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Flexible congestion control using fuzzy logic for Wireless Sensor Networks

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***Abstract*—** In WSNs, congestion seems to be an unpredictable stage caused by the packets collision and the overloaded network. The main reason of overloading is the neighboring nodes. In large networks, mainly neighbor nodes behave smartly to grasp the large amount of bandwidth in advance for packet transmission. The affect of low bandwidth causes the problem of packet delay and dropping rate. Both network and transport layer share the responsibility to control the congestion. To achieve these objectives, Flexible congestion control scheme (FCCFA) is proposed. FCCFA uses the closed loop congestion control technique to control the traffic rate accordingly by using three parameters. The Type-2 Fuzzy Logic System is used to estimates the adjustment rate to handle the uncertainty of data. Implicit notification system is used to notify the immediate nodes without wasting any energy. The simulated results give the proof of our promises and improvements.

***Keywords*—** Congestion Control Technique, Delay Ratio, Dropping Rate , Flexible, Fuzzy Logic System, Neighbors, Type-2 Fuzzy logic.

I. INTRODUCTION

All over the world most of the devices are connected to the internet of things. In future, the demand is going to be higher and higher. WSNs will play a fundamental, but essential role in the growth of IoT [1]. WSN is the network of randomly distributed devices where they all are communicating with each other [2]. WSNs have already been used in the various fields from medical to the education department. Vast usage of network resources can easily cause congestion resulting in low throughput [3]. Network congestion is defined as the queuing delay when a significant amount of data transfers beyond its limit. Overall, it affects the performance of the network. In [4], the author already has shown that when various nodes acquire high buffer space at once, then further nodes are unable to use the service and drop out. The retransmission produces a result of increasing the traffic. *This* situation will either create a problem of waiting or permanent failure. According to [5], as the number of nodes transfers their packets by using the same router, it may cause congestion at that router. This problem arises when the data generation rate is higher as compared to data transmission rate, which produces out of sequence order of packets.

In [6], the author has divided the techniques in two ways to control the congestion.In some methods, congestion can be control before its occurrence, and in some methods, congestion can be controlled after its existence. The technique is said to be the best if it minimizes the packet delay and reduces the packet dropping rate also. By considering these facts, a flexible congestion control technique (FCCFL) is proposed using fuzzy logic. Most of the research focuses on the transmission rate of the packet, but no one cares about the neighbors who connect to that node. In this paper, the primary focus is on the neighbor nodes which transfer their data through intermediate nodes in the network. Thus, the proposed algorithm is the extension of the congestion control technique[7]. The main reason behind the propose of this algorithm is to improve the dropping rate and end to end delay. In networking, some times sensors can generate uncertain data, like discrete, random, interval data as the input. Fuzzy logic helps to work on this approximation sensed data efficiently, rather than on any exact unit value.

The remaining paper is divided into various sections. Section II will discuss the various problems of congestion control. Part III explains the system model of our proposed extension method. Section IV illustrates our proposed method using the fuzzy logic system which takes three parameters. Section V discusses the results and compares the overall performance of FCCFL with the existing algorithm[9] in term of packet drop and the end to end delay. Finally, section VI conclude the work.

II. RELATED RESEARCH WORK

The problem of network congestion arises due to the overloaded nodes. The negative impacts are on many factors like delay time, privacy, overloading, bandwidth usage, energy factor [8]. Many researchers have worked in the direction of improving the performance. Some of the problems are discussed below:

