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FCCP – NS: A Fair Congestion Control Protocol with N-Sinks in Wireless Sensor Networks

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ABSTRACT

A wireless sensor network (WSN) leads to congestion and gets overloaded when the data rate is unfair with respect to network capacity. This leads to high packet dropping probability, waste of energy and very low throughput. Due to the event driven nature of WSN, packet dropping rate grows high when ample sensors transmit data at the same time which becomes a challenging task to control congestion. In this paper, we propose a new Fair Congestion Control Protocol with N - Sinks (FCCP - NS) that controls congestion and allocates a fair data share to all the nodes with multiple sinks. Based on observing the upstream as well as the downstream nodes along with the buffer occupancy, fairness is ensured and the network load is suitably balanced. Thus the emerging congestion is detected in earlier stage with our protocol. Simulation results show that the network life prolongs well with a good throughput and very low packet dropping probability.
Key words : Buffer occupancy, Congestion, N-Sinks, Throughput, Wireless sensor network

1. INTRODUCTION

Wireless Sensor Networks (WSN) lead to poor performances like very low throughput, high packet dropping probability & amplified energy consumption which is aggressive in fields like image sensing, battlefield sensing, military, object tracking, surveillance etc. In customary networks, data is not mobile toward a common point and appear to be crooked. But when compared to WSN, the sensor nodes move toward a common sink and that is why WSN is different from the other networks. Most of the earlier works were mainly enthralled only on the traffic control because it would decrease the level of congestion towards and around the sink it. Researches in congestion control tells how to make progress from a congestion, where congestion avoidance shows the way to prevent from congestion occurrence.

Congestion occurs in two types. (i)The first is node based congestion which materializes when the buffer occupancy exceeds a particular limit resulting in unpredictable packet loss and low throughput. Due to such packet loss, packets have to be retransmitted again which consumes surplus energy. (ii) When multiple nodes try to access the sink at the same time where channels are shared, congestion occurs which is called as link based congestion. This decreases the rate of link utility and throughput. Both types of congestion have severe effect on energy expenditure and Quality of Service (QoS). Consequently, congestion must be controlled using a good congestion control protocol that enhances energy efficiency prolonging the battery power of sensors. It should also minimize packet loss due to queue occupancy overflow and promote the desired throughput.

Generally, congestion can be controlled by (i) traffic control - It has two techniques and they are end-to-end and hop-by-hop. End-to-end technique streamlines the network design by adjusting source rate at each node. On the contrary, the hop-by-hop technique achieves fast response which cannot possibly adjust the data forwarding rate as it is dependent on any protocol like CSMA, MAC [1] etc. (ii) managing network resources - To mitigate congestion, the network resource is increased when congestion occurs. But this technique slows down the response time that is received (iii) routing – it can be single path, multi path, geographical, flat etc. Though there are many congestion control mechanisms, selecting a good mechanism that is close to our problem concludes a good solution.

In this paper, we propose a Fair Congestion Control Protocol with N Sinks (FCCP – NS) as a lot of research work has been carried out for sensor networks with a single sink. The motive behind multiple sinks is that when the first sink is becoming a hot spot it would provide collision among nodes whose queue occupancy is either full or about to be full. By using multiple sinks, the nodes are rerouted to the optimal sink among the available sinks and ensures near zero packet loss and achieves the desired throughput.

The rest of this paper is organized as follows: in Section 2, we bring out the related works regarding the various congestion control and avoidance mechanisms in WSNs and why we are motivated to design our protocol. Section 3 describes the network design and Section 4 is about the protocol design. Section 5 illustrates the performance evaluation in the network that is arbitrarily deployed over the network and compares with the other mechanisms. We conclude this paper with Section 6.

2. RELATED WORK

Congestion have a negative impact in the performance of WSN and hence it is critical to be either as link level congestion or node level congestion. Link level congestion occurs when nodes are shared in Media Access Control (MAC) as all nodes try to capture the channels at the same time, whereas node level congestion causes packet loss when the associated buffer overflows with respect to data. ISWF scheme [2] solves the problem of slow congestion detection by combining the traffic changes of node and the queue length and decreases the time taken for detecting congestion. Thus it achieves better fairness and increases the network throughput in a better manner.

