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Research Article

Hierarchical Tree Based Congestion Control using Fuzzy Logic for Heterogeneous Traffic in WSN

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Abstract

In wireless sensor networks (WSN), during congestion detection and control, the energy consumption is high. The packet drop ratio is in increased level causing decreased throughput. In order to overcome complexity in congestion control, in this paper, we propose a hierarchical tree based congestion control using fuzzy logic for heterogeneous traffic in WSN. Initially, the hierarchical tree is constructed using topology control algorithm. Then the congestion detection is performed using fuzzy logic technique based on the parameters such as packet service ratio, number of contenders and buffer occupancy. In order to control the congestion, a dynamic rate adaptation or adjustment is performed. If rate adjustment is not feasible, then source selects the alternate path from the established hierarchical tree. By simulation result, we show that the proposed technique reduces the energy consumption and increases the throughput.

Keywords: *Congestion Control, Fuzzy logic, Wireless sensor network*

1. Introduction

1.1 Wireless Sensor Networks (WSN)

A WSN is a collection of hundreds or thousands of nodes by which each node consists of its own sensor, data processing circuits, and communicating components such as transmitter and receiver. There are various types of sensors in a very small size, such as radar, thermal, visual and infrared, which can sense the environmental conditions such as temperature, pressure, sound and humidity. As sensors introduce several resource limitations due to their lack of memory, power and computational resources, in order to create a WSN it is very important to deploy and use them efficiently. WSNs are self-configuring, spatially distributed autonomous nodes with constraints in energy consumption. Communication and network protocols are being developed for WSNs, which are adaptable to variations in neighborhood nodes and smart network devices (M. Bala Krishna and M.N. Doja,2011),(Sara Ghanavati, JemalAbawajy and DavoodIzadi,2013).

1.2 Congestion in WSN

In wireless sensor networks, congestion problem always considered as a big challenge that influence QoS of the network. Congestion can occurs in WSN because of many sources like buffer overflow, concurrent transmission, packet collision, channel contention, reporting rate and many to one nature. Congestion generate in network because of access load is allocated on a link /node called as traffic. There are two type of traffic: i) Downstream traffic: The downstream traffic from sink to the sensor nodes usually is a one-to-many multi-casts. ii) Upstream traffic: Upstream traffic from sensor nodes to sink is a many-to-one multi-hop convergent. Therefore congestion most probability appears in the upstream direction.
There are two types of congestion could occur in WSN as. They are:

- Node-level congestion is caused by buffer overflow in the node and can result in packet loss, and increased queuing delay.
- Link-level congestion increases packet service time, due to this decreases both link utilization and overall throughput, and wastes energy at the sensor nodes (Sara Ghanavati, JemalAbawajy and DavoodIzadi,2013), (DiptiPatil and Sudhir N. Dhage,2012).

1.3 Congestion control in WSN

Congestion control is essential for enhancing the network efficiency as well as for saving the energy. Congestion control generally follows three steps: a) congestion detection b) congestion notification c) rate adjusting. Therefore there is a need of a protocol which detects & control congestion whose efficiency depends on how much it can achieve energy efficiency and how much it can support to the quality of services (QoS) (DiptiPatil and Sudhir N. Dhage,2012).

Congestion avoidance (CA) and congestion detection (CD) mechanisms are used, in order to counter the

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problems of congestion. CA pertains to algorithms that adjust the rates of the nodes to avoid packet loss whereas CD, respectively, to algorithms that detect if the network tends to get congested (Vasilis Michopoulos, Lin Guan and Iain Phillips, 2010).

Issues

Due to the energy saving and wireless link properties of the sensor networks, adopting the existing methods for congestion control is not suitable.

- Low node resources
- Collisions
- Packet drop
- Traffic rate (Sara Ghanavati, JemalAbawajy and DavoodIzadi,2013),(DiptiPatil and Sudhir N. Dhage,2012), (VasilisMichopoulos, Lin Guan and Iain Phillips,2010).

