Secure Human-Internet using Dynamic Human Body Communication

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Abstract— **Continuous miniaturization and cost reduction of unit computing has led to the prolific growth of smart wearable devices. These devices, present on and around the human body, form a complex network known as the Human-Intranet. The Human-Intranet is typically connected through Wireless Body Area Network (WBAN). However, Human Body Communication (HBC) has recently emerged as an energy-efficient and secure alternative that uses the human body as the communication medium. Human-human, human-machine interaction creates dynamic HBC channels, which allow these Human-Intranets to interact with each other forming a Human-Internet. In this paper, we present the concept and demonstration of Secure Human-Internet using dynamic HBC. We highlight important applications of Human-Internet and discuss the architecture of a wearable Human-Internet device capable of communicating through inter-body dynamic HBC. A custom-built hardware prototype is used to demonstrate for the first time information exchange (e.g. business card) during handshaking. Dynamic signal transfer characteristics during inter-body communication through handshake between two individuals wearing such devices are measured and analyzed. The effects of data transmission rate, handshake posture on the HBC based inter-body communication is explored to demonstrate its effectiveness and limitations under varying realistic scenarios. The specific COTS based HBC implementation shows > 8X better energy efficiency compared to the Bluetooth implementation.**

Keywords— Human-Internet; Human Body Communication (HBC); Body Coupled Communication (BCC); Dynamic HBC;

I. Introduction

Five decades of continuous scaling following Moore's law has enabled cheap, ubiquitous computing to be incorporated in everyday things like watches, earphones etc. On the other hand, rapid advancement in wireless communication technology has made it possible to connect these small computation units seamlessly, forming an internet of billions of devices. The emergence of cheap connected computing has resulted in the modern era of interconnected smart devices, commonly known as the Internet of Things (IoT), which will consist of more than 50 billion interconnected devices by 2020 according to some predictions [1]. Moreover, there are widespread availability of cheap on body sensors like Electrocardiography (ECG), Blood pressure, Glucose sensors to monitor vital physiological parameters. Soon it will be very common to have multiple connected devices like smartwatches, fitness bands, smart earphones and different physiological sensors being worn on the human body. The multitude of wearable devices will create a network of connected devices around each person, which has been termed as the *Human-Intranet* [2] (Figure 1a). These Human-Intranets are centered on an individual human being and may not necessarily be always connected to the cloud.

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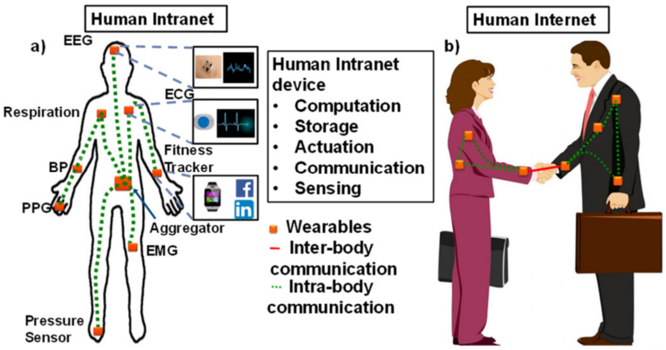

Figure 1: a) Human-Intranet formed by wearable devices around the human body b) Two such intranets interact to form a Human-Internet

Interaction between two human beings or a human and machine will provide an opportunity for these moving Human-Intranets to communicate with each other forming the ***Human-Internet*** (Figure 1b) allowing secure information exchange.

The Human-Internet will require an energy-efficient, secure medium of communication amongst the energy constrained wearable devices, due to their form factor and battery size limitations. As communication accounts for a significant portion of the total power consumption of a connected device, an energy-efficient communication medium will enhance battery life significantly. To connect these energy sparse devices, traditionally WBAN has been used. However HBC is an alternative to WBAN for secure and ultra-low power Human-Internet as can be seen from Figure 2. Typical state of the art wireless systems consume nJ/bit energy [3] whereas HBC system can consume as little as 10s of pJ/bit, which can enable energy harvested systems.

