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PAP: Priority Aware Protocol for Healthcare Applications in Wireless Body Area Network

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Abstract: ***Wireless Body Area networks (WBANs) are among the emerging research areas that supports healthcare applications. These are getting popular as they provide features like flexibility, mobility and real-time monitoring. But due to this real time monitoring and criticality of data, WBAN requires a highly secure and reliable communication. Further, the medical emergency requires the instant information while the regular activity can't be ignored. Therefore, this paper has proposed a reliable and optimized protocol, namely, Priority Aware Protocol (PAP) for WBAN. It transfers the data efficiently based on the priority of the data. PAP associates two priority values with each node i.e. fixed priority and dynamic priority. Fixed priority is computed according to the task assigned to the node while dynamic priority is computed on the basis of the data sensed by the node. The performance of proposed protocol has been compared with existing state of art techniques like DPPH, HOCA and IEEE 802.15.4 standard on the basis of throughput and end-to-end delay. The results show that the proposed PAP outperforms existing techniques.***

Keywords: Optimization, Priority, Dynamic Priority, WBAN, reliability

I. INTRODUCTION

Wireless Body Area Network (WBAN) is an area restricted sensor network where nodes can be placed on or inside the body. The WBAN topology generally has a coordinator node, all other nodes communicate the sensed information to the outside world via coordinator node [1] as shown in figure 1. The coordinator node communicates with the third party (Medical Server) for transferring the data. The sensor nodes are basically used to assess various body parameters for healthcare applications [2][3]. The number of sensor nodes that can be placed on or inside the body must be selected carefully as the radiation emitted by the node can affect the health of the person [4][5]. Considering the various challenges like managing interferences, high throughput requirements (1 kb/s to 10 mb/s) of various healthcare applications, energy efficiency of node etc. in BAN applications, reliability of BAN healthcare applications is of utmost importance [6][8][9].

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Reliability of transmission can be determined by guaranteed delivery of data i.e. optimized throughput and timely delivery of data i.e. minimum end-to-end delay[7][9]. Moreover, each sensor node is a battery-operated device and so the lifetime of the node must be large as the replacement of node or changing battery in WBAN is a difficult task. Therefore, communication of the information with minimum number of nodes and minimum battery usage are among the major requirements of WBAN.

The main focus of this paper is to transfer the information from node to the coordinator node to further medical server in an efficient and reliable way. The information must be transferred as per the priority without any loss. The next section focuses on the work done in the field.

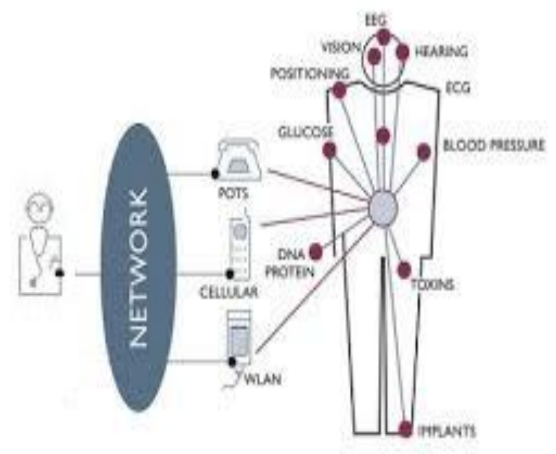

Fig 1: WBAN Topology

II. RELATED WORK

Various solutions specific to reliability in WSNs are proposed by many researchers previously. But little efforts have been shown by researchers for WBANs. Reliability in WBANs is of high important since they deal with human and lives can be endangered in case of communication failure. Dimitrios J. et. al [9] proposed NGL03-6 and talked about various QoS prerequisites for transmission of therapeutic information over broadband systems utilizing the remote Diffsery innovation. Distinctive sorts of biomedical sensors require diverse testing rates and in addition administration time which prompts the need of Qos provisioning in WBAN. IEEE 802.15.4[10] proposes a QoS Provisioning system by utilizing IEEE 802.15.4 super frame structure. It characterizes QoS provisioning plans with administration separation and prioritization. G. Wu et al. [11]

proposed an adaptive and flexible fault-tolerant communication scheme (AFTCS) that adopts a channel bandwidth reservation strategy to provide reliable data transmission when channel impairments occur.

