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PriTLP: A Priority-based Transport Layer Protocol for Low Rate Wireless Sensor Networks

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Abstract This paper presents a solution for priority-based data transmission in heterogeneous wireless sensor networks. Considering the requirements of each event separately while delivering a data simultaneously is a challenging task in the sensor networks. Therefore, we present the PriTLP protocol for prioritizing the information at various data processing units in the multi-hop topology network. It brings a distributed approach for taking decisions on behalf of the sink node which fastens the data processing, reduces the communication delays, and prolongs the network life. It performs two operations, namely data prioritization and scheduling; and identifying the congestion degree of the network. The reported work is implemented and validated over the RF TestBed by managing the buffer level. It shows high packet delivery ratio, greater throughput, and fewer communication delays of high priority-based traffic flow over regular flows.

Keywords: *priority approach, transport layer protocol, wireless sensor network, congestion control, buffer*

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1. Introduction

Recent development has shown the significant improvement in an industrial automation [1,2,3], residential projects, and smart city developments using the low rate heterogeneous wireless sensor technology (WSNs). This technology is mainly used for those applications which demand the low air data rate and long life. Due to its low-cost features, they can be deployed in remote areas where the physical access is almost impossible in person every time for upgrading the hardware, changing the setting, or recharging the batteries. Therefore, over the air features help to reconfigure the nodes as per application requirement or time to time upgrading the experimental setup. However, while developing the protocols for such works the real-time constraints [4,5] are need to be taken into consideration. The communication delays, transmission errors, packet loss due to link failures, multipath delay due to improper scheduling, and interference due to real-time physical obstacles are the factors which hinder the performance of sensor networks. In general, monitoring [6] and security surveillance applications [7] tolerate the packet loss. For this reason, the IEEE 802.15.4 [8] and Bluetooth [9,10] are used for achieving the target goals.

Network reliability is based on the node deployment [11,12], localization [13], communication protocol [14], and energy-aware routing protocols. In particular, transporting the required information in time is a challenging task in the wireless sensor network because of time constraints. The various protocols are developed for different applications by considering their needs. Therefore, the TCP and UDP protocols are not useful for WSNs. We address issues of data delivery approaches in real time network. Mainly, our work focuses on the prioritized data delivery for critical or time bounded applications. The reason for taking this problem for consideration is to deliver the data of sensitive applications first over the delay tolerant applications in heterogeneous WSNs. In a multi-event sensor network, handling the data simultaneously is a challenging task; therefore, we focus on this issue and developed PriTLP transmission protocol. The PriTLP performs prioritizing of information and scheduling the data packets over the multi-hop topology. The distributed approach is used to handle the data packets simultaneously. It helps to reduce the delay of getting the lost packets. The intermediate node identifies the gap in sequence number and informs to a particular node. The source node delivers that packets again and it continues till achieves the 100% reliability. To generate the multi-event sensor network, we equipped each sensor node with four sensing devices. It helps to generate the large amount of traffic in small size real time TestBed. The paper contributions are summarized as follows.

- The PriTLP presents the node prioritization and detection of congestion degree techniques.
- A priority metric is designed to handle the different traffics over the multi-hop topology.
- The congestion degree is measured by calculating packet loss ratio at every moment to regulate the traffic.

- It is developed over the real TestBed i.e. on the nRF24L01 Nordic controller with ioCare development board using ATmega 328 microcontroller. It is validated by performing the different experimentation in different scenarios with a variable time interval and hop count.

The remaining sections of the paper are structured as follows. Part 2 briefs about existing work related to priority-based data transmission approaches of WSNs. Part 3 gives an overview of proposed protocol description in terms of network model and assumptions; and implementation details. Section 4 shows the performance analysis of proposed work. Finally, work is concluded with future directions.

2. Related Work

This chapter highlights the existing work related to data delivery mechanisms for different types of sensors. The CSMA/CA with priority based approach [15] presents a solution for guaranteed data delivery of different classes in event-based sensor networks. The three different classes are taken into consideration of proposed protocol design. The reported work is tested over real TestBed platform with a star topology. The different clusters are formed and each one is controlled with one coordinator. All coordinators communicate with the main base station of the network. Coordinators and sensor nodes are synchronized in order to access the reserved slots; if the node is defined with priority type. The EDF algorithm is used to meet the deadline of the data packets. It claims the improved throughput and goodput of the network compared with the standard CSMA/CA beacon enabled MAC protocol. The collision rate is reduced using the GTSs of CFP window effectively. The GTS scheduling is based on EDF mechanism. Typically in the industrial application, the periodic real-time traffic flow scheduling mechanisms are developed but lack in deadline aware mechanism. Therefore, this paper has proposed an EDF with CSMA/CA priority approach for time bound applications in WSNs.