In this paper we design a HBC based Human-Internet device for inter-body communication that transmits data by capacitively coupling it into and conducting through the human body. A Commercial Off-The-Shelf (COTS) component based system is designed to transmit, receive and decode the attenuated signal at the receiver end. In this work, we build a Human-Internet device prototype, characterize its dynamic

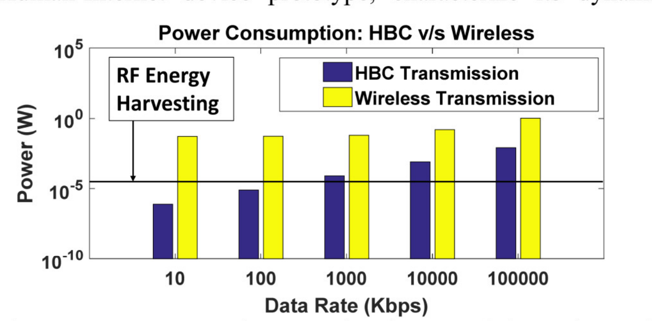

Figure 2: Power consumption comparison between wireless and HBC for different data rate showing ~2 orders less consumption in HBC, enabling energy harvested nodes in HBC upto a certain data rate. The energy/bit values are taken from literature ([3], [4], [5]) and scaled to get power.

signal transfer characteristics and demonstrate for the first time the framework for (1) human-human information exchange, as well as (2) human-machine information exchange.

The rest of the paper is organized as follows: Section II describes in detail about Human-Intranet and Human-Internet; Section III discusses previous intra-body HBC systems. Section IV defines and provides measured channel characteristics for different type of ***Dynamic HBC***; Section V describes the details of the Human-Internet device with measurement results and applications in Section VI. We consider further work in Section VII with conclusion in Section VIII.

II. Application

A. Human-Intranet

Figure 1a represents a scenario of a Human-Intranet formed by multiple wearable sensors and devices. Sensors like ECG, EEG, Blood pressure, Glucose sensors monitor and send those signals to an aggregator, which periodically transmits these data for further analysis and diagnosis. Smartwatch, fitness trackers, smart bands, smart earphones and other wearable devices can also be part of the Human-Intranet and provide a gateway to connect to the external world.

B. Human-Internet

Since the Human-Intranets are mobile (with the human) there will be many scenarios of two such intranets interacting with each other or with machines forming a Human-Internet, as shown in Figure 1b. Prevalent social gestures entail two individuals shaking hands when they meet each other leading to the formation of a dynamic HBC channel, which can be used as a secure communication channel for the Human-Internet. As an example, consider a scenario where a person wants to send a social/professional networking request (Facebook/LinkedIn request) or his/her business card to another person in a conference. This can be done from a smartwatch through standard wireless protocol, thus creating an interaction between two Human-Intranets and hence forming a Human-Internet. As an alternative to wireless transmission, the data can also be sent securely through HBC when the two individuals greet each other through a handshake.

C. Secure HBC based Human-Internet

Security and energy-efficiency are two primary concerns for implementation of the Human-Internet and HBC provides the following advantages compared to WBAN:

(1) Security: The cryptography algorithms on energy-sparse Human-Internet devices are often simple to save energy, making them vulnerable to security attacks. Since the HBC signals are primarily confined within the human body, it is less prone to eavesdropping as the attacker must physically touch or come very close to the person. Whereas broadcasted wireless signals can be easily intercepted, if not encrypted. Hence HBC provides a secure alternative of WBAN for Human-Internet.

(2) Energy-efficiency: Human body is a more energy-efficient communication medium compared to air due to lower losses and the ability to transmit broadband data without introducing energy inefficiency due to frequency up and down conversion. The energy consumption in wireless transmission is ~nJ/bit [3], [4] whereas HBC enables transmission in tens of pJ/bit [5].

(3) *Inter-device interference:* As the signal transmission in HBC is not broadcasted in a common medium like WBAN, a HBC based Human-Internet device will not be affected by transmissions going on in other Human-Intranets close by.

III. Human Body Communication

Human Body Communication (HBC) was first proposed as a method of connecting devices on a Personal Area Network in [6]. Both the receiver and transmitter have a pair of electrodes, are electrically isolated and battery powered. The transmitter capacitively couples the signal into the human body creating a small displacement current, which is picked up at the receiver end through a closed loop path formed by the "earth ground" consisting of the conductors and dielectrics in close proximity of the devices. This is an example of HBC through *Capacitive coupling*. Wegmueller *et al.* introduced *Galvanic coupling* [7] where the transmitted signal is applied between two electrodes directly connected to the human body and the potential difference created at the receiver due to the induced electric field at the transmitter is sensed. The frequency of operation in this mode is limited between 10KHz-1MHz due to the high signal loss characteristics of the body above this range [7].