In Traffic Aware Dynamic Routing (TADR) [3] two hybrid potential fields are used and it alleviates congestion by using the depth of node and queue length and clears the obstacles associated with congestion. Sergiou et al. proposed Dynamic Alternative Path Selection Scheme (DAIPaS) [4] in which the congested nodes are avoided by alternating the routing paths based on some critical parameters. Thus it maintains minimal overhead and improves performance of the network. Priority based Congestion Control Protocol (PCCP)[5] controls upstream congestion by maintaining a priority table that holds the priorities for each node. This is given based on the importance of each node and measures the level of congestion as a ratio of the packet service time and packet inter arrival time. The Hierarchical Tree Alternative Path (HTAP) [6] avoids energy holes and promotes a balanced energy consumption of the network. The work done by Li at al. [7] controls congestion for multiple class of traffic, schedules packets and detects congestion based on dual buffer threshold and weighted buffer difference.

The congestion control mechanism in [8] is a priority based rate control mechanism which distinguishes between a real time high priority and low priority traffic. The real time traffic requires high reliability and low latency and the level of importance goes high when compared with a non-real time traffic. Wang and Sohraby et al. [9] proposed an upstream congestion control mechanism based on the node priority index and congestion degree. A hop-by-hop mechanism is used for controlling congestion for single-path as well as multi-path routing. Cross Layer Protocol (XLP) [10] achieves congestion control, MAC and routing in a cross layer manner. It ensures reliable communication by enabling the distributed duty cycle operation and receiver based contention. Congestion Avoidance, Detection and Alleviation (CADA) [11] controls congestion by using some representative nodes from the event area. Hotspots are also alleviated using the source rate regulation and dynamic traffic multiplexing. Teo et al. [12] proposed Interference Minimized multi path routing [I2MR] that controls congestion by identifying the disjoint rotes for load balancing using a node disjoint multipath routing algorithm. In [13] a comparative study is made between reducing the data rate and creating multi path routes. This gives a clear idea about the advantages and disadvantages of both congestion control methods. A benchmark protocol for sharing mobile adhoc environment is proposed in [21].

The work done by He et al. [14] uses a Traffic Aware Dynamic Routing (TADR) routes packets around the congested areas and scatters the excessive packets to lightly loaded or idle nodes. Thus nodes cannot become a hotspot near the sink and achieves low overhead for dense networks. The Decentralized Predictive Congestion Control (DPCC) [15] mechanism controls congestion by predicting the channel quality based on an embedded channel estimator algorithm and buffer utilization. In [16], a Fairness Aware Congestion Control (FACC) [16] protocol categorizes nodes into near source nodes and near sink nodes. The near source nodes uses a light weight packet dropping algorithm based on packet hit and buffer utilization. The Rate Controlled Reliable Transport (RCRT) [17] protocol gives control only to the sink for rate allocation and achieves flexibility and efficiency. In [18], a buffer based congestion avoidance is implemented that solves hidden terminal problems inhibiting congestion. It uses multiple path routing and achieves near optimal throughput by using a 1/k buffer solution. Congestion Aware Routing (CAR) [19] identifies the congested areas that exists between sink and source data. It degrades the performance of low priority traffic and handles high priority data for congestion control based on MCAR. Feedback Congestion Control Protocol (FBCC) [20] uses a feedback scheme between the parent node and the children node and detects congestion using the queue length. The Lyapunov based approach is used to demonstrate the hop-by-hop congestion control and achieves high throughput and low energy consumption.

3. NETWORK DESIGN

A WSN is a collection of sensor nodes and sinks (also called base stations). A sensor node is said to be a neighbour of the other when both are in the same transmission range. This ensures reliability in transmitting data as packet loss is a critical issue leading to a congestion in the network. For this purpose, we use a protocol to identify the neighbours of each sensor node namely the Neighbourhood Identification Table (NIT). If all the forwarded packets are received by the neighbours, it results in an unnecessary energy expenditure and unstable packet delivery ratio. In order to avoid this, we use a MAC protocol that works based on TDMA or CSMA to resolve problems associated with contention. This is done by making only the intended receiver to receive the packet and the neighbouring nodes to reject / discard the packet. For simplicity, we use the symmetric way of communication link for forwarding data. This is because, if a node a have to transmit data to node b, a should have the prior knowledge that b is its neighbour.

