Performance Study of IoT enabled Wireless Body Area Network in Contiki Platform

Sumitt Mittal
Department of Computer Science and Engineering
National Institute of Technology
Rourkela, Odisa, India - 769008
217CS3314@nitrkl.ac.in

Sumit Kumar Nagdeo
Department of Computer Science and Engineering
National Institute of Technology
Rourkela, Odisa, India - 769008
217CS3315@nitrkl.ac.in

Judhistir Mahapatro
Department of Computer Science and Engineering
National Institute of Technology
Rourkela, Odisa, India - 769008
mahapatroj@nitrkl.ac.in

***Abstract*— Internet of Things (IoT) [1] is defined as connecting and interacting with things using Internet. In the context of IoT enabled Wireless Body Area Network (WBAN), WBAN [2] is a wireless networking paradigm of wearable sensors which can be referred as things. The sensors collect patients' vital sign parameters such as Electrocardiogram (ECG) and body temperature, and then send this vital information to Hub or Coordinator over wireless medium. In turn, the coordinator relays the information gathered from the sensors to the Border Router, and thereafter the information is posted on to the doctor's console for monitoring and analyzing the patient data. In this paper, we study the performance of IoT enabled WBAN in Contiki platform using Cooja simulator. We used the metrics for performance study are Average Delay and Power Consumptions which is in terms of percentage of Radio Transmissions, Receptions and ON. Our study shows that the average delay taken to deliver a packet for highest priority sensors is near to 450 milliseconds, which is about 14% less delay as compared to the lowest priority sensors. Also, our study shows that the average power consumed by highest priority sensors is near to 4.1% which is about 3% more as compared to the lowest priority sensors. It has also been observed that around 50% more packets of the highest priority nodes are delivered as compared to the percentage of packets delivered by the lowest priority nodes.**

Keywords*— Electrocardiograph (ECG), Internet of Things (IoT), Wireless Body Area Network (WBAN).

I. INTRODUCTION

An IoT is the new technological paradigm of networking, which is getting popular day by day, and getting more and more adaption of this technology in wide variety of applications in agriculture, healthcare, and automation. The technological advancements in the sensor technology make this technology more pervasive. At the same time, there are developments on the protocol stack of IoT while considering the various constraints such as power consumption and size imposed on the sensor nodes. The Network Stack of IoT (as shown in Fig. 1) mainly consists of four layers as follows: Network Layer, Medium Access Control (MAC) Layer, Radio Duty Cycle (RDC) Layer and Radio Layer [3]. Delivery of a data packet from a source node to a destination node in such type of networks involves all these layers of the protocol stack. The network layer is responsible for routing of the data from a source to a destination node. It decides the route on which the data packets will be traversed to arrive at the destination node. The MAC layer is used to provide the share of the wireless medium to the contending sensor nodes and it is used to avoid the occurrence of collision of packets when one or more number of sensors transmits data packets at the same time to a receiver in the network. Radio Duty-Cycle (RDC) layer is responsible for periodic wake-up of the nodes to listen to the channel for any packet transmissions from their neighbors. If a node is active and transmitting packets and till the time it completes the transmission, all of its neighbors are kept awake by the ContikiMAC for reception of those packets sent by the active node [4]. A sender or source node continues sending the packets till the time it receives a link layer acknowledgement from the receiver. Finally, the radio layer is responsible for transmitting and receiving of the packets over wireless medium.

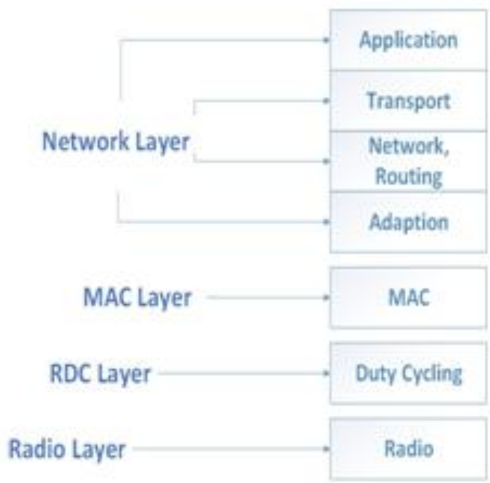

Fig. 1. Network Stack for IoT. This figure is redrawn from Ref. [3]

