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Examination Of IEEE 802.15.4 Zigbee Multi-Hop Transmission In Wireless Body Area Networks

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ABSTRACT

Wireless Body Area Networks (WBANs) in recent years is emerged as the most demanding research area. WBAN is concerned with the remote monitoring of patients health and timely delivery of sensed data. IEEE developed a standard for low power and low data rate communication which is IEEE 802.15.4; it is widely known also Zigbee. Sensor nodes in WBAN require different data rates, due to their different applications. Zigbee due to its low power and low data rate features is the ideal candidate for communication in WBAN. In this paper multi-hop Zigbee communication for WBAN is considered and nodes with different data rates are used. The main aim of this paper is to evaluate the performance of Zigbee for multi-hop transmission in WBAN with varying data rates and different frequencies. We consider a real-time scenario of a hospital where different patients with their symptoms like Electroencephalogram (EEG), Electrocardiogram (ECG), Blood pressure etc. are monitored. We simulate this scenario by taking into account the different frequencies and data rates.

Keywords: *WBANs, Multi-hop, Zigbee, Multiple frequencies*

1. INTRODUCTION

Many countries face ageing population, as number of senior citizens increasing all over the world. With increase in ageing population, there is a need to monitor their health on regular basis. Specialized health monitoring of serious cases are very important, however, it is quite expensive. With emerging technology, remote patient monitoring is possible. WBAN consists of interconnected sensors, either placed around body or small enough to be placed inside the body. It provides ease of connectivity with other systems and networks thus allowing proper health monitoring.

With help of WBAN, monitoring of patient is done remotely through internet, intranet or any other network. Wireless sensors are major part of the healthcare system, which works as sensing node and measure different physiological signals such as heart rate, body and skin temperature, blood pressure, Electrocardiography (ECG), Electroencephalogram (EEG), Electromyography (EMG) signals, oxygen saturation and respiration rate etc. These collected signals transferred to a central node or Coordinator or Data aggregator or Gateway. Coordinator node provides the connectivity with the external database server or medical server. These sensors continuously monitor data and send it to health care center.

In patient monitoring systems, data transmission reliability with low delay is very important. Different technologies have been used in transmission of medical data to health care center like Bluetooth connected to cellular system [1]. In this paper, we present Zigbee multi-hop transmission with varying data rates in WBAN.

A low cost and reliable approach is preferred for transmission of data from sensor nodes to health care center. Multi-hop transmission means that transmission of data through different hop to the main coordinator. Fig. 1 shows the complete structure of multi-hop transmission of medical data through Zigbee.

Bluetooth considered being a network that has easy connection with cellular systems. Zigbee and Bluetooth offer low power consumption, respective data rate and both are useful for short range communication. However, potential interference from different devices is a concern for Bluetooth [1]. Zigbee consumes less power than Bluetooth.

In this work, we focus on calculating overall delay, load and throughput of the network at different data rates by using different frequencies. Media Access Delay (MAD) is also calculated for the network. We consider multi-hop structure for each path, which consists of sensor nodes to Zigbee coordinator and then from Zigbee coordinator to main coordinator which is connected with the server.

Fig. 1 shows the complete scenario of Multi-hop transmission of medical data at varying data rates of 20, 40 and 250 Kbit/s. This diagram shows the multi-hop communication consisting of Zigbee network. In first hop, data is sent from nodes connected at body to the coordinator of that personal network. Whereas, in second hop coordinator sends the data to the main coordinator connected with the server room. There are three different data rates at which data is sent. Personal Area Network (PAN) 1 sends data at 20 Kbit/s, PAN 2 sends data at 40 Kbit/s and finally PAN 3 sends data at 250 Kbit/s. Three different data rates are used for the

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transmission of critical data at 250, intermediate data at 40 and least important data at 20 Kbit/s.

The rest of the paper is organized as follows. Related work and motivation are given in section II. Section III describes introduction of Zigbee. Simulation and results using OPNET Modeler are given in section IV. Section V concludes the work.