ESRT (Event to Sink Reliable Transport) [9] uses merely buffer occupancy to detect congestion , FLCE(Fuzzy Logic Based Congestion Estimation for QoS) [10] uses buffer Occupancy and Buffer Size as parameters for FIS to identify congestion. But both techniques only estimate the level of congestion; however, it does not suggest any control technique. After the increase in deployment of WSNs most of the researchers focused on controlling procedure. CCSFL [11] used buffer occupancy and congestion index to detect the congestion and control traffic rate accordingly. TFCC [12], a trust-based congestion control scheme is proposed to take actions against the malicious nodes. In this paper, packet nodes are filtered using the trust value. The system continuously checks the trust value which is generated by an embedded rule base generator. If the trusted value marks below the predefined threshold value, then the node is defected. It minimizes the effect of throughput on the network and controls the traffic automatically. IFCCDC [13], a Fuzzy Control Base Congestion Control Detection and control congestion uses congestion degree to detect congestion and generate the implicit notification message. The ratio of packet inter-arrival time and packet service time is known as congestion degree. Author[14] presented an algorithm which solved the real problem of traffic lights. In this system, real-time data are aggregated from daily traffic rate. By considering the traffic data, observations are made in terms of waiting time and quantity of traffic. As a result, a priority factor is decided to use the traffic lights smartly. In [15], a dynamic congestion control algorithm is proposed to set the path dynamically. A self-adaptive network is used to choose the optimal path which decided by the power consumption and current traffic rate of each link node. The motivating part is that it works on both buffer less or buffered system. FCCFA is the extension of CCSF [7] congestion control scheme. CCSF is mainly proposed to improve the packet dropping rate. It used only the buffer capacity and the congestion rate of each node to adjust the traffic rate accordingly. But the WSN can work in dynamic nature. So we should take care of the number of neighbors, which take part during transmission.

III. SYSTEM MODEL

WSNs are the network of multiple nodes, which are distributed in random order. Each node has its limited memory to store the temporary data to test our system. We use a small duplicate model which works as a WSNs network. Like WSNs, this system also includes one sink node and the multiple numbers of the source nodes. Every node aims to transfer the sensed data to the sink node.

Let us consider, S_n is the sink node and others are the source node:

N=[N_1, N_2, N_3,………, N_i]

Where N is the set of i source nodes. Our primary goal is to transfer the packet, efficiently without increasing the packet dropping rate. Before doing the implementation, some conditions have to be discussed.

- The whole network is organized randomly and all nodes are at the same priority level, including power consumption, energy, storage space, etc.
- There is one parent node, and rests all are their participants. Each participant can transmit their packets through their immediate parent node.
- Each parent node has a power to control the data rate.

Our whole proposed network used two types of data: first is source generated data and second is neighbors created data. In WSNs, nodes can be dynamic. Multiple nodes transfer their data dynamically by choosing any nearest router according to their distance. Thus, we have to focus on the neighbors' node to know the quantity and the distance between each node.

The number of neighbors of any node F is described as:

F=[f_1, f_2, f_3……f_i]

Where F is the set of neighbors of each source node, which chooses their immediate node to transfer their data to the sink node. By using this consideration, the proposed network improves the performance even in the busty network. At one time, both source and their neighbors' node will use same buffer queue to transfer their data. If 80% of the buffer queue space is full, then it indicates that the congestion can occurs and congestion can be avoided before the congestion to control the data rate.

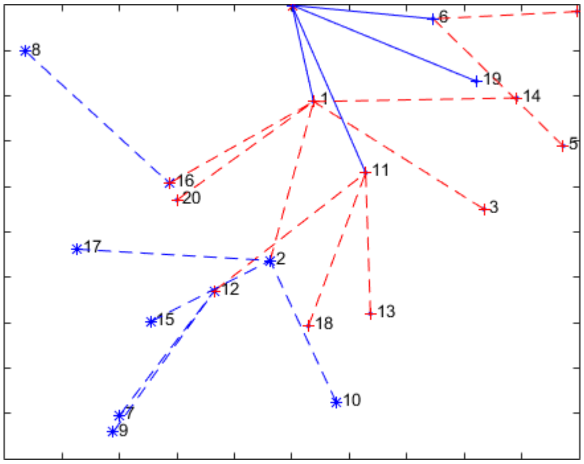


Figure 1. Many to one connected network

Figure 1, represents our complete network model having 20 nodes. There is only one sink node which already shows in red asterisk node, and the other remaining nodes are serving in the blue asterisk node. They all are connected to each other according to their distance value and the hop count values. These values are further used to know the number of immediate devices through which data must pass between source to sink. Initially, each source node has a hop count of 0 values. The immediate neighbors of the sink node are combined with a blue plain line. Red and blue dotted line represent the hop count value of 2 and three respectively. In WSNs, each node has their limited energy. During the transmission, neighbor nodes will utilize their energy ratio at the unitary time. If they have sufficient power, then they will transfer their data; otherwise, the packet will be dropped.

