FCLCC: Fuzzy Cross-Layer Congestion Control in Mobile Ad Hoc Networks

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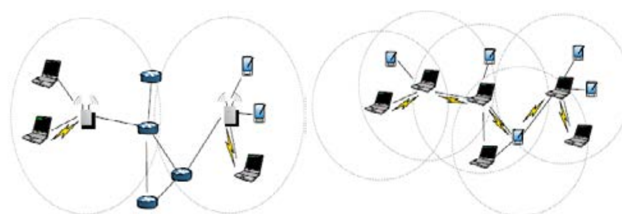
Summary
Mobile ad hoc networks (MANETs) are a collection of mobile nodes connected together without any infrastructure and central management. Congestion control is an important problem in MANETs and TCP congestion control mechanisms are incapable of managing special characteristics of the wireless channel in ad hoc networks. Moreover, several network layers are involved and adjusting each parameter on those layers can affect the other ones. A cross-layer approach is proposed in transport, network, and MAC layers in which Fuzzy Logic System is used in intermediate and destination nodes as a dynamic tool for controlling the congestion problem in MANETs. In the network layer, DSR routing algorithm is used and messages exchanged among nodes are put into the ACK packets. The simulation results show that in this method, end-to-end delay is reduced more for UDP packets and less for the TCP packet. Moreover, network throughput increased and packet loss rate slightly improved.

Key words:
Mobile Ad Hoc Networks; Congestion Control; Cross-Layer Design; Fuzzy Logic.

1. Introduction

Mobile ad hoc networks (MANETs) are a collection of mobile nodes connected together without any infrastructure and central management. The nodes in these networks, due to the limitations in their transceivers, cannot directly communicate with each other. In this case, the data will be sent by other nodes. Indeed, nodes play the roles of router and host (Feeney, 1999). Using their mobility feature, nodes make the network change constantly and cause different paths between two nodes to be created. Dynamic topology and other factors such as the size of large networks, heterogeneity of hosts, and various structures plus the limitations of batteries has resulted in routing protocols specifically designed for this kind of networks.

Using their mobility feature, nodes make the network change constantly and cause different paths between two nodes to be created. Dynamic topology and other factors such as the size of large networks, heterogeneity of hosts, and various structures plus the limitations of batteries has resulted in routing protocols specifically designed for this kind of networks. It is essential to have QoS in mobile networks because of the increasing demand for quality of service (QoS) applications (Lochert, Scheuermann and Mauve, 2007). As shown in Figure 1, without any infrastructure, mobile nodes communicate with each other. In these networks, in order to have a safe communication, different mechanisms are provided. These mechanisms such as congestion control and routing prevent packet loss during congestion and they will increase the efficiency of communication.



(a) (b)

Fig. 1 Architecture of ad hoc networks, (b) mobile networks, (b) structure based ad hoc networks (Lochert, Scheuermann and Mauve, 2007)

According to the properties of ad hoc networks, each network protocol faces many problems. In other words, designing routing protocols for these networks due to their dynamic structure, the limited bandwidth of wireless communications, and the limited energy of nodes is not simple. The main problems faced by the protocol in ad hoc networks can be summarized as follows: There are loops in routing, high overhead and wasted network bandwidth, long convergence time, great memory requirements in each of the nodes, high computational complexity, and excessive delays in routing and sending data packets.

A. The Congestion Problem

The most important characteristics of mobile ad hoc networks are node mobility and multi-hop shared wireless channel. Route changes due to node mobility and unreliable media result in packet delivery delay, jitter, and packet loss. Using multi-hop wireless channel, data transmission is allowed at the transmission range of each node. Therefore, close connections are not independent from each other and affect each other in a way that is revealed in network congestion to a great extent. A network with shared resources is required where several transmitters compete

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for link bandwidth so that the data rate used by each sender would be adjusted. Thus, the network would not be overloaded. Packets that arrive on a router and cannot be sent are discarded. As a result, a large amount of incoming packets in the network bottleneck causes a lot of packets to be discarded. These packets may have traveled a long way in the network and consumed adequate resources. In addition, packet loss often causes retransmission of packets. This means even more packets sent into the network. Therefore, network congestion can severely degrade the throughput. If a proper congestion control mechanism is not applied, it can cause the network to collapse resulting in no data being delivered successfully.

2. Related Works

In ad hoc networks, congestion can occur at any intermediate node (often due to resource constraints and when the packet is transmitted from source to destination). Congestion leads to packet loss, long delays, and wasted resources. As previously mentioned, the main objective of congestion control is using resources efficiently in the network. In ad hoc networks, with particular challenges such as frequent changes of topology, investigating congestion control is very important.

According to a research a method proposed a cross-layer congestion avoidance scheme (C3TCP) that improves the transport layer performance to obtain higher performance by gathering capacity information such as bandwidth and delay at the link layer. They also showed the performance degradation of transport layer protocols due to the congestion of wireless local area networks (Kliazovich and Granelli, 2006).

