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Performance Analysis of the Physical and Medium Access Control Layer Parameters with Effect of Varying Transmission Power using IEEE 802.15.4 Standard for Wireless Body Sensor Networks

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Abstract

Wireless Body Area Network (WBAN) consists of miniaturized, tiny, low power body sensor nodes communicating with a BAN (Body Area Node) Coordinator through Radio Frequency (RF) interface link. Recent advancements in the field of Information, Communication and microelectronics have led to the realization of WBAN, which will help in hazardous, long term health monitoring especially for elderly people. Most of the present day's Body Area Network node's MAC/PHY protocols are built using IEEE 802.15.4 and ZigBee standard. This standard will surely make an impact through its improvisation especially in MAC/PHY layers in the days to come. Already researchers have been working on the new WBAN standard. This paper emphasizes the basic structure of IEEE 802.15.5 MAC/PHY layers through experimentation on 7 specific, static body sensor nodes placed at appropriate points on the human body transmitting heterogeneous data using Time division multiple access and Contention access period of CSMA/CA protocol. The body area channels are considered with temporal and fixed path loss values. Physical layer parameters such as latency and fade depth distribution, MAC packets received and breakdown packets of MAC layer are presented. Packet with respect to the unique and useful parameters, packet received from Media Access Control layer of each node under various conditions of the channel and with Carrier Sense Multiple Access/Collision Avoidance comparing with Time Division Multiple Access techniques. Experimental results show that a transmitting-12dBm to -15dBm was found to be suitable for energy efficient WBAN system. For TDMA scheme, the algorithm may be fine-tuned to reduce the number of packet failure which improves the energy efficiency for any kind of channel.

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Keywords: WBAN; MAC; PHY; packet delivery; BAN Node

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1. Introduction

In recent days heart related disorders have become most common amongst the people of all ages and many irregularities in the functioning of kidney, pancrease and diabetes etc. which will lead to heart attacks. Major issues related to health will ultimately lead to cardiac disorder. There is such a need existing even in developing country like India, wherein there is a large ratio of people suffering from chronic illness such as heart malfunctioning leading cardiac arrest, kidney failure, diabetes leading to heart related hazards as well as lung infections [1]. Wireless Body Sensor Network has been evolved to provide health care for people suffering from chronic diseases or aged people who need extra medical facilities. It consists of tiny body sensor nodes worn on or implanted in the body which continuously monitors the health parameters and forwards to the Coordinator node. Later it may be sent to the doctor or it may be stored in the database of the hospital. So 'medical facility for anytime, anywhere' for the people who have worn the body sensors refers to as Ubiquitous health monitoring (UHM) system [2].

The communication network standard useful in establishing the radio frequency(RF) link at various interfaces are basically introduced by IEEE 802.15.4,4a and the new WBAN standard IEEE 802.15.6 [3]. In this paper,IEEE 802.15.4 standard with ZigBee has been considered as most of the commercial sensors make use of this standard [3]. In order to increase the life span of the body sensor node, energy consumption during the transmission of information must be regulated. Medium Access Control (MAC) and Physical (PHY) layer play an important role in the energy efficiency improvement process of the network. Thus performance verification of MAC and PHY layers of body sensor nodes in UHM systems are analysed for various transmission powers. No such efforts are made in the literature so far and in order to keep track of energy consumption, the appropriate transmitting power has to be known for the given scenario. Hence section 2 introduces UHM system, IEEE 802.15.4 standard MAC protocol and PHY layer attributes were dealt in section 3,followed by the transmission power information, the scenario created and the parameters set are considered in section 4 and section 5 discusses the results obtained and also the future scope.

2. Ubiquitous Health Monitoring System

Ubiquitous health monitoring system (UHM) consist of body sensor nodes positioned at certain positions on the body, measuring specific parameters, forwarding the information to a common hub called access point [7][8]. WBAN system consists of body sensor nodes such as Electro Cardio Gram (ECG), Electro Encephalo Gram (EEG), heart beat sensor, oxygen saturation, vibration sensor etc. are connected via Radio Frequency(RF) link to an access point as one of the configuration. Sensed data will be forwarded through intra body communication to the access point and then to the cloud based internet in order to construct Internet of Things (IoT) based WBAN system which is shown in Fig. 1.Generally the wireless networks are networked through star, tree and mesh network topologies; however star topology is the most suitable topology. In this type, an access point plays a vital role in collecting the information from all nodes and then forwarding to the cloud based server.

