A FUZZY APPROACH FOR REPRESENTATIVE NODE SELECTION IN CROSS LAYER TCP

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ABSTRACT

A cross-layer based improved Transmission Control Protocol (TCP) protocol ensuring fair throughput and reliability was proposed in the previous investigations. In this protocol, data path was segmented, and representative nodes are maintained in every segment for any TCP connection. A Transmission Controller Module (TCM) is used by the representative node to determine bandwidth and delay in transmission and a Local Acknowledgement (LACK) message is sent to the source. Each LACK's reception source calculates congestion window's desired size, based on the forward path bandwidth, and Round Trip Time (RTT) values on forward path thereby avoiding congestion for larger extents, and increasing network data transmission rate. This study proposes to extend TCP. Representative nodes use fuzzy logic concept, dynamically. A node becomes a representative node when its two hop neighbours have poor link quality, high mobility and reduced bandwidth. The fuzzy rule generated in this study ensures increased throughput and reduced delay compared to conventional TCP.

Keywords: *Transmission Control Protocol (TCP), Local Acknowledgement (LACK) message, Fuzzy Logic, Fuzzy Rule*

1. INTRODUCTION

Mobile Ad-Hoc Networks (MANETs) are dynamic networks without fixed infrastructure because of their wireless nature, deployed as multi-hop packet networks. It has dynamic topology due to node mobility [1]. MANETs are known for self-organizing capabilities, and rapid deployment ensuring that MANETs are used for rescue forces in emergencies [2]. MANETs are a collection of many mobile nodes forming temporary networks without any central access point. MANET's characteristics like dynamic topology, node mobility, ensure more freedom and self-organizing capability differentiating it from other networks. MANET applications are diverse and range from large, mobile, dynamic networks, to small, static networks constrained by power sources. In addition to legacy applications that change from traditional infrastructure environment to an ad hoc context, many new services can and are generated for new environments. It includes military battlefield, sensor networks, commercial sector, medical service, personal area network [3].

Transmission Control Protocol (TCP) is a transport protocol guaranteeing reliable data packets over wired networks. Tough tuned for wired networks, TCP performance is wanting in MANETs because TCP's assumption of congestion being responsible for packet loss is invalid in MANETs where wireless channel errors, link contention, mobility and multipath routing can corrupt packet delivery. When TCP misinterprets losses as congestion invoking congestion control procedures, it results in performance degradation and unfairness [4].

TCP is a connection-oriented protocol tuned to perform for wired links and stationary host networks. It is a reliable protocol adapting to network requirements and regulating packets it sends by inflating/deflating a window. For this, TCP sender uses cumulative acknowledgements from the receiver. TCP adapts to wired link problems. The main issue is delay due to packet losses through congestion. Regular TCP congestion control scheme has three main parts when implemented:

1. Slow-start

2. Congestion avoidance

3. Fast Retransmit.

Regular TCP was not designed for mobile hosts and so regular TCP cannot be expected to perform well in mobile networks. Figure 1 shows the taxonomy of Protocols to improve the performance of TCP on mobile networks. A reason for this is that wired links have low Bit Error Rates (BER), in contrast to wireless links which suffer from high bit error rates [5].
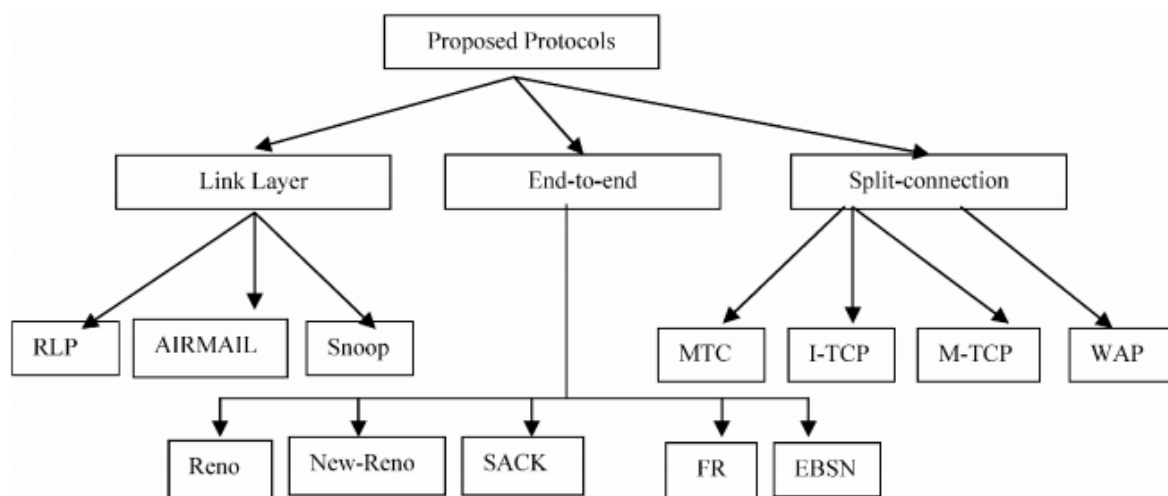

Figure 1: Protocols to improve the performance of TCP on mobile networks.

The TCP protocol was extensively tuned for good performance at the transport layer in conventional wired networks. However, TCP in its present form does not suit MANETs where broken routes related packet loss results in the counterproductive call of TCP's congestion control mechanisms. Though many studies are conducted and protocol modifications suggested, improving TCP performance in MANETs is still under study. Performance studies have focused either on specific protocols or are restricted to single TCP connection [6].