1.4 Problem Identification

In the existing works (CagataySonmez, OzlemDurmazIncel, SinanIsik, Mehmet YunusDonmez and CemErsoy, 2014),(CharalambosSergiou, VasosVassiliou and AristodemosPaphitis, 2013), (Muhammad Monowar, ObaidurRahman, Al-Sakib Khan Pathan and ChoongSeon Hong, January 2012), (SaeedRasouliHeikalabad, Ali Ghaffari, Mir AbolgasemHadian and HosseinRasouli, January 2011), (Li Qiang Tao and Feng Qi Yu, 2010) both congestion detection and control were handled. However (CagataySonmez, OzlemDurmazIncel, SinanIsik, Mehmet YunusDonmez and CemErsoy, 2014),(CharalambosSergiou, VasosVassiliou and AristodemosPaphitis,2013) the energy consumption is high. The packet drops ratio is in increased level as they are transmitted without controlling the transmission rate which causes decrease in the throughput (Muhammad Monowar, ObaidurRahman, Al-Sakib Khan Pathan and ChoongSeon Hong, January 2012). The packet drops occurs depending upon the buffer state(SaeedRasouliHeikalabad, Ali Ghaffari, Mir AbolgasemHadian and HosseinRasouli, January 2011), (Li Qiang Tao and Feng Qi Yu, 2010).

In case of congestion types of WSN in the existing methods, TADR(FengyuanRen, Tao He, Sajal K. Das and Chuang Lin,2011) fails to find enough idle nodes to cache all the dropped packets. The packet loss ratio increases in HCCC with the increase in the number of sensor nodes (Guowei Wu, Feng Xia, Lin Yao, Yan Zhang and Yanwei Zhu,2011),also the performance gets worse with the increase in the network scale. In FACC of (Xiaoyan Yin, Xingshe Zhou, Rongsheng Huang, Yuguang Fang and Shining Li, November 2009) there shows the occurrence of packet drops and decrease in the source rate.

Next in case of control mechanisms for congestion control, the congestion control mechanism used(Akbar Majidi and Hamid Mirvaziri,2014)however results in computational complexity and is energy consuming. In ACT (Joa-Hyoung Lee and In-Bum Jung,2010) as sensor node generates more packets and thus the network congestion became serious, more packets were dropped. In FBCC (Mingwei Li and Yuanwei Jing,2012)there occurs buffer overflow and significant drop in the packet.

Objectives

In order to provide efficient congestion control for WSN, the following functionalities should be followed.

- Adjustment of packet rates
- Accurate detection of congestion
- Congestion Control

Congestion control mechanism requires the consideration of two main issues; congestion detection and efficient rate adjustment. To address this, Prioritized Heterogeneous Traffic-oriented Congestion Control Protocol (PHTCCP) (Muhammad Monowar, ObaidurRahman, Al-Sakib Khan Pathan and ChoongSeon Hong, January 2012) is proposed. This generates and transmits data in the basis of priority. This uses a weighted fair queuing for scheduling and it uses hop-by-hop rate adjustment for controlling the congestion. This protocol is energy efficient with low packet drop rate.

However, as it uses hop-by-hop transmission rate, without controlling the transmission rate the packet ratio will be increased. Also the congestion detection method provided here is not effective since it uses only a metric such as packet service ratio.

Hence, in this paper, we propose to design a Fuzzy based congestion control mechanism.

2. Proposed solution

2.1 Overview

In this paper, we propose to design a Fuzzy based congestion control mechanism.

It involves the following three phases:

- Hierarchical Tree Construction,
- Fuzzy Based Congestion Detection
- Priority Based Rate Adjustment

In the initial phase, a hierarchical tree is constructed using topology control algorithm. Here using a control packet, a node makes aware of the congestion state of all the neighbors. In second phase, congestion detection is done by Fuzzy logic using the input metrics packet service ratio, number of contenders and buffer occupancy. The state of congestion is then estimated by the outcome of Fuzzy rules. A prioritized queue is maintained for different class of traffic and a weight value is assigned for each queue. In phase-3, according to the weight of the queue, dynamic rate adaptation or adjustment is done for controlling the congestion. If rate adjustment is not feasible, then alternate path can be selected from the established hierarchical tree.

