

Traffic Priority-Aware Medical Data Dissemination Scheme for IoT Based WBASN Healthcare Applications

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Abstract: Wireless Body Area Sensor Network (WBASN) is an automated system for remote health monitoring of patients. WBASN under umbrella of Internet of Things (IoT) is comprised of small Biomedical Sensor Nodes (BSNs) that can communicate with each other without human involvement. These BSNs can be placed on human body or inside the skin of the patients to regularly monitor their vital signs. The BSNs generate critical data as it is related to patient's health. The data traffic can be classified as Sensitive Data (SD) and Non-sensitive Data (ND) packets based on the value of vital signs. These data packets have different priority to deliver. The ND packets may tolerate some delay or packet loss whereas, the SD packets required to be delivered on time with minimized packet loss otherwise it can be life threatening to the patients. In this research, we propose a Traffic Priority-aware Medical Data Dissemination (TPMD²) scheme for WBASN to deliver the data packets according to their priority based on the sensitivity of the data. The assessment of the proposed scheme is carried out in various experiments. The simulation results of the TPMD² scheme indicate a significant improvement in packets delivery, transmission delay and energy efficiency in comparison with the existing schemes.

Keywords: WBANS; wearable technology; priority routing; eHealth applications; remote health monitoring



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1 Introduction

The present era belongs to technology. The advancement in information & communication technology has brought revolution in every walk of life [1]. However, human being is still facing a lot of challenges. One of the main challenges is the rapid increase in the world population and decrease in healthcare facilities with respect to the population ratio [2,3]. Generally, elderly people suffers from innumerable chronic diseases and need continues healthcare. These patients have to stay hospitalized or under continues observation of a healthcare professional, otherwise their life will be at risk [3–6]. So, there is an acute need of an automated healthcare systems for unattended health monitoring of such patients.

Keeping in view these challenges in healthcare, the researchers from Medical Science and Information Communication Technology introduced a new concept of healthcare system called Wireless Body Area Sensor Network (WBASN) by applying the concept of Internet of Things (IoT) where objects can sense and respond automatically. Wearable devices are introduced to retrieve the information of vital signs from human body in a contactless way. The WBASN make use of such devices to communicate with each other and forward sensory data to the healthcare facility through a gateway node. The WBASN is comprised of smart biomedical sensor nodes (BSN) with limited computing, storage and energy resources [7–9]. The BSNs collect vital signs from the patient's body and transmit to the health center through Coordinator Node (CN) [10–12].

Fig. 1 shows different kinds BSNs attached to a human body such as electroencephalogram (EEG), blood pressure, heart rate, temperature and, motion sensors. Each sensory data packet contains some value of the specific vital sign. These vital signs have specified normal range. For example, body temperature ranges from 97.8 to 99 degree Fahrenheit, pulse rate 60 to 100 beats per minute and respiration rate 12 to 16 breath per minute for healthy adults [13,14]. Based on the range, the data packets in WBASN can be classified into two basic categories; Non-sensitive Data (ND) and Sensitive Data (SD) packets. The packets containing value of vital signs within normal range referred to as ND packets whereas, the packets contains value beyond the normal range referred to as SD packets [15,16]. A traffic priority based data routing is a necessary requirement in WBASN because the data packets need to be delivered according to their priority. ND packets can tolerate some delay or packet loss. However, SD packets require on-time delivery with minimized packet loss. Several efforts have been made by the researchers in designing and implementation of priority based routing in WBASN, however most of the researches only focused on delivery of SD packet while paying less attention to the ND packets which leads to high packet loss of ND packets. Furthermore, the SD packets which could not be delivered within the Packet Timeout Period (PTP) also drops that could be life threatening to the patient.

