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AQM Model to Estimate and Mitigate Congestion using Priority RED in WSN

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Abstract: In Wireless Sensor Networks (WSNs), most of the issues related to management of topology, managing energy, estimation of bandwidth, calculating packet loss etc. are addressed. Several researches have addressed queue management issues, congrolling the congestion that is incorporated with Soft Computing (SC) techniques. Very few works have focused on mitigating or avoding the congestion, delay estimation and the required bandwidth for transmitting data packets in the sensor network. This paper presents an Active Queue Management (AQM) model for estimating congestion using priority Random Early Detection (RED) to mitigate the congestion. The proposed method integrates AQM model with fuzzy subsystem which controls the admission of packets into the network and the same is compared with several existing works and is simulated using Matlab Simulator. The results outperforms the existing methods in terms of packet loss probability, energy consumption, queue length, end-to-end delay and delay between intermediate nodes.

Keywords: Wireless Sensor Networks, Congestion Control, Active Queue Management, Random Early Detection, Fuzzy Subsystem, Admission Control

1. Introduction

Data is gathered from the monitoring area by the sensor nodes in the WSN and is forwarded to base station by the forwarding nodes for further processing as shown in 1. The deployed nodes in the network are powered by non replacable battries. Congestion may be seen at the junction nodes while forwarding the collected data because of the high traffic flowing towards the sink. Increase in the offered traffic load than the available capacity at any instance in a network causes the congestion. Increase in packet loss, re-transmission of lost packets and delay in packet arrival leads to increase in comsumption of battery and degrading the channel quality are some of the issues that rise due to the presence of congestion. Detecting congestion and mitigation should be addressed on priority for smooth network functions. Many researchers have proposed various protocls for addressing the congestion issue. Protocols are categorised into traditional and soft computing based congestion control protocols. End-to-end delay of packets is also an important parameter influencing the performance of the network. Delay may be caused due to the buffer occupancy in nodes and poor link quality. Predicting the future link quality of a node and buffer occupancy of a node is a challenging task which is dynamic in nature. Uneven load balancing in traffic load also causes congestion in the network. Traffic load has to be maintained according to the traffic handling capacity of the network.

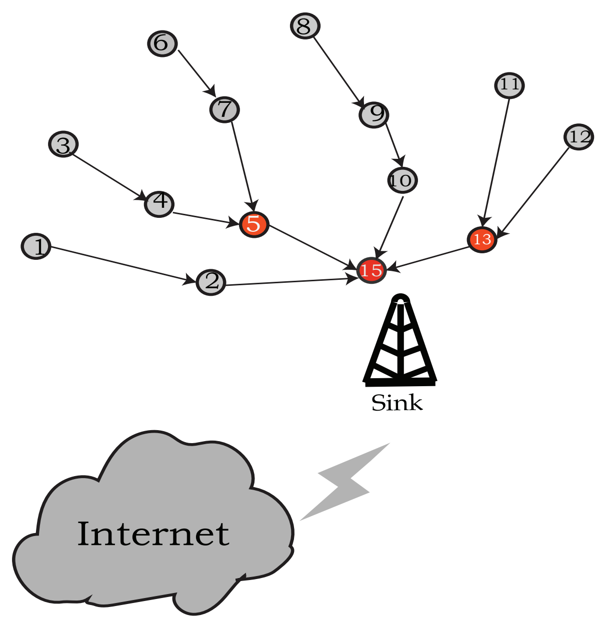


Figure 1. Network Scenario of WSN

A fuzzy based technique to find, estimate and mitigate the congestion is proposed in this work. The contributions made to the current work are as follows:

- Active Queue Management (AQM) is used in detecting and estimating the congestion level using Fuzzy Logic System (FLS).
- Implicit Congestion Notification (ICN) is used to inform the child nodes about the congestion.
- Rate adaptation method is used to mitigate the congestion.

It has been found from the related works that the traditional congestion control methods are proposed by many researches, but soft computing approaches have enhanced the performance of network with respect to resource management, improving lifetime and dealing with congestion.

The organisation of the paper is as follows: In Section 2, investigation is done on existing congestion control protocols in WSNs. Section 3 highlights the basic concepts of proposed protocol such as random early detection and fuzzy controller. The proposed congestion control method is described in Section 4. In section 5, simulation results are discussed and section 6 concludes the work.

2. Related Works

Extensive research work is carried out on congestion control protocols in recent years. This is made for various layers of WSNs. Packet loss and re-transmission of packets are due to congestion in the network which could be at node level or link level which wastes a notable amount of energy which is not abundantly available in sensor nodes. Controlling or avoiding and mitigation congestion improves the end-to-end delay in network along with improvement in lifetime of the network. Numerous protocols that have been proposed for controlling congestion, detecting congestion and congestion notification includes implicit and explicit congestion notification. Congestion control protocols can be classified into traditional congestion control protocols which are based on packet priority and traffic class, rate control and queue management. Different approaches like energy balanced zone based routing protocol method is proposed in [1] and a hierarchical multi-path routing protocol based on energy efficient to clear the congestion and balance the energy consumption is proposed in [2]. A grid based dynamic clustering and data aggregation scheme which attains low energy consumption is proposed for WSN in [3]. Using BFS algorithm, an optimal multipath routing is obtained that extends the life time of network by exploiting data aggregating techniques and balances traffic load. The aim of the work in [4] is to collect data, aggregate it and forward the same to a sink having mobility. Subgrids are created in the network and each subgrid is uniquely identified. Mobile sink is aware of the presence of the number of static sensor in each subgrid. At the time of data collection, the mobile sink for collecting data, move twards a potential subgrid to reduce energy consumed for transmitting data. This helps in utilising all the sensor node's energy equally.It is done by reconstructing the routing tree where new routing paths from sensors to sink are generated. Sink having mobility move towards a subgrid that have sensor nodes with adequate residual energy. This method collects data from all the sensors in the network and prolongs the lifetime of the network. Second classification is based on Soft Computing based which includes Learning Automata, Fuzzy Logic and Game Theory based.

