An Efficient Fuzzy based Congestion Control Technique for Wireless Sensor Networks

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ABSTRACT
In wireless sensor networks (WSN), congestion causes overall channel quality to degrade and loss rates to increase, leads to buffer drops and increased delays, and tends to be grossly unfair toward nodes whose data has to traverse a larger number of radio hops. In order to control the congestion in an effective manner, we need a complete congestion control mechanism which makes fuzzy based decisions. In this paper, we design an efficient fuzzy based congestion control algorithm which takes into consideration the node degree, queue length and the data arrival rate as parameters for congestion detection. The fuzzy table accepts the values of data arrival rate, node degree and the queue length as input and the output is given in the form of fuzzy variables which indicates the level of congestion. The output gives us a strict passive measure of the congestion level and will result in a perfect measurement for congestion estimation. Thus our algorithm proves to be more effective in controlling the congestion in wireless sensor networks. By simulation results, we show that our proposed technique attains better packet delivery ratio with reduced packet drops and delay.

Keywords
Wireless Sensor Networks (WSN), Congestion Control Technique, Node Degree (N), Data Arrival Rate (A), Queue Length (Q)

1. INTRODUCTION

1.1 Wireless Sensor Networks
Wireless sensor networks are rapid and help in easy installation and maintenance. Ease of installation, self-identification, self-diagnosis, reliability, time awareness for coordination with other nodes, some software functions and DSP, and standard control protocols and network interfaces are the enviable functions of the sensor nodes. The funding initiatives like Darpa sensit program, military programs, and NSF Program Announcements considers the importance of sensor networks. [1] In order to monitor the real-world environment, numerous numbers of small devices with a potential of sensing, processing, and communication are present in the wireless sensor networks. In future, wireless sensor networks are capable of playing a major role in critical military surveillance applications, forest fire monitoring and building security monitoring. In immense field the operational conditions are often harsh or even aggressive and so numerous sensor nodes are deployed to monitor the field. [2]

1.2 Reasons for Congestion
- The major reason for congestion occurrence is the packet loss which occurs during collision. The generality of many-to-one is considered for data transmission in sensor network under the single or multiple situations. [5]
- Different priorities are given for different types of sensor data. In order to meet the demands of the base station, each type of data is guaranteed by desired transmission rate based upon the given priority. Even for the unpredictable bursts of messages simple periodic events can be generated in this network. Due to interaction of concurrent data transmissions over varying radio links or due to increase in the reporting rate to the base station, congestion becomes more liable. Frequent congestion is due to the increased number of nodes in the network. Hence, efficient mechanisms which guarantee balanced transmission rates for different types of data are required for congestion control. [4]
- From a multi-hop network, the sensor forwards data generated by the nodes at a constant rate to a single sink. Rapid increase in the loss rates occur due to the increase in the offered load. The absence of buffer space at a sensor node causes error in the wireless channel and due to this, the losses are separated. The buffer drops are decreased by the channel losses and the offered load increases rapidly.
- There is a possibility of lack of resources due to high reporting rates by numerous events. This occurs though the event is few bytes long and leads to congestion and packet/event drops [16]

1.3 Types of Congestion
There are mainly two types of congestion in WSNs:

1. The node-level congestion and
2. The link-level congestion.

Node-level congestion: When a particular node, queue or buffer which is used to hold the packet overflows, then the congestion is known as node level congestion. Packet losses occur due to this congestion and so retransmission is required which consumes additional energy. The nodes which use the Carrier Sense Multiple Access (CSMA) simultaneously access to a common transmission medium and this leads to collisions among sensor nodes [6].This collision leads to buffer overflow in the node, increases the queuing delay and leads to packet loss. [8]

Link-level congestion: This type of congestion is familiar in sensor networks. Due to link congestion, there are chances of packet service increment and link utilization declining. The life span of wireless sensor networks can be diminished since these congestions affects the energy efficiency. Incoming traffic may cause increase in the capacity of the outgoing link and path loss leads to channel fading. The power of sensor nodes are decreased when the packet service time is decreased and when there is reduction in the link utilization and overall throughput. [8]

