Waseda University

Doctoral Dissertation

A Study on Health Care System Employing Intra-Body Communication

人体通信を用いたヘルスケアシステムに関する研究

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Summary

The technology era that spread in the past years drastically evolved traditional structures and systems. A unique feature of the technology and telecommunication industry is the relatively cheap prices of hardware and software involved in these systems. This induced researchers to utilize technology and telecommunication driven tools in overcoming traditional challenges and limitation of the Health Care industry.

One of the major problems in the design of an efficient mobile Health Care system is the unit's power supply.

The low power requirements of intra-body communication (IBC) as compared to near field electromagnetic waves, makes it a better choice for its application in Medical Body Area Networks (MBANs) for mobile Health Care system. Intra-body communication in which the human body is used as a signal transmission guide has attracted much attention in the study of Body Area Networks (BANs), one of the reasons is because electromagnetic noise and interference have little influence on signal transmission when signals pass through the human body. These characteristics are superior to those of other radio-based network technologies, such as Bluetooth and IrDA etc. However, a complete detailed analysis of the model for signal transmission in IBC has not been conducted so far by the research community. Moreover, the optimum frequency of transmission for consuming the least amount of energy has not yet been determined and studied exhaustibly. In this dissertation, we investigated the transmission characteristics of radio waves in the human body as a conductor of signal up to 2.4 GHz with considering different transmitter power consumption and data transmission rates in

different locations of human body. The evaluation of different data rates for a range of carrier frequencies has been done with error vector magnitude (EVM) as a measurement parameter.

In the chapter 1, the outline of challenges of wireless telecommunication in Health Care system is introduced. Firstly, the general perspective of global Health Care and its current situations and challenges are described. Then, the Health Care solutions in wireless telecommunication are presented.

In the chapter 2, the basic knowledge of wireless Body Area Network, technology and applications are explained. It includes wireless body area network, intra body communication's introduction and the expatiation of intra body communication method. The survey and some proposes of indoor applications, outdoor applications and some potential applications are explained.

In chapter 3, the concept of point to point intra body communication for personal Health Care monitoring system is introduced. The system architecture comprising of a set of sensors, the base station, receiver and the communication network is proposed. Investigation on the transmission characteristics for the human body on BAN point-to-point intra-body communication between ECG sensor (transmitter) and a central hub (receiver) worn on the wrist. An experiment was conducted by considering two different kinds of modulation techniques viz. QPSK and BPSK. EVM was measured by varying the carrier frequency at different data rates. These modulation schemes for IBC in terms of EVM are evaluated and the variation of EVM with carrier frequency at different data rates is plotted. Experimental results have shown that both QPSK and BPSK could be used for IBC at high data rate using low transmission power with minimum range of -30dBm and it also show that when transmission power decreases, the optimal carrier frequency shifts to the lower range of 75 MHz to 150 MHz and QPSK and BPSK provide good performance of high symbol rates up to 4 Msps in the case of transmission power of -30dBm in this range.

In chapter4, the concept of point to multi-point intra body hybrid communication for personal Health Care monitoring system is introduced. A system architecture comprising of a set of sensors, a base station, receiver and a communication network is proposed. Firstly, the transmission characteristics of the human body on BAN point-to-multi-point intra-body communication between central hub (transmitter) on the chest and sensors (receiver) worn on the wrists, head, waist are investigated. An experiment was conducted by considering two different kinds of modulation techniques viz. QPSK and BPSK, and EVM was measured by varying the carrier frequency at different data rates. Although 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).Secondly, Based on the proposed IBC optimal frequency, the Intra- body hybrid communication scheme with movable boundary as 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. The simulation was run under three different scenarios and it had further demonstrated that flexibility and efficiency of the proposed hybrid scheme.

In chapter 5, I conclude the dissertation and state the future works.

Chapter 1 Introduction

1.1 Introduction

Human's Health Care is one of the most crucial topics that are attracting unanimous attention worldwide. Having improved Health Care available to all in need is an objective that all nations strive for. Unfortunately, this humane objective is rarely achieved and the existing systems fall short of accommodating many sufferers who are incapable of paying the fees for the increasingly expensive Health Care services. A major cost of medical care is from checkups and monitoring of patients. A consequence of lack of monitoring is that health condition can have increasing severity if not diagnosed in the right time. Furthermore, more significant cost is burdened by families of elderly as conditions become more severe and frequent.

The caretaking of ageing populations in many nations with inversed demographic pyramid create a significant burden on nation's economy. This is due to the sharp increase in life expectancy worldwide and especially in OECD countries. For example in Japan there was a jump of 14 years in average age in the past 40 years. [1]Medical expenditure is age dependent. Health Research and Education Trust published a paper outlining the skewed distribution of medical costs toward age. According to the paper titled "The Lifetime Distribution of Health Care Costs" by Berhanu Alemayehu and Kenneth E Warner [2] the medication costs increase exponentially after the age of 50 years old. 82% of medical costs are spending in years after 40 years old and 59% are spent after 65 years old. Repetitive visits to hospitals and clinics and nursing homes also increase by age

There are several factors that contribute to the high price of medical treatment. In general there is a general deficiency in the number of doctors per capital (the rate of doctors per 1000 capita is 2.9 [1]) Moreover medical equipment industry is expensive due to the sensitivity of the equipment on health of patients. In addition lack of modularization among equipment manufacturers has led to lack of interoperability between parts which lead to higher maintenance costs. Checkups and monitoring of recovering patients requires longer stays at hospitals which charge substantial costs per bed per night.

These factors lead regulators, academics and industry pioneers and other decision makers to seek inexpensive Health Care solutions to improve the social welfare of the people. The technology era that spread in the past years drastically evolved traditional structures and systems. A unique feature of the technology and telecommunication industry is the relatively cheap prices of hardware and software involved in these systems. This induced researchers to utilize technology and telecommunication driven tools in overcoming traditional challenges and limitation of the Health Care industry.

The advancement of research in sensors technology lead to innovative small devices capable of detecting fluctuation in health related properties such as “temperature”, “pressure”, “sugar level” etc.. On the other hand, a system composed of sensors and signal transmitters and receivers situated on the patient’s body for the aim of diagnosing and monitoring health condition is known as Body Area Network (BAN).

BAN is a configuration of low price equipment that can be incorporated together to form a medical monitoring device. With BAN, patients will require less regular check-ups freeing up valuable doctors time for other patients in need. In addition, patients will require less hospital stays as monitoring can be done continuously remotely without the need of physical presence which will also reduce the demand for hospitals which leads to lower prices. As other medical related devices, premium quality is required for BAN systems. Limited standardization was therefore already been introduced in Europe and USA .Finally, the continuous information collected by the system are valuable information that can be used to know more about the disease and healing process and thus in the long term improve health.

Standardization is required to assure quality and system interoperability for better integration within the system or with other medical or telecommunication equipment. Chip design, transmission frequencies, antenna, power management and communication protocols should seamlessly work together in order to achieve required functionality.

Since BAN is in its early stage of development limited standardization has been put forward either by regulators or in industry. Researchers however argue that benchmark of automatic sensing should be “self management, self configuration, self optimization, self healing, self protection, self adaptation, self integration, and self scaling” [3].

Wireless telecommunication body area network is considered a viable safe means for establishing Health Care network that is both inexpensive and efficient. However such transmission mode is susceptible to electromagnetic noise. The main focuses of researchers was to create a system which (1) has power saving nodes and antennas (2) includes protocols which can best support the communication (3) has optimal frequencies for operations (4) has optimal allocation of nodes within the system. Since BAN efficiency of the overall system can rarely be contributed to individual device regardless to the overall distribution and transmission of signals, most researchers work on over all systems of BAN.

In the framework of designing ideal candidate for body area network, several issues remain of crucial importance. For example, the research is still undergoing re related to detecting optimal frequencies for transmission between body sensors, another area of research is related to Wireless BAN offer significant advantages over wired networks in terms of flexibility and applicability of sensors.

1.2 Challenges of Wireless Telecommunication in Health Care System

Despite the explicit role of wireless telecommunication in Health Care system, it suffers from many challenges as well. To utilize such technologies in Health Care system, such challenges need to be addressed for the system to work efficiently. Some of the challenges are listed below.

(i) The supporting staff at the patient end must be trained appropriately so that the patient data is collected and transmitted accurately.

(ii) The signal noise while transmission of signals from patient to the medical practitioner must be considered and taken care accordingly.

(iii) The high power consumption by various electronic interfacing units in transmission must be addressed.

One of the methods of wireless BAN is to use the body as transmission medium for transferring signals; this method is called Intra Body Communication (IBC). Such a system promises transmissions between sensors that are both safe and accurate and therefore could be utilized in establishing a communication network for monitoring and transmitting crucial data to a health center such as a hospital or a clinic over established external network. Another advantage for IBC is that it requires less power requirement since the transmitted signal is not broadcasted on air, but limited to the monitored body. Moreover such a system conveys less concerns regarding privacy issues that wireless network is susceptible to. This research is an attempt in recognizing a body area network called Intra Body Communication that uses the human body as a transmission medium.

Intra Body Communication network offer superior characteristics compared to wireless body area network in terms of power consumption and electromagnetic noise problems.

However, a detailed analysis of the model of signal transmission in IBC has not been conducted. Furthermore, the optimum frequency of transmissions for consuming the least amount of energy has not yet been determined. The aim of this research falls within developing a Personal Health Monitoring System using inexpensive, lightweight miniature sensors platforms. In particular, this research will investigate the transmission characteristics of the human as conductor of signal between sensors attached to the body.

1.3 Organization of the thesis

This remainder of this dissertation is organized as follows:

In the chapter 1, the outline of challenges of wireless telecommunication in Health Care system is introduced. Firstly, the general perspective of global Health Care and its current situations and challenges are described. Then, the Health Care solutions in wireless telecommunication are presented.

In the chapter 2, the basic knowledge of wireless Body Area Network, technology and applications are explained. It includes wireless body area network, intra body communication's introduction and the expatiation of intra body communication method. The survey and some proposes of indoor applications, outdoor applications and some potential applications are explained. In chapter 3, the concept of point to point intra body communication for personal Health Care monitoring system is introduced. The system architecture comprising of a set of sensors, the base station, receiver and the communication network is proposed. Investigation on the transmission characteristics for the human body on BAN point-to-point intra-body communication between ECG sensor (transmitter) and a central hub (receiver) worn on the wrist. An experiment was conducted by considering two different kinds of modulation techniques viz. QPSK and BPSK. EVM was measured by varying the carrier frequency at different data rates. These modulation schemes for IBC in terms of EVM are evaluated and the variation of EVM with carrier frequency at different data rates is plotted. Experimental results have shown that both QPSK and BPSK could be used for IBC at high data rate using low transmission power with minimum range of -30 dBm and it also show that when transmission power decreases, the optimal carrier frequency shifts to the lower range of 75 MHz to 150 MHz and QPSK and BPSK provide good performance of high symbol rates up to 4 Msps in the case of transmission power of -30dBm in this range.

In chapter4, the concept of point to multi-point intra body hybrid communication for personal Health Care monitoring system is introduced. A system architecture comprising of a set of sensors, a base station, receiver and a communication network is proposed. Dissertation

Firstly, the transmission characteristics of the human body on BAN point-to-multi-point intra-body communication between central hub (transmitter) on the chest and sensors (receiver) worn on the wrists, head, waist are investigated. An experiment was conducted by considering two different kinds of modulation techniques viz. QPSK and BPSK, and EVM was measured by varying the carrier frequency at different data rates.

Although 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).Secondly, Based on the proposed IBC optimal frequency, the Intra- body hybrid communication scheme with movable boundary as 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. The simulation was run under three different scenarios and it had further demonstrated that flexibility and efficiency of the proposed hybrid scheme.

In chapter 5, I conclude the dissertation and state the future works.

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Chapter 2 Body Area Network and Intra-body Communication

2.1 Introduction

Physiological sensors have grown rapidly, low power integrated circuits and wireless communication has enabled a new generation of wireless sensor networks which are used to monitor traffic, crops, infrastructure and health. The body area network (BAN) field is an interdisciplinary area which could allow inexpensive and continuous health monitoring with real-time updates of medical records via Internet. A number of intelligent physiological sensors can be integrated into a wearable wireless body area network, implanting very small bio-sensors inside the human body that are comfortable and cause no impairs. The implanted sensors in the human body will collect various physiological changes in order to monitor the patient's health status no matter their location. The information will be transmitted wirelessly to an external processing unit, and then transmitted in real time to the doctors throughout the world. In case of an emergency, the physicians will immediately inform the patient by sending appropriate messages or alarms. Currently the level of information provided and energy resources capable of powering the sensors are limiting. While the technology is still in its primitive stage it is being widely researched and once adopted, is expected to be a breakthrough invention in Health Care, leading to concepts like telemedicine and m-Health becoming real. [1]

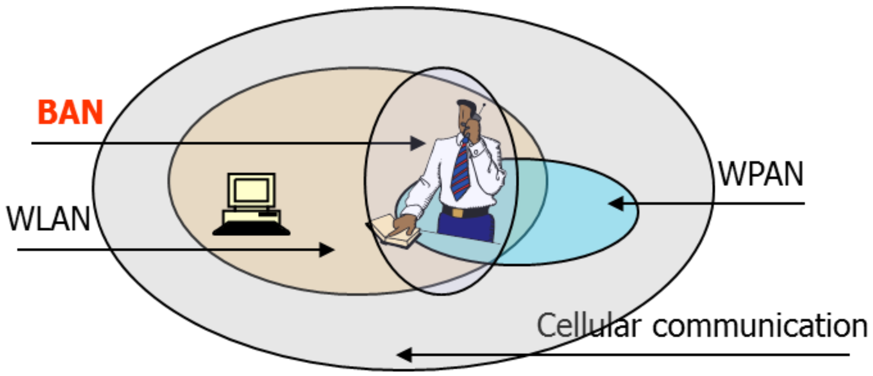

Fig 2.1 Body Area Network (BAN)

Professor Guang-Zhong Yang was the first person to formally define the phrase "Body Sensor Network" (BSN) [2] with publication of his book Body Sensor Networks in 2006. BSN technology represents the lower bound of power and bandwidth from the BAN use case scenarios. However, BAN technology is quite flexible and there are many potential uses for BAN technology in addition to BSNs. Twist makes the possibility of BAN sound more like science fiction than a real possibility, but several experts in the field expect to see BAN in production for general use by 2010 [3].