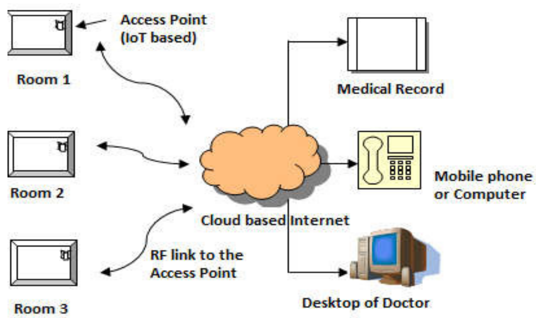

Fig. 1. WBAN system as UHM system

Wireless Body Area Networks are categorized under Wireless Personal Area Network (WPAN)s considered for low range, low power IEEE 802 standards. These communication standards define only the two layers of the International Standard Organization (ISO) Open System Interconnection (OSI) protocol reference model [5][7]; the physical (PHY) and the sub layer of data link layer namely Medium Access Control(MAC) layer. The other layers are not specified in the standard and normally specified by the industrial consortium formed by companies manufacturing and using the particular standard. WBAN is an IEEE 802 based model in which there are Upper application, middle LLC and MAC layers and the lower PHY layers as shown in Table.1.

The most common topology that can be used in UHM system is a star topology where the nodes are connected to a central coordinator in star manner[2].The sensor nodes are powered by tiny batteries whose power which is a trade-off between the size of the device and lifespan of the sensor node. Hence the energy consumption of the sensor node must be so small that the node acquires longer life. It is worthy to have maintenance free as well as unrechargeable battery in order to satisfy the patient's comfortability and satisfaction level. Hence it is with the hands of Medium access control layer algorithms to properly access the channel without collision being occurred for the packets as well as avoiding retransmission [3][4].

During the initial phase of the Wireless Personal Area Network setups for Body sensor network applications, IEEE 802.15.4 standard was used. Later, few more standards such as IEEE 802.15.4a and IEEE 802.15.6 were introduced with the intention of low power consumption and high data rate [5] [6].

3. IEEE 802.15.4 and Zigbee Standard

ZigBee has provided the layered architecture for WBAN system considering the IEEE 802.15.4 MAC and Physical layer standards. Commercial body sensor nodes are making use of ZigBee standard with Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol for multiple access method. Though the Bluetooth technology (IEEE 802.15.1 standard) also was one of the technology in the race of building communication standard its high data rate (≈1 Mbps), huge power consumption in comparison with ZigBee, IEEE 802.15.4a and the new IEEE 802.15.6 standard has inhibited the application in UHM system. The range was also limited in comparison with the other two schemes and the system was based on master and slave oriented protocols.

PHY layer is the lower most layers in the architecture of any network and hence WBAN network system. It mainly deals with the physical attributes such as bits in terms of analog/digital, voltage or current levels to represent the bits, modulation techniques etc. The measurable parameters from the PHY layer are Bit error rate/symbol error rate, Probability of error and data rate of the system [10].

The physical layer is responsible for

1. Activation and deactivation of the radio transceiver.
2. Clear channel assessment
3. Data transmission and reception
4. Preamble/start frame delimiter and packet structure.

Reliability for BAN healthcare applications needs to be met in the face of these four particular challenges for BANs. The signal from PHY layer will be transmitted as bit through wireless channel. During the propagation, there will be fading of the signal which is estimated with fade depth distribution. Latency is a prime parameter that decides the Quality of Service (QoS) of a WBAN system.

In WBAN, the RF part of the sensor consumes most of the energy and hence becomes one of the most important entities to be considered. MAC protocol plays a significant role in controlling/duty cycling the RF module and in reducing the average energy consumption of the sensor node. In other words, the MAC protocol is required to achieve maximum throughput, minimum delay, and to maximize the network lifetime by controlling the main sources of energy wastage, i.e., collision, idle listening, overhearing, and control packet overhead. A minimal number of control packets should be used for data transmission.

Generally MAC protocols are grouped into the following types.

3.1. Contention-based MAC protocol

In contention-based MAC protocols such as Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) protocol, nodes contend for the channel to transmit data. 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 problem with significant protocol overhead.

Multiple access protocol used in wireless body sensor network (WBAN) is Carrier Sense Multiple Access Technique/ Collision Avoidance (CSMA/CA).The following are the details of the frame structure of CSMA frame and power consumption [9][10].

(i) Superframe Structure

In CSMA/CA protocol frames, time is divided into slots. The structure formed by many such slots is called Superframe. A Superframe has beacon period, contention access period and control messages are transmitted.

