Academic Science

International Journal of Electronics, Electrical and Computational System
IJEECS
ISSN 2348-117X
Volume 6, Issue 7
July 2017

A Comparative study of Congestion Control in Wireless Sensor Networks using efficient Resource Management

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ABSTRACT

Congestion is one of the critical issues that have a negative effect on the performance of applications running in wireless sensor network. Congestion in wireless sensor networks is quite different from that in traditional networks. Due to the irregular and unpredictable load during the occurrence of an event and the limited number of resources the problem becomes more severe in wireless sensor network. It leads to energy wastage, reduction of throughput and dropping and delay of packets. Although a large to number of algorithms has been designed to combat congestion, it still remains a challenging issue. This paper presents a survey of resource number methods to deal with congestion. Resource control methods deal with the problem of congestion by managing the resources efficiently at the time of congestion. This paper presents the significance and limitations and finally compares them based on certain aspects.

KEYWORDS

Wireless Sensor Networks; congestion; congestion control; resource control

INTRODUCTION

A Wireless Sensor Network (WSN) comprises of sensor nodes that are distributed in spatially to create a network. The objective of a sensor node is to sense the environment conditions, assemble and direct the information to the sink or base station. But a WSN is very unlike a traditional network. The sensors making up a WSN have a limited amount of bandwidth, power, memory and computational ability. These restrictions lead to many issues in the deployment of applications such as battlefield surveillance, habitat monitoring [1], disaster monitoring, health care [2], etc.

Congestion is one crucial issue in WSN. There are two types of congestion: node level and link level. When data packets arrive at a fully loaded node then it leads to dropping of packets. This is known as node level congestion. Congestion may occur when all the sensors send the data at the same time leading to collisions. This is known as link level congestion [3]. Congestion causes loss and delay of important data packets and leads to the reduction of throughput. It also decreases the lifetime of the network due the wastage of energy in sending packets that are eventually not delivered to the sink. Congestion generally occurs when important and unpredictable events take place leading to burst of data traffic. Because of the convergent topology of WSN congestion is bound to take place unless avoided.

Two popular methods to avoid congestion are traffic control and resource control methods. The main idea of traffic control is to reduce the rate of sending the traffic flow either of the source or of the some upstream node. Resource control algorithms aims at managing the available resources in such a manner that handles the additional traffic without reducing the traffic rate. The efficiency of the former method is more in cases where the network is sparsely deployed and where the congestion is temporary in nature. The latter method is more efficient when the sensor nodes are densely deployed and where the congestion is persistent [4]. Their main aim is to satisfy the fidelity requirements of the application even when congestion occurs.

The remaining paper is arranged as follows: Section II discusses resource control methods to alleviate congestion. Section III makes a comparison between the discussed strategies in section II. Finally, the paper ends with conclusions in Section IV.

CONGESTION CONTROL METHODS USING RESOURCE CONTROL

The key idea behind resource control methods to control congestion is to create multiple alternate paths to the sink so that excessive packets flow through them bypassing the congested node. Below we discuss some of the resource control methods along with their significance and limitations.

A. Topology Aware Resource Adaptation (TARA)

TARA [4] is distributed congestion control method and its main objective is to alleviate congestion from intersection hot spots. It uses a capacity analysis model based on a graph-coloring problem to approximate the capacity of various topologies. It can adapt the network resources depending on the level of congestion.

During idle circumstances TARA [4] makes use of lesser number of nodes to route packets to the sink and keeps the additional nodes known as backup nodes in the sleep mode to save resources in the dormant state. As soon as the congestion is detected the sleeping nodes are switched on so that a new topology can be created with adequate capacity to cope up with the additional traffic.

The level of congestion is detected by determining the buffer occupancy of the nodes and the channel loading. If the level of congestion surpasses the threshold the node announces that congestion has occurred and becomes a hot-spot. Two important nodes are discovered: the distributor and the merger. A detour path from the distributor node to the merger node is formed. The distributor divides the traffic between the original path and the detour path. The merger is used to merge the traffic flows. The selection of the distributor and merger nodes, construction of detour path and division of traffic between the two paths is dependent on the topology.

It performs almost as ideal offline resource control method. TARA fulfills the application fidelity necessities. It controls congestion when it occurs otherwise it conserves energy by sending some backup nodes to the sleep state during dormant situations. Hence the network lifetime is increased. The disadvantage is that it incurs a lot of overhead by keeping not only local knowledge but also information about the end to end topology.

B. QoS Adaptive Congestion Control(QoS-ACC)

QoS-ACC [5] considers the problem of upstream congestion in wireless sensor network. It is an adaptive cross layer approach which treats real time and non-real time data differently with more priority given to real time data flow. For this the network layer maintains three different queues for real time data flow, non-real time data flow and for non-real time data which has not been acknowledged. The network layer also consists of a scheduler which schedules the packets according to the priority and sends the packet to the MAC layer. The authors use a "QoS distributed MAC manager" which sends the packet to the suitable following hop node after determining the QoS requirement of the data packet. The authors consider at least one route alongside the primary route to the sink. To detect congestion an index namely congestion scale is used which is taken as the ratio of mean packet service rate and mean packet arrival rate. If the congestion scale is less than one then it can lead to congestion. If congestion is detected, its notification is done implicitly.