A. Queue Based Schemes

Queue present in the node level are discussed under this section. Additive Increase Multiplicative Decrease (AIMD), a rate adjustment technique is used to maintain the queue length at lower levels. In AIMD, the increase is purely additive and the decrease is multiplicative. Congestion avoidance scheme based on buffer is experimented on CSMA with implicit ACKs and TDMA having fixed scheduling is proposed by Chen and Yang[5]. Along with this, hidden terminal node problem is also solved using $1/K$ buffer solution. The Interference-Aware Fair Rate Control (IFRC) protocols[6] controls the congestion in WSNs. It works with three parameters namely calculating the level of congestion, sharing the congestion information and adaptation of rate with the help of AIMD scheme. In IFRC, exponentially weighted moving average of queue length is taken into account for measuring the congestion. Congestion can be seen in the node level whenever the average length of queue is above permitted threshold. Whenever sensor nodes experiences congestion, it shares its queue length with the neighboring nodes to share the cogestion status. Queue based Congestion Control Protocol with Priority Support (QCCP-PS) [7] is the modified version of Priority-based congestion control protocol (PCCP). Queue management functionality is an enhancement made to PCCP. Length of the queue is used as a parameter to measure the degree of congestion. Depending on the degree of congestion, each source node's transmission rate either decreases or increases. Packet drop is minimised by regulating the buffer of each sensor node according tothe transmission speed of the sender nodes. A node's forwaring speed is assigned by the algorithm for avoding packet drop due to congestion. Bandwidth is equally allocated to source nodes and thus it resolves fairness problem. Transmission rates of the sensor nodes are adjusted to mitigate congestion when congestion is detected is presented in [8]. Queue Management Based Congesgtion Control (QMCC) [9] protocol efficiently decreases the packet loss by managing the queue. Node's queue length and its parent node's queue lengths are used as parameters to detect congestion and also to control the data transmission rate. In [10], an Optimized Congestion management protocol is presented for Healthcare Wireless Sensor Networks where patients are stationery. Protocol is designed in two steps : first, Congestion is avoided using AQM and QoS is included. On a single physical queue, separate virtual queues are used to handle the incoming packets from child nodes depending on the priority of the child node traffic. If incoming packets are allowed, three mechanisms are used in the congestion control phase. Healthcare Aware Optimized Congestion Avoidance (HOCA)[11] is presented for avoiding as well as controlling the congestion in WSNs. HOCA operates in four steps : In first, the sink sends a data dissemination request to all nodes. During this step, type of node, data priority, time and request type are determined. Nodes which are attached to patient body sends the event report to sink in the second step. The sink generates a path using multi-path routing in the third step. In the fourth step, during the time of congestion, data is forwarded using hop-by-hop source traffic rates.

B. Priority and RED Schemes

Different types of packets have different priorities. Packets having higher priority are dealt in a different manner than the packets having lower priority. Study on some of the protocols meant for congestion control based on priority are as follows: The congestion level is calculated with the help of the ratio between packet arrival time and the time taken for service of each packet is proposed in Priority based Congestion Control Protocol (PCCP) [12]. Different priority indicators are considered for using high bandwidth by a node for generating traffic at higher rates. Also considering the congestion level and node's priority index, rate is adjusted. For predicting the congestion and to dynamically distribute the traffic all over the sensor network in a fair way is proposed in Dynamic Predictive Congestion Control (DPCC) protocol [13]. Adjusting the rate dynamically using priority, selecting the node based on forward and backward mechanism and detecting the congestion based on predction method are three different parts of DCCP. A forwarding node is chosen by a node depending on the rate adjustment value fteched from its predecessor nodes. In MAC layer, DPCC detects congestion by integrating the node's unused buffer and traffic rate in the network. An efficient mechanism for controlling the rate for prioritized heterogeneous traffic is ensured in Prioritized Heterogeneous Traffic-oriented Congestion Control Protocol (PHTCCP) [14]. A packet is classified based on the priority when it enters a node and then it is placed in a specific class of traffic. When a node generates a packet, it assigns lower priority to it than a packet that is to be forwarded by neighboring nodes. Adopting implicit congestion notification, congestion is controlled on a hop-by-hop basis. Service rate of packet is used for identifying the congestion level in each sensor node. Source node's transmission rate varies depending on the congestion level of a node. Class Based Optimized Congestion Management Protocol (COCM) [15] have parts like congestion avoidance, control and service differentiation. Non-sensitive, sensitive data and control messages are taken into consideration in service differentiation. Data which is sensitive and high priority takes shortest path and non-sensitive data and control packets take alternate path. Transmission rate is adjusted at source nodes in case of congestion. Congestion control based on priority is addressed in Congestion Control Based on Reliable Transmission (CCRT) [16]. Congestion is detected using the length of the queue and variation rate of in the queue length. Variation in positive queue rate indicates the occurrence of congestion and negative variation rate indicates reduction in congestion. Constant increase in queue size indicates a higher probability of congestion ahead. For identifying the congestion in hierarchical cluster, congestion control clustering protocols based on application specific is proposed in[17]. Mobility of nodes and node heterogeneity is integrated for congestion detection. When congestion is detected, time-critical packets are given priority so that they arrive punctually to sink. High priority is given to those nodes which are positioned far away from cluster head. For controlling the congestion considering node priority and length of the queue, QCCP-PS[18] is proposed and is an improvement over PCCP by controlling the length of the queue. Prioritized heterogeneous traffic is not handled. A mechanism to control the congestion based on packet's priority is presented in Wireless Body Area Network [19], where queue length is considered. Quick start module begins with more number of packets, but the rate of packet forwarding to the base station is less. Detecting the congestion, notifying it and avoding the congestion are the three difference phases of congestion control module. A queuing model for WSN node based on M/M/1, queuing with priority, RED and a queuing model having priority based on RED is constructed using queueing theory in [20]. Theoritical analysis is done, for average dely and average queue length mathematical expresssions are derived.

C. Soft Computing Schemes

Though many traditional techniques are proposed by many researchers for improving the effectiveness of sensor networks, but soft computing techniques stay ahead in improving the effectiveness of sensor networks. Learning Automata (LA), Fuzzy Logic (FL) and Game Theory (GT) have been integrated for different sensor applications.