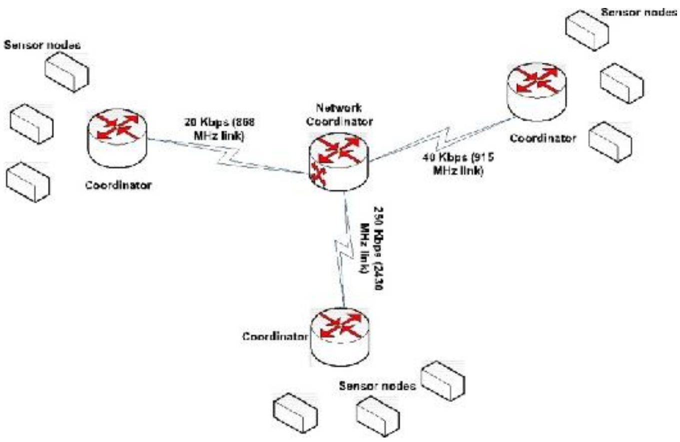

Figure-1: Multi-Hop Transmission at varying data rates

2. RELATED WORK

Authors evaluate overall transmission delay of ECG packets over two-hop wireless channel. ECG data from BAN are compressed and sent through a Bluetooth-enabled ECG monitor to a smart phone and thereafter to a cellular Base Station (BS). Exploiting the inherent heartbeat pattern in ECG traffic, they introduce a context aware packetization for ECG transmission in [1]. However, ECG is not only data that can be transmitted; other medical data at different data rates is also sent. In this paper we calculate the overall delay, throughput, load and medium access delay of multi-hop network at varying data rates which is not done in paper [1].

Authors in paper [2], state that IEEE 802.15.4 standard is designed as a low power and low data rate protocol with high reliability. They analyze un-slotted version of protocol with maximum throughput and minimum delay. The main purpose of IEEE 802.15.4 standard is to provide low power, low cost and highly reliable protocol. The standard defines a physical layer and a MAC sub layer. This standard operates in either beacon enabled or non-beacon mode. Physical layer specifies three different frequency ranges, 2.4 GHz band with 16 channels, 915 MHz with 10 channels and 868 MHz with 1 channel. Calculations are done by considering only beacon-enabled mode and with only one sender and receiver. However, it has high cost of power consumption. As number of sender increases, efficiency of 802.15.4 decreases. Throughput of 802.15.4 declines and delay increases when multiple radios are used because of increase in number of collisions.

In paper [3], authors adopt a tree protocol for ECG signal carried over Zigbee. A prototype of DSP platform enabling good performance in Zigbee is established. Symmetrical system architecture is developed. They develop mathematical model and simulated transmission time delay of ECG data. Mathematical model is built for CSMA/CA mechanism. However authors consider Zigbee, as it is for small coverage area and low data rate.

WBAN is used to develop a patient monitoring system which offers flexibility and mobility to patients. It allows flexibility of using remote monitoring system via either internet or intranet. Performance of IEEE 802.15.4/Zigbee operating in different patient monitoring environment is examined in [4]. However, authors simulate hospital network based on Ethernet standard. We simulate using multi-hop network for remote monitoring.

An application of wireless cellular technologies CDMA2000 1xEVDO, as a promising solution to wireless medical system is propose in [5]. Authors analyze end-to-end delay analysis for medical application using CDMA2000 1xEVDO. However, they only consider worst-case end to end delay over cellular network. They have not discussed about interoperability of CDMA2000 1xEVDO with WBAN. Also they only analyze mathematical equations for ECG data. In our paper, we analyze and simulate for general medical traffic.

Authors in [6] examine use of IEEE 802.15.4 standard in ECG monitoring sensor network and study the effects of CSMA/CA mechanism. They analyze performance of networks in terms of transmission delay, end to end latency, and packet delivery rate. For time critical applications, a payload size between 40 and 60 bytes is selected due to lower end to end latency and acceptable packet delivery rate. However, authors consider only single hop communication. We calculate and implement it with multi-hop transmission.

Authors present a new cross-layer communication protocol for WBANs, CICADA in [7]. This protocol setup a network tree in a distributed manner. This structure is used to guarantee collision free access to the medium and to route data towards the sink. Energy consumption is low because nodes can sleep in slots, where they are not transmitting or receiving. However, their proposed protocol only support node to sink traffic.

