

ReRMAC Congestion Control Protocol for Wireless Sensor Networks

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Abstract

Objectives: The Application specific protocols in the Wireless Sensor Networks (WSN) are developed to achieve specific goals such as delay, energy utilization and throughput. **Methods:** In real time scenario, the sensor node generates valuable data and it needs to be communicated to the sink reliably without any loss of information. In this paper the transport layer issue, end to end reliable data transmission has been evaluated by implementing the Reliable Routing Medium Access Control (ReRMAC) protocol. The ReRMAC uses functionality of network layer and MAC layer for achieving the reliability as well as minimizing the energy utilization. **Findings:** In order to recognize the congestion, the queue size of each node in the network is estimated and compared with a queue threshold value. If the node is identified as congested one, then the node does not take part in the current data transmission. Moreover, the nodes in the network are reconfigured by reschedules the routes to destination. It ensures the link quality for error free data transmission. The performance of the proposed ReRMAC is compared with the existing stated ones and it improves the link reliability and energy efficiency in an optimum manner. **Improvement:** This work can be further addressed by optimization issues while integrating more than one layer at the same time.

Keywords: Congestion Control, Cross Layer, Energy Utilization, MAC Protocol, Routing, Wireless Sensor Networks

1. Introduction

Media Access Control (MAC) is the sub layer of Data Link Layer in OSI model. The main objective of MAC protocol is to access the channel effectively without any collision. The MAC protocol broadly classified in two types namely contention based and reservation based MAC protocol. The contention based MAC protocol is used the control overheads to eliminate the collisions whereas the reservation based MAC used the central coordinator to assign the channels to the respective nodes in the group. The reservation based MAC uses different types of multiple access schemes like time division multiple

access, frequency division multiple access and code division access to achieve the collision free data transmission in order to maximize the life time of wireless sensor networks^{1,2}.

Generally the sensor nodes are self-configuring in nature. After the deployment the sensing devices are grouped together and forms the network as per the protocol design, either it may be of cluster or any different kind of topologies³. The broad classifications of routing protocols are proactive and reactive routing⁴. Proactive routing is nothing but table driven routing, in which every node in the network having the routing table. The routing table contains the addresses of the nearby nodes and

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nearer nodes of nearby nodes. The address in the routing table will be updated periodically or any route change in nearby nodes^{5,6}. Then the data transmissions can be achieved according to the routing table updates. Whereas reactive routing is also known as on demand routing, the nodes which are follows this kind of routing does not keep any routing tables and updates⁷. Recently more number of congestion control algorithms was developed to found and eliminate the congestion in the networks for increase the reliability and achieve the energy efficiency^{8,9}.

An algorithm CAS (Cooperation-Aware Scheme) focused the problems caused by traffic congestion on the sensor networks with huge amount of data flow, packet loss, bandwidth reduction and waste of energy utilization on the sensor devices¹⁰. A preset threshold value is defined in order to determine whether the node traffic is in the acceptable rate or not. Then the corresponding nodes are decided and command its child nodes to change the data transmission route. New sensor nodes are added into the network, once the traffic is exceeded to the overall network flow threshold.

Congestion in Wireless Sensor Networks and Mechanisms for Controlling Congestion deals with the issues of congestion occurred in the wireless sensor networks¹¹. This work mainly discussed the characteristics of congestion control in WSN and survey the research papers related to the congestion control protocols for WSN's. They analyze the performance characteristics of WSN's like fairness, energy utilization, quality of service and so on.

Hop-by-hop traffic-aware routing to congestion control in wireless sensor networks address the issues of congestion in the sensor network and analyze the performance metrics like packet loss, throughput and increased energy utilization¹². In this scheme the data transmission rate of the individual nodes are adjusted according to the proposed distributed traffic-aware scheme. This algorithm is designed a hybrid virtual gradient field and regulate the traffic to routing. It provides a balance between best possible paths and promising congestion on the routes towards the sinks.

The hierarchical energy aware MAC protocol along with delay aware routing in wireless sensor networks¹³. In this work, the parameters like remaining energy of the nodes and transmission delay is utilized to calculate the weight value, and the same is used to elect the cluster head of the clusters. The delay aware MAC switches the high delay cluster members to sleep mode. The remaining

less delay member nodes in the cluster is used to transmit the data packets to sink.

A latency and energy efficient flexible TDMA protocol for Wireless Sensor Networks¹⁴. In this work the MAC protocol combined with the routing protocol for data gathering in wireless sensor networks. Using the TDMA technique provides collision free communication, fairness and reduced idle listening in order to minimize the energy utilization. LEFT achieves the flexibility through slot resizing to improve the channel utilization and adaptation of dynamic traffic patterns of WSNs.