2.2 BAN Applications

BAN applications can be categorized into 3 different categories: 1- Health Care services 2- Assistance for people with disabilities 3- Body Interaction and entertainment.

Fig 2.2 BAN application categorization

In Health Care services, a BAN device is a transmitter communicating with a life sign sensor or a set of sensors (such as Blood pressure sensor, pH value sensor and such) and most of them can be detected using simple sensors. [4]

2.3 BAN Technologies

There are two types of BAN devices depending on the location where it operates; Wearable BAN and Implant BAN. The difference between these two types are; requirements on frequencies, power and consideration of tissue protection.

Some of the available frequency bands are:

- Medical Implant Communications System (MICS) bands: 402-405 MHz, USA, Europe, Japan, Australia, Korea, etc. 10 channels of 300 kHz, adaptive frequency agility and 25 μW EIRP.
- Med Radio: FCC proposed band 401-402 MHz and 405-406 MHz. In Europe, there is regulation to use these bands for medical applications (EN 302 537).
- Wireless Medical Telemetry Service (WMTS) Bands: Three bands are allocated by FCC. I.e., 608-614 MHz (TV channel 37), 1395-1400 MHz, and 1427-1432 MHz. Two bands, 420-429 MHz and 440-449 MHz, are allocated in Japan. There are also available frequency bands in Australia and Europe. However they are defined for short range devices (SRD).
- Industrial, Scientific & Medical (ISM) Bands: 868/915 MHz, 2.4 GHz, 5.8 GHz.
- UWB Bands: UWB low band (3.1-4.9 GHz) and high band (6.0-10.6 GHz).
- Other frequency bands such as ISM and Short Range Device Telemetry and Telecomm and. Inductive Link band and capacitive carrier-less baseband transmission are considered as well.

It should be noted that MICS frequency bands are selected from 401-406 MHz in most countries, which is narrow and limits high data rate applications. ISM band at 2.4 is available worldwide, but there are many wireless systems operating at that band (IEEE 802.11b, Bluetooth and Zigbee) (Table 2.1) [4]

Table 2.1 Wireless Communication Technologies and BAN [5]

Technology	Frequency	Data Rate	Transmission Power
WLAN	2.4/5.1 GHz	54 Mbit/s	100 mW
Bluetooth	2.4 GHz	723.1 kbit/s	10 mW
ZigBee	868 MHz	20 kbit/s	1 mW
Active RFID	134 kHz	128 bit/s	< 1 mW

2.4 Previous Research on BAN

Several research groups have developed projects aimed at designing such networks. For example the European commission “Wealthy” and MyHeart projects design cloths with embedded sensors. The MIThril project from Massachusetts institute of technology media lab has been developed body worn sensor network [2], furthermore, Code Blue project in Harvard University developed a medical sensor network which uses pulse oximeter, electrocardiography (ECG) and motion activity sensor motes. The advancement of research in the network was associated with advancement in development of advanced sensors. The European commission “healthy aims” project develop a series of sensors for specific applications such as “cochlear implants for hearing aids”, “retinal implants for vision aid”, ”implantable pressure sensors” and “glaucoma sensors” [2].

2.5 Intra-body communication (IBC)

Intra-body communication (IBC), a short-range communication solution between devices in which the human body is used as the signal transmission medium, is one of proposed technologies to achieve the goal of Body Area Networks (BAN). We believe that IBC will allow not only the interaction between devices that move with the user body but also between users and the surrounding environment. We believe that IBC could be employed e.g. in places such as train coaches and hospitals where the use of mobile phones is restricted or even not allowed. For example, E-payment could be another application suitable for handicapped people whereupon e.g. instead of purchasing a train ticket in the vending machines, they could access the ticket gate by just walking through gate and the person's credit card information stored in an IBC enabled device located e.g. in the wrist could be transmitted to an IBC enabled detector installed in the ground of the gate.

There are two solutions for IBC: electric field type and electromagnetic type. By means of the former solution, data could be sent across devices placed on or near the body by using a near field electric field. On the other hand, in the latter IBC solution, the human body is treated as a waveguide with high frequency electromagnetic signals generated at a terminal propagating THROUGH THE BODY [6].

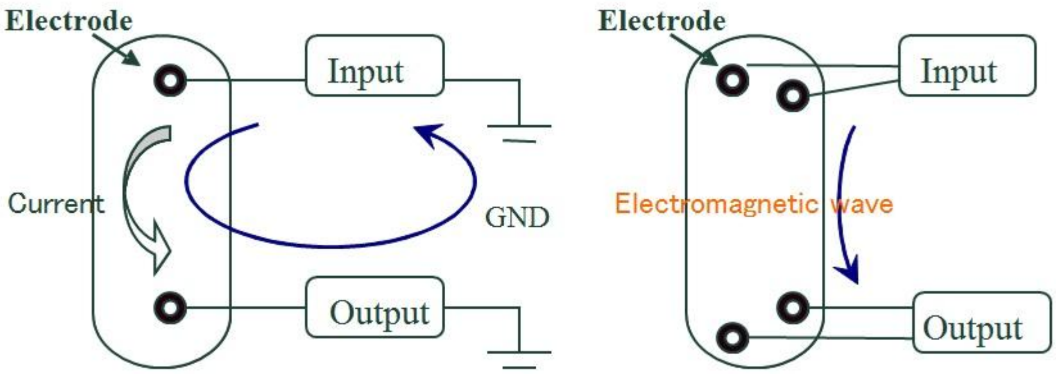

Fig 2.3 Intra-Body Communications

IBC has many advantages over traditional RF approaches. Because the communication mechanism is based on near-field coupling, transmission is not interfered by electromagnetic waves in free space and signal cannot be intercepted easily, while the signal is confined to the human body. Because the body channel has lower attenuation than the air channel, the power consumption is lower than other wireless technologies, such a Bluetooth and Zigbee. Intra-body communication has a wide application prospect in personal Health Care, assistant system for the disabled, and body area networks (BAN) system. IBC realizes a short-range “wireless” communication method with less electromagnetic interference and less susceptible to external interference in comparison with existing electromagnetic wave based communication technique. IBC promises to improve the Health Care systems. It is also expected that IBC can eventually help to reduce the size of the sensors on human body, less power consumption, as well as improve stability of overall Health Care system.

2.6 Previous research on IBC

Several groups around the world are involved and researched about the development of IBC devices. There are varieties of developed IBC systems where some are more oriented to medical application, and some are more oriented to non-medical purposes. Those developed systems mainly differ by the electromagnetic wave and the electrical field, the chosen frequency range, the signal modulation method, and the achieved data rates [20].

The original concept of Personal Area Networks (PANs) was presented in 1995 to demonstrate how electronic devices on or near the human body can exchange digital information through near-field electrostatic coupling [7]. However, the first successful PAN prototype used a capacitive signal coupling, a signal with amplitude of 30V, 330 KHz carrier frequency, and on-off keying (OOK) modulation. It has achieved the data rate of 2400bps and a power consumption of 1.5mW [8]. Although the developed devices are in various sizes and shapes, Zimmerman suggested it should be the items that are used in daily life such like watches, credit cards, eyeglasses, identification badges, belts or shoe pads.

Gray (MIT) explores the physical limits of intra-body communication [9]. The analysis of transmission channel showed that the amplifier noise and crosstalk with other IBC devices on the body have influence on the received signal and the final version of the hardware [10] was based on frequency shift keying (FSK) modulation which achieves a data rate of 9600bps. Hanada et al. (Japan) [11] has developed a wireless system with very small consumption designed for monitoring the ECG signal and alternate the signal with amplitude of 20uA was galvanically transmitted between the ECG detector and a receiver. It used the pulse width modulation (PWN) with a carrier frequency of 70 KHz and total power consumption of the system was around 8 uW. M. Fukumoto et al., NTT Human Interface Laboratories, developed a wireless wearable system for the finger-tip typing detection, Finge Ring [12]. The communication system of FingeRing is based on a variant of capacitive IBC, uses an analog frequency modulation with carrier frequencies between 50 kHz and 90 kHz and a consumption of 1.75 mW. Derek P. Lindsey et al. [13] was the reduction of volume of implantable de-vices or in vivo biometric measurements, and have developed a method that uses ionic properties of the human body for the signal transmission. The best results obtained by this application were using a current with amplitude of 3mA and frequency modulated (FM) signal with carrier frequency of 37 kHz.

K. Partridge et al. from the University of Washington have developed and described a system [14], based on the Zimmerman PAN prototype, with which they had achieved a data rate of up to 38.4 kbps. K. Partridge et al. used carrier frequencies of 180 kHz and 140 kHz with FSK modulation and a signal with amplitude of 22V and compared the data error rates and the received signal strengths for different distances between the body and the electrodes, positions of electrodes on the body.

K. Fuji and K. Ito (Japan) investigated transmission characteristics of the human body in the IBC system [15] and described the FDTD (finite-difference time-domain) simulation of electric field distribution around the numerical model of the human arm approximated by parallelepiped with following characteristics: dimensions 5 cm x 5 cm x 45 cm, relative permittivity er = 81 and conductivity o=0.62 s/m (dielectric parameters of the muscle). IBC transmitter that generates a signal amplitude of 3 V and a frequency of 10 MH was used a source of an electric field. K. Fuji and K. Ito compared the results obtained in simulations with the results measured using the biological tissue-equivalent solid phantom arm and found that the signal was spread as a surface electromagnetic wave along the surface of the skin. Simulation results were confirmed on realistic models of Japanese adults (male and female) [16, 17] and presented the spatial distribution of electric field [17] around the numerical model of the arm on which the IBC system was placed.

K. Hachisuka et al. used capacitive method of signal transmission, which called the electromagnetic wave, for intra-body communication. K. Hachisuka et al. showed that in the frequency range from 0.5 MHz to 50 MHz, frequencies around 10 MHz are optimal for the carrier frequency of IBC system with minimal power consumption [18, 19]. The carrier frequency they have chosen for their system was 10.7 MHz, due to the large number of (cheap) components on the market that support it. The signal amplitude of 3V and frequency of 10.7 MHz was successfully detected and demodulated at the receiver, for bothe the frequency (FM) [19] and the digital FSK modulation [18] and the data rate achieved using the FSK modulation was 9.6 kbps.

Japanese phone company NTT (Nippon Telegraph and Telephone Corporation) and its subsidiary NTT Do Como Inc. are among the first to use intra-body communication technology to successfully realize communication between electronic devices in everyday life. It achieves the data rate of up to 10 Mbps using the capacitive signal transmission method. High data rate is achieved using the electro optic crystals in the receiver, where change in the electric field with frequency of 10 MHz (which carries the information about the signal.

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Chapter 3 Point to Point Intra Body Communication for Personal Health Care Systems

3.1 Introduction

The population of elderly people in Japan is increasing rapidly. The Ministry of Public Management, Home Affairs, Posts and Telecommunications announced in 2005 that 20.1% of the total population is more than 65 years old, while the average number of the doctors per 100,000 people is 211 [1]. For this population, a visit to the hospital or their local practitioner for routine health check-ups becomes rather time and cost consuming. Additionally increase of stress and excessive alcohol consumption among youngsters is adding to the problem of deadly diseases and needs immediate attention. Large numbers of people die from cardiac diseases, and many of those lives could be saved if people bearing the risk of sudden cardiac failure could be monitored at all times by a mobile system that can automatically initiate emergency calls. Use of radio frequency identification (RFID) tags in medical applications has brought numerous advantages such as increased patient safety, comfort and mobility, improvements in quality of patient care, efficiency in hospital administration capabilities, and hence, a reduction in overall infrastructure cost. One of the major main problems in the design of an efficient mobile Health Care system is the unit's power supply. With the advancement of technology and embedded systems with large number of electronic chips including a number of processors, memory and other interfacing cards, management of power consumption to drive such electronic components is a critical task.

The low power requirements of intra-body communication (IBC) as compared to near field electromagnetic waves makes it a better choice for its application in Medical Body Area Networks (MBANs) in a mobile Health Care system. Intra-body communication in which the human body is used as a 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 signal transmission [2], [3]. These characteristics are superior to those of other radio-based network technologies, such as Bluetooth and IrDA etc. However, a complete detailed analysis of the model of signal transmission in IBC has not been conducted so far by the research community. Moreover, the optimum frequency of transmission for consuming the least amount of energy has not yet been determined and studied exhaustibly. The goal of our research is to develop a personal health monitoring system using inexpensive, lightweight, miniature sensor platforms. The sensors can be positioned on the body as tiny intelligent patches integrated into clothing to act as wearable sensors with little or no uneasiness to the subject. We expect that this will improve current Health Care services and at the same time significantly reduce the costs of public health systems. We are primarily looking to reduce the effect of wireless communication by using very low power IBC sensors, which can also increase the durability of the sensors. In this section, we investigate the transmission characteristics of radio waves in the human body as a conductor of signal up to 2.4 GHz considering different transmitter power consumption and data transmission rates. Many researchers have studied and explored the problems and their solutions in IBC, e.g. [2], [3], [6], [14], however, to the best of our knowledge, there is no comprehensive analysis carried out on the transmission power consumption with respect to different modulation schemes for IBC. For this reason, we evaluated the performance of two different modulation schemes based on phase shift keying viz. Quadrature Phase Shift Keying (QPSK) and Binary Phase Shift Keying (BPSK). The use of an optimal modulation scheme for IBC would be two-fold; one is increased data transmission rate and the other is low power consumption.

The evaluation of different data rates for a range of carrier frequencies has been done with error vector magnitude (EVM) as a measurement parameter. Error vector magnitude (EVM) is a measurement of demodulator performance in the presence of impairments. The measured symbol location obtained after decimating the recovered waveform at the demodulator output is compared against the ideal symbol locations.

The root-mean-square (RMS) EVM and phase error are then used in determining the EVM measurement over a window of N demodulated symbols.