A new method named fuzzy rate-based congestion control was proposed to prevent network congestion. On this basis, fuzzy ad hoc network congestion control rate aims to increase the efficiency of mobile ad hoc networks. Based on the proposed method, the performance of the channel with high accuracy and high reliability of packet transmission can achieve the results. Fuzzy logic congestion control determines the network congestion level based on the probability of congestion. Then, data rate is set based on the level of congestion. The simulation results (the throughput-fair allocation of resources) show that using the fuzzy method in ad hoc networks with random topology changes is suitable (Zare, Adibnia and Darhami, 2013).

In another paper, congestion detection and recovery techniques was proposed. The congestion status of nodes is specified by parameters such as queue length, data rate, and competitive medium access control. These parameters, for each node, are at three levels: high, medium, and low. When data is transferred from source to destination, intermediate nodes verify the congestion status along the path. If the congestion status or the status of each node was more of an intermediate node, a warning message is sent to the source. Then, the source selects a free alternative route for data generation. Then, the source selects the open alternative route for sending the data. The simulation results showed that when the packet delivery rate with high traffic increased, the proposed congestion detection based on route discovery minimized packet loss and delay (Uthariaraj, 2013).

A Research investigated load balancing due to limited communication resources, such as bandwidth, buffer space, and battery power. In addition, they investigated comprehensively the sharing network techniques. In this paper, a load balancing routing protocol was proposed for transmission of efficient data and focus on high load metrics in different conditions. In the proposed scheme, the probability of congestion is reduced by selecting no congestion paths for data transmission and alternate routes for network load (Shukla and Kanti, 2013).

In another research, a method is proposed to detect congestion control and routing control in ad hoc networks based on the average queue length in each node. Using the average queue length, the node detects the congestion levels and sends a warning message to its neighbors. After that, they try to put an alternative route to the destination. Dynamic congestion estimation mechanism ensures reliable communications in ad hoc networks. However, this method suffers some limitations such as packet loss due to congestion and wireless environment. These limitations can be a tendency for new research (Senthilkumaran and Sankaranarayanan, 2013).

In a new way of controlling congestion, agent-based congestion control technique is proposed. In this technique, network congestion information is collected and distributed by mobile agents. A mobile agent, at any time and from any node, starts moving towards the edge nodes and then the visited node is selected with an equal probability. Mobile agents with their own history of movement update the routing table of the visited node. Mobile agents calculate the data transmission rate of the corresponding nodes and then select the highest data rate. They also estimate the level of congestion for each traffic queue and associate a priority to each node based on measurements of the level of congestion. Therefore, a node with no traffic and insensitive delay would have higher priority for receiving more traffic than a low priority node (Mourya1and Singhal, 2014)

In a research, a classified cross-layer congestion control mechanism was introduced. In this paper, the route discovery algorithm and a congestion control algorithm are based on DSR in which congestion occurs due to competition between nodes, handle overflows, and failures. The cross-layer proposed model includes network, transport, and media access control layers. In this model, network and medium access layers play an important role to detect congestion and adjust it to the network and transport layers (Kamatam, Srinivas and Sekaraiah, 2012).

In a paper, a scheme for congestion control was proposed that consists of four phases. The first phase of the cross-layer scheme was introduced to ensure that information is shared between different layers in the protocol stack. In the second phase, congestion detection at the scale of congestion and packet loss rate is achieved. In the third phase, congestion control is achieved using the cross-layer approach. The congestion path is determined based on path gain and buffer fullness. In the fourth phase, a new framework is proposed for the packet (Sheeja and Pujeri, 2013).

Vehicular ad hoc networks (VANETs) are a kind of MANETs. According to the specific characteristics of vehicular ad hoc networks, a method was proposed a distributed control and detection congestion protocol. In the congestion detection phase, the information of each layer of the protocol stack was mapped to different congestion levels. In the next phase, congestion control parameters such as window size, transmission rate, and power are adjusted to improve network efficiency (Puthal, Mir, Filali and Menouar, 2013).

In a study, the authors developed an efficient energy-based congestion control scheme for MANETs to prevent congestion and to improve the energy efficiency of mobile nodes. In that method, a cross-layer scheme was proposed to improve network performance. In addition, they focused on multipath routing to prevent congestion that leads to increased network lifetime. It also used a mathematical model to show the energy consumption of nodes in the network. Therefore, the probability of packet retransmission decreases by calculating the energy level of acknowledgment and data packets (Sheeja and Pujeri, 2014).

A fuzzy logic based congestion control was proposed on ATM and WAN networks. This research shows that using rule based methods such as Fuzzy Logic System can be effective in the control of congestion (Pitsillides and Sekercioglu, 1999).

According to the works done on the congestion control problem, they can be summarized from the perspective of OSI model layers in Table I. In this table, the first group is based on the congestion control parameter configuration of MAC, the second group is based on appropriate routing and the third group is based on the transmission rate and congestion window changes adaption. In the fourth group, congestion control is based on the application layer and in the fifth one, cross-layer design mechanism is used. Indeed, due to congestion conditions in various environments, the need for coordination between the different layers of the OSI model is necessary because the problem of congestion in mobile ad hoc networks has its own complexity. Most of the methods described to control congestion deal with data link, network, and transport layers of the OSI model. Our proposed method is based on these three layers.