The priority-based CSMA/CA [16] describes the Markov chain model for priority based data transmission model for WSNs. Sensor nodes are classified into three types according to traffic load and traffic type. Each sensor node is defined with some priority level and the customized Markov chain model is applied to assess the network. It is mainly used to assess a throughput, energy, transmission probability. The data is classified because the multimedia data is more critical than other.

The PSSB algorithm [17] is proposed to mitigate the collision rate in congestion situations and multimedia data transmission using priority approach. The number of competing stations is reduced for high priority node to deliver the data in time. The backoff window is kept small for high priority nodes. The high priority stations experience the small waiting time compared with other nodes to gain the channel access. In the case of collision, high priority nodes have shared channel access provision to deliver their data. This proposed scheme reduces the fairness problem, collision rate, delay, and greater throughput against a BEB algorithm. Furthermore, the protocol performance is examined over voice and video multimedia data in detail. The reported work is compared with BEB algorithm.

A PriorityMAC [18] presents a novel solution for heterogeneous wireless sensor networks. It handles different data packets of different classes simultaneously over different latency requirements. It classifies each data packets into either high priority or normal priority traffics. The latency requirements of high priority packets are strictly followed over the regular traffic flows. It is implemented in ns2 and TelosB TestBed platforms. The experimental results have shown the remarkable improvements in terms of latency constraints. The three contributions are 1) service differentiation, 2) reduction in latency, 3) implemented in TinyOS and evaluated over the TelosB platform. The latency reduction is noted around 94% and 93% of high and secondary high priority traffic flows, respectively. Furthermore, collision rate minimization, adaptive routing, and cross-layer approaches are put forth for future enhancement.

PCCP [19]: It computes upward congestion and precedence level using weighted fairness. A node is defined with different significance with different throughput requirements based on the priority index. It uses the cross layer approach and follows the multiple hop topologies to manage the traffic jam and elaborated over single or multiple path routing protocols. Congestion levels of node and link are controlled using a PCCP protocol design for optimizing the congestion control through packet-based data computations. It exploits the packet inter-arrival and service time to compute traffic jam. Furthermore, according to the priority level, each sensor is configured with different sensing devices in an environment. Therefore, the projected results are priority dependent. A dual buffer is used for node traffic and transient traffic. It operates over MAC. The priority-based rate adjustment (PRA) designed for achieving the equality index of the node along with tree based transient traffic. The PRA takes care of adjustment of scheduling and source rate using node priority weight and sub-tree transient traffic priority weight to handle the link and node load. When the network does not experience the congestion, PCCP increases the scheduling and source reporting rate without considering the priority weight index whereas, in a congested network, the PCCP protocol reduces packet rate and performs scheduling.

MCCH [20]: A Multipath Congestion Control for Heterogeneous Traffic allocates different levels to different sensing devices according to sensed readings. An MCCH uses multi-path routing. Three different sensors are used to every source node and therefore, three buffers are designed for classifying the data packets. An MCCH achieves the desired throughput by assigning the different priorities to the source nodes. Every source node has multiple parents and its data reporting rate is the addition of all parents' reporting rate. The ratio of service rate and reporting rate for identifying the congestion level is used. It does not consider the priority of children nodes for managing the reporting rate. However, a queue scheduling is not addressed at the node level. In the MCCH, routed packets are considered as a high priority than packets generated by children node. Due to the use of piggybacking the network overheads are observed more.

APRC [21]: It is designed to control the congestion in the sensor networks. The interactive queue management approach is developed to fulfill of application requirements individually. To manage the different application requirements, the inter-queue and intra-queue management approaches are designed. To ensure high link utilization, node-based hop by hop priority scheme is also presented. It is observed that the proposed protocol has shown the remarkable results in terms of power utilization and throughput. The application-based queue levels are referred for updating the scheduling the reporting rate. The length of queue varies due to random access of channel. Furthermore, a packet rate is aligned with priority which depends upon the queue length instead of data.

PHTCCP [22]: It is developed over a signal path routing. A congestion level is measured using ratio of service and reporting rate. It presents the packet scheduler according to congestion level of parent and local nodes. Furthermore, PHTCCP protocol operates over the traffic aware MAC protocol with variable SIFS and backoff timer mechanisms.