As shown in Figure 3.1 below, the measured symbol location by the demodulator is given by w. However, the ideal symbol location (using the symbol map) is given by v. Therefore, the resulting error vector is the difference between the actual measured and ideal symbol vectors [18], i.e., e=w–v. The error vector e for a received symbol is graphically represented as follows:

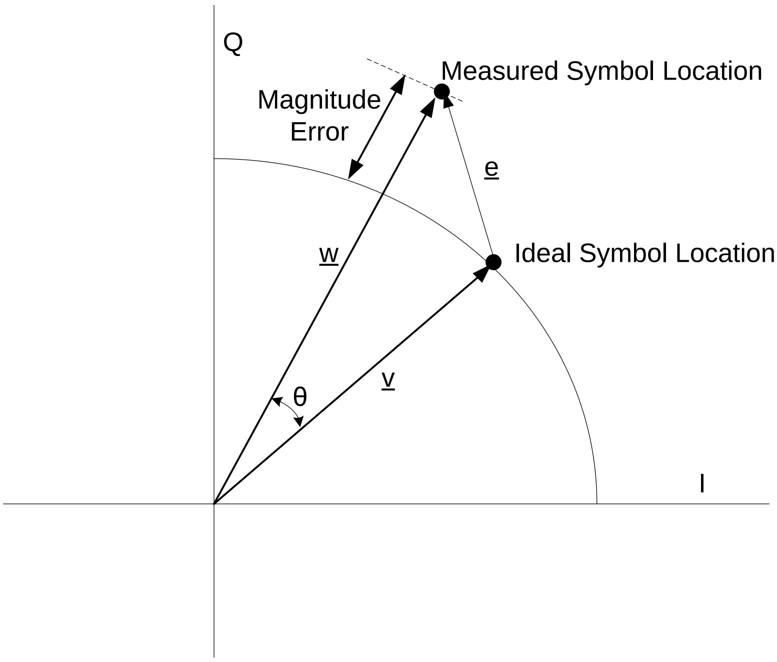

Fig 3.1 Graphical representation of Error Vector Magnitude

Where

v is the ideal symbol vector,

w is the measured symbol vector,

w–v is the magnitude error,

θ is the phase error,

e=w–v) is the error vector, and

e/v is the EVM.

This quantifies, but does not necessarily reveal, the nature of the impairment. To remove the dependence on system gain distribution, EVM is normalized by |v|, which is expressed as a percentage. Analytically, RMS EVM over a measurement window of N symbols is defined as [18]

$$EVM = \frac{\sqrt{\frac{1}{N}\sum_{j=1}^{N}\left[\left(I_j - \tilde{I}_j\right)^2 + \left(Q_j - \tilde{Q}_j\right)^2\right]}}{|\underline{V}_{max}|} \tag{3.1}$$

Where

I_j is the I component of the j-th symbol received,

Q_j is the Q component of the j-th symbol received,

$\tilde{I}_j$ is the ideal I component of the j-th symbol received,

$\tilde{Q}_j$ is the ideal Q component of the j-th symbol received.

EVM is related to the MER and ρ, where ρ measures the correlation between the two signals. EVM and MER are proportional.

SNR can be approximated from EVM by the following formula:

$$\text{SNR} = 20 \log \text{EVM} \tag{3.2}$$

$$BER = 0.5 \times \left(\sqrt{\frac{SNR}{2}}\right) \tag{3.3}$$

3.2 System Architecture

A mobile Health Care system is shown below in Fig.3.2. It comprises of the following main parts:

(i) set of sensors connected to a PDA

(ii) mobile phone or home computer (called the base station)

(iii) communication channel

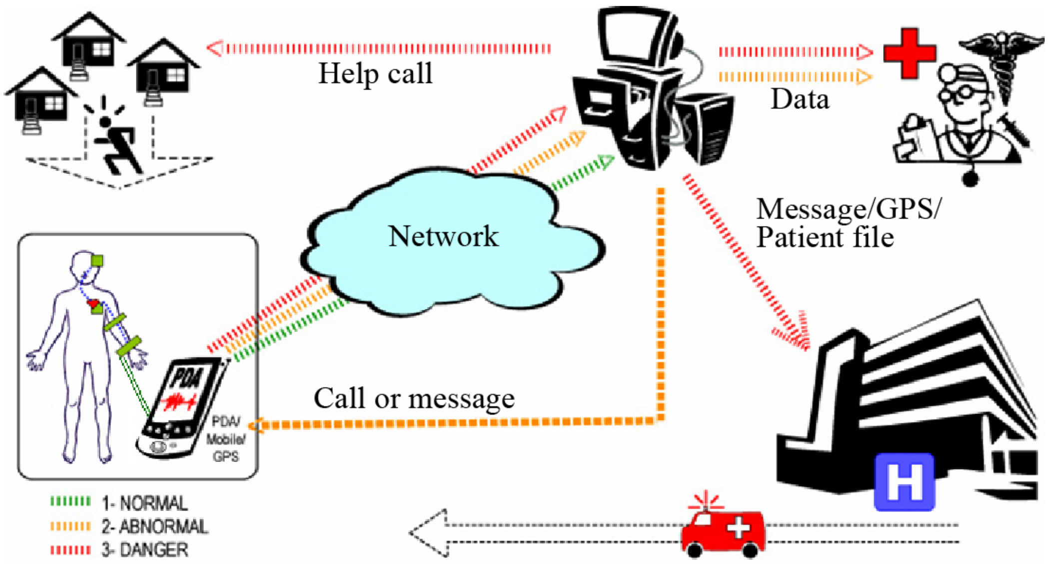

Fig 3.2 System Architecture

The base station transmits all the patient data captured from different sensors to the health center server or to the hospital sever in a secure way over to the communication channel. The data is encrypted using different encryption techniques used in communication theory so that data is accessible only to authorize personals such as medical practitioners, doctors or supporting staff from their computers both in real-time as well as data stored offline using data-loggers. The authorized personals not only can access the data but also can interact with the base station in a secure way. The base station also functions as the user interface to the system and connects to an internet-based electronic patient record (EPR) database which can be used by medical practitioners in future for diagnosis of similar diseases.

On top of that, we are also developing a generic modular platform for providing mobile medical services for diagnosis, monitoring and emergency rescue. This will include recording and, to a great extent, automatic analysis system to analyze vital patient parameters in the patients familiar surroundings. The doctors can have access to expert opinions on certain diseases, and patients can get optimized therapy and automatic reaction in emergency cases. Additionally, Health Care center and rescue personnel will have access to information about the status and medical history of the patient, which is necessary for optimal treatment. Personalized Health Care monitoring systems provide functions such as reminder services or medication support depending on measured signs and individual disease patterns. For locating patients in case of emergency, Global Positioning system (GPS) provided by mobile phone carriers can be used. It provides assistance chronically ill patient 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. We produced the trial product of such a wireless living body monitoring sensor (see Fig. 3.3). The data which we can acquire from this sensor are an electrocardiogram (ECG), a heartbeat count, body temperature, and posture data of the bodies with three axis acceleration sensors. The sensor specifications are given in Table 3.1.
2) Central hub: A hub for all the sensors in the mobile Health Care system. It records all the data from all the sensors and sends it in real-time or offline to the base station.

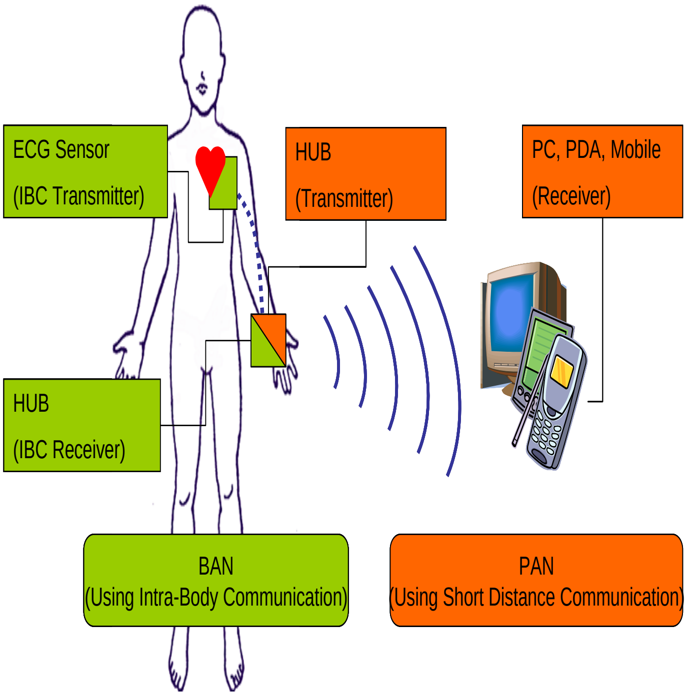

Fig 3.3 Communication Network

3) USB Receiver Unit: USB2.0/1-1 12Mbps connected to the base station to receive and forward the data from the central hub to the Health Care center.

4) Body Area Network (BAN) for communications between sensors on the patient's body and central hub on the same body using IBC.

5) Personal Area Network (PAN) for communications between central hub and the base station. PAN specifications are given in Table II.

6) Wireless cellular communication or ADSL or some other wire line communication between base station to medical center.

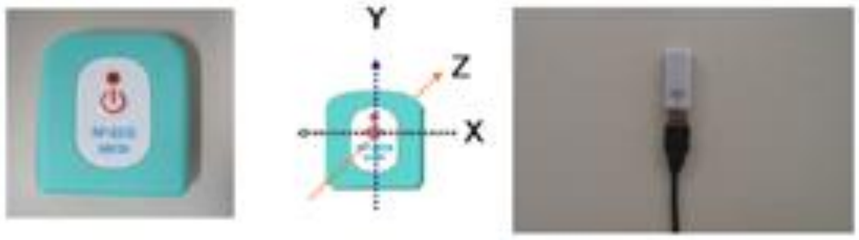

Fig 3.4 Wireless Sensor

Table 3.1 Wireless Sensor and Allied Unit Specifications

Sensor/Unit Specification	**Typical values**
Size in mm (w x l x t)	40 x 35 x 7.2 (+-2mm)
Transmission data rate	Max 1 Mbps
Battery	Lithium, 3 V
Receiver interface	USB 2.0/ 1.1 12Mbps
Receiver software	Windows XP

3.3 Experimental Setup

Fig. 3.5 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), received and demodulated in the receiver (Rx). The distance between Tx and Rx is 57 cm. Fig. 3.6 shows the transceiver used which is composed of a signal electrode and a ground plane (GND).

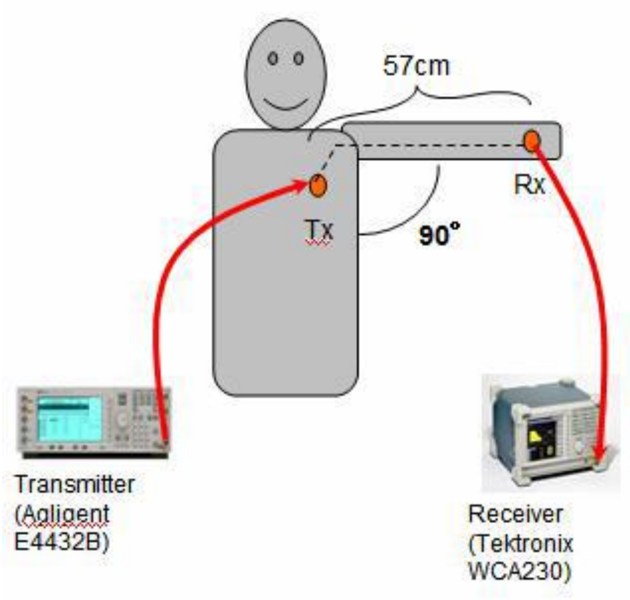

Fig 3.5 Experimental Setup

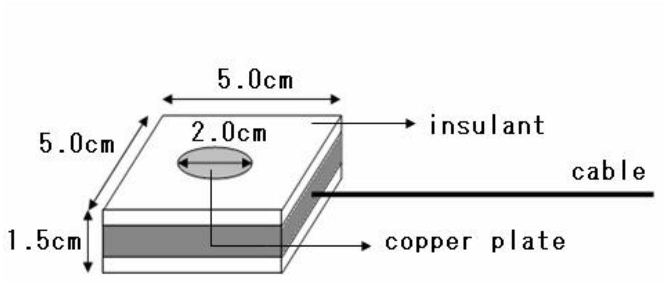

Fig 3.6 Transceiver Unit and its Physical Dimensions

Table 3.2 Typical values for experimental setup

Parameter	Typical Values
Modulation scheme	QPSK, BPSK
Carrier Frequency [MHz]	37.5 to 2400
Symbol rate [Ksps]	4000, 2000, 1000, 500, 250
Transmit Power [dBm]	0, -10, -20, -30
Distance Tx and Rx [cm]	57

The signal electrode was implemented with a round copper plate that touched the skin. Copper was selected as the electrode material because of its good conductivity, and also due to the result of the study of contact impedance between body and electrodes using seven commercial metals (aluminum, copper, bronze, brass, stainless steel, nickel silver, and silver/silver chloride) carried out in [2][7], which showed that the contact impedance of the electrodes was independent of the type of metal. We investigated the optimal TX and RX configuration by considering TX and RX with or without GND electrode touching the skin and changing the signal and GND electrode diameter sizes (from 1 cm to 3 cm), the size of the GND circuit board (10 cm x 5 cm, 5 cm x 5 cm, and 2 cm x 2cm), and the distance between the signal electrode and the circuit board (from 0.7 cm to 2.1 cm). We concluded that the best TX and RX configuration, in terms of the lowest path loss, was composed of only signal electrode 2 cm in diameter touching the skin, and a 10 cm x 5 cm GND circuit board at a distance of 1.5 cm from the signal electrode [14]. The error vector magnitude (EVM) at the RX is measured in the wireless communication analyzer. EVM is an important metric for testing the modulation accuracy. EVM quantifies the difference between the ideal (reference) and the measured signals.

As QPSK and BPSK modulation schemes are widely used in mobile communication [2], [11], [12], 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 transmitter power levels. Table3.2 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 [13], [14]. This study recommended a basic limit exposure of 0.08W/kg for the human body. Considering an average weight of 65kg, 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.

3.4 Experimental Results and Discussion

In order to evaluate the performance of QPSK and BPSK, the error vector magnitude (EVM) is measured at different carrier frequencies, transmission power levels, and symbol transmission rates between TX and RX. EVM is measured in percent root mean square (%RMS) units. The threshold for EVM is set as 17.5% for QPSK [15] and 20% for BPSK [16].

3.4.1 QPSK Modulation

Figs. 3.7 to Fig.3.11 present the EVM results for QPSK for transmitter power of 10 dBm, 0 dBm, -10 dBm, -20 dBm, and -30 dBm respectively. It is inferred from the results obtained for different carrier frequencies at various data rates that performance is better if the EVM is below the threshold value.

