Optimum Placement of Gateway Node on Human Body for Real-time Healthcare Monitoring using WBAN

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ABSTRACT: *Wireless Body Area Networks (WBAN) is an emerging type of real-time monitoring used in the healthcare sector. It has the potential to revolutionize the healthcare sector by allowing patients not to physically visit doctor clinics or hospitals for medical checkups. But implementing such a system is challenged by many factors. The most important one is energy consumption. Energy consumption of all nodes in general and that of the gateway node in particular is critical. The gateway node is responsible for conveying sensor information to medical servers or doctors. Failure of the gateway node means failure of the overall WBAN system of a patient. Thus, extending the life time of the gateway node is a desirable objective in designing WBAN systems. As energy consumption is directly related to the end-to-end delay, Packet Delivery Ratio (PDR) and medium accessibility rate. So, placement on the human body in a location that is affected the least by delay and has high PDR and medium accessibility should be chosen as the placement location for the gateway node. In this paper, we identify the optimal placement location on the human body for a gateway node in terms of end-to-end delay, PDR, and back-off duration period.*

Keywords: WBAN, Packet Delivery Ratio (PDR), End-to-End Delay, Back-off Duration, Gateway Node

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1. Introduction

Recent advancement in wireless technology, networking and embedded sensors has led to the development of Wireless Body Area Network (WBAN) as an emerging technology to improve the quality of human life [1-2]. In healthcare sector, a WBAN is setup through a number of miniaturized sensors on, in or near the human body. These sensors collect and report data via a wireless communication channel towards a node generally referred to as gateway node. The gateway node is further responsible to forward the received data to Personal Digital Assistant (PDA) or mobile phone. The data is then forwarded to medical server or doctor via any wireless network including cellular, WiFi, Bluetooth etc. Accordingly, the use of a WBAN will enable continuous and remote monitoring of patient's physiological signals, and this could be benefic to trigger first aid assistance and to detect emergency situations [3-4].

One of the key issues among others in WBAN is to select optimum placement for gateway node for efficacious and economical operation of WBAN. As far as we know, very few attempts have been made in the past regarding this issue. In [5], two mechanisms were proposed: relaying and cooperation. The first solution introduces relay nodes, which only handle traffic relaying. In the second solution, it relays cooperate in forwarding the data from one node towards the sink. The network lifetime is increased, though the positions of relay nodes are fixed and are not optimized. An integer linear programming model which optimizes the number and location of relays to be deployed and the data routing towards the sinks was proposed by minimizing both the network installation cost and the energy consumed for wireless sensors and relays [6]. This work was further extended in [7]. However, relaying is not an optimal solution for migratory patients. In [8-9], the impact of network architecture, maximizing end to end Packet Delivery Ratio (PDR) and minimizing the number of retransmission is investigated. However, the experiments were designed in the way that the interval between the transmission of each node is 8 seconds. We think that such an interval is a very long keeping human mobility in perspective. On the other hand, [10] and [11] have done a full-mesh WBAN measurement campaign but the subject was instructed to walk for a series of experiments 3 seconds long, which might be too limited to fully represent human mobility. The author in [12] has done a study on the cooperative communication in WBAN and he has shown the improvements in terms of average probability and average fade duration using a simple forward relay scheme.

1.1 Overview of Paper

Here, in this paper, we try to further investigate the matter. We have simulated sensor nodes attached to different parts of human body. QoS parameter like Packet Delivery Ratio (PDR), End to end delay and medium inaccessibility duration of time, referred to as backoff duration, is calculated. Three human body postures are assumed here namely walking, standing and sitting. The rest of the paper is organized as follow.

Section 2 considers various aspects of WBAN and how energy consumption of a node is related to the three parameters. Section 3 is reserved for the simulation environment and results. Section 4 concludes the paper.

2. Architecture, Working Principle and Issues in WBAN

WBAN is a new idea first came to hear in the last century where it was conceived that instead of going to hospital or clinic for a doctor, where a patient can be checked medically by appending different kinds of sensors to his body, he may be monitored via communication between the sensors appended to his body and the doctor responsible for his checking up, no matter wherever he walks, sits or sleeps. All these seemed possible due to the immense advancement in electronic sensing devices capabilities, especially regarding decrease in size and hence energy consumption and increase in battery life. A patient of heart disease will no longer be required to go to hospital and attach a bundle of wires to his body for checking different heart-related parameters e.g. systolic, diastolic blood pressure. A simple sensor fixed inside or outside the skin above heart will be sufficient for providing all such data regarding heart when and where required [13].