2.2 Estimation of Metrics

2.2.1 Packet Service Ratio (P)

It is defined as the ratio of the average packet service rate (γ_{SE}^{i}) and packet scheduling rate (γ_{SCH}^{i}) in each node N_i. It is given using following equation

$$P(i) = \frac{\gamma_{SE}^{i}}{\gamma_{SCH}^{i}} \quad (1)$$

Where γ_{SE}^{i} is inverse of packet service time t_i

t_i is the time interval when packet is arrived and transmitted to next hop. It includes packet waiting time, collision resolution and packet transmission time. t_i is estimated using following equation (2)

$$t_i = (1-a)^* t_i + a^*inst(t_i) \quad (2)$$

whereinst(t_i) = instantaneous service time of packet which was transmitted

a = constant in the range {0, 1}

The following case 1 and case 2 reveals that the congestion state is low and case 3 reveals that the congestion state is high causing link level collisions.

Case 1: When P = 1, $\gamma_{SCH}^{i} = \gamma_{SE}^{i}$

Case 2 When P > 1, $\gamma_{SCH}^{i} < \gamma_{SE}^{i}$

Case 3 When P < 1, $\gamma_{SCH}^{i} > \gamma_{SE}^{i}$

2.2.2 Number of Contenders (W)

The contenders are the neighbor nodes which contain the packets in their queue waiting to be transmitted in the contention region at the MAC layer and not on the path. It is computed using RTS/CTS packets which are generated by the neighbor nodes.

If W = high,
Then
    Collision probability is high
End if

2.2.3 Buffer Occupancy (Q)

Each node contains input and output buffer to store the data packet temporarily in queue before processing.

If Q = High
Then
    Congestion probability is high
Else
    Congestion probability is low
End if

2.3 Hierarchical Tree Construction

Let L_0, L_1, L_2 , …., L_n be the tree levels

Let L_mes be the level discovery message

In this phase, the hierarchical tree is constructed using a topology control algorithm. The steps involved in this algorithm are as follows:

1) Initially each node N_i is assigned with L_0. It then sends aL_mes to its neighbor nodes (Neigh$_i$).
2) Each Niegh$_i$ that receives the L_mes is considered as child node and assigned L_1.
3) Each Neigh$_i$ broadcasts L_mes and the next level node is assigned L_2.
4) The above process is repeated until all nodes are assigned a level and its ceased when all the L_mes reaches sink node (S).
5) After complete process, S may receive more than one L_mes from different nodes with different levels. This indicates that disjoint paths also reach S. During this scenario, S retains the message from the lower level node alone.
6) When any node that receives L_mes does not have upstream nodes to forward the packet, then it broadcasts negative acknowledgement message (N_{ack}). When an upstream node receives N_{ack}, it decides that the relevant node cannot route any packets.

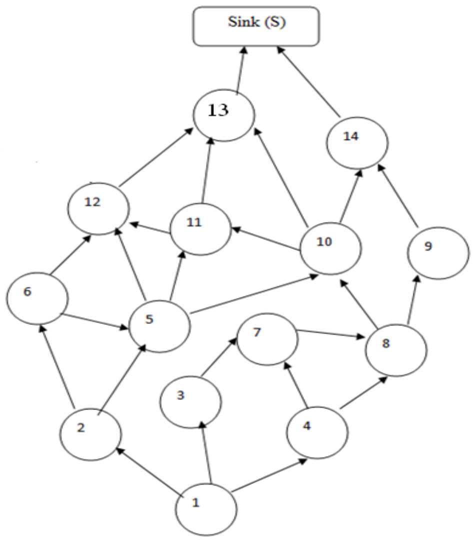

Fig. 1a Hierarchical Tree Construction

Figure 1a illustrates the hierarchical tree construction.

Let node N_1be the source node.

N_1 broadcasts L_mes to the N_2, N_3, and N_4 in its transmission range and assigns L_1. Then N_2, N_3, and N_4 transmit this message to the nodes N_5, N_6, N_7, and N_8 and assigns L_2. This process is repeated until the L_mes reaches sink.

If S receives more than one packet from the node, it retains the packet from nodes which are close to source. That is lower level nodes.

For example, N_5 is connected with $N_6$and N_2. S receives the packet from N_6 placing it at L3 and packet from N_2 placing it at L_2. N_5 considers N_6 as upstream node and becomes a L_2 node and requests other neighbors to become L_3 node.