(a) Contention Access Period

During the CAP, biosensors contend for the channel access. This is called channel access using CSMA/CA protocol. Here, dedicated or Guaranteed Time Slots are not used (which means that GTS = OFF) as shown in the Fig. 2.

Beacon	CAP [GTS=OFF]	CFP [GTS=ON]	Inactive period

Fig. 2. Superframe structure

(b) Contention Free Period

It allows dedicated time slots (GTS = ON) to individual biosensors for their transmission of data using TDMA protocol scheme as shown in Figure 4. This slot may also be used to transmit emergency data. However it can also be utilised to implement TDMA principle. Fig. 3.shows the Superframe with Contention free period (CFP) slots.

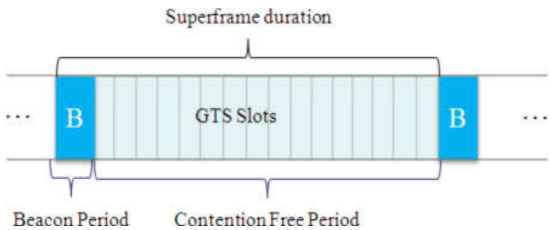

Fig. 3. Superframe with GTS slots

Battery powered devices are operated using duty cycling to reduce power consumption. Each device periodically listens to the channel to check whether the message is pending or not. During inactive period, the body sensor enters into “sleep” state. The protocols are energy conserving protocols because the duty cycle is reduced and there are no contention, idle listening, and overhearing problems. However, common TDMA needs extra energy for periodic time synchronization.

3.2 Schedule-based MAC protocols

In schedule-based protocols such as Time Division Multiple Access (TDMA) protocol, the channel is divided into time slots of fixed or variable duration. These slots are assigned to nodes and each node transmits during its own slot period. These protocols are energy conserving protocols. The duty cycle of the radio is reduced and there is no contention, idle listening and overhearing problems. However, these protocols require frequent synchronization. TDMA-based protocols provide good solutions to the traffic correlation, heavy collision, and Clear Channel Access (CCA) problems. All the sensors (with and without data) are required to receive control packets periodically in order to synchronize their clocks.

4. Effect of Varying Transmitting Power on the performance of the WBAN system

Energy efficiency is a key parameter for any wearable wireless body sensor node wherein it is a crucial parameter for implantable body sensor node. The range of the body sensor node depends on the amount of transmitting power (Pt)used while transmitting information.

If P_r is the receiving power from an access point whose antenna of gain *Gr*, linked through radio frequency(RF) with the a sending body sensor node with an antenna of gain *Gt*, then according to Friss transmission law,

$$RSSI = P_r = \frac{Pt\ Gt\ Gr\ \lambda^2}{158\ d^2} \tag{1}$$

$$d^2 = \frac{P_t \lambda^2}{158\ RSSI} \tag{2}$$

where Pt is the transmitting power, λ is the wavelength of the RF signal, d is the distance from the transmitting node antenna to the receiving node antenna and $RSSI$ is the Received Signal Strength Indicator. Equation (1) is useful to calculate the received power and Equation (2) provides the distance information. Also, for the sake of simplicity, the gains $Gt\ Gr$ are considered to be unity.

Greater the Transmitting power, larger will be the range at which the information reaches. But this will increase the power consumed by the node, reducing the efficiency and hence life span of the body sensor node. Though it increases Signal to noise ratio, it leads to the reduction of life of a node.

(a) Experimental Setup

In order to provide a trade-off between values of Transmitting powers, a scenario has been created with 7 wearable, static body sensor nodes transmitting heterogeneous data packets to the BAN coordinator, choosing star topology. The details of the heterogeneous data type and Body node placements on the body are as shown in Fig. 4 and the types of body sensor nodes considered are as given in Table 1.

Two MAC protocols such as Contention Access Period of CSMA/CA and TDMA have been considered. The condition of Guaranteed Time slot (GTSon) is considered for the scheduled slots with Time Division Multiple Access scheme. Similarly GTSoff state is considered to be the contention access period of CSMA/CA scheme. Both of these schemes are considered under two environments surrounding the body sensor nodes namely fixed path loss and temporal path loss. They are the two most common channel models for a WBAN. Transmitting powers are considered to be any of the values among, -20dBm,-15dBm,-12dBm and -10dBm which are the standard values for transceivers or radios. The following results are obtained.

