3.5 Secure Intra-body Wireless Communications (SIWiC) System Project

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Abstract: SIWiC System is a project to investigate, design and implement future wireless networks of implantable sensors in the body. This futuristic project is designed to make use of the emerging and yet-to-emerge technologies, including ultra-wide band (UWB) for wireless communications, smart implantable sensors, ultra low power networking protocols, security and privacy for bandwidth and power deficient devices and quantum computing. Progress in each of these fronts is hindered by the needs of breakthrough. But, as we will see in this paper, these major challenges are being met or will be met in near future. SIWiC system is a network of in-situ wireless devices that are implanted to coordinate sensed data inside the body, such as symptoms monitoring collected internally, or biometric data collected of an outside object from within the intra-body network. One node has the capability of communicating outside the body to send data or alarm to a relevant authority, e.g., a remote physician.

1.0 INTRODUCTION

The SIWiC system centers upon the concept of a network of implanted sensors within the human body responsible for either in vivo monitoring and reporting the status of multiple biological markers, or collecting data from sensing outside the body and storing it in a database within the body. These networked sensors have the ability to collect and forward data to a central node for uploading to a database management system where the sensor data can be processed and analyzed to aid physicians and concerned officials in caring for patients with chronic ailments requiring immediate attention. To prove our concept we have researched models that attempt to mimic and exhibit the many different dielectric properties of human body tissue including bone, fat, skin and muscle tissues. We then turn our attention to models of communication networks, specifically ultra-wide band networks (UWB). We believe that UWB spectrum will provide an adequate data rate with nominal power consumption. Lastly, we take a look at the state of nano-sensor technology and a proposed security mechanism protocol that will ensure that only relevant data reaches the individual user that has need of it.

2.0 BODY

Human body has been modeled for simulation to be used in medical science. There are various models and approaches, see for example [8-11]. One of the main challenges has been to decide on the granularity of a good model. For symptom monitoring, the scale varies from sub-cell level to a limb level, but for implanting the sensor, the requirements will naturally be more relaxed. A sensor should be conveniently located in close proximity of the sensed area, which will be either a small to large general area for medical implants, or an area that can easily collect data from outside of the body still hiding the sensor in a proficient manner. These less restricted requirements make the design of a simulation model for human body a rather application specific issue, where the propagation characteristics of the body material will be used for small or large general area. Such a model has not been reported in literature before, and is the main subject of current funding of the SIWiC system design.

Even though not much work is available on the intra-body channel, many researchers have successfully implemented Body Area Networks (BANs) atopic to the human body in the form of wearable sensors [1] and still others have been successful with standalone, non-networked implanted devices that monitor a specific function of interest [2]. Of greater interest is a network of implanted devices that each monitor a specific function, are capable of exchanging data among themselves and with a central node. This central node will also offload data to a remote server for further processing and storage. Such a network will use human tissue as medium to propagate data signals from one node to another. In other words, the nodes in the network will use human bone, muscle and fat to convey signals through the body to other nodes in the much the same way as sound travels from a source through air or water to a receiver.

2.1 SIWiC Node

A typical SIWiC node consists of a sensing element, ideally a smart sensor such as conforming to IEEE specifications [27], that senses analog data and uses inductive coupling or direct connection to the sensed area. For inductive coupling, a transducer converts the sensed data on location into equivalent electrical signal and this signal is picked up by a coil at a distance (e.g., both being on different sides of a membrane). The signal, analog in nature, passes through an analog to digital convertor (ADC), which generates a digital stream to be packetized by a network protocol, such as IEEE 802.15.6 [28] or IEEE 802.15.4a [26] that sends packets to an UWB physical layer. In case of a smart sensor, the digitization occurs inside the sensor assembly and the output of the sensor is ready for UWB network. The output of UWB module is secured and networked in general to a database inside the body. The signal will be weak enough so that it does not travel outside the body, except for a node with the 'symptoms' database (SDB) that will be highly secured and linkable externally using a secure protocol. Figure 1 shows a schematic of the SIWiC node interconnection.

Most work in the direction of implementation for the SIWiC node is yet to be done. In this paper, we address the channel modeling for the networking part where human body acts as a wireless communications medium.

