Congestion Control Techniques in Wireless Sensor Networks : A Survey

Sharmila Kharat
Dept. of Computer Engineering
MIT Academy of Engineering, Alandi (D)
Pune, India.

***Abstract*— With the recent advances in technology of Wireless sensor network different protocols are proposed which takes care of congestion detection and control. As congestion in the networks causes less packet delivery rate, decreased energy efficiency, decreased overall throughput of the system. This paper surveys the congestion control protocols of wireless sensor network. The congestion control protocol is divided into two categories traffic controlled protocol and the resource allocation based protocols. Each protocol's methodology with its advantages and disadvantages is discussed in this paper.**

***Keywords* —Congestio detection, congestion control, traffic control, rate control, Wireless sensor networks.**

I. Introduction

Wireless sensor network is collection of microcomputers which have sensing ability. The sensor nodes are generally equipped with sensing, communication as well as computing capabilities. This enables sensor nodes to observe and reach to different events. The nature of the traffic is WSN differs with the application. The traffic can be event based, continuous, query based or Hybrid. The sensor nodes are generally battery operated devices which has restriction for energy as well as computing. The effects of congestion are very worse as congestion in wireless sensor network increases energy consumption because of more number of retransmission required and packet drops. Even the overall throughput of the system and packet delivery ration degrades due to congestion. So it is very important to detect and control congestion. There are mainly two types of congestion Node level congestion and the Link level congestion. The node level congestion in WSN is caused by buffer overflow in the node. Due to node level congestion more number of packets is lost. Increase in packet loss leads to more energy consumptions and the decrease in link utilization. The link level congestion occurs when more than one sensor node tries to acquire the channel at same time.

For congestion detection wireless sensor networks generally uses one or more of the four mechanisms use (i) Buffer queue length (ii) channel loading time (iii) Reporting rate and (iv)The packet service time by packet interarraival time ration. Buffer queue length without link layer acknowledgments can not exactly portrays the occurrence of congestion [2].The channel loading time required can quickly detect the status of congestion in the network. To calculate the channel loading time we need to listen to the channel and which consumes more energy so channel loading time is sensed using sampling method. The certain application in wireless sensor demands a specific reporting rate. In such application the reporting arte can be a measure of congestion. If we continuously getting the lesser reporting rate than the expected reporting rate it can be because of congestion. If packet service time becomes more than the packet interarraival time then the more number of packets will be queued as the service time is slow. So the ration of packet service time to packet interarraival time can detect the congestion.

There are two general mechanisms for congestion control: (i) traffic control and (ii) resource control. In traffic control type of congestion control the congestion is controlled by adjusting the incoming traffic rate. The rate is increased or decreased based on the state of the congestion. Traffic control can effectively mitigate the transient type of congestion. The traffic control mechanism is less costly and simpler than the resource control algorithm. In traffic control there can be significant loss in packet at the time of monitored event takes place so in such cases the resource control strategies can perfume better. The traffic controlled type of congestion can be further classified as the end to end traffic control and hop by hop traffic control. Reduction of traffic rate during the crisis state is undesirable as there will be loss of significant data. As reliability of the information in case of crisis state is very much. In such cases the resource control strategy is used. Here the extra resources are applied near the congestion hotspot to mitigate the congestion. Extra bandwidth or nodes can be deployed in the area of congestion hotspot. The main challenge of the resource control strategy is that it not only requires the local knowledge but also the knowledge about the end to end topology.Some resource control protocols like TARA calculates the capacity of possible topologies and based on that good capacity topology is selected. In this paper the summarization of different protocols congestion control techniques is done. Even its performance in different scenarios in discussed.