A. Human Body Channel Model

The human body channel model has been studied widely but the developed models vary quite a lot due to the experimental setup used for performing the measurements, especially the grounding effect of transmitter, receiver and measuring equipment. A few channel models and the experimental setup for those measurements are discussed in *TABLE I.* ([8]–[13])

TABLE I: Human Body Channel Model and Receiver (Rx), Transmitter (Tx) configuration comparison

Reference	Experimental Setup	Channel Response	Comments
Cho *et al* [8]	Tx: Battery operated device Rx: Oscilloscope/ Spectrum Analyzer	Bandpass; Stop band loss at 100KHz is 90dB, Passband: 10MHz, 35-60dB loss	Passband loss depends on transmitter, receiver distance and size of the ground electrodes
Lucev *et al* [9]	Tx, Rx: Network Analyzer	Flat band in 100KHz-100MHz range, 20dB loss	Loss depends on the distance between the Tx, Rx and is less due to common ground
Lucev *et al* [9]	Tx,Rx: Network Analyzer isolated by balun	Bandpass; Stop band loss at 100KHz, ~80dB; Pass band: 35MHz, loss ~20dB	Adding baluns changed the response from flatband to bandpass. Loss is less at high frequency, in range of tens of MHz.
Bae *et al*. [10]	Tx: battery operated transmitter Rx: oscilloscope isolated through a balun	Bandpass; Passband: ~40-60MHz	Loss depends on Tx-Rx distance; variations are significantly higher than in [9]
Hwang *et al*. [11]	Tx: Battery operated; Rx: Oscilloscope isolated through a differential probe	Flatband; ~75dB loss at 10-100MHz.	Connecting the oscilloscope ground to Rx keeps the response flatband contrary to [9]
Ruiz *et al*. [12]	Tx, Rx: Network Analyzer	Lowpass; ~20dB passband loss	Common ground measurements, loss depends on electrode configuration and size
Callejon *et al*. [13]	Tx: Battery operated Rx: Oscilloscope	Flatband response in 10KHz-1MHz range with ~20dB loss	Experiments done with human phantom, authors discard any setup with baluns on Rx side, which has been used in [9], [10]

B. Interference on Human Body

The human body acts like a monopole or dipole antenna in the 40-400 MHz range [14]. The FM radio band (88MHz-108MHz) falls within this range, making FM interference one of the primary bottlenecks for high speed low power human body communication. The interference from the FM signal can be -30dBm whereas the signal from the transmitter can be typically -50dBm making the signal to interference ratio (SIR) as low as -20dB [15], requiring strong interference rejection properties from the HBC receiver. However, in this paper FM interference is not a limitation due to low operating frequencies.

A 4 channel adaptive frequency hopping [15] receiver in the 30-120MHz range, a full duplex HBC transceiver [5] operating on two channels of 40MHz bandwidth centered around 40MHz and 160MHz are two proposed narrowband techniques used to avoid FM interference. However, this leads to (1) low data-rate, (2) high-power needed for up and down-conversion, resulting in energy-inefficient HBC. Recently a broadband integrating Dual Data Rate HBC receiver has been proposed which utilizes an integrating receiver to provide interference robustness and the low loss human body channel to enable broadband energy efficient data transfer through HBC [16],[17].

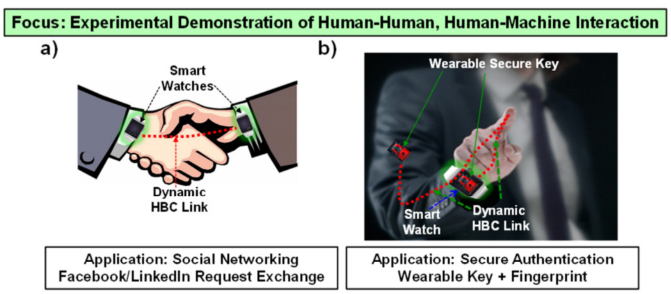

Figure 3: Human-human, human-machine interaction through dynamic HBC a) Social/ Professional networking message exchange in a gathering b) Secure Authentication using body worn secret key