IEEE 802.15.6 special task group standardized WBAN. According to the standard, three physical layer technologies were specified for WBAN namely Human Body Communication (HBC), Narrow Band and Ultra Wide Band [14]. HBC is not mostly considered in literature for use in WBAN because of its inefficiency in data rate requirements of WBAN. UWB guaranties high data rate but also requires complex receiver structure. NB is the best choice thus we have. [15-16].

Inter-node communication is generally referred to as tier-1 communication in WBAN. Since nodes communicate with gateway node which is further responsible for forwarding the data to PDA or mobile phone. This level of communication is referred to as tier-2 communication in WBAN. The PDA or mobile phone transmits the data to medical server or doctor through WiFi, Bluetooth or cellular network [16]. This level is referred to as tier-3 communication in WBAN. The overall structure is shown in figure 1.

Among the many issues that need to be resolved in WBAN implementation, the most important one is energy consumptions of

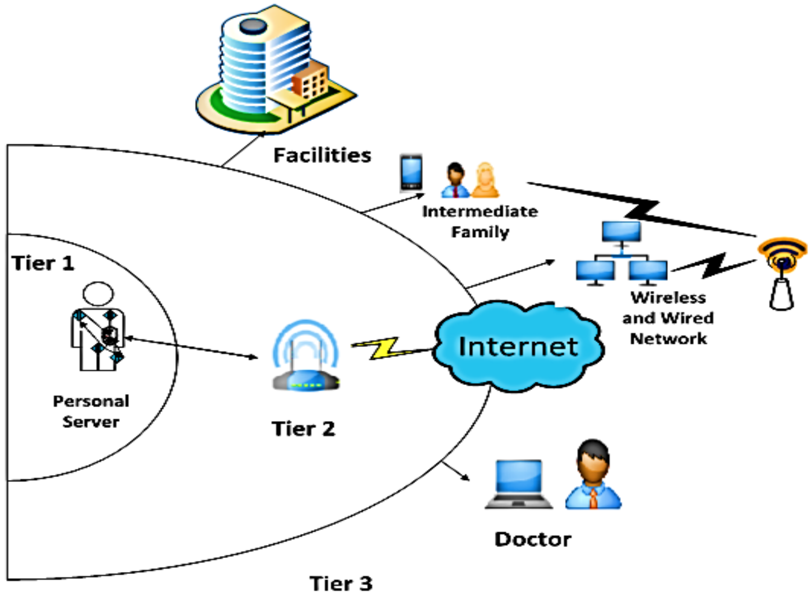

Figure 1. Communication tiers in WBAN

the nodes which is directly related to their life time as well as to the life time of the whole network. Energy consumption is contributed by many factors within the network [17]. For example, in a highly lossy environment, sensor node will have to consume most of its power in the form of retransmission (if packet failure occurs) and transmission with high power for encountering the effect of such environment. Similarly, in highly dense environment of nodes which takes place normally during sitting posture of human body, topological changes occur and medium accessibility gets more difficult. As a result, more waiting and active time becomes inevitable for nodes. Here we have analyzed which posture is more suitable for best QoS and which node is in worst or best position for worst or best QoS.

2.1 Energy Consumption Relationship with Backoffs

It is found that energy consumption of a node is directly dependent on the fact how easily it finds a medium accessible for data transmission as is shown in the following equations [18].

$E_{SB} = P_{IDLE} * T_{SB}$, where (1)

E_{SB} = Average energy consumed at a node during backoff for a successful transmission

T_{SB} = Average bakeoff time at a node for a successful transmitted packet.

Similarly, $E_{SC} = N_C * [P_{RX-TX} * T_{RX-TX} + T_C * P_{TX} + P_{TX-RX} * T_{TX-RX}]$, where (2)

E_{SC} = Average energy consumed at a node during collision for a successful transmission

N_C = Average number of collisions for a packet successfully transmitted

Also, $E_{TX} = T_{TX} * P_{TX} =$, where (3)

E_{TX} = Average energy consumed at a node when transmitting packet

T_{TX} = Average time to transmit a packet

So we have,

$E_S = E_{SB} + E_{SC} + E_{TX}$, where (4)

E_S = Average energy consumed at node during successful transmission of packet

2.2 Energy Consumption with PDR

PDR also has a significant impact on the overall energy consumption of a node [18]. The following equations illustrate this.