NCC [23]: it proposes the solution for monitoring the vital sign in the biomedical sensor networks. It presents a solution for congestion control and differentiation in service using priority approach for monitoring the vital sign of the patient at a real time. An NCC protocol assigns the priority weight based on criticalness of vital sign information and schedules the highly essential data packets first. It considers the congestion level at parent node and allocation of more bandwidth to child node based on anomaly received information of patient state. The queue length is followed for detecting the congestion level and updating the data packet rate of the child node.

QCCP-PS [24]: Authors propose an adaptive transmission rate control approach for multimedia networks. The rate control approach depends upon the priority level with a degree of congestion. The buffer management is the core operation of the QCCP-PS protocol. In wireless multimedia networks, a reliable transport delivery approach performs a vital role in achieving minimum energy utilization, greater throughput, and higher packet delivery ratio. The results describe that the proposed works claim the less packet delivery ratio.

DST [25]: A Delay Sensitive Transport layer protocol is proposed to handle the critical sensitive application data where the timely delivery is important. The event time is a difference time taken in-between reported time and event detection to the base station. To meet the deadlines, it uses the prioritized MAC to ensure the hard deadlines. The short deadline packet is considered as high priority packet over long deadline packet. A packet does not meet the deadline then particular application leads to failure. It also defines and achieves the event reliability based on interval concept. The observed packet rate is low then reporting rate in increased. A DST protocol identifies the level of congesting by considering the packet delay and buffer occupancy. This helps to detect the congestion around the node. The congested node notifies to the sink node about congestion by sending the congestion notification packet. Furthermore, considering the current network condition and reliability requirement indicator, the sink node updated the reporting rate time to time in each decision interval.

FTW-WCM [26]: It presents the Fault Tolerance for wireless sensor networks using the weighted criteria matrix to reduce the unnecessary transmission of faulty data to the base station. A cluster head uses this approach to detect the faulty data and tries to recover it from the source node. It immediately discards the faulty data. It uses four major parameters such as residual energy, hop count, selection count, and source rate using the WCM mechanism. A node which has the highest rate is selected among the neighboring nodes as a successor for further data transmission. The proposed work shows the significant performance with regards to PDR, network life, and residual energy.

DFRTP [27]: Authors proposed fuzzy based routing approach for improving the packet delivery ratio and enhancing the life of a sensor network. It works over the hop by hop network by using the fuzzy logic procedure for delivering the data to the destination node. It uses two input parameters, namely, neighbor nodes and distance whereas one output parameter i.e. traffic probability. A node forwards data to next upstream node which is part of candidate nodes (CNs). These nodes have higher power and buffer space than average in general. Two input parameter are used to calculate the traffic probability. It has shown the remarkable performance against the greedy and A* heuristic routing schemes in terms of PDR and network life using A-star and fuzzy methods.

OPCA [28]: It provides solution for congestion particularly for Wireless Body Sensor Networks. This proposed method has focused only on controlling the level of congestion, especially for body area sensor networks. It works over the hop by hop topology. Each data packet is prioritized using two attributes, namely node priority, and data volatility. A three priority queuing system is designed at the intermediate node where their priority is updated. Each node selects its upstream node using congestion-aware routing strategy. Achieving event reliability and solving traffic control are the goals of OPCA. It has shown the significant improvements over the existing methods in terms of network throughput, packet loss ratio, traffic load, and network life.

3. Protocol Description

3.1. Network Model & Assumptions

The multi-hop topology is used for protocol configuration in real time environment. The nodes are placed randomly around 70m distance away from each other so that they join automatically to nearest node. The routing of data is dynamic. Each node is having the capability of self-joining, self-healing, and self-routing the packets into the network. This feature helps the network to become stable in any extreme condition. If any link goes down then that particular node immediately joins and reroute the packets via another route.

This dynamic routing protocol is used to data transmission. Every node is configured with high power mode with 70m distance line of sight. A 2.4GHz nRF 24L01 Nordic radio [29] is used and for processing, we used the Arduino Nano ATmega328 [30] ioCare development board as shown in Figure 1. This setup is used to perform the various experiments over the hop by hop topology.

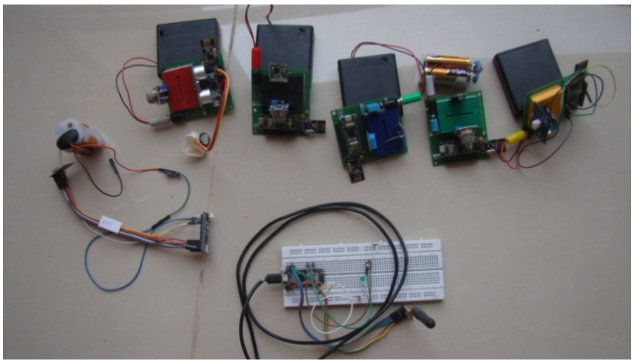

Figure 1. 6+1 RF TestBed Setup used in mesh based topology for heterogeneous wireless sensor networks. Over the breadboard, the coordinator is set up for controlling all source nodes