IV. CONGESTION DETECTION AND CONTROLLING APPROACH

Figure 2 shows the complete architecture of our congestion control scheme. It contains three subsystems. Namely, congestion detection unit, congestion evaluation unit, congestion control unit.

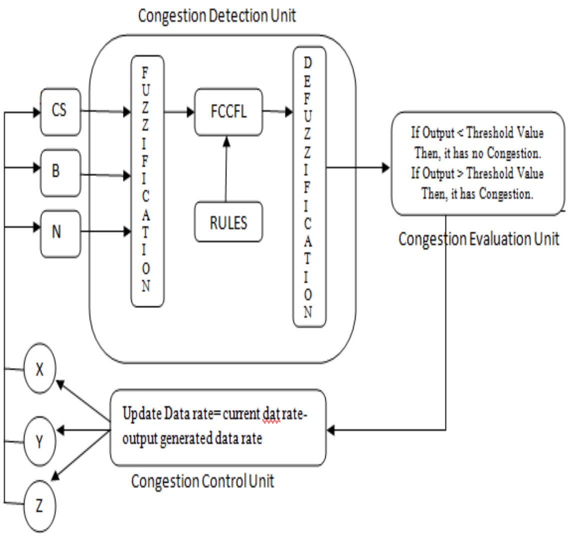


Figure 2: The Structure of proposed protocol

A. Congestion detection unit:

Congestion detection is the first and most crucial subsystem, which are used to design an efficient and accurate protocol. A type-2 fuzzy logic system(FLS) is used to handle the uncertainty about the value of membership function. Type-2 FLS is the fuzzy system through which interval values can be accessed. Type-2 FLS also consider the input parameter of type-1 so that more uncertain data can be handled[16]. In WSNs, the sensed data from the multiple sensors are in the form of approximation ratio, not in an exact manner. To overcome the problem of fluctuated sensed data, the fuzzy logic system(FLS) was used.

The proposed type-2 FLS generate the accurate result by three input parameters, buffer occupancy, congestion score, neighbor nodes. By considering these factors, our FLS can estimate that the congestion will occur or not. The input parameters which used in our protocol are defined as:

1. Congestion score*:*

Congestion score is defined as the ratio of the data generated rate and the data transmitted rate at that particular time [7]. CS calculated for all following nodes, which is defined as:

$$\boldsymbol{CS = \left(1 - \frac{R_i^G}{R_i^T}\right) \times T_i}$$

Where, R_i^G is the total generated data packets of node i, and R_i^T is the total transmitted data packets of node i during the time interval T. R_i^G Is the data queue of two different nodes, which is described as:

$$R_i^G = r_i^p + r_i^f$$

Where r_i^p represents the total input packet rate of the source node, and r_i^f represents the packet rate, which is transmitted by its neighbor nodes. Through this, we can measure the number of active nodes within a particular channel and provides a score if CS lies between 0 to 1 it indicates the congestion free state, otherwise it indicates the congestion occurrence state.

$$\text{CS}=\begin{cases} \text{congestion free state if } \mathrm{R_i^G} < \mathrm{R_i^T} \\ \text{congestion rises state if } \mathrm{R_i^T} < \mathrm{R_i^G} \end{cases}$$

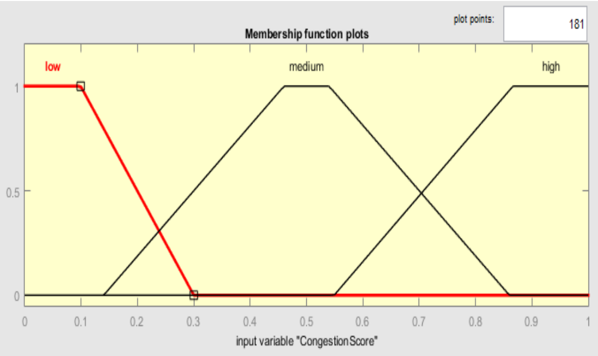


Figure 3: Congestion score membership function

In figure 3, the Trapezoidal function is used to show the linguistic variable in the form of low, medium, high according to their predefined interval range .

