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A Real Time Routing Protocol for Detection of Time Critical Events in Wireless Sensor Networks

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Abstract— Many applications of Wireless Sensor Network (WSN) are designed for vital event monitoring and to ensure timeliness and reliability for the measured environmental values. The communication protocol needs to prioritize the real time data and ensure the timely delivery of the data to the sink node. In this paper, a routing protocol for WSN has been proposed with congestion and delay aware mode to realize a highly reliable information delivery with timeliness to the sink. In case of occurrence of congestion, it is mitigated by data rate adjustment. The effectiveness of the proposed protocol depends upon how successfully the management packets are delivered, which carries the vital congestion and delay information. A simulation is conducted to investigate the result of the proposed protocol. The results of the proposed protocol have been compared with the similar known technique.

Index Terms — Congestion Mitigation, Timeliness, Relaibility, Wireless Sensor Network (WSN), Efficacy function.

1 INTRODUCTION

A typical WSN may consist of tens to thousands of sensor nodes and these sensing nodes are deployed in a particular field where they work together to accomplish a particular task [1]. In general the sensors are deployed in the remote and inaccessible areas. In order to achieve proper functionality, the sensors require continuous power supply and hence these sensors have their own inbuilt power supply, but it becomes very mammoth work to replace the battery after depletion of the energy. The existing research works have emphasized only on the energy consideration for a WSN [2]. The most expected and desired factors are reliability and timeliness. There are many situations like fire detection, where the reliable and timely data communication becomes very important where we get temperature data of the nodes that are high compared to the threshold temperature. Here, information delivery success rate of those crucial nodes is equally important because of the energy effectiveness. But reliable information delivery is inherently correlated to congestion. Congestion within the network causes packet drop that reduces the reliability of information transmission [3]. It is required to get a proper congestion management technique to realize the specified level of reliability. In case of event sensing WSNs, time criticality of transmitted information is important. Some real time event will be controlled with minimal effort if the event is detected early. Beside the congestion management, a delay aware routing of information is required in these phenomena to meet the time criticality in order to make early detection of events feasible.

In this paper, we take into account the applications where sensor nodes are deployed in ad-hoc manner to detect crucial events in the deployed space. All sensor nodes forward their information towards one static sink node.

It is necessary to design a routing protocol that proactively avoids congestion and meets delay needs of transmitted information by selecting gently loaded and low delay incurring nodes during information forwarding towards the BS. All nodes broadcast periodic management information packets describing the congestion status and delay measurements in order that the neighboring nodes will utilize this information throughout route discovery process. The performance of the proposed theme is very avid about the successful delivery of those management packets. Special effort has been created to enhance the success rate of those control packets. Real time routing protocol for detection of time critical events in wireless sensor networks (RRDTE) additionally contains a congestion mitigation technique. A feedback from the MAC layer is sent to the network layer regarding the achievable information forwarding rate. If the application layer contains a higher traffic generation rate, the protocol suggests the application layer to lower its rate. The network layer merely drops an applicable fraction of packets received from different nodes if the incoming rate is more than the data forwarding rate of MAC layer. In this protocol, our primary objective is to improve the reliability and the timeliness of data transmitted by the vital nodes (i.e., nodes close to the current event) through congestion avoidance and mitigation. The rest of the paper is organized as follows: section II provides a discussion on relevant existing works; section III thoroughly explains the design issues of the proposed protocol whereas its its performance has been examined in section IV and finally section V presents conclusions on this research work.

2 RELATED WORK

One of the factors contributing to the loss of packets in WSN is the development of congestion. This will affect the real time delivery of packets within the dead line in WSN. Every WSN communication system is considered with the priority to miti-

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gate the congestion as soon as it emerges. Many of the protocols which are mentioned in CODA [4], Siphon [5] and TARA [6] mitigate congestion rather than avoiding it. Congestion in the communication pathway causes the drop of packets and thus the reliability of the WSN communication system is reduced. The technique like congestion avoidance plays a vital role in mitigating the drop of packets. RTMC [7] provides a reliable transport with memory considerations of the nodes. A node defers transmission till it gets a node with free buffer area. H. Zhou et al. in the algorithm claim to realize congestion management, actually they avoid congestion without considering delay in data transfer. CAM [8] provides a routing protocol that tries to avoid congestion to confirm successful event detection similar to that of RTMC. The theme assumes that a high variety of vital packets (packets sent by the nodes close to an event) have successfully reached the sink node because of the successful detection of critical events. But generally it will not consider the delay of those packets. In most cases, an event packet reaching the destination or the sink has some significance only if it reaches within the required deadline provided the network is under the regime of such significance driven packets. Moreover, the performance of the protocol depends on periodic neighbor node management table broadcasted by nodes; however the theme has no special technique to confirm successful delivery of the broadcasted messages.