Ali et. al[12] proposed an urgency based MAC convention (U-MAC) for BAN. It characterizes a need access instrument that permits sensor hub with earnest wellbeing data to battle the correspondence channel more than the hub with non-critical data. M. Barua et. al[13] has discussed a model for the WBAN scheduling with different concerned issues.

A cross layer based optimized energy efficient model for WBAN is described in [14] where the authors proposed the model using IR-UWB transceivers. Deepak et al. [15] basically optimize the packet size for energy efficient cooperative wireless body area network. The authors of [16] focused on the delivery of the critical data using TOPSIS. Rezaee et al. [17] proposed a Healthcare aware optimized congestion avoidance (HOCA) protocol for the wireless sensor networks that avoids the congestion due to lot of data packets at periodic interval. The author of [18] proposed a Prioritization based congestion control protocol i.e. PCCP that controls the congestion in the network on the basis of priority of the data while the author of [19] uses learning automata for congestion avoidance. The author of [20] & [21] gives DPPH protocol i.e. Dynamic priority-based packet handling protocol and also compress the performance with exiting state of art techniques to prove its significance. The author of [22] uses the fuzzy to control the congestion in the network. The author controls the congestion on the basis of priority of the data.

The existing work uses the fixed priority of data packets while the medical emergency is ignored. Some authors focus on medical emergency while ignoring other data packets. This paper considers the medical emergency as well the regular activity on priority basis and is discussed in next section.

III. PROPOSED WORK

This section describes the proposed protocol i.e. Priority Aware Protocol (PAP) for healthcare applications in wireless body area network. PAP works for both medical emergency as well as normal situation. Initially some data transmission rate (dtr) and a sensing interval (si) is associated with the network. Data transmission rate is the rate with which data will travel from source to destination and sensing interval is the time gap in between two data packets. PAP considers two level of priority i.e. Fixed priority (α) and Dynamic priority (ß) to calculate dynamic dtr and si respectively. Fixed priority (α) is assigned to the node at the time of deployment on the basis of task assigned to it. Dynamic priority (ß) is calculated on the basis of criticality of data being sensed. The transmission of data can be fasten if dtr and si can be updated according to the priority of data packet.

Fixed priority (α) of a node is assigned at time of plantation on the basis of the task assigned to the node and patient medical history. Those nodes which measure highly critical data like ECG, EEG etc. are assigned fixed priority 1. Fixed priority 2 is assigned to those nodes which measure less critical data but sudden and large variations may lead to harmful effects e.g. sudden rise in Blood Pressure (BP) or glucose level. The nodes which monitor the parameters that can be affected by variations in data measured by nodes with priority 1 and priority 2 are assigned fixed priority 3 as shown in Table 1 below.

Table 1: Fixed Priority (α)

Sr. No.	Nature of task assigned to Node	Fixed Priority (α)
1	Highly Critical Parameters	1
2	Less critical but harmful Parameters	2
3	Moderate/ Normal Parameters	3

Working of PAP:

The proposed protocol PAP is composed of three units i.e. Sensing unit, Controller unit and Medical server unit as shown in Figure 2.

The Sensing unit senses the data, assigns the dynamic priority to data packet on the basis of values measured and then dispatches it to the controller unit according to calculated priority of the data packet.

The controller unit sets an alert flag according to the priority of data packet and accordingly an alert is generated to the doctor and/or to the emergency contact. Each unit has been elaborated in following subsections.

3.1 Sensing Unit

Sensing unit comprises of two components i.e. Priority assignment and Processing and dispatching. Initially data is sensed by individual node as per the task assigned to it like measuring blood pressure, heart beat rate etc. and fixed priority of the data packet is determined as per the fixed priority of the node. 1 is the highest priority and 3 is the lowest priority.

