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Development of an Intelligent Fuzzy-Based Algorithm for Data Congestion Management Scheme in Wireless LAN

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Abstract— ***Network congestion control remains a critical issue and a high priority, especially given the growing size, demand, and speed (bandwidth) of the increasing wireless services. Congestion control is the problem of managing network traffic or a network state where the total demand for resources such as bandwidth among the competing users exceeds the available capacity. This paper presents a fuzzy logic approach to congestion mitigation in TCP oriented network using University of Nigeria Nsukka (UNN) situated at the South-Eastern part of Nigeria as a case study. Using a deductive study mechanism, an intelligent fuzzy-based algorithm for the congestion management is developed while showing a validation analysis plot of the proposed scheme in relation to other TCP variants such as TCP Tahoe, TCP Reno, TCP-New Reno, TCP Vegas and TCP selective acknowledgments (SACKs), i.e.TCP-TRONVS. From the implementation of the proposed scheme, it was observed that a significant improvement in the Quality of service (QoS) metrics (such as latency, throughput, buffer utilization, and packet Loss Ratio) for users is practically feasible.***

Index Terms— ***Network congestion, latency, packet loss, buffer utilization, throughput.***

I. INTRODUCTION

The astronomical increase in the demand for wireless infrastructure to transmit data, voice and video information has made the wireless channel and infrastructure to be grossly crowded. These crowded natures of the scarce communication channel have brought about the loss of information as a result of congestion in the network infrastructure. When the electrical channel is insufficient compared to the amount of data it receives, the tendency is that those data are queued up in the system thereby causing delays in date transmission as the transmitted data cannot be delivered to its destination on schedule. However various queuing theories have been developed in various literatures to ameliorate the rate at which these information are lost, but due the persistent increase in the number of network users on daily basis, the complex nature of the loads in the network seems to defy all the effort that were geared toward eliminating it. Hence, continuous work are been done by network providers to find the robust technique that can withstand the complex system and reduce the rate at which data are lost in the network.

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Congestion management is one of the key aspects of information management in wireless network because of the limited communication channels, and the need arises to make efficient use of the available scarce resource such as channel. This paper therefore, proposes an efficient algorithm capable of managing congestion in wireless networks. The proposed intelligent Fuzzy-Based algorithm will be capable of taking decisions whenever the rate at which data arrive at the input outweighs the rate at which they leave to the output.

However, various authors had proposed some techniques of reducing congestion in the network. The Flow-Aware Networking (FAN) concept, which was first proposed by [1] is relatively new in today's wireless networks. The main goal of FAN is to achieve efficient packet transmission with the minimal knowledge of the network. In flow aware networks, the traffic is sent as flows (streaming or elastic). The first type of flows is usually used by real-time applications while the second one carries best effort traffic. Two scheduling algorithms were proposed for FAN viz: Priority Fair Queuing (PFQ) and Priority Deficit Round Robin (PDRR). Interestingly, congestion management in FAN (wired and wireless environments) has continued to attract attention in the networking market segments. With the increasing awareness of mobile cloud computing with reference to wireless networks, there is an indication that wireless networks will play an important role in future inter-networks supporting Cloud Computing Services (CCS), service virtualization [2], Smart cities and Smart Grid Communication Network (SGCN) [3], among other emerging technologies. Congestion management in WLAN considering existing network transport protocols such as Transmission Control Protocols (TCP) and User Datagram Protocol (UDP) have limitations when deployed into these new technologies. Essentially, congestion control schemes such as TCP Tahoe, TCP Reno, TCP-NewReno [4], TCP Vegas and TCP selective acknowledgments (SACKs) [5], i.e.TCP-TRONVS are the mostly TCP congestion control variants in literature vis-à-vis flow aware networks. With respect to real-time loads, TCP-TRONVS cannot handle traffic congestion in a WLAN for scalable Internet traffic. This paper, then presents an enhanced self-adaptive congestion control mechanism in layer-4, based on fuzzy logic estimation referred to as Dynamic Modulation Feedback (DMF) TCP scheme which can fit into the network condition dynamically according to the parameters given by upper layer and the network layers (buffer windows, data rates, average queuing length (AVQL), channel conditions or packet error rate-PER).

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The approach in context is based on fuzzy logic adaptive control. In order to deploy this technique effectively, the data centre network of University of Nigeria Nsukka (UNN Lionet) WLAN was used to monitor the data flows in the network. The key performance indicators monitored in the network to evaluate the system performance include; throughput, packet loss, packet delays. With the obtained data simulations using matlab were performed using the developed models to ascertain the amount of throughput and delays that ensue as the proposed technique is deployed in the system. It was found that when the layer-4 DMF congestion mechanism is deployed in the DCN, WLANs will scale gradually thereby improving the QoS of the network.

II. RELATED WORKS

For TCP-TRONVS, the most related work was carried out in [6]. In the work, a study through extensive simulation scenarios on the performance characteristics of five representative TCP schemes, namely, TCP New Reno, Vegas, Veno, Westwood, and BIC, in WiMAX (and WLANs) networks, under the conditions of correlated wireless errors, asymmetric end-to-end capabilities, and link congestion was carried out. Their target was to evaluate how the above conditions would affect the TCP congestion control and suggest the best schemes to be employed in WiMAX networks.

Beside, efforts have been made in the use of intelligent schemes to address congestion in some selected wireless networks. For instance, in [6], the authors proposed a fuzzy based congestion control algorithm which takes into consideration the node degree, queue length and the data arrival rate as parameters for congestion detection. The fuzzy table accepts the values of data arrival rate, node degree and the queue length as input and the output is given in the form of fuzzy variables which indicates the level of congestion. The output gives us a strict passive measure of the congestion level and will result in a perfect measurement for congestion estimation. Their result showed packet delivery ratio with reduced packet drops and delay.

In [7], the authors made an attempt to develop a fuzzy logic control based QoS management (FLC-QM) scheme for Wireless sensor/actuator networks (WSANs) with constrained resources and in dynamic and unpredictable environments. A basic QoS analysis was carried out while arguing that their FLC-QM has the advantages of generality, scalability, and simplicity. Similarly, the authors in [8] leveraged fuzzy logic to address the challenge of network congestion in resource constrained Wireless Multimedia Sensor Networks (WMSNs) where large volume of multimedia data is transmitted through the network while identifying faulty nodes and blocking them from data communication by using the concept of trust. In [9], the authors explored Active Queue Management (AQM) based on fuzzy logic system in mobile ad-hoc in order to handle the congestion in its queues during traffic overflow. Extensive performance analysis via simulation showed the effectiveness of the proposed method for congestion detection and avoidance improving overall network performance. Congestion related proposals using fuzzy logic in ad hoc networks have been further studied in SWAN [10], INSINGIA [11], FQMM [12] and FPWICC [13]. A representative sample of works on fuzzy logic algorithm for congestion mitigation was also studied in TCP/IP networks [14], Multimedia [15], AQM [16].