2. Buffer Occupancy

The other important parameter is buffer capacity, which is defined as the ratio of the total available buffer size and the total number of buffer queue[7]. It can be calculated with the following formula:

$$B=\frac{b^s-o^s}{b^s}$$

Where b^s is the size of buffer and o^s is the size of working place in the buffer. When o^s is 0, it indicates the empty buffer , and it demands to add further new packets, and when o^s is equal to b^s, it means the buffer is full, and the chances of congestion are increased. As it is clear that large value of B is the indication of high congestion state. The membership function of B is described as

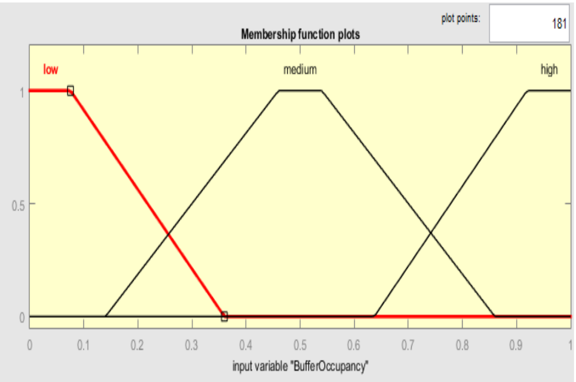


Figure 4: Buffer occupancy membership function

3. Active Neighbors

Each source node may contain either one or more neighbors which use their data queue to transmit the packets. Initially, the value of each source node is assigned as zero and then gradually increases when any neighbor requests to use the buffer space. This condition helps to know the waiting and service time accordingly. If the number of neighbors is increasing at any source node, then it has the high probability of congestion, which leads to packet dropping rate. The rate of active neighbors calculated at each source node is described as

$$F = length\ of\ \boldsymbol{F_I} \div max\ neighbors$$

Where $\boldsymbol{F_I}$ is total visited neighbors at node i which is calculated by each source node, and sink node calculates max followers. The membership function of neighbors rate is represented as:

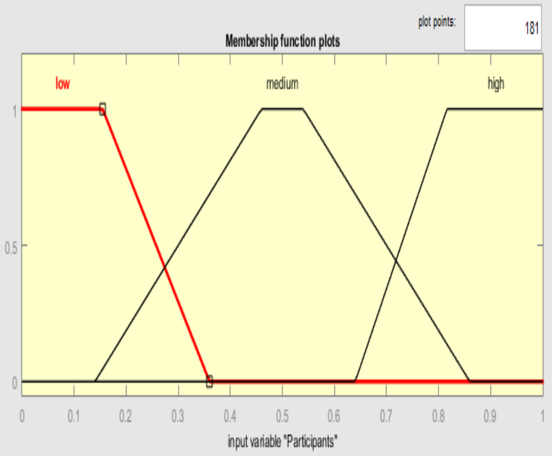


Figure 5: neighbors membership function

From these three membership functions of CS, B and N, an output factor is generated over the fuzzy rule generator, i.e. Rate adjustment factor. The membership function in Fuzzy logic system shown in figure 6. It consists of five linguistic variables to estimate the congestion score. The linguistic variable of output factor RAF having the values of DVL, DL, DM, DH, DVH whose abbreviations are decrease very low, decrease low, decrease medium, decrease high, decrease very high respectively. When the congestion rate is going high, then all transmitted nodes will be informed to reduce their data transmission rate. Indeed, fuzzy logic controller helps in reducing congestion by decrease data rate.

After deciding the factors affecting FLS, number of steps which are designed to carry out the congestion control is to be discussed. Fig 6 describes the complete fuzzy logic system designed to estimate data rate from fuzzification to defuzzification.