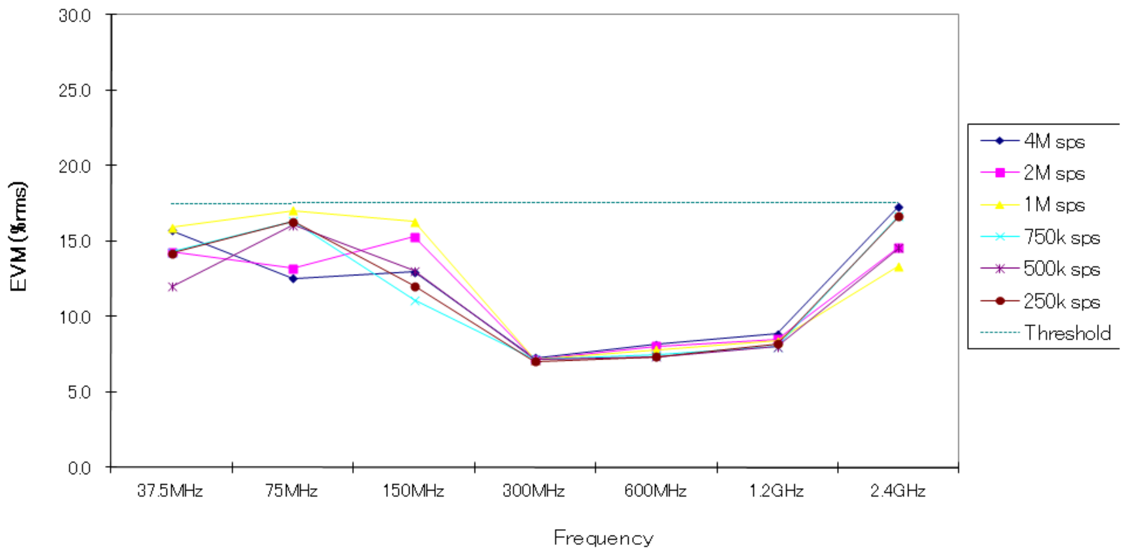

Fig 3.7 EVM vs carrier frequency at 10 dBm for QPSK

Fig. 3.7 shows the EVM output for a range of carrier frequencies. As seen from the graph, it is obvious that the EVM is below the threshold for a wide range of carrier frequencies (37.5 MHz to 2.4 GHz). Although, EVM output seems to be towards desired range, but keeping in view the large power consumption, this configuration is not used. Moreover, 10 dBm is not considerable for intra-body communication.

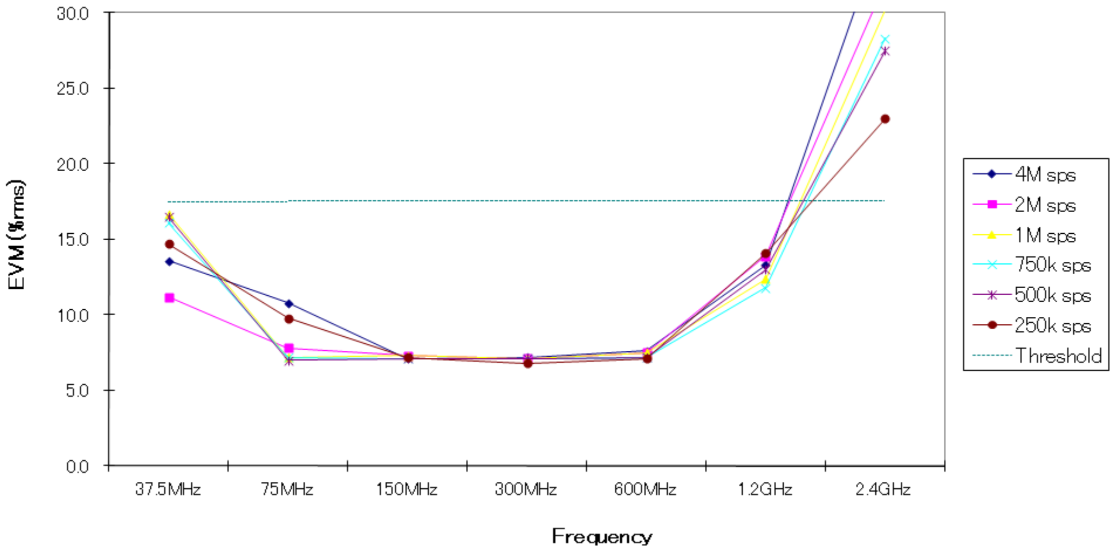

Fig. 3.8 EVM vs carrier frequency at 0 dBm for QPSK

Fig. 3.8 shows that at 0 dBm, QPSK yields good EVM results below the threshold for symbol rates between 75MHz and 1.3GHz. The best results are obtained between 150 MHz and 600 MHz. At 2.4 GHz, the EVM is above threshold for all symbol rates.

The data rates from 4 Msps to 250 ksps, the EVM is different. It is seen that EVM for a data rate of 4 Msps, is little higher than that obtained with data rate of 2MHz whereas for the range of 150MHz - 600MHz, the EVM is almost for all the data rates. Therefore, at 0dBm, any of the data rates is suitable within a carrier frequency of 150 MHz - 600MHz.

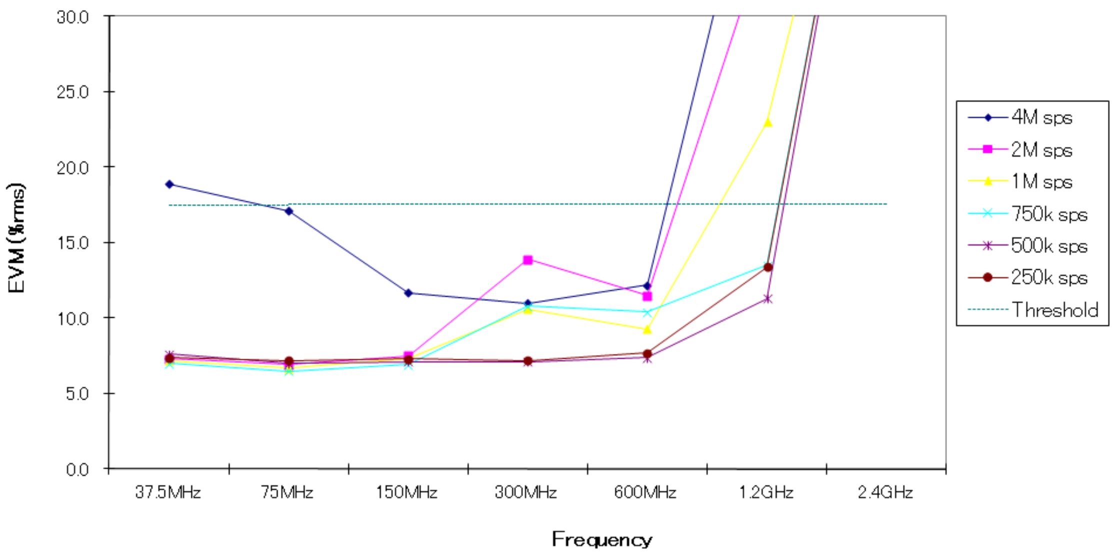

Fig. 3.9 EVM vs carrier frequency at -10 dBm for QPSK

Fig. 3.9 shows that at -10 dBm, QPSK yields good EVM results below the threshold for symbol rates between 1.2 GHz and 37.5 MHz. The best results are obtained between 120 MHz and 600 MHz. At 2.4 GHz, the EVM is above threshold for all symbol rates. In this case, there is large variation in EVM output for different data rates, e.g. considering the range of carrier frequencies from 150 MHz – 600 MHz, if the data rate is 2 Msps, the EVM approaches threshold value at about 450 MHz whereas for data rates of 250 ksps, it is much lower than the threshold value.

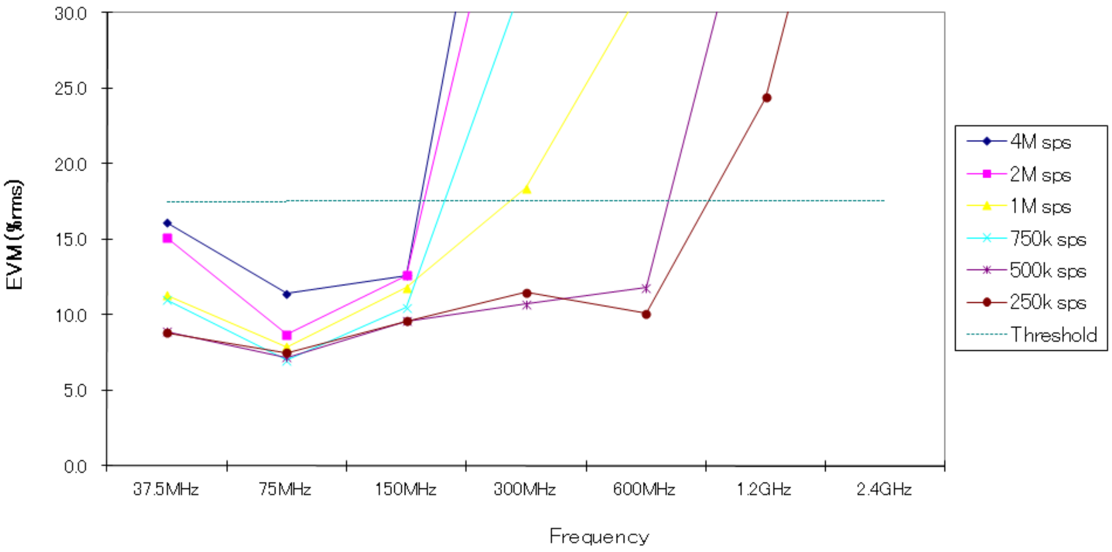

Fig. 3.10 EVM vs carrier frequency at -20 dBm for QPSK

Fig. 3.10 shows that at -20 dBm, QPSK yields good EVM results below the threshold for symbol rates between 37.5 MHz and 600 MHz only for data rates of 250 ksps and 500 ksps whereas if the data rate is 1 Msps, the EVM shoots up the threshold value and is not useful. For the specified carrier frequencies, data rates above 750 ksps are not suitable as these correspond to higher EVM values. The best range of carrier frequency at -20 dBm is from 75 MHz – 200 MHz for a data rate of 250 ksps and 500 ksps.

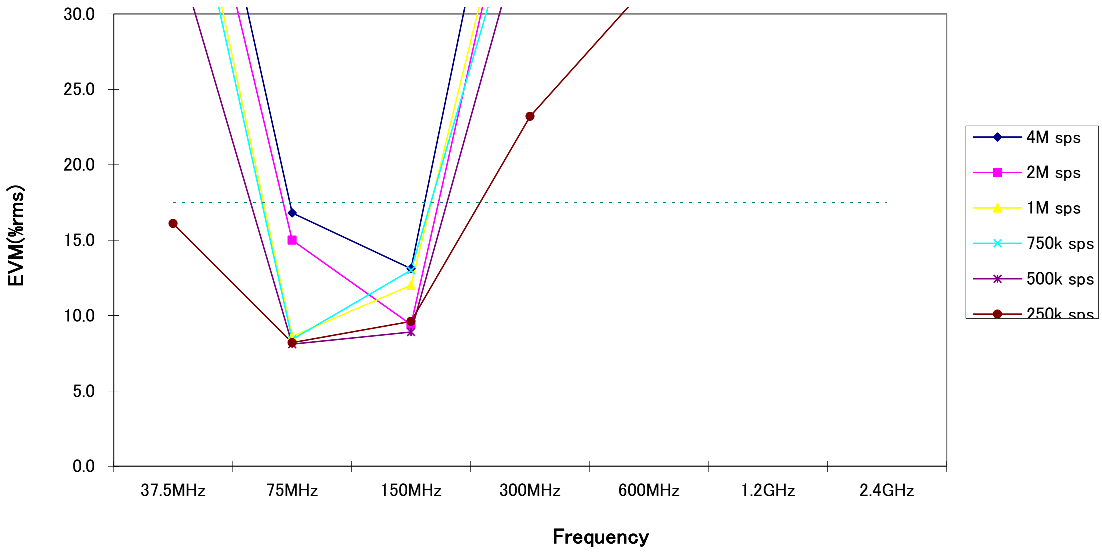

Fig. 3.11 EVM vs carrier frequency at -30 dBm for QPSK

Fig. 3.11 shows that at -30 dBm, QPSK yields good EVM results below the threshold for all symbol rates only between 150MHz and 75MHz. For data rates of 4 Msps to 250 ksps, the EVM shoots if the carrier frequency is outside the range of 75 MHz – 150 MHz. From the above plots, a conclusion is drawn for the optimum power level and maximum carrier frequency so that the EVM is much below the threshold for good performance.

Table 3.3 Summary of optimum carrier frequencies for QPSK

Power Level	Maximum Frequency
0 dBm	1.2 GHz
-10 dBm	600MHz
-20 dBm	150 MHz
-30 dBm	150 MHz

From Table 3.3 summarizes the conclusion. A clear trend is observed wherein the optimal carrier frequency range for high transmission rates reduces as the power level is decreased.

3.4.2 BPSK Modulation

Similarly, Figs. 3.12 and 3.16 presents the EVM results for BPSK for transmitter power of 10 dBm, 0 dBm, -10 dBm, -20 dBm and -30 dBm. As in QPSK, experiment was conducted by first fixing the carrier frequency and measuring the EVM by changing the data rates from 4 Msps to 250 ksps, and then varying the carrier frequency and repeating the experiment. Following observations are obtained which are plotted as plots shown below.