1.4 Effects of Congestion

- Due to congestion, there occur buffer drops and increased delays in the traditional wired networks and cellular wireless networks..
- The traffic from various parts of the network leads to congestion which in turn degrades the radio channel quality.
- Though the system has a well-regulated traffic, the pitiable and time-varying channel quality, asymmetric communication channels, and unseen terminals make the deliverance of the packets weaker. When a packet traverses a larger of radio hops under traffic load, it gets penalized by multi-hop wireless sensor networks. This leads to large degrees of unfairness.
- Buffer drop may occur due to the reason that overall channel quality decrement and also due to increase in the loss rate. Delay can also be increased in the network due to this. [3]
- For the nodes which traverse a significant number of hops, the traffic flow becomes unfair and this affects the performance and the lifetime of the network. There are certain limitations in wireless sensor networks based on the energy, memory and bandwidth. [7]
- The link-level congestion causes increase in packet service time and decrease in link utilization. Energy efficiency and QoS is affected by both these congestions which decreases lifetime of the wireless sensor networks. [8]
- Congestion in TCP causes all segment losses and due to this the window-based flow control and congestion control are triggered. This style acquires that, when there is no congestion, the TCP reduces the transmission rate but packet losses from the bit-error. Particularly, only under the multiple wireless hops, low throughput is achieved in this behavior. [9]
- Diverse rate data which include data from very low rate periodic data to a very high rate event data are sent by the sources in WSN. Hence the capacity of the network is lesser than the aggregate traffic rate around the bottleneck. [10]

1.5 Congestion Control Techniques

A congestion control technique which uses the queue length as an indication of congestion degree was proposed named as Queue based Congestion Control Protocol with Priority Support (QCCP-PS). Priority index and current congestion degree are taken as main metrics for rate assignment to each traffic source. [17]

In wired local-area, wide-area networks and in sensor networks, the hop-by-hop flow control is proposed. A congestion bit is set in the header of every outgoing packet. Congestion feedback is provided to all nodes in a radio neighborhood with every transmission due to advantage of the broadcast nature of the wireless medium. [18]

The node monitors the aggregate output and input traffic rates in the distributed congestion control algorithm. The decision either to increase or decrease the bandwidth which is allocable to a flow originating from itself and to those being routed through it is based upon the difference of the two.. [19]

Priority Based Rate Adjustment technique (PRA): A congestion notification bit obtained during congestion in AIMD gives the information about the transmission rate increase or decrease. Hence transmission rate is necessary to overcome the congestion. [20]

- Short Term Congestion Control: When congestion occurs, the real time traffic is splits the child node on to its alternate parent (route). A weight factor w_i is taken as the proportion for splitting the traffic.
- In long term congestion control technique, the congestion control is commenced once the source node receives a back pressure message.
- The priority based congestion control technique, inter arrival time and the packet service time are used together. Congestion degree can be estimated using the Hop-by-Hop control technique.
- A simple, robust and scalable transport is considered in the Pump Slowly Fetch Quickly, PSFQ technique. The needs of different data applications can be met by PSFQ.

1.6 Problem Identification and Proposed Solution

The fuzzy logic methodology helps us having a pro-active approach to solve QoS related issues. Fuzzy logic is very effective to manage the performance of a highly dynamic nonlinear system, e.g., a WSN, without requiring a mathematical model of the system. A fuzzy controller is essentially a direct (nonlinear) mapping between its input, in a node, and output, unlike other controllers such as PID (proportional, integral, and derivative) controllers. Fuzzy control theory provides formal techniques to represent, manipulate, and implement human experts' heuristic knowledge for controlling a plant, e.g., a wireless network, via if-then rules rather than relying on mathematical modeling of the plant. [13]. So, a fuzzy logic based congestion control algorithm is desirable for the wireless sensor networks.

Some of the existing Fuzzy based congestion control techniques are [12] and [13].

In [12] a buffer model has been designed, with the given packet arrival rate, given buffer size and the current transmission rate. They calculate these and maintain a fuzzy table for the conditions of buffer getting congested at the current time.

In [13] the awful case which is estimated is quite distrustful in the presence of load balancing. This estimation is based on virtual queue lengths. Here effective queue length can be developed to solve the issue.

But both these fuzzy based congestion control algorithms were developed based upon only the buffer size or only with the queue length. They did not consider the MAC layer contention as one of the parameters. Moreover fuzzy logic was not estimated for system wide congestion estimation in WSN. So we need a complete congestion control mechanism which makes fuzzy based decisions considering buffer size or queue length, data arrival rate and contention.

In this proposal we design a congestion control algorithm which takes into consideration the node degree, queue length and the data arrival rate. A fuzzy table is maintained which takes the values of data arrival rate, node degree and the queue length as input and gives us an output in the form of fuzzy variables so that a decision needs to be taken or not. The output gives us a strict passive measure of the congestion state and will result in a perfect measurement for congestion estimation.