All the previously discussed studies concerning circuit design and channel measurements focuses on intra-body HBC. The possible applications of inter-body HBC and human-machine interfaces have been discussed in [6], [16] and human-machine interaction for health monitoring has been presented in [18]. In this paper, we focus on hardware demonstration of inter-body dynamic HBC for information exchange. The key contributions of this work are:

1) *Transient Characterization of the signal transmission of dynamic HBC during a handshake event*

2) *Experimental demonstration of Inter-body Dynamic HBC information exchange using COTS platform.*

3) *Characterization of various Inter-Body HBC channels.*

4) *Energy-efficiency and Signal Quality (Bit Error Rate) Improvement Analysis*

IV. Dynamic Inter-Body HBC

A HBC based Human-Intranet communicates through a static human body channel. On the other hand, the proposed HBC-based human-internet devices will communicate with each other through dynamically formed channels when a human comes in contact with another human or a machine.

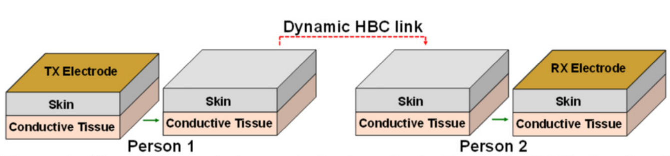

Figure 4: Signal Transmission path for inter-body Dynamic HBC: the signal goes through 4 layers of skin instead of 2 as in intra-body HBC.

When two humans interact through some social gestures such as handshaking, it results in a ***human-human*** interaction. One potential application of dynamic HBC during *human-human* interaction (Figure 3a) is to enable secure, directed exchange of (1) social, professional networking requests, (2) business cards during a social gathering, conference or meeting, by activating a software switch on a smart watch/ phone.

Exchange of information through HBC between a machine and a body worn device results in ***human-machine*** interaction (Figure 3b). Secret key transmission for authentication, data transfer between a smartwatch and a laptop through touch, are examples of human-machine interaction through dynamic HBC.

The signal transmission path for inter-body dynamic HBC is different compared to intra-body HBC, as highlighted in Figure 4. In intra-body HBC the signal goes through the less conductive skin into the conductive tissue underneath and is then received through an electrode placed on the skin. Since the signal has to transfer from one person to the other in dynamic HBC, it has to go through two extra layers of skin.

Figure 5 shows the measured loss characteristics for intra-body HBC and human-human, human-machine inter-body HBC in the 10-500KHz frequency range. For each type of HBC, the loss is measured for two different distances (d) between the transmitter and receiver. To ensure realistic scenario with non-common ground, in all these cases the transmitter is a wearable battery operated generator and the received signal is measured using an oscilloscope with the receiver either worn by the same (intra-body) or different person (human-human), or kept on a table (human-machine). The intra-body path loss is ~3-4dB less than the inter-body loss. For measuring human-machine interaction channel loss, the Human-Internet device is kept on the table and used as a receiver to emulate a machine and a body worn device is used as a transmitter. The measured loss is lesser compared to the other two types of HBC. These flat-band channel response shows the potential usage of HBC as a broadband communication medium in the Human-Internet.

V. Human-Internet Device Design

A. Components

A Human-Internet (HI) device is built which communicates using the human body as the communication medium through dynamic HBC. To this end, the device should take external

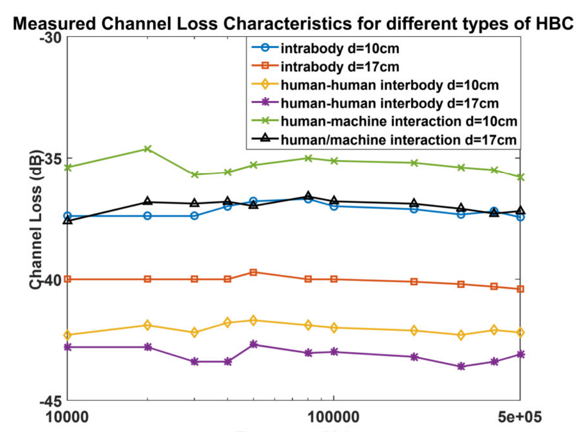

Figure 5: Measured HBC channel loss characteristics for intra-body, human-human and human-machine interaction. For each type of HBC the loss is measured for two different transmitter-receiver distances (d).

input, process, store the data and communicate it. The system level block diagram and actual implementation of the COTS based HI device is shown in Figure 6.