This paper proposes a Traffic Priority-aware Medical Data Dissemination (TPMD²) scheme for WBASN to deliver the data packets according to their priority. We introduces a novel Time to Deliver (TTD) function for routing of SD packets. TTD is the time needed to deliver a packet from source to destination though a specific route. The proposed TPMD² scheme calculates TTD for each available paths and route the SD packets on the path which have TTD value less than PTP. Further, in order to make energy efficient delivery of ND packets, we used a Path Cost Function (PCF). The evaluation of the TPMD² scheme is conducted in various experiments using MATLAB. The experimental results are compared with CEPRAN [17] and PCRPP [18] priority based data routing schemes in WBASN. The results point to a noteworthy enhancement in TPMD² scheme with regard to data delivery of both SD and ND packets, transmission delay and energy efficiency in contrast to the benchmark schemes.

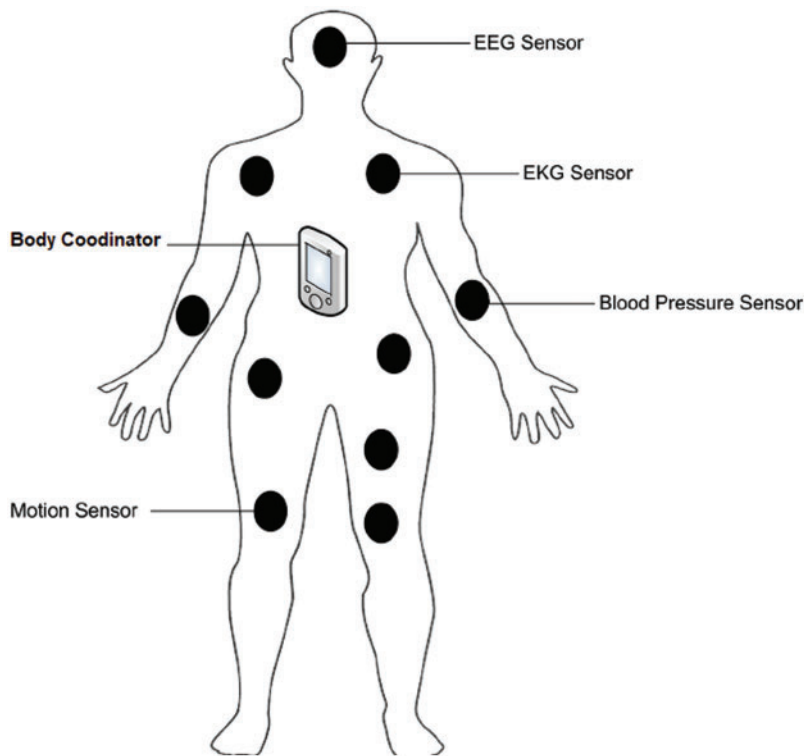


Figure 1: Type of BSNs in WBASN

Rest of the paper is segmented as follows: Section 2, reviewed the existing work. The proposed TPMD² scheme is described in Section 3 and its subsections. Section 4 discussed the simulation results and comparison with the benchmark works. Section 5 concludes the paper along with the future directions.

2 Related Work

Several researches [18–28] attempted to provide solutions for priority based routing of data packets in WBASN. Djenouri et al. [19] were the first to introduce four different categories of WBASN data packets focusing on reliability, delay, critical and non-critical data. It uses two kinds of sinks for each patient. Each data packet is forwarded towards both sinks to increase the packet delivery. However, in this scheme, high number of duplicate packets reach to the destination (medical server) from both sinks and hence, results in wastage of bandwidth and other resources in the network. Razzaque et al. [21] proposed a Quality of Service (QoS) based data routing scheme named DMQoS for WBASN. This scheme prioritizes data packets and forwards them through the respective queues one after the other according to their priority. Lower priority queue can send packets after the higher queue finished sending. The routing decision is taken by using location based on number of hop-counts. However, this proposed scheme does not consider delivery of SD packets within PTP which results in packets drops.