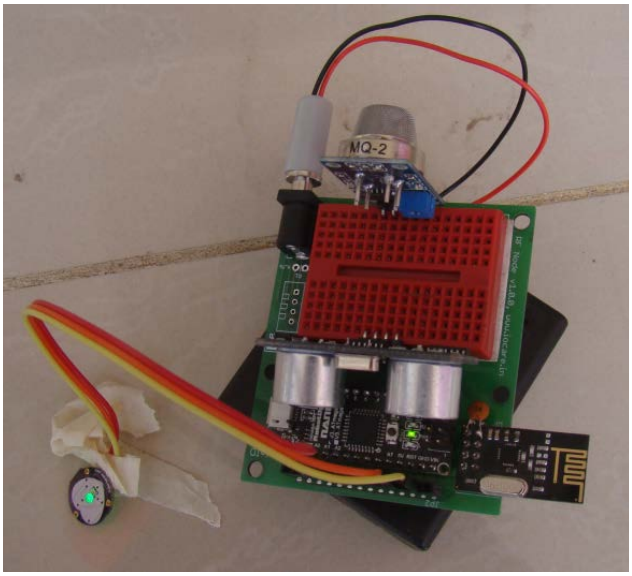

Figure 2. (RF Node) photograph shows the single node RF node view. A node is equipped with an additional breadboard for connecting the multiple sensing devices for achieving the different types of traffic in small size networks

The customized nodes are designed and developed to implement the proposed work which is reported in this paper. A breadboard is used at each node so that multiple sensors could be attached and heterogeneous traffic is generated. A real time clock is attached at the back of every sensor node to measure real time. To measure the power utilization AA batteries are used and through widgets at the run time graphically energy consumption is visualized in terms of percentage. A single node pictorial view is rendered in Figure 2. The figure clearly visualizes the provision made for using the multiple sensing devices.

We use the battery powered development board and measured the various parameters of the protocols. The CSMA MAC protocol is used. A priority approach is designed at the top of MAC protocol. The data transmission rate is set to 250kbps according to the IEEE 802.15.4 standard. The proposed work includes the priority metric and identification of congestion degree using a buffer. The buffer occupancy is the key to identifying to know the level of congestion called as node congestion. We use node priority and node congestion terms for further discussions. Each node including the router is equipped with four sensors, namely temperature, humidity, heart beat counting, and water level sensor. The TestBed setup consists of 6 nodes and one coordinator. We tested the protocol by varying the workload at different conditions in order to check the correctness of the accuracy of distributed priority approach. The inbuilt FIFO is modified as per the protocol requirement. The time bound constraint is out of the scope of protocol design.

The cloud solution is designed and used for monitoring the node traffic and visualizing the real-time view graphically. The various widgets are used to monitor the data packets effectively online. It is observed that node automatically reroute the packets according to the availability of link at that particular instance. During the experimentation, the topology screenshot is captured and depicted in Figure 3. It shows how nodes join with each other in discovery mode. After self-joining, they route the packets towards base station automatically.

The energy consumption of each node is calculated and monitored graphically through online cloud solution during experimentation as shown in Figure 4.