Link Quality algorithms are classified through various criteria, one being the type of input that the algorithm's use for prediction. Inputs can be location measurements, signal-power measurements or other measurements like the ratio of transmitted to received packets in a time interval. Input type is an important criterion by which to classify LQP algorithms as it represents algorithms focus. Signal-power measurements based predictions focus on radio propagation model while predictions based on location measurements focus on mobility model. Another criterion which classifies existing algorithms is LQP output. If the output is a finite set of states subset, the prediction is classified as deterministic. Usually, deterministic prediction algorithms have two possible output states; packets are predicted as either lost or received for some time in the future. If LQP algorithm output is an infinite set of states subset, the prediction is classified as stochastic as output is such cases is usually a probability. Another classification criterion is LQP application. Successful applications are found in routing, multicast communication, group communication and clustering. A final classification criterion is radio propagation model based on LQP algorithm. As link quality is dependent on radio propagation model, algorithms focusing on location measurements and mobility models are explicitly/implicitly derived with regard to specific radio propagation models [7].

In this research, the extension of TCP is proposed. The representative nodes are dynamically selected using fuzzy logic concept. A node can become representative node if its two hop neighbours have poor link quality, low bandwidth and high mobility. The rest of the paper includes literature survey of related works, materials and methods used and results.

2. RELATED WORKS

A cross-layer design for TCP throughput optimization in cooperative relaying networks was proposed by Wei, et al., [8]. The authors investigated TCP throughput in cooperative relaying networks and resorted to a cross layer design approach when selecting a relay for TCP throughput optimization. Compared to the suggested scheme under different physical layer and link-layer parameter simulations it was revealed that TCP throughput improved greatly through the use of optimal relay selection scheme.

TCP congestion control using fuzzy regulation approach was proposed by Lian, et al., [9] which included a Takagi-Sugeno (T-S) fuzzy controller for Active Queue Management (AQM) with Explicit Congestion Notification (ECN) for improving Internet communications performance. Compared to other AQM schemes, experiments showed that suggested AQM had improved performance regarding packet loss, throughput and queue length fluctuation.

A fuzzy logic congestion control in TCP-IP differentiated service networks for quality of service provisioning was proposed by Chrysostomou, et al., [10]. A brand new AQM scheme ensuring congestion control in TCP-IP networks using a fuzzy logic control approach was presented. The fuzzy control method offered major improvements to control congestion in TCP-IP Diff-Server networks providing quality of service.

A delay-based approach using fuzzy logic for improving TCP error detection in ad hoc networks was proposed by Oliveira and Braun [11].The authors investigated fuzzy logic theory to assist TCP error detection mechanism in networks. An elementary fuzzy logic engine was an intelligent technique to discriminate packet loss caused by congestion due to wireless induced errors packet loss.

An energy efficient cross-layer routing protocol in WSN based on fuzzy logic was proposed by Jaradat, et al., [12] which suggested an energy aware routing scheme based on a cross-layer approach for WSNs aimed at minimizing overall consumed energy and thereby increasing network life. The proposed cross-layer algorithm's performance was evaluated using discrete event simulation

A new cross layer TCP pacing protocol for multi-hop wireless networks was proposed by Xie [13]. The authors proposed a cross layer TCP pacing protocol through control of contention window's lower bound for optimization of overall TCP throughput on multi-hop topology. Comparison of simulations was done to verify the proposed protocol's improvement.

The impact of hidden node collisions on multi-hop TCP flows performance was focused on by Valletta, et al., [14] which traced the issue of collisions between RTS frames from starved flow and long data frames from active flow. Such collisions result in rapid MAC contention window increase at TCP sender of starved flow; this along with TCP's congestion control algorithm allows running flow to hold channel for long till the situation is reversed. They revealed that a multi-channel MAC can ease flows competition.

A Div-TCP solution running ordinary TCP algorithm with two extra operations regarding the handoff process was proposed by Assaf [15]. The operations are triggered by Div-TCP when the handoff is anticipated. Retransmission Time Out (RTO) is concerned with ensuring a suitable RTO at every node in end-to-end connection to prevent triggering congestion algorithms where Buffer Division (BufDiv) maintains sender's throughput by creating a TCP connection before the occurrence of handoff.

A cross layer approach enhancing TCP performance over wireless networks was proposed by Priya and Murugan [16]. A new cross-layer approach (Link Layer CLAMP) which avoided TCP Acknowledgement (ACK) packet transmission over a wireless channel was proposed, saving time which can be used by nodes for data packet delivery.

A cross-layer interaction of TCP and ad hoc routing protocols in multi hop IEEE 802.11 Networks was proposed by Mahmoodi, et al., [17] where a TCP-aware dynamic ARQ algorithm was proposed to use TCP timing information for prioritized ARQ packet retransmissions. Numerical investigation of the proposed algorithm improved performance through this approach when compared to TCP-agnostic link-layer approaches.

A cross-layer mechanism for TCP connection over wireless uplink in cellular networks was proposed by Yu and Yin [18]. It controlled the retransmission timer startup in TCP layer at MH according to information from radio link control (RLC) layer, enabling TCP protocol to operate over uplink without suffering packet losses due to fading channel and mobility. Additionally, implementation of the proposed mechanism only needed modifications of MH protocol stack.