The following are the identified research gaps from literature:

1. In most schemes, their existing feedback control technology cannot deal with the impact of unpredictable changes in traffic load on the QoS.
2. Most works use Active Queue Management (AQM) or Drop-Tail policy where the node drops the incoming packets to its queues during overflow condition introducing latency overhead on the network.
3. Most works discussed congestion management in the context of mobile ad hoc wireless network which works in a small geographical enclave.
4. Existing works have failed to compare their performance metrics with the traditional TCP-TRONVS.

The approach followed in this work is to study an existing wireless network on the basis of its congestion control scheme while collecting data from the network and then comparing its data with the proposed scheme. This leads to the deductive study mechanism which is deployed in this paper.

A. Deductive Study Mechanism

The methodology adopted is based on quantitative and qualitative research approaches. First, an experimental testbed methodology was used in the context of TCP-TRONVS traffic flows in a WLAN configured in Basic Service Set (BSS) mode. The experimental approach presents a congestion measurement based on TCP SACK with respect to data frame sizes characterizing a real life testbed in University of Nigeria Nsukka (UNN Lionet). The study enabled the understudying of the challenges of a realistic load WLAN design using various softwares and hardware for data measurement and analysis in the propagation environment. In the network, the traffic scenarios comprise of heavy database access, email access, file transfers and video conferencing. The access points connect to a dynamic host configuration server which allocates the respective IP addresses to client machines after a challenge handshake authentication from the network server. In order to optimize network performance, the Airspace AP's are designed to support dynamic channel assignment, client load balancing, and transmission power control. The dynamic channel assignment and power transmission controls were enabled. Dynamic channel assignment was used as a technique that switches the AP's operating channel, depending on parameters such as traffic load and the number of users associated with the APs. Nevertheless, the testbed was configured such that the wireless network traffic was well distributed between the three orthogonal channels 1, 6, and 11. Also, the access points could then to switch channels dynamically to balance the number of users and traffic volume on the three channels.

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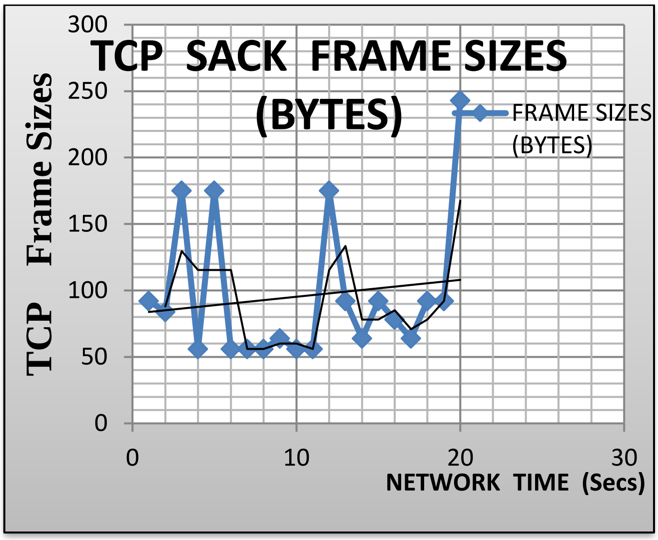
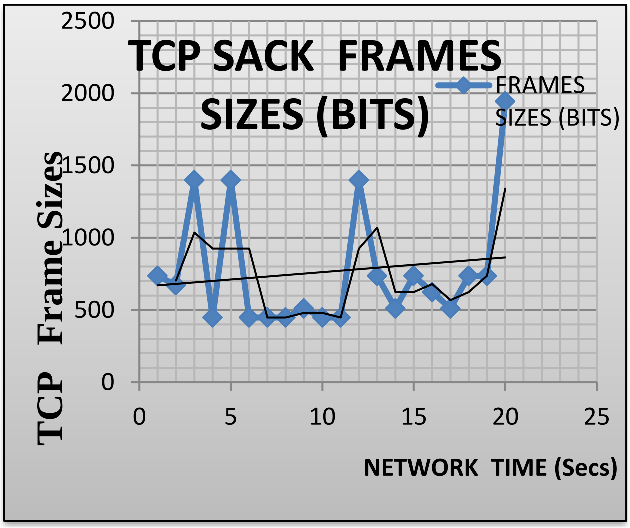


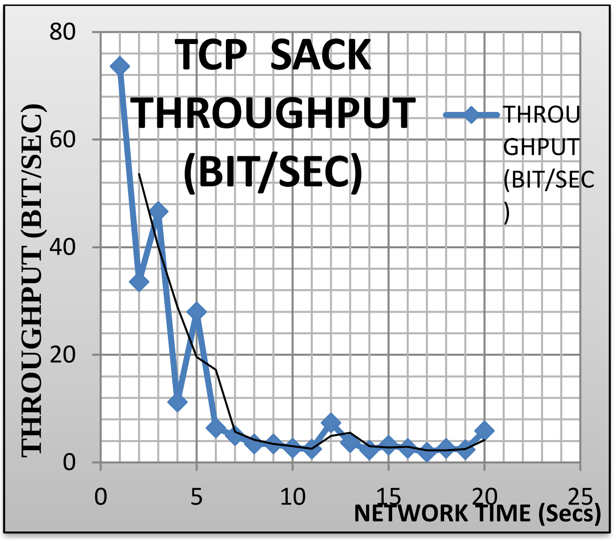
(1a)



(1b)

Figure 1: Congestion TCP SACK Frame size behaviour in (bytes/secs) and (bit/secs)

With the network sniffer (Ethereal Wireshack), TCP measurements were taken on the network on a random basis from each access point. The attributes (settings) of the access points were first configured and the network sniffer was used to measure the TCP frame sizes, throughput, delay, signal strength, the MAC address, the access point types, the speed, the noise level, vendor etc. Various TCP captures were derived and plotted. Figures 1 show the variations in the frame sizes as users make use of the network. The larger the sizes, the more congested the network and hence more packets drops results In figure 2, the TCP SACK easily gets saturated and once this occurs, a gradual decrease in the throughput response follows suite with time particularly with corresponding increase in the number of users on the network.