Thus our algorithm proves to be more effective that the previous fuzzy logic congestion control algorithms.

2. RELATED WORK

Feng Xia et al [11] have developed a fuzzy logic control based QoS management (FLC-QM) scheme for WSANs with constrained resources and in dynamic and unpredictable environments. In WSANs, the feedback control technology is used in order to deal with the impulsive changes of traffic load. The sampling period to the deadline miss ratio coupled with the data transmission can be adapted using a fuzzy logic controller in the sensor node. In order to achieve the required QoS, the deadline miss ratio needs to be sustained at a pre-determined desired level. The FLC-QM has the advantages of generality, scalability, and simplicity. Improvement of the FLC-QM scheme for large-scale WSANs through, e.g., developing a unified framework; 2) extensive simulation studies on WSANs with more complex network topology; and 3) experimental studies and practical implementation of the FLC-QM scheme in WSANs are the future works to be done in this scheme.

Saad A. Munir et al [12] have proposed a congestion estimation model for QoS in wireless sensor network, and implement it using fuzzy logic with fuzzy set variables. They present a model for fuzzy logic based congestion estimation within a proposed QoS architecture. For the purpose of QoS administration, both at the node level and the sink, the QoS management and control module is essential. Here, the resource constrained wireless sensor network will not be impeded since the the QoS module implemented at sensor node forms a subset of the larger QoS Management and Control module so that system has a wider information. System wide congestion estimation and influence in the increase of congestion related parameters are considered for future work.

Can Basaran et al [13] have presented a lightweight distributed congestion control method in WSNs. The queue lengths and the channel conditions which are observed in one hop neighborhood are the metrics used here for detecting the congestion. Based on the estimated level of congestion, each node dynamically adapts its packet transmission rate and balances the load among the one-hop neighbors to avoid creating congestion and bottleneck nodes.

Ping-Min Hsu et al [14] have studied the congestion control problem of local wireless sensor networks. The time-delay compensation without delay estimation can be solved using this novel control design strategy. The firmness of this controller is guaranteed since this controller has been designed using a delay compensator. The property for single connection of the wireless network is taken into consideration in the future works.

JANG-PING SHEU et al [15] have addressed the problem of congestion control in the sensor networks. Both the packet delivery rate and the remaining buffer size are included in the Hybrid Congestion Control Protocol (HCCP). Congestion detection, congestion information advertisement, and data rate adjustment are discussed in the congestion control problem. The congestion detection phase helps in taking preventive measures since it calculates the congestion prior to a time period of T. Larger data rate can be allocated to the upstream neighbors in the data rate adjustment phase.

Moufida Maimour et al [16] have investigated the use of load repartition for congestion control of video flows in a wireless sensor network with multi-path support. When the video flow is split on multiple-path, the quality needs to be maintained. This technique avoids the transmission rate decrement and thus various load repartition strategies can be evaluated.

3. PROPOSED WORK

3.1 Calculation of Node Degree (N)

In this section we propose a weighted centroid algorithm for hop-count based localization by adding the node degree on the paths to the referenced anchors into the weights.

- Initially we assume a static two dimensional plain scenario with K random uniformly distributed nodes and this gives a constant average node degree.
- The same wireless module is used by each node with a fixed unidirectional communication range.
- The 1-hop neighbors are the nodes within the communication range C and they can communicate with each other.
- Only one node is taken as the central node in the middle of the observance area.

The node density D is given by

$$D = \deg(K) / \Pi C^2 \quad (1)$$

- If the shortest communication path by means of shortest hop-count is n, then the two nodes are denoted as n-hop neighbors.
- The probability $T(w)$ of a random node pair with distance w to each other to be n-hop-neighbors.
- We also observe the mean distance w_m between n-hop neighbors.
- There is a similarity between the mean value of the distance of all possible n-hop-neighbors and the expected distance of randomly chosen n-hop-neighbors since the nodes are uniformly and independently distributed and is placed randomly.
- The communication range C will be set to 1 (distance unit) as simple scaling, resulting in a unit-disc-graph.

The probability T1(w) that two nodes with distance w to each other are 1-hop-neighbors is

$T1(w) = 0$ if $w \le 0$
$T1(w) = 1$ if $0 < w \le 1$
$T1(w) = 0$ if $w > 1$

as two nodes are 1-hop-neighbors if and only if they have a positive distance less equal to the communication range.