QoS-ACC [5] uses two congestion control methods: one for short term and the other for long term congestion. When dealing with short term congestion child node of the congested node splits the real time traffic to the alternative path in ratio of the weights of the routes. The weight of the routes depends on the end-to-end delay from the alternative path of the child node to the sink. During the long term congestion the intermediate nodes send backpressure message in the reverse path to the source. If the backpressure message reaches the source then the source also sends real time traffic along the alternate paths based on the weights allotted to the routes. The primary route is updated along with time due to the dynamic conditions of the network.

The authors show that QoS-ACC uses lesser energy than No Congestion Control and CCF [6].

C. Dynamic Alternative Path Selection (DAlPaS)

DAlPaS [7] resource control method to control congestion which is dynamic and distributed in nature. DAlPaS starts with the setup phase in which first the nodes learn about other nodes and then the neighbor tables are constructed and initialized. Then the nodes find out the least distance to the sink. The nodes then begin to forward data.

The algorithm makes use of two stages: a soft and a hard stage. A soft stage is entered when a node start getting packets from two or more data flows. Soft stage is an approach to avoid temporary congestion by advising the upstream transmitting node to find an alternative path. Factors such as the empty buffer space, the residual power of nodes, the medium interference and the distance of the node from the sink are considered to pick up a substitute node. If these transmitting nodes continue to transmit the packets through the same node then the receiving nodes must continue to receive. In the hard stage the transmitting node is compelled to find a different route on moving beyond the "performance threshold". By setting the value of the flag to "false" in the next ACK packet that it broadcasts, the node makes sure that it is not able receive any more data traffic temporarily or permanently. A different node to route the packets must be determined which is dependent on its availability and the total number of hops it is away to the sink.

DAlPaS uses the same topology every time that was formed in setup phase whereas TARA[4] uses a different topology with just enough capacity to hold data traffic each time the network is altered. TARA works at alleviating the intersection hotspots during permanent congestion whereas DAlPaS tries to relieve both transient and permanent congestion. DAlPaS incurs less overhead than TARA.

D. Traffic-Aware Dynamic Routing (TADR)

TADR [8] borrows the concept of potential from classical physics to forward packets to the sink. The basic idea is to make use of a scalar potential field which is a combination of depth field and queue length. The depth potential field represents the depth or the shortest route length to reach the sink. This field provides the basic routing purpose to move the packets to the sink using the shortest path. The queue length potential field refers to the ratio of total number of packets in the queue to the total size of the queue. The queue length is used to detect congestion. This field makes the algorithm aware of the traffic in the network and makes the additional packets move through multiple paths comprising of nodes whose buffer is lighter loaded in case of congestion.

The nodes need update messages to keep it informed of the depth and queue length. It also avoids the dropping of packets nearby the sink. To meet the objectives it spreads the packets not only through multiple paths but also over time.

TADR is scalable and distributed in nature. The throughput and the number of packets received at the sink in TADR are better than that obtained in MintRoute. Also TADR [8] provides better energy consumption than MintRoute. The disadvantage of this algorithm is that it does not take priority of the packet into consideration thus not achieving fairness.

E. Hierarchical Tree Alternative Path (HTAP)

HTAP [9] is a congestion control method where dynamic alternative paths are used to route away the packets from the congested areas in WSN. It makes use of a topology control method based on a variation of the Local Minimum Spanning Tree (LMST) [10]. It makes use of an adaptive ''congestion threshold'' to avoid transient congestion. It produces substitute paths to the sink to deal with permanent congestion [9]HTAP makes use of the following four strategies:

1) *Topology control*: LMST is used for keeping the network connected by making use of minimum energy. After each node has discovered its visible neighboring nodes, it exchanges information with them. The information of only those neighbor nodes is listed that are at one hop distance and nearer to the sink. Then a local minimum spanning tree is created using Prim's algorithm. After the construction of topology the power to reach each of the neighbor nodes is found out.

2) *Creation of Hierarchical tree*: The hierarchical tree creation algorithm starts after the source node starts sensing some event. All the nodes in the network are assigned a level. Now a connection among every pair of transmitter and receiver is created by making use of a two-way handshake. The congestion information of the receiver can be notified to the transmitter using this packet exchange. A dedicated control packet is used to inform the upstream nodes of the congestion when the pre-specified congestion limit of the child node is surpassed.

3) *Creation of Alterative path*: An alternate route is created when there is a likelihood of congestion at a particular node. A lightweight congestion detection algorithm is run on all the nodes. When the buffer occupancy reaches a given limit, the congestion detection algorithm starts observing the rate of packets arrival at the nodes. The congestion detection uses the ratio of the total receiving rate to the maximum transmission rate. When this ratio is big then backpressure messages are sent to the nodes that relay packets through it to inform them to search for alternative routes. The upstream node searches for an alternative path with the parent node at the same level as the previous node and update the neighboring tables. The information is updated when the congested node becomes available again.