The problem of transport layer protocols performance degradation due to of wireless local area networks congestion was presented by Kliazovich and Granelli [19]. After analysis of available solutions, a cross-layer congestion avoidance scheme (C3TCP) capable of higher performance by gathering capacity information like bandwidth and at the link layer delay was presented.

3. METHODOLOGY

This work proposed to improve LACK protocol by proposing QOS parameter estimation and selection of representative node using fuzzy logic. Detailed discussion of each technique is discussed.

3.1 Overview

Delay and bandwidth estimation is performed at destination and transmitted to the source to reveal successful data reception. When node number which is to traverse network increases it leads to increased network delay caused by the fact that path length to be traversed is proportional to delay in data transmission. Hence, acknowledgement message reception at source consumes much time and increases network delay problem resulting in network congestion.

This research develops an improved TCP protocol to offset the above problems. The data transmission path is split into segments initially in this protocol. A representative node is maintained for bandwidth and delay calculation for every segment. On receipt of data packet, the representative node generates a Local Acknowledgement (LACK) message and forwards it to source with calculated bandwidth and delay value. The representative node transfers it to next representative node in the destination path. The source on receipt of LACK message determines bandwidth and delay value and estimates congestion window accordingly. Thus, in this protocol, Delay and bandwidth involved in data transmission are estimated faster thereby maximizing network efficiency.

3.2 Bandwidth and Delay Estimation

3.2.1 Bandwidth estimation

Bandwidth B available for transmission of certain data is got by knowing the size of data D and time T taken for transmission of data over specific link.

Bandwidth is calculated by

$$B = \frac{D}{T} \qquad (1)$$

where

$$T = T_{in} - T_{out} + T_{tr} \qquad (2)$$

T is the time required for transmission of a single data packet using CSMA/CA.

T_{in}-T_{out} includes data queuing delay that corresponds to time a node was waiting for all nodes to finalize pending transmissions and also channel to channel access delay using random back off and optional RTS/CTS exchange.

T_{tr} is the time required for data frame transmission and corresponding acknowledgement.

It is necessary to consider the framework used by the physical layer. According to physical and link layer specifications, time required for data packet delivery (including data frame and corresponding ACK) is calculated as follows:

$$T_{tr} = T_{data} + SIFS + T_{ack} + DIFS \qquad (3)$$

$$T_{data} = \frac{PLCP.preamble + PLCP.header}{Basic\,rate} + \frac{MAC.header + FCS}{Data.Rate} \frac{Data}{Data.Rate} \qquad (4)$$

$$T_{ack} = \frac{PLCP.preamble + PLCP.header}{Basic\,rate} + \frac{ACK.header + FCS}{Data.Rate} \qquad (5)$$

The bandwidth measurement algorithm is the following:

1. Store timestamp T_{in} for data arrived at the link layer for further transmission. Data can arrive from other nodes for forwarding or it can be generated by upper layers of the protocol locally.

2. Prior data frame transmission, at time T_{out} calculates time for packet delivery including

queuing and packet transmission time T_{tr} using Equation (3).

3. Calculate bandwidth experienced by packet using Equation (1).

3.2.2 Delay estimation

In proposed delay estimation technique forward and backward delays are differentiated. Forward delay has data pipe length between the sender and receiver nodes while backward delay measures time needed for TCP ACK packets delivery.

1. Forward delay: A data burst's single-hop forward delay includes channel access delay; time needed for data delivery to the physical layer including related physical and link layer overhead. It excludes link layer queuing delay.

Forward delay is calculated using Equation (2) setting T_{in} to be equal to time packet leaves queue preparing for actual transmission on link layer. Such estimation avoids insertion of link layer queuing delay to the T_{in} - T_{out} component.

$$D_{forward} = T_{tr} \qquad (6)$$

2. Backward delay. TCP reliability is achieved by implementing a positive acknowledgement scheme. The receiver acknowledges successful data delivery with TCP ACK packets going back to sender.

Contrary to forward delay measurement technique described, TCP ACK delay includes transmission and queuing delays, i.e. equal to the difference between time TCP ACK packet was generated by receiver node and reception by TCP sender. Single link backward path delay is calculated using Equation (2).

$$D_{backward} = T_{in} - T_{out} + T_{tr} \qquad (7)$$

Total delay $D = D_{forward} + D_{backward} \qquad (8)$

3.3 Link Quality

The link quality is estimated on the basis of Expected Transmission Count (ETX) [20] in this study. The route with least expected number of transmission is found using ETX metric. It finds routes with high throughput regardless of loss in packets [20]. The predicted number of transmission required to send a packet through a link gives the ETX of a link and sum of link ETX in a route gives the route ETX. The ETX of a link is computed based on forward delivery ratio, d_f, and reverse delivery ratio, d_r, of the link. The probability of a packet arriving successfully to the destination is d_f and the probability of the ACK packet successful received is d_r and $d_f \times d_r$ gives the expected probability of a transmission that is successfully received and acknowledged. Retransmission from a sender occurs only when packet is not successfully acknowledged. The expected number of transmissions is:

$$ETX = \frac{1}{d_f * d_r} \qquad (9)$$

3.4 Protocol Functionalities

1] The path involved in TCP data packet transmission from source S to destination D is divided into segments with each segment having a node called as representative node R being maintained for delay estimation and bandwidth.

2] The path is divided into predetermined hop count based segments.

3] Representative node selection is based on maximum bandwidth capability i.e., node within predetermined hop count supporting maximum bandwidth and reduced delay is chosen as representative node.