Where

$E_{DB} = P_{IDLE} * T_{DB}$, Where (5)

E_{DB} = Average energy consumed at a node during backoff for a packet dropped

T_{DB} = Average backoff time for a packet dropped.

Similarly,

$E_{DC} = (R + 1) * [P_{RX-TX} * \ T_{TX-RX} + * \ T_c * P_{TX} + \ P_{TX-RX*} T_{TX-RX}]$, Where (6)

E_{DC} = Average energy consumed at a node due to collision for a packet dropped

R = Maximum number of retransmissions of a packet

T_c = average collision time and

$E_D = E_{DB} + E_{DC}$, Where (7)

E_D = Average energy consumed by a node due to a packet dropped

2.3 The Path Loss Model

The path loss associated with the adopted channel model is log-normal path loss model.

$PL\ (d) = PL\ (d_0) + 10\ \eta\ log\ (d\ /\ d_0) + X_\sigma$ Where (8)

'd' is the distance between transmitter and receiver in metres,

$PL\ (d_0)$ is known path loss at a reference distance d_0,

η is path loss coefficient, and

X_σ is a random Gaussian variable, with zero mean and standard deviation equal to σ.

3. Basic Parameters

The following parameters were put to observations in simulations.

- End to end delay for all of the three postures
- Backoff duration for all of the three postures
- Packet Delivery Ration (PDR) for all of the three postures.

4. Simulation Results

We have simulated a total no. of 7 nodes fixed on various parts of the human body. Node ID and its placement on the body is shown in the figure 2. Three types of human body postures are considered namely sitting, walking and standing. In walking posture, we have assumed that the body makes almost all kinds of movements like that the body makes during day to day life. Whereas human body is considered completely at rest for sitting and standing postures. We used CSMA/CA as medium accessing technique.

4.1 OMNeT++ Simulator

For simulation we used OMNeT++. OMNeT++ is an open source simulator which have specialized framework MiXiM for sensor networks. We have used MiXim for our simulation.

The various characteristics associated with the defined nodes are as follow.

Tx-Rx, Rx-Tx (transition time)	0.02 ms
Rx-Sleep, Tx-Sleep (transition time)	0.194 ms
Sleep-Rx, Sleep-Tx (transition time)	0.05 ms
Tx (power consumption)	3 mW
Rx (Power consumption)	3 mW
Sleep-Rx, Sleep-Tx (power consumption)	1.5 mW
Rx-Sleep, Tx-Sleep (Power consumption)	1.5 mW
Sleep power level	0.02 mW

Table 1. Characteristics of the Nodes

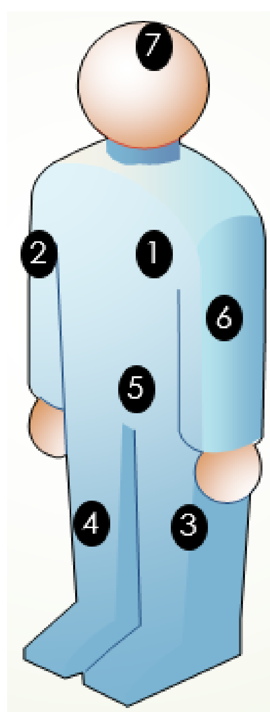

Figure 2. Node's placements on human body

4.2 End to end Delay in Standing Posture

End to end delay is defined as the total amount of delay associated with all the packets received successfully to a node. End to end delay varies according to environmental and topological changes. As surrounding becomes lossy, packets may get lost and retransmission becomes inevitable. Retransmissions for lost packets further add to the delay. We get the following results from our simulation for all the three postures.

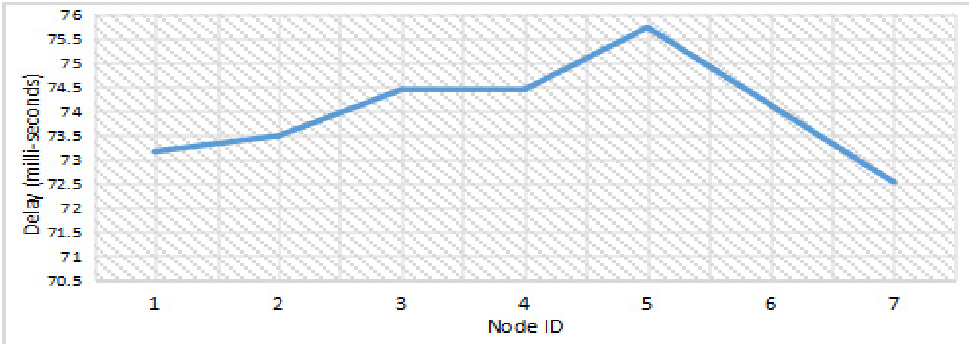

Figure 3. End to end delay in standing posture

In standing posture, node 5 has the highest amount of delay of nearly 75.724 milli-seconds while node 7 has the minimum delay of about 72.52 milli-seconds delay in overall communication.