The conceptual diagram (Figure 6a) shows that the device consists of a communication module, processing module, memory, power source, display, sensor and an interface with the human body. The communication module is used to send and receive data. The processing module processes external inputs coming from sensors, performs operations on them and interfaces with the display module. The device is battery-powered to emulate the scenario of a wearable device. The display module displays the received information. A sensor, chosen as a touch sensor, is used to receive input from the user. An interface electrode is required to couple the transmitted data into the body and receive the data transmitted through the body. A Texas Instruments *TM4C123G* LaunchPad evaluation kit consisting of an ARM Cortex M4 based *TM4C123GH6PM* microcontroller is used for implementing the communication and processing module together. A Duracell rechargeable Lithium ion battery is used as power supply. A *BOOSTXL-K350QVG-S1 Kentec QVGA* touchscreen display module is interfaced with the microcontroller. The touchscreen module acts as both the sensor and display, taking external input as well as displaying received data. The coupling of the signals between the microcontroller and the human body is done through bands consisting of copper electrodes.

B. HBC based Human-Internet: Challenges and Solutions

1) Environment Noise: During our experiments the human body picked up 60Hz power supply noise from the laboratory environment whose amplitude was almost 20dB higher compared to the received data signal. The AC coupled bias circuit cutoff frequency was set to reject this noise.

2) Capacitance between wearable band and body: The capacitance between the electrode and body adds a series capacitance to the biasing circuit capacitance, thus reducing the effective capacitance. Also the capacitance depends on how tightly the band is worn. So it affects the high pass filter cutoff frequency of the bias circuit, which limits low frequency operation. This sets a lower limit of the bias resistor, given a frequency of operation.

3) Biasing/Offset of the integrator: Since the received signal amplitude is ~30mV, it is necessary to match the biasing at the integrator inputs (offset cancellation).

4) Data Rate constraints: The environmental noise and high pass effect of the bias circuit limits the low frequency operation of the system. The high frequency operation for this implementation is limited by the maximum sampling rate of the ADC (*10^6 samples/sec).* To ensure correct decoding of the received signal the data is sampled twice for each bit period setting the maximum possible data rate to 500Kbps.

5) Lower Received signal for Inter-body HBC: The channel loss for human-human inter-body HBC (Figure 5) is higher compared to intra-body HBC. This makes inter-body HBC more prone to offset and interference. An integrator is used to solve the interference problem as described in next subsection.

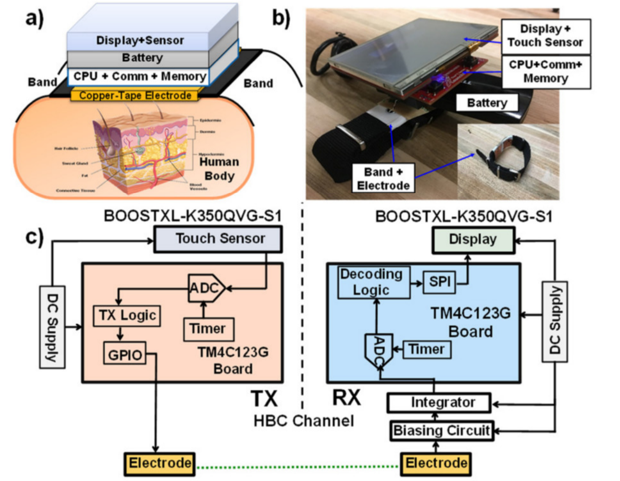

Figure 6: a) Conceptual diagram of the Human-Internet device b) Actual implementation of the device showing the different modules c) System level block diagram showing different basic blocks

Among the aforementioned problems, (1)-(4) are common to both intra-body and inter-body HBC whereas (5) is more significant to inter-body HBC.

C. HBC based Human-Internet System Level Design

Since, in HBC, the receiver and the transmitter do not share a common ground, only AC signals can be transmitted through the human body and it is attenuated due to weak return path.