Energy-aware Routing Protocol (ERP) for query-based applications in WSNs¹⁵. ERP classified into two main phases namely, query broadcasting phase and data forwarding phase. After completion of these phases, ERP finds an optimal trade-off between energy balancing and energy saving operations. The above same is achieved by using fuzzy sets and learning automata techniques along with zonal broadcasting in order to reduce the energy utilization. The implementation of the ReRMAC discussed in Chapter 2. The performance outcomes of the proposed system compared with the existing stated algorithms are illustrated in Chapter 3. Finally, the conclusion of this paper is presented in Chapter 4.

2. Reliable Routing Medium Access Control

The proposed system is the modification of the delay aware routing MAC protocol. In ReRMAC the routing layer utilize the functions of the transport layer and MAC layer for achieving the reliable end to end delivery of data packets as well as reducing the energy utilization of the nodes in the network. The transport layer function will be divided into two phases namely, 1. congestion detection and 2. congestion elimination. The congestion in the nodes is detected by the proposed system and it is cleared by altering the routes made to the destinations. The interaction between the successive layers will be defined in Figure 1. Here the network layer uses the functionalities of MAC layer and eliminate the congestion in the transport layer.

2.1 Congestion Detection

Every node in the sensor network has its own queue length. It is important to note that, the queue length of the node become shorter the packet overflows can be

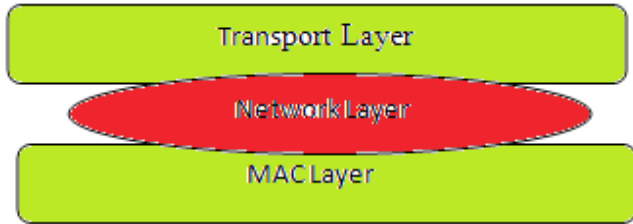


Figure 1. Cross layer illustration of ReRMAC.

occurring; it may lead the packet drop and retransmission of data packets. The retransmission of data packets indirectly increases the energy utilization of the nodes. On the other case, if the queue length is high, the data transmission delay can be increased. The increase in delay will also increase the energy utilization. Hence accurate trade-off is needed to obtain the minimal delay and error free end to end reliable information transmission. In order to recognize the congestion, the queue size of each node in the network can be estimated and compared with a queue threshold Q_{th} value. If the result of the comparison higher than the threshold, there will be congestion occurred in the node, else there is no congestion.

The queue size of the corresponding node is appended in the route request (R_req) packet and same will be analyzed by the fourth coming node. Upon receiving the R_req packet the indented node calculates with the queue threshold value (Q_{th}). Figure 2 illustrates the set of nodes transferring data through each other. Each node in the network consist specified amount of packets in its queue. Upon receiving the route request packet, the node 5 in the diagram finds the congestion and send the route error packet to source for discover the new route.

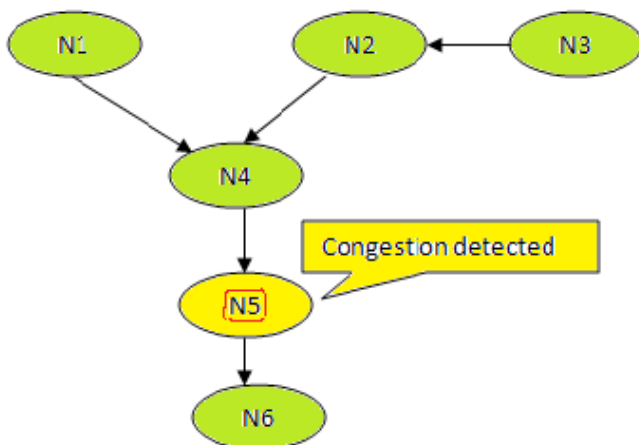


Figure 2. Congestion detection.

Let Q_{th} be the queue threshold value of the individual node and Q_r be the received queue status of the individual node.

Let C_{status} be the congestion status, it will be calculated by the below algorithm.

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If  $Q_{th} > Q_r$  then
 $C_{status} =$  No congestion
Else if  $Q_{th} < Q_r$  then
 $C_{status} =$  Congestion occurred
End if
    
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2.2 Congestion Elimination

If the node is identified as congested, then the node does not take part in the current data transmission. The particular node will take part in the communication, once its queue state value comes lesser than the fixed queue threshold value (Q_{th}). The Figure 3 and 4 illustrates the route request and reply packet format, which is used to transfer the control information's. If not so, the indented node replies with a route error packet to the sender for new route discovery. Then the sender of the congested node identifies the congestion and follows the different path. The nodes in the new path should have limited queue state value. Then the sink verifies and acknowledges the route request packets which are received from more than one path with different nodes. The sink chooses the shortest path which are having low link cost with sufficient queue size and greater link reliability. The selected path information is sent to the source by route reply packet. After completion of route request and reply processes the source node starts transmission in the selected path. As soon as any congestion occurred during data transmission, the upstream node in the route sends route error message to the source node to find the new route. Congestion elimination achieves the reliable end to end transmission without any packet loss and drop as well as reduced energy utilization.