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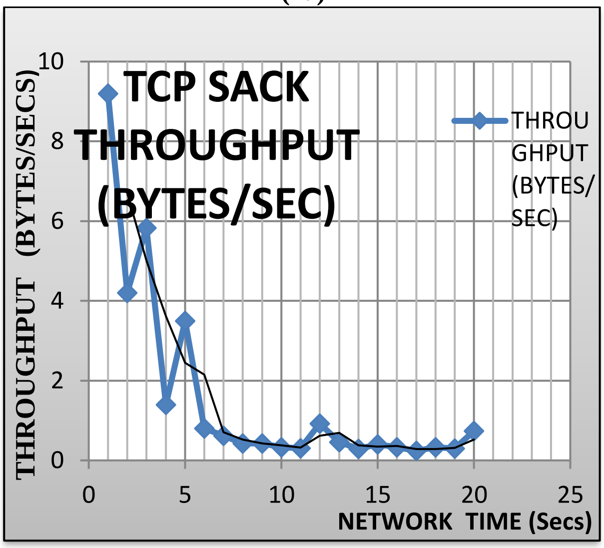
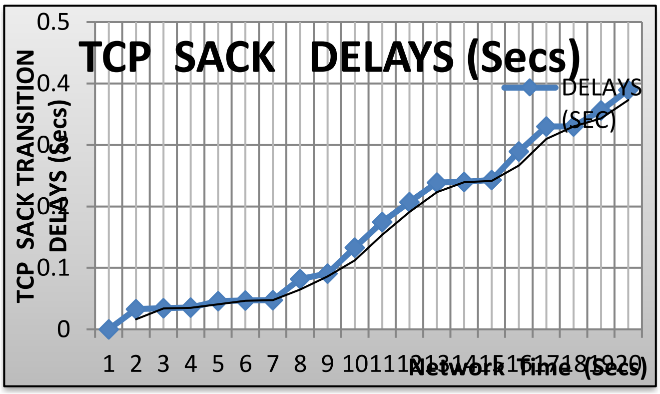


(2b)

Figure 2: Congestion TCP SACK Throughput behaviour in (bit/secs) and (bytes/secs)

Figure 3 shows the delay transitions under the influence of TCP SACK congestion. The delay gradually builds from an initial gradient to a maximum of about 1second before switching on the users to the network. This behaviour is peculiar to all the captured trace files.



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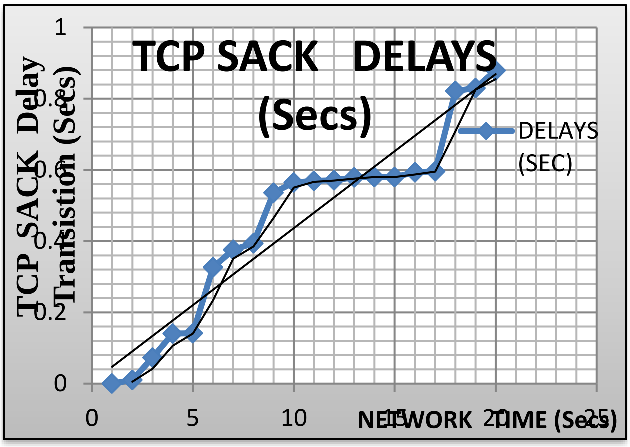

(3b)

Figure 3: TCP SACK delay transition plot

An analysis of the data from the ethereal window and the trace file metrics shows that the large number of users at peak times accessing the internet via the access points resulted in heavy utilization of the wireless network with multiple periods of congestion. Based on the analysis in context, the following main observations are made:

- The throughput metrics in TCP SACK scheme is largely unacceptable for WLAN as packet drops at peak times are very common.
- The delay time based on TCP SACK is too large for a network intensive service provisioning.
- The use of RTS.CTS by a few nodes in a heavily congested environment (frame size context) prevents those nodes from gaining fair access to the channel.
- The number of frame transmissions at 11Mbps is low while that of 54Mbps are high for all congestion levels. Current rate-adaptation implementations make scarce use of the 2Mbps and 5.5 Mbps data rates irrespective of the level of congestion.
- At high congestion levels, the time to successfully transmit a large frame sent at 54Mbps is *lower* than for a small frame sent at 11 Mbps.
- At high congestion levels, the delay time consumed by frames transmitted at 54Mbps is only about half the time consumed by frames transmitted at 11Mbps. Yet the number of bytes transmitted at 54Mbps is approximately 300% more than at 11Mbps.

These observations offer important insight into the operation and performance of congested wireless networks.

The network model in this research is a common scenario of BSS (wireless- to-wired) unicast, and broadcast network topology model. The developed network architectures in figure 4, 5 and 6 seek to investigate the fuzzy logic based traffic control protocol performance considering the peculiarity of the wireless link. The network model consists of affixed host (FH) which is defined over the wired link via an AP and IP gateway through an IP cloud to a wireless last hop consisting of two pair of servers (FTP and HTTP servers). The process network model consists of a mobile host (MH) with an AP in a wireless cellular network LAN. Within this model, the wireless channel in cooperates a DMF (dynamic modulation feedback) signal in terms of TCP ACK used to return back the estimation of congestion state and channel variations in terms of the wireless packet error rate (PER) over wireless channel.

III. SYSTEM DESIGNS

The proposed flow aware networks are shown in figures 4, 5 and 6. From figure 5, the considered key preliminaries required to predict the congestion (packet dropping rate) based on the fuzzy logic adaptive queuing controller in the WLAN and Rayleigh fading channel is as follows:

- Multiple TCP flow traffic is considered for all mobile receivers.
- The network is assumed to be stable without heavy or bursty TCP traffic.
- The TCP packet error rate (PER), (i.e., *Pr)*, is caused by the variations of wireless channel when only highly bit errors occurs during traffic transmission. Assuming there is no congestion at the router buffer of AP base station.
- *Pr* is measured by the channel estimator at mobile receiver and returned back via the ACK feedback of the round trip of TCP to indicate the sender about the channel bit errors, so we consider Pr changes from 5% to 30%.
- The TCP rate regulator at the AP router queue of the AP base station is required *if and only if* multiple TCP flows are present. This rate regulator is mainly used to distinguish the packet error (dropping) due to the variations of wireless channel and the packet loss due to congestion of buffer overflow. In our assumption, there could be packet dropping due to AP buffer overflow in extreme congestion. So, the link could be under or over utilizing bandwidth and the queue threshold of the APs could be exceeded.