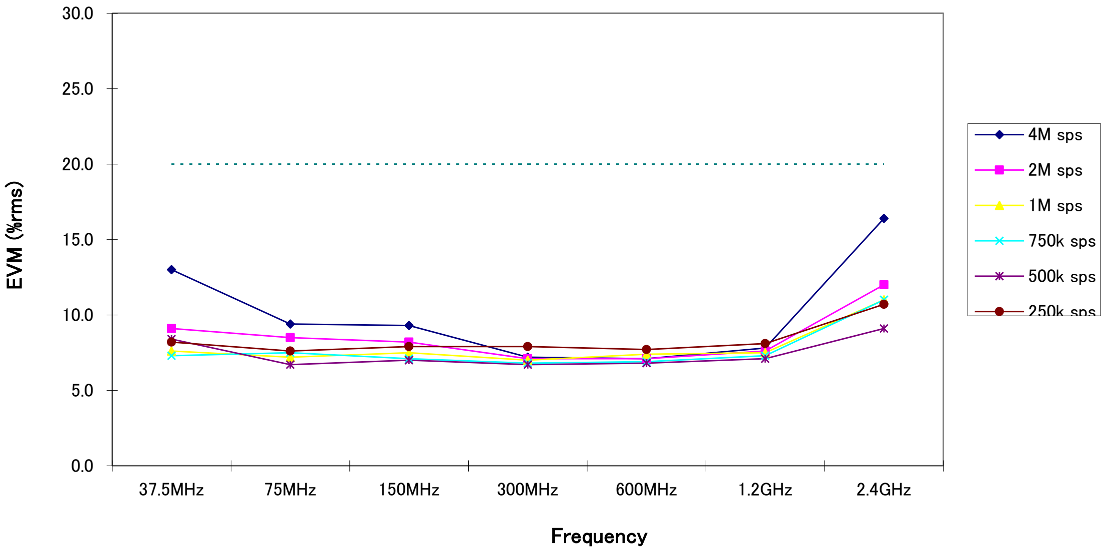

Fig. 3.12 EVM vs carrier frequency at 10 dBm for BPSK

Fig. 3.12 shows that at 10 dBm, BPSK yields good EVM results below the threshold for symbol rates between 37.5 MHz and 2.4 GHz for data rates ranging from 4 Msps to 250 ksps. Although the EVM is much below the threshold value for the data rates at 10 dBm, but being higher transmission power, it is not used. Further, 10 dBm is not considerable for intra body communication.

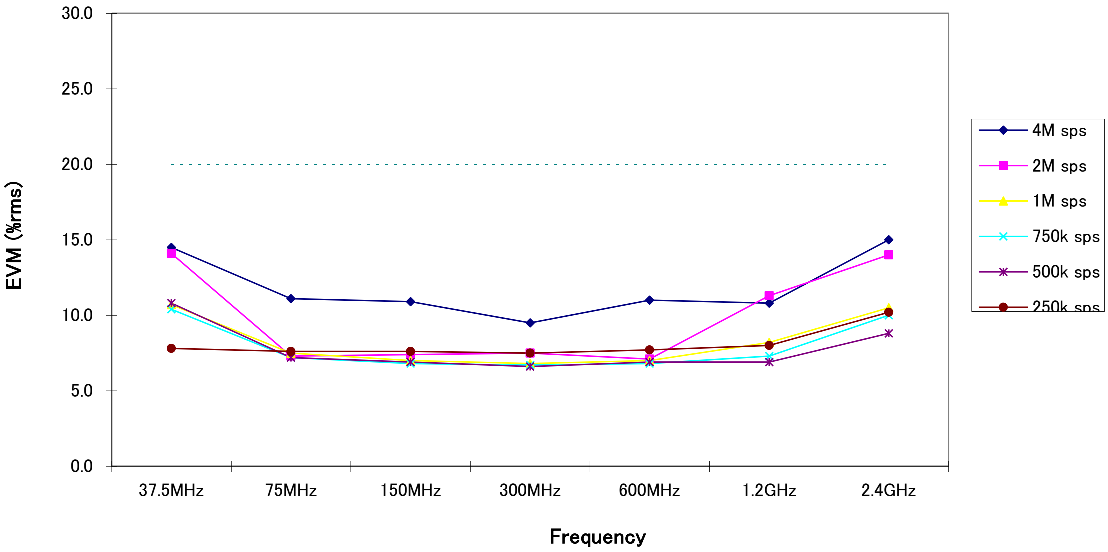

Fig. 3.13 EVM vs carrier frequency at 0 dBm for BPSK

Fig. 3.13 shows that at 0 dBm, BPSK yields good EVM results below the threshold for symbol rates between 37.5 MHz and 2.4 GHz for data rates in range of 4 Msps to 250 ksps. Above carrier frequency of 2.4 GHz, EVM shoots above the threshold for all the data rates. Considering the carrier frequency between 37.5 MHz to 2.4 GHz, as the data rate is increased, the EVM also rises relatively but being less than threshold in every case. The best range of carrier frequency is from 75 MHz- 1.2 GHz. Further, analyzing the graph, it is seen that at 500 ksps data rate, carrier frequency of 150 MHz – 800 MHz gives good EVM output.

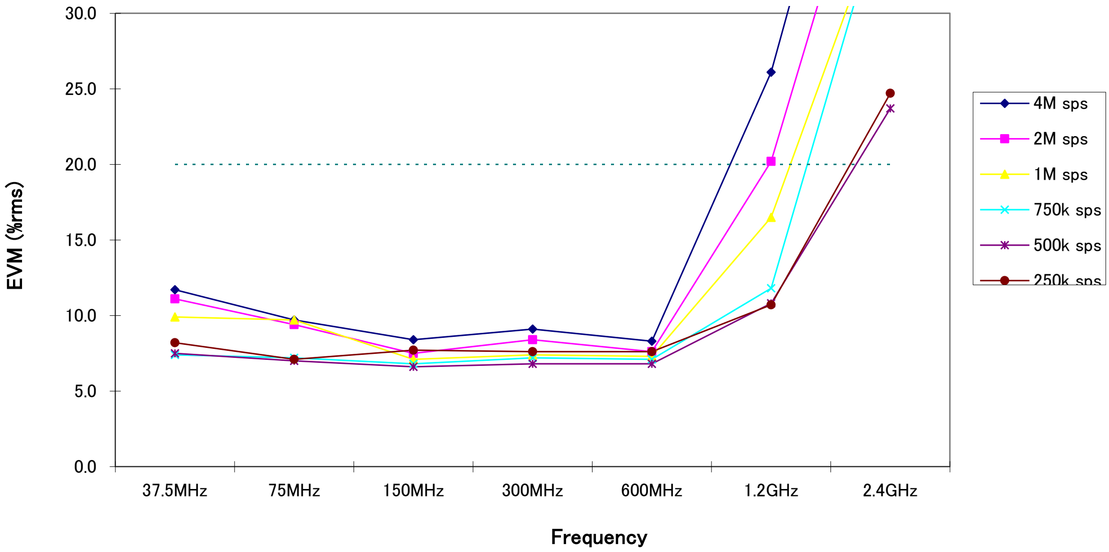

Fig. 3.14 EVM vs carrier frequency at -10 dBm for BPSK

Fig. 3.14 shows that at -10 dBm, BPSK yields good EVM results below the threshold for symbol rates between 37.5 MHz and 1.2 GHz for data rates of 2 Msps to 250 ksps and with increase in carrier frequency above 1.2 GHz, the EVM rises above the threshold value. For the range of 37.5 MHz – 600 MHz, all the data rates give almost same EVM output. There is slight rise in EVM if the data rate rises from 250 ksps to 2 Msps. The best range of carrier frequency in case of -10 dBm is 75 MHz – 300 MHz.

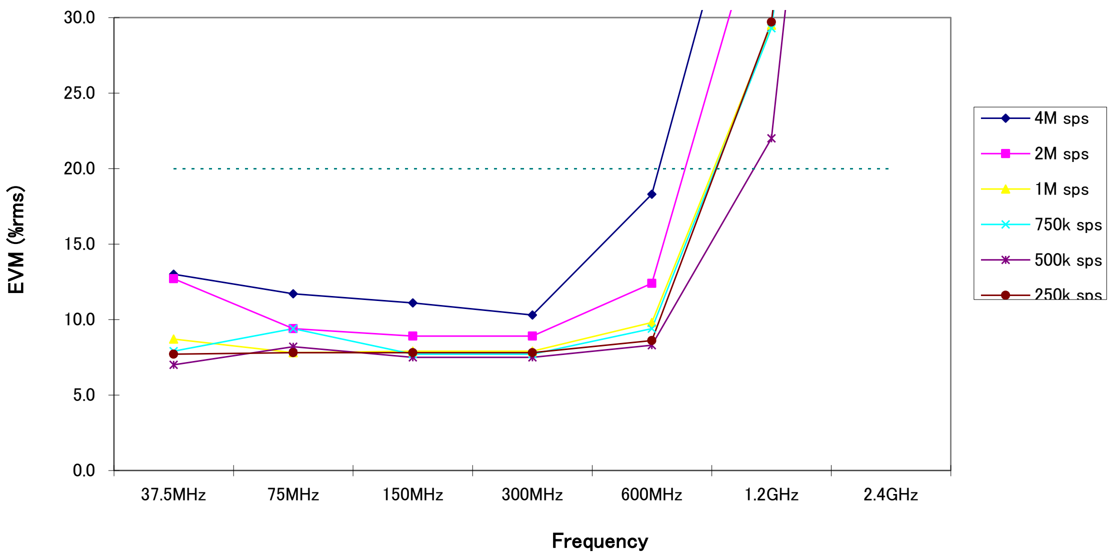

Fig. 3.15 EVM vs carrier frequency at -20 dBm for BPSK

Fig. 3.15 shows that at -20 dBm, BPSK yields good EVM results below the threshold for symbol rates between 37.5 MHz and 600 MHz. After carrier frequcy of 800 MHz, the EVM rises above the threshold value. The EVM variation for different data rates varies to large extent in this case. As seen from the graph, the EVM is fluctuating a lot for a data rate of 2 Msps where is more stable for data rate of 250 ksps. The best range of carrier frequencies for -20 dBm is 75 M Hz – 600 M Hz for data rates of 250 ksps and 500 ksps.

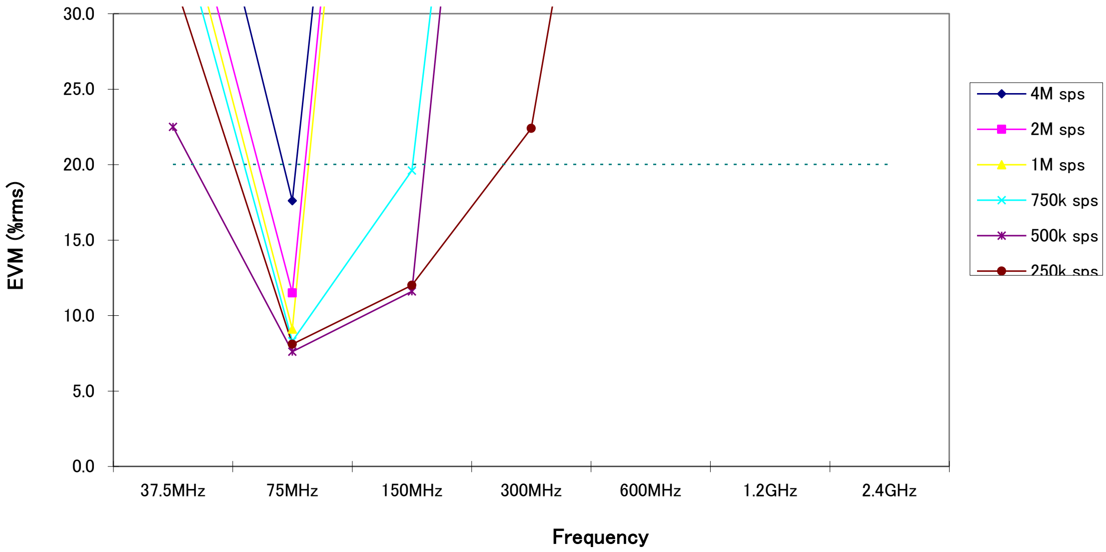

Fig. 3.16 EVM vs carrier frequency at -30 dBm for BPSK

Fig. 3.16 shows that at -30 dBm, BPSK yields good EVM results only for a narrow range of carrier frequencies. The variation of EVM with change in data rates is high. The useful carrier frequency in this case is between 75 MHz to 200 MHz only for data rates of 250 ksps and 500 ksps. For data rate of, for example, 1 Msps, the EVM shoots above the threshold and stays below the threshold only around 75 MHz.

Based on the experiment conducted by varying the carrier frequency and measuring the EVM for different data rates, following conclusion is drawn which is summarized in Table 3.4

Table 3.4 Summary of optimum carrier frequencies for BPSK

Power Level	Maximum Frequency
0 dBm	2.4 GHz
-10 dBm	1.2 MHz
-20 dBm	600 MHz
-30 dBm	75 MHz

It is inferred that BPSK could be potentially used even at 2.4 GHz. Fig. 3.16 shows that at -30 dBm, BPSK yields good EVM results below the threshold for all symbol rates only between 150MHz and 75MHz similar to QPSK. Similar to the results for QPSK, the optimal carrier frequency range reduces as the transmitter power level is reduced from 0 dBm to -30 dBm as shown in Table 3.4.

3.5 Conclusion

In this Chapter, we introduced the concept of point to point intra body communication for personal Health Care monitoring system. A system architecture comprising of a set of sensors, a base station, receiver and a communication network is proposed. 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. An experiment was conducted by considering two different kinds of modulation techniques viz. QPSK and BPSK. EVM was measured by varying the carrier frequency at different data rates. We evaluated these modulation schemes for IBC in terms of EVM. The variation of EVM with carrier frequency at different data rates was plotted. Experimental results have shown that both QPSK and BPSK could be used for IBC at high data rate using low transmission power with minimum range of -30 dBm. Our experimental results show that 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.

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Chapter 4
Intra-Body Hybrid Communication Scheme for Health Care System

4.1 Introduction

One of the major issues in mobile Health Care system is the unit's consumption of power supply to accommodate the rapidly increasing performance of processors, memory units and other components [1]. The low power requirements of intra-body communication (IBC) as compared to that of near field electromagnetic waves, makes it better choice for Medical Body Area Networks (MBANs) in a mobile Health Care system [1]. Intra-body communication (IBC) is a technique in which the human body is used as a medium for signal transmission guide that has attracted much attention in the study of Body Area Networks (BANs), because as signals pass through the human body there will be little influence of electromagnetic noise and interference on transmission [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 radio based 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 chapter [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 chapter, first 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.

Second, 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 chapter 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 simulations results and discussion. Finally the seventh section concludes the paper.