Sensor nodes are dynamically deployed and packets are forwarded from the sensor nodes to the sinks. The sinks are connected through a common network and thus has no difference of which sink receives the forwarded packet. Congestion and collision are common in a sensor network which results in buffer overflow and radio range collision. The possible solutions are CDMA, TDMA, and CSMA etc. Radio range collision problem is addressed by a random back off method and buffer overflow is resolved by fair sharing of media.

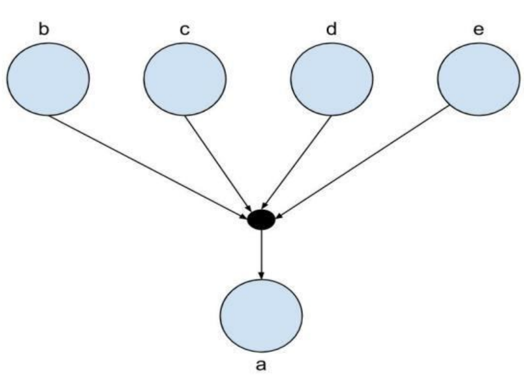

Figure 1: Queue overflow in CSMA

Consider Figure 1 which causes queue overflow in node a. When the nodes b,c,d and e have equal and fair share of bandwidth, a will receive four packets at the same time it has to forward. This clearly explains how packet overflow occurs in node a as its internal queue with its own data and that of the other four nodes will build up and subsequently overflow. We need to provide a solution such that a is able to send data at an increased rate along with the collective rate of b,c,d,e. This becomes much more complicated in a dynamic environment in which sharing of bandwidth is not constant, and that is what is addressed in this paper.

4. FCCP – NS PROTOCOL DESIGN

Our proposed congestion control algorithm addresses congestion control for a network with a single sink and N – sinks.

4.1 Congestion control with a single sink

We consider a WSN with n slave nodes (also called candidate nodes), a source node S and a sink. They are deployed in a square shaped area with a non-colliding MAC.

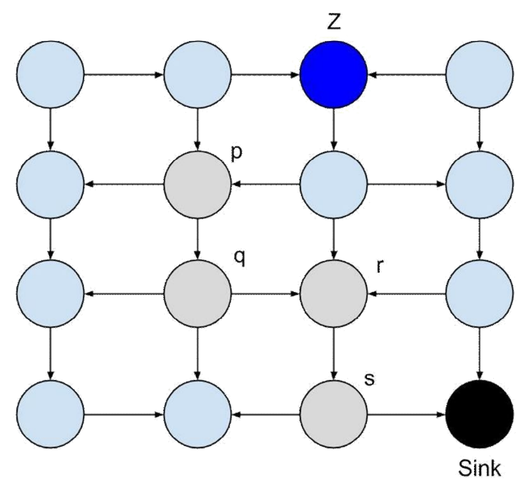

Figure 2: WSN with a single source node and a sink

In Figure 2, the nodes p,q,r and s are said to be slave and Z as the source node. For our convenience, we consider them to list down the number of top stream (αn) nodes that are close to S and bottom stream (βn) nodes that are close to the sink. The arrow marks represent the paths from S to the sink.

A. Congestion Ratio

Each sensor node in the network should have the knowledge of the total number of αn and βn and their ratio is said to be the congestion ratio (δ). There may be multiple paths from S to the sink which may lead to a collapsed state. In order to avoid that, we find αn and βn for each node which is represented in Table I. From Fig: 2, αn (p) = 2 and βn (p) = 2. Therefore,

δ (p) = 2/2 =1

δ (q) = 2/2 = 1

δ (r) = 1/3 = 3

δ (s) = 1/2 = 0.5

If the value of δ for any node equals zero, it means that either it has no αn and βn or is disconnected from the sensor network. These values are updated in NIT and the table varies on every updating of the node. A sample NIT is listed below.