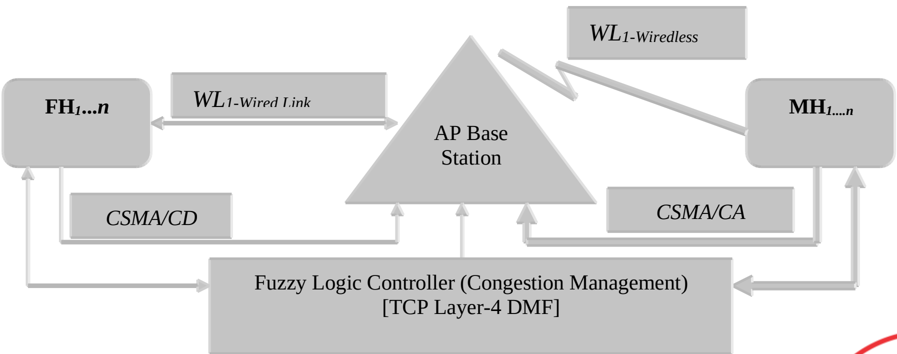

Figure 4: Unicast-Broadcast Fuzzy WLAN model

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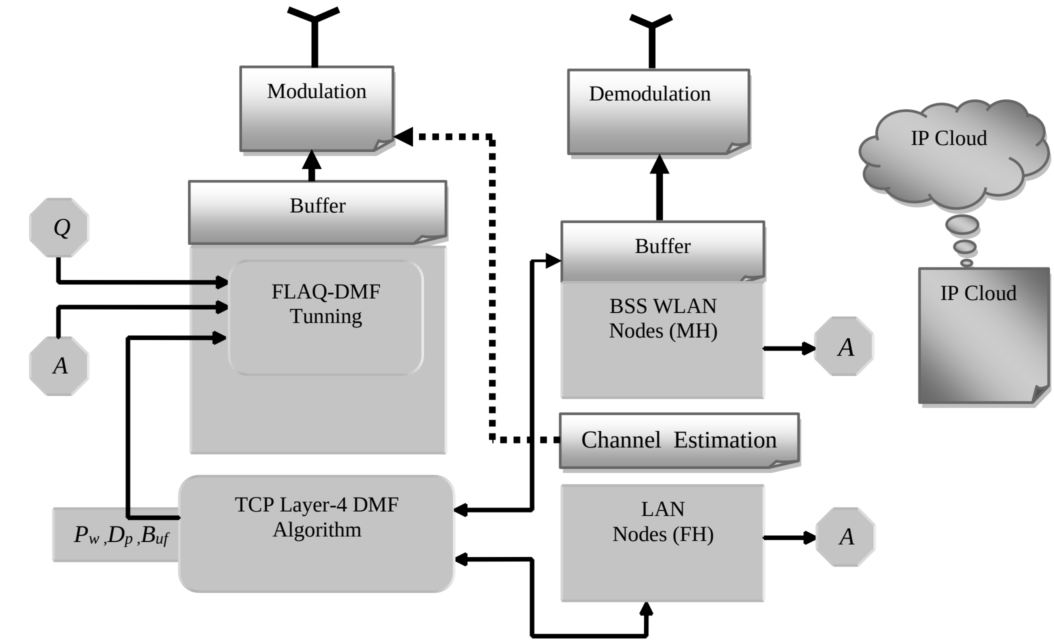

Figure 5: Fuzzy WLAN Process Model

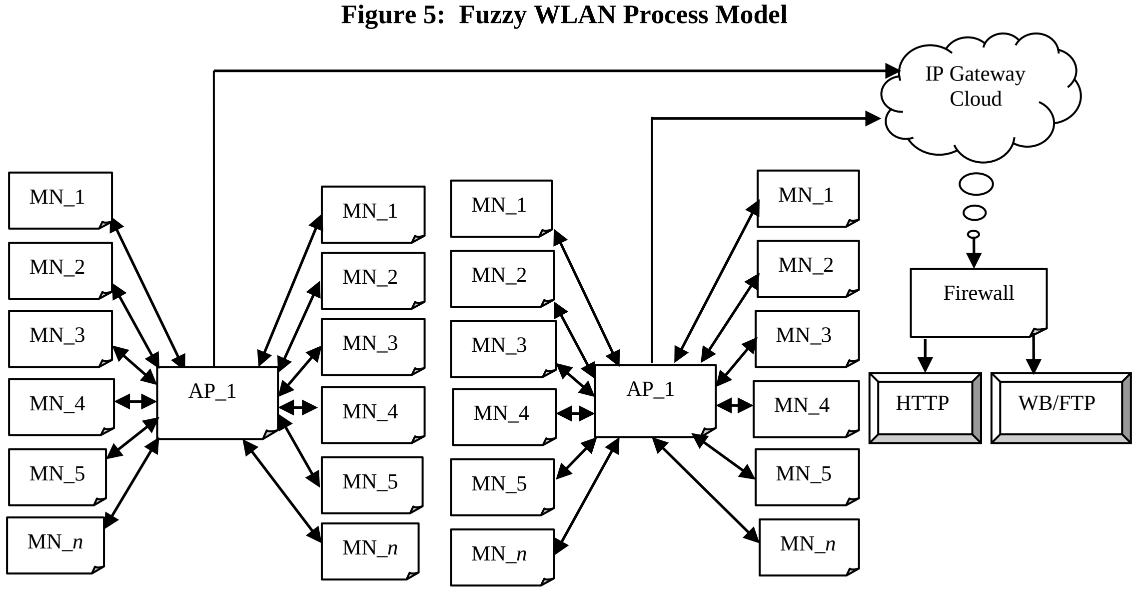

Figure 6: System Architecture for WLAN

At the AP base station (BS), the following assumptions were considered:

- Let the buffer size = 256kb packets
- The AP router queue with *Qmin* =50kb [packet] ,and *Qmax* =150kb [packet]
- If the average queue length is less than 50kb no packets are dropped→No TCP congestion
- If the average queue length is more than 150kb, all the arriving packets are queued while DMF regulates the feedback flows to and from the MH or MNs.
- If the average queue length is between *Qmin* and *Qmax* then the packets should be controlled by the fuzzy logic controller depending on the inputs ($AVQL_{congestion}$, P_r)
- Packet loss rate at AP base station is compensated by DMF algorithm (hence, there is no packet loss at the event of congestion) under realistic loads.

A Proposed AP Base Station DMF Controller

A fuzzy logic controller (FLC) block was used in developing the intelligent decision-making behaviour. In FLC, the input-output relationship is expressed by using a set of linguistic rules for relational expressions. The conceptual components of a FLC basically consist of a fuzzifier, a defuzzifier, an inference engine and a rule base. Figure 7 shows the FLC architecture. Since in many fuzzy control applications, the input data are usually crisp, a fuzzification is necessary to convert the input crisp data into a suitable set of linguistic value that is needed in inference engine. Singleton fuzzifier maps the crisp input to a singleton fuzzy set.