In this figure, N_{13} represents the node with no upstream neighbor for performing routing. It is removes from the upstream node table.

Fuzzy based Congestion Detection

The congestion state of the node (CS) can be determined using fuzzy logic technique. The parameters packet service ratio, number of contenders and buffer occupancy are taken as input for the fuzzy member ship functions and based on the fuzzy rules, the state of congestion is estimated as output.

The steps that determine the fuzzy rule based interference are as follows.

- Fuzzification: This involves obtaining the crisp inputs from the selected input variables and estimating the degree to which the inputs belong to each of the suitable fuzzy set.
- Rule Evaluation: The fuzzified inputs are taken and applied to the antecedents of the fuzzy rules. It is applied to the consequent membership function.
- Aggregation of the rule outputs: This involves merging of the output of all rules.
- Defuzzification: The merged output of the aggregate output fuzzy set is the input for the defuzzification process and a single crisp number is obtained as output.

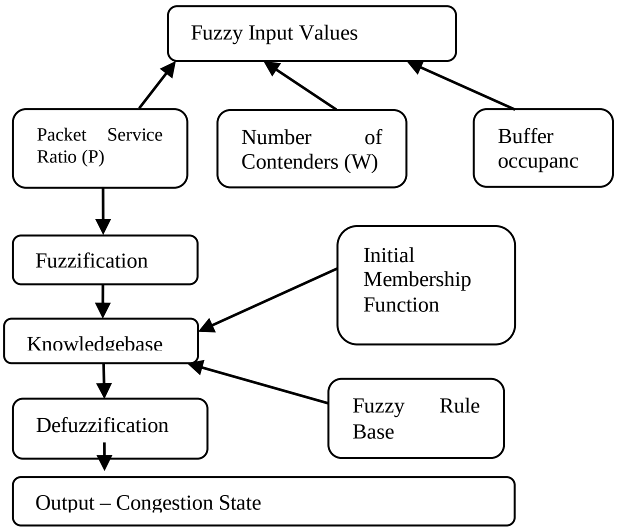

Fig. 1b Fuzzy Interference System

Fuzzification

This involves fuzzification of input variables such as packet service ratio (P), number of contenders (W) and buffer occupancy (Q) (Estimated in sections 3.2.1-3.2.3) and these inputs are given a degree to appropriate fuzzy sets. The crisp inputs are combination of P, Wand Q. We take two possibilities, high and low for P, W and Q.

Figure 2, 3, 4, 5 and 6 shows the membership function for the input and output variables.The triangulation functions are utilized which are widely utilized in real-time applications. Also a positive impact is offered by this design of membership function