4] A Transmission Controller Module (TCM) is inserted in each representative node below transport layer to avoid changes at protocol stack's transport layer.

5] When data packet is transmitted from source S to first representative node R1, TCM asks for bandwidth required and transmission if any from the link layer. This is delivered with TCP data packet.

6] R1 sends a LACK message with MAC header to source.

7] TCM traces outgoing LACKs having access to TCP data packet headers. If produced LACK acknowledges received TCP data packet, TCM forwards request to link layer to include stored bandwidth–delay information into MAC-layer header of outgoing TCP data packet.

8] MAC header includes measured bandwidth and delay value in the option field. ''Options'' is a variable length field extending standard MAC header and consists of ''Header Length'' field that specifies the total length of MAC header, including options list. Header length has to perform data

separation encapsulated in the frame from MAC header.

9] At source's side, TCM requests end-to-end measurements from link layer on receipt of LACK message and then calculates the congestion window's desired size based on the forward path's bandwidth and RTT values.

10] Source S transfers next data packet to the destination.

11] Meanwhile representative node R1 forwards data packet to destination through remaining intermediate and representative nodes.

12] Representative node R2, on receipt of data packet calculates delay and bandwidth involved and sends LACK message to R1.

13] R1 on receipt of LACK message calculates congestion window based on bandwidth and delay values delivered.

14] Representative node R1 forwards next data packet to representative node R2.

15] Data packets are also transferred through intermediate and representative nodes till destination is reached.

16] On receipt of data packet at destination, an end to end acknowledgement (ACK) message is generated along with LACK message at destination D. LACK message is forwarded to previous representative node and ACK message to the source.

Transport layer functionalities are divided into congestion control and end-to-end reliability. Correspondingly, the transmission window at source is also split into congestion window and end-to-end window. The congestion window is always a sub-window to the end-to-end window. While congestion window changes with rate of arrival of LACKs from next proxy, end-to-end window changes with rate of arrival of end-to-end ACKs from destination.

3.5 Protocol Architecture & Flowchart

Data packet transmission from source to destination is shown in figure 2. It is assumed that predetermined hop count is four. Representative nodes are R1 and R2. On receipt of data packet at representative node R1, a LACK message is generated and forwarded to source by R1 includes estimated bandwidth and delay value. R1 forwards data packet to R2. On receipt of LACK message at source, it transmits next data packet to R1. When R2 receives data packet, it transmits LACK message to R1 and forwards data packet to the destination node, D. The latter on receipt of data packet, generates LACK and end to end acknowledgment message, ACK. Destination node, D forwards LACK message to R2 and ACK message to the source.
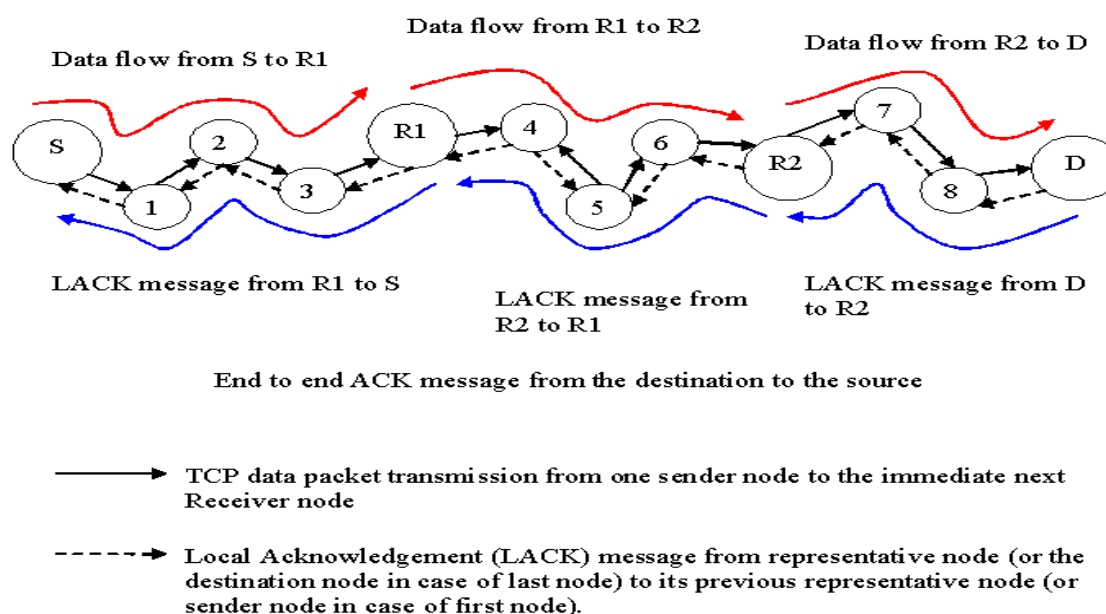

Figure 2: *Data packet and LACK message transmission through the representative nodes.*

The suggested protocol has following advantages:

- It handles congestion control and end to end reliability separately reducing control overhead.

- It uses cross-layer interactions with MAC

- It adapts to changes in topology.

- It ensures improved throughput for contesting flows.

3.6 Fuzzy Logic Control

The fuzzy logic control model includes fuzzy rules, fuzzifier, fuzzy inference engine, and defuzzifier. The common fuzzy inference technique called Mamdani Method [21] is used as it is simple. The process has four steps:

- Fuzzification of input variables energy, concentration and centrality - taking crisp inputs from these and determining the degree to which inputs belong to appropriate fuzzy sets.