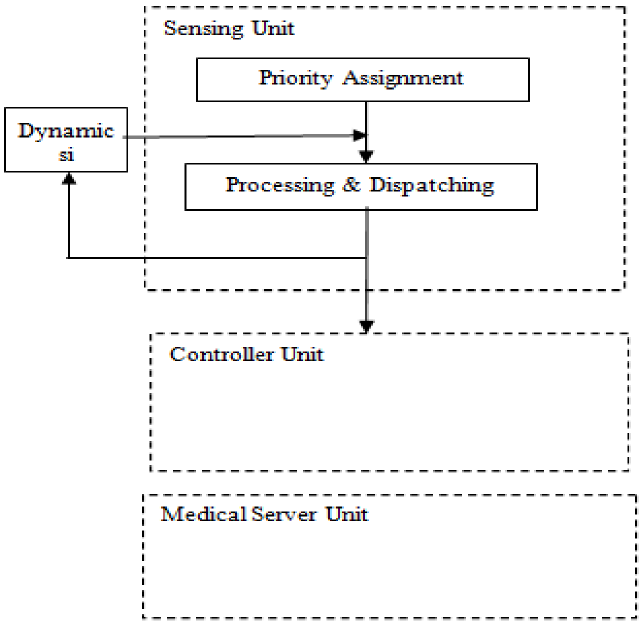

Fig 2: Proposed PA Protocol

3.1.1. Priority Assignment:

This component computes and assigns dynamic priority (β) to each data packet. β is computed on the basis of criticality of data sensed by the node.
For this purpose, each node maintains four threshold levels i.e $th^{n}_{low}, th^{n}_{high}$, $th^{H}_{low}, th^{H}_{high}$ corresponding to the lower and upper bounds for normal and high risk data respectively. For example, a node measuring Blood Pressure (BP) can have the threshold values as shown in Figure 3.

Fig 3: Threshold values for Blood Pressure

On the basis of the threshold values, some classification rules have been devised as stated in Table 2. The dynamic priority (β) can be assigned to the data packet according to these classification rules.
As per classification rules stated in Table 2, if the measured data is in normal range then dynamic priority (β) 3 is assigned to data packet. But if the measured data is lower than normal threshold or greater than high threshold then dynamic priority 2 is assigned to the data packet. If measured data value is critically low or critically high then dynamic priority 1 is assigned to the data packet. Dynamic priority 1 is the highest priority and 3 is the lowest priority.

Table 2: Dynamic Priority with threshold values

Measured Data	Dynamic Priority of Data Packet (ß)
$< th^{H}_{low}$	1
$> th^{H}_{low} \; and < th^{n}_{low}$	2
$> th^{n}_{low} \; and < th^{n}_{high}$	3
$> th^{n}_{high} \; and < th^{H}_{High}$	2
$> th^{H}_{high}$	1

3.1.2. Processing & Dispatching:

Here, dynamic Data Transmission Rate (DTR) and dynamic Sensing Interval (SI) are calculated on the basis of initial data transmission rate (dtr) and initial sensing interval (si).
On the basis of initial data transmission rate (dtr),dynamic data transmission rate (DTR) can be calculated using either Fixed priority or Dynamic priority whichever is higher as per equation (1).
That is,
if α is higher than or equals to β then

$$DTR=dtr/2^{\alpha-1} \quad \text{.......(1)}$$

Else

$$DTR=dtr/2^{\beta-1} \quad \text{.......(1)}$$

Here, α denotes the Fixed priority, β denotes the Dynamic priority and 'dtr' is the initial data transmission rate.

