC between implanted device and external device. The Authors have utilized ionic fluids to conduct the electric signal. Since ionic fluids are utilized for the conduction, the operating frequency should be in the range of MHz [10].

Comparison of Galvanic coupling with capacitive coupling is tabulated below:

Capacitive	Galvanic
An electric potential controls the induced signal	A current flow controls the induced signal
Only signal electrodes of Tx and Rx are attached to the body, while both ground electrodes float	A pair of Tx and Rx electrodes are attached to the body.
The ground is required as a reference	The ground is not required as a reference
The dominant signal transmission pathway is the environment	The dominant signal transmission pathway is the body tissue.
Higher transmission data rate and channel gain	Lower transmission data rate
The human body is modeled as a perfect conductor	The body is modeled as a waveguide for signal conduction.
Signal quality influenced by the environment around the body	The dielectric properties of human tissue influence signal quality.
Interference from surrounding devices that could take capacitively coupled directly to the IBC device	Sensitive to the body location because of the dependence on interelectrode distance and orientation along the body.
Does not require direct human body contact but only to be in proximity.	Direct contact with human body tissue is necessary. Capable of both on the body and implantable data communication.

Table1. Capacitive coupling Vs. Galvanic Coupling

Though the Gal-IBC exhibits low data rates, it is preferred more as the physiological signals do not require a very high data rate of <100Kbps.

III. SIGNAL PROPAGATION MODELS

The Signal propagation model of the human body is dependent on the electrical properties of human tissue/skin. The dispersion mechanism is based on three regions: α for low-frequency range, β for RF range, and $\gamma$for high frequency in Gigahertz range[21].

The Cole-Cole equation is used to predict the change of dielectric properties of tissue over the frequency:

$$\varepsilon^{*}(\omega) = \varepsilon_{\infty} + \frac{\varepsilon_s - \varepsilon_{\infty}}{1 + (j\omega\tau_n)^{1-\alpha_n}},$$

where$\tau$is the relaxation time constant of the polarization mechanism in the relaxation regions andε_∞permittivity at $\omega\tau \gg 1$ and εspermittivity at frequencies and$\omega\tau \ll 1$, frequency-independent part ε_∞ is due to ion conduction and a frequency-dependent part related to dielectric relaxation. However, the dispersion region may be broadened by many mechanisms due to the complexity of both the structure and composition of biological material. Therefore more specifically described by multiple Cole-Cole dispersion:

$$\varepsilon^{*}(\omega) = \varepsilon_{\infty} + \sum_{n} \frac{\varepsilon_s - \varepsilon_{\infty}}{1 + (j\omega\tau_n)^{1-\alpha_n}} + \frac{\sigma_i}{j\omega\varepsilon_0}$$

The human body was parametrically modeled using mathematical models and Analytical models. Analytical models were demonstrated firstly by K. Hachisuka et al. [15], who modeled human arms in the kHz range in various positions and achieved a higher gain in the kHz range. N. Cho et al. [3] modeled the human body as a distributed RC model with a High pass in the gain in 0.1-100MHz. S. H. Pun et .al; used a quasistatic model to achieve high pass characteristics in the sub-MHz region. M.Wegmueller et al. [13] developed a simple four circuit model for low-frequency Gal-IBC. R. Xu et al. modeled an EF-IBC channel path by a cascade of π-shaped circuits. Mathematical models are very accurate compared to analytical models but are time-consuming.Finite Element Method (FEM) and Finite Difference Time Domain(FDTD) are used to study the signal propagation through human tissue/Skin[19],[22],[23]

IV. COMMUNICATION PERFORMANCE OF IBC SYSTEMS

The Channel characteristics help us to select transmission parameters like frequency band and modulation methods. The main concern in IBC transceiver design is power consumption, data rate, carrier frequency, and modulation methods.

Dynamic behavior of the body is required compared to the static behavior, as the physiological signals have to be measured without hindering the daily activities of the human body. From the experimental investigation, it was found that basic movement of the body like sitting, standing had little effect on data transmission, but the joint movement had an effect on gain variations and phase[11][12]. The noise in the channel is mainly due to the electronic components[13] and the electrode skin interface[14], which follows the additive white Guassian noise (AWGN) property.

The carrier frequency and modulation method are selected based on the channel characteristics. For a low path loss, a high carrier frequency is selected in the range of 200MHz[16], while for a maximum channel gain, a low frequency of 10MHz was chosen[15].

Among the BPSK, QPSK, MSK, and 16 PAM, QPSK was chosen for fewer hardware complexities, while BPSK was chosen considering the empirical measurements.PSK is used for low bit rate application and moderate error performance

For capacitive coupling, OOK provided a data rate of 2.4Kbps[1], which was enhanced to 9.6Kbps using FSK..164Kbps, and 1.313 Mbps was achieved using delay-locked loop based BPSK. Wideband signaling could achieve a data rate of 2Mbps using a directly coupled interface(DCI). The human body behaved as a bandpass filter with a bandwidth of 100MHz.[21]. Frequency hopping FSK and DSSS extended data rate up to 10Mbps. Recently, a wideband signaling HBC transceiver with a high data rate between 1Mbps to 40Mbps was developed by Chung et al.[17]. Manchester code could provide a data rate of 10Mbps with a power consumption of 22uW[23].

Galvanic coupling, 0.9Kbps, was achieved using PWM. Using FSK,9.6kbps data rate was achieved using a carrier frequency of 10.7 MHz. A data rate of 255 kbps and 128 kbps was obtained using BPSK and FSK, respectively[15][19]. Complexity of hardware is similar for OOK and PPM. An energy-efficient PPM transmitter was designed for galvanic IBC as PPM is time-based and is more immune to false detection compared to OOK, which is a shape-based modulation scheme[21]. A data rate of 1.56Mbps was achieved with a power consumption of 2.0mW. Modifications to WBS was done in terms of encoding scheme where NRZI was used to transmit data[22]. This encoding scheme provided a data rate of 40Mbps with a power consumption of 1.94mW.

V. CONCLUSIONS

Considering the HBC system design, achieving the channel capacity is challenging. The works carried so far by various researchers have not identified any specific communication parameters to achieve a high data rate at low power. Even though the multicarrier system with optimal power allocation can achieve the capacity, the multicarrier system can lead to a high peak-to-average power ratio. Therefore, it is preferable to develop a single carrier system for HBC applications. Then how to design a single carrier system to achieve channel capacity and satisfy the special requirements on applications (high QoS, low power consumption, high data rate, and low hardware complexity) is a future research topic.

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