1) Fuzzy Based Protocols

QoS related issues are solved using fuzzy logic techniques which provides proactive approaches in solving a problem. Fuzzy logic enhances the performance effectiveness of WSNs without a mathematical model. Protocols belonging to this category are described as following: Fuzzy logic controller is used for detecting and managing congestion in Fuzzy Based Adaptive Congestion Control (FBACC) [21]. Fuzzy logic controller is used for predicting congestion and adjusting the traffic rate. Number of nodes participating in data transfer, data rate and the buffer occupancy are taken as inputs for fuzzy logic controller and data transmission rate is the output obtained from the algorithm. After identifying the congestion, a node sends congestion notification to its neighboring nodes so that the transmission rate is adjusted. Congestion detecting and controlling method considering Type 2 fuzzy logic systems (T2-FLS) is proposed by Ghanavati et al. in [22]. Buffer capacity is used to identify the congestion and thereafter transmission rates are adjusted. Important control signals are categorised and prioritized based on their importance.

Congestion Control protocol using active queue management and fussy systems have found space in medical applications and is proposed in [23].PID and fuzzy logic is combined to regulate queue buffer and adjust transmission rate for each node in the network. Integrating RED and Fuzzy PID controller, congestion is detected and notification is implicitly done. Fuzzy controller sets the transmission rate for managing the congestion. An optimized fuzzy logic-based congestion Control method with Exponential Smoothing Prediction in WSNs (OFES) is proposed in [24] having three stage path determination architecture : i) initial route construction in a top-down hierarchical structure, ii) deriving a path with the help of energy aware routing and iii) predicting the congestion via exponential smoothing. The work in [25] addresses the issues like message latency, reliability of data transmission and enhancing the battery life and in turn network lifetime. A fuzzy logic algorithm is proposed for solving the above mentioned issues to optimize energy consumption and decrease the packet drops. Queue length and traffic rate of each node is considered for computation. Solving the problem of performance of network degradation which is caused by the congestion at intermediate nodes is addressed in [26]. This work presents an algorithm working on standard particle swarm-neural PID congestion control (PNPID). Queue management is applied with PID control theory and followed by self-learning and self-organising ability of neurons is applied for online adjustment of weights for adjusting proportion, integral and differential parameters of PID controller. Data sources which are irregular in nature causes congestion in network. To address this, Proportional Integral Derivative (PID) controller is proposed in [27]. PID algorithm is executed by cluster head and realises sensed data. Slow parameter optimization, poor optimization of traditional PID and limited adaptive ability problems are solved using a fuzzy control algorithm termed as Cuckoo Fuzzy-PID Controller (CFPID).

2) Game Theory Based Protocols

For performing activities like coverage optimization, packet forwarding, security, designing routing protocol, QoS, topology control, saving energy, collecting data and allocating bandwidth game theory has been used in WSNs. A stochastic differential game theory protocol [28] is used for congestion control using game theory. Three game models are suggested:co-operative, partially co-operative and non-co-operative models. These models are used to compute net transfer cost, cost of data transfer and penalty cost for data invalidity. Game theory approach reduces transmission cost.

3) Learning Automata Based Protocols

Learning based techniques which uses intelligence, try to avoid the occurrence of congestion. These techniques learn from the past working and by time they improve their performance in congestion control. Following are the learning based protocols proposed in the past:

Learning Automata-based Congestion Avoidance algorithm in sensor networks (LACAS) [29] uses the sink and the forwarding nodes to control the flow rate of data depending on the packet drop count. Forwarding nodes or intermediate nodes sends feedback to source node and source node adjust their transmission rate depending on the outcome of automata available in them and automata continuously performs this work. In MLACAS [30], mobile nodes are used for LACAS approach instead of static nodes. PBCCP for healthcare monitoring application in WSN is proposed in [31]. It prioritizes patient's important signs in health surveillance system and also controls congestion. Based on the priority index and congestion level, bandwidth assignment is done. Packets having more importance are assigned higher priority.

3. Preliminaries of the Proposed AQM Model

A. Active Queue Management

AQM proactively drops all the incoming packets before the buffer of a node is full. Different Quality-of-Service (QoS) is provided for different traffic class and different node priority. AQM technique is having better performance of two thresholds over single threshold. Threshold values can be adjusted for less delay for same throughput.

B. Queue based on Priority and Random Early Detection

1) Priority Queue in WSN

Different user packets in WSNs have different requirements for QoS and also have different servicing method for incoming packets with different priority. Packets can be categorised into different groups and in this work, for the sake of simplicity, packets are categorised into two types having different priority. Packets with different priority are assumed to continuously arrive at a node in the network as shown in Figure 2. The rate of arrival of packets are denoted as λ_1 and λ_2 for high priority and low priority packets. Packet having higher priority may interrupt a service which is given to a packet having lower priority. When packets having same priority will get service based on first come first serve (FCFS) rule. μ denotes the rate of service for the packet forwarding module. Packets exit from the node after completing the service. Let P_1 and P_2 be the high priority and low priority packets respectively. The average arrival rate of packets at a node is denoted by λ and service utilization of packet forwarding module be denoted by $\rho = \lambda/\mu$. Service utilization of P_1 is $\rho_1 = \lambda_1/\mu$ and of P_2 is $\rho_2 = \lambda_2/\mu$, then $\rho = \rho_1 + \rho_2$. Let m number of P_1 and n number of P_2 packets are arriving at a node in the sensor network and can be denoted as $N(t) = \{m, n\}$. If number of packets varies and is viewed as different states, this changes in state is a Markov chain. When m and n number of nodes are available in P_1 and P_2, the state probability can be denoted by $p(m, n : t) = P\{N(t) = (m, n)\}$.

2) Random Early Detection (RED)

It is one of the frequently adopted technique in AQM. Probability of the congestion is identified using RED and when congestion detected, the packet which is arriving