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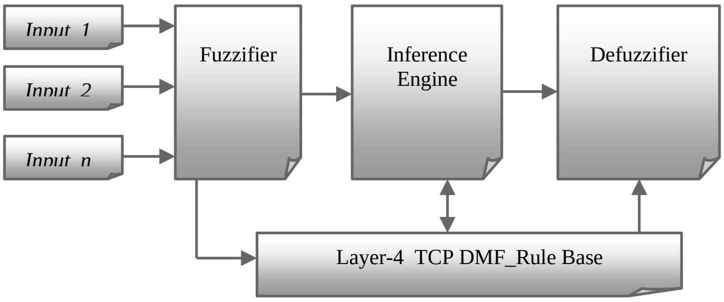

Figure 7: Proposed layer-4 DMF Fuzzy Logic Controller

In the rule-base of an FLC, a set of fuzzy control rules, which characterize the dynamic behaviour of system, are defined. The inference engine is used to form inferences and draw conclusions from the fuzzy control rules. The output of inference engine is sent to defuzzification unit as shown in figure 7. Defuzzification is a mapping from a space of fuzzy control actions into a space of crisp control actions.

To implement DMF scheme, this work used a combination of two methods posited by Abdel-Jaber*et al.* (2008) [32] to construct the fuzzy linguistic rules: (1) The trial and error (Heuristics) and (2) The theory method. This is because the first method depends on domain expert knowledge and experience, and the second method tunes the input and output linguistic parameters to accurate values. Thus using both methods together, the output D_p can be obtained in more accurate.

In the proposed layer-4 DMF as depicted in figure 7, the FLC consists of (1) fuzzification (2) Rule base engine (3) Inference engine for aggregation the outputted rules, and (4) defuzzification, to compute the output *DMF_prediction* at the AP BS router queue. Then, the proposed layer-4 TCP DMF employs two input linguistic variables ($AVQL_{congestion}$, P_r) with aim to evaluate a single output linguistic variable *DMF_prediction*. The general bell membership function is used to represent all linguistic variables. The generalized bell function depends on three parameters *a*, *b*, and *c* as given in Equ 1

$$f(x,a,b,c) = \frac{1}{1+\left|\frac{x-c}{a}\right|^{2b}} \qquad (1)$$

Where a, and *b* are usually positive, c locates the centre of the performance curve. From Eqn 1, every linguistic variable is linked to a fuzzy set of the input and output linguistic variables as defined in Table 1.

Table 1 Linguistic variables ranges

Variable ranges	Linguistic Variables
$AVQL_{congestion}$= 50kb-150kb [packet]	$AVQL_{congestion}$={Low, Medium, High, Very High}
Pr = 5%-30%	*Pr* ={Low, Medium, High, Very, High}
Buffr Size =8kb - 256kb	*Buf* ={Low, Medium, High, Very, High}
DMF_predict = 0% - 30%	*DMF_prediction* ={Low, Medium, High, Very, High}

B Fuzzy Rules Base Formulations

This paper proposes a Fuzzy-Logic Adaptive Queuing based RED scheme in the FAN using Mamdani Fuzzy–Logic when General Bell function of Equ 1 is considered in Figure 6 and 7. The memberships of linguistic variables viz: *AVQL*, *Pw* and *Dp* are adjusted depending on the wireless environment in order to introduce the resultant fuzzy logic system decision surface. Outlined below are the step by step modelling approach in the proposed layer-4DMF Algorithm.

Step 1. Fuzzification of Inputs (Process variables)

The first step is to take the inputs (the process variables- *Buffer Size*, $AVQL_{congestion}$ *and Pr*) and determine the degree to which they belong to each of the appropriate fuzzy sets via membership functions. In the Fuzzy Logic Toolbox, the input is always a crisp numerical value limited to the universe of discourse of the input variable and the output is a fuzzy degree of membership in the qualifying linguistic set. Fuzzification of the input amounts to either a table lookup or a function evaluation in the rule base and inference engine.

Step 2. Application of the Fuzzy Operator

After the process variables have been fuzzified, the degree to which each part of the antecedent has been satisfied for each rule is ascertained. If the antecedent of a given rule has more than one part, the fuzzy operator is applied to obtain one number that represents the result of the antecedent for that rule. This number will then be applied to the output function. The input to the fuzzy operator is two or more membership values from fuzzified input variables. The output is a single truth value.

Step 3. Application of the Implication Method in the Rule Editor

Before applying the implication method, the rule's weight was taken care of in the fuzzy inference system (FIS). Every rule has a *weight* (a number between 0 and 1), which is applied to the number given by the antecedent in the rule editor. From time to time, the weight of one rule in the algorithm is varied relative to the others by changing its weight value to something other than 1. Once proper weighting has been assigned to each rule, the implication method is implemented. In this context, a consequent is a fuzzy set represented by a membership function which weights appropriately the linguistic characteristics that are attributed to it. The consequent is reshaped using a function associated with the antecedent in the rule editor. The input for the implication process is a single number given by the antecedent, and the output is a fuzzy set. Implication is implemented for each rule in the rule editor.

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Step 4. Aggregation of all Outputs

The TCP_fuzzy logic algorithm (layer-4 DMF) decisions are based on the results of testing all the rules in an FIS. The rules are combined in order to make intelligent decisions. Aggregation procedure was used in the controller. In this case, the fuzzy sets that represent the outputs of each rule are combined into a single fuzzy set. Aggregation only occurs once for each output variable, just prior to the defuzzification phase.

Step 5. Defuzzification

The input for the defuzzification process is a fuzzy set (the aggregate output fuzzy set) and the output is a single number which serves as a control signal for driving the output interface systems. As much as fuzziness helps the rule evaluation during the intermediate steps, the final desired output for each variable is generally a single number (matching signal). However, the aggregate of a fuzzy set encompasses a range of output controlled values, and so must be defuzzified in order to control the dashboard or other output interface units. The centroid calculation, (the TCP_layer-4 DMF defuzzification method) which returns the center of area under the curve in the FIS model was carefully setup in the design. This work leverages on the open and easily modifiable fuzzy inference system (FIS) structure of the Fuzzy Logic Toolbox. In this context, within the basic constraints of the TCP_layer-4 DMF process, this work customized the fuzzy inference process for the TCP_layer-4 DMF algorithm to achieve a highly available and reliable system. Figure 8 shows the implemented Mamdani Inference System used to model the TCP_layer-4 DMF housing the membership functions in the FIS for the TCP_layer-4 DMF algorithm. The above procedure was primarily implemented in Algorithm I for the proposed scheme as shown in table 2.