WBAN is a networking paradigm of wearable sensors such as Electrocardiogram (ECG) and Electroencephalogram (EEG), which is used to deliver patient's vital signs to specialized medical entity such as doctor and emergency ward in a hospital. The main objectives of the WBAN is to improve the speed, accuracy, and reliability of packet delivery within, and in the immediate proximity of a human body [5]. However, the technology presumes that it does not allow the external entity to have interactions with the sensor nodes after its deployment on the human body. Therefore, it continuously sends the sensed physiological data to the coordinator. In our work, we are attempting to integrate the IoT technology with WBAN technology whereby providing the external entity to get control over the physiological sensors of the WBAN.

In this paper, we propose to study the performance of the WBAN by integrating it with IoT technology. One of the Quality of Service(QoS) parameters for WBAN is the end-to- end delay. Each of the sensor nodes in the WBAN is assigned a priority based on its type such as medical emergency and non-emergency. We then study how much channel accessing delay is experienced by each of the priority type. In other words, sensors having highest priority will get the channel faster than the other types of sensors during the contention process. We propose to study the fact that the average delay that takes to deliver the packets of the highest priority sensors will have less as compared to the average delay of the lowest priority sensors as found in Ref. [6]. As per the IEEE 802.15.4 standard, average delay to transmit the packets for each node is near about similar, because the waiting period to access the shared channel is chosen uniformly a random period from the same range for each node [7]. To provide the QoS to different nodes, the concept of assigning priority to each node is introduced in IEEE 802.15.6 standard. Thus, we propose to study the end-to-end delay of sensors with different priorities in IoT enabled WBAN in Contiki Platform.

The organization of the paper is as follows. We discuss the IoT protocols in Section II. Transmission of packets over the network having connected to a WBAN and MAC Protocol of WBAN is discussed in Section III. The performance metrics and the parameters considered in the simulation are discussed in Section IV-A and the simulated results and discussions are provided in Section IV-B. We, finally, conclude the paper in Section V.

II. INTERNET OF THINGS (IOT)

In the context of wireless health monitoring systems and IoT, the physiological sensors used to capture the physiological signs of the patient or a human body can be reffered as *Things* in the IoT [8]. Each physiological sensors of WBAN gets an IPv6 address like a thing in IoT gets an unique Internet protocol address for routing. Routing of the data packets from any networking node to any other node over Internet carried out using a routing protocol. However, the routing protocol used in IoT is different from the routing protocols used in Internet.

RPL is a IPv6 Routing Protocol for Low power and Lossy Network [9]. RPL was developed for the networks consuming less power and networks which tend to lose packets or where packets might get lost, that is, networks in which the possibility of losing a packet is much higher than the conventional networks. The main functionality of this protocol is to help each node in finding its neighbour nodes and route to their neighbour nodes. In network topology, there are two types of nodes: *Coordinator Node* which is referred as RPL Server, and *Non-Storing Node* which is referred as RPL Client. RPL Server decides a network topology for routing after collecting information about the nodes in the network and their neighbour list and the topology is termed as Destination Oriented Directed Acyclic Graph (DODAG). The direction of the nodes in the topology for forwarding data packets is set towards the destination or a coordinator. The intermediate nodes in the DODAG help in routing the packets of leave nodes towards the Coordinator. Leaf nodes send their data packets to the intermediate nodes. The RPL protocol runs only in intermediate nodes. Thus, the intermediate node determines the best routing link to the coordinator from the available links. RPL objective function is to select the best routing link based on the metrics and as follows: Expected transmission (ETX), minimum-hop count, latency and energy consumption.

