Performance Analysis of Preamble-Based TDMA Protocol for Wireless Body Area Network

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Original scientific paper

Abstract: **A wireless body area network (WBAN) allows the integration of low power, invasive or non-invasive miniaturized sensors around a human body. Each intelligent sensor has enough capability to analyze and process the physiological parameters and to forward all the information to a central intelligent node for disease management, diagnosis and prescription. The data transmission rate of various biosensors is heterogeneous. Furthermore, the limited energy resources and computational power of these sensors have urged the development of low power energy efficient medium access control (MAC) protocol. This paper studies the performance of Preamble-Based time division multiple access (PB-TDMA) protocol for a heterogeneous non-invasive WBAN. Simulation results show that the performance of PB-TDMA protocol outperforms S-MAC and IEEE 802.11 DCF in terms of throughput and power consumption.**

Keywords: **medium access protocol, preamble, low power, wireless body area network,**

I. Introduction

According to National Center of Health Statistic (NHCS), the leading cause of annual deaths in the US is heart disease, i.e., 652,486 and 150,074 people die due to cardiovascular and cerebrovascular diseases [1]. The ratio is 17% in South Korea [2]. The healthcare expenditure in the US is expected to reach 2.9 trillion by 2009 and 4 trillion by 2015, or 20% of Gross Domestic Product (GDP) [3]. Cardiovascular disease is the leading cause of death and it accounts for approximately 30% of all deaths worldwide [4]. In UK, it is 39% of all deaths [5]. In Europe, 90% of people die due to arrhythmogenic event [6]. Irregular heart beat causes such deaths and can be monitored before heart attack. Holter monitor is used to collect cardio rhythm disturbances but the system doesn't provide real-time feedback and the ECG data is collected for offline processing.

Manuscript received June, 2008 and revised Octobar, 2008.
This research was supported by the MKE (Ministry of Knowledge Economy), Korea, under the ITRC (Information Technology Research Center) support program supervised by the IITA (Institute of Information Technology Assessment) (IITA-2008-C1090-0801-0019).
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Transient abnormalities are sometimes hard to capture. For instance, many cardiac diseases are associated with episodic rather than continuous abnormalities such as transient surges in blood pressure, paroxysmal arrhythmias or induced episodes of myocardial ischemia and their time cannot be predicted. The accurate prediction of these episodes provides high quality health services.

Wireless body area network (WBAN) is a key technology to prevent the occurrence of myocardial infarction, monitoring episodic events or any other abnormal condition and can be used for long term monitoring of patients. The seamless integration of small and intelligent wireless sensors is used to monitor the patient's vital signs and provide real-time feedback. They are used to develop a smart and affordable healthcare system and can be a part of diagnostic procedure, maintenance of chronic condition, supervised recovery from a surgical procedure and to monitor effects of drugs therapy. A WBAN usually consists of three levels [7]. The first level is called sensor level, which consists of low power miniaturised sensors such as electrocardiogram (ECG)-used to monitor electrical activity of heart, oxygen saturation sensor (SpO2)-used to measure the level of oxygen, electromyography (EMG)-used to monitor muscle's activity and electroencephalography (EEG)-used to monitor brain's electrical activity. The second level comprises of a PDA or central intelligent node, which gathers vital information of a patient and communicates with a remote station. The third level consists of a remote base station, which keeps patient medical records and provides diagnostic recommendations. A proactive and adaptable WBAN system requires the resolution of many technical issues and challenges such as biosensor design, power scavenging issue, low power RF data paths, scalability, fault tolerance, low power MAC protocol, mobility, interoperability, security and privacy. In this paper, we investigate the energy efficiency and throughput performance of a Preamble-Based TDMA (PB-TDMA) protocol for a WBAN. We consider the heterogeneous characteristics of miniaturized biosensors throughout the simulation. The simulation results are compared with S-MAC and IEEE 802.11 distributed coordination function (DCF) protocols.

The rest of the paper is categorized into five sections. Section 2 reviews related work on a WBAN. Section 3 briefly discusses PB-TDMA protocol. In section 4 and 5, we present simulation setup and results. Section 6 concludes our work.