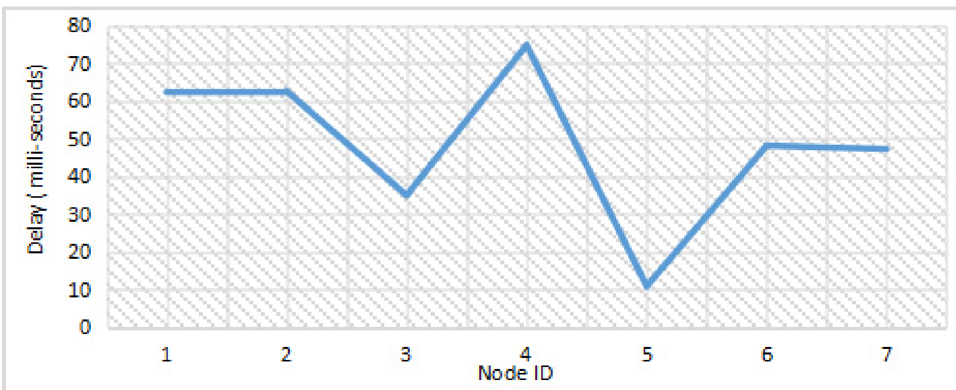

Figure 4. End to end delay in walking posture

In walking posture, node 4 has the highest amount of delay of nearly 74.75 milli-seconds while node 5 has the minimum delay of about 10.91 milli-seconds.

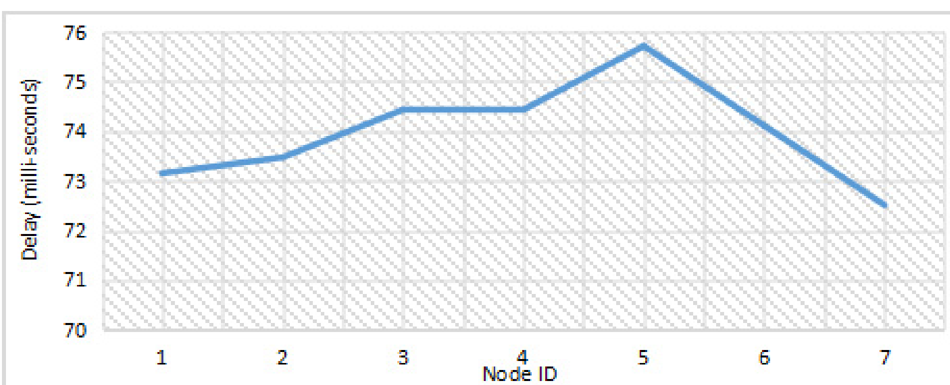

Figure 5. End to end delay in sitting posture

In sitting posture, node 5 has the highest amount of delay of nearly 75.71 milli-seconds while node 7 has the minimum delay of about 72.51 milli-seconds delay in overall communication.

4.4 Packet Delivery Ratio (PDR)

PDR is an important measure of QoS of a network. PDR is defined as the ratio between the total packets sent to the total packets received. A high figure of PDR of nodes is indication of smooth operation of a network. We get the following results from our simulation for PDR.

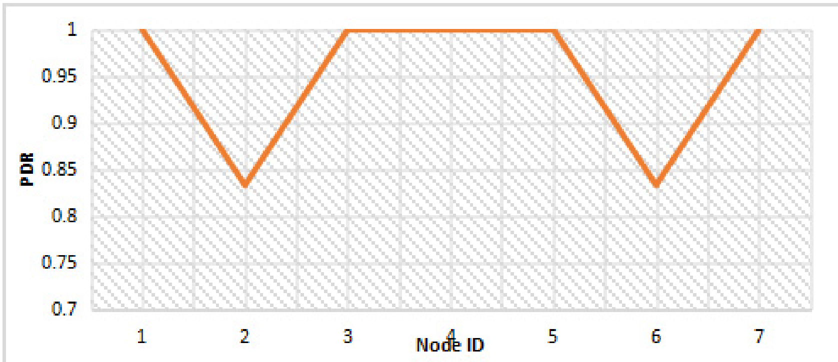

Figure 6. PDR in standing posture

In standing posture, node 1,3,4,5 and 7 has the highest amount of PDR, getting almost no loss of packets. Node 2 and 6 have, however, some loss of packets with PDR values of nearly 83%.