Annur et al. [22] presented with priority-aware algorithm for emergency data routing in WBASN. This algorithm immediately assigns channel bandwidth to SD packets whereas, ND packets are delayed until successful delivery of SD packets. However, channel reservation to specific type of data

traffic only is a wastage of limited available resources of BSNs and results in starvation for ND packets [18]. Rezaee et al. proposed HOCA [23] data routing scheme for WBASN. This scheme is designed for two objectives including congestion control and priority based routing. In this scheme, each BSN maintains two different routing tables. The routing table for SD data traffic stores only one path which is the best among the available paths. Whereas, the routing table for ND packets has many paths but other than the best one. In this way, only SD are forwarded to the best routing path whereas, ND packets are forwarded to non-best paths. Therefore, ND packets experience large number of packet loss. In Ben Elhadj et al. [24], proposed PCLR scheme for WBASNs. The authors in PCLR prioritized data packets into three different classes and introduced separate slots for each type of packet. The routing decision is made by computing the energy of BSNs and available of TDMA slots. However, this scheme experience a number of SD packet loss.

Sagar et al. [16] proposed CDR scheme for transmission of SD packets in WBASN. In this protocol, the authors placed all the BSNs inside the human body on equal distance from CN so that all the BSNs can send their data directly to CN. BSNs categorizes data packets into two categories that is critical and non-critical, similar as SD and ND packets. In case when SD is to be transmitted, all the ND packets are discarded. In this way, the delivery of critical data is ensured. However, non-critical data packets experience high packet loss in this scheme. Awan et al. presented PCRCP [18], a congestion control scheme based on data priority for WBASN. The authors classified the network traffic into SD and ND packets. To select the routing path, the PCRCP calculates congestion, signal to noise ratio and energy level of all available forwarder nodes in the network. This protocol achieved lower delay in data delivery and high throughput as compared to its benchmark schemes. However, it suffers from high computational complexity which leads to lower the network lifetime.

Recently, Geetha et al. presented CEPRAN [17], a data priority based routing protocol by using network coding method. The protocol initially selects a relay node from the available BSNs based on energy, distance and path loss by using Cuckoo search method. Further, Random Linear Network Coding technique is used into the relay node to increase the data delivery ratio. This scheme improved the energy efficiency. However, prioritized delivery of SD traffic is less focused in this scheme.

3 Traffic Priority-Aware Medical Data Dissemination Scheme

The Traffic Priority-aware Medical Data Dissemination (TPMD²) scheme is developed based on modular approach and exploits different modules for various tasks. The TPMD² modules consist of Packets Classifier, Data Priority Identifier, Queuing Module and Routing module are explained in following subsections and shown in Fig. 2.

3.1 Packets Classifier

Packet Classifier segregates the Data Packets (DP) and Hello Packets (HP). The DPs are sent to Data Priority Identifier, while the HPs are used to construct Neighbour Table (NT) based on the information received from the neighbour nodes. HPs are the control packets which are broadcasted by all the BSNs in the network to update their status. The HP contains information about residual energy and number of hop counts to the CN.

3.2 Data Priority Identifier

On receiving of DPs from Packet Classifier, the Data Priority Identifier categorizes them into SD and ND packets using Algorithm 1. The priority P is then assigned at the last bit of header in data packets, known as P -bit. If the measured value of vital sign is within the normal ranges, the type of

data packet is classified as ND packet and P -bit is turned to 0 for normal priority. Whereas, if the measured value of vital sign is beyond the normal ranges, the type of data packet is classified as SD packet and P -bit is turned to 1 for higher priority.