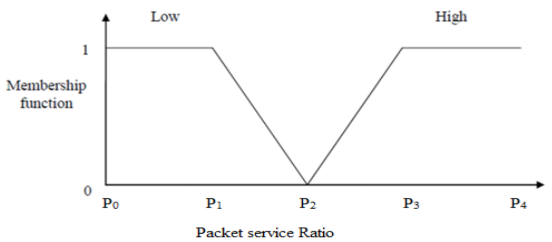

Fig. 2 Membership Function of Packet Service Ratio

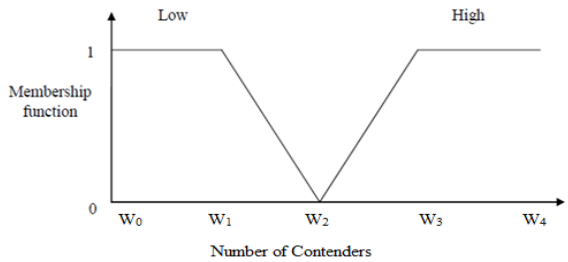

Fig. 3 Membership Function of Number of Contenders

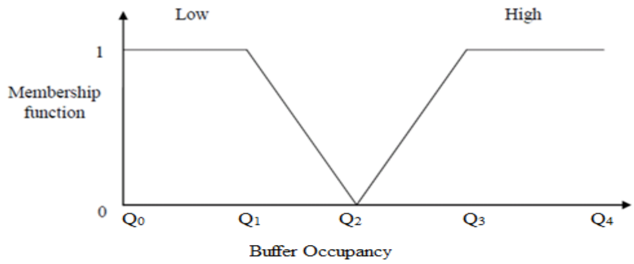

Fig. 4 Membership Function of Buffer Occupancy

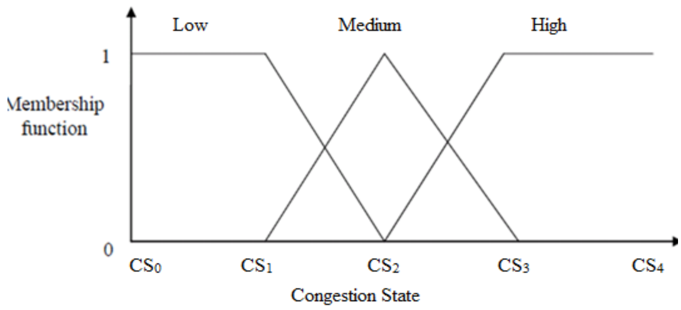

Fig. 5 Membership Function of Congestion State

In table 1, P, Wand Q are given as inputs and the output represents the congestion state.

Table 1 Designed fuzzy inference system

S.No.	Packet Service Ratio (P)	Number of Contenders (w)	Buffer Occupancy (Q)	Congestion State (CS)
1	Low	Low	Low	Low
2	Low	Low	High	Medium
3	Low	High	Low	Medium
4	Low	High	High	High
5	High	Low	Low	Low
6	High	Low	High	Low
7	High	High	Low	Low
8	High	High	High	Medium

Table 1 demonstrates the designed fuzzy inference system. According to inputs it generates the fuzzy decision.

For example
Let us consider Rule 15.

If (P = low, W & Q = High)

Then

CS = high

End if

Defuzzification

Defuzzification is used for extracting a crisp value from a fuzzy set as a representation value. We consider the centroid of area strategy for defuzzification.

$$F_{QoS} = \frac{\int_f \eta_{agg}(F)_{fdf}}{\eta_{agg}(F)_{df}} \tag{3}$$

Where $\eta_{agg}(F)$ = aggregated output of membership function

2.4 Priority Based Rate Adjustment

Let n (G(i)) be the number of active child nodes of parent node at time t
Let H be the number of child nodes of parent node.
In this phase, a dynamic rate adaptation or adjustment technique is processed based on the queue state to control the congestion.
When N_i finds that all the child nodes of its parent are in active state at time t, then it adjusts scheduling rate by reducing it to $\gamma_{SCH}^{p_i}$/H of its parents scheduling rate.
That is,
If n (G(i)) = H,
Then

$$\gamma_{SCH}^{i} = \gamma_{SCH}^{p_i}/H \tag{4}$$

End if
When N_i finds that some child nodes are idle, then it adjusts the scheduling rate with weight factor and link capacity value.
That is,
If n (G(i)) < H,
Then

$$\gamma_{SCH}^{i} = \gamma_{SCH}^{p_i} + e_i(t)\, M(t)$$

End if
Here $e_i(t)$ = Weight factor for node *i* at time *t*
M(t) = Excess link capacity at time t
M(t) is estimated using following equation

$$M(t) = \sum_{n=1}^{H} \gamma_{SCH}^{p_i} / H - \sum_{n=1}^{n\,(G(i))} \gamma_{SCH}^{p_i} / H \tag{5}$$

$e_i(t)$ is estimated using following Eq

$$e_i(t) = \left\{ \frac{Av_i^z(t)}{\sum_{i \in n(G(i))} Av_i^z(t)} \, i \in n\,(G(i)) \right. \tag{6}$$

where Av_i^z = weighted average queue length of N_i at t.

$$Av_i^z(z) = \frac{\sum_{j=1}^{N} \beta_j^i \times z_j^i}{N} \tag{7}$$

Where z_j^i = current queue length of j^{th} queue of N_i where j = 1, 2, ..,n

β_j^i = priority of j^{th} queue
N = number of queues
$e_i(t)$ shows the method to allocate the excess link capacity among the active nodes and it is normalized such that:
$i \in \sum$ n (G (i)) $^{e_i(t)}$ =1
Following scheduled rate computation, each N_i updates their original nodes (γ_{oi})rate using the following equation

$$\gamma_{oi} = \frac{\gamma_{SCH}^{i} * \beta_i}{\beta_1 + \beta_2 + \ldots + \beta_n} \tag{8}$$

If the rate adjustment is not feasible, source selects the alternate path from the established hierarchical tree.