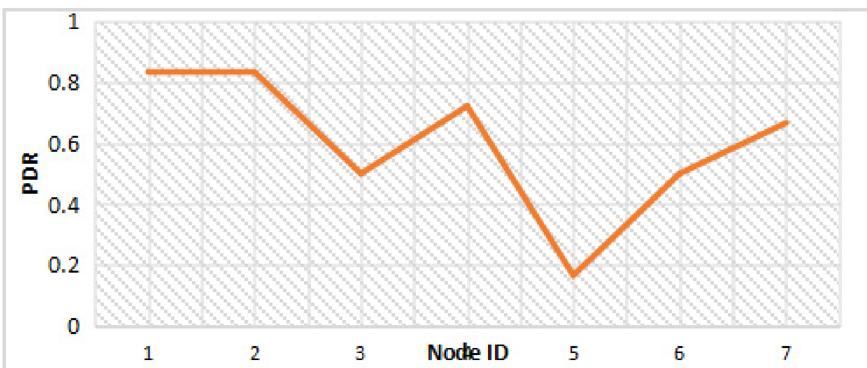

Figure 7. PDR in walking posture

In walking posture, only node 1 and 2 demonstrates highest PDR of above 83%. Node 5 has the lowest one with almost 16%.

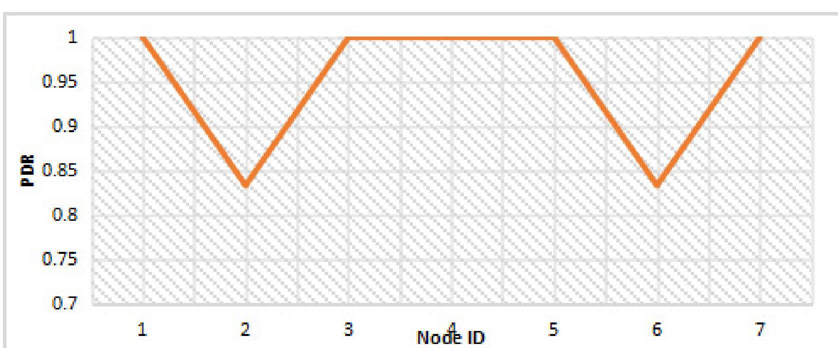

Figure 8. PDR in sitting posture

In sitting posture, again node 1,3,4,5 and 7 has the highest value of PDR with almost zero loss of packets. Node 2 and 6 have, however, some loss of packets with PDR values of nearly 84%.

4.5 Backoff Duration

Backoff duration is also an important measure of QoS which usually refers to accessibility of node to medium in a network. Backoff duration is defined as the total time duration during which a node keeps a transmitting packet in waiting queue because of medium unavailability after the packet transmission attempt has been made. Our simulation results illustrate backoff duration for each node below.

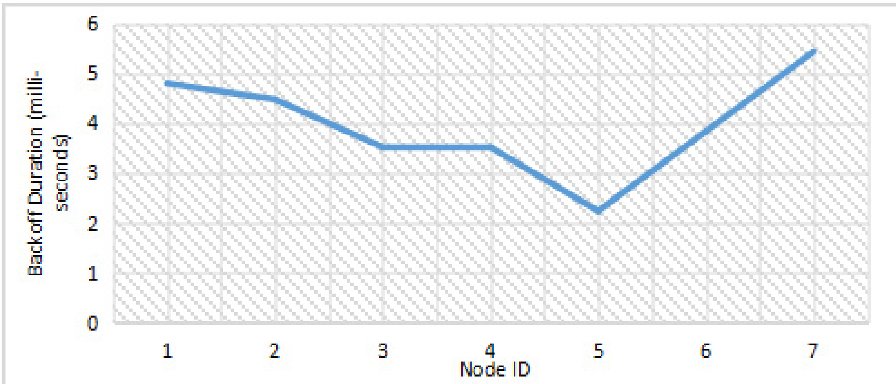

Figure 9. Backoff duration for standing posture

Node 7 suffers the most with backoff duration of 5.44 milli-seconds in standing posture while node 5 has the least amount of such duration with value of 2.24 milli-seconds.