II. Rate Control Based Congestion Control Protocols

A. CODA

CODA i.e. Congestion detection and Avoidance in Sensor Network [2] consist of three mechanisms for congestion control (i)receiver based congestion detection (ii) open loop hop by hop backpressure and (iii) closed loop multisource regulation. For congestion detection CODA uses both present and past channel loading status as well as buffer occupancy level. As it has been proved that buffer occupancy can't indicate exact congestion level without link layer ARQ. Even in some situations it gives false information about congestion [

].CODA considers node density as well as data rate to alleviate the congestion. For the networks having high node density and high data rate, there is more probability of persistent congestion near source node and far from sink node. In this case it uses backpressure message from the point of congestion hotspot to the source nodes. In case of sparsely deployed sensors with low data rate the congestion will be of transient type and located near sink node. CODA controls this type of congestion using combination of backpressure as well as packet dropping. For the sparsely deployed sensor nodes with high data rate event it can cause both transient and persistent congestion. CODA controls this by using fast open loop hop by hop backpressure mechanism and closed loop traffic rate control of all the nodes which cause in creating congestion hotspot. There is explicit congestion notification mechanism in CODA so it is time consuming. The one more disadvantage of CODA is reliability is not ensured as based on backpressure mechanism the packets are dropped. CODA uses AIMD approach for rate control which is dependant of distance from the sink. In CODA the backpressure mechanism may increase the intensity of congestion because of high channel loading time. CODA uses explicit ACK mechanism which will result in overheads.

B. CCF

CCF i.e. Congestion control and Fairness for Many to one Routing in Sensor Networks [5] assures congestion control as well as fairness of packet received at the sink node from all the source nodes.CCF assumes that all nodes generates data as this situation is reducible to event driven traffic scenario.CCF proposes a distributed algorithm which executes at each and every sensor node. It first measures the packet sending rate. The rate is divided among all its children and also based on the queue size. The rate is compared with the sending rate from parent and minimum of the two is used for sending the data towards sink. For congestion detection CCF uses the queue threshold value. When queue is full it reduces the transmission rate of all the downstream nodes. When queue become empty it will increase the rate of all its children nodes which can again cause congestion level. This cycle employs the phase shifting effect on the nodes at different hops. So nodes at different hops will generate and transmit the packets at different times. So congestion will be minimized. CCF can mitigate both transient as well as persistent congestion by controlling the rates of its children nodes. As this algorithm runs at each and every node the nodes will adapt to the environment.

C. ESRT

ESRT i.e. Event to sink Reliable Transport protocol [3] aims for reliability while causing minimum energy consumption and with congestion mitigation. This is mainly designed for event driven traffic assumes that for event driven traffic there is no need of end to end reliability event to sink reliability is enough. It proposes five characteristic regions in normalized event reliability versus reporting frequency. Based on the required reliability level of the application the optimal reliability region is found out. and to gain this ESRT uses congestion control mechanism at sink node. Congestion detection is done locally at every node using the buffer occupancy. As the reporting rates changes at every reporting interval the change in buffer size is expected constant after each reporting interval so if at interval I if the sum of current buffer size and constant change after each interval exceeds that the buffer size then it can be predicted that there will be congestion in the next reporting interval. Congestion Notification bit is set at this interval. For congestion control in ESRT reporting frequency is controlled based on the reliability level. The performance ESRT depends on the persistence of congestion as well as the delay required to receive the feedback. The congestion detection will be very late in case of cases like transient congestion of large feedback delay. Even in case of ESRT there is problem of scaling the network as the delay required for feedback is dependent on the Diameter of the network.

D. RCRT

RCRT i.e. rate controlled reliable transport protocol for wireless sensor network[14] takes care of reliable end to end delivery of data as well as controls congestion. The congestion control in RCRT is done at the sink node. Congestion control is centralized in RCRT. For congestion detection RCRT uses centralized detection at the sink node. The sink node decides congestion based on the time required to repair the loss. If it is more than the round trip time then congestion is detected. The congestion index tells how many RTT are required to recover the loss and if it is greater than a upper threshold value then the network is said to be congested. If the congestion index is lesser than the lower threshold value then the network is said to be underutilized. There are four components of RCRT :(i) Reliable end to end transmission (ii) congestion detection (iii) rate adaptation and (iv) rate allocation. End to end loss recovery is done at source and sink node using end to end NACK mechanisms. The use of NACK avoids the ACK implosion. RCRT uses AIMD approach for rate adaptation .Unlike general AIMD approach the rate adaptation in RCRT is on total aggregate traffic rate observed by the sink node. In case of congestion sink node sends the improved rate and wait for three RTTs to see the effect of the decision. Again congestion index is calculated and based on that new decision is taken. After rate adaptation the rate allocation component come into picture. Three strategies demand proportional, demand limited and Fair are used for taking decision of rate allocation. In RCRT if there is a limit on retransmission will be less end to end packet delivery. The main disadvantage of RCRT is its convergence is very slow for the network having varying RTTs.