A Traffic-adaptive MAC protocol (TaMAC) is introduced by using traffic information of sensor nodes in [8]. TaMAC protocol is supported by a wakeup radio which is used to support emergency and on-demand events in a reliable manner. Authors compare TaMAC with beacon-enabled IEEE 802.15.4 MAC, WiseMAC, and SMAC protocols. They study co-existence of heterogeneous WBAN traffic. However, authors have not simulated delay in a heterogeneous environment.

Authors in [9] propose a MAC protocol for WBAN using wakeup radio mechanism. TDMA based scheme combined with wakeup radio is used to design an energy efficient Medium Access Control (MAC). However, their simulations are only for single hop communication. Moreover authors have not done simulations for multi-hop communication, as we have done in our paper.

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3. ZIGBEE

It is small, low-power digital radio, based on IEEE 802.15.4 standard for Personal Area Networks. It is less expensive than other Wireless Personal Area Networks (WPANs), such as Bluetooth. Zigbee is used in those applications where we need low data rate, long battery life and secure networking. It supports data rate up to 250 Kbit/s. It is best suited for periodic data or single signal transmission from sensor to other device input. Low cost of Zigbee allows it to be widely deploy in wireless control and monitoring applications like sending of medical data from sensor node on human body to other devices. Its network layer supports both star, tree and mesh networks. Zigbee builds up MAC layer and Physical layer for low data rate WPANs.

Nodes in Zigbee go from sleep to active mode in 30ms or less due to which its latency is low. Due to long sleep time of nodes, its power consumption is low and gives long battery life. Its protocols are intended for low data rates and have low power consumption thus resulting network uses small amount of power. Zigbee devices are of three types:

Zigbee Coordinator (ZC)**:** This is root of all networks and makes bridges with other networks. There is exactly one Zigbee coordinator in each network because it starts the network.

Zigbee Router (ZR)**:** It runs an application function and can act as router passing data from other devices.

Zigbee End Device (ZED)**:** It only communicates with the coordinator or router. Nodes in ZED are in sleep mode thereby giving long battery life. ZED requires least amount of memory and therefor it is less expensive than ZR and ZC.

4. SIMULATION AND RESULTS

We simulate the scenario using OPNET Modeler. The parameters used for simulation are in Table I. We consider the communication of three different nodes with their corresponding coordinator and then their coordinator is connected to the network coordinator, and this makes three-hop scenario. Performance is evaluated on the basis of delay, load, throughput and medium access delay. Moreover the delay of each hop is also evaluated.

Fig. 2 shows the network scenario used for the purpose of simulation. The fig. 3 shows overall delay of the network. Delay represents end to end delay of all packets, received by the 802.15.4 MACs of all WBAN nodes in the network and forwarded to the higher layer. Maximum delay in this network is 11 milli-seconds, which is at start of communication. As the communication goes on delay is decreasing and becomes constant. Minimum delay of network is 3 milli-seconds.

Table-I: Simulation Parameters

Parameter type	Value
Beacon Order	6
Super frame Order	0
Backoff Exponent	3
Maximum Number of Backoff	2
Packet Inter-arrival time	0.004 bit/sec
Packet Size	512 bytes
Start time	Uniform (Min 20, Max 21)
Stop time	Infinity
ACK Mechanism	Disabled
Transmit power	0.03 Watts