In another research, authors present a lightweight congestion control and early avoidance congestion control scheme. This scheme is based on the Cross-layer solution between the MAC and network layers in order to detect congestion. The cooperation between nodes lead to the sender node find an alternative route based on Triangular Matrix Table (TMT). This mechanism controls the network resources rather than the data traffic.

In another cross layer method, authors suggested a scheme that TCP packets get prioritized by dynamically adapting to contention window parameters. Traffic class monitors the MAC queue and computes Transmission Opportunity (TXOP) limits value at runtime. This results in reduced delay and loss factor. They also incorporate the cross layer approach by exploiting the physical and MAC layer information to initiate corrective measures at the Transport and Network layer to enhance best effort traffic performance.

In another paper, authors presents the early congestion control (ECC) and a new cross layer mechanism In order to improve TCP performance in wireless networks. They implemented it as an active queue management (AQM), that dynamically changes the value of the window field from TCP headers according to the utilization of the router queue. In this method, lead to enhance the performance of the TCP protocol.

In a recent research, authors highlights on congestion control issues in real time environment and they propose an upgraded traffic shaping mechanism in TCP/IP protocol suite of network model for real time applications with basic concept using the token bucket traffic shaping mechanism during packet routing at the intermediate nodes. Their simulation findings present better performance in highly congested traffic scenario with reduced queuing delay and improved packet delivery ratio.

In a cross layer congestion control research, authors propose an adaptive reliable and congestion control routing protocol to resolve congestion and route errors using bypass route selection in MANETs. In this method, the congestion detection is based on utilization and capacity of link and paths. When a source node detects congestion on a link along the path, it distributes traffic over alternative paths by considering the path availability threshold and using a traffic splitting function. If a node cannot resolve the congestion, it signals its neighbors using the congestion indication bit. Their simulation results in reliability of this technique and reaching more throughput with reduced packet drop.

Table 1: Congestion control mechanisms based on OSI layers

References	Data Link Layer	Network Layer	Transport Layer	Application Layer
(Ma et al., 2010), (Mahendra and Senthil, 2010), (Jang-Won et al., 2006), (Berger et al, 2004)	✓			
(Chang et al., 2007), (Narsimha, 2012), (Tran and harish, 2005), (Soundararajan and Bhuvaneswaran, 2012), (Rath et al., 2017)		✓		
(Rahman and Hasa, 2010), (Mehrotra et al., 2010), (Zhai et al., 2005),			✓	
(Adamczyk et al., 2007), (Shameem and Raihana, 2007), (Yan et al., 2008), (Peter, 2005)				✓
(Chen et al., 2006), (Thilagavathe and Duraiswamy, 2001), (Suryaprakash and Chenna, 2013) (Gawas et al., 2016)	✓	✓	✓	
(Rahem et al., 2016), (Vadivel and Baskaran, 2017)	✓	✓		
(Talau et al., 2016)		✓	✓	

3. THE Proposed Method

This paper aims at solving the congestion control problem in ad hoc networks using a fuzzy controller named Fuzzy Cross-Layer Congestion Control (FCLCC). In this kind of network, using a fuzzy controller can help the mobile users to route each packet before sending it. The routing algorithm used is DSR. A primary route should be established before sending packets from the sender to the receiver.

In this algorithm, the transmitter node sends a route request message to all nearby nodes. Each intermediate node sends this message to other nodes. This will continue until the route request message reaches the receiver. The receiver sends a packet for creating a path according to a path that is traveled by the route request packet. Therefore, the receiver selects this path as its own primary path.

In this method, MAC, network, and transport layers are used for exchanging information in order to control congestion. The transport layer is used for congestion control and determining UDP and TCP packets, the network layer for routing based on DSR, and the Mac layer for putting messages into the ACK packet in order to send it to the receiver.

The procedure of this algorithm is that when a node starts sending data packets to the network, due to the increased transmission rate and buffer fullness, the nodes begin to discard packets. If there is no control over congestion at the intermediate nodes, packets will move from the sender to the receiver by using the primary route. Since mobility is relatively lower than the packet forwarding rate, this sending method causes congestion at the intermediate nodes. Therefore, our congestion control scheme starts by changing some parameters mentioned in what follows. In this mechanism, changing the route or changing the transmission rate is based on the information sent to the intermediate node or the source node. This information is put into the ACK packet in a message. Then, these packets based on the congestion level read the available information in the media access layer before they are sent to the higher layer. If the packet contains commands to change the route, the nodes start a new route discovery procedure and remove the current path. If the packet contains commands to change the path as well as the transmission rate, the packet is delivered to the next node so that it would be sent to the source node for decreasing the transmission rate. The process of algorithm is illustrated in Figure 2.