E. ECODA

ECODA i.e. enhanced congestion detection and avoidance for multiple class of traffic in sensor networks [7] consist of three mechanisms. (i)Congestion detection based on dual buffer threshold (ii)Packet scheduling based on flexible queue scheduler and (iii)Source sending rate control scheme based on bottleneck. ECODA define three buffer state based on two threshold values i.e. accept state, filter state and reject state. As the nature of WSN is like tree there is unfairness in bandwidth allocation for different nodes. To ensure the fairness ECODA uses flexible queue scheduler. The queue scheduler in case of ECODA takes care that while dropping a packet a packet with least priority is dropped. There are two sub queues one for locally generated packets and other for the transient traffic packets. In transient traffic queue packets are sorted based on source. Based on Round robin algorithm one packet from one source is sent from the queue then the locally generated packet is sent. CODA periodically updates the data sending rate of each node based on congestion level of the neighbor. For rate control ECODA uses bottleneck node based source data sending rate control. For this it first decide routing path status from the node to the sink node. The node which is one hop away from the sink piggybacks its data forwarding delay in its data packet headers which will be overheard by its children which compares its own data forwarding delay with the parents data forwarding delay and maximum value is piggybacked into its header .This process will execute recursively which will set the data forwarding delay of the source nodes. For rate control in ECODA on getting a backpressure signal the source node or the intermediate node will decrease the data sending rate. but if no backpressure message then ECODA doesn't increase the data sending rate additively.

F. *CCF for WSN*

Congestion control and fairness in wireless sensor networks [10] proposes a distributed scheme for congestion controls which try to adapt optimal transmission rate for the nodes. To separate modules are used which take care of utilization of the network as well as the fairness.CCF for WSN first calculated the difference between the aggregate output rate and aggregate input rate which gives the aggregate change in rate required. Based on fairness module the decision of the increase and decrease in the data rate is calculated. Here at each node for each control interval CCF measures the average output rate, average input rate and minimum number of packets in the queue. Based on the difference between the average input rate, average output rate and. number of packet in the queue the aggregate change in the data rate is calculated .The calculated aggregate change in rate is distributed among individual flows to ensure fairness in the network. The bandwidth computed for individual flows are compared with the bandwidth of the parent node and the lesser bandwidth is propagated toward the source nodes. The nodes which are one hop away from the sink node are called as the gateway node and at these gateway nodes at every control interval this congestion control cycle runs. In CCF for WSN even there are changes in underlying technology or in the routing protocol the performance will remain unaffected as CCF do not consider the underlying technology and routing layer technology for congestion control. The main disadvantage of CCF is that it uses feedback mechanism which will cause delay in congestion control process.

G. *UHCC*

Upstream hop by hop congestion control protocol [8] in wireless sensor networks consist of two major components : congestion detection component and rate adjustment component. For Congestion detection UHCC uses the difference between the unoccupied buffer size and the traffic rate to calculate congestion index. The buffer unoccupancy is calculated based on the difference between the total buffer size and buffer occupancy where the traffic rate can be calculated based on the total generated packets subtracted by the outgoing traffic rate and added with the incoming traffic rate. If congestion index is less than zero then it indicates that at next interval there will be congestion in the network. UHCC considers two types of traffic at any node transient traffic and the source traffic .UHCC calculated the priority of both the traffics of the node. If congestion index is less than zero then the current buffer size not holds the packets in the next interval. This is estimated based on congestion tendency which is the difference between congestion index and upcoming traffic and if this congestion tendency is less than zero then there will be congestion in the next interval which is mitigated by using rate adjustment which again considers the traffic priority. Even if there is no congestion tendency the priority based rate adjustment is done which gives maximum utilization of the traffic capacity of the network. As UHCC considers the traffic priority for rate adjustment and tendency is observed one interval before the congestion the very less number of packets dropped in UHCC. The packet loss ratio is independent of the buffer size in case of UHCC