The technique presented in Residual Time Aware Forwarding for Randomly Duty-Cycled Wireless Sensor Networks [9], deploys the residual-time-aware routing where every sensor node is static and randomly duty cycled of alternative nodes. The scheme is applicable when only one node within the network acts as a data source. Moreover, end-to-end data delivery is not guaranteed. It cannot be employed in event detection system where end-to-end data delivery from multiple vital nodes is crucial. In EARQ: Energy Aware Routing for Real-Time and Reliable Communication in Wireless Industrial Sensor Networks [10], Heo et al. gift a routing protocol where every node considers energy, delay and reliability of its neighbors to choose an acceptable route. Nodes periodically broadcast beacon messages to exchange management knowledge with neighbors. Here, the successful transmission of the beacon message is the key factor which influences the performance of the protocol. The protocol considers IEEE 802.11 DCF as its MAC protocol, however does not take any special effort to ensure successful transmission of beacon messages which may get collided and also the performance of the protocol can be considerably degraded. On the other hand Munir et al. proposes a mathematical model which may play a vital role to reduce the delay within the network through the selection of appropriate transmission scheduling and is described in Distributed Algorithm for Minimizing Delay in Multi-Hop Wireless Sensor Networks [11]. This model is suitable where the sampling process is incorporated by individual transmission schemes. There are certain scenarios or the occasions where the sampling process of some nodes changes abruptly in response of certain events and thus the mentioned model does not work well, additionally the model is computationally expensive. So the model will be applied to networks with few nodes and hence cannot be used for large WSNs for event sensing. SPERT [12] provides an energy aware real-time routing protocol. In order to decide the optimum acceptable route, every node uses the energy level and hop-count of its neighbor node. Hop-count of a node suggests the number of intermediate nodes required to transmit the packet to sink node or destination. This protocol uses hop-count of the node to measure the delay of the node, which may not be suitable for large WSNs. Because of congestion around a selected event, every link can have a unique delay associated with it. Hop-counts of neighbors are obtained exclusively once during the network setup, however energy levels of neighbors are obtained periodically through management messages sent by neighbors. CAM [8] and EARQ [10] protocols will not take any special effort to enhance success of management messages. All schemes in [9], [10], [11], [12] treat all the data packets with equal importance. However we have to consider the nodes that are near to the critical events and provide them with high generation rate. The remaining nodes will generate the data with a normal generation rate. Our protocol aims at routing the critical data in congestion and delay aware manner in order that the vital data will reach the destination or the sink node timely which is crucial for successful event detection.

3 CONGESTION AND DELAY AWARE ROUTING

Here we have designed a Delay Aware Routing Protocol for Detection of Time Critical Events that tries to enhance end-to-end data delivery success rate of nodes that are close to the critical events and additionally tries to scale back the latency of those time critical data. We consider a static WSN with one sink node where nodes generate monitoring or regular data with a low generation rate. Once a node senses a critical event, same node generates critical data packets with a higher generation rate. To detect the event successfully, the sink node should receive a high range of critical data packets. Moreover, each vital data packet should reach the destination within a certain time after its generation. Delay of normal data arriving at the sink node or the destination is not harmful. The critical data generating nodes are known as vital nodes and alternative nodes are known as normal nodes. When the event is no longer critical, the vital nodes would become normal nodes.

3.1 Evasion of Congestion

The assumption is that all nodes have the same fixed transmission power. We consider contention based MAC protocols, as it is faster in event notification. The efficacy function is described in algorithm 1:

Algorithm 1:

Step 1: find the ratio of distance (D_e) of the next node (say e) towards the BS from the node B to the maximum distance that can be covered by the transmission power of each node (D_{max}).
Step 2: multiply the ratio derived in step 1 by a constant η and $0 < \eta < 1$.
Step 3: find, HR_e which is the hit rate of node e defined as the

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ratio of the number of packets transmitted from MAC layer to the number of packets forwarded from network layer to MAC layer over a small period.