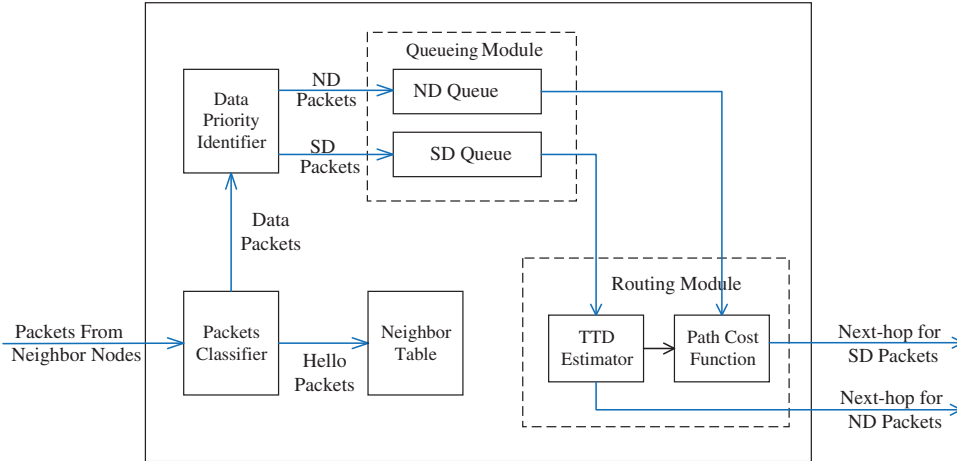


Figure 2: Block Diagram of TPMD² Scheme

Algorithm 1: Data Priority Identifier algorithm for TPMD² scheme

Notations:

DP = Data Packet

Th_{min} = Minimum threshold value of vital signs

Th_{max} = Maximum threshold value of vital signs

$Val_{current}$ = Current value of vital signs measured by the BSN

ND = Non-sensitive Data

SD = Sensitive Data

P -bit = Priority bit

Inputs:

DPs from priority identifier module

Process:

1. **start**
 2. **for** each DP received at Priority Identifier Module **do**
 3. **if** ($Val_{current} < Th_{min}$) or ($Val_{current} > Th_{max}$) **then**
 4. DP \in SD
 5. P -bit == 1
 6. **else if** ($Val_{current} > Th_{min}$) and ($Val_{current} < Th_{max}$) **then**
 7. DP \in ND
 8. P -bit == 0
 9. **end if**
 10. **end for**
 11. **end**
-

The minimum and maximum threshold values of the vital signs considered in Algorithm 1.

Table 1: Threshold values of vital signs

Vital signs	Minimum threshold value	Maximum threshold value
Heart rate (HR)	50 beats/min	120 beats/min
Respiratory rate (RR)	11 break/min	20 break/min
Temperature	97.8 degree fahrenheit	99 degree fahrenheit

3.3 Queuing Module

Once Data Priority Identifier has categorized the data packets as ND and SD, these packets are sent to the Queuing module. The queuing module processes them through the respective queues according to their priority. Two separate queues are maintained in each BSN to store two different types of data packets, which are Non-sensitive Data Queue (ND-Q), and Sensitive Data Queue (SD-Q). The SD packets are processed through high priority queue that is, SD-Q whereas the ND are processed in ND-Q as shown in Fig. 2.

3.4 Routing Module

The routing module determines the separate path for each data packet based on their priority. For ND packets, the next-hop is selected on the lowest value of Path Cost Function (PCF) which is computed using Eq. (1).

$$PCF = \frac{h}{RE} \quad (1)$$

where in Eq. (1), RE is the residual energy of the BSN, h is the number of hops from that specific BSN to CN. The BSNs keep track of their residual energy by calculating current value of RE value using Eq. (2) and broadcast to the neighbouring nodes.

$$RE = E_i - E_c \quad (2)$$

In Eq. (2), E_i represents the initial energy and E_c is the energy consumed in a transmission round.

In order to route the SD packets, Time to Deliver (TTD) is computed along with the aforementioned the PCF. The next-hop for SD packets is selected based on minimum value of TTD and PCF. Each BSN calculates TTD from the information received from the neighbouring nodes through Hello packets and store it in the Neighbour Table (NT). The TTD from node i to CN for a packet P can be calculated using Eq. (3).

$$TTD_{i,CN}(P) = \sum_i^{CN} TT_{i..CN}(P) \quad (3)$$

In Eq. (2), $TT_{i,CN}$ is the transmission time required to deliver a packet from node i to CN through intermediate nodes. The procedure of next-hop selection is elaborated in Algorithm 2. Further, the flow chart of the TPMD² scheme is presented in Fig. 3.