The average distance W_{1m} between 1-hop-neighbors can be computed and simplified as

$$W_{1m} = 1/Q\int_Q T1(w)\,\mathrm{ddxdy} = 2/3 \qquad (2)$$

with Q being the unit circle as all nodes in the unit circle around Node Zero are a 1-hop neighbor of it. For 1-hop-neighbors W_{1m} is independent of the node degree.

Two nodes with a distance w equal less to 1 are already 1-hop-neighbors. If the distance

w is greater than 2 no common neighbor can be found for the node pair. Therefore only node pairs with a distance $1 < w \leq 2$ are potential 2-hop-neighbors. The probability T2(w) is equal to the probability to find a third node to establish a 2-hop-neighborhood. This third node must be placed in the intersection area *Q* of the communication range circles of the first two nodes. This area *A* can be computed for communication range c = 1 as

$$Q = 2\arccos(\mathrm{w/d}) - \mathrm{w}(\sqrt{4 - \mathrm{w}^2})/2 \qquad (3)$$

The probability T2(w) that one random but specific neighbor node is placed in the intersection of the two communication areas is

$$T2(w) = Q/\mathrm{II}c^2 \text{when} 1 < \mathrm{w} \leq 2 \qquad (4)$$

This can be computed as

$$T2(w) = 1 - (1 - (2\arccos(\mathrm{w/d}) - \mathrm{w}(\sqrt{4 - \mathrm{w}^2}))/\mathrm{II} * \deg(\mathrm{K}) \qquad (5)$$

As expected a high node degree offers more possibilities to find a third node and an increased probability to find this third node even for node distances d close to the maximum of 2.

The average distance of 2-hop-neighbors can be computed using polar coordinates again

$$W_{2m} = 1/Q\int_Q T2(w)\,ddxdy = 2/3$$
$$\int_{c-1}^{2} (1 - (1 - (2\arccos(w/d) - w(\sqrt{4 - w^2})/II)\deg(K)c^2 dc \qquad (6)$$

which is not independent of the node degree.

For node degrees close to infinity we may assume that all nodes within an annulus but not positioned on the inner circle, are n-hop neighbors though it has large radius C = *n* and a smaller radius *c* = *n* − 1. For example all nodes within the centered annulus Q1,2 with c = 1 and *C* = 2 are 2-hop-neighbors of the central node at (0, 0). Therefore the probability b Tn(w) of 2 nodes with distance d to be n-hop-neighbors for high node degrees is

Tn(w) = 0 if w ≤ n-1
Tn(w) = 1 if n-1 < w ≤ n
Tn(w) = 0 if w > n

The average node distance Wn^ for an almost infinite high node degree can be computed as

$$Wn\hat{} = 2/3\left\{[n^3 - (n-1)^3]/[n^2 - (n-1)^2]\right\} \qquad (7)$$

which equals 2/3 for n=1 as expected and converges to n-1/2 for n -> ∞ [25]

3.2 Calculation of Data Arrival Rate (A)

- In order to calculate the unknown packet arrival rate of earlier computing nodes, here we use the information about the packet arrival rate of a previous node.
- The average packet rate of a node tends to be constant when a node communication of WSNs enters into a stable state.

Here we design an iterative method in this algorithm.

We initially set values to the network status, and by using the iterative method the values gradually revise the last time packet arrival rate.

1. In the queuing network model, the connection for each node is obtained according to transition probability. Here we determine the External packet arrival rates T_b^X
2. The total packet arrival rates T_a^0 of the n nodes are initialized.
3. Total packet arrival rate for queue j in queuing network is calculated as:

$$\text{Data arrival rate (A)}: \mathrm{T_b} = T_b{}^x + \sum_{a=0}^{m} T_a \rho_{ab} \qquad (8)$$

The following constraints are created as per the connection of each node.

$$T_b 1 = T_b x + \sum_{a=0}^{m} T_a^0 \rho_{ab} \qquad (9)$$

The packet arrival rate can be calculated using the previous results.

$$T_{b+1}^1 = T_b{}^x + \sum_{a=0}^{m} T_a{}^1 \rho_{ab} + \sum_{a-b+1}^{n} T_a{}^0 \rho_{ab} \qquad (10)$$

In this way the total packet arrival rates of nodes are calculated.