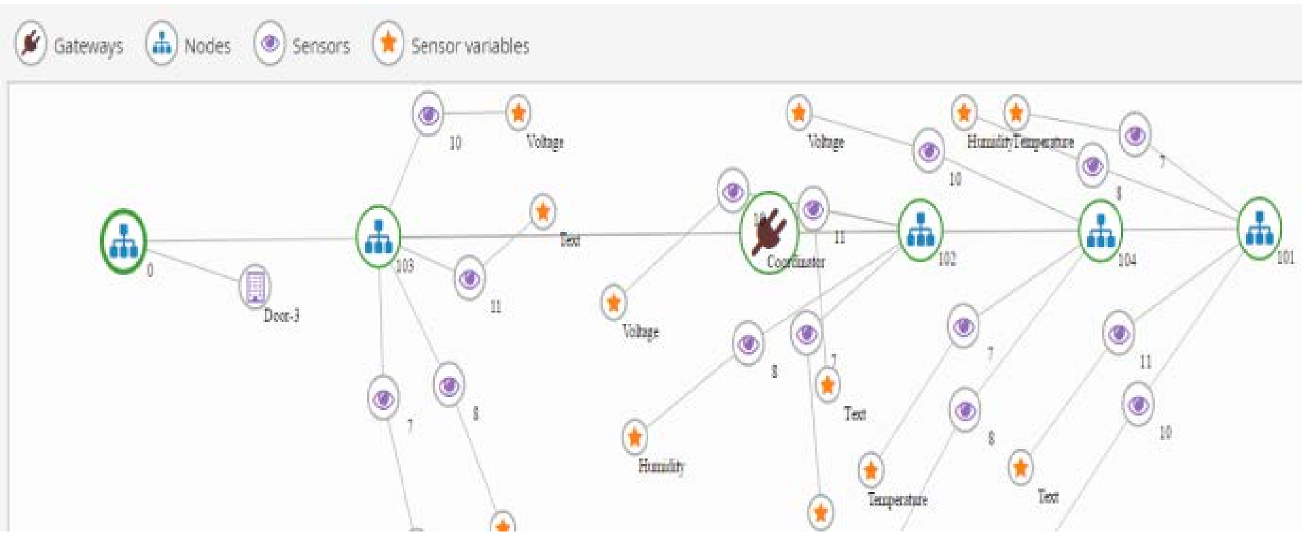

Figure 3. Screenshot of 3-hop node topology captured during run time experimentation in real time scenario using a cloud solution. Eye symbol and star symbol indicates sensing device logical id and sensing device type.

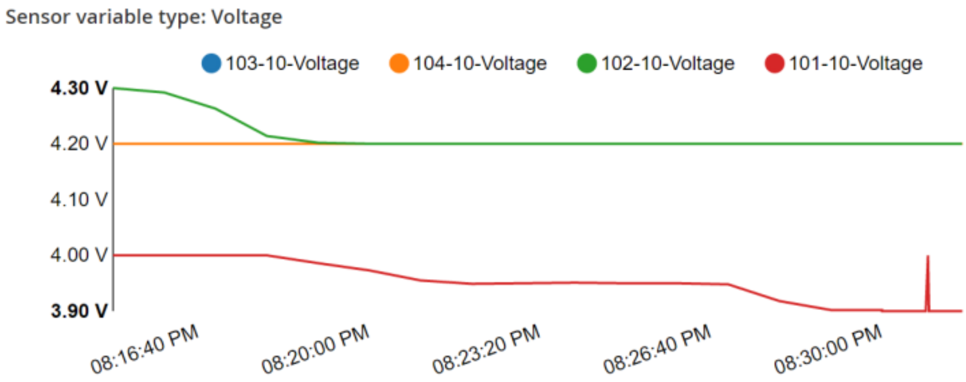

Figure 4. Analysis of energy consumption of each node captured during experimentation. It helps to keep the track of all nodes (for example, 4 sample nodes are depicted)

Figure 5. The screenshot is captured during analysis of a patient state. It shows the ECG signal of a patient and would be used to analysis the patient wirelessly by the practitioner

Figure 6. Graphical view of all sensor readings at a glance. An image is captured during experimentation at the run time using a cloud solution using group view representation

For instance, the graphical view of heart beat counting is shown in Figure 5. It helps to monitor the patient state wirelessly and could be used in the hospital in different wards. It is easy to the practitioner to keep the track of many patients simultaneously on the single display. The anomaly would be detected in advance before any harmful situation occurs. This system is very useful to assign the priorities to the patient based on the run time-criticalness of the patient. Hence, we develop the priority approach to delivering the data efficiently to the desired location based on event type. Furthermore, at a glance, we can analyze the min, max or aggregate value of any sensor readings which are rendered in Figure 6.

3.2. Protocol Implementation

The proposed work splits into two parts, namely node prioritization and detection of congestion degree based on the packet loss count. The priority of the data packet is computed according to priority index. An index is updated using a number of hops that node has traveled. As it travels from one hop to another hop, the priority of packets get increased. This approach is included to reduce the packet loss in the dense network where the hop count is large. In the case of delay sensitive applications, delivering the packets is not the only goal of data transmission protocol but sending them in time is most important otherwise, data becomes useless if it is not delivered in time. Therefore, to avoid the packet loss of long distance high priority packets, the priority approach is introduced. Simultaneously, the packet loss is also taken into consideration. If the network experiences the packet loss then it is considered that the congestion occurs. The probability is computed according to a number of packet loss occur consecutively. A degree of congestion (c_d) is measured in equation 1.

$$c_d = s_i * r_c \qquad (1)$$

Where, s_i be the source node and r_c be the retry count. To handle the traffic simultaneously, the priority approach is designed. It considers the number of hops it has crossed and node priority index. It is measured at each hopping node as expressed in equation 2.