Table 1: Neighbourhood Identification Table

Slave node ID	α_n	β_n	Congestion Ratio
p	2	2	1
q	2	2	1
r	3	1	0.3
s	1	2	2
S	2	1	Source Node
Sink	2	0	Sink

B. Advertising Buffer Capacity

The buffer size have to be advertised by each node so that the nodes can have the knowledge of αn and βn of their neighbours from the NIT. This is done by each slave node in a periodic manner that gives the current state of each node in the network and the overhead that is associated with the control packets is resolved. Whenever a buffer gets filled up, it should however not overflow that would lead to loss of packets. So when the buffer of a node is about to overflow, the bottom stream nodes should be filled up for regulating the data flow so as to avoid congestion.

C. Congestion Avoidance

We have discussed that the top stream nodes do not transmit data when the bottom stream nodes do not have the required buffer capacity to hold the incoming data packets. This is because if it is done so, packets have to be dropped and there will be no way to retrieve it. The condition gets worse in case of emergency situations for ex: health care monitoring – when there is only a single path to reach the sink. Thus our proposed scheme regulates data flow and avoids congestion. There will be ample sensors with a number of incoming and outgoing packets and can obviously have collisions, which is avoided by eluding the unnecessary transmissions.

Let us consider Figure 3, a scenario in which node a have nine slots buffer with the first slot being reserved as packet header and the other eight slots await to be filled up. Assume that node b tries to transmit a packet to node a. In such a condition node b will silence all its neighbours within its transmission range.

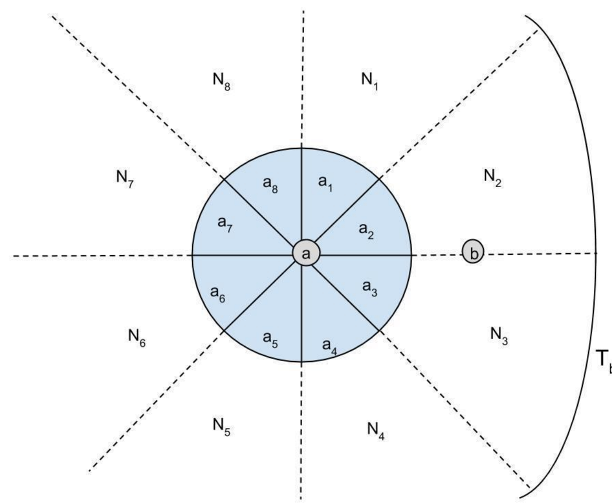

Figure 3: Neighbours around node a

N1, N2….N8 are the neighbours of node a and among them N1…N3 will not have buffer advertisements or data transmissions until all the slots are emptied by a. Meanwhile N4…N8 will overhear about b and will also be idle for transmissions from a. This situation continues until a new advertisement is made.

Before making the decision of packet forwarding, the value of congestion ratio (δ) is assessed. If δ >1, it means that the node has many bottom stream nodes and may need a queuing mechanism for forwarding the packets in a smooth manner. We are using the Weighted Fair Queuing (WFQ) method where other mechanisms like Weighted Round Robin Scheduling (WRR) can also be used. If the value of δ falls below 1, a rate reducing method [13] is used so as to avoid congestion due to many top stream nodes. Also when δ = 1, the buffer size of slave nodes are checked and are routed in a fair manner on receiving a new buffer capacity advertisement message. Thus energy expenditure is minimized to a greater extent, congestion is avoided and the desired throughput is achieved. The pseudo code for algorithm I is given below.

Algorithm I: Congestion Control with a single sink

1. Initialize NIT
2. while buffer(Q) is not full then
3. Forward packets through NIT on iteration
4. end while
5. Check buffer_size(Q)
6. if buffer_size(Q) = limit then
7. Calculate Congestion ratio(δ)
8. if δ > 1 then
9. Use WFQ
10. else if δ < 1 then
11. Use data rate reducing method
12. else if δ =1 then
13. Check buffer_size(slave nodes)
14. Send packets through slave nodes on receiving buffer capacity advertisement
15. end if
16. end if
17. end if
18. end if

4.2 Congestion control with n – sinkss

We now discuss the case of congestion control with n – sinks. Let us assume a network scenario with five sinks S1….S5 and a source node Z as represented in Figure 4.The slave nodes are a,b,c and d. The resolution of data forwarding is based on the congestion ratio that is calculated at each node.