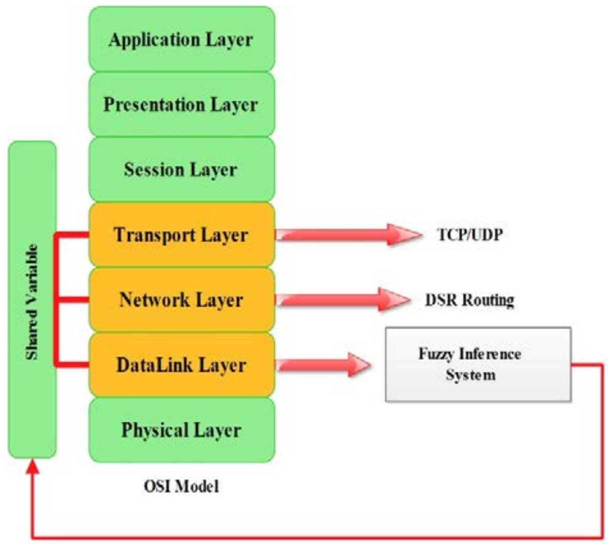


Fig. 2 The proposed method based on OSI Model

In the proposed method, at first, node information is extracted, and then it is sent to a fuzzy system. Thus, based on the input parameters, the congestion level will be determined. After finding out about their congestion level, the nodes send the route change message to their upstream nodes. This will result in the creation of knowledge of the congestion status of nodes in this network. It should be noted that in the intermediate nodes block diagram, the low level of congestion is a condition that involves no medium and high congestion. In this situation, the network will continue its normal operation. In this section, by modeling node behaviors, efforts are made to address the congestion problem from an abstract view. In Figure 3-2, a hypothetical network was considered in which there are three types of nodes: the intermediate node, the target node (receiver), and the source node (sender). Decoupled behavior and tasks of each node in the network can influence the behavior of the transmission rate adjustments. All nodes within the transmission path should not be involved in congestion. In most of the existing methods, due to step-by-step congestion control, single-hop upstream nodes are in charge of the congestion control task. But in this method, a certain number of the pathway nodes are in charge of controlling the congestion rate that will be explained later in this paper.

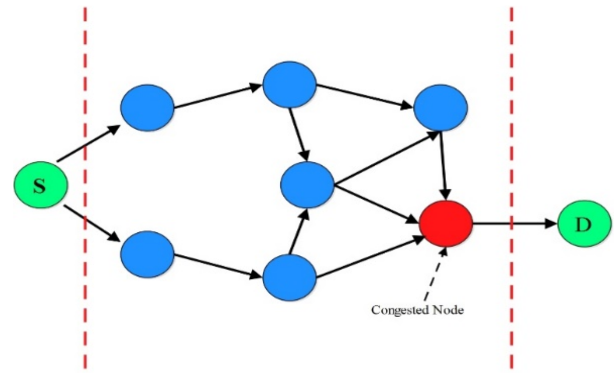


Fig. 3 Behavioral models of network nodes

A. Behavioral models

As shown in Figure 3, the behavior of nodes was divided into three categories:

• **Source node behavior:** The source node creates a network load beside it that plays an important role as an indicator of the congestion level in the network. Thus, when the node receives a control message, it has to do what it was asked such as reducing the rate or choosing an alternate path.

• **Destination node behavior:** Each intermediate node between the source node and the target node is in charge of sending packets. At the beginning, the packet is sent from the primary path between the intermediate nodes to the source node. At any point in time, the intermediate node specifies the congestion level using a fuzzy function and the appropriate decision is made.

• **Intermediate node behavior:** The destination node behaves like intermediate nodes. The main point here is that different applications such as FTP or VOIP connection or other applications have special conditions. In what follows, it is shown how TCP and UDP connection can affect the network and how congestion can be controlled when it happens in this kind of network.

B. Congestion Model

Four congestion levels are assumed, namely low congestion, high congestion, moderate congestion, and critical congestion. The nodes will behave as described below according to which level they belong to:

Low mode: In fact, in this state there is no congestion in the network and the intermediate node sends packets normally. Low congestion in the proposed method was introduced in order to consider all situations in the model. Nothing will happen for controlling congestion.

Moderate mode: In this state, the nodes experience a small congestion. To avoid congestion in the network, the congested node announces a warning message to 1/2 its upstream nodes to find a new alternative route for packet transmission.

High mode: In this state, the intermediate nodes suffer high congestion and the congested node announces a warning message to 2/3 its upstream nodes to find a new alternative route in order to transmit packets.

Critical mode: In this state, the congestion level is too high and the intermediate node that suffers from congestion announces to the source node to find a new alternative route and reduces its transmission rate.