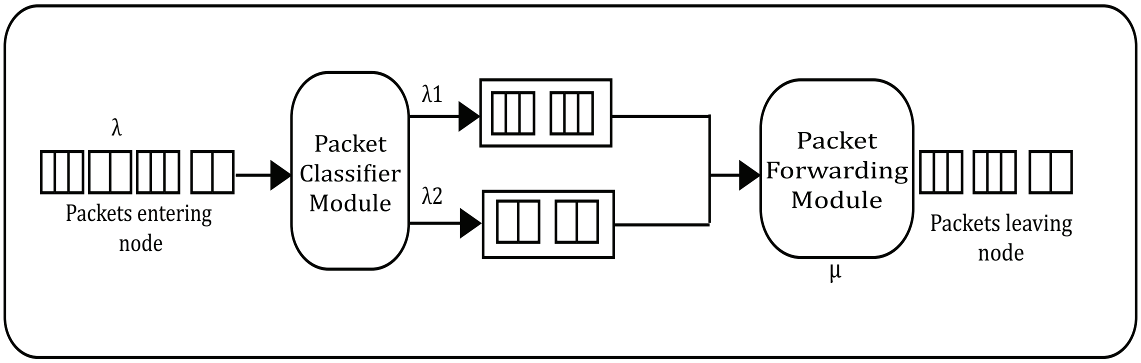


Figure 2. Queuing Model at a Node in WSN

is marked or dropped. Working of RED is shown in 3. Whether an incomeing packet is to be marked or dropped is decided on the average weighted queue length ($Q_{len_{avg}}$). As soon as a packet enters a node, the status of the weighted average queue is checked wheather it is lesser value than $MinTh$, i.e, the minimum threshold, if so, incoming packet is allowd to stay in the queue. If ($Q_{len_{avg}}$) value is more than $MaxTh$, i.e, the maximum threshold, the incoming packet is dropped or will be marked. When the average queue length value is found between $MinTh$ and $MaxTh$, incoming packets will be marked as P_a, the packet drop probability. The devault value for the maximum packet drop probability is Max_p. The probability for marking a packet or dropping is as shown in Eq. 1:

$$P(a) = \begin{cases} 0 & Q_{len_{avg}} < MinTh \\ \frac{Q_{len_{avg}} - MinTh}{MaxTh - MinTh} \times Max_p & MinTh \leq Q_{len_{avg}} < MaxTh \\ 1 & MaxTh < Q_{len_{avg}} \end{cases} \quad (1)$$

If max_p is having higher probability, then congestion is at greater level in sensor network and the incoming packet will be dropped by the algorithm. If Max_p is less, the packet is processed upon entering the queue.

C. Fuzzy Inference

1) Fuzzy Controller

To arrive at a proper decision at critical times, an appropriate system is required which works on the basis of rules. Such a system is called Fuzzy Logic System (FLS). It works like a human expertise in making decisions and uses $if - then$ rules to make proper decisions. FLS has four steps namely, fuzzifier, rule based, inference and defuzzifier. Figure 4 shows the diagram of Fuzzy Logic System. Fuzzifier transforms the system inputs, which are crisp values, into fuzzy sets. Rule bases stores $if - then$ type of rules. Inference mechanism simulates the human expertise reasoning process using the fuzzy inference on the inputs and $if - then$ rules. Defuzzifier transforms the fuzzy set fetched using the inference engine into a crisp value.

D. Congestion

Link level and node level are two types of congestion that are seen in WSNs. Sensor nodes shares the wireless channel with the help of CSMA protocol for transmitting the packets. When multiple nodes attempt to acquire channel simultaneously, it leads to link level congestion. Utilization of link is decreased and service time for packets get increased because of link level congestion. When packet service time is slower than the arrival time of packet, it leads to overflow of buffer and it causes node level congestion leading to queuing delay and packet loss. Congestion control have three mechanism: Congestion Detection (CD), Congestion Notification (CN) and Congestion Mitigation (CM).

E. Delay Estimation

Transmission delay, propagation delay, queuing delay, processing delay and delay in re-transmission are some of the delay components present at intermediate nodes. Average end-to-end delay is computed for every source along a path having single hop and multi-hop to sink node. Estimating average end-to-end delay in multi-hop transmission mode is a challenging task. Average end-to-end delay can be kept low by keeping the re-transmissions of packet at lower rates.

4. Network Model

Wireless Sensor Network can be modeled as a graph $G = (V, E)$, where set of nodes is represted by V and set of bidirectional communication links are represented by E. An edge $(u, v) \in E$, if two sensor nodes are operating within the communication range of each other in the network. Deployed nodes in the network are autonomous, computes and communicates with other nodes by exchaning and forwarding the messages.

A. Problem Statement and Objectives

Detecting the congestion in the network and mitigating it is the main objective of this work and is done by adopting fuzzy mechanism. Fuzzy system proposed here takes two variables as inputs and the output generated depnds on