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II. RELATED WORKS

Traditionally, Holter monitors were used to collect cardio rhythm disturbances for offline processing without real-time feedback. Some other monitoring systems such as portable Holter monitors [8], simple pulse monitors [9] and activity monitors [10] have been developed. However, these traditional systems are unsuitable for ambulatory health monitoring. The sphymacor and portapress system are installed in laboratories and hospitals for hypertensive study. Both methods provide invalid information of arterial health and do not reflect any form of arrhythmias [8]. A WBAN project called ubiquitous monitoring environment for wearable and implantable Sensors (UbiMon) aims to develop a smart and affordable healthcare system and is designed by using six components: sensors, remote sensing units, local processing units, central server, patient database, and workstation. This project has enabled the development of a body sensor network (BSN) hardware platform called BSN node. With 26mm size, BSN node enables the development of biosensors and provides a versatile environment for pervasive healthcare applications [16]. The BSN node uses Tiny OS and requires 0.01mA in active mode. A Harvard University project called CodeBlue aims to provide real-time triage decisions and long term health monitoring [12]. This project has developed accelerometer, EMG sensor and gyroscope sensors. The MobiHealth has focused on the development of generic platform for affordable healthcare system [13]. A project called Connect has concentrated on the development of wireless communication infrastructure that enables disable people to customize their wireless devices, i.e., allows them to communicate with the medical expert [14]. Many ongoing projects have considered the emerging UWB technology for a WBAN. A pulse-based UWB scheme for on-body communication networks [15], UWB channel measurement with antennas placed on human body [16] and UWB antennas for a WBAN [17] have facilitated research in reducing the baseline power consumption of sensor nodes.

A limited research effort is dedicated to investigate a low power MAC protocol for a WBAN. A novel TDMA protocol called H-MAC has been proposed in [18]. This protocol exploits the biosignal features to perform TDMA synchronization and improves the energy efficiency of a WBAN.A number of researchers have considered IEEE 802.15.4 standard [19] at 2.4 GHz band for a non-invasive WBAN. A performance analysis of IEEE 802.15.4 standard has been presented in [20], where a star network configuration with a non-beacon mode has been adapted to prolong lifetime of sensors from 10 to 15 years. However, in a non-beacon mode, the coordinator cannot communicate with the nodes until invited by them. In a beacon-enabled mode, the coordinator can initiate the communication with nodes. But nodes must wake up to receive the beacon frames, which is not suitable for a WBAN where some sensors do not always send the data. A detailed discussion on the theoretical throughput of low power wireless standards in the context of a WBAN is presented in [21]. The adaptation of IEEE 802.15.4 standard is sufficient for some of the medical applications but is not always enough. The heterogeneous data rate characteristic of miniaturized sensors in a WBAN has restricted the adaptation of IEEE 802.15.4 standard. For instance, the average data transmission rate of ECG (10kbps) and EMG (1Mbps) sensors are different, which cannot be accommodated by any existing standards. To best of our knowledge, no one has analyzed any MAC protocol, which considers the heterogeneous data rate characteristic of biosensors in a non-invasive WBAN.

III. PREAMBLE-BASED TDMA PROTOCOL

MAC protocols are classified into contention-based and TDMA-based protocols. In contention based protocols, nodes contend for the channel using CSMA mechanism. If the channel is busy, the node defers its transmission until it becomes idle. These protocols are scalable with no strict time synchronization constraint. However, they incur significant protocol overhead. In TDMA-based protocol, the channel is divided into time slots of fixed duration. These slots are assigned to nodes and each node can transmit during its slot period. These protocols are energy conserving. Because the duty cycle of radio is reduced and there is no contention, idle listening and overhearing. But these protocols require frequent synchronization.