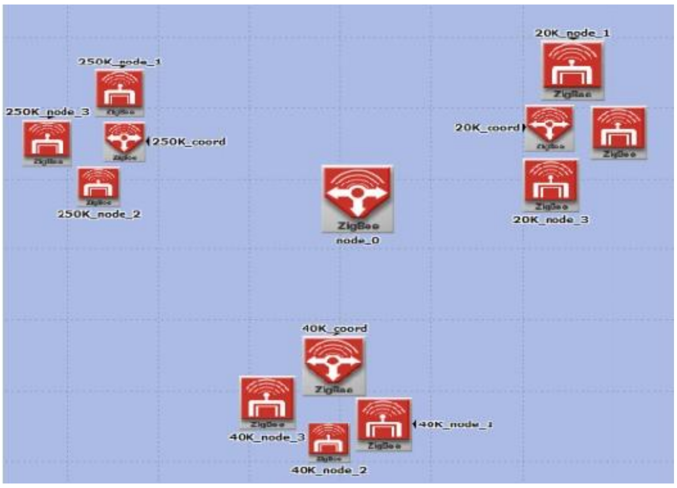

Figure-2: Simulated Network Scenario

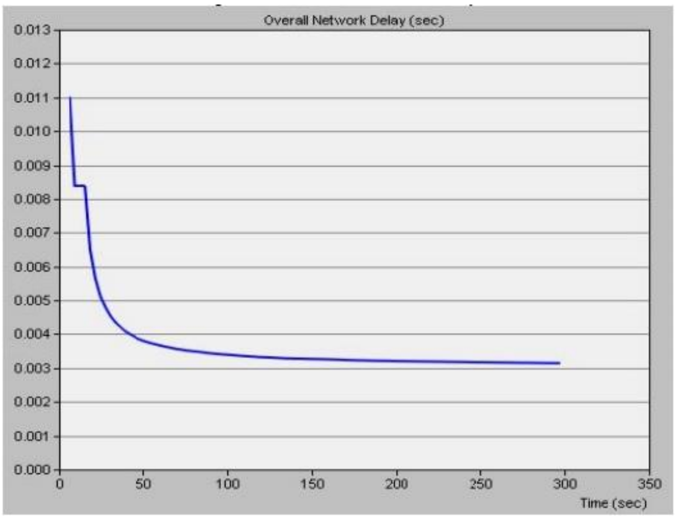

Figure-3: Overall Network Delay

Overall network load is shown in Fig. 4. Maximum load in the network is around 9000 bits/sec. As communication starts, load in the network is also increasing due to fact that nodes are transmitting data into the network.

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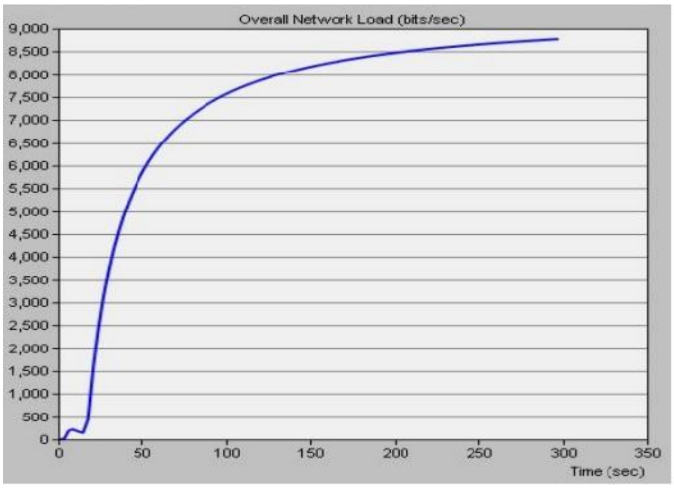

Figure-4: Overall Network Load

Fig. 5 shows the media access delay in network. Media access delay represents the total time of queuing and contention delays of the data frames transmitted by the all 802.15.4 MACs. For each frame, this delay calculated as the duration from time when it is inserted into the transmission queue, which is arrival time for higher level data packets and creation time for all other frames types, until the time when the frame is sent to the physical layer for the first time. Maximum value of media access delay is 2.4 milli-seconds and minimum is 1 milli-second.

