INTRA-BODY HYBRID COMMUNICATION SCHEME FOR HEALTHCARE SYSTEMS

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ABSTRACT

Intra-body communication (IBC) is a type of Body Area Network (BAN) that utilizes human body as the medium for data transmission. The low power requirements of intra-body communication (IBC) as compared to near field electromagnetic waves showed that it can be a suitable solution for Medical Body Area Networks (MBANs) in a mobile health care system. In this paper, we investigate the transmission characteristics of the human body as a conductor of signals by considering different data transmission rates of multi-point to point network in order to reduce overall power consumption of the BAN. Furthermore, we utilize IBC and propose a new scheme to combine Slotted ALOHA, TDMA, and Reservation ALOHA together to increase the throughput and decrease the delay. By using our new hybrid scheme with the movable boundary designed for health status monitoring, we are able to increase the efficiency of data transmission by prioritizing the more critical data from the sensors.

KEYWORDS

Body area network, Intra-body communications, Hybrid communication scheme,

1. Introduction

The main problem in the design of a mobile health care system is the unit's power supply trying to accommodate the rapidly increasing performance of processors, memory and other components [1]. The lower power requirements of intra-body communication (IBC) as compared to near field electromagnetic waves, implies that it can be a suitable solution for Medical Body Area Networks (MBANs) in a mobile health care system [1].

Intra-body communication (IBC) in which the human body is used as a medium for signal transmission guide has attracted much attention in the study of Body Area Networks (BANs), because signals pass through the human body, electromagnetic noise and interference have little influence on transmissions [1] [2] [3].

There are two solutions for IBC: electric field type [4]-[5] and electromagnetic type [6]-[7]. Our proposed IBC is based on electromagnetic type.

IBC characteristics are superior to those of other radiobased network technologies, such as Bluetooth and IrDA. However, a completely detailed analysis of the model of signal transmission in IBC has not been conducted. Moreover, the optimum frequency of transmissions for consuming the least amount of energy has not yet been determined [1].

In our previous works [1] we investigated the transmission characteristics of the human body on BAN point-to-point intra-body communication between ECG sensor (transmitter) and a central hub (receiver) worn on the wrist. In this paper, we investigate the transmission characteristics of the IBC up to 2.4 GHz by considering different transmitter power consumption and data transmission rates of multi-point to point IBC to find the optimal transmission frequency. Based on optimal frequency we propose hybrid communication scheme with the movable boundary which combines Slotted Aloha, Reservation Aloha, and TDMA. Our proposed system categorizes the data into random access data (higher priority data) and periodic data (lower priority data) which will increase the throughput and decrease the delay of transmission in our system.

The rest of the paper is organized as follows. In the next section we present the system architecture. The third section describes the IBC experiment setup while the results are presented in the fourth section. Section five explains the hybrid communication scheme with movable boundaries. The sixth section presents the simulation results and discussion. Finally the seventh section concludes the paper.

2. Proposed System Architecture

Figure 1 overview of distribution and types of sensors within intra-body communication network

The healthcare system as shown in Fig. 1, is composed of a set of different sensors connected to health network, that transmits all the patient data to the healthcare centre server or to hospital server in a secure way.

The system provides assistance to chronically ill patients with mobile services that enhance their quality of life, and support and optimize their treatment in case of emergency.

The components of the IBC system are:

- 1) Sensor: a device that receives and responds to a signal or stimulus. the sensor specifications are given in Table I.
- 2) Central hub: A hub for all the sensors in the mobile healthcare system. It records all the data from all the sensors and send it in real-time or offline to the base station.
- 3) USB Receiver Unit: connected to external device to receive the data from the central hub and forward it to the healthcare centre.

Table 1 Information and No. of Sensors [8],[9]

Type of Bio-signal	No. of Sensors	Information Rate [kbps] per sensor
ECG	5	15
Heart Sound	2	120
Heart Rate	1	0.6
EMG	2	600
Respiratory Rate	1	0.8
Blood Pressure	1	1.44
Body Temperature	1	0.08
Pulse Oximetry (SpO2)	1	7.2
EEG	20	4.2

3. Experiment Setup

To find suitable carrier frequency for our IBC mobile health care system, we investigate the transmission characteristics of signal up to 2.4 GHz by considering different transmitting power consumption and data transmission rates. Furthermore, as QPSK and BPSK modulation schemes are widely used in mobile communication [2] [10][11], they were analyzed in the experiments. Several transmission rates were considered to study the maximum data rate achievable through QPSK and BPSK schemes at different transmitting power levels. We evaluate the performance of two different modulation schemes: QPSK and BPSK in terms of the error vector magnitude [EVM]. EVM is an important metric for testing the modulation accuracy. It quantifies the difference between the ideal (reference) and the measured signals which is measured at the RX by the wireless communication analyzer in percent root mean square (%RMS) units. The threshold for EVM is set to 17.5% for QPSK [12] and 20% for BPSK [13]. We also investigate the Variation of the sensors location (wrist, head, waist) and its effect on the performance of IBC.