3. Simulation results

3.1Simulation Model and Parameters

The Network Simulator (NS2), is used to simulate the proposed architecture. In the simulation, 50 mobile nodes move in a 1000 meter x 1000 meter region for 50 seconds of simulation time. Transmission range ofAll nodes are 250 meters. The simulation parameters and settings are summarized in table.

No. of Nodes	50
Area Size	1000 X 1000
Mac	IEEE 802.11
Transmission Range	250m
Simulation Time	50 sec
Traffic Source	CBR
Packet Size	512
Flows	2,4,6,8 and 10
Initial Energy	8.5J
Transmission Power	0.660
Receiving Power	0.395
Rate	50,75,100,125 and 150Kb

3.2 Performance Metrics

The proposed Hierarchical Tree Based Congestion Control Using Fuzzy Logic (HTCCFL) is compared with the Prioritized Heterogeneous Traffic-oriented Congestion Control Protocol (PHTCCP) (Muhammad Monowar, ObaidurRahman, Al-Sakib Khan Pathan and ChoongSeon Hong, January 2012). The performance is evaluated mainly, by following metrics.

- **Packet Delivery Ratio:** It is very useful metrics,It is ratioofnumber of packets received and the number of packets sent.
- **Packet Drop**: It refers the average of packets dropped during the transmission
- **Energy Consumption**: It defines the amount of energy consumed by the nodes to transmit the data packets to the receiver.
- **Delay**: It is the time taken by the nodes to transmit the data packets.

3.3 Results

1) Based on Flows

In our first experiment flows are varied as 2,4,6,8 and 10.