Let's take an example, if initial dtr is 4mbps, α=1 and β =2, then as per equation 1, DTR will be $4/2^{1-1}=4/2^{0}$=4mbps. And if α=2 and β =2, then DTR will be $4/2^{2-1}$=4/2=2mbps.
It means the data transmission rate gradually decrease with decrease in priority and vice a versa.
Once DTR is calculated, the dynamic sensing interval (SI) is calculated on the basis of dynamic priority of data packet. The data packet with higher dynamic priority has less sensing interval as compared to the data packet with less priority. The dynamic Sensing Interval (SI) is calculated using equation (2):

$$SI = 2^{\beta-3} * si \quad \text{.....(2)}$$

Here, si is the initial sensing interval. β is the dynamic priority assigned to packet.
For example, if the BP value sensed by the node is higher than the high threshold then dynamic priority is 1 and if the ECG value is within normal range then dynamic priority is 3. Then considering si=4, SI of two BP packet is $2^{1-3}*4=2^{-2}*4$ =(4/4) = 1 second while SI between two ECG packet is $2^{3-3}*4=2^{0}*4$ =1*4 =4 seconds. It means the sensing interval decreases with the increase in dynamic priority of data value as shown in Table 3 below:

Table 3: Dynamic Sensing Interval (SI)

Dynamic priority (ß)	si	$SI = 2^{\beta-3} * si$ *in seconds*
1	4	1
2	4	2
3	4	4

Then, the sensed data value is transmitted to the controller node as per the calculated DTR and SI will be applicable to the next data packet to be dispatched.

3.2 Controller Unit

Controller unit receives the data from the sensing unit and then generates an alert flag for medical server. This unit consists of Aggregation and Queuing and Alert generation as discussed below:

3.2.1 Aggregation and Queuing:

Here, the data transmitted by different nodes is aggregated and queued in the doubly ended queue according to priority of data packet. The controller node generates an alert flag that can have 'U', 'H' or 'N' values for Urgent, High or normal alert respectively on the basis of fixed priority (α) and dynamic priority (β) of data packet by using the rules stated in equation (3).

$$C = \begin{Bmatrix} U | \alpha = 1 \& \beta \le 2 | \alpha = 2 \& \beta = 1 \\ H | \alpha = 3 \& \beta \le 2 | \alpha = 2 \& \beta = 2 \\ N | \quad \beta = 3 \end{Bmatrix} \quad \text{...(3)}$$

Here α and β are the fixed and dynamic priority respectively.

If both fixed and dynamic priority of data packet is high or moderate i.e. 1 or 2, then an 'Urgent' alert (U) is generated, if fixed priority is moderate or low i.e. 2 or 3, but dynamic priority is high or moderate i.e. 1or 2, then a 'High' alert (H) is generate and for every other case a 'Normal' alert (N) is generated.

The priority assignment rules are also stated in the Table 5. The table clearly shows that the controller node sets alert flag for each data packet by using fixed priority and dynamic priority of data packet.

As there are 3 possible values of α and β both, so there are 9 (3*3) rules which are feasible and hence listed in Table 4.

Table 4: Alert flag generation

Fixed Priority (α)	Dynamic Priority (β)	Alert Flag at Controller Node
1	1	U
1	2	U
1	3	N
2	1	U
2	2	H
2	3	N
3	1	H
3	2	H
3	3	N

If the alert flag is 'U' i.e. urgent then controller node directly transmit corresponding data packet to the medical server without any delay. If the alert flag is 'H' then the controller node inserts this data to the front end of the doubly ended queue, while if the alert flag is 'N' i.e. normal then data is inserted to the rear of the doubly ended queue. The deletion takes place only at front end of the doubly ended queue.

For example if the BP (group 2 node) of a person is very high then this data packet is transmitted without any delay to the medical server due to 'U' flag which is decided according tofixed priority '2'of group 2 and dynamic priority of data packet '1' (Table 1). Now the data is transmitted to the medical server from the controller node as per the alert flag generated.

3.3 Medical Server Unit

This unit is responsible to generate and send an alert signal to the doctor and the emergency contact on the basis of alert flag received from the controller unit.