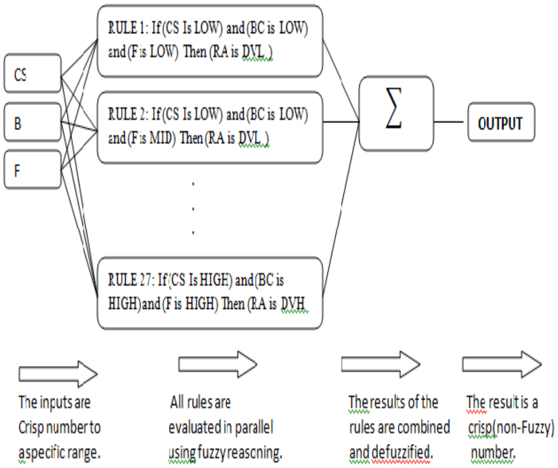


Figure 6: structure of FCCFL system

Step 1: Fuzzification

The first step in FLS is the fuzzification phase where, three input parameters are CS, B, F ,where CS is congestion score, B is the buffer occupancy, F is the rate of visited neighbors rate. The sensed inputs are always in the form of crisp. These input parameters fed into the fuzzy controller. To get the crisp value of the degree of membership by pre-defined trapezoidal function. The output generated by a linguistic variable.

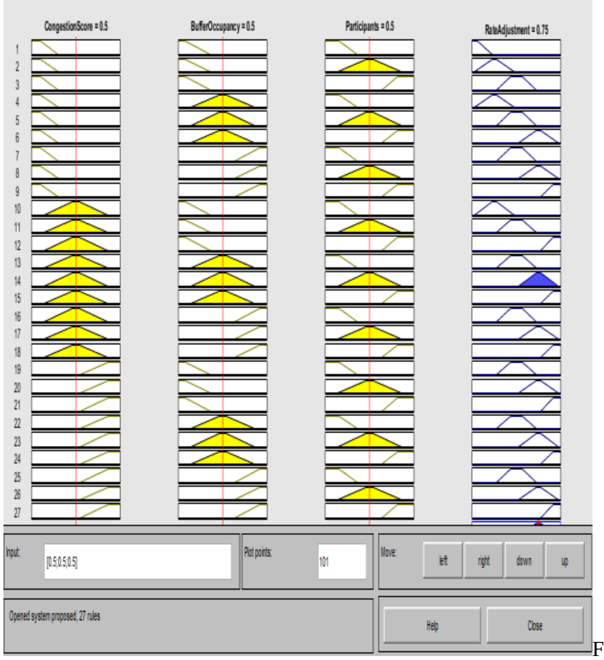
CS'= Fuzzy set of congestion scores = {LOW, MID, HIGH}

B'=Fuzzy set of active buffer capacity= {LOW, MID, HIGH}

F'=Fuzzy set of rate of visits neighbors= {LOW, MID, HIG

Step 2: Implication

The step is the application of implication method. In this process, weights to multiple rules are applied. These rules are predefined conditions which are generated during the process[16]. These rules applied in the antecedent and consequent phases. In the antecedent phase, membership function is defined for fuzzy set, and then the output is transferred to the consequent phase. In consequent phase, the output is generated and then reshaped using the appropriate function. Implication method is implemented itself for further rules.



Input: [0.5;0.5;0.5]

Plot points: 101

Opened system proposed, 27 rules

Figure 7: Rate Editor

In our system, the rule-based system generates 3^3=(27) different rules because of three fuzzy sets with their three linguistic variables. These multiple rules of our system which are described below in table 1: Table 1: Set of Fuzzy Logic Rule

S.NO	RULES
1	If (CS Is LOW) and (BC is LOW) and (F is LOW) Then (RA is DVL)
2	If (CS Is LOW) and (BC is LOW) and (F is MID) Then (RA is DVL)
3	If (CS Is LOW) and (BC is LOW) and (F is HIGH) Then (RA is DVL)
4	If (CS Is LOW) and (BC is MID) and (F is LOW) Then (RA is DVL)
5	If (CS Is LOW) and (BC is MID) and (F is MID) Then (RA is DVL)
6	If (CS Is LOW) and (BC is MID) and (F is HIGH) Then (RA is DVL)
7	If (CS Is LOW) and (BC is HIGH) and (F is LOW) Then (RA is DVL)
8	If (CS Is LOW) and (BC is HIGH) and (F is MID) Then (RA is DVL)
9	If (CS Is LOW) and (BC is HIGH) and (F is HIGH) Then (RA is DVL)
10	If (CS Is MID) and (BC is low) and (F is LOW) Then (RA is DVL)
11	If (CS Is MID) and (BC is LOW) and (F is MID) Then (RA is DVL)
12	If (CS Is MID) and (BC is LOW) and (F is HIGH) Then (RA is DVL)
13	If (CS Is MID) and (BC is MID) and (F is LOW) Then (RA is DVL)
14	If (CS Is MID) and (BC is MID) and (F is MID) Then (RA is DVL)
15	If (CS Is MID) and (BC is MID) and (F is HIGH) Then (RA is DVL)
16	If (CS Is MID) and (BC is HIGH) and (F is LOW) Then (RA is DVL)
17	If (CS Is MID) and (BC is HIGH) and (F is MID) Then (RA is DVL)
18	If (CS Is MID) and (BC is HIGH) and (F is HIGH) Then (RA is DVL)
19	If (CS Is HIGH) and (BC is LOW) and (F is LOW) Then (RA is DVL)