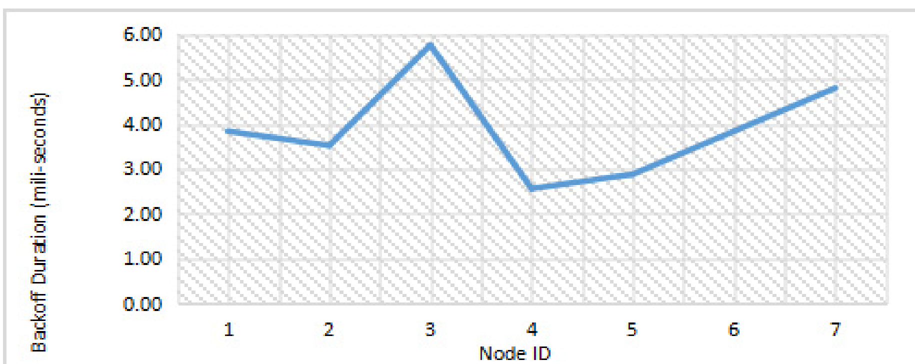

Figure 10. Backoff duration for walking posture

In walking posture, node 3 has the highest backoff duration of about 5.76 milli-seconds while node 4 has the least amount of backoff duration with value of 2.56 milli-seconds.

In sitting posture, the results are almost resembling the standing posture with node 5 having the least backoff duration of about 2.24 milli-seconds and node 7 having the highest backoff duration with value of 5.44 milli-seconds.

5. Conclusion

From the simulation results we see that node 5 has the least backoff duration in both sitting and standing postures and marginally higher than node 4 in walking posture.

Node 5 has the least delay of about 11 milli-seconds in walking postures, while node 7 has the least delay of 72.51 and 72.52 milli-seconds in sitting and standing postures respectively.

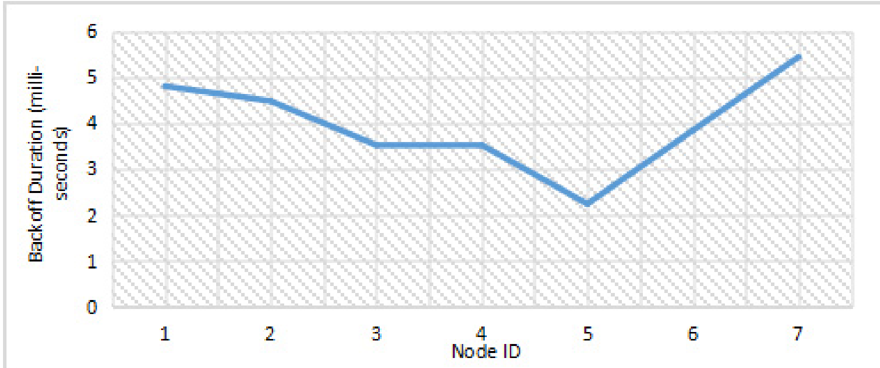

Figure 11. Backoff duration for sitting posture

Node 1 and node 2, both have highest PDR of above 80% in walking postures, while node 1, node 2, node 4, node 5 and node 7 has the highest PDR of almost 100 % in both standing and sitting postures.

We see that various nodes are affected differently from topological change. It may because such changes bring various nodes move in or out of coverage of the WBAN. The decision for gateway node placement is, therefore, application based. It is concluded that for delay-sensitive WBAN applications, sink node placed on the position of node 5 will give the best performance in terms of delay as well as energy consumption for stationary patients. Node 4 is best, however, for ambulatory patients. For PDR-sensitive applications in WBAN, positions held by node 1 and node 2 should be selected as a placement for gateway node which will give highest PDR and highest energy saving for ambulatory patients. Any node among 1, 3, 4, 5 and 7 can be chosen as gateway node for stationary patients.

5.1 Future Work

Our future work will focus on WBAN implementation in underwater. The underwater environment innately carries a host of challenges and issues as compared to terrestrial one. Radio Frequencies suffer greatly in underwater environment [19]. Therefore, acoustic frequencies are traditionally used in wireless sensor networks where distant and reliable communication system is focus of objective [20]. In WBAN, since distance is not sizeable among sensors, so RF might be the best choice. However, we will also study benefits of low losses of acoustic frequency when outer networks are communicated by the gateway node.

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