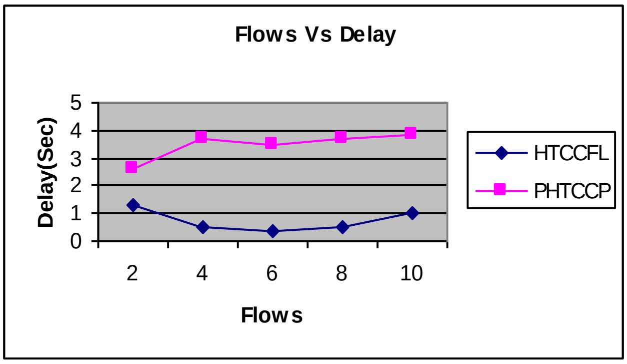

Fig. 6 Flows Vs Delay

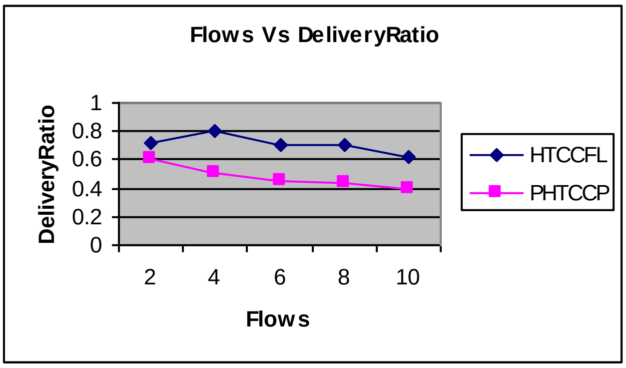

Fig. 7 Flows Vs Delivery Ratio

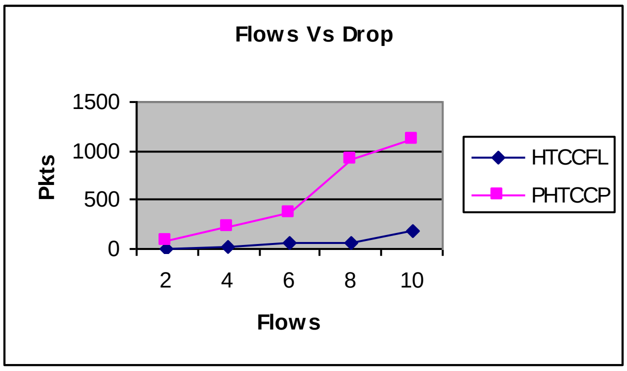

Fig. 8 Flows Vs Drop

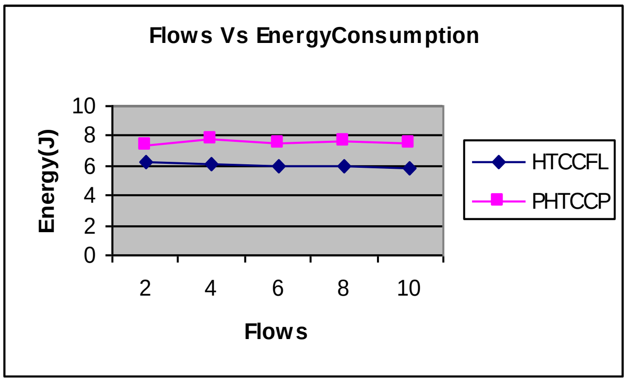

Fig. 9 Flows Vs Energy Consumption

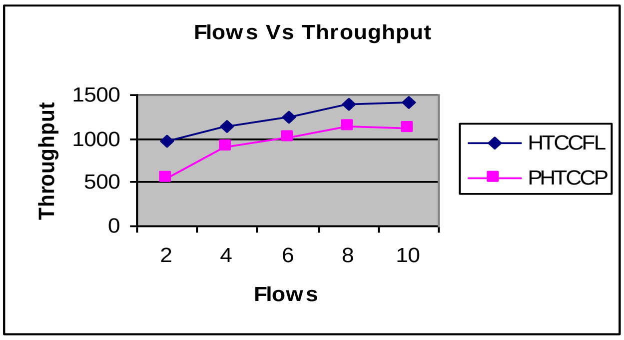

Fig. 10 Flows Vs Throughput

Figure 6 shows the delay of HTCCFL and PHTCCP techniques for different number of flows scenario. We can conclude that the delay of our proposed HTCCFL approach has 77% of less than PHTCCP approach.

Figure 7 shows the delivery ratio of HTCCFL and PHTCCP techniques for different number of flows scenario. We can conclude that the delivery ratio of our proposed HTCCFL approach has 32% of higher than PHTCCP approach.

Figure 8 shows the drop of HTCCFL and PHTCCP techniques for different number of flows scenario. We can conclude that the drop of our proposed HTCCFL approach has 87% of less than PHTCCP approach.

Figure 9 shows the energy consumption of HTCCFL and PHTCCP techniques for different number of flows scenario. We can conclude that the energy consumption of our proposed HTCCFL approach has 21% of less than PHTCCP approach.

Figure 10 shows the throughput of HTCCFL and PHTCCP techniques for different number of flows scenario. We can conclude that the throughput of our proposed HTCCFL approach has 24% of higher than PHTCCP approach.

2) Based on Rate

In our second experiment we vary the transmission rate as 50,75,100,125 and 150Kb.

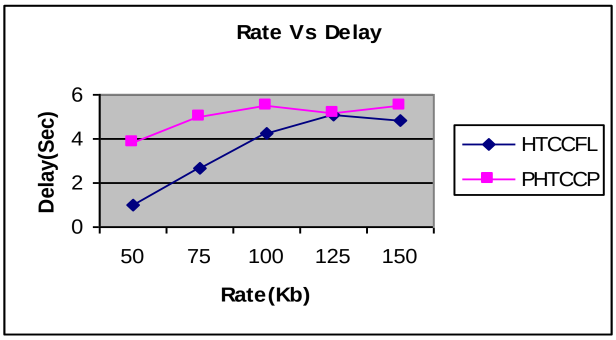

Fig. 11: Rate Vs Delay

Figure 11 shows the delay of HTCCFL and PHTCCP techniques for different rate scenario. We can conclude that the delay of our proposed HTCCFL approach has 31% of less than PHTCCP approach.