When the node starts to send the data to sink, it initiates the transport layer functionalities along with the delay aware MAC. After accomplishing the congestion detection and elimination phases the delay aware MAC mechanism has been triggered.

2.3 Estimation of Metrics

Let E_{res} be the Residual energy of the node and E_{ini} be the initial energy of the node. Let E_{tx} , E_{rx} be the Energy consumed by the node for transmission and reception

Type	data length	identifications
	Target address	
	Address [1]	
	Address [2]	
	
	Address [n]	

Figure 3. DSR R-req packet format.

Type	data length	L Reserved
	Target address	
	Address [1]	
	Address [2]	
	
	Address [n]	

Figure 4. DSR R-rep packet format.

respectively. The residual energy of the node will be calculated by Equation 1.

$$E_{res} = E_{ini} - (E_{tx} + E_{rx}) \tag{1}$$

Let E_{tot} , E_{uti} be the total energy and energy utilization of the node respectively. The energy utilization of the individual node will be calculated by Equation 2.

$$E_{uti} = E_{tot} - E_{res} \tag{2}$$

Let N_i be the set of nodes in the network, and N_p be the number of nodes effectively take part in the communication.

$$N_p \in N_i \text{ Where, } i = 1 \text{ to } N. \tag{3}$$

Let N be the number of nodes in the network.

The total energy utilization (E_{tuti}) of the entire network will be calculated by Equation 4.

$$E_{tuti} = N_p \times E_{uti} \tag{4}$$

When x bits of packet need to be transmitted from source node (N_t) to destination node (N_r) at transmission rate (α) bps, then the transmission delay (D_{tr}) will be computed using Equation 5.

$$D_{tr} = \frac{x}{\alpha} \tag{5}$$

The packet waiting time (D_{wt}) is nothing but the time taken for processing the data packet by the individual node. The total Delay (D) will be calculated by Equation 6.

$$D = D_{tr} + D_{wt} \tag{6}$$

3. Performance Evolution

The proposed ReRMAC evaluated with Cooperative Aware Scheme (CAS) and Multipath Dynamic Source Routing (MPDSR), and the numerical results are analyzed in terms of energy utilization, delay, packet drop, packet delivery ratio and throughput. The CAS scheme balance the network traffic by providing alternative path based on nodes congestion. It implements the AODV routing scheme for its evaluation. However that, It is analyzed various routing protocols and recognized that DSR has a higher resource congestion control capability. Hence the ReRMAC modifies the DSR routing scheme by transacting the queue size information for evaluation. The MPDSR balance the energy utilization of the nodes and enhance the life time of the nodes in the network by taking the network congestion in order to reduce the routing delay and improve reliability. NS2 is a event driven network simulator which is widely used to analyze the performance of the WSN research environment. The proposed WSN environment deployed with NS2 simulator with the specified parameters listed in the Table 1.

The Figures 5 and 6 shows that the performance analysis of no. of nodes versus average energy utilization and delay. In the Figure 5, the energy utilization of ReRMAC is comparatively low than other two existing stated algorithms namely CAS and MPDSR when number of nodes increased from 20 to 70. After that the energy utilization is likely equal to all. The difference in less energy utilization is achieved by implementing the delay aware MAC along with the proposed one. The implementation of network layer and MAC layer functionalities implies reduced delay compared to the existing stated. The delay of ReRMAC in the range 20 to 50 is slightly more than CAS. In the range of above 50 the delay of ReRMAC is considerably better

Table 1. Simulation parameters

No. of nodes	100
Area	750×750 m
MAC	HEDA-MAC
Routing Protocol	DSR
Initial Energy	14.3 J
Traffic	CBR
Transmit power	0.395 w
Receiving power	0.660 w
Packet Size	512 bytes

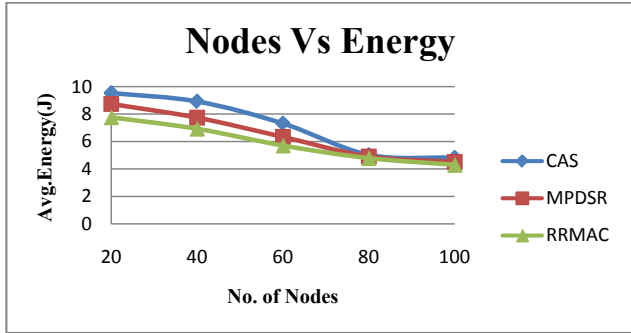


Figure 5. No of nodes vs avg energy utilization.