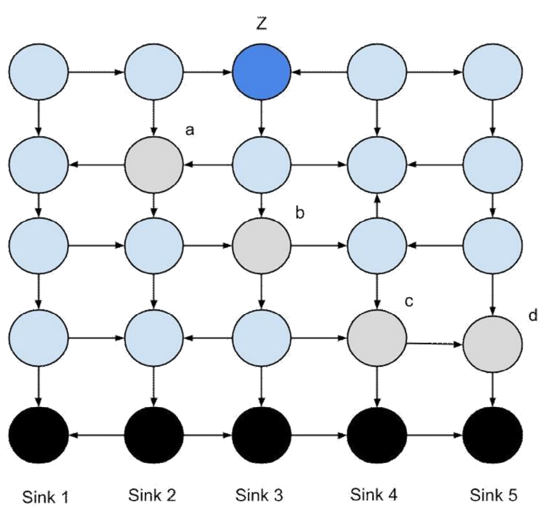

Figure 4: WSN with a single source node and n - sinks

Let each sensor node have the knowledge of the list of their neighbouring nodes through which packets are routed to the sink. The first node in la has the highest precedence and the last node has the lowest precedence. Thus a separate list of next hops (la) is maintained by each sensor node. Let Y be a set of sinks. i.e., Y = (S1….Sn). Every sink is based on a separate routing method and a precedence of the list is also created for all the sinks. This list is based on the geographical distance from a neighbour to the sink that is closest to it. It is of three tuples and la = < h, c, d > in which h is the next hop neighbour, c is the closest sink to h and d is the distance from h to c. When a node a is ready to forward packets, it executes the following algorithm to find the closest sink to which it has to forward packets in order to lessen the energy expenditure. The pseudo code for algorithm II is given below.

Algorithm II: Congestion Control with n – sinks

1. Identify closest sink (a)
2. loop < h, c, d > on the basis of precedence do
3. if buffer_size (h) is not full then
4. return c
5. end if
6. loop < h, c > on the basis of precedence do
7. if nextslot <h> cannot hold packets
8. Forward packets through nextslot (a, c)
9. return c
10. Repeat until new buffer capacity advertisement is received from la

Thus the closest sink to any node is identified from the set of all sinks and avoids the chance of congestion in routing among multiple paths. After identifying the closest sink, the problem is narrowed down to algorithm I that controls congestion with a single sink as discussed earlier. Each sensor node uses la to select the optimal sink and the intermediate node a uses lax to forward the packets to sink x. When it is understood that no neighbouring nodes in la can hold the incoming packet, there is no choice other than to wait till any node frees its buffer space even when it belongs to another sink. In such situation, a packet can be allowed to skip the destined sink for a limited number of times. This can be avoided by a Time To Live (TTL) field in the header part of the packet. Each time it skips a sink, the value of TTL is decremented by one so as to avoid infinite number of skips.

5. PERFORMANCE EVALUATION

In this section, we evaluate the proposed congestion control algorithm with the network simulator NS2 version 2.29. The simulation parameters are defined in Table II.

Table 2: Simulation parameters

Parameter	Value
Total Number of nodes	100
Number of sink nodes	1….5
MAC Protocol	802.11
Simulation Area	500 * 500 m^2
Average packets per node	30
Nature of Traffic	Variable
Packet Size	512 kbps
Radio Range	100m
Life time of NIT	5 seconds
Beacon interval	1 second
Simulation Time	300 seconds

5.1 Performance Metrics

We have some quantitative metrics for performance evaluation and they are as follows.

1. Throughput – The ratio of the total number of packets sent to the sink to the number of packets sent by the source node is the throughput obtained. It is used to find the stability of the bandwidth in the system and is measured in Kbps. This can be affected by various factors like unacceptable signal to noise ratio, damages in wires and poor channel utilization.