$$P_{wt} = s_i^p * h_c \qquad (2)$$

Where, P_{wt} be the priority weight of the packet, s_i^p be the source priority index, and h_c be the hop count. The distributed data classification and scheduling are explained in the algorithm. An algorithm describes the operational flow of data gathering, data classification, and data scheduling to the next upstream node. It is implemented over the multiple hops. It helps to serve and verify the data in time. It also reduces the load of the coordinator. Taking the decision at the coordinator node increases a delay which affects network life. Thus there is need to handle data at various points in the network. Another advantage is to find the packet loss at an early stage and would be retrieved them from the downstream node immediately without much delay. It reduces the requirement of memory at various points and that decreases the energy consumption of a node to a great extent. The operational flow of PriTLP is described in Figure 7 in detail.

As shown in Figure 7, PriTLP protocols include data classification, storing, and scheduling the data packets. Data packets are updated based on their priority weight and flow is controlled using congestion detection metric as expressed in equation (1). The congestion level is predicted based on the number of retransmission recorded in the last sessions. Sometimes, it suffers due to link failures. But in the scope of our proposed scheme, we consider the packet loss ratio to traffic jam situation. It helps to decrease probability of blocking going to happen in the future at the node level. An algorithm describes priority-based data transmission mechanism over the beaconless CSMA approach.

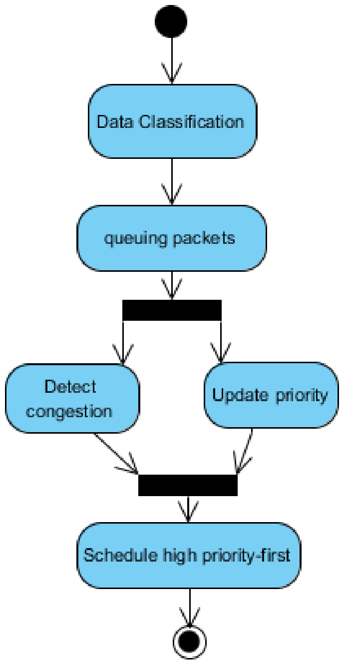

Figure 7. Operational flow of intermediate node over hop by hop topology

Initially, the priority is assigned to all source nodes. The auto retransmission mechanism is used. The retry limit is set to 3 to avoid unnecessary retransmission number of times in case of a congested network. It is one of an attribute for congestion level detection. The upper limit for congestion detection is set to 2. The auto retransmission mechanism helps to attain 100% PDR. The priority approach is used to update the data packet priority at hop node in order to serve the high priority packet first against the normal traffic. To regulate the traffic in the network, an additive increase and multiplicative decrease method are used.

Algorithm: PriTLP: A Priority-based Transport Layer Protocol

Input: Node index and sensor ids
Output: data classification and data scheduling
Prerequisites: priority assignment and multi-hop topology formation
Begin

1. while(buffer!=NULL)
2. sortPackets();
3. updatePriority(pckt); // refer equation 2
4. Schedule(pckts);
5. If(retryCount>=2)
6. detectCongestionDegree(); // refer equation 1
7. accessAIMD();
8. End of If
9. End of while loop

End

4. Results & Discussions

The performance of PriTLP is measured with regards to packet delivery ratio, power utilization, system throughput, and packet latency.

Scenario-1: A network is setup with 3 and 5 hop topology with a 0.1-second interval. A setup comprises the 6 sensing nodes and each one is equipped with 4 sensing devices. The performance is evaluated over 3 and 5 hop topology.

Figure 8 plots the packet delivery ratio over variable experimentation time period and tested over 3 hop topology. It is observed that due to distributed priority approach and auto retransmission mechanism the packet delivery ratio is greatly improved. It has shown approximately 99% packet delivery ratio. The packets cashed until source node receives the positive acknowledgment from the upstream node.

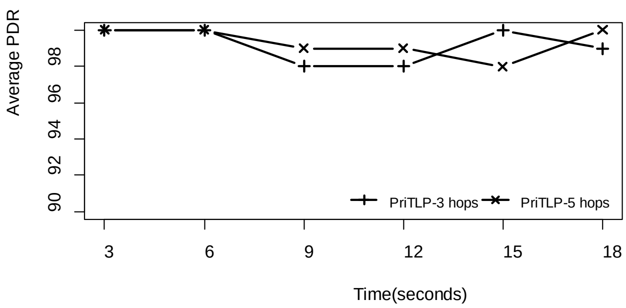

Figure 8. Analysis of Packet Delivery Ratio over 6+1 RF nodes with 3 and 5 hop topology at different simulation time. The placement of nodes is random

Once the packets are successfully delivered then it clears the buffer. For this reason, hop by hop notification message is used to regulate the different traffic flows. It is observed that the packet delivery ratio is greatly improved due to multiple hops traffic control approach. The purpose of auto retransmission mechanism is to achieve the 100% packet delivery ratio from the application perspective. The packet delivery ratio over 5 hop topology is 99%.