20 If (CS Is HIGH) and (BC is LOW) and (F is MID) Then (RA is DVL)

21 If (CS Is HIGH) and (BC is LOW) and (F is HIGH) Then (RA is DVL)

22 If (CS Is HIGH) and (BC is MID) and (F is LOW) Then (RA is DVL)

23 If (CS Is HIGH) and (BC is MID) and (F is MID) Then (RA is DVL)

24 If (CS Is HIGH) and (BC is MID) and (F is HIGH) Then (RA is DVL)

25 If (CS Is HIGH) and (BC is HIGH) and (F is LOW) Then (RA is DVL)

26 If (CS Is HIGH) and (BC is HIGH) and (F is MID) Then (RA is DVL)

27 If (CS Is HIGH) and (BC is HIGH) and (F is HIGH) Then (RA is DVL)

Step 3: Aggregation

Aggregation is the process in which, a mathematical formula is used to combine the various information and generates a single valuable factor like RA. In Fuzzy, linguistic variables are used to decide any decision. Aggregation operator offers various methods to handle the fuzzy intervals (range of expected values). In fuzzy logic, aggregation operator offers an effective way to combine the multiple preferences into a single highly prefered value.

Step 4: Defuzzification

This is the final process in which, the output fuzzy set mapped into a single crisp value[17]. There are multiple defuzzification methods are used, but for this application the most efficient is the centroid method. We used a Mamdani inbuilt defuzzification function in MATLAB. It generates the output that based on a range of DVL, DL, DM, DH, DVH which are described by the trapezoidal function.

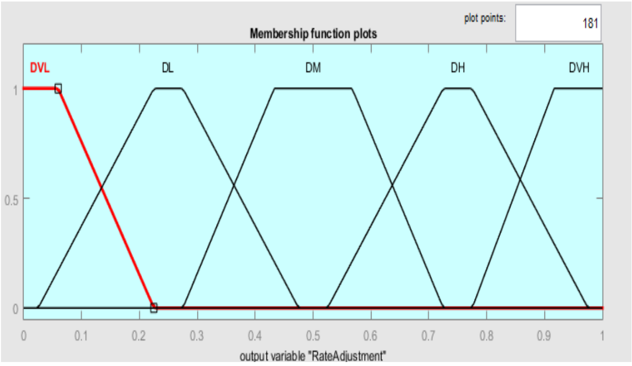


Figure 8: rate adjustment membership function

B. Congestion evaluates unit

Congestion evaluation unit helps to know the congestion occurrence state over output value. The output generated value further compared with the threshold value. If the output value is higher than the threshold value, then congestion will be arises. If the output is less than the threshold value, then there is no congestion.

C. Congestion controlling unit

The congestion control unit is helping to send the necessary information to other sources. Once the congestion detect, sink node sends the implicit notifications to other neighbors' nodes to update their data rate. When neighbors receive a newly updated data rate, then it updates their data accordingly.