2. Energy Expenditure – It is the average energy consumed by each packet and the sensor nodes should be energy efficient as the life time of each sensor node is dependent on the restricted energy resource. So whenever the node is not in use the radio power supply should be put off so as to save the battery. For an energy efficient WSN, the limited energy resource should be conserved less which will be much helpful when it is deployed in remote and hostile environments.

3. Packet loss – Whenever the packets in queue become full, they are dropped due to collision among nodes and the packet service time is below the arrival rate of packets. In such a case, packets have to be retransmitted again for those that are lost. The possible reasons for loss of packets are signal deprivation, deterrence in network etc. and affects the performance in a poor manner. It is a very important metric as nothing seem to be successful in a network with loss of packets.

4. Fairness – All the sensor nodes should have a fair share of bandwidth which results in successful transmission of packets via the communication path. When channel allocation is not uniform, the expected throughput is not obtained which also leads to implementation overhead.

5.2 Simulation Setup

Our proposed congestion control mechanism is analyzed with some simulation parameters to understand the effectiveness of the same. In a 500 * 500 m2 network area, 100 sensor nodes are randomly deployed with the radio range of 100 m. The packet transmission size is 512 Kbps and due to the energy constraint, a sensor node should not constantly send data at a high rate. Hundred sensor nodes are randomly deployed with 1 to 5 sinks. Each node has a maximum of 30 packets and the nature of traffic is said to be variable. The life time of NIT is 5 seconds and the beacon interval is 1 second which is totally simulated for 300 seconds.

5.3 Comparative Analysis

We compare the performance of our proposed protocol FCCP - NS with the other schemes TADR [3], ECODA [7] and No Congestion Control.

A. Throughput Comparison

The throughput comparison of our proposed protocol with TADR, ECODA, and No Congestion Control with respect to traffic is simulated for 300 seconds. No congestion control suffers more than the other schemes as no criteria is implemented to accomplish the expected throughput. It has an unrestrained packet flow and the number of packets a node receives is lesser than the transmitted packets resulting in decreased throughput. It peaks at 200 Kbps and decreases throughput from there which possibly creates congestion, but drops down after 600 Kbps that is far below the acceptable level. Next, TADR has a good throughput level up to 700 Kbps and falls down as time exceeds making sure that it could not tolerate pressure. It is obvious that when traffic is increased, the likelihood of congestion is higher leading to an unpredictable level of throughput. ECODA stabilizes after 500 Kbps but is not steady after a certain load. But our simulation has the highest throughput rate and the comparative results are represented in Figure 5.

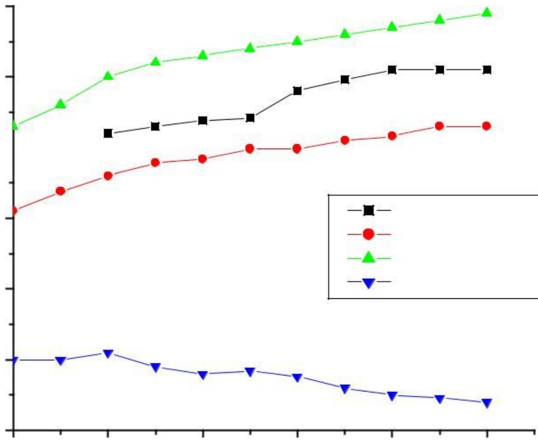

Figure 5: Throughput with respect to traffic

B. *Energy Expenditure*

The ratio of the total number of transmissions made in the network to the successful number of transmissions made to the sink is the total amount of energy spent by the sensor nodes in the network. Each efficacious transmission moves a packet one hop adjacent to the base station. The comparative analysis of energy consumption with respect to time is made and is represented in Fig 6. Our proposed protocol FCCP-NS is more energy efficient when time grows on when compared with the other existing schemes.