Step 4: multiply HR_e by (1-η).
Step 5: add the results in step 2 and 4 to get the efficacy function f (e).
η is the constant, used to adjust the packet transmission rate. By setting a required value of this constant we can set the rate at which the packets are transferred.

$$\text{Efficacy function} = (1-\eta) * HR_e + (\eta * D_e / D_{max}) \quad (1)$$

To calculate *f* for each neighbor *e*, node *B* needs the values of D_e and HR_e. The protocol assumes that each node knows its location. Each node *e* can broadcast its location and *HR* value using management packets after receiving a fixed number of packets from other nodes or after a fixed interval whichever is earlier. With its own and *e*'s locations, *B* can calculate D_e .We calculate the value of efficacy function so that, the data transmission rate can be controlled and adjusted based on the value of the efficacy function. By this the congestion can be effectively evaded in the network and assures high success rate of received vital data and in turn assures the reliability of message delivery.

3.2 Delay Management

Every node has the possibility to measure the end to end delay of its data packets. A node will simply substantiate the delay of a packet (queuing delay and medium access delay) within it. MAC layer records the current time CT when a packet arrives from higher layer. Subsequently, the packet is transmitted and MAC layer receives acknowledgement for this packet at time AT. Now, total delay of this packet incurred at this node is AT – CT. The nodes that are having direct communication to the sink node will get their end-to-end delays by this approach. With different data, they periodically broadcast delay information using the management packets. After receiving these management packets, different nodes will calculate their end-to-end delays by adding their own delays to their neighbor's end-to-end delays. Continuing this method, finally all nodes will get their end-to-end delays. A path travelled by a packet in a sensor network can be modeled as a sequence of queuing systems. The total end to end delay will be the sum of delays incurred at each queuing system [16]. As sensor nodes are densely deployed and also the communication range is very small, the propagation delay can be ignored. Every critical information packet incorporates a header field that indicates its deadline by which it should reach the BS. The deadline field indicates the priority of the packet. The intermediate nodes check this field before it forwards the packet to the next node. If an intermediate node has end-to-end delay that cannot meet packet's deadline then the node sets the delay flag in the header of the packet and forwards the packet to the next node. The destination nodes check the presence of the delay flag while processing the packets. In sub-section F, we describe a method to ensure high success probability of a message that carries the delay measurement. This message is called as the management message with delay measurements.

3.3 Maintaining Uniform Node Density

Although planned deployments of nodes in accessible environments are attainable, inaccessible areas typically need aerial distribution or dropping of sensor nodes during which ensuring uniform node density is a difficult task. One novel solution is to deploy the sensor nodes with high density. Every node then finds its position through localization techniques [13],[14] and sends its location to the sink node. When obtaining all nodes' locations, the sink node can select the required nodes to be active to cover the maximum attainable sensing space and can instruct different nodes to remain inactive. The network can currently operate exclusively with active nodes making certain coverage by which achieving uniform node-density is approximately feasible. We should deploy the nodes with higher communication range. If nodes have higher communication range, then active nodes remain connected to sink node which results in energy depletion of the node. Empirical study will confirm the desired ratio of communication range to sensing range for various sizes of sensing fields. The proposed protocol needs uniform node density and this could be a part of network setup section solely.

3.4 Congestion Alleviation

Once the network layer gets the feedback from the MAC layer, it calculates the HR value and then sends it to the application layer. If the value of HR is a smaller than that of the application layer, it reduces the data generation rate to HR factor of the current rate.