- Rule evaluation - taking the fuzzified inputs and applying them to fuzzy rule antecedents. It is applied to consequent membership function (Table 1).

- Aggregation of rule outputs - process of unification of rules outputs.

- Defuzzification - input for defuzzification process is aggregate output fuzzy set chance and output is one crisp number.

During defuzzification, it locates the point where a vertical line slices aggregate set chance into two equal masses. The Centre of Gravity (COG) is calculated over points sample on aggregate output membership function using the following formula:

$$COG = \left(\sum \mu_A(x) * x / \sum \mu_A(x) \right) \qquad (10)$$

where, $\mu_A(x)$ is membership function of set A.

The system structure identifies the fuzzy logic inference flow from the input variables to the output variables. The fuzzification in the input interfaces translates analog inputs into fuzzy values. The fuzzy inference takes place in rule blocks which contain the linguistic control rules. The output of these rule blocks is linguistic variables. The defuzzification in the output interfaces translates them into analog variables.

The following figure 3 shows the whole structure of this fuzzy system including input interfaces, rule blocks and output interfaces. The connecting lines symbolize the data flow.
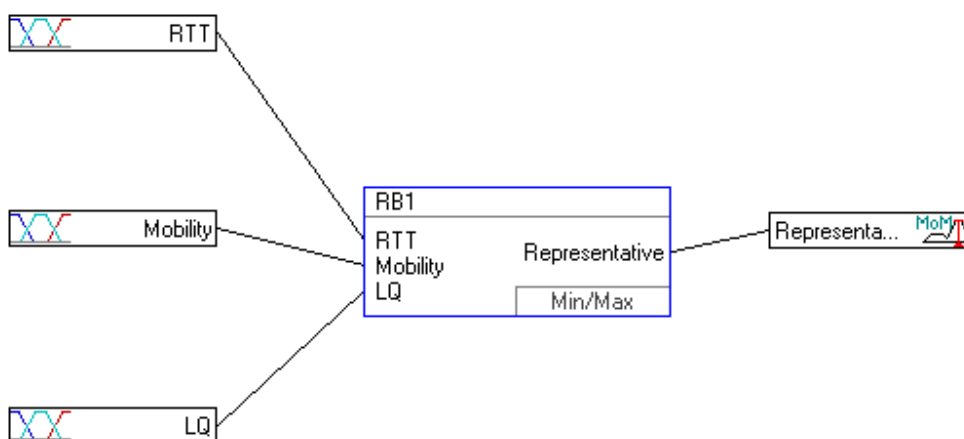

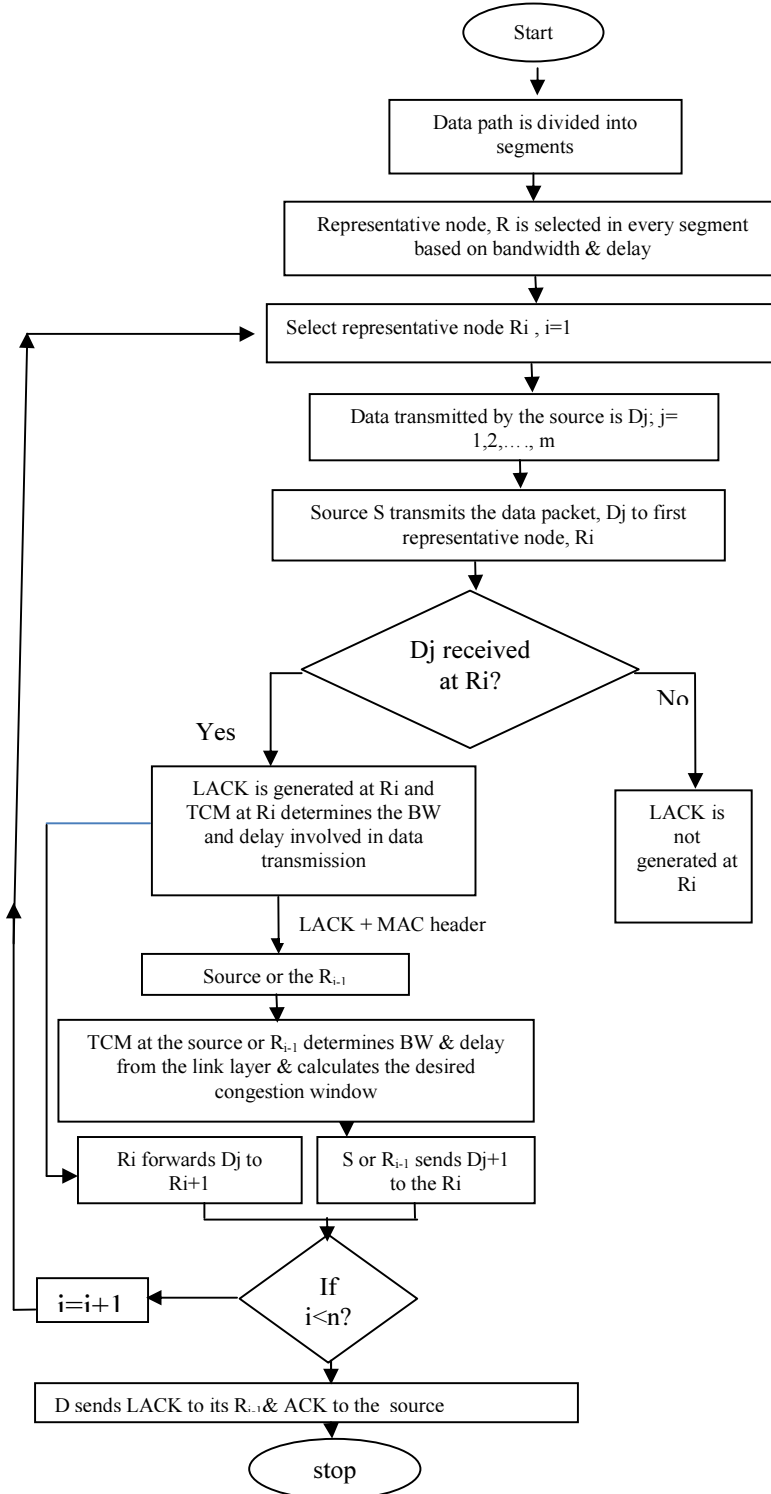*Figure 3: Structure of the Fuzzy Logic System*