Figure 9 depicts an analysis of power utilization for battery-powered sensor devices. Graph clearly illustrates the less energy consumption for transmission of data packets due to efficient scheduling mechanism at the multiple hops.

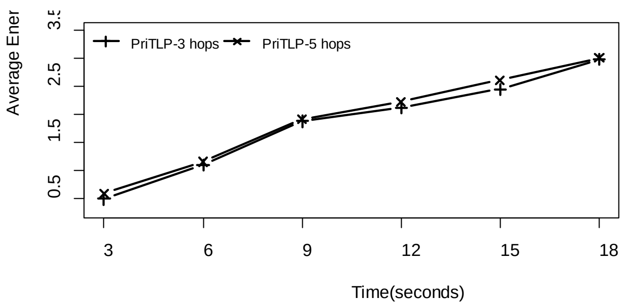

Figure 9. Analysis of average energy consumption over 6+1 RF nodes with 3 and 5 hop topology at different simulation time. The placement of sources is random

It is observed average12ms time is taken for generating and sending the data packets at the node level. It can be noted that the processing time is reasonably minimal. Thus it shows less processing overheads even at the node level though the data prioritization and packet scheduling are the part of a router operation. The multiple hops mechanism reduces the communication delays which results in less power utilization of a node. The average energy consumption over different simulation time is 2%, shown in Figure 9.

An analysis of communication delays by varying simulation time is shown in Figure 10. The graphs clearly illustrate that the priority approach takes very less time for processing the packets. This distributed approach works better over the multiple hops for processing the packets in time. End to end data packet processing takes more time because of the centralized approach for data gathering and identifying the loss packets. The overheads to retransmitting the lost packets are more.

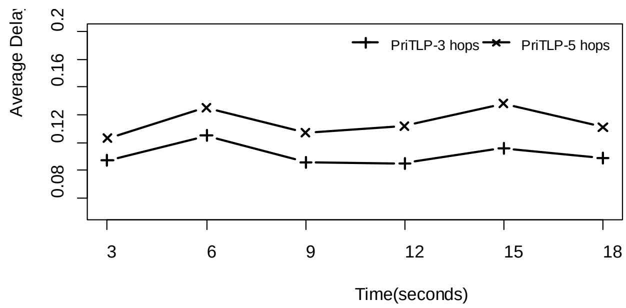

Figure 10. Analyzing an average delay using 6+1 RF nodes over 3 and 5 hop topology at different simulation time. Nodes are placed randomly

It utilizes the whole network for delivering the lost packets. Thus, it takes more time to get the lost packets and consumes more energy too. The end to end transmission delay is noted around 0.111 seconds and 0.134 seconds in Figure 9, respectively.

Figure 11 shows the throughput analysis over different simulation time. Due to auto retransmission and distributed priority approach, the packets are served in time.

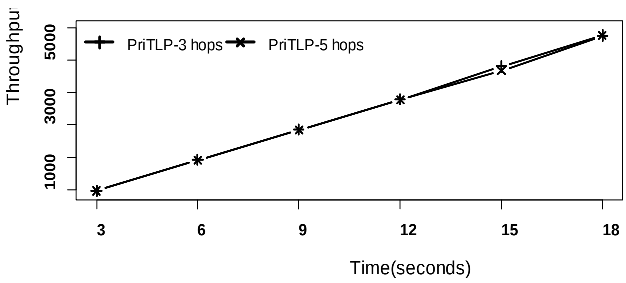

Figure 11. Analysis of average throughput over 6+1 RF nodes with 3 and 5 hop topology at different simulation time. The placement of nodes is random

It is observed that the achieved throughput is good and this approach would be useful for delay sensitive applications. The average throughput is observed approximately 288 bits per seconds with 0.1s packet inter-departure interval. Though the auto retransmission increases the more power requirements but it is acceptable from delay sensitive application point of view.

Scenario-2: A network setup includes 6 source nodes out of which each node is configured with 4 sensing sensors. The inter-packet departure time is set to 0.05 seconds. A system analysis is computed with regards to

PDR, energy, packet latency and system throughput. Figure 12 plots the average packet end to end latency. It can be noted the difference from 9% to 30% over the 3 hop and 5 multiple hops topology. The average delay analysis is observed around 16%.