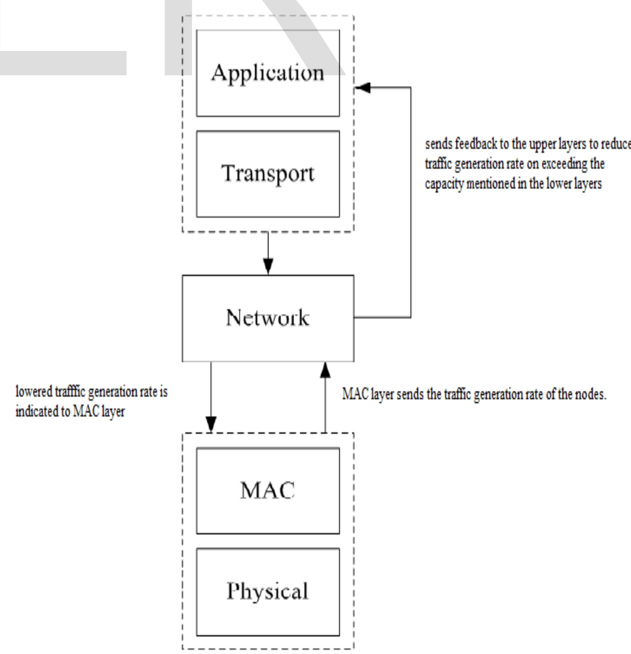

Fig. 1. Inter Layer Communication Model

If the application layer encompasses a lower data generation rate than its targeted rate and therefore the value of HR is one, then it will increase its data generation rate by a small fraction. With this method, the application layer continuously maintains its targeted data generation rate when there is no conges-

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tion. The network layer tries to forward critical packets so that the BS will get the maxmimum number of critical packets that are required to detect the event reliably and timely. If the network layer finds a deadline field with a higher priority value in a packet then it will consider it as critical packet.

3.5 Flow management in MAC Layer

The aim of protocol is to deliver high quantity of critical data at the interval specified. When critical data packet comes from network layer to MAC layer, the packet is inserted to the front-end of transmission queue which specifies that the packet has an early deadline. Every regular data packet is appended at the rear of the transmission queue. This system can reduce the typical delay of critical packets, though it will increase the delay of normal packets. Every management packet (that consists of location, delay and HR information of a node) is placed specifically at the front of the queue.

3.6 Improving the Success Rate of Management Data

The performance of the protocol highly depends on successful receipt of management packets broadcasted by different nodes. This subsection is dedicated to a widely used MAC protocol, IEEE 802.11 DCF [15]. A highly effective technique is applied to enhance the success probability of management packets. When a node decides to broadcast a packet, it initializes the broadcast packet using the protocol described in IEEE 802.11 DCF. Once transmission is complete, the same node waits for a Short Interval Frame Space (SIFS) [15] and then immediately retransmits same management packet if the packet is not received by the receiving node. Consider two neighboring nodes A and B, with each node having collision domains known as CA and CB. Nodes periodically broadcast management packets, but independent of one another. Therefore, there is a small chance that node A and node B can broadcast management packets at the same time. If A and B transmit management packets at same time and if they collide, then they can retransmit packets after *SIFS* and in this scenario, no other node can transmit management packet [15]. However there is a high likelihood that node A in CA sends a bearing packet (initial management packet which has the information about initial node set-up) at a time. This initial management packet may simply collide with different node's data packet. After collision, apart from A, all nodes await Distributed Interval Frame Space (*DIFS*) [15] before transmitting any data. As A retransmits management packet after *SIFS* (*SIFS* < *DIFS*), all other nodes in CA will sense that transmission and that they all wait until A finishes its transmission. Thus management packet of A will not be destroyed by different nodes' data within CA. In this protocol the bearing packets are sent in the set up phase wherein all nodes in the network would initially know the position of all other nodes and their transmission ranges. These packets are sent in the initial stage of network set up where congestion is minimal. And this technique can considerably improve success likelihood of the management packets.

4 RESULTS AND DISCUSSIONS

In order to investigate the performance of the protocol, we have compared it with similar protocols. But the proposed protocol ensures high success rate of delay sensitive critical data. In distance vector based schemes the focus is on routing the data based on the distance to the neighboring nodes. In the proposed scheme the routing is based on distance as well as node status. This would improve the success probability of the vital packets and increase the reliability of the protocol in relation to the objectives.

4.1Simulation Environment

In this simulation we have considered an average of one sensor per square meter area with uniform node distribution. Desired node density is achieved by applying the technique described in section III-C. All nodes have a fixed transmission power. We have considered an ideal environment and also considered energy expenditure only during transmission (as energy loss during reception is low). We have employed 1 Mbps IEEE 802.11 DCF MAC protocol. We have considered both critical data generation and regular data generation.