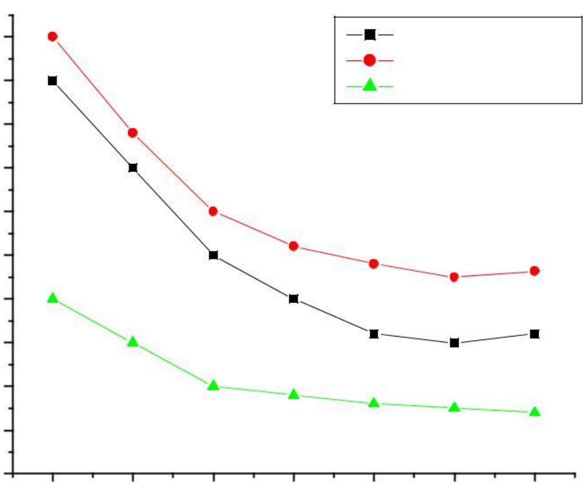

Figure 6: Energy expenditure per packet over time

Figure 7 represents the comparative analysis of energy expenditure with respect to traffic and we understand that No congestion control consumes more energy and reaches the sink with truncated packets. TADR and ECODA has better performance than No congestion control but does not override our proposed protocol as it gets neutral after 400 Kbps. This assures that the number of successful transmissions made to the sink is also greater in FCCP – NS than the other existing schemes.

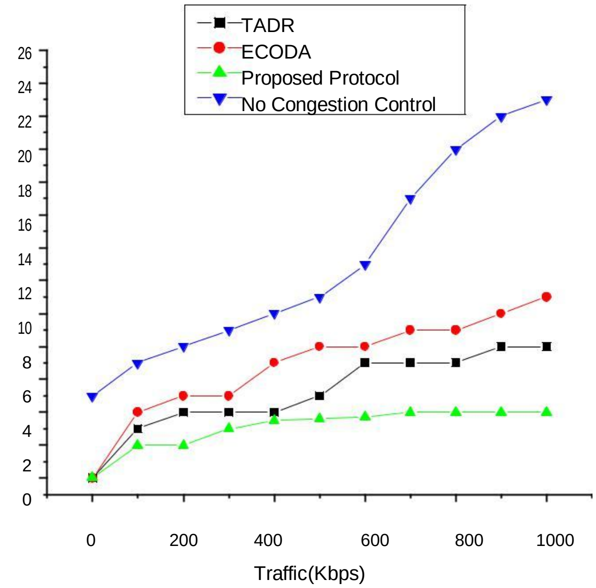

Figure 7: Energy Expenditure with respect to traffic

C. *Packet Loss Probability*

Packet loss occurs due to congestion in the network, buffer overflow, battery loss etc. Our simulation shows that packets are infrequently dropped where the other schemes do have packet loss. Fig 8 shows the number of packets dropped versus time in the network. With no congestion control, packets are dropped exponentially and is highly probable of having a collided network as there is no scheme to monitor and control congestion. On comparing TADR and ECODA, TADR drops lesser number of packets and stabilizes at a certain level and ECODA drops some more packets as time grows. Our proposed protocol tries to avert congestion and hence results in near zero or no packet loss.

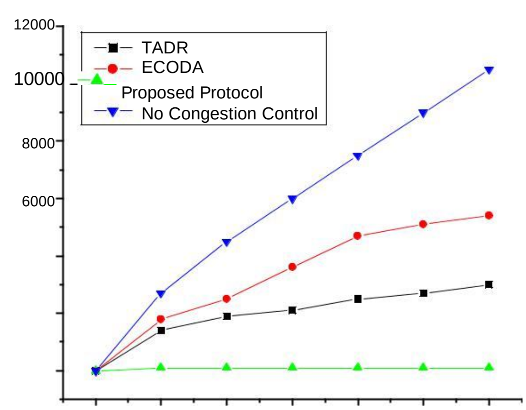

Figure 8: Packet loss versus time

Figure 9 shows the total number of packets dropped versus source rate. Whenever the source rate is increased, packets are also aggressively dropped. This is true for TADR and ECODA and cannot stabilize properly where our proposed scheme is more flexible in leading unnecessary traffic to other paths.