4.2 Proposed System Architecture

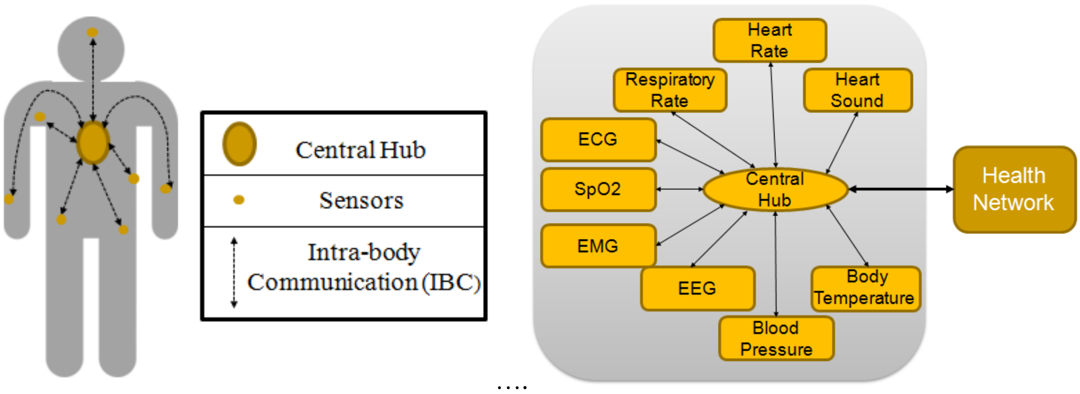

Fig. 4.1 Distribution and types of sensors within IBC Health Care system

The Health Care system as shown in Fig. 4.1 is composed of a set of different sensors connected to health network, that transmits all the patient data to the Health Care centre server or to hospital sever 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 4.1.

2) Central hub: A hub for all the sensors in the mobile Health Care system. It records all the data from all the sensors and sends 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 Health Care centre.

Table 4.1 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

4.3 Experiment Setup

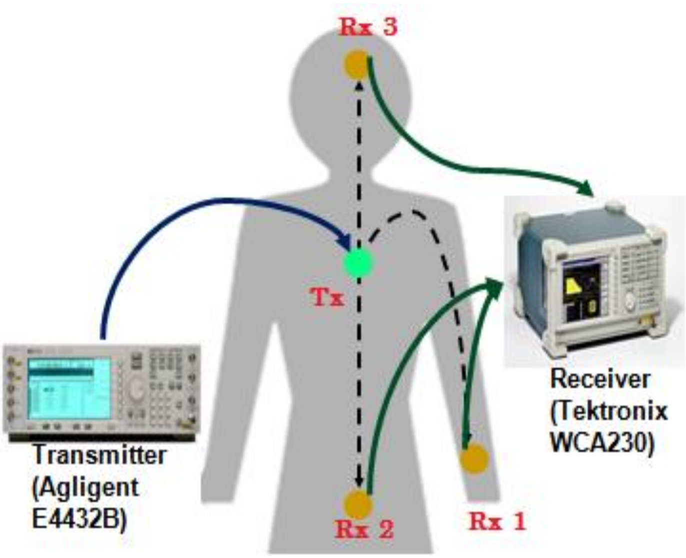

Fig. 4.2 Experiment measurement setup

Table 4.2 Experiment parameter

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

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, and waist) and its effect on the performance of IBC.

Fig. 4.2 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.

Table 4.2 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 0.08W/kg for the human body. Considering an average weight of 65kg, 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.

4.4 Experimental Results and Discussion

Experiments results show that when we decrease transmission power, the optimal carrier frequency shifts to the lower range. The results of higher symbol rates for BPSK and QPSK optimal carrier frequency under a -30dBm power transmission are shown below. Since our goal is to achieve the power consumption, therefore we considered -30dBm only. 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 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) shown in Tables [4.3][4.4][4.5][4.6].

Fig. 4.3 Shows that at -30 dBm, BPSK yields good EVM results only for a narrow range of carrier frequencies. The variation of EVM with change in data rates is high. The useful carrier frequency in this case is between 75 MHz to 200 MHz only for data rates of 250 ksps and 500 ksps. For data rate of, for example, 1 Msps, the EVM shoots above the threshold and stays below the threshold only around 75 MHz. Fig 4.4 Shows that at -30 dBm, QPSK yields good EVM results below the threshold for all symbol rates only between 150 MHz and 75 MHz. For data rates of 4 Msps to 250 ksps, the EVM shoots if the carrier frequency is outside the range of 75 MHz – 150 MHz.

Fig. 4.5 shows that at -30 dBm, BPSK yields good EVM results below the threshold for symbol rates between 37.5 MHz and 170 MHz for data rates of 4 Msps to 250 ksps. But in case of 4Msps and it was below the threshold in case of 37.5MHz only, and for 2Msps it was in 75MHz and 37.5MHz. Fig.4.6 shows that at -30 dBm QPSK yield good EVM results below the threshold for symbol rates between 75MHz and 150MHz for data rates 4Msps to 250Ksps. But in case of 150MHz, 4Msps and 2Msps was over the threshold.

Fig. 4.7 shows that at -30 dBm, BPSK yields good EVM results below the threshold for symbol rates between 37.5 MHz and 150 MHz for data rates of 4 Msps to 250 ksps. But in case of 4 Msps and it was below the threshold in case of 150 MHz only. Fig. 4.8 shows that at -30 dBm, QPSK yields good EVM results below the threshold for symbol rates between 37.5 MHz and 150 MHz for data rates of 4 Msps to 250 ksps