4. The internal packet arrival rates for every node can be modified using T_b^1, b is the node number.
5. Let Th be the threshold value.
   If the difference between the internal packet arrival rates for two computing tasks doesn't exceed Th,
   5.1 then go to step 6.
   Else
   5.2 Jump to Step 3
   Iterative calculation
6. Return the total packet arrival rate of each node T_b^n , where n is the number of iterations. [26]

3.3 Calculation of Queue Length (Q)

Let,

S_a be the scheduling rate of a particular sensor node b

P_a = { P_{al1}, P_{al2}, ……P_{alN}} be the priority levels of different applications.

Av = Average queue length of sensor node a.

L = Total number of sub-queues.

1. Initially the data generation rate assigned for node a, is assigned according to Weighed Fair Queuing (WFQ). Here the scheduler sends H number of packets from network layer to MAC layer at each unit time.

The data generation rate assigned for node a is given by:

$$\frac{S_a * P_a}{P_{a11} + P_{a12} + \ldots P_{a1N}} \qquad (11)$$

2. For diverse applications, we need to combine the sub-queue with the protocol queuing model and each of the application has different priority levels i.e $P_a = \{P_{al1}, P_{al2}, \ldots P_{alN}\}$. The equation 12 gives the average queue length of a sensor node a. [27]

$$Q = \sum_{b=1}^{L} C_b / L \quad (12)$$

3.4 Fuzzy Based Congestion Estimation

3.4.1 Fuzzification

The mapping from a real-valued point to a fuzzy set is known as Fuzzification which receives other robots information in order to convert it into fuzzy linguistic variable inputs.

The fuzzy logic is chosen based upon the following two reasons: a) In between the normal and abnormal events, clear boundaries are not present, b) Fuzzy rules should level the normality and abnormality separation. The fuzzy set can be represented using the mathematical formation known as membership function.

Rule definition: Conditional statements are used to implement a membership function which characterizes a fuzzy set A in x. When the fuzzy statement in an antecedent is true to some degree of membership, the consequent of the same degree also proves to be true.

Rule structure: If antecedent then consequent

The rule: When both the variables have different values high and low, then we can get a generous output otherwise a malicious output is detected.

For a fuzzy classification system, the case or an object can be classified by applying the set of fuzzy rules which depend upon the linguistic values of its attributes. The rule is functioned at the number given by the antecedent which has a value between 0 and 1. The input can be fuzzified by evaluating the antecedent and then essential fuzzy operators can be applied. The consequent obtains this result as the inference.

We will now describe our methodology for fuzzy logic approach to control congestion in the network. In controlling congestion, the three most important variables are the net data arrival rate, Average queue length and the Average node degree. With fuzzy logic, we assign grade values to our three variables. Our fuzzy set therefore consists of three fuzzy variables

Fuzzy set = { N, A, Q }

Fuzzy logic implements human experiences and preferences via membership functions and fuzzy rules. In this work, the fuzzy if-then rules consider the parameters: Average node degree, Average queue length and the net data arrival rate.

The fuzzy logic uses three input variables and one output variable. The three input variables to be fuzzified are Average node degree (N), Average queue length (Q) and the net data arrival rate (A). The inputs are fuzzified, implicated, aggregated and defuzzified to get the output. The linguistic variables associated with the input variables are Low (L), and high (H). The output variables use three linguistic variables A1, A2, and A3 where A1 denotes less congestion, A2 denotes Medium congestion and A3 denotes High congestion.

The first parameter Node degree N can be represented as a fuzzy set as

Node degree N = Fuzzyset [{A1, a}, {A2, b}, {A3, c}]

a is the membership grade for Less congestion in node degree calculation.
b is the membership grade for normal congestion in node degree calculation.
c is the membership grade for High congestion in node degree calculation.

For eg: If a= 0.2, b = 0.4 and c = 0.6, then the possibility of high congestion is more.

The second parameter Data arrival rate A can be represented as a fuzzy set as

Data arrival rate A = Fuzzyset [{A1, d}, {A2, e}, {A3, f}]

d is the membership grade for Less congestion in data arrival rate calculation
e is the membership grade for normal congestion in data arrival rate calculation
f is the membership grade for high congestion in data arrival rate calculation

For eg: If d = 0.4, e = 0.3 and f = 0.1, then the possibility of lesser congestion is more.

The third parameter Average queue length Q can be represented as a fuzzy set as

Average queue length Q = Fuzzyset [{A1, g}, {A2, h}, {A3, i}]

g is the membership grade for Less congestion in Average queue length calculation.
h is the membership grade for normal congestion in Average queue length calculation
i is the membership grade for high congestion in Average queue length calculation.