PB-TDMA protocol employs traditional TDMA principle [23]. The nodes are assigned specified slots for collision-free data transmission. These slots are repeated in fixed cycle. A complete cycle of these slots is called frame. In PB-TDMA protocol, each TDMA frame contains a preamble and a data transmission slot as illustrated in Fig 1. A node always listens to the channel during preamble and transmits in a data transmission slot. The preamble contains a dedicated subslot for every node. These subslots are used to activate the destination node by broadcasting the destination node ID of outgoing packet. After receiving the preamble, the destination node identifies the source node. Each node turns off its radio when it has no data to transmit. This mechanism avoids unnecessary power consumption of sensor nodes. The radio is turned on, when the node finds its ID in the preamble or when the node has data to transmit. Current NS-2 [24] supports a single hop TDMA protocol for wireless sensor network, which is an ideal topology for a WBAN.

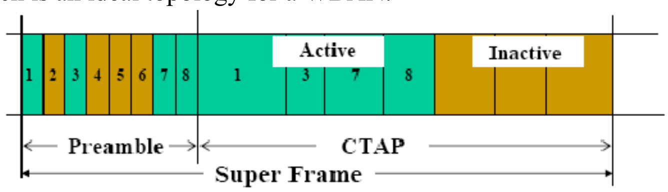

Fig 1. PB-TDMA Superframe Structure

IV. SIMULATION SETUP

NS-2 has been used for simulations. The following part gives an insight to our simulation environment.

4.1 PHY Setup – We consider low power Nordic nRF2401 transceiver for simulations. This radio transceiver operates in the 2.4-2.5 GHz band and is most suitable for a WBAN. The optimum transmission power is -5dBm. But we verify the performance for various transmission powers, down to -45dBm. The simulation parameters of Nordic transceiver are listed in Table 1.

4.2 Propagation Model – Currently NS-2 supports three propagation models, i.e., FreeSpace, Shadowing and TwoRayGround. Shadowing model is used as a propagation model throughout the simulation. This model considers the crossover distance after which the reflecting rays may interfere with the direct ray and drastically reduce signal strength. The path loss exponent, shadow deviation and reference distance for a WBAN are listed in Table I.

TABLE I. Simulation Parameters

Parameter	Measured Value
Shadowing propagation model	
Path loss exponent	7.4
Reference distance	0.1m
Wavelength	0.125m
Shadow deviation	9dBm
Transmitting antenna gain	1.0
Receiving antenna gain	1.0
Nordic nRF2401	
Output power	-5 dBm
Maximum data rate	1000kbps
Supply current in transmit	10.5mA
Supply current in receive	18mA
Sensitivity	-90dBm
Threshold to avoid collision	-95dBm
Voltage	1.9V

4.3 Nodes Setup – We consider 9 nodes firmly placed on a human body as illustrated in Fig 2. The nodes are connected to the coordinator in a star topology. The initial node energy is 5 Joules. The data rate of the nodes is heterogeneous. The average data transmission rate of ECG is 10kbps, EEG is 70kbps and EMG is 1Mbps. All other nodes transmit data at 1kbps speed. The simulation area is 1 × 1 meter and each node generates Constant Bit Rate (CBR) traffic. The packet size is 128 bytes. The transport agent is User Datagram Protocol (UDP). Every node forwards data to the coordinator for diagnostic analysis. The simultaneous transmission of multiple nodes at the same time is triggered in order to get context aware information. The reason is that sometimes environmental factors can influence the precision of ECG measurements. Moreover, the human body can respond differently in cold temperature or high altitudes. This may, for example, restricts the blood flow to fingers and consequently leads the SpO2 sensor to incorrect measurement. Therefore, not only ECG measurement is important to monitor patient's activity, but also context information such as location, environment and current patient status.

4.4 Performance Metrics – We use two performance metrics to evaluate the performance of MAC protocols.

1- Energy loss – The loss of energy at each node during simulation time. It is measured in Joules/Second.

2 – Packet Delivery Ratio – The ratio of number of data packets received at the coordinator to the number of data packets generated by CBR sources.