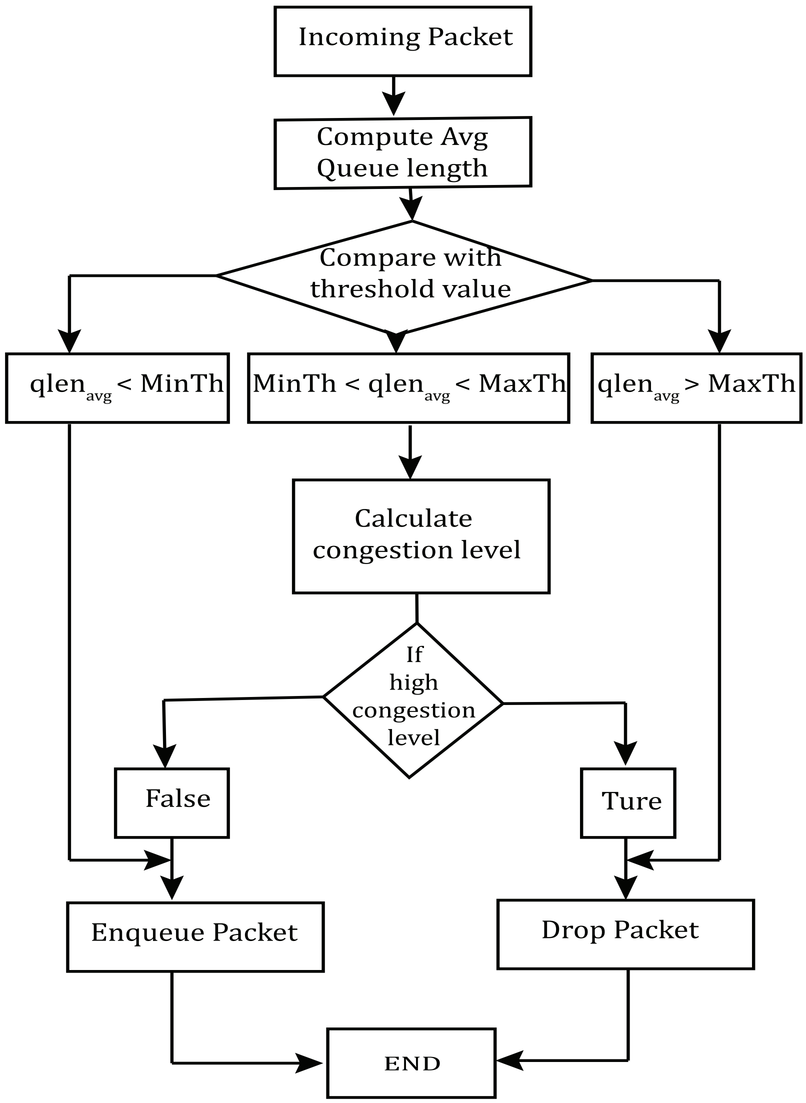


Figure 3. Operation of RED

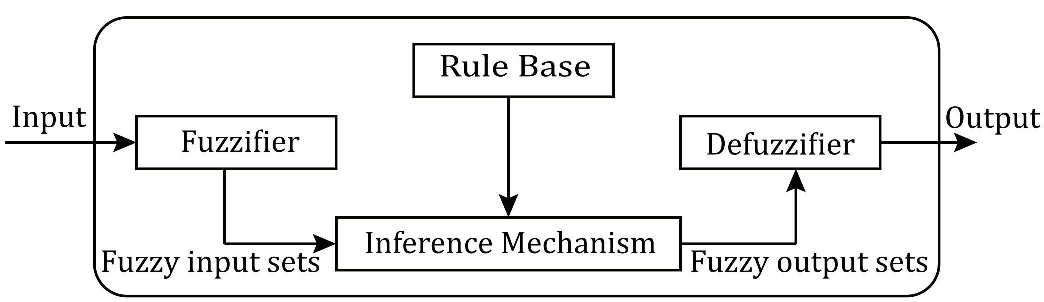


Figure 4. Fuzzy Logic Control Model

the inference mechanism and informs about the level of congestion. Depending on the level of congestion, congestion notification is sent to child nodes. Rate adaptation mechanism is adopted to mitigate congestion.

B. System Architecture

Architecture of the system comprises of three different modules and are as follows: congestion detection module, congestion notification module and congestion mitigation module. Figure 5 shows the architecture of the proposed system model.

1) Congestion Detection Module

Protocols used earlier in congestion control techniques for WSN considered parameters like length of the queue, arrival rate of packet, buffer occupancy of nodes and service rate of packet. Considering any one of the above said parameters is not sufficient to detect congestion in the network. Performance of detecting the congestion can be improved if fuzzy logic based mechanism is applied. Following are some of the parameters that can be used as inputs to the fuzzy logic system: average queue size, the number of competitor nodes that are waiting to transmit their data packets, ratio of the incoming and outgoing packets and average delay faced by the packets. Number of neighboring nodes waiting with packets in buffer to transmit them into MAC layer rather than transmission path is termed as competitor nodes. Count of the competitor nodes is computed using RTS/CTS packets that are origination at neighbor nodes. Increase in probability of collison of packets can be seen when the number of contender nodes are more. Thus the count of contender nodes take major part in identifying congestion. Presence of the hop count value in the packet header is initialised to zero. A node, at each hop, increases the current hop count value by one when a packet arrives. This reveals the total hops travelled by a packet originating from source node. Packet header also contains information about the total delay experienced by a packet. A sensor node prior to transmitting a packet, computes the time interval between the time a packet is received and the time at which a packet is forwarded. Average delay of packets is calculated by dividing sum of delay by current hop count value. The average delay of the packets is divided into four different intervals d_1, d_2 and d_3 where $d_1 < d_2 < d_3$. The weight of the average delay of packets (W_d) is calculated as follows:

$$W_d = \begin{cases} 0 & if\ average\ delay \le d_1 \\ 1 & if\ d_1 < average\ delay \le d_2 \\ 2 & if\ d_2 < average\ delay \le d_3 \\ 3 & if\ d_3 < average\ delay \end{cases} \tag{2}$$

Fuzzy logic system is using number of competitor nodes that are waiting to send data and the average delay of packets as parameters. Therefore fuzzy set have two fuzzy variables as mentioned in 6.

$$F = (C, D) \tag{3}$$

where C denotes the number of competitor nodes waiting to transmit data and average delay of packet is denoted by D.

The number of competitior nodes and average delay is embedded in fuzzy logic system to a single value so that the congestion level can be estimated in the network. Membership functions for two inputs are mentioned using three linguistic variables viz. $Low(L)$, $Medium(M)$ and $High(H)$. Membership functions for output are having four linguistic variables viz. $Zero(Z)$, $Low(L)$, $Medium(M)$ and $High(H)$. As the available resources are not abundant in sensor network, membership function used is triangular in shape and also is easy to compute. Membership functions used for fuzzy variables C and D are given in Figure 7.

Fuzzification and defuzzification phase uses two membership function set, each have separate function for L, M and H linguistic variables. Triangular shaped membership function is used for the ease of computation taking into consideration the limited power available for processing on the sensor devices. In FLS, the first step is fuzzification. In this proposed work, singleton fuzzifier is used by fuzzy system to map each crisp value to a fuzzy value using membership function. Fuzzifier have three different fuzzy classes Viz. L, M and H for each fuzzy variable:

$$F : (\alpha, \beta) \rightarrow (\alpha^f, \beta^f) \tag{4}$$

$$X^f = \left[\mu_X^L, \mu_X^M, \mu_X^H\right] \tag{5}$$

In inference, the second step, combining fuzzy rules from fuzzy rule base is used to generate the output variables. Fuzzy rules consists of $if-then$ condition with a conclusion. It has two fuzzy variables with three differnt fuzzy classes for each variable and rule base have $3^2 = 9$ different rules. Rule Evaluation Method (REM) is used to calculate the output of each rule. The structure of r in the rule base is as follows:

$$r = \text{if} \quad \alpha_r \quad \text{is} \quad f_\alpha^r \quad \text{and} \quad \beta_r \quad \text{is} \quad f_\beta^r \quad \text{then output is} \quad f_c^r$$

where f_α^r and f_β^r is one of the fuzzy classes L, M or H. The weights of the fuzzy classes for α and β are assigned as $L = 1$, $M = 2$ and $H = 3$. The output of a fuzzy rule θ_r is calculated by adding the weight of f_α^r and f_β^r. Rule base of the proposed fuzzy system is shown in Table 1, where θ corresponds to the output calculated using REM.