There are radio duty-cycling mechanisms for wireless sensor networks having been developed due to energy constraints on the sensor nodes. ContikiMAC mechanism is inspired through the existing protocols of Radio Duty Cycle. Contikimac mechanism is comparatively more energy efficient than the existing RDC protocols [10]. Therefore, we propose to study the performance of the network running RPL and ContikiMAC as its network layer and duty cycling layer protocol, respectively.

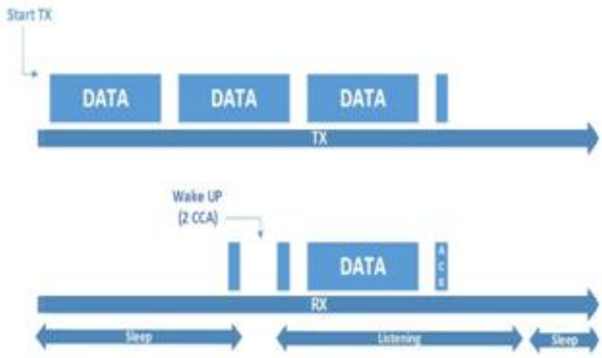

Fig. 2. ContikiMAC repeatedly sends the packet until an ACK is received. This figure is redrawn from Ref. [4]

Sender sends data continuously without having the knowledge of whether receiver is active or not, i.e., receiver can be in any of the states as follows: sleeping, listening, or wake-up. When receiver is in sleeping state, it will not receive packets. When it is in wake-up state, it senses channel, and if it finds any other node is transmitting the data, then it goes to listening state where it receives the data and then acknowledges the sender that it has received the data, as shown in Fig. 2.

In working of ContikiMac, clear channel assessment (CCA) time which is actually a wake-up time and the value of it must be set greater than or equal to the delay between two consecutive data packets sent by a sender, if this condition satisfies then only receiver efficiently can sense the data packets that are in transmission.

In this paper, we have considered the cost of the link between the sensor node and coordinator (or hub) in the network topology in such a way that the routing protocol shall always choose the coordinator as next hop. The network topology used in this simulation is as shown in Fig. 3.

III. WBAN MAC

Carrier Sense Multiple Access (CSMA) is a channel sensing approach, in computer networking, in which nodes continuously sense the channel in order to transmit only when the channel is sensed to be *idle*, to avoid collision. When nodes get the chance to transmit over the medium, they are allowed to send the entire packet.

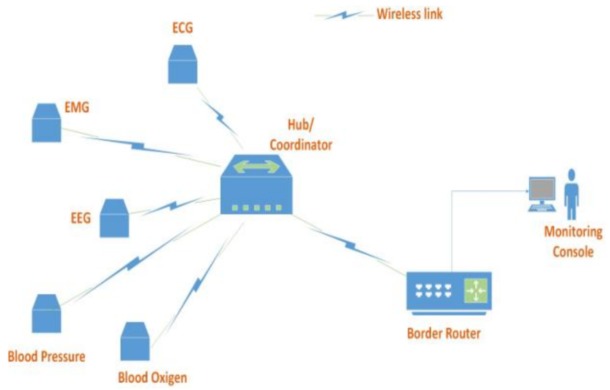

Fig. 3. Network Topology for Simulation

CSMA/CA protocol carries out two major task and as follows: First, carrier sensing, that is, sensing the channel to check whether it is idle or not, before transmitting any of the information through the channel. Second, collision avoidance, if before transmitting, node sensed another node is accessing the channel or transmitting any information, node waits for a period for the other node to stop transmitting before it starts sensing the channel again. As per the IEEE Std 802.15.4, the waiting period is usually random within a common specified range for every node, whereas In IEEE Std 802.15.6, this waiting period is decided as per the priority of the node [6]. Each node is assigned a back-off counter value and it gets decremented when the channel is sensed as idle, when the node having back-off counter value as zero, gets to transmit the data through the medium, hence, the collision is avoided. As per the IEEE Std 802.15.6, the value of Back-Off counter is decided as per the Contention Window (CW) range [6], priority index and their corresponding Contention Window range is mentioned in the Table I.