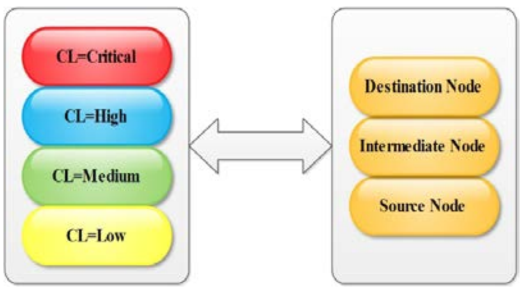


Fig. 4 Communication between the nodes' behavioral model and the proposed congestion behavioral model

The congestion problem lacks a clear solution. Diagnosis and management of congestion leads to increased network performance. If nodes are considered in terms of their behavior, the congestion problem can be solved as a behavioral problem. A behavioral model of congestion at the nodes helps to modify the behavior of nodes. Whenever congestion occurs in the network, nodes change their attitude towards other neighbor nodes and network nodes and in the event of severe congestion situations, they have distinct behaviors from the past.

The proposed method consists of two phases to detect and prevent congestion. At the diagnosis step, the behavioral model and the fuzzy system are used. At the prevention step, the behavioral model and cross-layer variable are used. This is shown in Figure 4. The main reason of using the behavioral model is to have an abstract view of the congestion control problem. This view leads to solving the problem from the perspective of different layers. For example, sometimes TCP and UDP packets are required to exhibit distinct behaviors. Although in video or voice transmission applications a slight delay may cause no problems, for delay-sensitive applications it may lead to adverse effects. Therefore, the behavioristic view can solve the problem from a behavioral perspective. Fuzzy systems implemented at each intermediate node are shown in Fig. 5 and their rules are also shown in Table II.

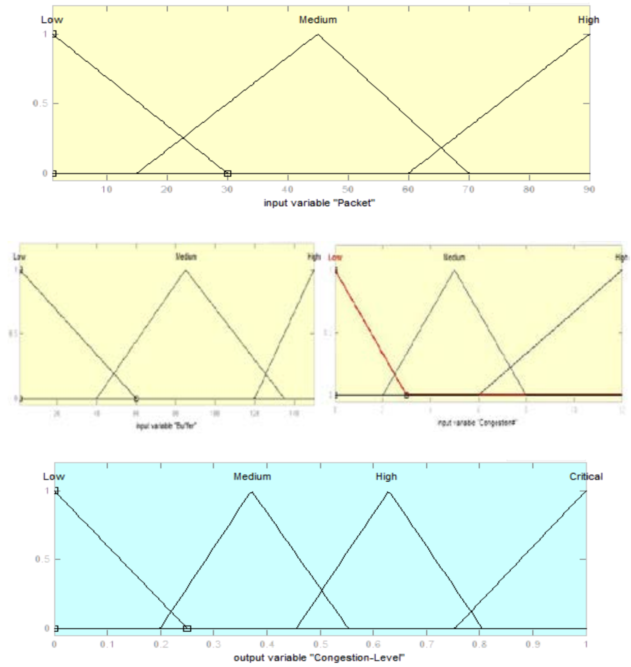


Fig. 5 Membership function for intermediate nodes

Table 2: Fuzzy rules at intermediate nodes

S#	Packet Length	Buffer	Congestion#	Congestion-Level
1	High	Low	Low	Medium
2	Medium	Low	Medium	Medium
3	High	Low	Medium	Medium
4	Medium	Low	High	Medium
5	High	Low	High	Medium
6	Medium	Medium	Low	Medium
7	High	Medium	Low	High
8	Low	Medium	Medium	Medium
9	Medium	Medium	Medium	High
10	High	Medium	Medium	Critical
11	Low	Medium	High	Medium
12	Medium	Medium	High	High
13	High	Medium	High	Critical
14	Low	High	Low	Medium
15	Medium	High	Low	High
16	High	High	Low	Critical
17	Low	High	Medium	High
18	Medium	High	Medium	High
19	High	High	Medium	Critical
20	Low	High	High	High
21	Medium	High	High	Critical
22	High	High	High	Critical

After the process of sending and receiving packets, each intermediate node at each moment determines the congestion level based on the size of the buffer, the frequency of congestion, and the length of the transmitted packet.

After determining the congestion level at each node, the congested node, according to the congestion, sends its own status to the other nodes over the network. If the congestion level is moderate, the congested node announces to 1/2 of the upstream nodes to find a new alternative route for packet transmission. If the congestion level is high, the congested node announces for replacing a new alternative route to 2/3 of its upstream nodes. If the congestion level is critical, the intermediate node notifies the source node to reduce its transmission rate as well as to find a new alternative path. The algorithm procedure is shown in Figure 6.

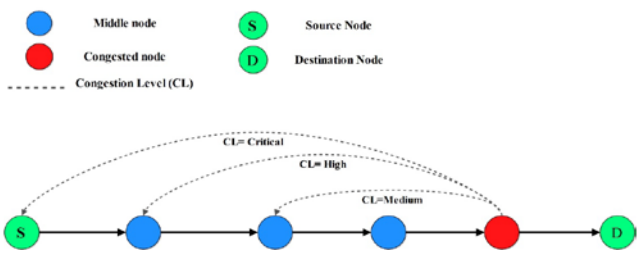


Fig. 6 Algorithm process at intermediates nodes

Nodes begin to extract information at the start of the simulation time. This information includes the buffer node, packet length, and the congestion level. This information is examined at each moment and delivered to the fuzzy system existing in each node. Then, depending on which level the nodes are at, the congestion level (CL) of each node is determined. At this point, when the level of congestion is detected, a warning message is put into the ACK packet and sent to the upstream node. The intermediate nodes receive this message and inspect it. If the message destination is this node, then it reads the content of the packet and sends its command to the network layer. If the node is not the destination of this message, it will be sent to the upstream node and the same procedure will continue until the time of simulation finishes.