Proposed fuzzy inference system uses the product inference rule as it supports mathematical simplification in the defuzzification. Therefore,

$$\mu_r = \mu_\alpha^{f_\alpha^r}(\alpha) \times \mu_\beta^{f_\beta^r}(\beta) \times \mu_c^{f_c^r}(\theta_r) \tag{6}$$

Final step is dfuzzification and is the process of converting the output fetched using fuzzy inference system to a crisp value. The defuzzifier output can be computed as shown in

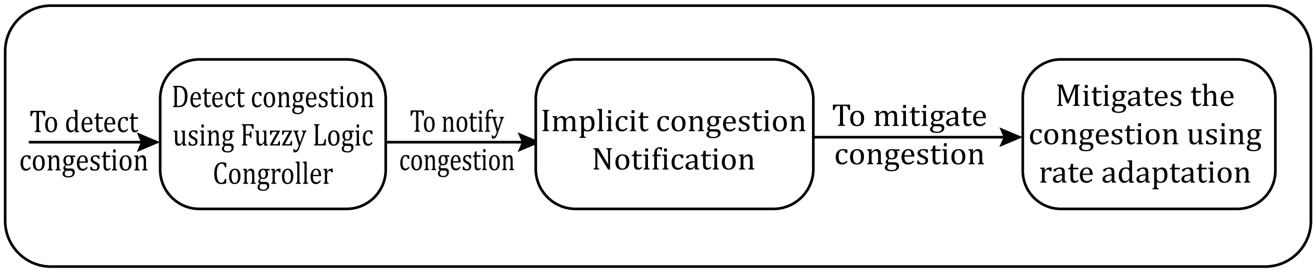


Figure 5. System Architecture of the Proposed Method

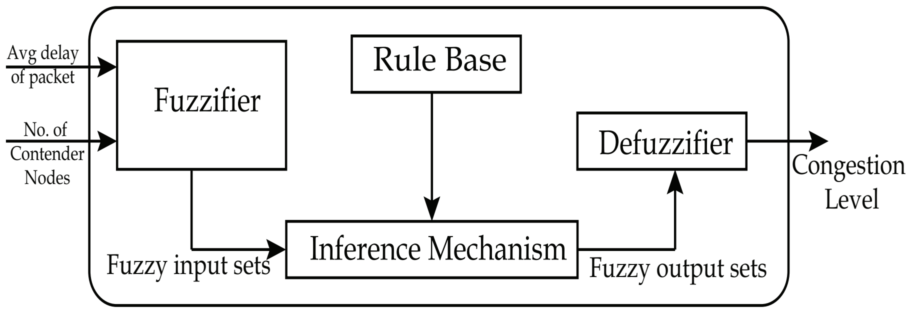


Figure 6. Congestion Detection Module

TABLE I. Fuzzy Rules

α	β	θ
L	L	2
L	M	3
L	H	4
M	L	3
M	M	4
M	H	5
H	L	4
H	M	5
H	H	6

the Eq. 7:

$$w = \frac{\sum_{n=1}^{9} \theta_r \mu_r}{\sum_{n=1}^{9} \mu_r} \quad (7)$$

where μ_r and θ_r is the output of product-inference system and output of the rule respectively. w is the output of the fuzzy logic system which generates a crisp value.

2) Congestion Notification Module

Implict Congestion Notification (ICN) is used to inform about the congestion to the intermediated nodes in the network upon detection of congestion. Congestion information is piggybacked in the packet header to intermediate nodes. It also avoids an extra control message in the network.

3) Congestion Mitigation Module

The crisp value w is categorized into three different classes viz. $NoCongestion(NC)$, $MediumCongestion(MC)$ and $HighCongestion(HC)$. During NC level, as sensor nodes are able to handle the offered traffic load, no action is initiated. If the detected congestion level is at (MC) or (HC), congestion mitigation module starts to work. This is done using rate adaptation method. The generic function for the rate adaption method is as shown below:

$$r = \begin{cases} r_1 & \text{if } CL = NC \\ r_2 & \text{if } CL = MC \\ r_3 & \text{if } CL = HC \end{cases} \quad (8)$$

Where CL is the congestion level and r denotes rate of data packets fo the application. r_1, r_2 and r_3 defines data rates by the application. Depending on the r value at the congestion mitigation module, the rate at which data packets are transmitted are adjusted. **??** shows the algorithm for congestion mitigation module.

5. Experimental Results and Discussions

In this work, proposed protocol is compared with priority-based congestion control protocol (PCCP)[12] and Prioritized Heterogeneous Traffic-oriented Congestion Control Protocol (PHTCCP)[14] protocols. *Matlab* is used to implement Fuzzy systems and simulation. Parameters used for simulation are listed in Table 2. Depending on the applications, some of the packets might get lost in transmission. To calculate the packet loss rate, following equation is used:

$$LossRate = Packetloss/Time \quad (9)$$

Packet loss ratio is shown in Figure 8, which is the number of packets that are lost per unit time. It is normalised between [0.0 to 1.0]. At the initial times, rate adjustment is not initiated and packet loss is high. Later when the transmission rate is adjusted, decrease in the packet loss

Algorithm 1: Congestion Mitigation Algorithm

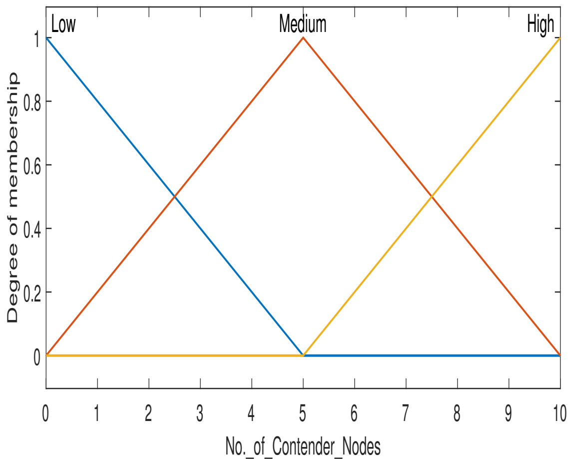
```
Input: Congestion Level (CL)
Output: Drop Packet/ Retain Packet
while true do
    if CL == NC then
        En queue the packet
    end
    else if CL == MC then
        En queue the packet
        Activate rate adaptation method
    end
    else
        De queue the packet
        Activate rate adaptation method
    end
end
```