Fig. 2 shows the measurement system scenario where the digitally modulated radio signals were generated in the signal generator, input in the body through the transmitter (Tx), then received and demodulated in the receivers (Rx1, Rx2, Rx3). The distance between Tx and Rx1 was 57cm, Rx2 = 45 cm, Rx3 = 32 cm.

Figure 2 experiment measurement setup

Table 2 shows the main measurement setup parameters. The input signal power was selected based on the study about the possible health effects of exposure to electromagnetic fields carried out in [14], [15]. This study recommended a basic limit exposure of 0.08 W/kg for the human body. Considering an average weight of 65 kg, the maximum transmit signal power could be 37 dBm. We used input power levels of 10 dBm, 0 dBm, -10 dBm, -20 dBm, and -30 dBm.

Table 2 experiment parameters

Parameter	Value
Modulation scheme	QPSK, BPSK
Carrier Frequency [MHz]	30~2400
Symbol rate [Ksps]	4000, 2000, 1000, 750, 500, 250
Transmit Power [dBm]	0, -10, -20, -30
Distance Tx and Rx [cm]	45, 57, 32

4. Results and Discussion

Experiments results show that when we decrease transmission power, the optimal carrier frequency shifts to the low range. The results of higher symbol rates for BPSK and QPSK optimal carrier frequency under a -30 dBm power transmission are shown below.

The results have shown that both QPSK and BPSK could be used for IBC with high data rate. When we decrease transmission power, the optimal carrier frequency shifts to the low range of 75 MHz to 150 MHz. QPSK and BPSK provide good performance of high symbol rates up to 4 Msps in case of transmission power of -30 dBm in this range between central hub (transmitter) and the sensors at (wrists, head, waist) shown in Tables [3][4][5][6].

Table 3 experiment results of maximum achievable data rate in case of 150 MHz BPSK

	Data Rate	EVM
Rx1 (hand)	750 Ksps	19.6
Rx2 (waist)	1 Msps	15.1
Rx3 (head)	4 Msps	19.5

Table 4 experiment results of maximum achievable data rate in case of 150 MHz QPSK

	Data Rate	EVM
Rx1 (hand)	1Msps	12.2
Rx2 (waist)	1 Msps	10.0
Rx3 (head)	4 Msps	15.7

Table 5 experiment results of maximum achievable data rate in case of 75 MHz BPSK

	Data Rate	EVM
Rx1 (hand)	4Msps	17.6
Rx2 (waist)	2 Msps	20.0
Rx3 (head)	2 Msps	19.5

Table 6 experiment results of maximum achievable data rate in case of 75 MHz QPSK

	Data Rate	EVM
Rx1 (hand)	4 Msps	17.5
Rx2 (waist)	4 Msps	16.0
Rx3 (head)	4 Msps	15.5

5. Hybrid Communication Scheme with Movable Boundary

In our proposed scheme, the critical data are treated as random access data with higher priority of transmission. On the other hand, the less critical data are treated as the periodically transmitted data, which has lower priority. Through categorizing the data into random access data and periodic data, we are able to increase the throughput and decrease the delay of transmission in BAN.

Hybrid scheme with the movable boundary is a communication scheme that combines Slotted Aloha, Reservation Aloha, and TDMA.

We divide the time line into the frames. Each frame consists of three parts:

- 1- random access assignment time slots (RAT).
- 2- demand assignment time slots (DAT).
- 3- periodic data assignment time slots (PAT).

In addition to the different types of time slots within a frame, we also categorize the data into two types:

- 1- Periodic data (PD).
- 2- Random access data (RAD), which can be further broken down into two parts:
 - a- random access packet (RAP)
 - b- demand assignment packet (DAP).

Random access data accesses RAT arbitrarily in the same manner as the Slotted Aloha does. As the RAP is successfully transmitted to RAT, the DAP will be transmitted to the designated DAT instantaneously. On the other hand, if the RAP is sent to the non-RAT time slots, the DAP will not be transmitted, and the RAP will be re-transmitted randomly to one of the time slots in the next RAT. Since the RADs are transmitted randomly, the data collisions might occur undoubtedly. When the collision occurs, the DAP will not be sent, and the RAP will be re-transmitted. The demand assignment packets never encounter collisions since there are reserved time slots for all DAPs. However, there are cases in which the DAT in the current frame is not sufficient to accommodate any more DAP. In this case, the DAPs are to be assigned to the next DAT in the next frame.

Different from the transmission methodology of RAT, periodic data accesses PAT periodically in every frame. The number of the PAT is identical to the number of the stations that send the periodical data. Each PD has its own designated PAT so each transmission is a success.

The designed frame is changed dynamically with the data structure. There are times that the length of the data occupies only 1 time slot, and the data only contains the RAP, not the DAP. In this case, the frame will adjust its structure according to the data and the slots of DAT will be allocated to RAT since the data has contained no DAP. This is what we called the “movable boundary” in our hybrid scheme.