TABLE I PRIORITY MAPPING TO THE SENSOR NODES

Priority Type	**Contention Window Range** $[CW_{min}, CW_{max}]$
0	[16, 64]
1	[16, 32]
2	[8, 32]
3	[8, 16]
4	[4, 16]
5	[4, 8]
6	[2, 8]
7	[1, 4]

To explain how the WBAN MAC is different from CSMA/CA used in IEEE 802.11, Let us consider an example of two nodes contending for the shared medium, one having priority index of 7 and another node having priority of 2, then the back off counter value for both the nodes is selected randomly as per their corresponding contention window range i.e. [1, CWmin]. It is clear that, the node having higher priority, i.e. 7, its back off counter value will reach zero first after decrementing consecutively after the sensing the channel is idle, hence, it will get first chance to transmit data, then the other nodes, having the lesser priority. But if back off counter value for both sensor becomes zero at the same time then collision is encountered, and if m is odd where m is the number of consecutive collisions, then CWmin will remain unchanged, otherwise, CWmin will be doubled. When CWmin exceeds CWmax then the value of CWmin will be set to CWmax [6].

IV. ANALYSIS

For studying the IoT enabled WBAN, we have assigned each mote a different priority value and a topology for the network is set as shown in the Fig. 3. The priority value ranging from 0(lowest) to 7(highest). The performance of the proposed scheme is studied using the following metrics [11] as follows:

Average Delay: It is defined as average time required for transmitting packets from the sensor to the coordinator.

Radio On: It is defined as average amount of power consumed by a sensor node to be in an active state.

Radio RX: It is defined as average amount of power consumed by a sensor node to receive a packet.

Radio TX: It is defined as average amount of power consumed by a node to transmit a packet.

A. Simulation settings

We have used the simulator Cooja for network simulation in Contiki Platform. We have simulated the network consisting of WBAN motes (representing sensors) deployed within the simulation area of 40m 40m. The simulation carried out for 180 seconds. Size of each packet is 97 bytes. It has been assumed that each sensor node has always a data packet in the buffer for transmission. In this paper, we study the network performance using the protocols as follows: ContikiRPL for Network Layer, WBAN MAC for Data Link Layer, and ContikiMac (RDC) for Physical Layer.

Description about the parameters and the values used in the simulation are provided in Table II.

B. Results

Fig. 4 shows the average delay to send a packet from a sensor node to the coordinator with respect to varying the number of nodes (i.e. 8, 16, 24, 32, 40). Our study also confirms the fact that the node whose priority is high will get the channel faster and more frequently. As per the results, it shows that the average delay taken to deliver a packet for the highest priority sensors is near to 450 milliseconds, which is about 14% less delay as compared to the lowest priority sensors.

TABLE II SIMULATION SETTINGS

Parameters	**Value**
Simulation area	40m × 40m
CCA threshold	- 45 dB
MAC protocol	802.15.6 CSMA/CA
Mote Type	SKY Mote
Slot Time	20 μs
CCA Time	15 μs
Channel Check Rate	128 Hz
Radio Channel	26
RTS/CTS	Off
Packet size	97 bytes
Clear channel assessment (CCA)	On

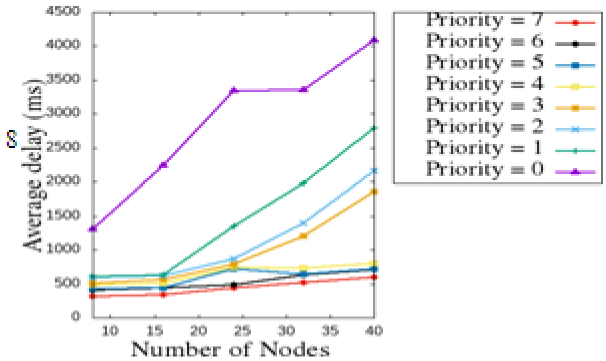

Fig. 4. Delay in percentage for nodes having different priority

Fig. 5 shows the power consumed (in percentage) by a sensor to send and receive the packet. The amount of time it is active for sending and receiving the packets is termed as radio ON. Our study shows that the average power consumed by the highest priority sensors is near to 4.1% which is about 3% more as compared to the lowest priority sensors. As we can see in the Fig. 5 that sensor whose priority is high consuming more power because it sends and receives packets more than other sensors whose priority are low.