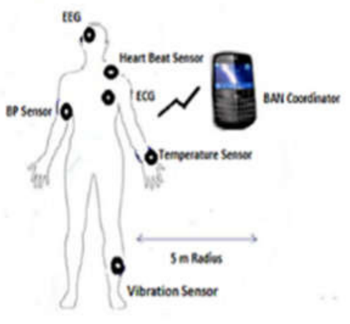

Fig. 4. Experimental Scenario with 6 body area sensor nodes and a BAN Controller

Table. 1. Body sensor nodes and no. of packets

Node No.	Body sensor node	No. of packets sent/sec
1	ECG	10
2	EEG	10
3	Heart Beat sensor	1
4	Blood Pressure sensor	2
5	Temperature Sensor	2
6	Vibration sensor	3

(A) Application Latency

The application level latency shown in Fig. 5 is for a contention access period of CSMA/CA multiple access scheme with temporal pathloss.

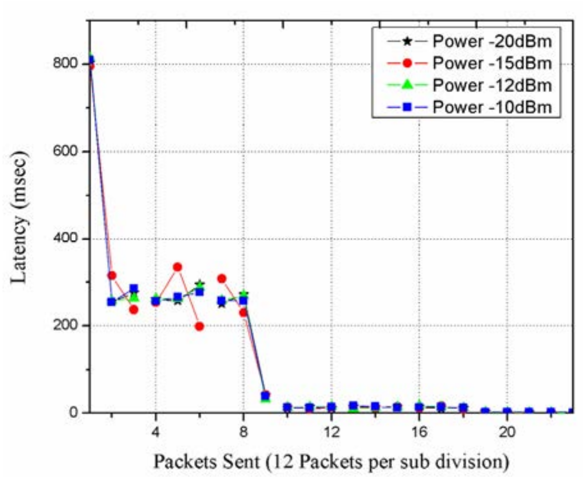

Fig. 5. Application level latency for Contention access period with temporal pathloss

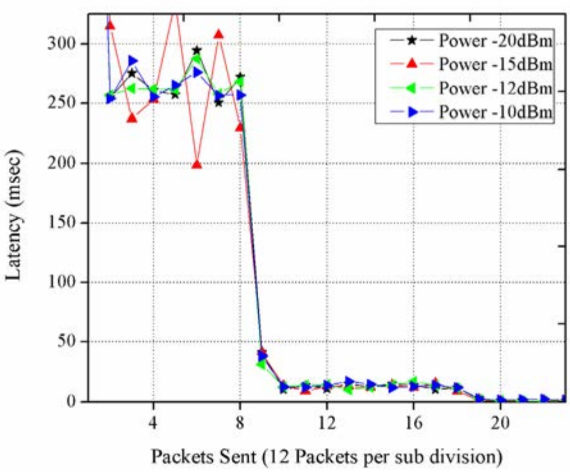

Fig. 6. TDMA with temporal pathloss

In this case, only from packet size of 24 to 96, there was a fluctuation in the latency value between 200 – 300 msec. Initially, for packet size less than 24, there was a huge latency of 800 msec due to the initial setup of the network and it got stabilized after 96 packets.This is shown in Fig.5.

The node was readjusted for the given size of buffer from 24 packets onwards upto around 96 packets. Then onwards the network management has resulted in stabilization and latency was found to be minimum (≈10 msec). The performance was similar for fixed and temporal pathloss. In both cases of path loss models, the higher(-10dBm) and lower(-15dBm) powers, there was an oscillating latency. This means that the performance for Contention access period with temporal or fixed path loss remains the same irrespective of the channel.

(B) TDMA with Temporal pathloss

When there is a dedicated timeslot for packet delivery, up to 120 packets, there is a fluctuating latency for all powers. Once the numbers of packets were increased from 120, latency was found to be minimum around 25msec, up to a packet size of 240.More oscillations were found in these regions with -10dBm. Also, delay was more with Pt = -20dBm and minimum with Pt = -15dbm.TDMA with temporal pathloss is as shown in Fig. 6.

(C) Fade depth distribution

The information was tested for fading characteristics at different channel types under four transmitting powers as shown in Fig.7. From the graph, it can be concluded that the fading distribution reduces from -20,-15,-10 and -12 dBm respectively.

As the transmitting power was changed from lower to higher values, the number of packets failed due to unavailability of acknowledgement increases. This is because the signal strength for acknowledgement will be missed with the contention period of the CSMA/CA protocol. But the MAC algorithm counter reacts to this situation by receiving the packets through second attempt.

However there were no packet failures occurred due to buffer overflow, busy channel and PAN coordinator being unready. Contention Access Period (CAP) for fixed pathloss case with packet reception and failure details are shown in Table 2.The results obtained are almost similar to the case of CAP with fixed path loss.