4.2Simulation Results

We have explored three different scenarios. In the first scenario, transmission ranges of every node and the critical data generation rate are kept fixed whereas the regular data generation rate is varied. Transmission ranges of nodes and the regular data generation rate stay constant whereas the critical data generation rate is varied in the second scenario. In the third one, data generation rate is constant and transmission range of nodes is varied. Packet success rates and average packet delays of each regular and vital node is measured in each experiment. Lifetime of the network is limited by the utmost energy employed by any node within the network.

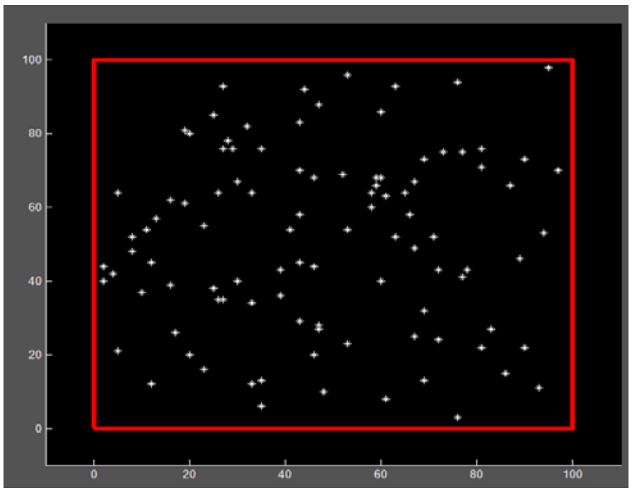

Fig. 2. Initial Node Deployment.

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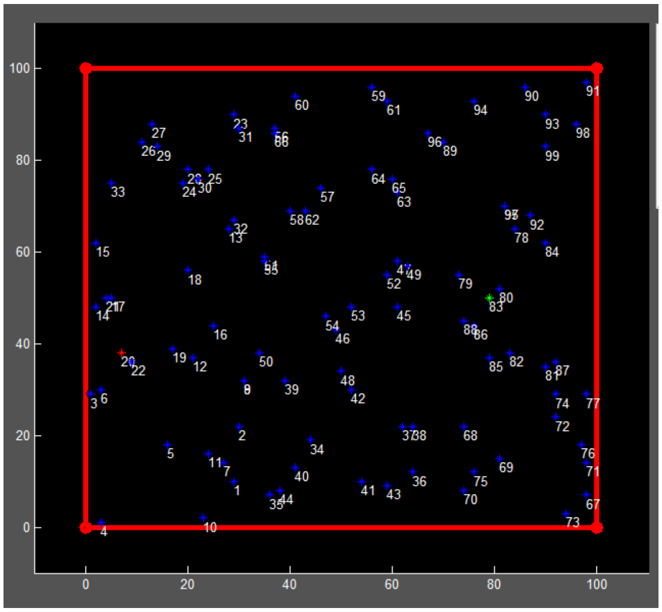

Fig. 3. Uniform Node Deployment Achieved through RRDTE.

Fig. 2. represents the initial sensor node deployment. Fig. 3. indicates the uniform node density achieved through the protocol RRDTE. This is done by dividing the whole plane into 9 parts and deploying equal number of nodes in each part so that the uniform node density is maintained.