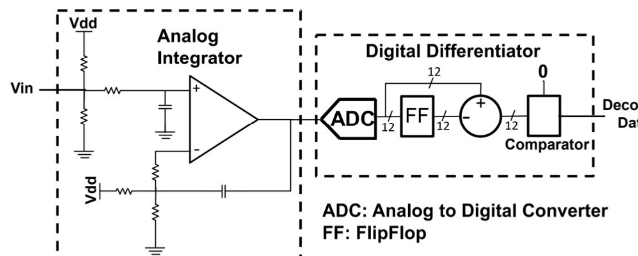

Figure 7: Diagram showing the basic decoding scheme at the receiver

The human body acts as a single wire so data must be communicated serially, but standard serial protocols such as UART, SPI, I2C cannot be used for reception due to lack of a common ground reference and attenuation. Therefore, the received AC signal is capacitively coupled onto a DC level set by a resistive divider, integrated and sampled through an ADC.

Since the received broadband signal is low and susceptible to interference, its Signal to Interference-plus-Noise Ratio (SINR) is low. To detect this signal with COTS components we introduce an integrator before applying it to an onboard ADC. Since the received data is broadband and the interference is a narrowband sinusoidal wave, the SINR significantly improves through integration. A higher integration period will result in a larger SINR as the integrated data keeps on increasing but the interference integration does not increase proportionally. In the absence of integration with reset (as in [16]) due to a COTS based implementation the starting point of the integration is dependent on the previous bit. So, differentiation is required to decode the received signal, which is done in digital domain by sampling the integrated signal through an onboard 12-bit ADC (Figure 7).

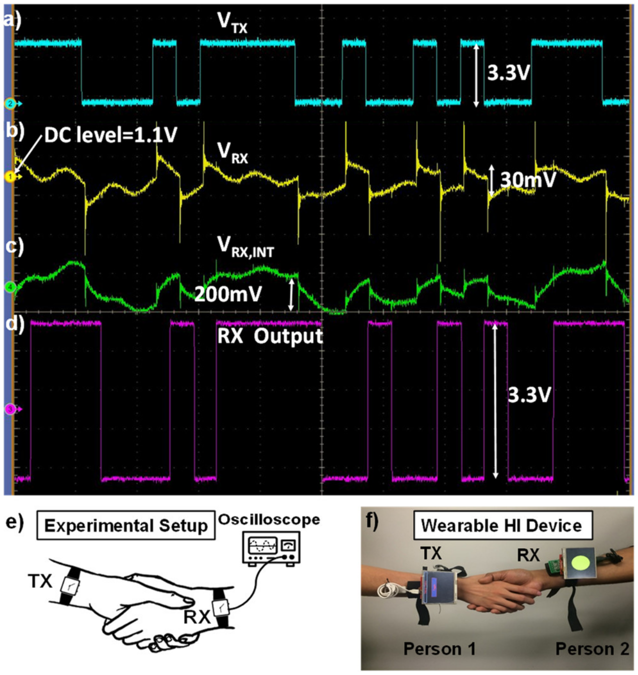

Figure 8: Dynamic Signal Transfer Characteristics of inter-body HBC a) Transmitted Signal b) Received signal with DC biasing c) Integrated received signal, which is applied to ADC d) Receiver decoded output. The received signal (30mV) is significantly attenuated from the transmitted value (3.3V) and does not contain any DC component. e) Conceptual diagram of experimental setup f) Picture showing handshake wearing HI devices

VI. Human-Internet System Experimental Results

A. *Information Exchange*

The signal transmission characteristics, during information exchange between two Human-Internet devices through a human-human dynamic HBC link formed by a handshake, are analyzed by sending a continuous bit stream from the transmitter to the receiver. As an application, we also demonstrate interactive information input, capture and transmission through dynamic HBC.

1) Signal Transmission Characteristics

We send a repetitive sequence of data at 130 Kbps and look at the signal characteristics in an oscilloscope at 4 points on the transmission path: a) output of the transmitter (V_{TX}), b) received signal after DC biasing (V_{RX}), c) Integrated received signal ($V_{RX,INT}$) d) decoded output of receiver.