H. *WFCC*

Lower bound of weighted fairness guaranteed congestion control protocol [12] assumed that the importance of data generated at different nodes is of different importance levels so WFCC assigns weights to each and every node. For congestion detection WFCC uses the ratio of the average packet service time to average packet interarraival time. The average packet sending time and average packet interarraival time is updated using extended weighted moving average i.e. EWMA method when data packet is sent. When the average packet sending time becomes more than the average packet interarraival time the congestion will take place. For congestion control in case of WFCC the incoming rate is modified at regular intervals. At every interval node i receive a data packet which consists of information of the total weighted fairness of the node which are rooted at node I and incoming traffic rate of the parent node k. By using this rate adjustment algorithm calculates its own incoming rate as well as the sampling rate. The both the rates are piggybacked so that child node j will overhear this information from node i and s the sampling rate and transmission rate .Node I then calculates its total weighted fairness rooted at the node j and incoming traffic rate of node j. It piggyback this information in packet and broadcast it. This process will continue at every time interval .In WFCC there are separate approaches are used for congestion control in sink node and non sink node. For non sink node if the congestion occurs no sharp rate adjustment is done. For non sink node which are the transmission rate is not calculated. For sink node simple AIMD approach is used for the rate adjustment which again do not increases or decrease no sharp rate adjustment is done. As in WFCC we have seen no sharp rate reduction the throughput of the overall network is maintained and even the weighted fairness is extended till a factor of 0.95.The disadvantage of WFCC is overhead of feedback at each interval.

III. RESOURCE ALLOCATION BASED CONGESTION CONTROL PROTOLS

A. *TADR*

TADR [13] i.e. traffic aware dynamic routing to alleviate congestion in wireless sensor networks is a resource control type congestion control protocol. As in some application it is undesirable to decrease the rate. In TADR the alternate path is found dynamically. TADR method overcomes the disadvantage for finding alternate path in BGR where random bias was used to alleviate congestion. So if congestion is there based on the potential filed model TADR decides the nest node to transmit the traffic. TADR protocol proposes a potential filed model in which WSN is viewed as a bowl with hole in middle. So if there are no bulges in the bowl the traffic will be smooth but if there are bulges then there is possibility of congestion .The bulges are equivalent to queue length i.e. queue potential field. The depth potential filed is the buffer size. So using queue TADR becomes traffic aware . The superposition of queue potential filed and the depth potential filed the decision of the nest node which will receive traffic i.e. the parent node is decided. The potential filed model is updated in three cases. First for the update intervals .Even if there are topology changes in the network or queue length exceeds the threshold value the model is updated. TADR provides good utilization of resources and good packet receiving rate .Disadvantage of TADR scheme is the routing loops In TADR scheme we can't avoid routing loops occurrence and the delay caused by that.

B. DA1PaS

DA1PaS [9] i.e. a performance aware congestion control algorithm in wireless sensor networks chooses alternate path if there is congestion.DA1PaS considers the energy consumption, congestion level as well as nodes remaining power to take the decision of the alternate path. For Setup phase the algorithm proposes a technique by using which the level of each and every node is found out and neighbor table is updated.DA1PAS mechanism after setup phase is divided into two stages: soft stage and hard stage. In soft stage DA1Pas tried to receive data at one node from one flow only as flow from multiple node can cause congestion. This can be achieved by finding alternate paths. The hard stage is the stage where the network forces the flows to change direction in one of the three cases. (i) Buffer occupancy is reaching its upper limit or (ii) low remaining power or (iii) higher level node unavailability in hard stage algorithm first flag decision algorithm is run. The algorithm is dynamic so the number of hops to sink to the node may change in the processing of this path selection algorithm. The next node to forward the data is found out based on its availability and number of hops from the sink. It sorts all the available nodes based on the hop distance and remaining power from the sink node and the least distance node is selected as the next node.