4) *Handling of power exhausted nodes*: The powerless nodes are detached from the network. The neighbor tables of the nodes are updated.

The delay in HTAP [9] is less than TARA [4]. Also it offers better energy usage than [4]. It exhibits better performance when nodes are densely deployed near possible hot spots like sources and sinks. It is easy to implement, is robust and incurs notably less running cost than [4].

F. Hybrid Resource And Traffic Control(HRTC)

HRTC [11] uses the advantages of both traffic control methods and resource control methods to control congestion. The node sends a backpressure message hop-by-hop to the source when it faces congestion. Each node in the reverse path to the source node checks whether or not resource control can be applied. If resource control can be applied then it stops sending the backpressure messages. If the backpressure message finally reaches the source then traffic rate is reduced. Thereafter, every packet that it transmits contains a specific bit signifying that the traffic rate is reduced. Now the nodes that receive the data from the source node know that the data rate is reduced. As the network is dynamic in nature these nodes may now be able to apply the resource control, that is they may be able to send additional packets through alternative paths. In such a case they may send a backpressure method to the source node to inform them to send packets at full rate.

As the topology of the network is changing continuously the nodes figure out which congestion control strategy would best at that particular time applying resource control strategy if possible otherwise it considers traffic rate control.

This method to control congestion is better than traffic control and resource control methods individually. Compared to both of the traffic control and resource control methods it improves the throughput and lifetime of the wireless sensor networks. The limitation is that the priority of packets is not taken into consideration.

G. Hop-by-hop traffic-aware routing

Hop-by-hop traffic-aware routing to congestion control in [12] makes dynamic routing choice using two different gradient fields for depth and traffic loading.

The depth field is determined by the shortest path algorithm. It is used so that the packet moves through the shortest path to the sink. The traffic loading field combines three factors: normalized buffer size field, congestion degree, and average cumulative queue length to find the traffic load condition of a particular node. It is used to find the traffic condition of a neighbor node to check whether or not it can become the forwarding node of the alternative path to the sink. These two gradients can be combined to make decisions about which path to use to forward packet to the sink. Basically these two gradients are combined to move the extra packets through the idle sensor nodes to reduce congestion. After identifying the neighbor with lowest gradient field as the forwarding node to the sink, it adjusts the traffic rate by comparing the buffer occupancy ratio and the congestion degree of the current node with that of the upstream node.

This algorithm uniformly distributes the traffic in the WSN. It reduces the end-to-end packet delay and average energy consumption and improves the packet delivery ratio with respect to other mechanisms like CODA [13], ESRT [14], and GRATA [15]. The biggest drawback is that it incurs a lot of overhead in sending and receiving awareness packet to gather information about the total number of hops to the sink and the queuing statistics of the nodes.

COMPARATIVE ANALYSIS

The congestion control approaches discussed above use resource control but differently taking different factors into consideration, giving different level of performances. We compare the above discussed strategies to control congestion in Table 1.

TABLE 1. COMPARISON OF RESOURCE BASED CONGESTION CONTROL PROTOCOLS USED IN WSN

Protocol	Number of sinks	Congestion Detection	Congestion notification	Congestion mitigation Strategy	Fairness	Focus on
TARA	Multiple sink	Buffer occupancy and channel load	Using control packet	Alternative path based on merger and distributor nodes selected on the basis of congestion level and node location	Yes	Permanent congestion
QoS-ACC	Single sink	Ratio of mean packet service rate and mean packet arrival rate	Implicit Congestion Notification	Using alternate paths depending upon their weights	Yes	Both transient and persistent Congestion
DalPaS	Single sink	Available buffer space and medium interference	Using an ACK packet	Based on availability, number of hops, power, buffer occupancy and medium interference	No	Both transient and persistent Congestion
TADR	Single sink	Queue length	-	Using multiple paths after determining the queue length potential field	No	Transient congestion
HTAP	Single sink	Buffer occupancy, ratio of total receiving rate to maximum transmission rate	Using a dedicated control packet.	Uses Local Minimum Spanning Tree for selecting shortest available path	No	Both transient and persistent Congestion
HRTC	Single sink	-	Sends backpressure message hop by hop to the source	Hybrid of traffic control and resource control	No	Both transient and persistent Congestion
Hop-by-hop traffic-aware routing	Multiple sink	Uses buffer occupancy ratio and congestion ratio	Using Awareness Packet sent upstream	Hybrid of traffic control and resource control	No	Transient Congestion

CONCLUSION AND FUTURE WORK

Congestion in wireless sensor network is a very crucial issue that degrades the performance of the application in WSN. Handling of congestion may lead to smooth flow of packets which may increase the throughput of the application along with increasing the lifetime of the network by decreasing the dropping and delay of packets.

Resource control methods do not tend to decrease the incoming rate of traffic. Instead they tend to tune the resources available to manage the additional traffic. This leads to satisfaction of the fidelity demands of the application. Hence more packets carrying information collected during burst traffic are delivered to the sink.

This study can be useful in understanding how different resource control methods work and may function as a base for further work to improve the prevalent techniques to mitigate congestion.

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