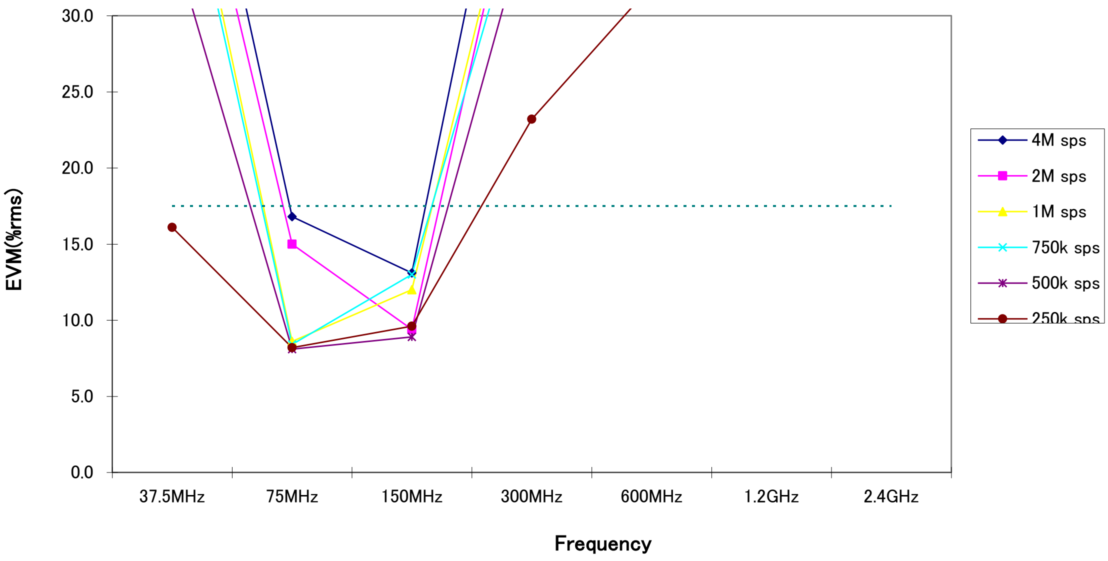

Fig. 4.3 Rx1 EVM vs carrier frequency at -30 dbm for QPSK

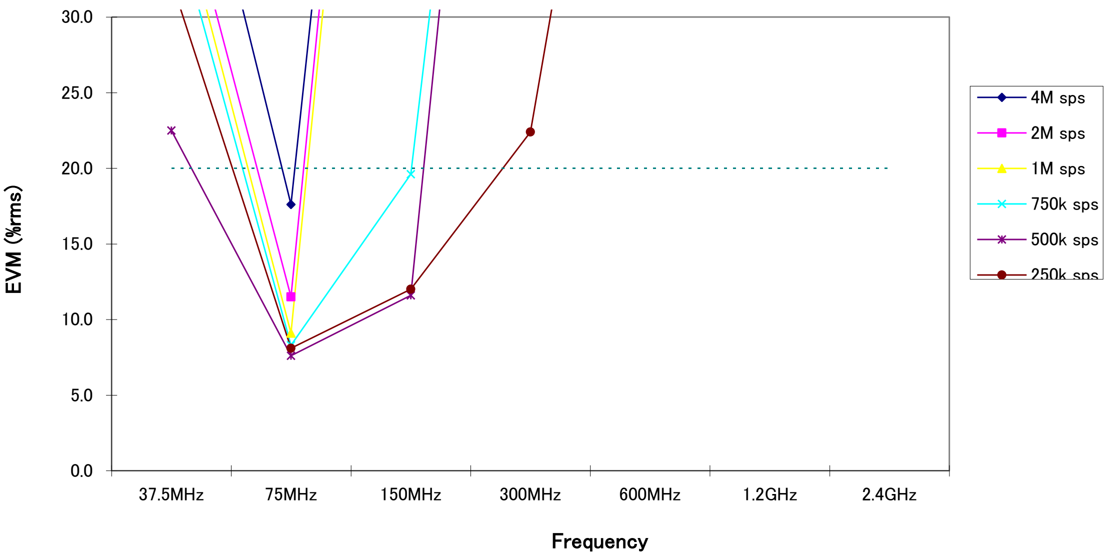

Fig. 4.4 Rx1 EVM vs carrier frequency at -30 dBm for BPSK

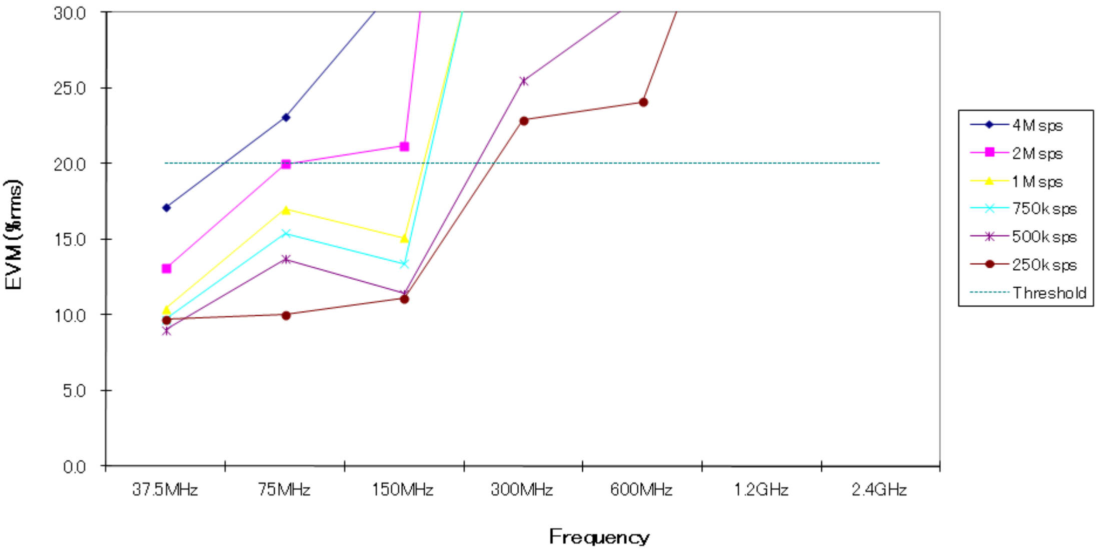

Fig. 4.5 Rx2 EVM vs carrier frequency at -30 dBm for BPSK

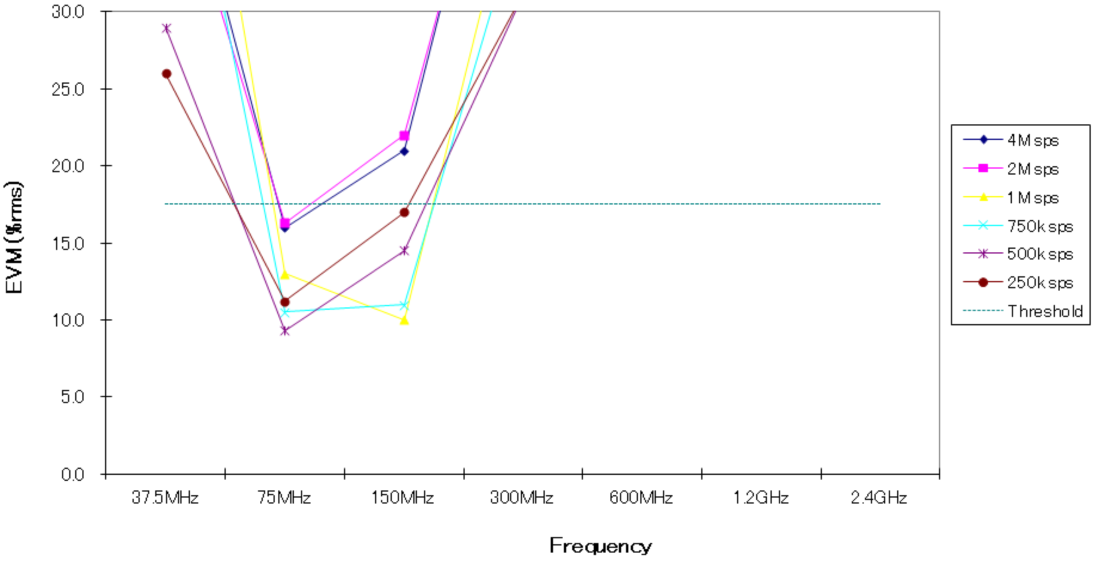

Fig. 4.6 Rx2 EVM vs carrier frequency at -30 dBm for QPSK

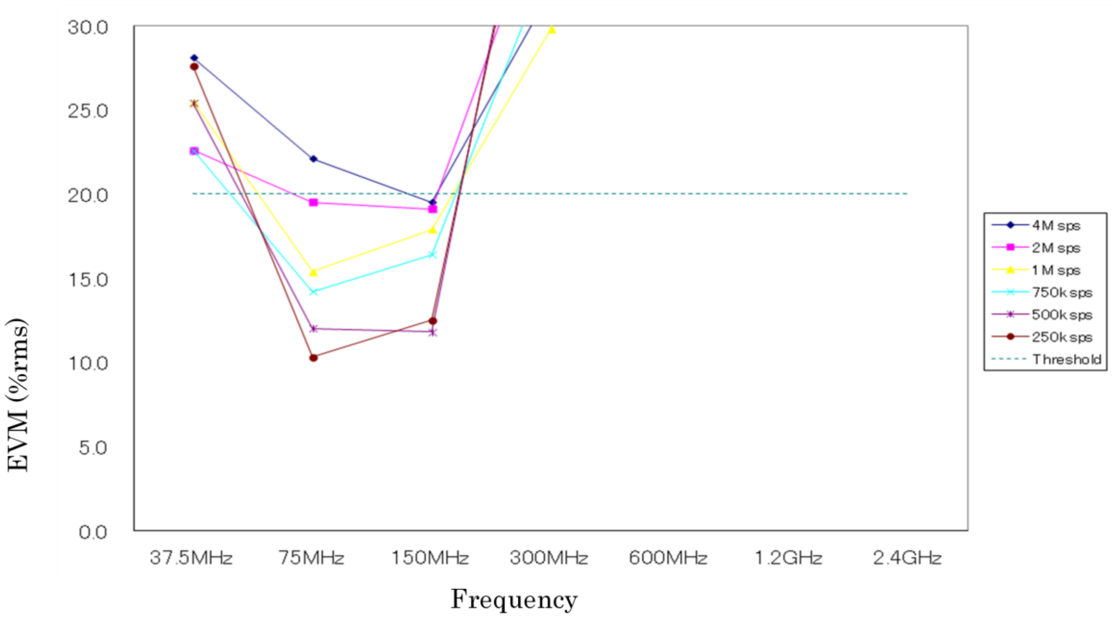

Fig. 4.7 Rx3 EVM vs carrier frequency at -30 dBm for BPSK

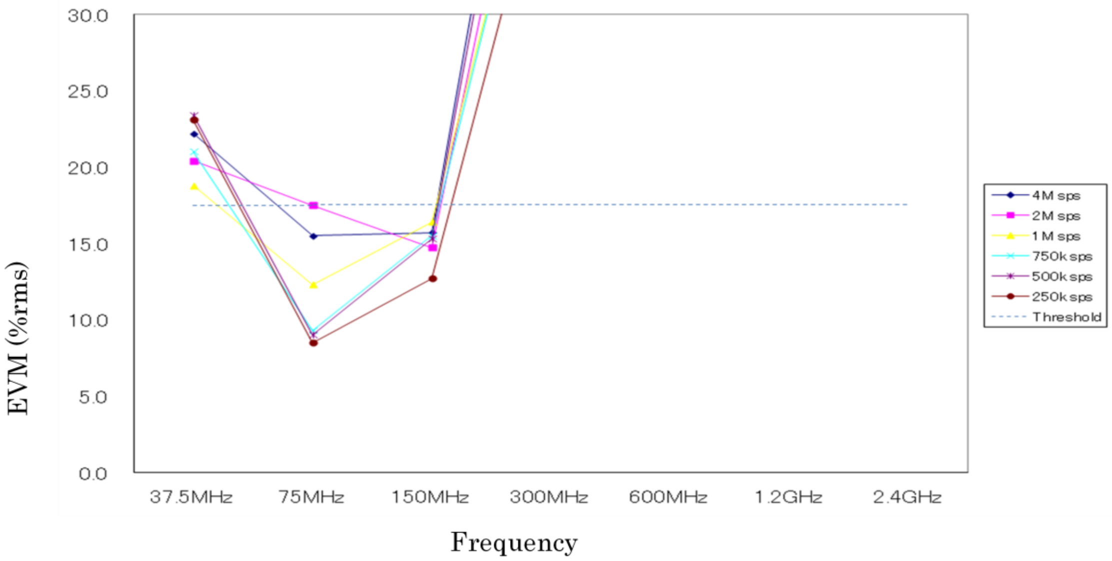

Fig. 4.8 Rx3 EVM vs carrier frequency at -30 dBm for QPSK

Table4.3 Experiment results of Maximum achievable data rate in case of 150MHz BPSK

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

Table 4.4 Experiment results of maximum achievable data rate in case of 150 MHz QPSK

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

Table 4.5 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 4.6 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

4.5 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 access 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 access 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 the it's 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.

4.6 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 4.7 and 4.8 and the results are shown in Figure 4.9-4.14. 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 4.7.

In figure 4.9 & 4.10 for Group 1 sensors we can see how the allocation number of Demand Assignment (DA) slots can alter the systems performance in terms of its delay and throughput for both data length of 8 and 4 respectively. When the value of DA=5, the system throughput value of 0.35(bit/s) was obtained for both 8 and 4 data length while the delay value of 65(ms) and 68(ms) respectively. Also when DA=27 the system improves its delay value to 36(ms) for both 8 and 4 data length while the throughput value of 0.65(bit/s) and 0.35(bit/s) was obtained respectively. The optimal value when the data length is 8 was obtained when DA=23, which provide system delay value of 40 (ms) and throughput value of 0.75(bit/s). Nevertheless, when the data length is 4 the optimal values for system delay and throughput was 46(ms) and 0.55(bit/s) respectively with DA=15.

In figure 4.11 & 4.12 for Group 2 sensors When the value of DA=5, the system throughput value of 0.33(bit/s) was obtained for 8, and 0.34(bit/s) for 4 data length while the delay value of 56(ms) and 55(ms) respectively. Also when DA=27 the system improves its delay value to 36(ms), 37(ms) for 8 and 4 data length while the throughput value of 0.56(bit/s) and 0.33(bit/s) was obtained respectively. The optimal value when the data length is 8 was obtained when DA=23, which provide system delay value of 39(ms) and throughput value of 0.65(bit/s). Nevertheless, when the data length is 4 the optimal values for system delay and throughput was 42(ms) and 0.41(bit/s) respectively with DA=15.

In figure 4.13 & 4.14 for Group 3 sensors When the value of DA=5, the system throughput value of 0.53(bit/s) was obtained for 8, and 0.84(bit/s) for 4 data length while the delay value of 120(ms) and 119(ms) respectively. Also when DA=27 the system improves its delay value to 47(ms), 50(ms) for 8 and 4 data length while the throughput value of 0.83(bit/s) and 0.51(bit/s) was obtained respectively. The optimal value when the data length is 8 was obtained when DA=23, which provide system delay value of 57(ms) and throughput value of 0.93(bit/s). Nevertheless, when the data length is 4 the optimal values for system delay and throughput was 79(ms) and 0.61 (bit/s) respectively with DA=15.

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 4.7 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	1	7.2	Periodic	The amount of oxygen that is being carried in a patient's blood.

(SpO2)				
GROUP 3				
EEG	20	4.2	Random	Measurement of electrical spontaneous brain activity and other brain potentials