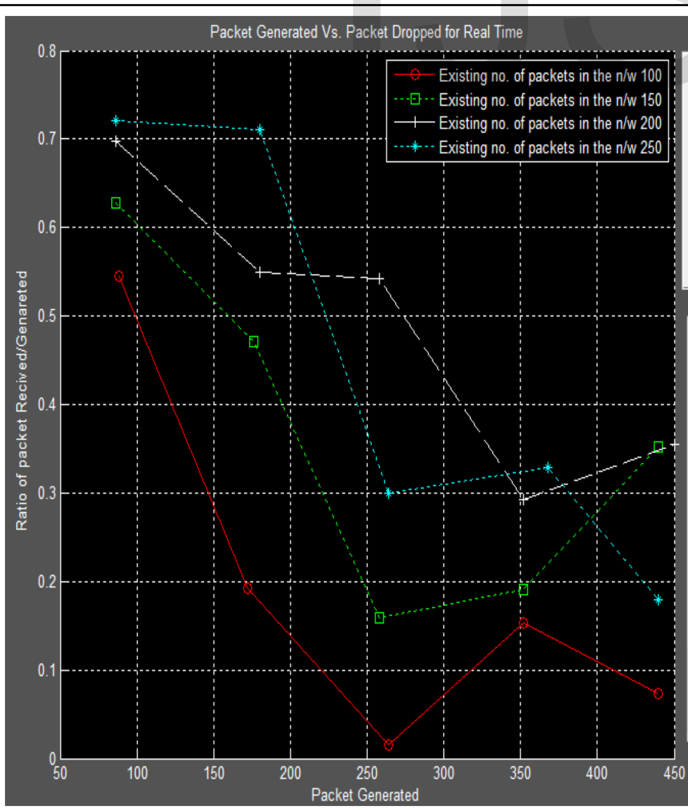

Fig. 4. Distance vector based analysis for real time packet generated v/s packet drop

Fig. 4. is the representation of the distance vector based analysis for the packets generated and the real time packets dropped

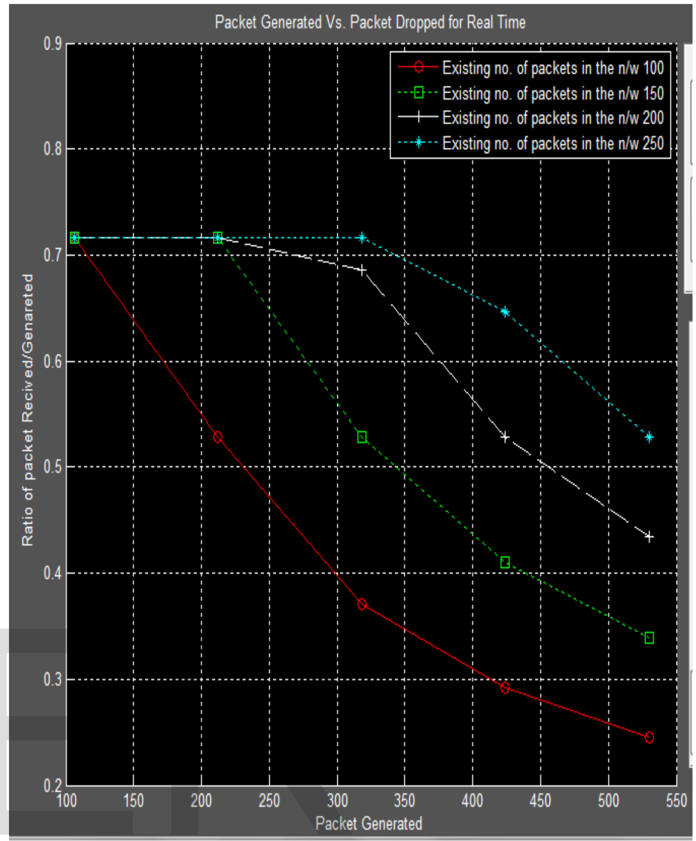

Fig. 5. Relative output analysis for the generated and the dropped packet for real time with RRDTE

Fig. 5. depicts the relative output analysis of the WSN nodes for the generated packets to the dropped packets for real time data with the proposed RRDTE.

Fig. 6. is the representation of the distance vector based analysis for the non real packets generated and the packets dropped.

Fig. 7. depicts the relative output analysis of the WSN nodes for the generated packets to the dropped packets for non real time data with the proposed RRDTE.

We have considered 100, 150, 200 and 250 packets per second as the packets initially existing in the network in these experiments.