TABLE II. Simulation Parameters

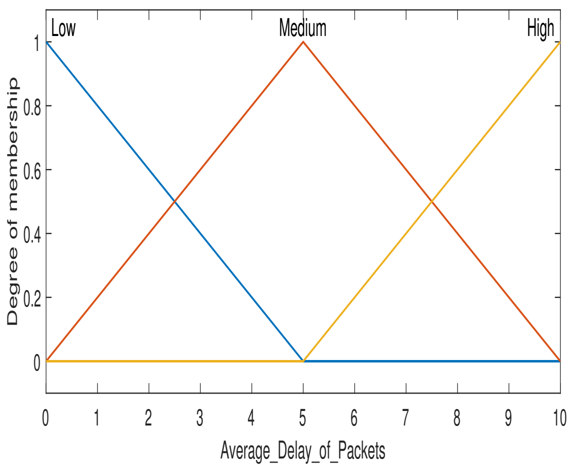
Simulation Parameters	Values
Simulation Area	500 × 500 sq. mts
Number of Sensors	20
Number of Sink	01
Sink Energy	Unlimited
Node initial energy	50J
Sensor node placement	Uniform, grid
Buffer size of sensor node	50 packets
Buffer size of sink node	100 packets
Packet size	512 Bytes
Traffic type	Temperature, Pressure
Application type	Event driven

is recorded. The End-to-End delay is the sum of delays at a source node and relays on a path or can be defined as the time between the generation of data packets and delivered to the destination node. In Figure 9, a lesser End-to-End delay is observed in the protocol when compared with PCCP and PHTCCP protocols. During the initial states of simulation, an increase in delay can be seen in the proposed protocol due to the lack of rate adjustment. As time elapses, a decrease in end-to-end delay can be seen as rate adjustment using fuzzy logic is adopted. Data packets can reach the destination node with less latency. Figure 10 depicts the comparison of energy consumption of proposed approach with PCCP and PHTCCP for a sensor node near to the sink node. It is observed from the result that the average energy consumption of the proposed method used for sending packet traffic is lower when compared with PCCP and PHTCCP and is because of the rate adjustment done through fuzzy logic. Rate adjustment process is performed starting from the node having congestion and heading towards the source node in a hop-by-hop fashion. It continues until congestion is under controll or no notification is sent to the source nodes to adjust their transfer rate. Figure 11 depicts the graph for source node data generating rate. Data transfer rate is more initially, over time the source nodes remain at a constant rate keeping the congestion level low. The total number of packets stored in a queue is termed as queue length. It is an important parameter used in calculating the delay in the network. Increase in queue length can be seen when the inter arrival time of the packets is more than the time spent in servicing the packet. Better congestion control algorithm have shorter queue length and at the time of failure in congestion control algorithm, it results in increased queue length at intermediate nodes in the sensor network and reduced throughput. Throughput defines the amount of data that enters and leaves the node in the sensor network. Throughput can also be used to refer how quick a node in the sensor network forwards data through its components which icludes processor, buffer and transreceiver. Packet forwarding rate to each sensor is allotted by the fuzzy rate adjustment unit so that output rate will always maintained equal to or at higher rate than the input rate of the packets. Figure 12 depicts the average queue length of a node staying close to the sink node. The Average Queue Length Q_{avg} is calculated by exponential weighted moving average as shown in Eq. 10:

$$Q_{avg} = (1 - w) \times Q_{avg} + w \times Q_{Sample} \quad (10)$$



(a) No. of Competitor Nodes



(b) Average Delay of Packets

Figure 7. Membership Functions For Fuzzy Variables (a) C and (b) D

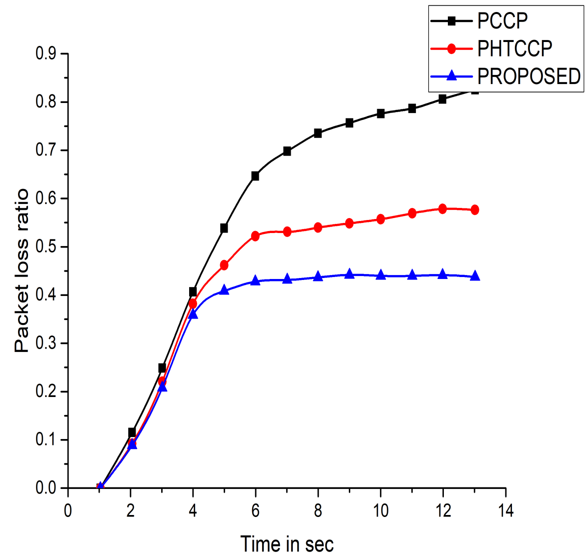


Figure 8. Packet Loss Ratio

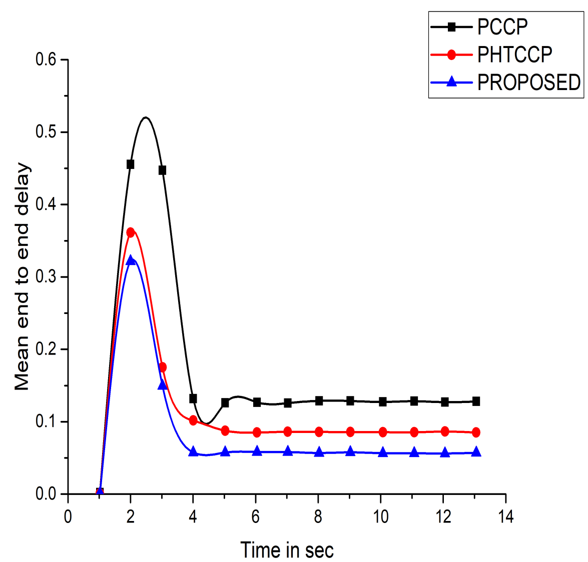


Figure 9. Mean End-to-End Delay

where $0 \leq w \leq 1$. Q_{Sample} denotes actual queue length at the time it is measured. It is measured whenever a packet arrives at the node. The proposed method's result is having a queue length shorter than PCCP and PHTCCP techniques. Proposed method performs well for the applications that are delay intolerant. Frequency of packet drop at a node is revealed by packet loss probability. Figure 13 depicts that at the initial stage, there is an increase in packet loss and is regulated after some time by the proposed method.

Figure 14 shows the graph for average queuing delay in the network. Queueing delay increases with respect to increase in number of packets at nodes and decreases with decrease in number of packets. Average queuing delay is less than PCCP and PHTCCP approaches. The average queuing delay is the sum of the delays faced by a packet between the time of injecting into the network and the time of delivery to the destination node divided by the number of nodes in the path. The average delay experienced by a packet is defined as $\frac{1}{\mu-\lambda}$ and can be used when packet drop from the queue is 0.