For eg: If g = 0.3, h = 0.6, i = 0.5, then the possibility of normal congestion is more.

Table 1. Fuzzy Set using Node degree, Queue Length and Arrival rate

S.No	N	A	Q	Congestionlevel
1.	L	L	L	A1
2.	L	L	H	A2
3.	L	H	H	A3
4.	H	L	L	A1
5.	H	H	L	A3
6.	L	H	L	A2
7.	H	L	H	A2
8.	H	H	H	A3

If N is less, A is less, and Q is less, then Congestion level is A1.
If N is less, A is less, and Q is high, then Congestion level is A2.
If N is less, A is high, and Q is high, then Congestion level is A3
If N is high, A is less, and Q is less, then Congestion level is A1
If N is high, A is high, and Q is less, then Congestion level is A3
If N is less, A is high, and Q is less, then Congestion level is A2
If N is high, A is less, and Q is high, then Congestion level is A2
If N is high, A is high, and Q is high, then Congestion level is A3.

3.4.2 Defuzzification

The cosmos of fuzzy control action which were defined in an productive universe of dissertation can be mapped into a cosmos of non-fuzzy control actions using the defuzzification. This defuzzification strategy provides a crisp control action which superlatively expresses the possibility distribution of inferred fuzzy control action.

Center of Area (COA): Here, the center of gravity of the output membership function is used for selecting the output crispy value.

$$U_O = \frac{\int w\mu(w)dw}{\int \mu(w)dw}.$$

This defuzzification method is used in our Ant based QoS routing.

Center of Sums (COS): The contribution of the area of each fuzzy sets is considered while the computation of the union of the fuzzy sets are avoided in the Center of Sums method.

$$U_O = \frac{\int w\sum_{j=1}^{l}\mu(w)dw}{\int \sum_{j=1}^{l}\mu(w)dw}$$

Height Method (HM): Height Method (HM): Evaluation of the centroid of each output membership function for each rule is done first and the averages of individual centroids are calculated as the output.

$$U_O = \frac{\sum_{j=1}^{n} w_j \mu(w_j)}{\sum_{j=1}^{n}\mu(w_j)}$$

Middle of Maxima (MOM): The mean value of all local control actions is generated by this MOM strategy. Their membership functions reach the maximum.

$$U_O = \sum_{j=1}^{l} w_j / l$$

Center of Largest Area (COLA): The crisp output value is determined from the convex fuzzy subset with the largest area which is defined as the Center of area of the particular subset.

First of Maxima (FM): The smallest value of the domain which has maximum membership degree is taken from the union of fuzzy sets.

$$U_O = \inf\{ w \in W \mid \mu(w) = hgt(W)\}$$

Height Weighted Second Maxima (HWSM): Evaluation of the second maximum of each output membership function for each rule is done and the average of individual maxima is calculated as the output.

$$U_O = \frac{\sum_{j=1}^{n} w_j \mu(w_j)}{\sum_{j=1}^{n}\mu(w_j)} \qquad [24]$$

3.4.3. Congestion control using Rate Reduction

In case of medium and low level congestion, it implies that the aggregate incoming rate is more than the outgoing rate and there is moderate number of upstream nodes, thereby requiring a rate reduction to prevent incipient congestion. As the node's queue fills up, it needs to inform its neighboring upstream nodes to send lesser number of packets. The chosen rate reduction scheme may be any of the existing mechanisms such as the Fusion [21] or by using backpressure messages [22].

4. SIMULATION RESULTS

We use NS2 [23] to simulate our proposed protocol. In our simulation, the channel capacity of mobile hosts is set to the same value: 2 Mbps. We use the distributed coordination function (DCF) of IEEE 802.11 for wireless LANs as the MAC layer protocol. It has the functionality to notify the network layer about link breakage.

In our simulation, mobile nodes of sizes 25, 50, 75, 100 and 125 move in a 1000 meter x 1000 meter region for 20 seconds simulation time. We assume each node moves independently with the same average speed. All nodes have the same transmission range of 250 meters. In our simulation, the minimal speed is 5 m/s and maximal speed is 25 m/s. The Speed is varied as 5,10,15,20 and 25sec. The simulated traffic is Constant Bit Rate (CBR).