Table 2: Algorithm for Fuzzy Rule Base System

Algorithm I: FAN Fuzzy Rule Base System
INPUT: *Buffr_Size, AVQL_congestion, Pr_rate* .
OUTPUT: *DMF_predicted*
Procedure {begin}:
If (*Buffr_Size* is low) and (*AVQL_congestion* is low) and (*Pr_rate* is low) then (*DMF_predicted* is very_low)If (*Buffr_Size* is low) and (*AVQL_congestion* is medium) and (*Pr_rate* is medium) then (*DMF_predicted* is very_low)
If (*Buffr_Size* is low) and (*AVQL_congestion* is high) and (*Pr_rate* is High) then (*DMF_predicted* is very_high)
If (*Buffr_Size* is low) and (*AVQL_congestion* is very_high) and (*Pr_rate* is very_High) then (*DMF_predicted* is very_high)
If (*Buffr_Size* is medium) and (*AVQL_congestion* is low) and (*Pr_rate* is low) then (*DMF_predicted* is very_low)
If (*Buffr_Size* is medium) and (*AVQL_congestion* is medium) and (*Pr_rate* is medium) then (*DMF_predicted* is medium)
If (*Buffr_Size* is medium) and (*AVQL_congestion* is high) and (*Pr_rate* is high) then (*DMF_predicted* is high)
If (*Buffr_Size* is medium) and (*AVQL_congestion* is very_high) and (*Pr_rate* is very_high) then (*DMF_predicted* is high)
If (*Buffr_Size* is high) and (*AVQL_congestion* is low) and (*Pr_rate* is low) then (*DMF_predicted* is high)
If (*Buffr_Size* is high) and (*AVQL_congestion* is medium) and (*Pr_rate* is medium) then (*DMF_predicted* is low)
If (*Buffr_Size* is high) and (*AVQL_congestion* is high) and (*Pr_rate* is high) then (*DMF_predicted* is medium)
If (*Buffr_Size* is high) and (*AVQL_congestion* is very_high) and (*Pr_rate* is very_high) then (*DMF_predicted* is high)
If (*Buffr_Size* is very_high) and (*AVQL_congestion* is low) and (*Pr_rate* is low) then (*DMF_predicted* is low)
If (*Buffr_Size* is very_high) and (*AVQL_congestion* is medium) and (Pr_rate is medium) then (*DMF_predicted* is medium)
If (*Buffr_Size* is very_high) and (*AVQL_congestion* is high) and (*Pr_rate* is high) then (*DMF_predicted* is high)
If (*Buffr_Size* is very_high) and (*AVQL_congestion* is very_high) and (*Pr_rate* is very_high) then (*DMF_predicted* is very_high)
End;

The Mamdani Fuzzy Inference System was used to realize the proposed TCP Layer-4 DMF Algorithm. The implemented was carried out using fuzzy Logic Toolbox in MATLAB 7.9.0 version R2009b software. The algorithm basically shows the general rule-base conditions for the proposed TCP algorithm. After creating the fuzzy systems using the GUI tools, the system was embedded directly into a simulation following its surface diagram plots of the fuzzy inference processes viz:

1. Fuzzification of the input variables (*buffer_sizes, AVQL_congestion and Pr_rate*)
2. Application of the fuzzy operator (AND) in the antecedent
3. Implication from the antecedent to the consequent,
4. Aggregation of the consequents across the rules.
5. Defuzzification. A three-input, one-output, and nine-rule base algorithm shown in figure 8.

The basic structure of this case is shown in Table 1with the variable ranges and its linguistic variables labelled as the TCP-layer-DMF algorithm fuzzy sets viz: *Low, Medium, High and Very High*. Information flows from left to right, from three inputs to a single output (*DMF_predicted*). The parallel nature of the rules is one of the more important aspects of fuzzy logic systems. Figure 10 shows the TCP layer-4DMF Rule editor for AP controller in Mamdani FIS. In this work, the

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MATLAB rule viewer and surface viewer was used for the result analysis after configuring the algorithm in the rule editor in fig. 10.The rule viewer is a MATLAB based display for the fuzzy inference system as shown in figure 8.

Used as a diagnostic, it shows which rules are active and how individual membership function shapes are influencing the results of the proposed TCP layer-4 DMF algorithm II. The Surface Viewer is used to display the dependency of one of the outputs on any one or two of the inputs—that is, it generates and plots an output surface map for the system. Figure 9 shows the TCP layer-4DMF membership function for AP controller while Figure 10 shows the DMF prediction output in the FIS editor.