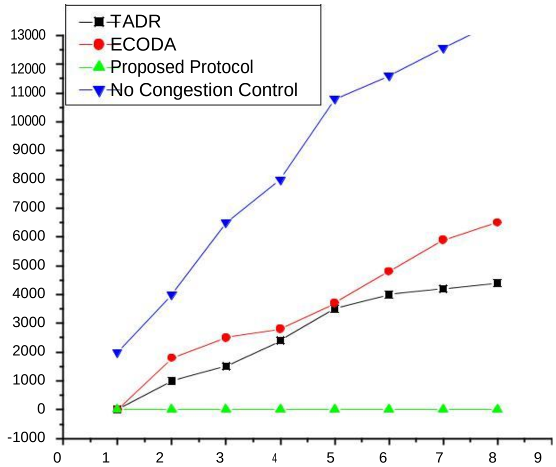

Figure 9: Packet loss versus source rate

Figure 10 shows the number of packets dropped with respect to the number of source nodes. When the source nodes are increased, network traffic also gets increased giving way to congestion thereby dropping more packets than desired. TADR is built on a traffic aware method and so it does not aggressively lose packets in the network but drops packets in a small slope. On the other hand, ECODA drops packets whenever the number of source nodes are increased with new source rates. But our proposed protocol has a near zero packet loss probability and have a positive impact.

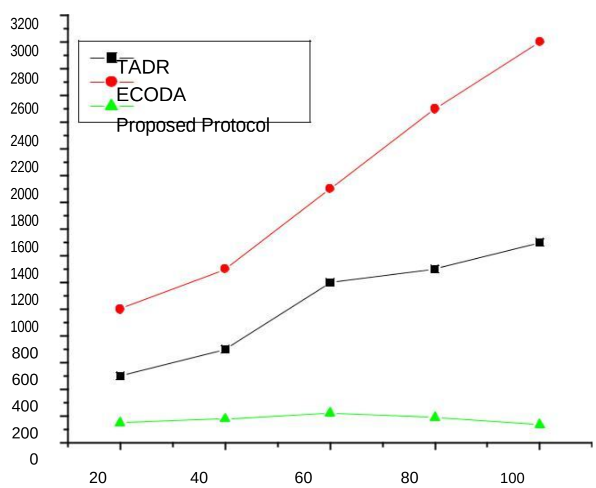

Figure 10: Source Nodes versus Packets dropped

D. Fairness Comparison

A fair share of bandwidth among sensor nodes provide smooth transmission with a near zero or no congestion for each flow of data. Also sensor nodes can successfully transmit packets only when bandwidth is shared well with good channel utilization. Figure 11 represents the fairness comparison of our proposed protocol against the other protocols. No congestion control results in catastrophic fairness and ECODA slopes down when compared with TADR. All the flows from 1 to 10 have diverse interventions and FCCP – NS achieves better fairness for longer as well as shorter flows and achieves maximum throughput.

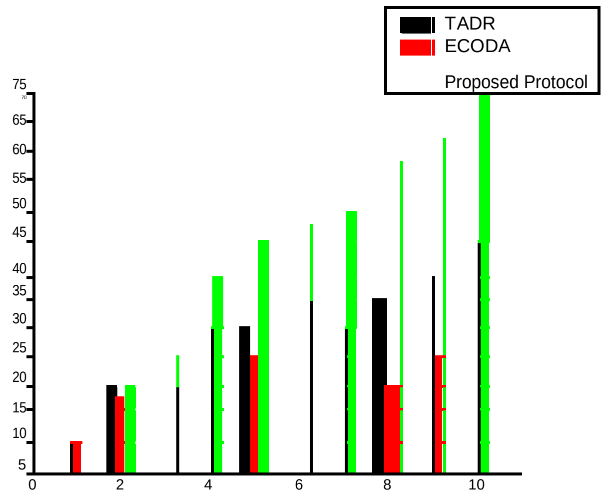

Figure 11: Fairness with respect to different data flows

6. CONCLUSION & FUTURE WORK

In this paper, we have proposed a fair congestion control protocol called FCCP – NS that uses n number of sinks. It observes the top stream and bottom stream nodes for choosing the optimal sink among the available sinks for avoiding hotspots which is a common congestion factor. Thus traffic is well regulated and reduces chances of collision among nodes. This approach alleviates congestion and will be much better for an application oriented WSN. Thus a common framework that holds the solution for many factors can be extended as our future work. We have shown that FCCP- NS has remarkable throughput, acceptable energy consumption and near zero or no packet loss with a fair share of bandwidth for longer and shorter data flows.

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