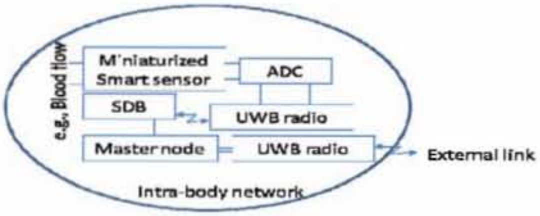

Figure 1. SIWiC System node and its relation to SDB.

2.2 Existing Efforts

In our research we have reviewed a few different ideas/models for implementing a Body Area Network and even some ideas on internal BAN channels. In this section we will expound on a few of the more promising approaches to include ideas from the Swiss Federal Institute of Technology-Zurich (ETH), the National Institute of Standards and Technology(NIST), the Electronics and Telecommunications Research Institute(ETRI) and Samsung's Electric Field Communication. We will also, very briefly, discuss some of the human dielectric properties that are important factors in modeling the human body as a communication channel.

First we will discuss the model proposed by the Swiss Institute of Technology-Zurich. In this paper galvanic coupling is presented as a possible transmission mechanism inside the human body. Galvanic coupling was investigated by Oberle [4] and analyzed by Hachisuka et al [5] [6]. Galvanic coupling uses the body's electrical potential stored in each cell to generate the electrical energy needed to propagate the data signal from source to receiver through cell clusters inside the human body. The signal is applied differentially over two transmitter electrodes and received differentially by two receiver electrodes [7]. The source electrical signal is modulated into the body and received differentially by the receiver electrodes as shown in Figure 2.

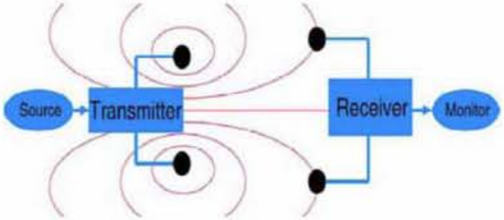

Fig 2. Signal Propagation via galvanic coupling IEEE Transactions on Biomedical Engineering, VOL 54, No. 10, October 2007

This method uses current with a peak amplitude of 1 mA between 10 KHz and 1MHz establishing a certain potential distribution in the human body. To determine paths of least resistance Electrical Impedance Tomography (EIT) and Finite Element (FE) modeling is used to map the impedance distribution of human tissues [8] – [11].

The IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs) is the next statistical model we will discuss. This model was developed within the National Institute for Standards and Technology and proposes a simple statistical model for representing the path loss for communication to/from an implant or between two implants inside a human body. The path loss model is modeled on the center frequency of 403.5 MHz, the Medical Implant Communication Service (MICS) band. This is an unlicensed band allocated for communication between an implanted medical device and an external controller, with these primary benefits; better propagation characteristics for implants, reasonable size antenna for implants, worldwide availability and limited threat of interference. It is our point of view that the required antenna size and power are still way too high and only UWB can satisfy these requirements at this time.

To study the propagation characteristics of MICS, NIST proposed a 3D simulation & visualization scheme because in-body measurement and experiments prove very difficult at this point in time. The 3D simulation & visualization system components consist of dielectric properties from over 300 male human body parts that are user definable. The system uses a 3D full-wave electromagnetic field simulation (HFSS) propagation engine accurate to within 2mm. Some of the user-selectable input parameters include antenna location, antenna orientation, operating frequency, transmit power, range and resolution. The study simulated near surface implants such as pacemakers and deep-tissue implants in the form of endoscopy capsules 95 mm below the body surface. The resulting data was filtered into 3 sets: in-body propagation, all points completely within the body; in-body to body-surface and in-body to out-body propagation. See Figure 3 for NIST model.

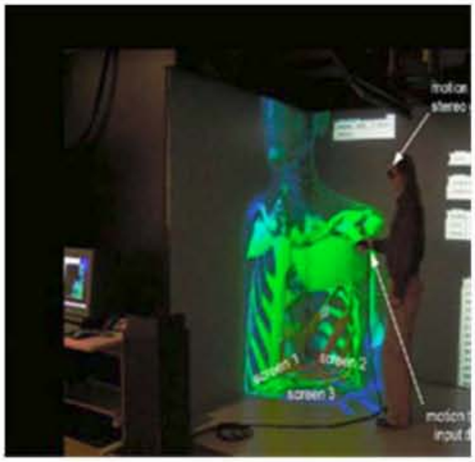

Fig 3. NIST 3D Simulation & Visualization Model, IEEE 802.15-08-0519-01-0006

The Electronics and Telecommunications Research Institute (ETRI) HBC (Human Body Communication) PHY Proposal for Body Area Network suggests that the physical channel of the body area network should have a data rate of 10 Kbps to 10 Mbps, be of low complexity, low power consumption and within regulatory compliance and operate from distances of 1 m to 3 m. The HBC should feature touch and play operation, be intuitive and easy to setup and use. Privacy and security should be afforded and power consumption should be extremely low.