Figure 8 shows the measured signal characteristics between two Human-Internet devices during a handshake between two individuals. The transmitted signal with peak to peak amplitude 3.3V (Figure 8a) is coupled through a copper electrode band into the body and at the receiver end an ac signal with ~30mV peak to peak amplitude is received, representing a loss of ~42dB. The received signal is then coupled onto a DC level of 1.1V through a coupling circuit (Figure 8b) and applied to an integrator (Figure 8c), whose output is sampled synchronously through an ADC with a resolution of 0.8mV. The difference in consecutive sample values is used to detect a data transition. The delay between the decoded received waveform (Figure 8d) and the transmitted waveform is from the write delay of the General Purpose Input Output (GPIO) pins of the microcontroller.

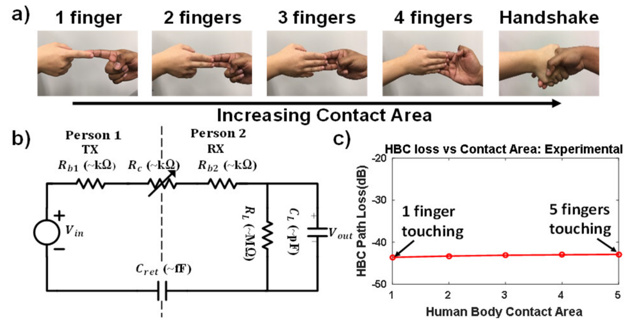

Figure 9: a) Postures with different contact area used for measurement b) Simplified Human Inter-body Communication circuit model. c) Experimental results showing constant loss for different postures in a)

2) Effect of Contact Area

The dependence of data transmission quality on the contact area of handshake between the two individuals is explored by measuring the received signal for 5 different postures (Figure 9a) keeping Rx, Tx distance at 10cm. Our experiments show that the amount of signal transmission is almost independent of the contact area of the handshake as shown in Figure 9c. It can be explained from the inter-body HBC circuit model shown in Figure 9b. The coupling capacitance between the human body and surrounding atmosphere (C_{ret}) provides the signal return path in HBC [6], which is in the order of Femto-farads. The contact area between the two bodies affects the resistance in the signal path, higher contact area providing less resistance and vice versa. The intra-body transmission path resistance (R_{b1}, R_{b2}), skin contact resistance (R_c) are in the order of Kilo-ohms. The voltage-mode receiver can be resistive or capacitive. In case of a resistive receiver since the receiver input impedance (R_l ~MΩ) is considerably higher than skin contact resistance (R_c ~KΩ) the loss characteristics is not dependent on the change in contact resistance, hence contact area. In case of capacitive receiver, at the frequency of operation around 100 KHz, the capacitive division between the load and return path capacitance primarily determines the output loss. This is also independent of the skin contact resistance.

3) Application: Interactive input through touchscreen

Interactive data input and transfer through inter-body dynamic HBC is demonstrated by providing input through a touchscreen on a person's body and transmitting the command during a handshake to control the display on the wearable of the other person. Figure 10 shows the setup where touching the "Toggle" button in one display toggles the circle color from red to yellow and vice versa on the other display. A series of pulse generated by the transmitter during the touch event is transmitted through the human body and toggles the display at the receiver end.

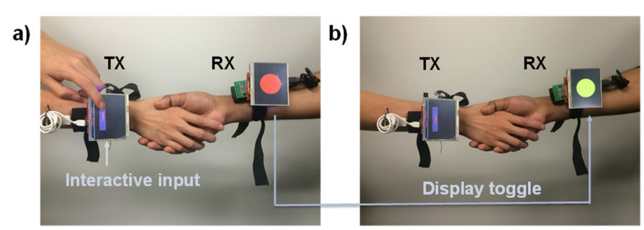

Figure 10: Interactive input and display toggle through HBC a) One person provides toggle input through his/her own touchscreen b) The display worn by the other person toggles according to this command

B. Reliability, BER of HBC based Human-Internet

The Bit Error Rate (BER) of a link is dependent on its SINR. The primary sources of noise in our current implementation of HBC system are the ADC input referred noise and any environmental noise picked up by the human body. In the laboratory environment, two primary sources of noise were at 60Hz and around 55KHz. The 60Hz noise was rejected using the filter at the biasing circuit. The 55KHz noise had a peak to peak amplitude of ~4mV. The input referred offset of the ADC is around 2.88mV. The received signal has an amplitude of ~30mV. Since the signal at the input of the ADC is an integrated version of the noise, the SINR is dependent on the sampling instant and the worst-case SINR will be when the integrated interference and noise is maximum. Since the primary source of noise is a narrowband interference around 55KHz the worst-case noise is calculated assuming a sinusoidal wave. Hence, the worst-case SINR in this case is around 26dB, which results in BER of around 3.2e-6 for a NRZ signal (Figure 11a).