C. TARA

TARA [6] i.e. Topology aware resource adaptation to alleviate congestion in sensor network is a resource control type of protocol. Here more number of nodes becomes active in case of congestion. As more number of nodes become active the overall network capacity increases which can alleviate the congestion. As blind extra resource allocation can worsen the congestion scenario, TARA uses capacity analysis model which estimates the capacity of various topologies possible and based on that the extra nodes are made active. It considers three congestion scenarios source hotspot, sink hotspot and intersection hotspot. The formulation of this capacity analysis model is based on graph coloring algorithm. The capacity of the network is the maximum throughput of the network. Without existences of the links which interfere the throughput of the network will be the maximum possible throughput of the network .To decides the degree of interference of these links is the main motivation of capacity analysis model. TARA takes care of both the queue length as well as the channel loading. There are two important nodes in TARA distributor node and the merger node. A path called a detour path is established from the starting of the distributor node to the end of the merger node. As the name indicates the distributor distributes the traffic in original path and the detour path and the merger nodes merges the traffic of this original path with the detour path.

IV. CONCLUSION

Due to limited resources and .The congestion can lead to more energy consumption due to the overheads of packet retransmission and packets dropped. So it must be controlled efficiently In this paper we have discussed the different techniques for congestion detection and congestion controlled. Different protocols in traffic controlled and resource allocation type of congestion control are studied. The need of controlling the congestion is very application specific in case of the WSN is considered.

REFERENCES

[1] Kazem Soharaby,Daniel Minoli and TAIEB ZNATI,"WIRELESS SENSOR NETWORKS Technology, Protocols, and Applications", John Willy and sons publication, 2007.

[2] C.-Y. Wan, S.B. Eisenman, and A. T. Campbell, "CODA: Congestion detection and avoidance in sensor networks", in Proc. ACM SenSys, Nov.2003.

[3] Özgür B. Akan, *Member, IEEE*, and Ian F. Akyildiz*, "*Event-to-Sink Reliable Transport

[4] in Wireless Sensor Networks", IEEE transaction on Networking, VOL. 13, OCTOBER 2005.

[5] C.-T. Ee and R. Bajcsy,"Congestion control and fairness for many-to one routing in sensor networks", in Proc. ACM Sensys, Nov. 2004.

[6] Jaewon Kang," TARA: Topology-Aware Resource Adaptation to Alleviate Congestion in Sensor Networks" in transaction on Parallel and Distributed system, VOL. 18, JULY 2007.

[7] Li Qiang Tao; Feng Qi Yu," ECODA: enhanced congestion detection and avoidance for multiple class of traffic in sensor networks "in Consumer Electronics, Aug. 2010.

[8] Guangxue Wang and Kai Liu," Upstream Hop-by-Hop Congestion Control in Wireless Sensor Networks" in IEEE journal on selected areas of communication ,2009.

[9] C Sergiou ,V Vassiliou," DAlPaS A performance aware Congestion Control Algorithm in Wireless Sensor Networks " in IEEE 18th international conference of telecommunication , 2011 .

[10] Swastik Brahma and Mainak Chatterjee," **C**ongestion **C**ontrol and **F**airness in Wireless Sensor Networks" in Pervasive Computing and Communications Workshops,8th IEEE International Conference,2010.

[11] Young-mi Baek, Byung-hwa Lee, Jilong Li, Qin Shu, Ji-hun Han," An **a**daptive **r**ate **c**ontrol for congestion avoidance in wireless body area networks" in Cyber-Enabled Distributed Computing and Knowledge Discovery, 2009.

[12] Guohua li,jianazhong Li and Bo Yu,"Lower bound of Weighted Fairness Guanteed Congestion Control Protocol for WSNs",in INFOCOM 2012 Procedeengs IEEE,2012.

[13] Fengyuan Ren,Sajal Das and Chuang Lin,"Traffic Aware Dynamic Routing to alleviate congestion in WSN",in IEEE transaction on parralel and distributed systems,vol 22,No 9,September 2011.

[14] Jeongyeup Paek and Remesh govindan ,"RCRT : Rate controlled reliable transport protocol for wireless sensors networks",in ACM transactions on Sensor Networks, Vol 7,Issue 3September 2010.