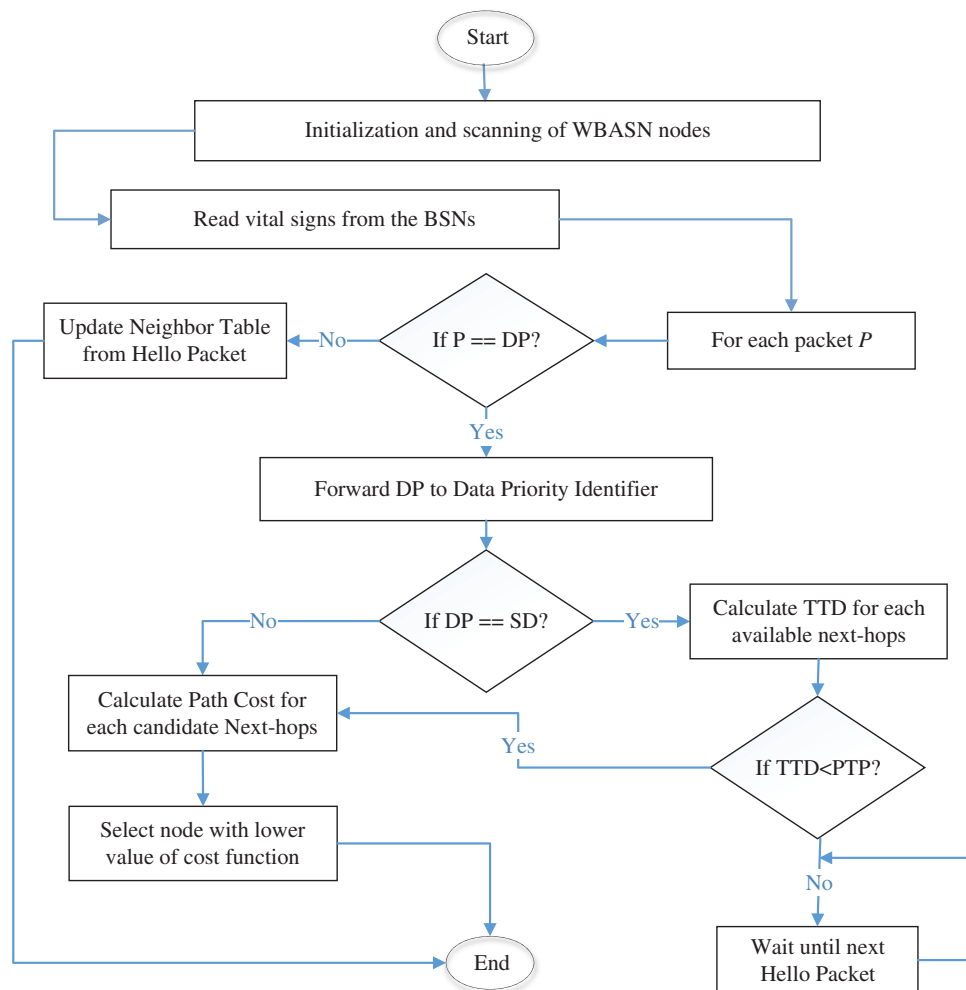


Figure 3: Flow chart of the TPMD² scheme

Algorithm 2: Routing algorithm for TPMD2 scheme

Notations:

DP = Data Packet

ND = Non-sensitive Data

SD = Sensitive Data

TTD = Time to Deliver

PTP = Packet Timeout Period

NH_{SD} = Next-Hop for SD packets

NH_{ND} = Next-Hop for ND packets

Inputs:

ND and SD packets from Queuing Module

(Continued)

Process:

-
1. **Start**
 2. **for** each data packet DP **do**
 3. **for** each DP \in SD **do**
 4. Calculate TTD
 5. **if** TTD < PTP **then**
 6. Calculate PCF
 7. Enlist values of PCF for each node
 8. Sort List in ascending order
 9. $NH_{SD} \leftarrow$ First element of the list
 10. **else**
 11. Discard node
 12. **end for**
 13. **for** each DP \in ND **do**
 14. Calculate PCF
 15. Enlist values of PCF for each node
 16. Sort List in ascending order
 17. $NH_{ND} \leftarrow$ First element of the list
 18. **end for**
 19. **end for**
 20. **end**
-

4 Experimental Results

A various experiments have been conducted to evaluate the performance of the TPMD² scheme. The simulation parameters are set according to Nordic nRF 2401A chipset [29] which are used in most of the relevant researches such as [16,30,31] and presented in Tab. 2. The performance of TPMD² scheme is assessed for both ND packets and SD packets by varying the number of nodes in the network. The results are compared with CEPRAN [17] and PCRP [18] in the form of packet loss, delay and energy efficiency of the network.