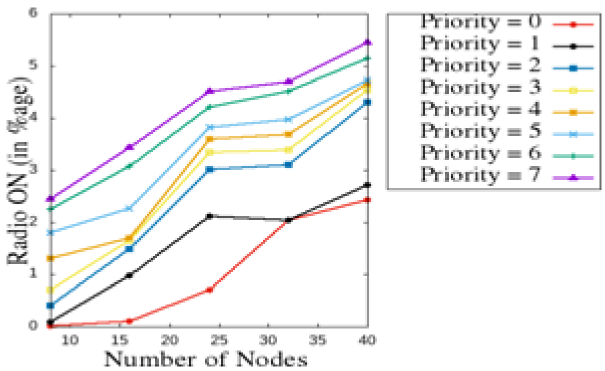

Fig. 5. Average Power Consumption (Radio On) in percentage for nodes having different priority

Similarly, from Fig. 6 and Fig. 7, we observe that power consumption metrics Radio TX and Radio RX is gradually decreasing as we decrease the priority values of the nodes.

Because the node having the highest priority will be transmitting packets faster and receiving the acknowledgements or packets frequently as it will have faster access to the shared channel than other nodes having the lower priority value.

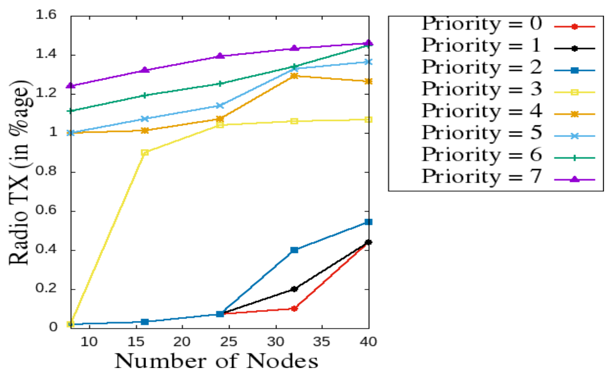

Fig. 6. Average Power Consumption (Radio TX) in percentage for nodes having different priority

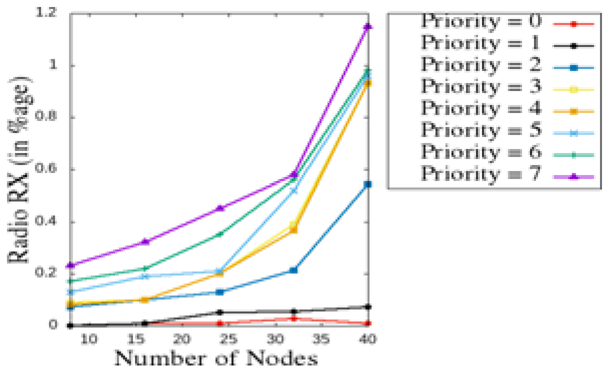

Fig. 7. Average Power Consumption (Radio RX) in percentage

Finally, we show that the number of packets got successfully delivered at the border router are recorded as shown in the Table III. It shows that around 50% more packets of the highest priority nodes are delivered as compared to the percentage of packets delivered by the lowest priority nodes.

TABLE III PACKET DELIVERY STATISTICS

Priority of nodes	0	1	2	3	4	5	6	7
# packets delivered	18	24	25	30	34	36	38	39

V. CONCLUSION

In this paper, we present a performance study on the IoT enabled Wireless Body Area Networks. The figures shown in our analysis is an indicative data for considering the IoT integrated with WBAN for medical applications. We show that the nodes having different priority has different time delay and power consumption, where nodes having higher priority have least time delay and maximum power consumption, which states the higher priority node is getting more opportunity to send the packet via shared channel than other nodes having lesser priority. As per our initial study, we conclude that our proposed solution may be considered for healthcare monitoring.

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