Table 4.8 Parameters for the Simulation for Each Group

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	1	1	1

(PAP)			
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

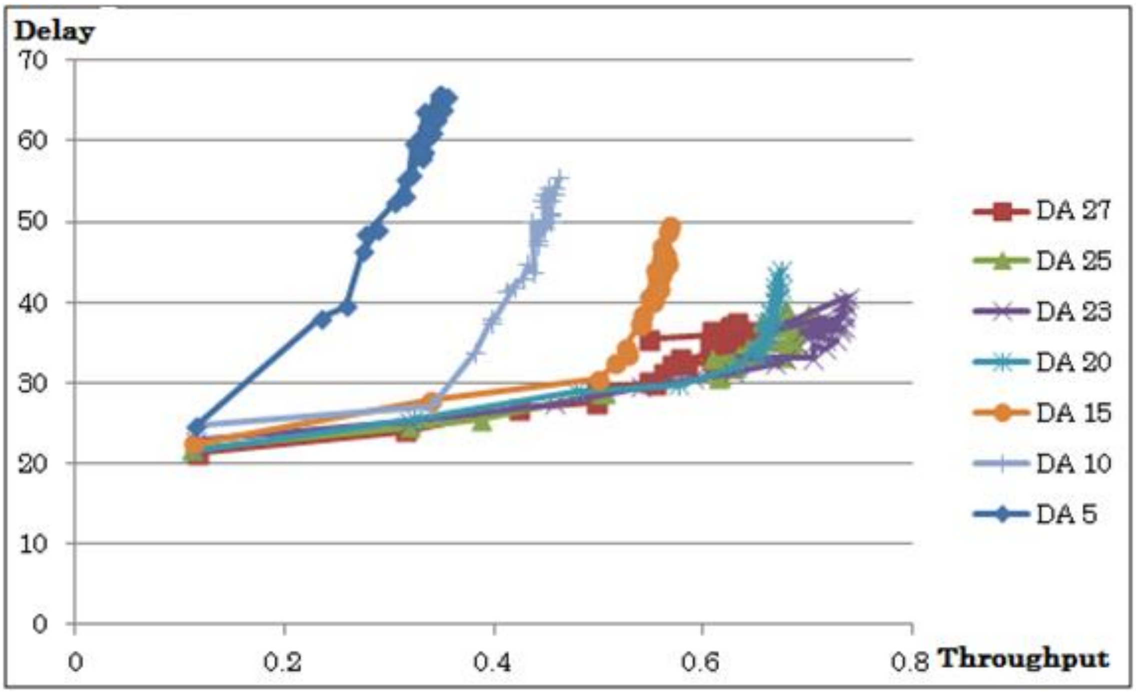

Fig. 4.9 throughput vs delay BPSK-150MHz-750ksps group1 data length 8

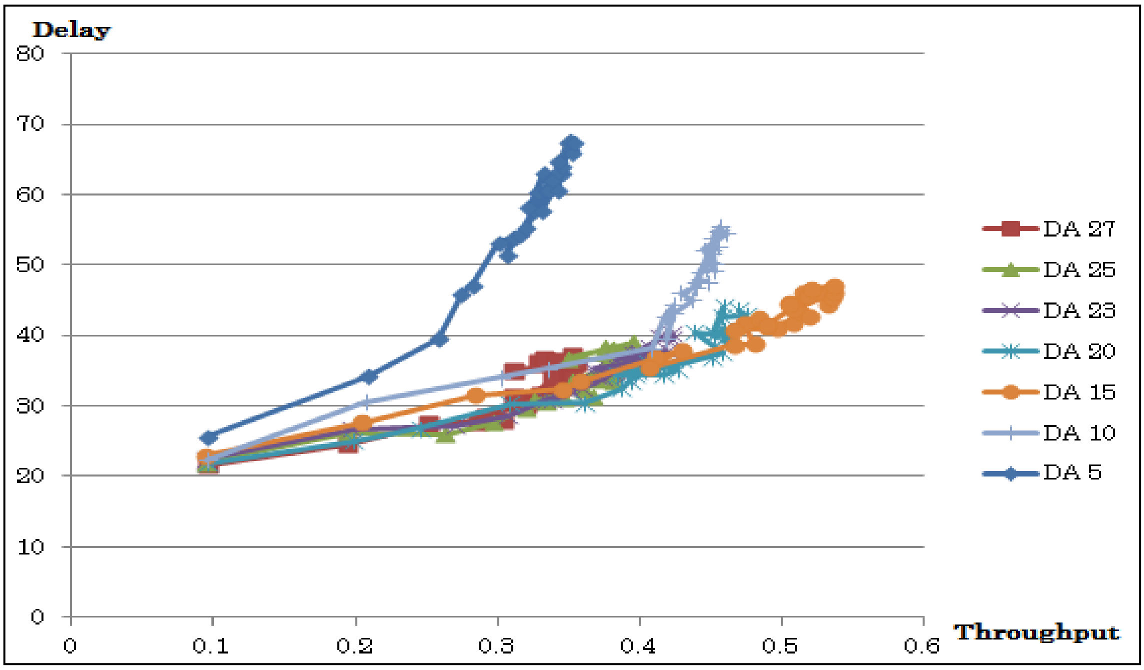

Fig. 4.10 throughput vs delay BPSK-150MHz-750ksps group 1 data length 4

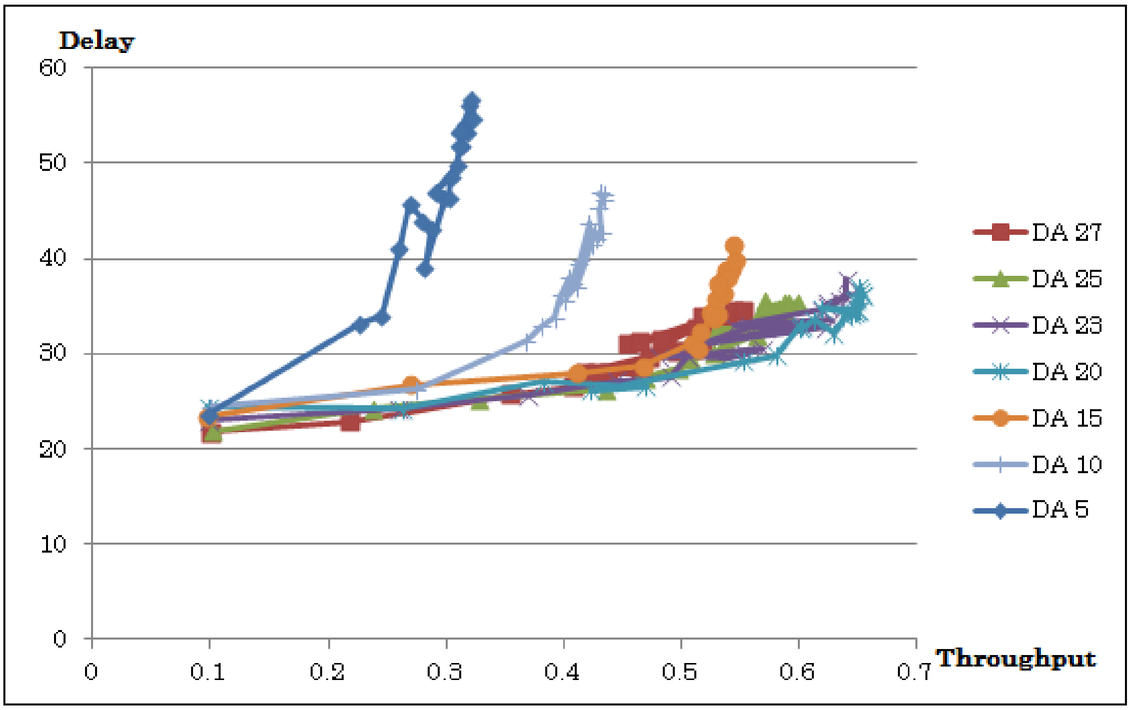

Fig. 4.11 Throughput vs delay BPSK-150MHz-750ksps group2 data length 8

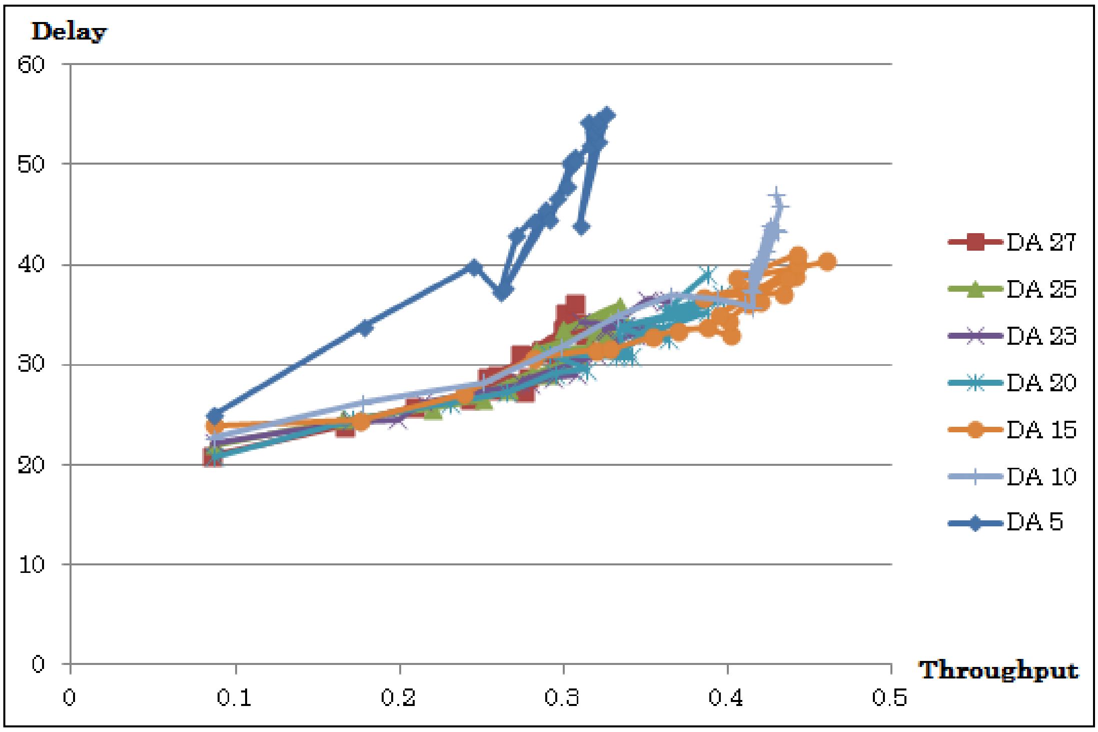

Fig. 4.12 Throughput vs delay BPSK-150MHz-750ksps group 2 data length 4

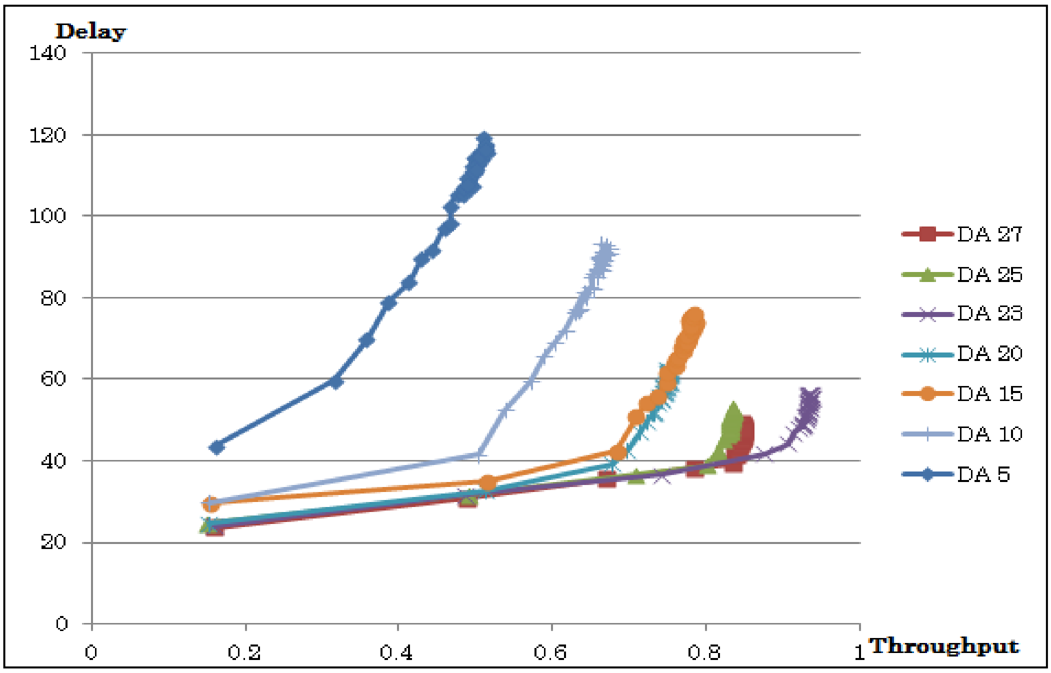

Fig. 4.13 Throughput vs delay BPSK-150MHz-750ksps group3 data length 8

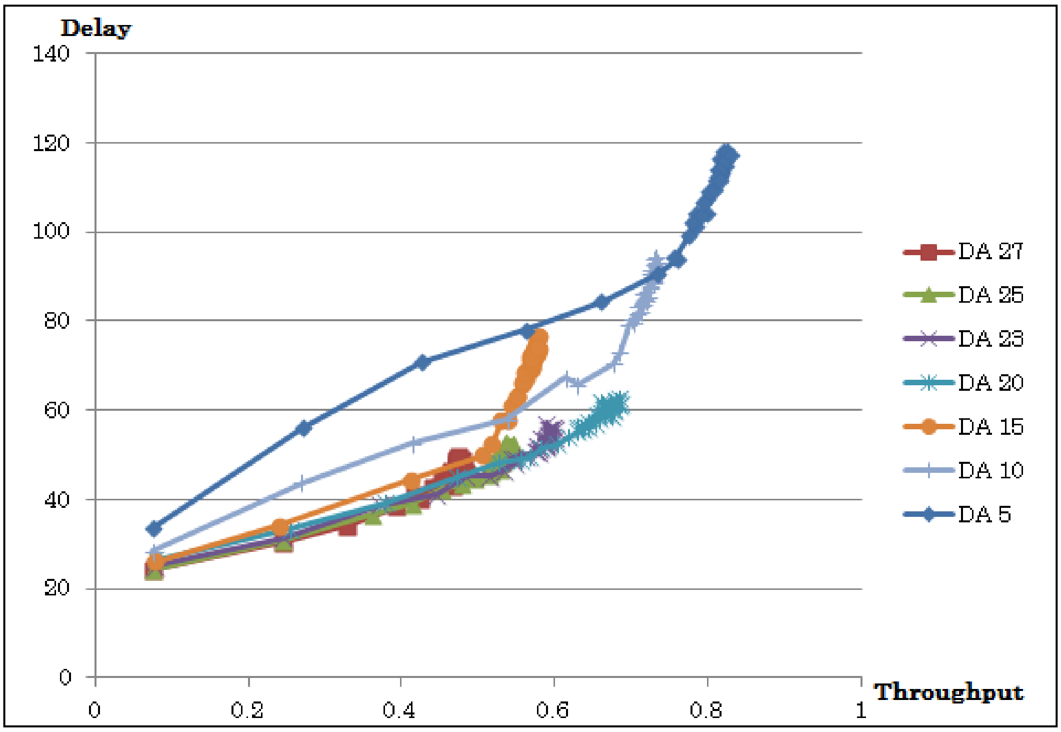

Fig. 4.14 Throughput vs delay BPSK-150MHz-750ksps group3 data length 4

4.7 Conclusion

In this chapter, the concept of point to multi-point intra body hybrid communication for personal Health Care monitoring system is introduced. A system architecture comprising of a set of sensors, a base station, receiver and a communication network is proposed. Dissertation

The transmission characteristics of the human body on BAN point-to- multi-point intra-body communication between central hub (transmitter) on the chest and sensors (receiver) worn on the wrists, head, waist are investigated. An experiment was conducted by considering two different kinds of modulation techniques viz. QPSK and BPSK, and EVM was measured by varying the carrier frequency at different data rates.

Although 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).Secondly, Based on the proposed IBC optimal frequency, the Intra- body hybrid communication scheme with movable boundary as 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. The simulation was run under three different scenarios and it had further demonstrated that flexibility and efficiency of the proposed hybrid scheme.

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

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Chapter 5: Conclusion

5.1 Conclusion

The technology era that spread in the past years drastically evolved traditional structures and systems. A unique feature of the technology and telecommunication industry is the relatively cheap prices of hardware and software involved in these systems. This induced researchers to utilize technology and telecommunication driven tools in overcoming traditional challenges and limitation of the Health Care industry.

The advancement of research in sensors technology lead to innovative small devices capable of detecting fluctuation in health related properties such as "temperature", "pressure", "sugar level" etc.. On the other hand, a system composed of sensors and signal transmitters and receivers situated on the patient's body for the aim of diagnosing and monitoring health condition is known as Body Area Network (BAN).

One of the methods of wireless BAN is to use the body as transmission medium for transferring signals; this method is called Intra Body Communication (IBC). Such a system promises transmissions between sensors that are both safe and accurate and therefore could be utilized in establishing a communication network for monitoring and transmitting crucial data to a health center such as a hospital or a clinic over established external network. Another advantage for IBC is that it requires less power requirement since the transmitted signal is not broadcasted on air, but limited to the monitored body. Moreover such a system conveys less concerns regarding privacy issues that wireless network is susceptible to.

In this thesis, we have proposed our mobile personal Health Care system. We investigated the transmission characteristics of the human body on BAN (point-to-point, point-to -multi point) intra-body communication between sensors and a central hub by considering different transmitter power consumption and data transmission rates in different location on the body. We evaluated QPSK and BPSK modulation schemes for IBC in terms of EVM. Experiment results have shown that both QPSK and BPSK could be used for IBC with high data rate. Our experiments results show that 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.

We propose hybrid communication scheme with the movable boundary that combines Slotted Aloha, Reservation Aloha and TDMA. The proposed system categorizes data into random access data (high priority data) and periodic data (low priority data) which increases the throughput and decreases the transmission delay in the system and has been verified in the experimental results section.

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 itra-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 furthur demonstrated that feasiblity and efficiency of our proposed hybrid scheme.

5.2 Future Work

The experiments in this thesis were performed on a healthy 24 years old Japanese male under controlled condition. A natural extension of this research is to expand the variables set and conditions. For example, a male or a female conducting sports activities or different skin types or body types (height, weight and age) of the subject. Furthermore, other schemes and modes of signal transmission could be investigated.

Another area of investigation could be a comparison between the throughput properties between wireless BAN and IBC and investigation of a combining these two approaches for integrated BAN. Also, we will study the Interference effects by other radio station using same Frequencies of IBC. In same time the effect of IBC on the pace-maker device.

Finally, this thesis was a mile stone in discovering a new and growing field of research that promises to change structures of Health Care system. This implies that a fully multi disciplinary research is required which to achieve the promised qualities of such system. An integrated effort of between telecommunication engineers and health professionals as well as their respective institutes from telecommunication companies and hospitals and health centres is essential to bring this innovative technology to reality for the benefit of mankind.

Appendices

List of Academic Achievements:

Category (Subheadings)	
Articles in refereed journals	○Abdullah Alshehab, Chiu Tung Wu, Nao Kobayashi, Sikieng Sok, Shigeru Shimamoto (2012). "Intra-body Hybrid Communication scheme for Healthcare Systems". International Journal on Bioinformatics & Biosciences (IJBB) Vol.2, No.1.March 2012. ○Abdullah Alshehab, Nao Kobayashi, Jordi Ruiz, Ryosuke Kikuchi, Shigeru Shimamoto, and Hiroshi Ishibashi. "A study on intra body communication for personal Healthcare monitoring system". Journal of telemedicine and e-health. Vol. 14 no. 8. pp. 851-857. October 2008 NAO Kobayashi, Tung Wu Chiu, Abdullah M. Alshehab, and Shigeru Shimamoto "Schemes for Fingers Identification and Hand Behavior Analysis Employing Intra Body Communication" (2010) IEICE TRANSACTIONS Vol. J-93- B No. 7 pp. 955- 964 NAO Kobayashi, Tung Wu Chiu, Abdullah M. Alshehab, and Shigeru Shimamoto "Research on Human Body Part Shapes Identification Scheme by Utilizing SWR" (2012) IEICE TRANSACTIONS Vol.J95-B, No.06 pp.

international conferences	○<u>Abdullah Alshehab,</u> Nao Kobayash, Ryosuke Kikuchi, Jordi Ruiz, Shigeru Shimamoto & Hiroshi Ishibashi. “A study on intra-body communication for personal Health Care monitoring system”. 10th IEEE Intl. Conf. on e-Health Networking Applications and Service (HEALTHCOM 2008). (2008) Singapore. （Best paper ） Nao Kobayashi, <u>Abdullah M. Alshehab,</u> Jordi Agud Ruiz, Shigeru Shimamoto. “Experimental Evaluation of Detection Methods for Finger Identification Schemes Based upon Intra-body Communication”. IEEE ICC 2008. Beijing Shigeru Shimamoto, <u>Abdullah M. Alsehab,</u> Nao Kobayashi, Dagvadorj Dovchinbazar, Jordi Augud Ruiz. “Future Applications of Body Area Communications”, IEEE ICICS 2007
Domestic conference	○ALSHEHAB, Abdullah, KIKUCHI Ryosuke, SHIMAMOTO Shiger, ISHIBASHI Hiroshi (2007) “Mobile Health Care System Employing Body Area Sensor Network (BASN)” 第27回医療情報学連合大会 （日本医療情報学会より若手奨励賞授与）
Local workshops and forums	Nao Kobayashi, <u>Abdullah M. Alshehab,</u> (2007). A study on finger identification scheme employing Phase. GITI Forum. October 2007 Nao Kobayashi, <u>Abdullah Alshehab</u> (2008)"人体通信を用いた人体部位特定に関する研究" GITS workshop. October 2008. Nao Kobayashi, <u>Abdullah Alshehab</u> (2009)"Study on Propagation Model for Palm Writing" GITS Workshop. October 2009