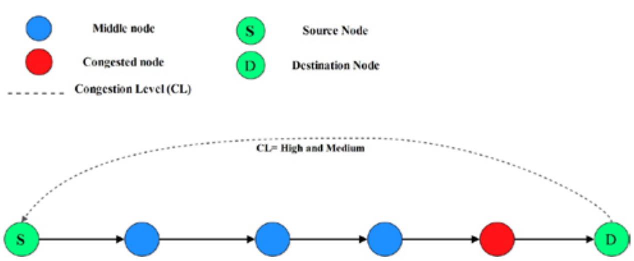


Fig. 7 Algorithm process at the target node

In the proposed method, for the target node, fuzzy systems that deal with TCP and UDP packets are considered separately because of different behaviors. Also with regard to the overall objectives of the network contribution to the congestion control problem, packet loss rate is used as an important parameter in the system.

In what follows, the membership function values of each parameter for the number of nodes, packet length, and packet loss rate in Table III, IV and V are shown respectively. Their rules are also shown in Table VI.

Table 3: Membership function for hop numbers

Up to 40% × node	Low
40% × node to 60% × node	Medium
60% × node to 90% × node	High

Table 4: Membership function for packet length

Up to 30% × PL	Low
30% × PL to 60% × PL	Medium
60% × PL to 90% × PL	High

Table 5: Membership function for packet loss rate

Up to 30% × PLoss	Low
30% × PLoss to 60% × PLoss	Medium
60% × PLoss to 90% × PLoss	High

The target node, just like the intermediate nodes, will monitor the network behavior. The difference is that the important parameters in the target are different from those existing in the intermediate nodes. Each of the three parameters such as packet length, the number of nodes in the route, and packet loss rate can determine congestion in the network. Depending on the type of the packet, the target node can choose different situations. For example, UDP packets have more tolerance capability when congestion occurs. Therefore, by reducing the transmission rate and service quality, they can send the data in the network. But it is not the same for TCP packets because of requiring a permanent connection.

As shown in Figure 7, after extracting information, determining the level of congestion and packet type (TCP or UDP), the target node puts its message in the ACK packet and sends it directly to the source. When the source receives the ACK packet, it executes its command (to redirect route or to reduce the transmission rate). In fact, these commands are sent to the network layer and the transport layer at the source node.

Table 6: Fuzzy rules at intermediate nodes

S#	Packet Length	Hop#	Packet Loss	Congestion-Level
1	High	Low	Low	Medium
2	Medium	Low	Medium	Medium
3	High	Low	Medium	Medium
4	Medium	Low	High	Medium
5	High	Low	High	Medium
6	Medium	Medium	Low	Medium
7	High	Medium	Low	High
8	Low	Medium	Medium	Medium
9	Medium	Medium	Medium	High
10	High	Medium	Medium	Critical
11	Low	Medium	High	Medium
12	Medium	Medium	High	High
13	High	Medium	High	Critical
14	Low	High	Low	Medium
15	Medium	High	Low	High
16	High	High	Low	Critical
17	Low	High	Medium	High
18	Medium	High	Medium	High
19	High	High	Medium	Critical
20	Low	High	High	High
21	Medium	High	High	Critical
22	High	High	High	Critical

The behavioral pattern of the target node is shown in Figure 3-6. As can be seen, the input information includes the packet loss rate, packet length, and the number of nodes extracted in the route and sent to the fuzzy system. Congestion is detected based on the fuzzy system rules. Then, at the next step, after determining the level of congestion, the fuzzy system sends a message to the source. It should be noted here that if congestion is not medium or high or critical, then it is low resulting in continuing the normal operation of the nodes in the network. The pseudo-code algorithm for intermediate node and destination node are shown in Figure 8 and Figure 9 respectively.

```
Begin
  // Start simulation and Getting Node Informations in during simulation time for cheking node's status
  // N_b=Node's buffer
  // N_p=Node's Packet Length
  // N_c=Node's Congestion Status
  // CL=Congestion Level
      Input: N_b, N_c, N_p
  // Performing Fuzzy rules based on input informations:
      If N_p=Low and N_b=Low and N_c=Low then CL=Low
      If N_p=Medium and N_b=Medium and N_c=Low then CL=Medium
      If N_p=Medium and N_b=Medium and N_c= Medium then CL=high
      …
      If N_p=High and N_b=High and N_c= High then CL=Critical
  // Conditional congestion control rules based on CL
      If CL=Medium Then put warning message in ACK and send to 1/2 upstream node
      Else if CL=high Then put warning message in ACK and send to 2/3 upstream node
      Else if CL=Critical Then put warning message in ACK and send to source node
      Else send ACK without warning message
  // When warning message received in intermediate node
  // Then Check Congestion Level in Node
  // If this node is destination node D_n=True else D_n=false
         If CL=Medium or CL=High and D_n=True Then send received message to network
      layer for discovering new route
      Else D_n=False Then send ACK to upstream node
      If CL=Critical and D_n=True Then send received message to Network Layer for
      discovering new route and to Transport Layer for decreasing transmission rate
      Else D_n=False Then send ACK to upstream node
// Continue until get to the end of simulation time
  End
```