Table. 2. Packet delivery and failures for Contention Access Period with fixed pathloss

Failed, no ack	Success, first try	Success, not first try
35.4	937.2	36.2
0.4	92.8	6.8
59	910	39
7.2	185.8	8
18.6	258	25.4
14.4	266	21.6

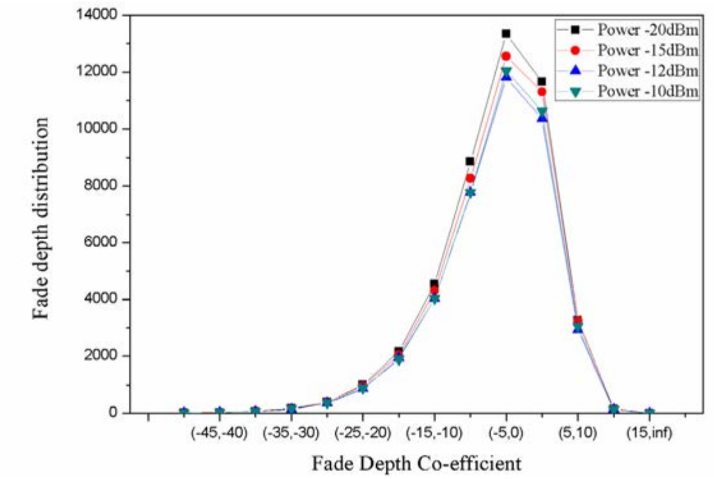

Fig. 7. Fade depth distribution

There was a situation of no acknowledgement being received by the sending sensor nodes. This has resulted in packet Contention Access Period with Temporal pathloss. For a case of TDMA with temporal pathloss, the failed packets are due to buffer overflow and PAN coordinator being unready. There are few packets failed due to no acknowledgement being sent. This situation can be overcome by dynamically adjusting the buffer size depending on the packet congestion. The problem with synchronization is observed here between the nodes and PAN coordinator leading to packet failure. Table 3 shows the overall performance of CSMA/CA and TDMA.

Table 3. Overall average performance in terms of received/failed packets of MAC layer per node

Channel access scheme	Packet failure due to buffer overflow	Packet failure due to No acknowledge -ment	No. of Successful packets (I try)	No. of Successful packets (II try)	Successful Packet percentage
Contention Access Period of CSMA/CA	0	35.4	937	36.2	96.5
TDMA	154.4	33.2	797.6	16.8	81.3

(Pt = -15 dBm; Pathloss : temporal and fixed; Number of packets = 10; Simulation time = 100 sec)

Regarding packet delivery of MAC layer are concerned, Contention Access Period of CSMA/CA was found to be more efficient than TDMA multiple access schemes. The reasons for packet failure in this case were due to buffer overflow and no acknowledgement being received. There is a need for dynamic algorithm in TDMA to take care of the packet failure due to these facts or to go for more defined second try. This modification in the algorithm will be incorporated in the future work.

5. Discussion and Conclusion

Wireless Body Area Network consists of body sensor nodes transmitting physiological data to the access point through radio frequency link. Since the nodes are tiny in nature, energy consumption of each node while being in the network is essential as it decides the lifespan of the sensor nodes. Hence, appropriate transmitting power should be chosen for the given practical application. For a scenario with 7 wearable body sensor nodes, with heterogeneous packet transmission, Contention access period of CSMA/CA and TDMA schemes are incorporated in the simulation using Castalia Network Simulator. Two wireless radio propagation BAN channels namely fixed and temporal pathloss are considered. Latency for Contention access period with temporal or fixed path loss remains the same irrespective of the channel. It was found that with low data traffic, Contention Access Period of CSMA/CA multiple access schemes offers huge latency (around 800 msec) for both temporal and fixed pathloss channels. Whereas with the same scenario, TDMA provided 300 msec latency in spite of huge fluctuations. Hence, for UHM system with TDMA,the performance and fading characteristics was found to be better especially at a transmitting power of -15dBm, but at higher traffic, Contention Access Period of CSMA/CA showed smaller latency. For medium Access Control layer, packets with Contention Access Period and any kind of pathloss channels, there was only minimum average MAC packet failure due to no acknowledgement being received at -15dBm. But packet delivery percentage was found to be excellent in CSMA/CA multiple access technique than TDMA scheme. Future work includes the comparison of CSMA/CA with WBAN specified IEEE 802.15.6 standard and modifying the algorithm of TDMA for mobile nodes in such a way that the packet failure rate will be reduced due to buffer overflow, no PAN coordinator being ready as well as acknowledgement being unsent.

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