Table 2: Simulation parameters

Parameter	Value
Number of BSNs	15
Initial energy	1.0 Joule
Traffic type	Constant bit rate
Packet size	32 Bytes
Transmission power	10.5 mA
Reception power	18 mA
Transmitter electronics	16.7 nJ/bit
Receiver electronics	36.1 nJ/bit
Transmit amplifier	1.97 nJ/bit/mn

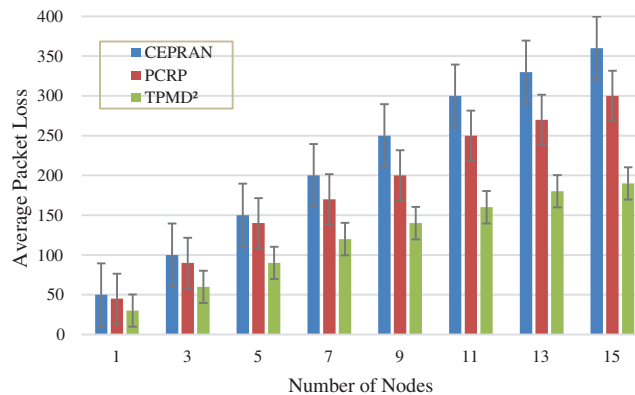
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Table 2: Continued

Parameter	Value
Supply voltage	1.9 V
MAC protocol	802.15.6
Simulation time	1200 s

4.1 Analysis of Packet Loss

These experiments were performed to assess the impact of varying the number of nodes on both ND and SD packets loss is analyzed while each BSN generates same number of SD and ND packets randomly. Figs. 4 and 5 show the average packet loss of ND and SD packets respectively in the CEPRAN, PCRP and the proposed TPMD² scheme. In Fig. 4, the results show that the average number of ND packet loss in TPMD² scheme is 31.2% and 26.3% lower than CEPRAN and PCRP schemes respectively. Lower packet loss is achieved due to efficient next-hop selection based on energy efficient strategy in the TPMD² scheme.

**Figure 4:** Average ND packet loss by varying number of nodes

In addition, Fig. 5 shows the average SD packet loss in TPMD² scheme is 37.3% and 28.5% lower than CEPRAN and PCRP schemes respectively. Lower SD packet loss is achieved by the proposed TPMD² scheme due to the next-hop selection criteria based on TTD. The TTD helps in estimating the packet delivery time through each candidate next-hops before forwarding the packet. However, the CEPRAN and PCRP schemes do not consider TTD to make next-hop selection for SD packets, which is why packets sometimes are sent to the node, which cannot guarantee the delivery before the packet timeout period.

4.2 Analysis of Packet Delay

In this section, the average delay in packets transmission is examined for both ND and SD packets while varying number of nodes in the network. The objective of conducting this evaluation is to measure the average time taken to deliver data packets from source to CN. Figs. 6 and 7 show the average packet delay of ND and SD packets respectively in the proposed and benchmark schemes. In Fig. 6, it is noteworthy that TPMD² has 27.3% and 19.2% lower delay for ND packets as compared to CEPRAN and PCRP schemes respectively. Furthermore, Fig. 7, shows 32.4% and 23.6% less delay

for SD packets in the TPMD² scheme in comparison to CEPRAN and PCRP schemes respectively. This is because of employment of the TTD, which helps in guaranteeing packet delivery with minimum delay. Since, the total time required by various paths are already estimated before forwarding packet to the qualified next-hop.