6. Simulation Results and Discussion

Based on the IBC experiment results we chose BPSK 150 MHz as frequency of intra body communication, and that frequency was used in the subsequent simulations. Running the simulations under different DAT we were able to demonstrate the capability of moving boundary of the proposed idea as well as finding the most appropriate DAT which achieves the highest throughput.

The bandwidth that we have assumed for our proposed model is 4 Mbps, which is sufficient to accommodate the traffic of the sensors. The parameters used during the simulation are shown in **Table 7 and 8** and the results are shown in **Figure 3-8**. We have assumed that the packet size is 10 kb. Frame bandwidth divided by the packet sizes gives us the slots per second. Under the assumption that the frame duration is 0.1 second, we are able to obtain the frame length with 40 slots. In our simulation, we have categorized the sensors into 3 groups and the simulations are run based on these 3 groups. Group 1 includes the sensors related to heart diseases. Group 2 mainly observes the skeletal muscles, and other vital signs can also be observed as the periodic transmitting signals in the meantime. For group 3, the EEG sensors are we have decided to use total of 38 sensors. The distribution of the sensors is described in the Table 7.

From the simulation result, we have learned that data length with 8 time slots has outperformed the data length with 4 time slots in all three groups. In addition, the results with the demand

assignment length of 23 (denoted as DA 23 on the figure below) outperform the rest of other demand assignment length in all three groups as well

Table 7 distribution of sensors

Type of Bio-signal	No. of Sensors	Information Rate [kbps] per sensor	Signal Type	Description
GROUP 1				
ECG	5	15	Random	Electrical activity of the heart
Heart Sound	2	120	Periodic	A record of heart sounds
Heart Rate	1	0.6	Periodic	Frequency of the cardiac cycle
GROUP 2				
EMG	2	600	Random	Electrical activity of the skeletal muscles
Respiratory Rate	1	0.8	Random	Breathing rate
Blood Pressure	1	1.44	Periodic	The force exerted by circulating blood on the walls of blood vessels, especially the arteries
Body Temperature	1	0.08	Periodic	Measurement of the body temperature
Pulse Oximetry (SpO ₂)	1	7.2	Periodic	The amount of oxygen that is being carried in a patient's blood.
GROUP 3				
EEG	20	4.2	Random	Measurement of electrical spontaneous brain activity and other brain potentials

.Table 8 Parameters for the Simulation for Each Group 3

Simulation Parameters	Group 1	Group 2	Group 3
Bandwidth	4 Mbps	4 Mbps	4 Mbps
Frame Duration	0.1 second	0.1 second	0.1 second
Packet Size	10 kb	10 kb	10 kb
Slots / Second	40 slots/sec	40 slots/sec	40 slots/sec
Frame length	40 slots	40 slots	40 slots
Data length (DL)	8/4 slots	8/4 slots	8/4 slots
Random Access Length (RAT)	10/12/14/17/22/27/32	10/12/14/17/22/27/32	10/12/14/17/22/27/32
Demand Assignment length (DAT)	27/25/23/20/15/10/5	27/25/23/20/15/10/5	27/25/23/20/15/10/5
Periodic Assignment Length (PAT)	3	3	0
Random Access Packet (RAP)	1	1	1

Demand Assignment Packet (DAP)	DL - RAP	DL - RAP	DL - RAP
Periodic Assignment Packet (PAP)	1	1	1
Timeslot	100000	100000	100000
Sensors	8 (5 Random Access, 3 Periodic)	6 (3 Random Access, 3 Periodic)	20 (Random Access)
Retransmission Probability	0.01	0.01	0.01

Figure 3 throughput vs delay BPSK-150MHz-750ksps group1 data length 8

Figure 4 throughput vs delay BPSK-150MHz-750ksps group1 data length 4

Figure 5 throughput vs delay BPSK-150MHz-750ksps group2 data length 8

Figure 6 Throughput vs delay BPSK-150MHz-750kps group2 data length 4

Figure 7 throughput vs delay BPSK-150MHz-750kps group3 data length 8

Figure 8 throughput vs delay BPSK-150MHz-750ksps group3 data length 4

7. Conclusion

QPSK and BPSK could be used for IBC with high data rate. However, when we decrease transmission power, the optimal carrier frequency shifts to the lower range of 75 MHz to 150 MHz. QPSK and BPSK provide good performance of high symbol rates up to 4 Msps in case of transmission power of -30dBm in this range between central hub (transmitter) and the sensors at (wrists, head, waist).

The Intra-body hybrid communication scheme with movable boundary is a promising scheme to apply on the body area network for the medical application. It provides higher throughput and less delay comparing with other communication schemes such as TDMA and Slotted Aloha. Regardless of the different types of sensors, which include those that transmit data randomly and periodically, the intra-body hybrid communication scheme is capable of adjusting the slots allocation to maximize the throughput and minimize the delay. Our simulation was run under three different scenarios and it had further demonstrated that feasibility and efficiency of our proposed hybrid scheme.

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