Figure 4: Flowchart of Proposed Method

Variables

Inputs

Table 1: Variables of Group "Inputs"

#	Variable Name	Type	Unit	Min	Max	Default	Term Names
1	LQ		Units	0	1	0.5	low medium high
2	Mobility		Units	0	1	0.5	decrease steady increase
3	RTT		Units	0	1	0.5	low medium high

Outputs

Table 2: Variables of Group "Outputs"

#	Variable Name	Type	Unit	Min	Max	Default	Term Names
4	Representative		Units	0	1	0.5	negative zero positive

Input Variable "LQ"
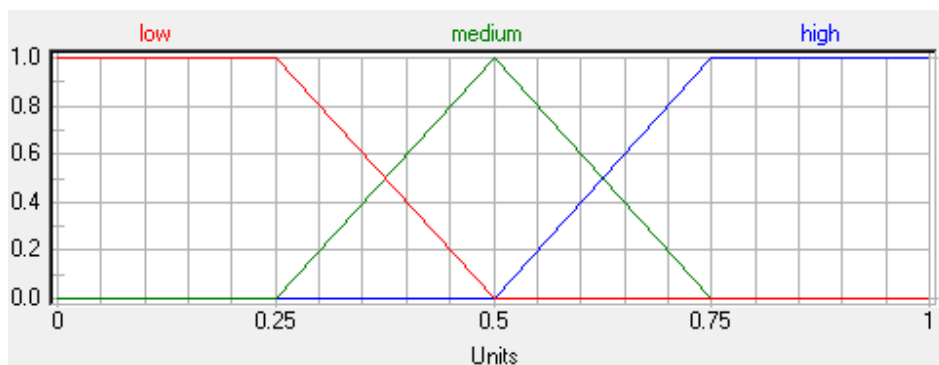
Figure 5: MBF of "LQ"

Table 3: Definition Points of MBF "LQ"

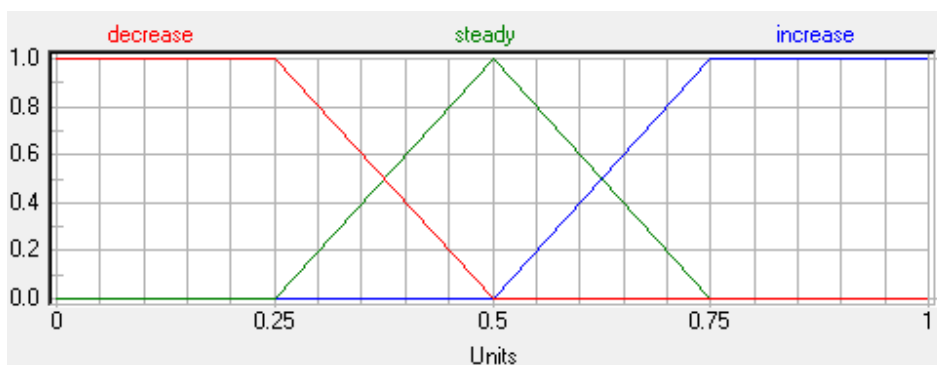| Term Name	Shape/Par.	Definition Points (x, y)		
low	linear	(0, 1) (1, 0)	(0.25, 1)	(0.5, 0)
medium	linear	(0, 0) (0.75, 0)	(0.25, 0) (1, 0)	(0.5, 1)
high	linear	(0, 0) (1, 1)	(0.5, 0)	(0.75, 1)

Input Variable "Mobility"

Figure 6: MBF of "Mobility"

Table 4: Definition Points of MBF "Mobility"

Term Name	Shape/Par.	Definition Points (x, y)		
decrease	linear	(0, 1) (1, 0)	(0.25, 1)	(0.5, 0)
steady	linear	(0, 0) (0.75, 0)	(0.25, 0) (1, 0)	(0.5, 1)
increase	linear	(0, 0) (1, 1)	(0.5, 0)	(0.75, 1)