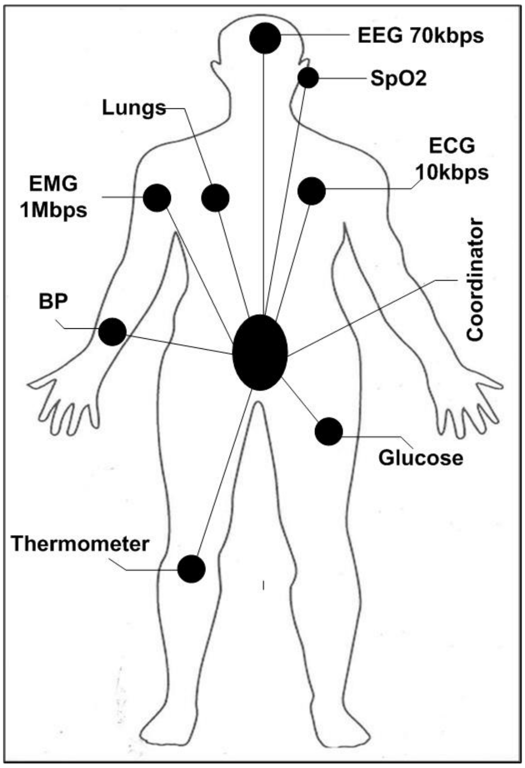

Fig 2. Nodes deployment in 1 × 1 meter WBAN

V. SIMULATION RESULTS

To verify the performance of PB-TDMA, a number of simulations have been carried out in NS-2 to determine the energy loss at each node for different transmission powers. The simulation time is 500 seconds. We consider BP, ECG, EMG and EEG for performance analysis. The reason is that all these sensor nodes have heterogeneous data rate. Fig 3 shows the residual energy at each node during simulation time. After the nodes finish their transmissions, they go into sleep mode. ECG sensor, for instance, goes into sleep mode after 150 seconds. EMG node has a considerable energy loss compared with other nodes due to its high transmission speed of 1Mpbs. The coordinator has substantial energy loss, because it always listens to other nodes. However, the energy is conserved at coordinator when few nodes transmit the data. At 300 seconds, when the data transmission of EEG sensor is finished, the coordinator consumes less energy as indicated by slight change in the curve. But in a WBAN, the power consumption at coordinator is not a critical issue.

Fig 4 shows the residual energy of EMG sensor node for different transmission powers. We notice a minor change in energy loss at EMG node for three transmission power. We conclude that reducing the transmission power doesn't save energy. This requires an efficient power management scheme. Fig 5 illustrates the residual energy at EMG using IEEE 802.11 DCF, S-MAC (100% duty cycles) and PB-TDMA protocols. As S-MAC requires 41 seconds for nodes synchronization, the real-data transmission starts after synchronization. The PB-TDMA protocol transcends both S-MAC and 802.11 DCF in terms of power consumption. S-

MAC reduces less energy than IEEE 802.11 DCF but gives poor packet delivery ratio. Fig 6 shows the packet delivery ratio for various transmission powers. At -5dBm, IEEE 802.11 DCF gives better packet delivery ratio, almost 100%, but is paid by considerable power consumption. PB-TDMA gives 90% value for -5dBm, while S-MAC gives only 5% value. The reason is that S-MAC protocol is intended for a multi hop wireless network. The average packet delivery ratio of PB-TDMA is better than 802.11 DCF and S-MAC.