Fig. 8 pseudo-code for intermediate nodes

```
  // Destination node Get Node Informations in during simulation time
  // P_L=Packet Length
  // P_Loss =Packet Loss
  // H_n=number of Intermediate nodes between Source and Destination
  // CL=Congestion Level
      Input: P_L, N_c, Hop#
  // Performing Fuzzy rules based on input informations:
      If P_L=Low and P_Loss=Low and H_n=Low then CL=Low
      If P_L=Medium and P_Loss=Medium and H_n=Low then CL=Medium
      If P_L=Medium and P_Loss=Medium and H_n= Medium then CL= Medium
      …
      If N_p=High and N_b=High and N_c= High then CL=High
  // Conditional Goal Based congestion control
  // If this node is destination node FD_n=True else FD_n=false
  // P_T=Packet Type

      If CL=Medium and and FD_n=True and Then P_T=TCP put warning message in ACK
and send to Source node
      Else if CL=high and FD_n=True and Then P_T=UDP Then put warning message in
ACK and send to Source node

  // When warning message received in Source Node
  // Then Check Congestion Level in Node
         If CL=Medium and D_n=True and P_T=TCP Then send received message to
      network layer for discovering new route
         If CL=Medium and D_n=True and P_T=UDP Then send received message to
      Transport Layer for decreasing transmision rate.
       If CL=High and D_n=True Then send received message to Network Layer for
      discovering new route and to Transport Layer for decreasing transmission rate
// Continue until get to the end of simulation time
   End
```

Fig. 9 pseudo-code for destination nodes

To change the route, the same path where the congestion nodes are not used. On the other hand, in our DSR algorithm, the nodes with congestion are removed from the neighborhood table. In this situation, it is possible that there is not an appropriate route to the target node and then packets are sent via the primary route without changing the route. This process continues until the packet reaches the target. As mentioned in the target node, based on whether the transmitted packet is a TCP or a UDP, the packet is determined to continue the process.

4. Performance Evaluation

In this simulation, both the sender and the receiver exist. A sender and a receiver are considered for both TCP and UDP. All intermediate nodes are distributed randomly in a square area with dimensions of 20 by 20 square meters. Other simulation parameters for this scenario are given in Table VII. It is assumed that source and target nodes are fixed in place. First, a random traffic is created at any intermediate node. Then, each node will create a table as a neighborhood table. In fact, each node calculates its distance from all nodes on the network. If it is less than the communication range of that node, it is chosen as a neighborhood node. Given that the nodes are mobile and change their distance, at each step, the neighborhood table will be updated.

Table 7: Simulation parameters

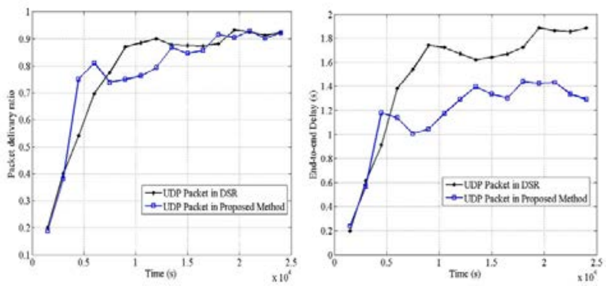
Parameters	Values
Topology	Random
Antenna	Omni Directional
Nodes	40,60
Routing Algorithm	DSR
Speed Model	Random Way point
Speed	0.5 m/s
Dimension	20×20
Simulation Time	10 minutes
Packet Size	30

The outputs of the control method are evaluated for two networks with 40 and 60 nodes. As previously mentioned, according to the type of packets, availability in the transport layer can affect the congestion control procedure. In simulation, these two kinds of packets are considered as the important parameters of the target node. During congestion, the proposed method will behave differently from TCP and UDP packets.

At first, the proposed method is evaluated in a network with 40 nodes. Then, in order to evaluate the proposed method in more congestion conditions, a network with 60 nodes was examined.

In Figure 10-(a), it is shown that in the early times of the simulation, the packet delivery ratio of the proposed algorithm is high in UDP packets, but over time the process is reduced. When the simulation reaches the end, the rate is increasing.

In Figure 10-(b), the time delay for UDP packets is examined. At the beginning of the simulation in this figure, delay increases due to the use of fuzzy logic systems. Then, according to the mechanism used for UDP packets, when network traffic increases, better performance is observed in the network. Therefore, delay is reduced compared with DSR algorithm.