C. Energy Efficiency of HBC based Human-Internet

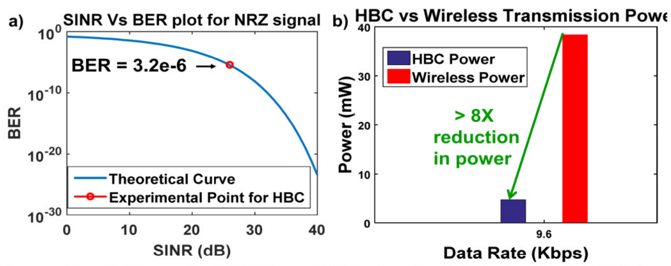

Figure 11: a) Theoretical BER vs SINR plot for NRZ signal, At 130kbps transfer rate has a SINR of 26dB and a corresponding BER of 3.2e-6. b) Power consumption of HBC based Human-Internet showing almost 8X lesser power consumption compared to wireless transmission.

The power consumption of the current HBC based implementation of the Human-Internet device is measured as an indicator of its energy efficiency compared to a wireless system. A HC-06 Bluetooth module, which can transmit data at 9.6kbps, is used for comparison. For data transfer at the same rate the HBC system has > 8X less communication power (Figure 11b) compared to the Bluetooth based system. For fair comparison purposes, the integrator power (separate OpAmp IC, old technology and hence large power) is not included as a similar low-frequency integrator can be implemented in ASIC with fraction of the system power budget (e.g. ~10uW in 65nm). Although both the HBC and Bluetooth implementations are sub-optimal, this shows the potential power benefit of HBC utilizing the relatively low loss human body channel. An ASIC implementation of HBC however can potentially give up to 25-100X energy efficiency/bit compared to a wireless system.

D. Transient Signal Characteristics during a Handshake event (Dynamic HBC)

Finally, Figure 12 shows the transient signal at the receiver end observed through an oscilloscope during a handshake event. Initially with no contact, there is no signal at the receiver end, as the contact is made the received signal amplitude increases and decays as the contact goes away. Dynamic HBC information exchange happens during the physical contact.

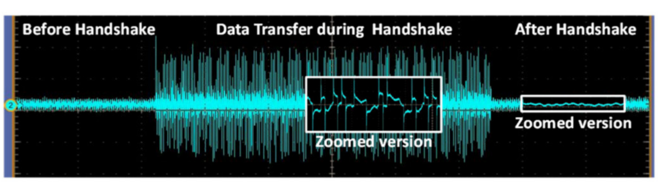

Figure 12: Transient signal characteristics during a handshake event along with the zoomed in view of signal during and after the handshake

VII. Discussion

The primary focus of this paper is to build the physical layer of a HBC based Human-Internet and provide a hardware implementation of the same. However, signal transmission between two intranets in the Human-Internet can affect the transmissions within the intranets, which requires developing the Medium Access Control (MAC) layer for the Human-Internet. A possible solution is to start transmission in a Human-Internet (1) only on the press of a touch button or (2) by using a sensor to detect such dynamic HBC. The automatic detection of a handshake event is part of future research.

VIII. Conclusion

The rapid growth of wearable devices and on-body sensors has made it possible to have a complex network of connected devices around the human body called the Human-Intranet. The concept of Human-Intranets communicating with each other to form (1) Human-Internet through (2) Dynamic HBC is proposed. Given the security and energy-efficiency benefits of HBC over WBAN for connecting the Human-Internet, dynamic HBC channel characteristics were measured and a HBC based Human-Internet device has been developed. For the first time, inter-body dynamic HBC has been demonstrated at data rates up to 130Kbps, with > 8X better energy-efficiency compared to WBAN, opening the possibility of significant future research in the domain of Human-Internet.

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