6. Conclusion

The mechanism used for controlling the congestion is based on fuzzy logic system is presented. The count of competitor nodes that are having data to transmit to their parent nodes and the packets average delay are the two input variables

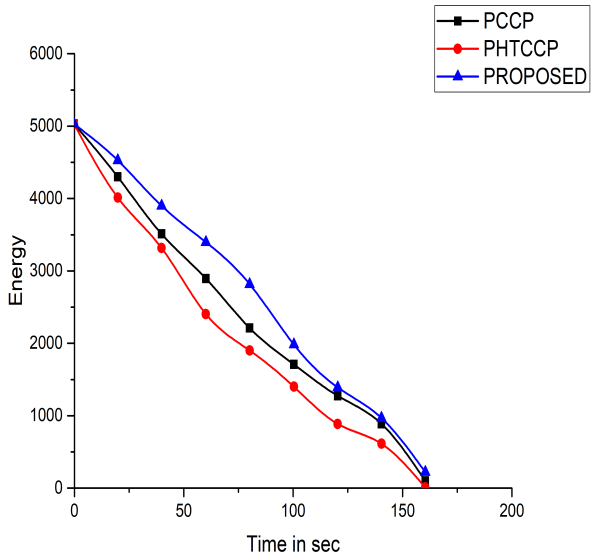


Figure 10. Average Energy Consumption of Node Close to Sink

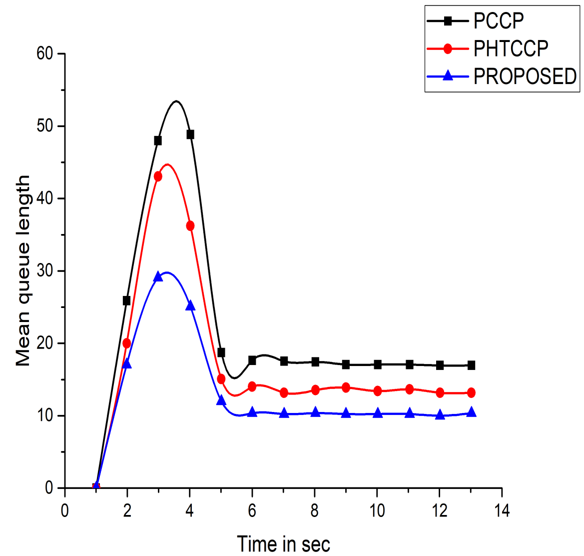


Figure 12. Average Queue Length

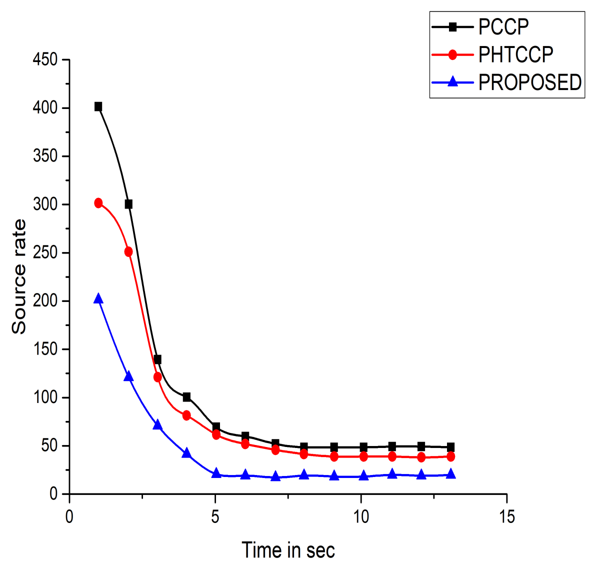


Figure 11. Source Data Generation Rate

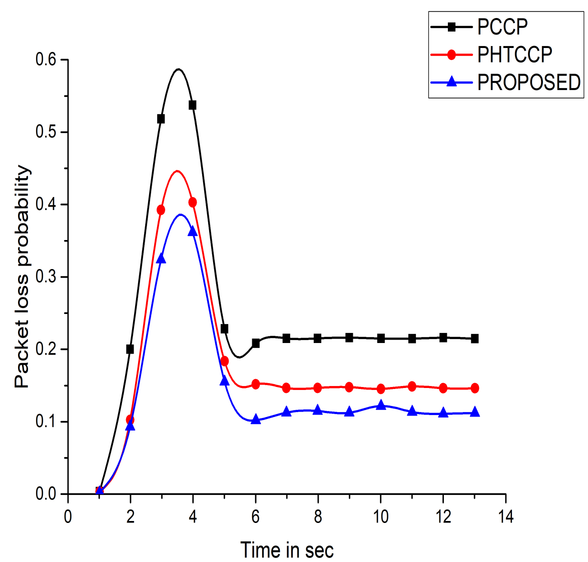


Figure 13. Packet Loss Probability

used for fuzzy logic system. Congestion level is determined by the output of the fuzzy system. Congestion mitigation and avoding packet drops is implemented using rate adjustment technique. Results obtained sows the parameters viz. averange length of the queue, end-to-end delay, packet loss ratio, average energy consumption of nodes performs better than PCCP and PHTCCP techniques.

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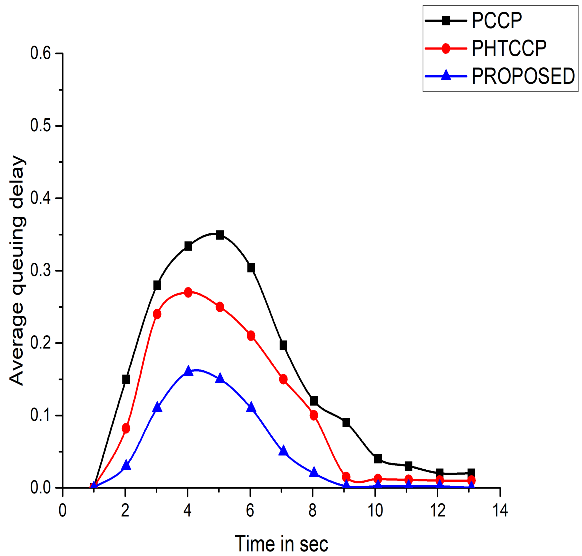

Figure 14. Average Queuing Delay

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