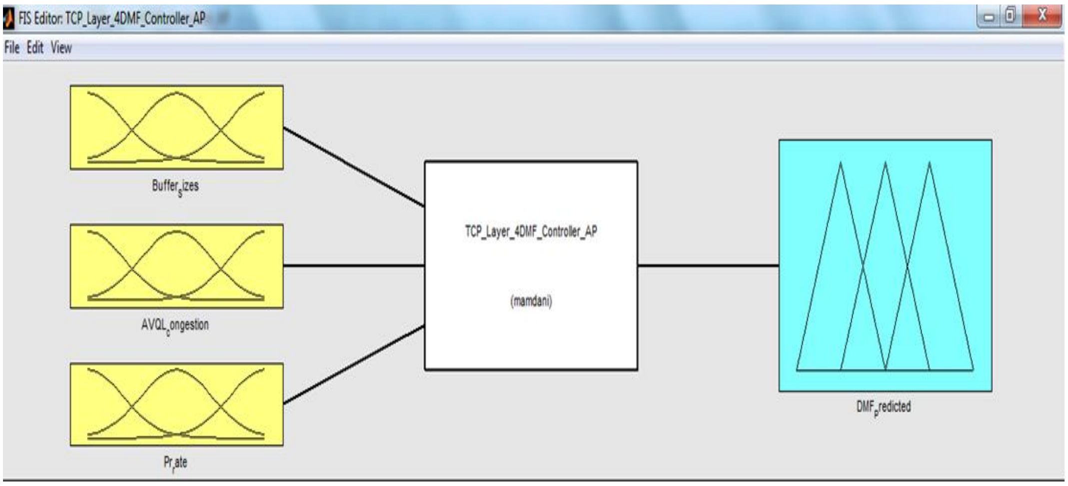

Figure 8: TCP layer-4DMF Mamdani fuzzy inference engine with TCP Layer_4 DMF

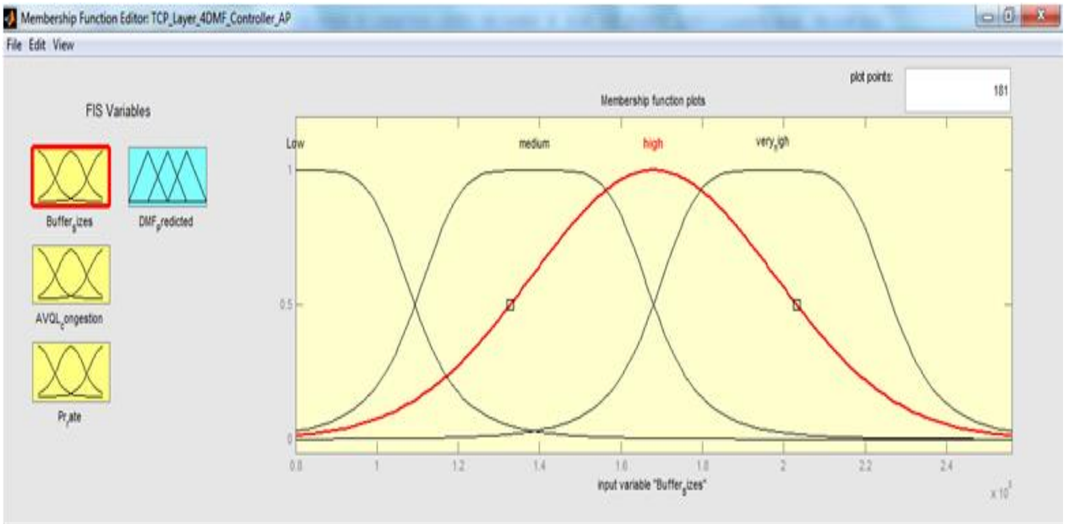

Figure 9: Membership function for AP controller

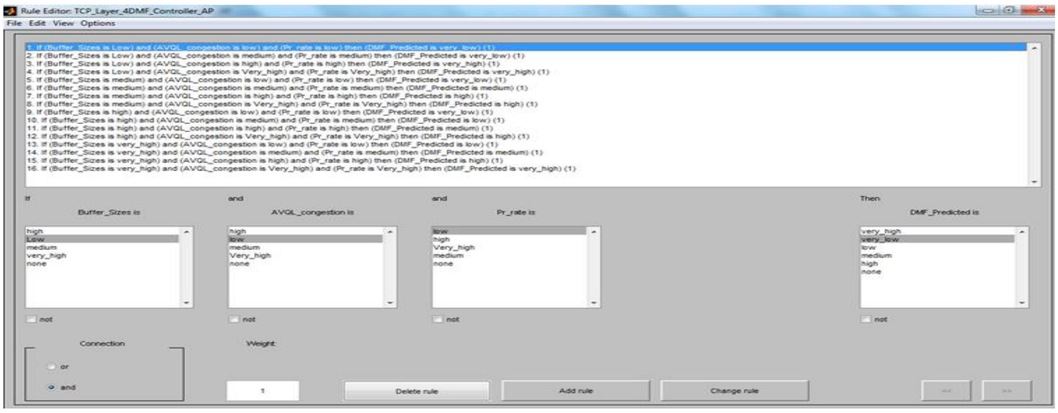

Fig 10: DMF_prediction output

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Figures 11 show the MATLAB fuzzy surface viewer plots of the proposed layer-4 DMF algorithm under analysis. The surface viewer plots for the process variables and control variable (*DMF_Predicted*) in a non-optimized state is shown in Fig 11 while Fig 12 shows the optimized state.

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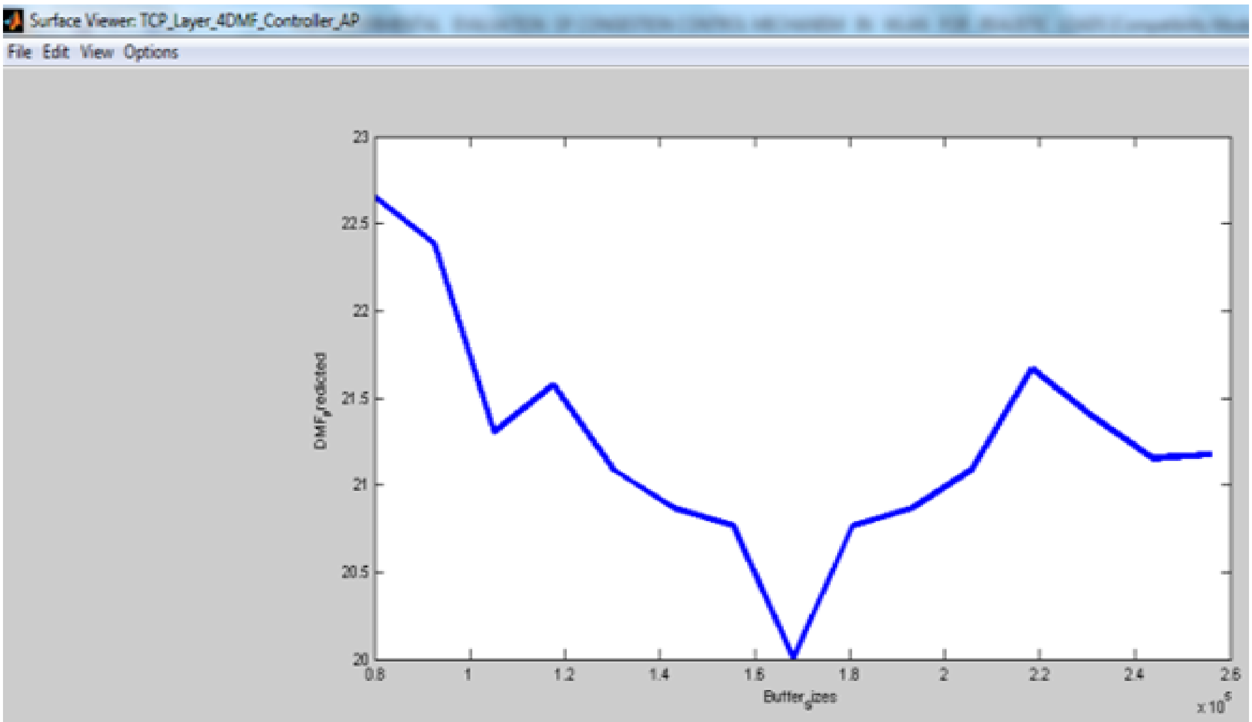