3.3.1. Alert Generation

Alerts are generated by the medical server to alert the doctor and emergency contact about the current health condition of the patient. The alert is generated on the basis of flag set at controller node. If the flag is 'U' then server transmit the message to the doctor and emergency contact, also makes an automated voice call to the doctor. If the flag is 'H' then server transmit the message to the doctor and emergency contact. In case of 'N', data is saved into the log of medical server only. The whole process can be described with an algorithm explained in next section.

IV. IMPLEMENTATION OF PAP

4.1 Algorithm

Sensing Unit

1. Data Generated from node having pre-assigned priority α
2. Sense Data Value at node and Assign dynamic priority say β
3. if α is higher than or equals to β then

DTR=dtr/2$^{\alpha-1}$

Else

DTR=dtr/2$^{\beta-1}$

4. $SI = 2^{\beta-3} * si$
5. Transmit the data with SI and DTR to controller node.

Controller Level

6.

$$C = \begin{Bmatrix} U \left| \alpha = 1 \& \beta \leq 2 \right| \alpha = 2 \& \beta = 1 \\ H \left| \alpha = 3 \& \beta \leq 2 \right| \alpha = 2 \& \beta = 2 \\ N \left| \quad \beta = 3 \right. \end{Bmatrix}$$

Medical Server Unit

7. If C='U'

Server transmits the message and voice call to the doctor and a massage to the emergency contact

Else if C='H'

Server transmits the message to the doctor and emergency contact

Else

Save data to log file

End if

The algorithm describes the complete process for data transmission on the basis of the priority of the data i.e. importance of data in the real world.

In order to implement PAP, the computed fixed and dynamic priorities are transmitted to the controller node by appending them in the header of data packet as shown in Figure 4.

Destination Address
Hop Count
Sequence Number
Pre-assigned Node Priority
Dynamic Priority of Data Packet

Fig 4: Packet Header Format

For example, if initial dtr is 4mbps and si is 4 seconds and if the node belongs to Group 2, then fixed priority of the node will be 2. The dynamic DTR calculated at node will be $4/2^{2-1}=4/2^1=4/2=2$mbps.

Further if the data sensed by the node is of high risk then dynamic priority will be 1. In that case, dynamic SI will be $2^{1-3}*4=2^{-2}*4=4/4=1$ second as the data sensed is of high-risk range.

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The data is now transmitted to the controller node at the dynamic DTR and SI along with the Fixed and Dynamic priority appended in the packet header.
Next, these Fixed and dynamic priorities are used at controller node to calculate alert flag and then send it to the Medical server. Medical server then generates and sends alert signals accordingly.

V. RESULTS AND DISCUSSION

The PAP algorithm described in the previous section has been implemented using the network simulator NS2. The protocol performance has been verified for the Intra Ban scenario where, a room with a patient and several sensing nodes and a coordinator node.
The scenario consists of controller node and the 7 other sensing nodes (EEG, ECG, BP, Glucose, Toxin, temperature, oximetry etc.). The parameter name along with their values is shown in the Table 6.

Table 6: Network Simulation Scenario

Parameter	Value
Area	$5*4m^2$
Number of Sensing nodes	7(1 EEG, 1 ECG, 1 BP, 1 Glucose, 1 Toxin, 1 temperature,1 oximetry)
Controller Node	1
Area Covered by Sensing Nodes	$0.4*0.4m^2$
Range of Node	5m

The network scenario consists of maximum 8 nodes including the controller node and 7 sensor nodes. This network has been analyzed on 7 different scenarios by changing the number of sensing nodes**.** The seven sensing nodes have the functionality, group and fixed priority shown in the Table 1.
The fixed priority and dynamic priority of data packet is transmitted to the controller node by appending the same in the header format of routing protocol. Here, the performance has been analyzed by using DSDV as routing protocol.
The priority received at the controller node is used to set the flag the at controller unit by using Table 5 and transmit the alert message to doctor. The performance of DSDV routing protocol with the edited packet header and appended behavior of proposed system has been described in following subsection.