Input Variable "RTT"
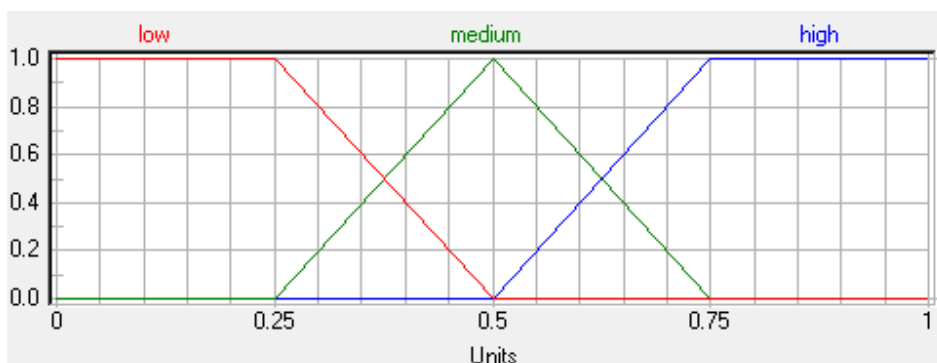
Figure 7: *MBF of "RTT"*

Table 5: Definition Points of MBF "RTT"

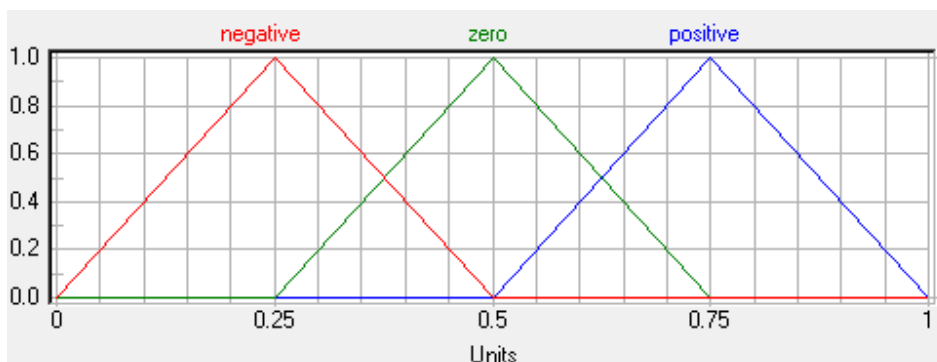| Term Name	Shape/Par.	Definition Points (x, y)		
low	linear	(0, 1) (1, 0)	(0.25, 1)	(0.5, 0)
medium	linear	(0, 0) (0.75, 0)	(0.25, 0) (1, 0)	(0.5, 1)
high	linear	(0, 0) (1, 1)	(0.5, 0)	(0.75, 1)

Output Variable "Representative"

Figure 8: MBF of "Representative"

Table 6: Definition Points of MBF "Representative"

Term Name	Shape/Par.	Definition Points (x, y)		
negative	linear	(0, 0) (1, 0)	(0.25, 1)	(0.5, 0)
zero	linear	(0, 0) (0.75, 0)	(0.25, 0) (1, 0)	(0.5, 1)
positive	linear	(0, 0) (1, 0)	(0.5, 0)	(0.75, 1)

Rule Blocks

Parameter

Aggregation:	MINMAX
Parameter:	0.00
Result Aggregation:	MAX
Number of Inputs:	3
Number of Outputs:	1

Table 7: Rules of the Rule Block "RB1"

IF			THEN	
RTT	**Mobility**	**LQ**	**DoS**	**Representative**
Low	steady	Low	0.94	negative
Low	increase	Low	0.73	positive
Low	increase	Medium	0.50	negative
Low	increase	Medium	0.11	positive
High	decrease	Low	0.84	positive
High	decrease	Medium	0.51	negative
High	steady	Low	0.71	positive
High	steady	Medium	0.31	negative
High	steady	High	0.60	negative
High	steady	High	0.63	positive
High	increase	Low	0.59	positive
High	increase	Medium	0.48	positive
High	increase	High	0.91	positive

4. RESULTS AND DISCUSSION

In this study, the extension of TCP is proposed. The representative nodes are dynamically selected using fuzzy logic concept. A node can become representative node if its two hop neighbours have poor link quality, low bandwidth and high mobility. The fuzzy rule generated in this research provide increased throughput with reduced delay, when compared with traditional TCP.
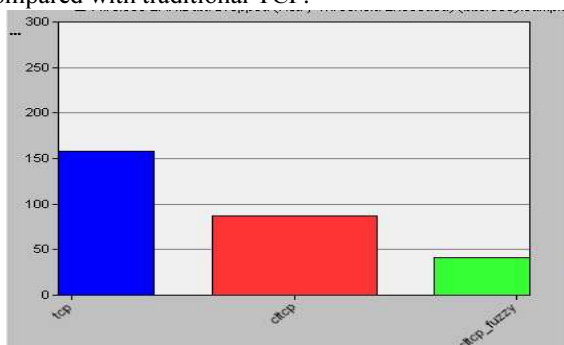

Figure 9: Average Data Dropped

From figure 9, it is shown that proposed fuzzy cross layer TCP provide low average data drop compared to TCP.
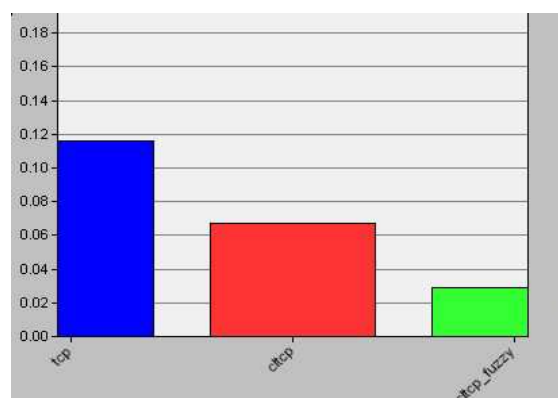