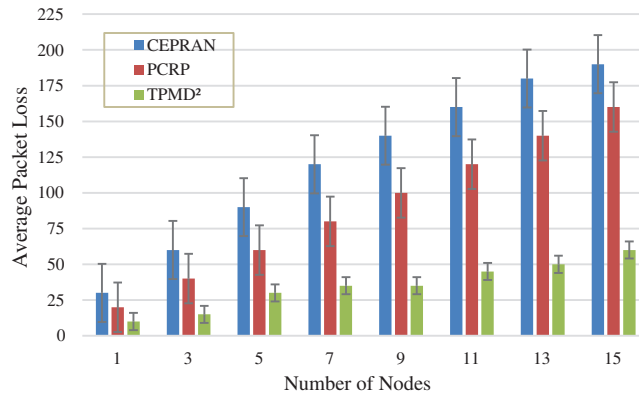


Figure 5: Average SD packet loss by varying number of nodes

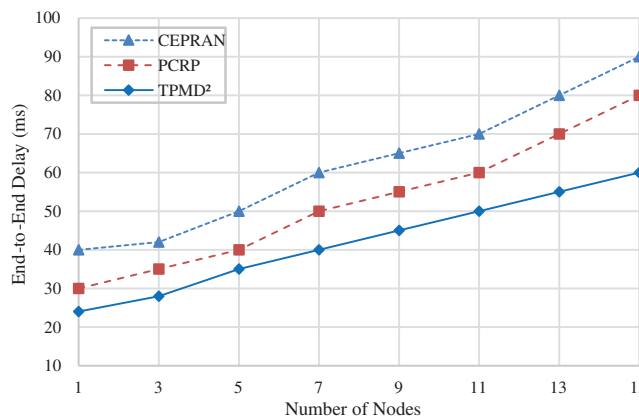


Figure 6: Average ND packets delay by varying number of nodes

It is obvious from the results that the proposed scheme outperforms against benchmark schemes due to the improved routing schemes that exploits the PCF and TTD for selecting the next-hop for delivery of data packets.

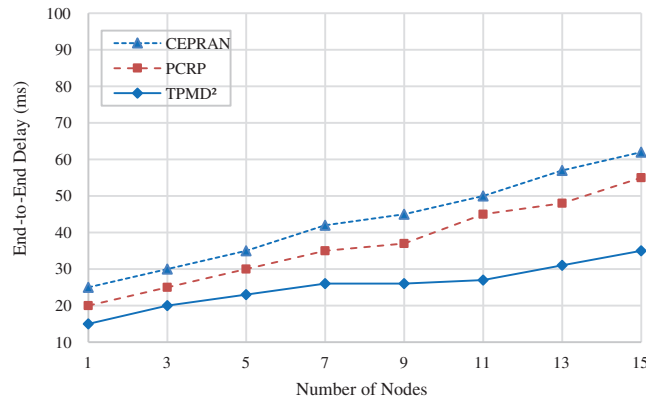


Figure 7: Average SD packets delay by varying number of nodes

4.3 Analysis of Energy Consumption and Network Lifetime

These experiments were performed to gauge the energy consumption in the TPMD² and benchmark schemes. Fig. 8 demonstrates the average energy consumption for each packet delivered from source to destination in the proposed TPMD² and other schemes with varying number of nodes. The results reveal that by increasing number of nodes in the network, the flow of traffic (both ND and SD packets) also increases resulting the nodes to consume more energy. However, the proposed TPMD² scheme maintains energy consumption of nodes by keeping track of their residual energy along with other criteria in the PCF for selecting the best next-hop for data delivery.