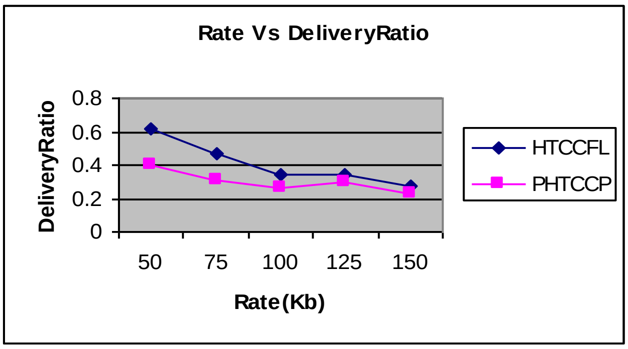

Fig. 12 Rate Vs Delivery Ratio

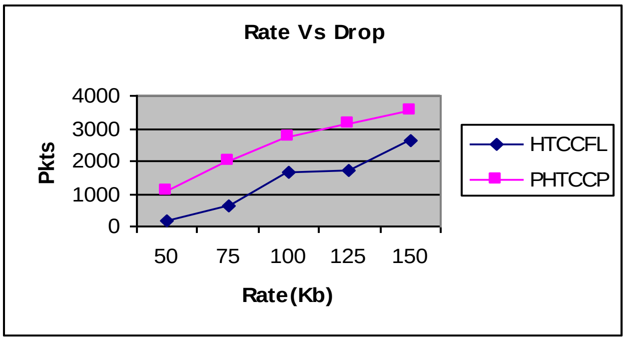

Fig. 13 Rate Vs Drop

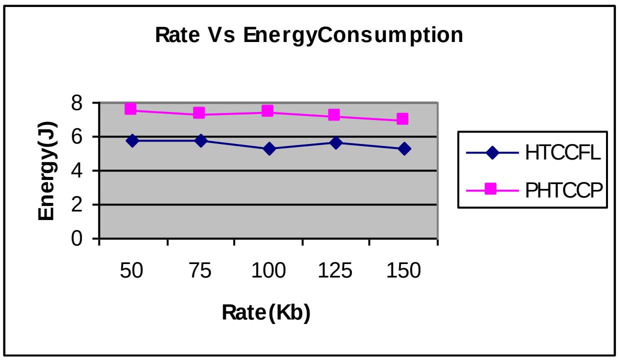

Fig. 14 Rate Vs Energy Consumption

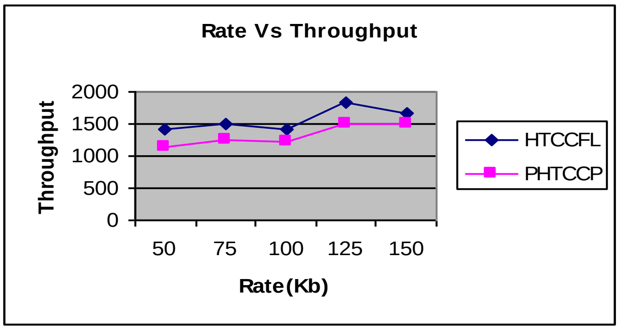

Fig. 15 Rate Vs Throughput

Figure 12 shows the delivery ratio of HTCCFL and PHTCCP techniques for different rate scenario. We can conclude that the delivery ratio of our proposed HTCCFL approach has 25% of higher than PHTCCP approach.

Figure 13 shows the drop of HTCCFL and PHTCCP techniques for different rate scenario. We can conclude that the drop of our proposed HTCCFL approach has 53% of less than PHTCCP approach.

Figure 14 shows the energy consumption of HTCCFL and PHTCCP techniques for different rate scenario. We can conclude that the energy consumption of our proposed HTCCFL approach has 24% of less than PHTCCP approach.

Figure 15 shows the throughput of HTCCFL and PHTCCP techniques for different rate scenario. We can conclude that the throughput of our proposed HTCCFL approach has 15% of higher than PHTCCP approach.

Conclusion

In this paper, we have proposed a hierarchical tree based congestion control using fuzzy logic for heterogeneous traffic in WSN. Initially, the hierarchical tree is constructed using topology control algorithm. Then the congestion detection is performed using fuzzy logic technique based on the parameters such as packet service ratio, number of contenders and buffer occupancy. In order to control the congestion, a dynamic rate adaptation or adjustment is performed. If rate adjustment is not feasible, then source selects the alternate path from the established hierarchical tree. By simulation result, we have shown that the proposed technique reduces the energy consumption and increases the throughput.

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