Figure 10: Average Retransmission Attempt

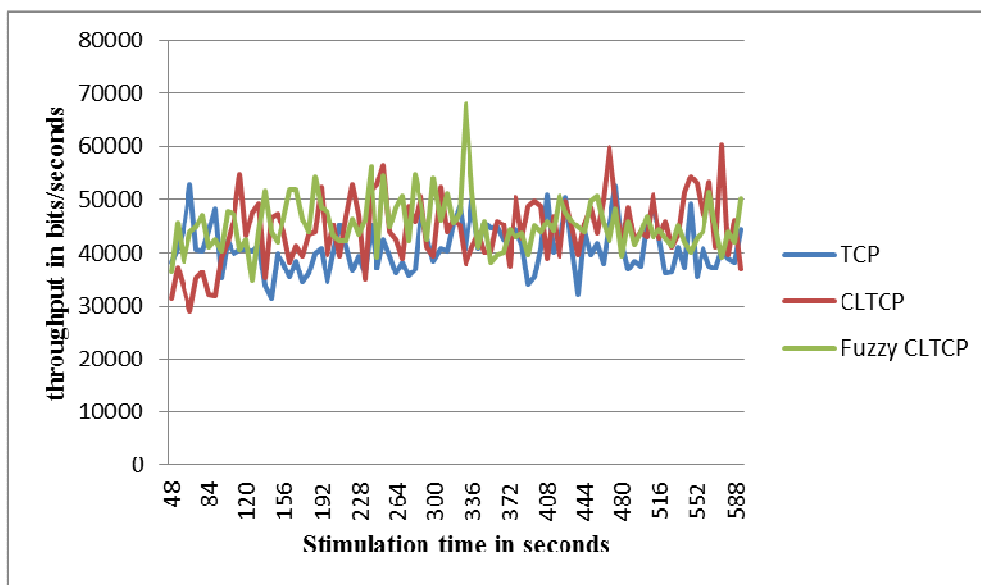Graph 10 shows that the proposed fuzzy Cross Layer TCP shows less average retransmission

Figure 11: Throughput in bits/seconds

From the figure 11, it is obtained that the proposed fuzzy Cross Layer TCP throughput increases at 11.1 % from TCP and 2.3% from CLTCP respectively
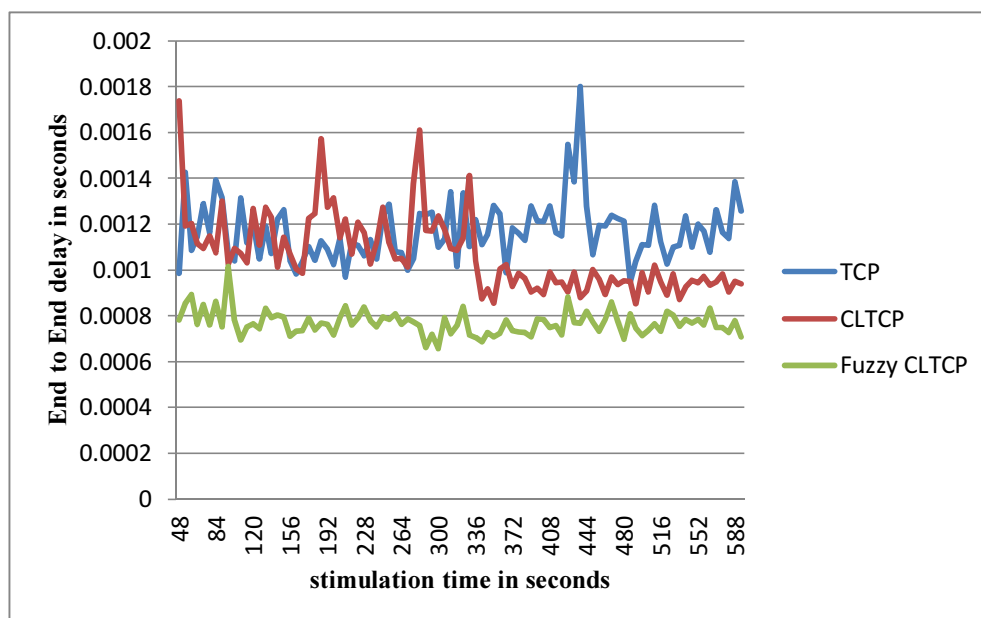

Figure 12: End to End delay in seconds

From the figure 12 it is obtained that the proposed fuzzy Cross Layer TCP End to End Delay decreases at 34.24 % from TCP and 27.94% from CLTCP respectively.

5.   CONCLUSION

This paper developed a fuzzy cross-layer based improved TCP protocol to ensure efficient data transmission in wireless ad hoc network assuring

fair throughput and reliability. The path selected for data packet transmission in this technique is divided into segments based on a predetermined hop count. In each segment, a representative node calculates bandwidth and delay involved. A congestion window is estimated from LACK message transmitted by representative nodes to the source or previous representative node on receipt of data packets. On receipt of LACK message, source sends next data packet. Data packets are thus transmitted to destination through representative nodes. On receipt of data packets at the destination, it generates LACK message with normal ACK message to be transmitted to source assuring end to end reliability. Hence this technique ensures congestion control with reliability and improved throughput. Simulation results revealed that the suggested protocol achieves, increased throughput with reduced delay when compared to conventional TCP and CLTCP.

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