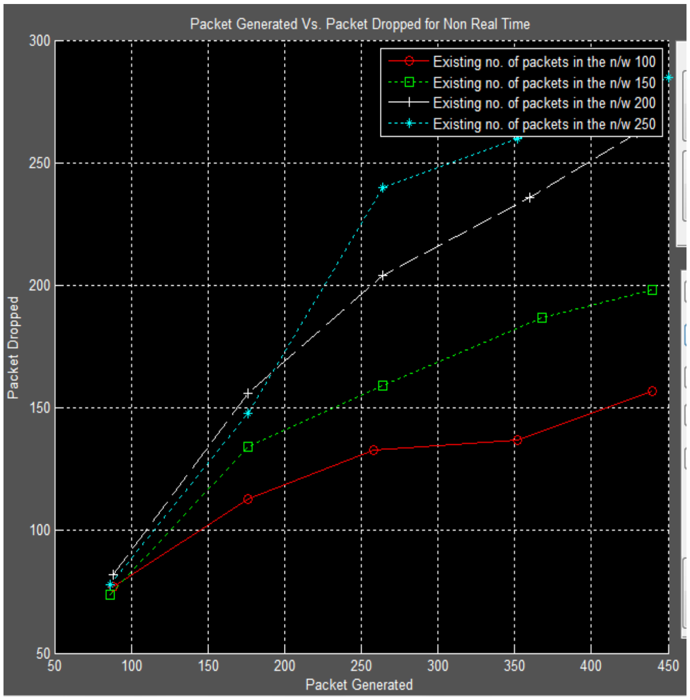

Fig. 6. Distance vector based analysis for the non real time packet generated v/s packet drop

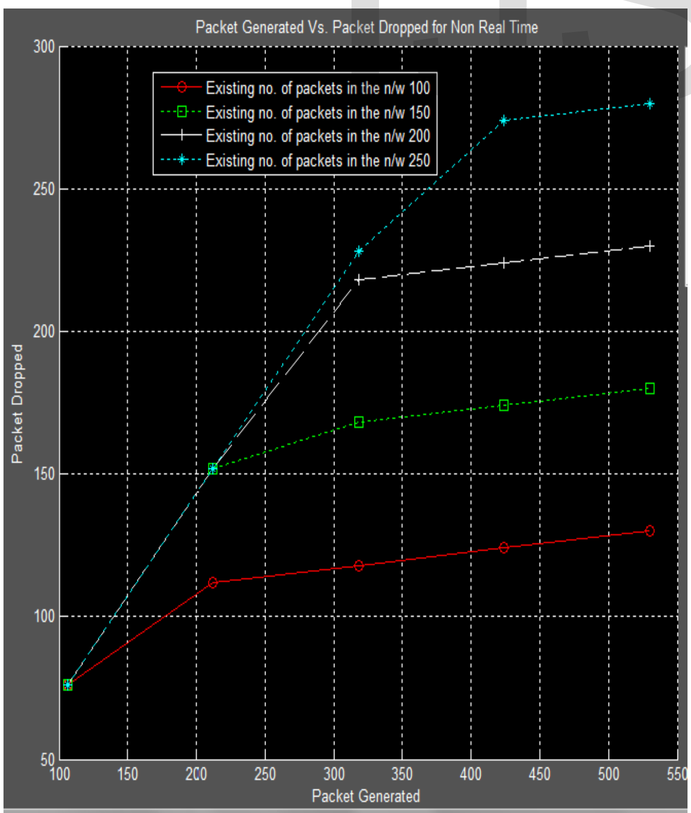

Fig. 7. Relative output analysis for the generated and the dropped packet for non real time with RRDTE

5 Conclusion

In this protocol we have contributed in the following ways: (a) designing a simple and sophisticated architecture or method to ensure uniform node density distribution in the hard to access area (b) a potential technique which can facilitate the nodes to measure the end-to-end delay of its packets reaching the sink or the destination node and can route data packets in a deadline-aware manner and (c) a MAC layer specific approach which can ensure the high success probability of control data sent by different nodes in the network which are utilized by neighboring nodes to choose appropriate routes.

The protocol presented in this paper has the potential to scale back congestion by avoiding congested nodes throughout route discovery process. It provides high success rate by accurately adjusting the data rate of a node throughout congestion mitigation. In achieving its success, this protocol utilizes congestion parameters into routing and at the same time, it works in a distributed manner because it wants management data solely from neighboring nodes. It conjointly endeavors to provide higher success rate of management packets that will increase its reliability. Simulation results show that this protocol provides significantly high success rate and low average packet delay of critical data that eventually leads to reliable and timely event detection. Future study can focus in enhancing the success rate of the control packets reaching the BS by improving the value of efficacy function. As individual nodes are located at completely different locations of the network, completely different values of η for various nodes may accurately sense the node's congestion level and that in turn might facilitate higher congestion management which will ensure higher success probability of data delivery for the real time data.

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