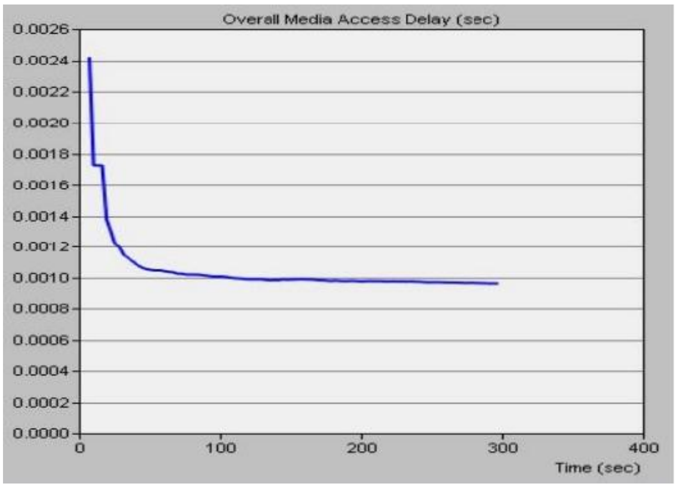

Figure-5: Overall Medium Access Delay

As there are multiple hops and each is using different set of frequencies and data rates. So, the delay of each hop is different. This is depicted in Fig. 6. This figure shows the delay at each coordinator of different hop. It is seen that maximum delay is at 20 Kbps (868 MHz) network and minimum delay is at 250 Kbps (2.4 GHz) network.

Fig. 7 shows the overall throughput of network. This figure shows the network throughput that it experience while sending data at maximum load. Throughput varies with different data rates as maximum data rate of 250 Kbps experiences highest throughput.

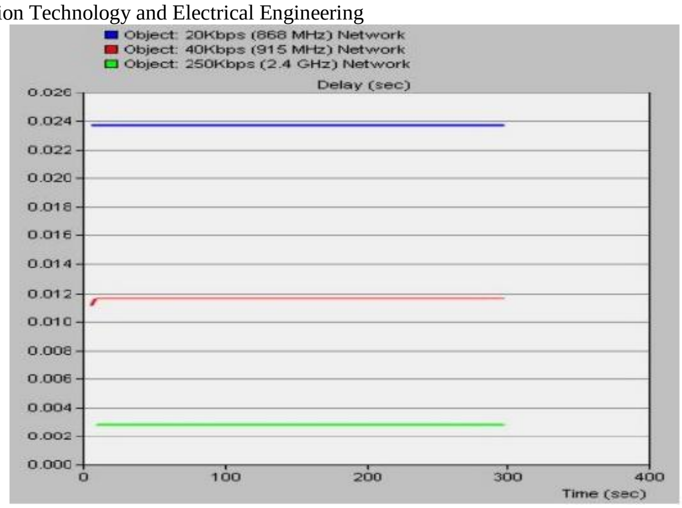

Figure-6: Delay at each coordinator (each hop) of different frequencies and data rates

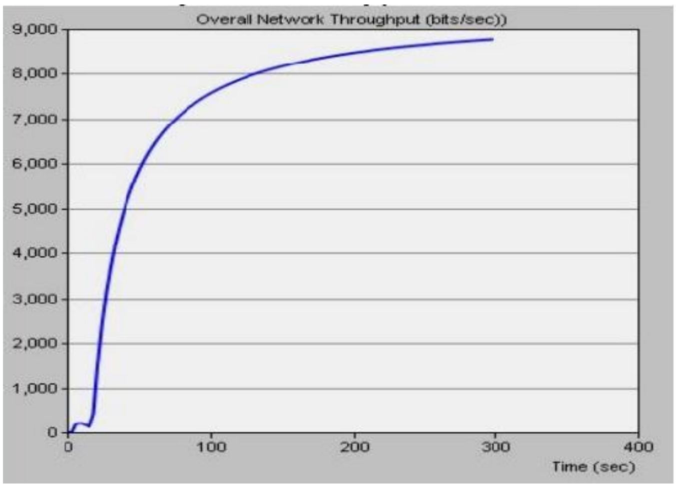

Figure-7: Overall Throughput of Network

5. CONCLUSION

We analyze performance of Zigbee under varying data rates and different frequencies in a multi-hop transmission. Minimum delay of around 3 milli-seconds is achieved at 2.4 GHz with 250 Kbps data rate and maximum delay of 2.4 milli- seconds is at 868 MHz with 20 Kbps. So we suggests that time critical applications in WBAN should use 2.4 GHz frequency with data rate of around 250 Kbps. And for delay tolerant application 868 MHz band with low data rate of around 20 Kbps can be used in WBAN.

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