Our simulation settings and parameters are summarized in table 2

Table2. Simulation Parameters

No. of Flows	2,4,6 and 8
Area Size	1000 X 1000
Mac	802.11
Radio Range	250m
Simulation Time	20 sec
Traffic Source	CBR
Number of Nodes	50
Mobility Model	Random Way Point
Rate	150Kb
Max.Packet in queue	50
Rate	50, 75,100,125 and 150kb.

4. 1. Performance Metrics

We compare our FCC protocol with the PCCP [8] protocol**.** We evaluate mainly the performance according to the following metrics.

Average end-to-end delay: The end-to-end-delay is averaged over all surviving data packets from the sources to the destinations.

Average Packet Delivery Ratio: It is the ratio of number of packets received successfully to the total number of packets sent.

Drop: It is the number of packets dropped during the data transmission.

Throughput: It is the number of packets received by the sink successfully.

A. Based on Flow

In the first experiment, we vary the number of data flows from 2 to 8 and measure the above metrics.

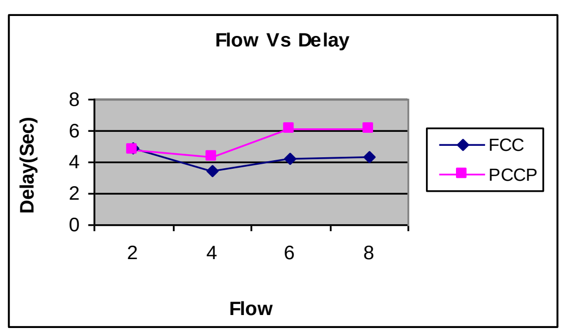

Figure 1: Flow Vs Delay

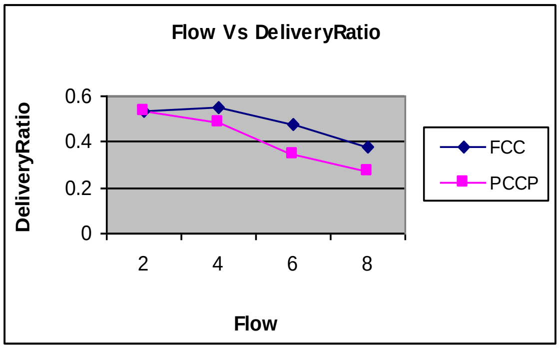

Figure 2: Flow Vs Delivery Ratio

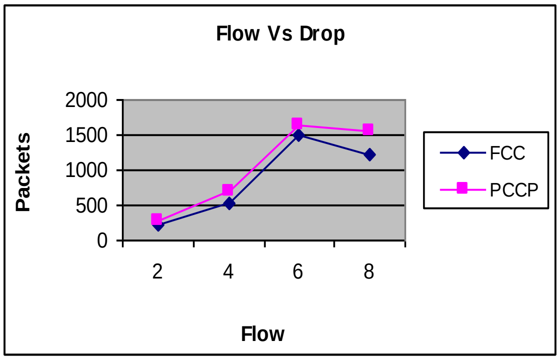

Figure 3: Flow Vs Drop

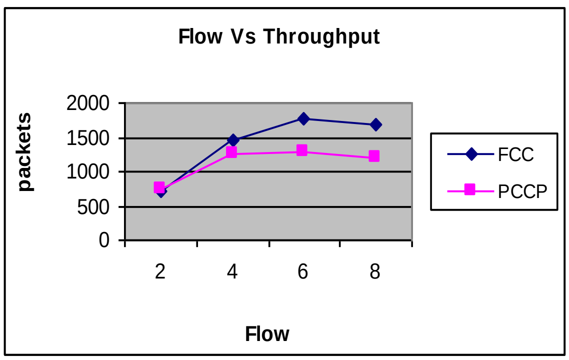

Figure 4: Flow Vs Throughput

From Figure 1, we can see that the average end-to-end delay of the proposed FCC protocol is less when compared to the PCCP protocol.

From Figure 2, we can see that the packet delivery ratio for FCC increases, when compared to PCCP, since it utilizes robust links.

From Figure 3, we can see that the Packet drop for FCC is less, when compared to PCCP .

Figure 4 shows the throughput of the protocols. The values are considerably high in FCC when compared with PCCP.

B. Based on Rate

In the second experiment, we vary the data sending rate as 50 to 150kb and measure the above metrics.