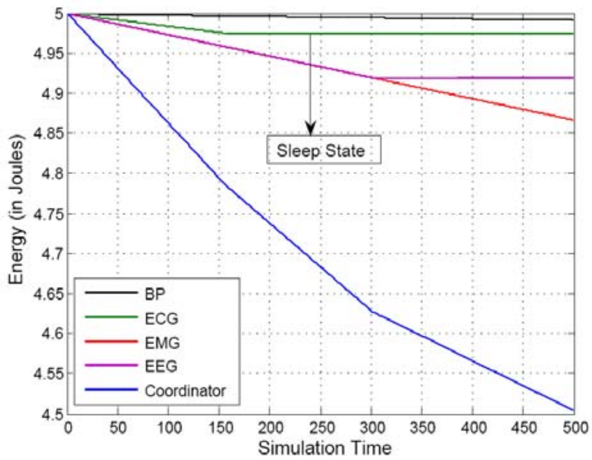

Fig 3. Energy loss at sensor nodes

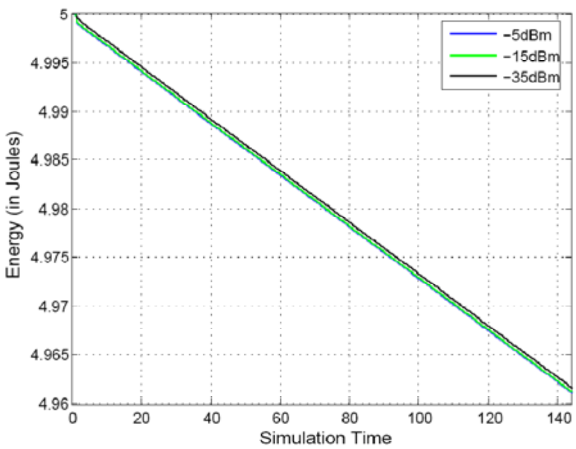

Fig 4. Energy loss at EMG sensor for different transmission powers

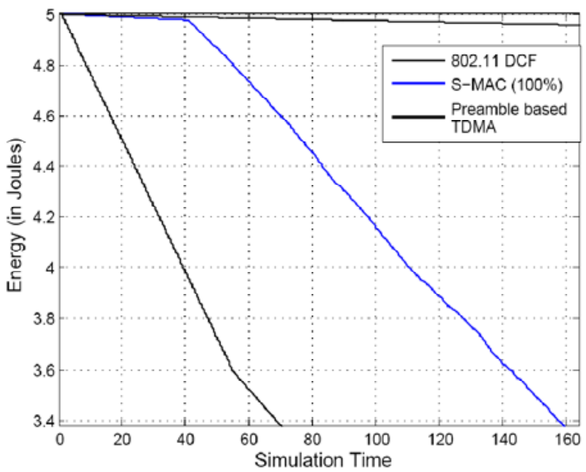

Fig 5. Energy loss at EMG sensor for various MAC protocols

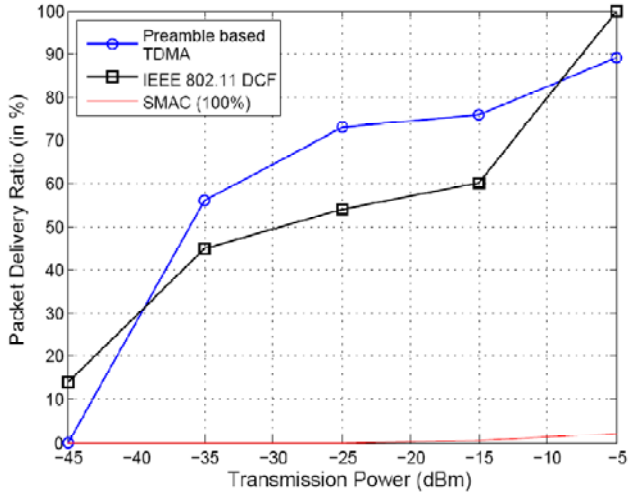

Fig 6. Packet delivery ratio of PB-TDMA, S-MAC and IEEE 802.11 DCF.

VI. CONCLUSIONS

In this paper, we analysed the performance of PB-TDMA protocol for a wireless body area network. We studied the heterogeneous characteristics of different biosensors in a non-invasive WBAN. Furthermore, we concluded that reducing the transmission power of sensor nodes doesn't save energy. This requires optimal management scheme. The simulation results were compared with IEEE 802.11 DCF and S-MAC protocols. The PB-TMDA protocol gives better performance compared with IEEE 802.11 DCF and S-MAC in terms of throughput and power consumption.

Future work includes the improvement of PB-TDMA protocol, which considers both periodic and sporadic traffic to handle life threatening events. The new protocol will find innovative solutions to satisfy the critical data rate requirement of a WBAN.

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