The system principles include a frequency response range of 5 MHz ~ 50 MHz using a FSBT (Frequency Selective Baseband Transmission.) The FSBT allows a direct digital transmission without the need of a radio and offers more processing gain while avoiding low frequencies. FSBT employs sub-groups of Walsh codes and spreading techniques to increase processing gain. The HBC consists of a microcontroller, a signal electrode and the modem with its various sub-components (i.e. transmitter, receiver, buffers and noise filters, see Figure 4). The simulation parameters include a data rate of up to 10 Mbps, a maximum chip rate of 64 Mcps, the Walsh spreading code, and a baseband transmission square wave.

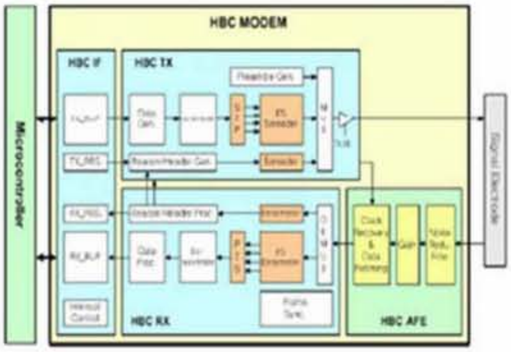

Fig 4. Human Body Communication System Architecture, IEEE 802.15-09-0348-00-0006

The Physical and MAC Layer proposal for the IEEE 802.15.6 Working Group for Wireless Personal Area Networks also received a model from Samsung Electronics. The proposal is for non-medical applications in an everyday environment such as entertainment or home office. The WPAN is intended for on-body to on-body communication with data rate ranges up to several Mbps. Lastly, as with all wireless personal area networks, low power consumption is critical. Communication is based on an Electric Field using the human body as the dielectric material, as shown in Figure 5. It has been determined that the human body has about 300-500 times more permittivity than air [12].

The Electric Field Communication physical layer consists of the transmitter which employs orthogonal modulation using frequency shaping coding, the sensor electrode, the medium (human body) the receiver electrode and the receiver which filters the data, compares it, and outputs the raw data. The data rate is scalable and the frequency bands range between 10 and 50 MHz. The packet structure of the PHY layer consists of the preamble, start frame delimiter and the payload. The payload maximum size is < 1 K Octets and is further divided into the MAC Header, MAC payload and the Frame Check Sequence. The receiver makes use of a single electrode instead of a 50 Ω antenna which eliminates the need for RF carrier signal blocks.

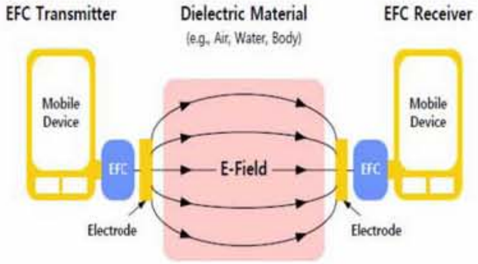

Fig 5. Electric Field Communication Architecture , IEEE 802.15-09-0318-02-006

2.3 UWB Models

In order to better understand PAN channel models we reviewed a number of models for Personal Area Networks. For example, the authors of [24] describe a few of the more popular UWB communication models and the primary characteristics of the multipath channels that make them up; root mean square (RMS) delay-spread, power decay profile and number of multipath components. Three indoor channel models were considered; the tap-delay line Rayleigh fading model [3], the Saleh-Valenzuela (S-V) model [4] and the Δ-R model described in [5]. Each model was suitably modified to fit the important channel characteristics described above. Of the three, the (S-V) model was chosen to model the multipath of an indoor environment for wideband channels on the order of 100 MHz. This model requires four main parameters to describe an environment, which can be adjusted for different environments; the cluster arrival rate, the ray arrival rate within a cluster, the cluster delay factor, and the ray decay factor.