V. Results & Simulative Performance Evolution

In this section, the evaluated performance of our proposed method compared with the existing congestion control technique [9] over the end to end delay and the packet delivery rate. In MATLAB, simulated result are performed on the Mandani's fuzzy logic controller. We designed a many to one transmission model on 100 m sq area. It uses 25 nodes. The simulations run for the 100 seconds. The buffer size of each node is ten packets which transmitted simultaneously, and the threshold value is set at 10. Now we represent the performance result of our proposed model. Evaluated performance results are shown below:

A. Packet delivery rate

Figure 9 shows the comparison of packet delivery rate between FCCFA protocol and the priority- based congestion control protocol. The packet delivery rate is defined as:

$$\text{Packet delivery rate}=\frac{\textbf{no of recieving packets}}{\textbf{no of transmitted packets}}$$

As it is clearly shown that, the packet delivery rate of FCCFA becomes nearly equal to the double of the base scheme. It is obvious that, the packet delivery rate is inveresly proportional to the packet dropping rate. The increase in packet delivery rate causes the reduction in traffic rate which becomes the reason of the decrement in packet retransmission.

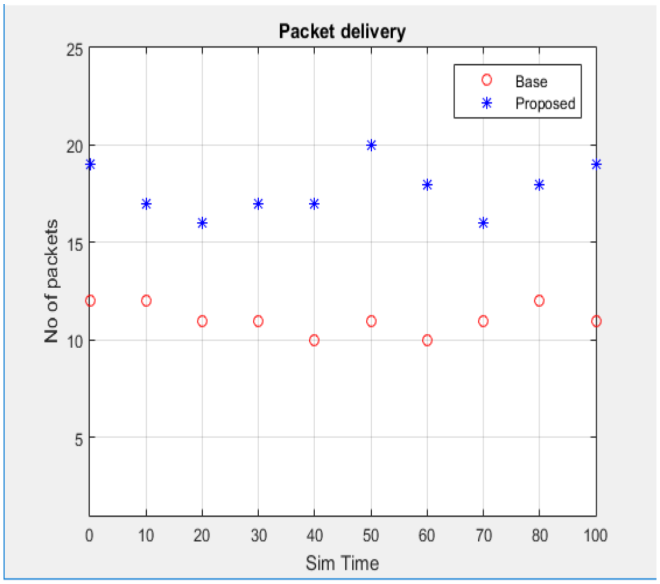


Figure 9: the comparison in term of packet delivery ratio

B. End to End delay

Figure 10 shows thae comparison of end to end delay over time which uses 25 packets per seconds. The end to end delay rate is defined as the total time taken to transmit the data from source node to destination node. As the diagram shows the output of two end to end delay. Where the FCCFL shows more transactions using less time but the other base protocol takes more time consumed while transfering the data packets. These results shows that proposed FCCFA is the superior of the existing priority-based congestion control protocol.

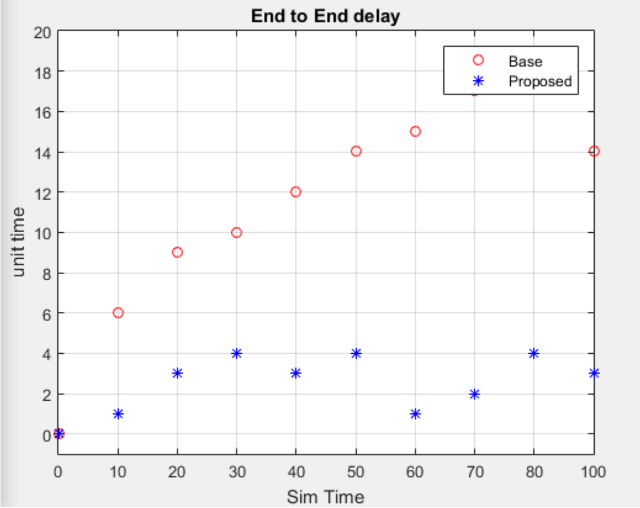


Figure 10: the comparison in term of the end to end delay

VI. Conclusion

In this paper, we designed a new protocol of Flexible congestion control using fuzzy logic(FCCFL) for WSNs which improve the performance of packet dropping rate and delay ratio by considering the three parameters congestion score, buffer occupancy, and participants. When congestion score increases, then it notifies the updated data rate to each neighbor to control the rate to be transmitted data. The rate adjustment ratio is directly proportional to the product of buffer occupancy and the active neighbors. FCCFL gives better results as compared to existing priority-based algorithm. We uses type-2 fuzzy logic for computing the accurate consequence which further used to handle the uncertain data. FCCFL simulated only on the small network of area 100m*100m. So in further research, we will focus on the broad network area using the real-life scenarios.

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