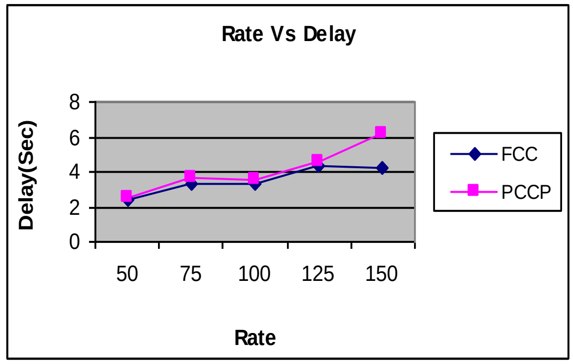

Figure 5: Rate Vs Delay

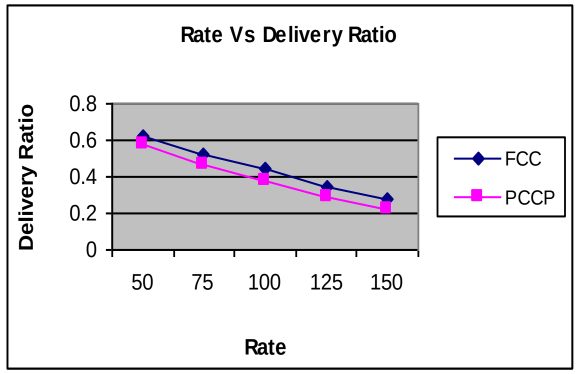

Figure 6: Rate Vs Delivery Ratio

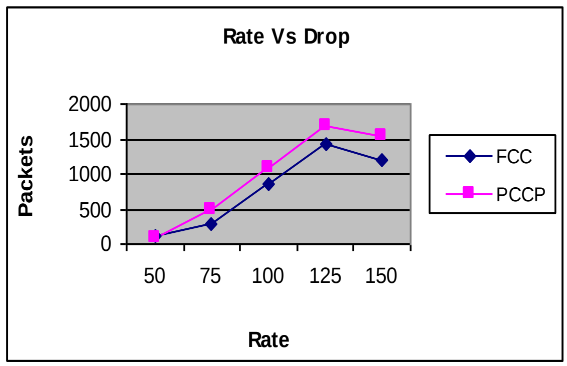

Figure 7: Rate Vs Drop

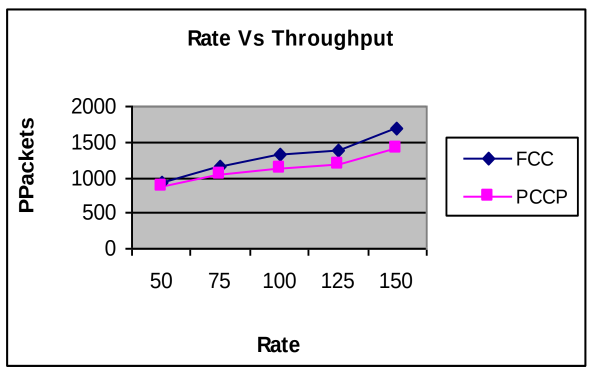

Figure 8: Rate Vs Throughput

From Figure 5, we can see that the average end-to-end delay of the proposed FCC protocol is less when compared to the PCCP protocol.

From Figure 6, we can see that the packet delivery ratio for FCC increases, when compared to PCCP, since it utilizes robust links.

From Figure 7, we can see that the Packet drop for FCC is less, when compared to PCCP.

Figure 8 shows the throughput of the protocols. The values are considerably high in FCC when compared with PCCP.

5. CONCLUSION

In this paper, we have designed an efficient fuzzy based congestion control algorithm which takes into consideration the node degree, queue length and the data arrival rate. We calculate the value of the node degree using a weighted centroid algorithm for hop-count based localization by adding the node degree on the paths to the referenced anchors into the weights. In order to calculate the unknown packet arrival rate of earlier computing nodes, here we use the information about the packet arrival rate of a previous node. The average queue length is calculated based upon the priority levels. The fuzzy table is maintained which takes the value of data arrival rate, node degree and the queue length as input. Then the output is given in the form of fuzzy variables which indicates the level of congestion. Taking two values: Low and High in the input, the output is decided as A1, A2, and A3 which indicates the level of congestion. Then defuzzification is done to get a crisp value of the output. The output gives us a strict passive measure of the congestion level and will result in a perfect measurement for congestion estimation. Thus our algorithm proves to be more effective in controlling the congestion as we consider these parameters. By simulation results, we have shown that our proposed technique attains better packet delivery ratio with reduced packet drops and delay.

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