The average energy consumption by varying the number of hops is depicted in Figure 13. Power utilization varies from 8% to 20% when they are compared with each other. The energy consumption on an average is 13% less in the case of 3 hop topology as compared with 5 hop topology. But at a real time scenario, sometimes it comes close which is reasonably acceptable. The reported results vary as per distance in between the nodes. We tried to keep distance around 20m – 50 m with physical obstacles so that their radio interference will disturb and can join to the nearest node in order to form the multi-hop topology.

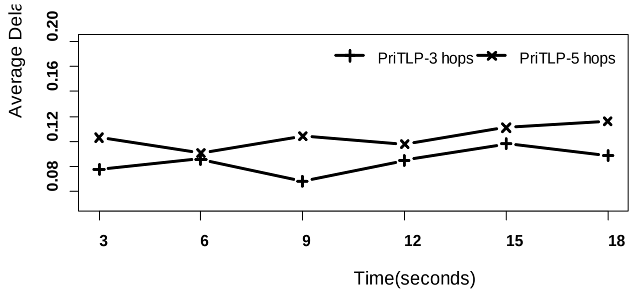

Figure 12. Analysis of delay by varying hops with 0.05seconds inter-packet departure time

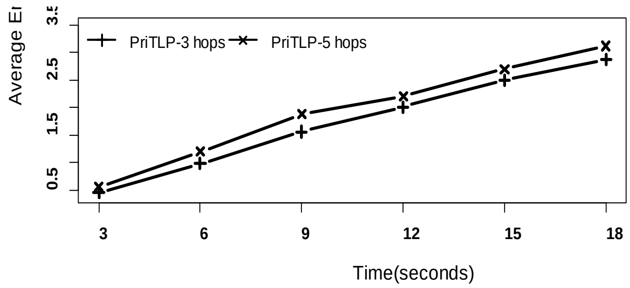

Figure 13. Comparison of energy consumption of PriTLP over 3 and 5 hops topology with 0.05 seconds packet inter-packet interval time

The average packet delivery ratio is depicted in Figure 14. The graph clearly shows that the PDR ratio is approximately close to 100%. It is achieved due to priority weight and congestion detection mechanism. It is updated using the mathematical approach with auto retransmission mechanism. In most of the case, it has been observed that the packet delivery ratio is 100%, but we purposefully put the worst case for discussion.

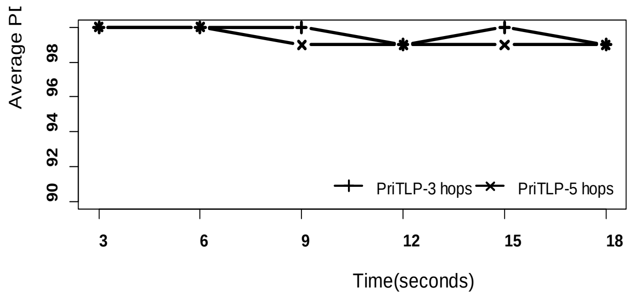

Figure 14. Analysis of average packet delivery ratio with variable hop count (0.05sceond interval time)

The system throughput is depicted in Figure 15. As discussed in Figure 14, due good packet delivery ratio, the throughput of the network is remarkable. It is also observed that in very few cases the goodput of the network is noted different. Otherwise, both are observed same in most of the cases.

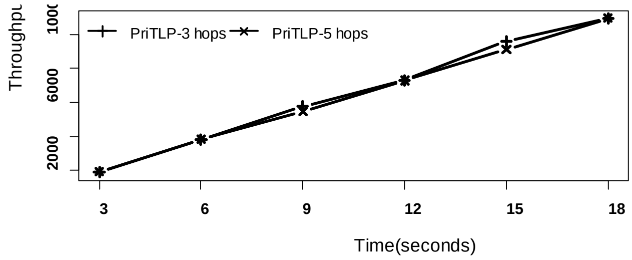

Figure 15. Analyzing system throughput over multiple hop topologies with different experimentation timing

5. Conclusion & Future Directions

In this paper, the reported work shows the noteworthy upgrading with regards to packet delivery ratio, throughput, and delay. The distributed priority approach and congestion detection mechanism help to minimize the network overheads. The objective of the PriTLP proposed protocol is to reduce the delay and improve the throughput of the network. It is designed for an emergency event or critical application perspective. It can be noted that the PDR is 99% and average communication delay is observed approximately 0.111 s and 0.134s over 3 hops and 5 hop topology, respectively. In future, we plan to enhance the priority approach by considering the time bounds and layering overheads. In addition, it can be also tested over the different link strengths and can be incorporated the link aware scheduling approach.

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