In [13] an electromagnetic "creeping wave" is considered for modeling a communication channel around the human body. The authors have concluded that electromagnetic waves can travel through the human body or in a near surface channel around the body. This channel around the body is the one of interest and provides the least amount of delay and path loss, see Figure 6. To simulate this path around the human body a Finite-Difference Time-Domain EM simulator is used the XFDTD by REMCOM. Frequencies in the ISM bands (US) of 315 MHz, 915 MHz and 2.4 GHz are used because these are the bands that will most likely be used to develop a prototype and also because these higher bands allow the use of smaller antennas[13].

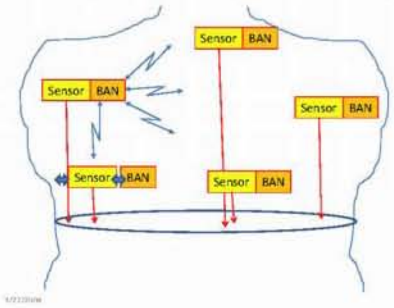

Fig 6. Wireless Communication Channel Around Human Body

Much work is needed in order to come up with a UWB model for human body that will predict the most realistic amount of transmission power needed to exchange a signal between two devices within the body.

3.0 DISCUSSION

3.1 State of Nanosensor Technology

There are many new companies using nanotechnology in very exciting ways in all industries across the board from military aircraft to cars, bicycles, and tennis rackets [25]. A new company known as NanoDynamics plans to use nanomaterials to bring about less weight shift inside of golf balls as they spin, drastically reducing hooks and slices [15]. Nanotechnology is a collection of technologies for building materials and devices "from the bottom up," atom by atom and usually includes items on the length scale of approximately 1-100 nanometers.[16] In our research we are primarily concerned with nanosensors; devices used to sense biological markers inside of the human body. Nano-sensors are already in the market [25] and are expected in near future to go to a scale where they can be implanted.

3.2 Security

It is well known in the health care field that patient privacy and rights are of utmost importance. SIWiC will use a novel wireless security protocol that satisfies the requirements of the HIPAA (Health Insurance Portability and Accountability Act) in the United States while maintaining timely access to vital patient information. HIPAA provides the guidelines for managing healthcare information and patient's privacy rights, ensuring that only individuals with a need-to-know have access to a patient's personal healthcare data.[19-22] Satisfying the requirements of HIPAA, in some instances, may prove to hinder the timely care of some critical patients and therefore must be addressed.

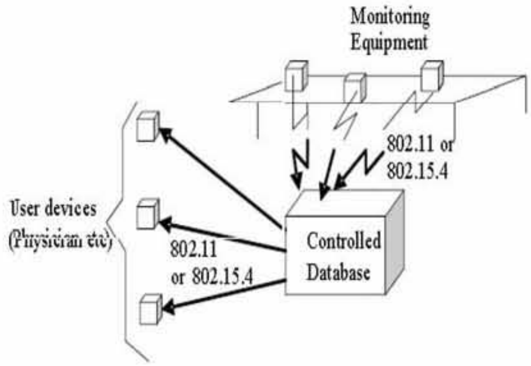

Figure 7. Privacy in a HIPAA compliance system can be implemented by sending all data to a controlled database.

A security protocol inside the symptoms database (SDB) addresses this issue by introducing a centralized database into the system architecture responsible for determining access levels based on a *HIPAA filter* and previously stored information tables.[23] Individuals and entities are assigned levels of access and stored in the database. Patient information is received at the database and immediately filtered to determine the type of information and assigned a classification level. Once a wireless request is received the system checks the credentials of the requestor against the level of information requested and determines whether access is granted or denied.

4.0 CONCLUSION

Given the current state of technology and the advances in nanosensor technology, a network of implantable sensors is feasible in near future, and will be a state-of-the-art in future. The hurdles are few and include adapting or developing an optimal human dielectric tissue model, adequately powering our sensor nodes and implantation of the nodes themselves. Additionally, although not addressed in this paper, the social stigma of having monitoring devices implanted within the body, by most individuals would have to be overcome. For the patients that stand to gain, by living fuller, longer and healthier lives, the benefits far outweigh the drawbacks associated with Implantable Sensor Networks.

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