5.1 Performance Evaluation

The performance of PAP is analyzed on the basis of three parameters i.e. Throughput, End-to-End Delay and Node Idle time.

Throughput

Figure 5 shows the comparison of PAP throughput at different priority level. The dynamic priority 3 means the measured data is in normal range. In this case the data must get stored on to the log file and the data transmission rate is less due to low priority of data. This is the reason that the throughput for the data at priority 3 is less. While the data at priority 2 and 1 has the high and the urgent data respectively. This data is transmitted at high data transmission rate which results in high throughput as compared to throughput with low priority data. This analysis has been done on different networks having 1000, 2000, 3000, 4000, 5000 seconds as the simulation time. In each scenario the throughput for high and urgent data is larger as compared to the throughput of low priority data.

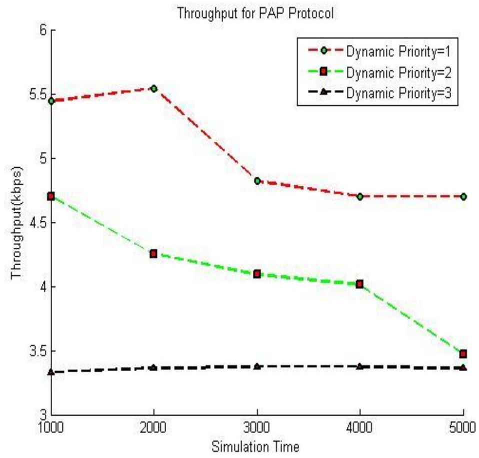

Fig 5: PAP Throughput on Different Dynamic Priority

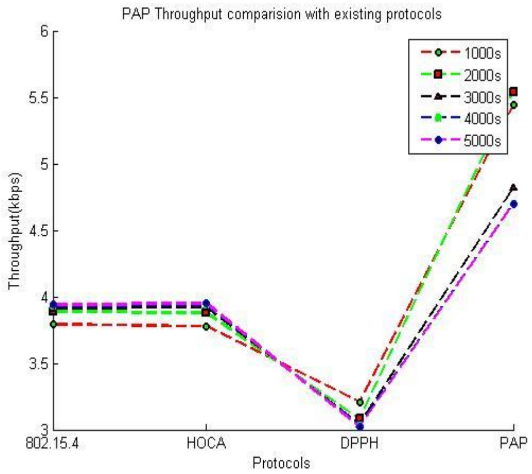

Fig 6: PAP throughput comparison with Existing State of Art Techniques

Figure 6 compares the throughput of PAP with 802.15.4, HOCA and DPPH for the scenario having 1000, 2000, 3000, 4000 and 5000 seconds simulation time. The 802.15.4, HOCA and DPPH description has already been given in section two i.e. Related work. The comparison clearly shows that PAP outperforms the other protocols as the throughput is increased in each scenario as compared to other state of art techniques.
The throughput of the PAP is higher in each scenario i.e. Low, High and urgent data as compared to the other exiting state of art techniques. This is due to the fact that PAP transmits the data as per the priority of the measured data which avoid the period checks and other hello signals.

End-to-End Delay

Figure 7 shows that PAP is having minimum End-to-End delay at highest priority i.e. 1. The data packet with priority 2 has somewhat higher delay as compared to the data packet with priority 1 and data packet with priority 3 is having highest End-to-End Delay. This is due to the change in the sensing interval and the data transmission rate according to the priority of the node.

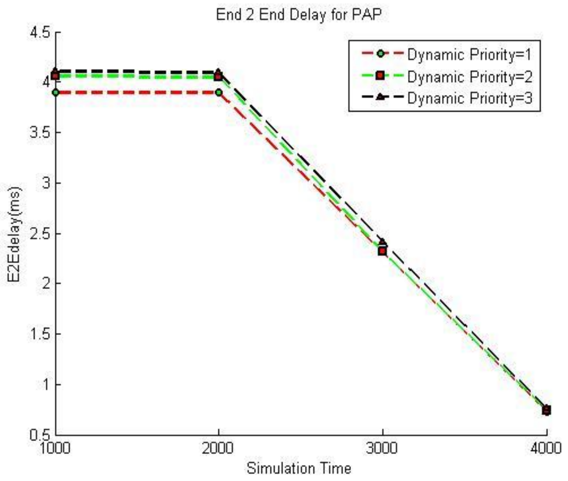

Fig 7: PAP E2E Delay on Different Dynamic Priorities

Figure 8 compares PAP with other protocols and it clearly shows that PAP performs better than existing technologies by having minimum end-to-End delay with highest priority.