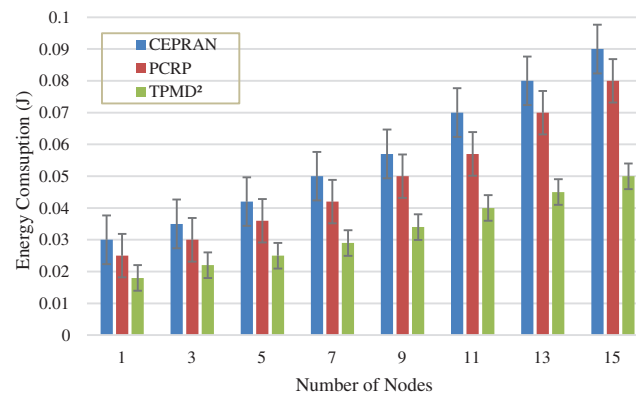


Figure 8: Average energy consumption vs. varying number of nodes

Similarly, Fig. 9 presents overall energy consumption in the network with respect to the simulation time. It is depicted from Figs. 8 and 9 that the proposed TPMD² scheme outperforms CEPRAN and PCRP by 27.3% and 19.5% respectively in attaining lower energy consumption which leads to longer network lifetime. The network lifetime is referred as time elapsed since the network starts working till the last node dies due to out of energy. Fig. 10 compares network lifetime of the proposed scheme in contrast to the existing schemes by varying number of nodes in the network. It was observed in Fig. 10 that the TPMD² scheme outperforms CEPRAN and PCRP by 35.3% and 24.5% respectively. The reason behind is that the TPMD² scheme exploits PCF for energy efficient next-hop selection to

send data packets to the CN, which helps reduce the energy consumption and leads to longer network lifetime.

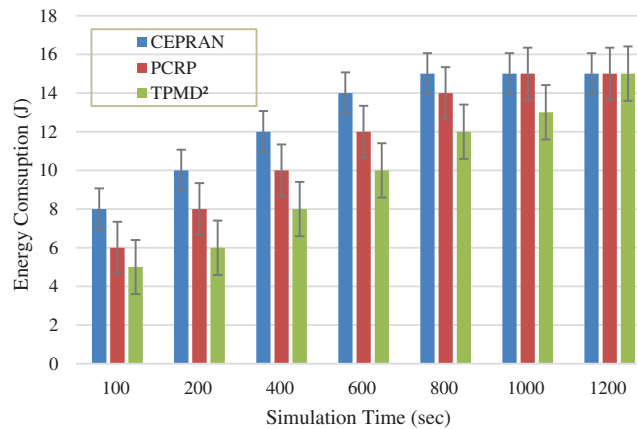


Figure 9: Overall energy consumption vs. simulation time

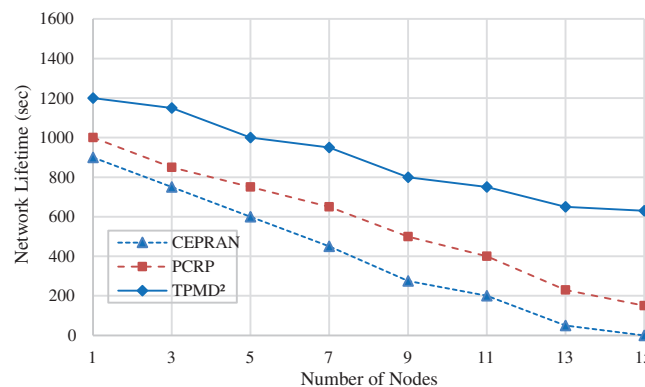


Figure 10: Overall network lifetime vs. number of nodes

5 Conclusions

The WBASN data generated by BSNs are classified into two categories; SD and ND. In order to deliver the SD and ND packets according to their priority the TPMD² scheme is developed. The proposed TPMD² scheme calculates Time To Deliver (TTD) for each available next-hop before forwarding SD packets. The nodes having TTD less than Packet Timeout Period (PTP) are further evaluated by the PCF. The node that has TTD less than PTP along with less value of PCF is selected as next-hop for SD packets. This approach ensures delivery of SD packets with minimum delay and packet loss. Moreover, the ND packets are forwarded in energy efficient manner based on the PCF. The contribution of the research work includes a significant improvements in terms of reduced packet loss, end-to-end delay and energy consumption along with increased network lifetime as compared to the benchmark schemes.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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