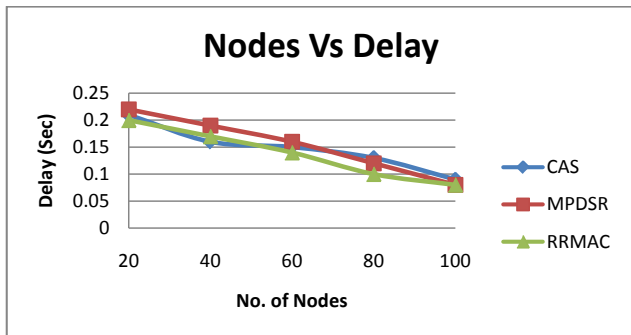


Figure 6. No of nodes vs delay.

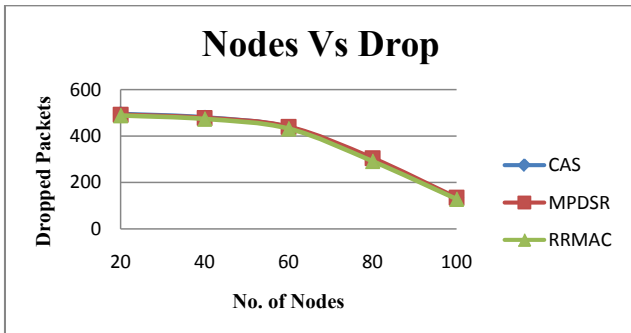


Figure 7. No of nodes vs dropped packets.

compared to others. The graph plotted in the Figure 7 is between the numbers of nodes versus packets drop. The dropped packets of ReRMAC are much more likely less than other like CAS and MPDSR algorithms. The numbers of dropped packets are reduced when increasing the number of nodes. This particular scenario is clearly verified in the graph.

The performance analysis of no. of nodes versus packet delivery ratio and throughput are clearly illustrated in the Figures 8 and 9. In the Figure 8, the packet delivery ratio of ReRMAC yields higher value compared to the CAS and MPDSR. The delivery ratio of ReRMAC saturated after

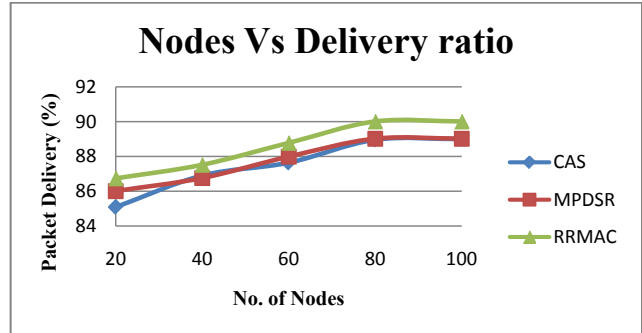


Figure 8. No of nodes vs packet delivery ratio.

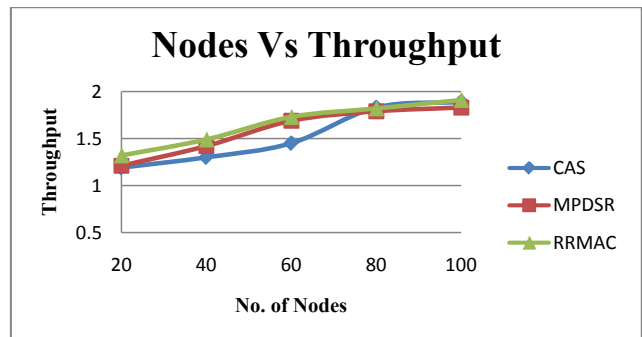


Figure 9. No of nodes vs throughput.

the number of nodes increased above 70. Throughput is one of the important performance metric in WSN, which is defined as the average rate of successful data transmission to the destination. The throughput of the proposed system is compared and analyzed in Figure 9. It shows that the outcomes of the ReRMAC and MPDSR are approximately same and slightly higher than CAS in the range of nodes 20 to 50. After increasing the number of nodes from the previous level, all the implemented algorithms are provided more or less same performance.

4. Conclusion

The performance of the proposed ReRMAC implemented with NS2 event driven simulator and verified with the existing stated algorithms. The lower three layers are more than enough to configure the WSN design. The transport layer functionality itself gives reliable end to end data transmission. This kind of scenario can be used in a domain where the reliable communication is needed, like military surveillance and so on. The congestion and reliability issues are achieved by implementing ReRMAC. The performance results of the ReRMAC show that, it yields better energy utilization compared to the

previously stated. Implementing the cross layer design with more number of layers causes little overhead but, it implies reliable transmission without any data loss. In future this work can be extended to solve the optimization problems in order to enhance the cross layer design.

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