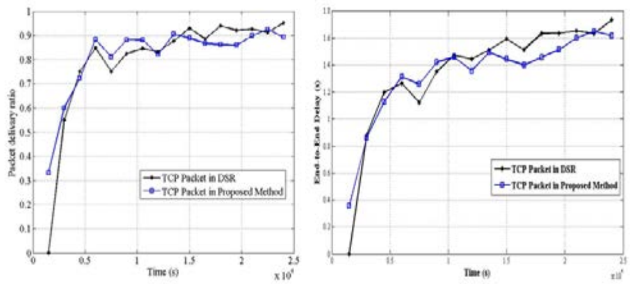


(a) (b)

Fig. 10 Packet delivery ratio with 40 nodes for UDP packet (a). Packet delivery ratio with 60 nodes for UDP packet (b).

For TCP packets, as indicated in Figure 11-(a), at the start of simulation, packet delivery rate is high like UDP packets. But in the simulation process, it can be seen that packet delivery decreases due to network congestion. As is known, when the simulation time approaches to half, the packet delivery rate has a little fluctuation. Figure 11-(b) shows the delay for TCP. Given that for TCP packets the route change is used instead of the transmission rate, it is observed that the delay of the proposed method is much improved compared to the case of using UDP packets. As can be seen, at the end of the simulation time, low delay in the proposed method is achieved compared to a standard DSR.

For end-to-end network delay, it is observed that delays in UDP packets are low and in TCP packets are improved compared to DSR algorithm. In case the proposed algorithm is used, high load was reached. In the proposed algorithm, even if the buffer of the first intermediate node becomes full, the packet is sent to other nodes and, therefore, this increases the network load. But when the proposed algorithm is not used and the path between the source and the destination does not exist, sending of the packet stops because the first node buffer is full. So, on average, load is high when the proposed algorithm is used.



(a) (b)

Fig. 11 Packet delivery ratio with 40 nodes for TCP packet (a). Packet delivery ratio with 60 nodes for TCP packet (b).

In Figure 12, the proportion of packets sent to reach the destination or the packet loss is shown. It is observed that the packet loss at the beginning of the simulation is a bit more and this trend is reduced further on. As shown, in general, the packet loss of our proposed algorithm is less.

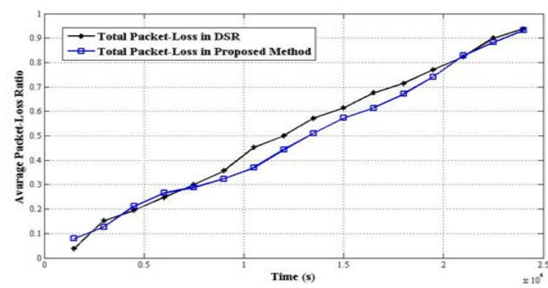


Fig. 12 Total packet loss ratio

Finally, in Figure 13, the network throughput with the proposed method adopted has been demonstrated. It is observed that at the beginning when the network load increases, throughput decreases. But during the simulation time, due to congestion detection and control according to our proposed mechanism, network efficiency reduces its downward trend and increases its upward trend, while in DSR algorithm the network throughput reduces when the network load increases. As a result, the throughput graph shows the throughput of the proposed method is more efficient than that of the DSR standard algorithm.

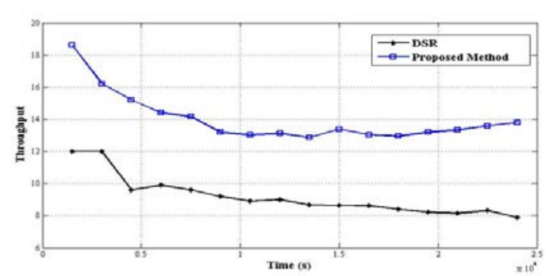


Fig. 13 Total Throughput

5. Conclusion and Future Work

Due to the fact that mobile networks are multi-hop networks, a high data transfer rate causes congestion in this network. The proposed method has three features, namely detection, notification, and adjustment of the transmission rate. Congestion is detected given buffer conditions and the number of times that the buffer becomes full. At the notification step, given the congestion level determined by the fuzzy controller, upstream nodes are informed. Finally, at the step of adjusting the transmission rate, according to the congestion level of each node, they adjust their transmission rate. The characteristics of the proposed method can be summarized as follows:

- Rapid detection of congestion
- Congestion notification commensurate with the level of congestion on the network
- To prevent congestion again in a route
- To consider both TCP and UDP packets at the transport layer

Although there are improvements in evaluation parameters compared with DSR algorithm given the evaluated results of the proposed method, some other methods can be used with fuzzy logic systems to control and to adjust layers such as clustering for bandwidth fairness, game theory in the media access layer for competitive space, and learning algorithms such as the Queue learning algorithm in the network layer for correct and useful routing. In fact, these methods create a network that is in the process of a cognition in which the dynamic characteristics of mobile networks will be more compatible. As a result, using the above methods and their cross-layer cooperation, the nodes can better and more optimally adjust the transmission rate based on observation and knowledge.

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