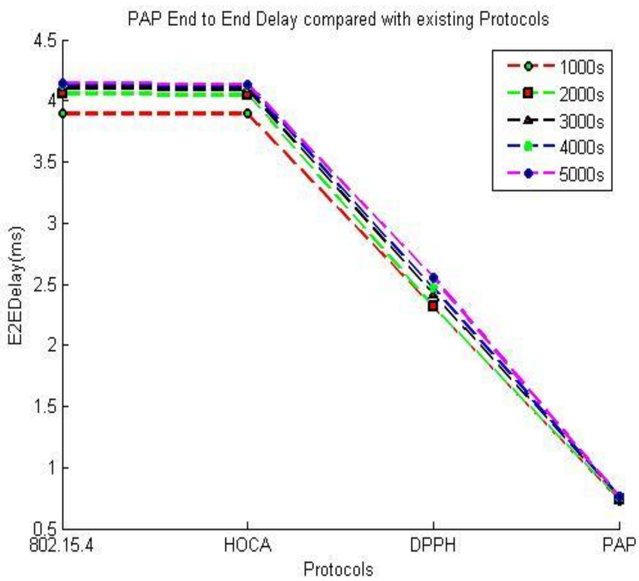

Fig 8: PAP End-to-End Delay compared with Existing State of Art Techniques

Remaining energy

Figure 9 shows that consumption of energy is high on higher priority due to the fact that high priority data is to be transmitted on high data rate which leads to more consumption of energy. Consumption of energy decreases with decreases in priority i.e. remaining energy is less on high priority and more on lowest priority as shown in figure.

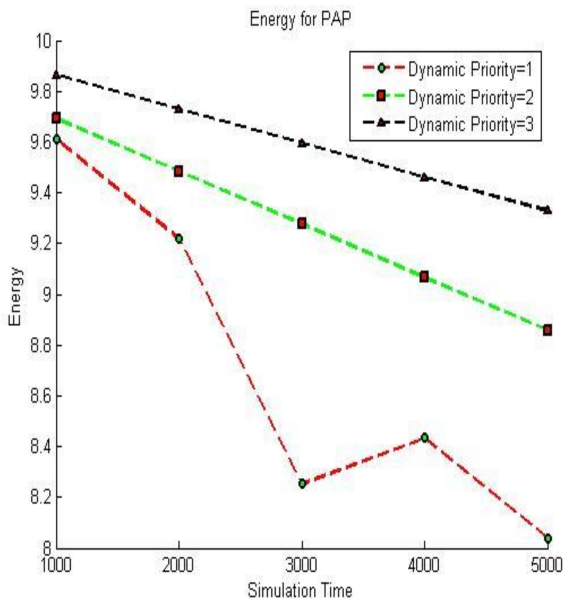

Fig 9: PAP Remaining Energy on Different Dynamic Priorities

VI. CONCLUSION

This paper designs a technique that transmits the data as the healthcare priority of the data. The healthcare priority of data includes the sensitivity of data being measured and the value of the data observed. The sensing interval and the data transmission rate is calculated on the basis of healthcare priority of data. This protocol has been analyzed on different scenario's having different priority data. The performance has been compared with DPPH, HOCA and the 802.15.4. protocol. The significant improvement of 20% in throughput and 50% in the e2edelay for the high priority and the urgent data shows the effectiveness of the technique. In future this technique can be analyzed on real world test beds.

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