Figure 11: Non Optimized surface viewer plot for the process variable

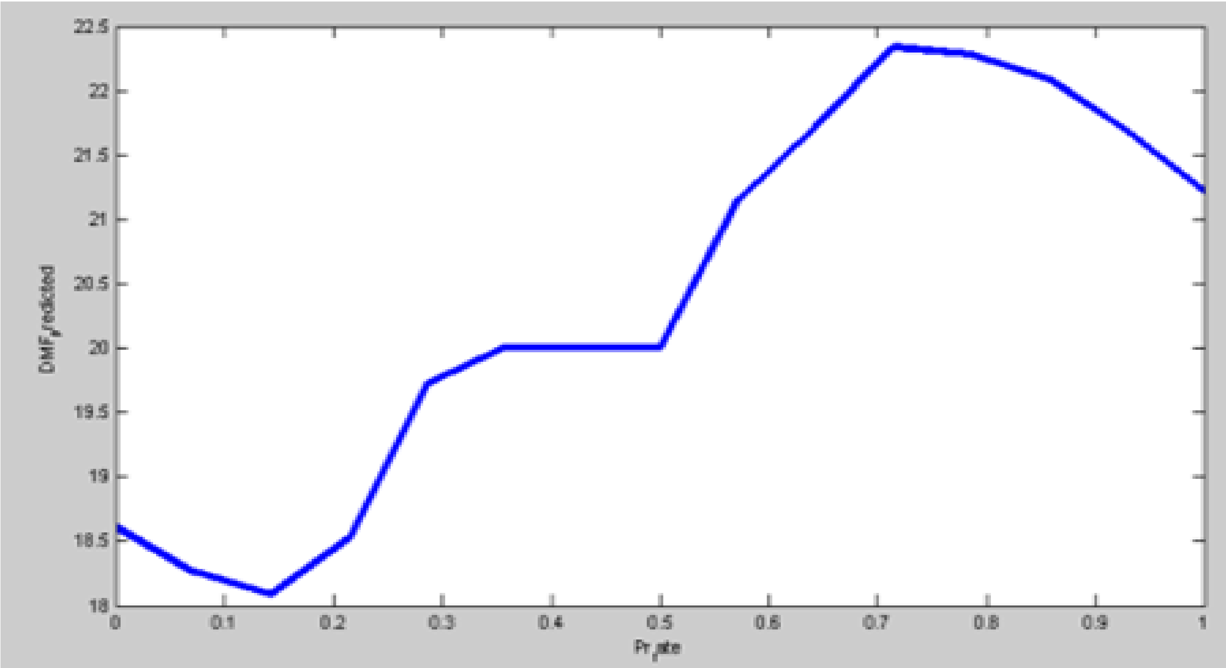

Fig 12: Optimized control variable

IV. RESULTS AND DISCUSSION

A. *Performance Evaluation (Validation Study)*

In this work, an evaluation on various TCP variants including the TCP SACK was carried out using MATLAB Riverbed Model file. In this case, the parameters of TCP-TRONVs and the Fuzzy scheme were defined in [17]. This section seeks to address the UNN field deductions. A discussion on the evaluation results is presented below.

i. *Latency Plot Response*

From Figure 11 the average latency for all TCP variants except Vegas and the proposed TCP DMF maintained fast rise latency throughout the transitions as depicted by the trend curve beginning from 0.00125ms up to 0.00127ms. The proposed TCP DMF showed a comparative latency response with TCP Vegas (0.0075ms). It maintained a steady rate of about 0.0076ms relative to TCP Vegas.

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Therefore a difference in the values of latency in the face of equal load per time over the AP controller makes the frame size distribution over TCP variants a major consideration. It was observed that the average end-to-end latency of the TCP Vegas is better than all TCP variants. But this scales fairly with the TCP DMF. Consequently, traffic optimization WLAN will suffer little wait states by the proposed TCP DMF algorithm since it has smaller parameters to evaluate at initialization as well as under peak congestion states.

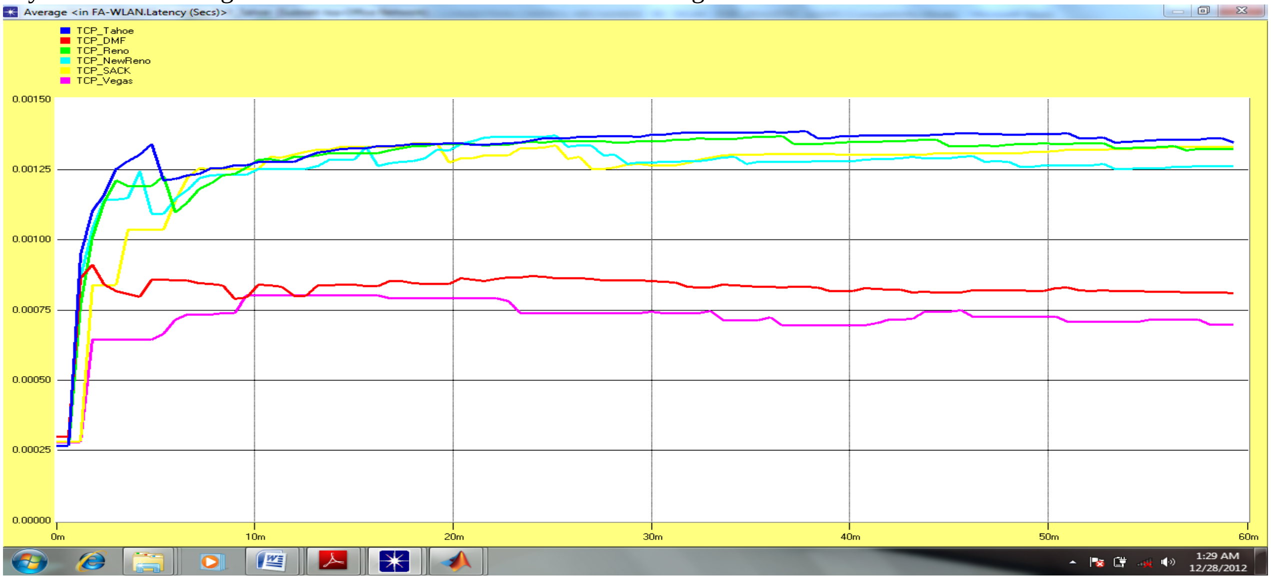

Fig 11: A latency Plot of TCP-TRONVs Vs Fuzzy layer-4 DMF

ii. Throughput Response

Figure 12 compares the steady-state throughput response achieved by all TCP variants. Interestingly, it was observed that the proposed layer-4 TCP DMF algorithm had slightly better throughput behaviour of about 8870 packet/bits compared with TCP Tahoe, Reno, NewReno, SACK and Vegas. This is evidenced by the fact that the transmission of realistic traffic witnessed reliable frame data delivery with active connections transmitting data between the mobile nodes and the AP server, with an emulated round trip time equal to 100 ms (a near zero packet loss rates). The measures of frame sizes greater than 1200 bytes in the real scenario is validated by the results obtained and provide a further support on the advantages of proposed layer-4 TCP DMF algorithm over TCP TRONVS. The proposed TCP DMF offered a higher throughput than any other TCP version due to its intelligent connection oriented behaviour leading to accurate fuzzy estimate of the available bandwidth, buffer size, average queuing length, packet error rate, and fair distribution of frame sizes (packets) under realistic load conditions.

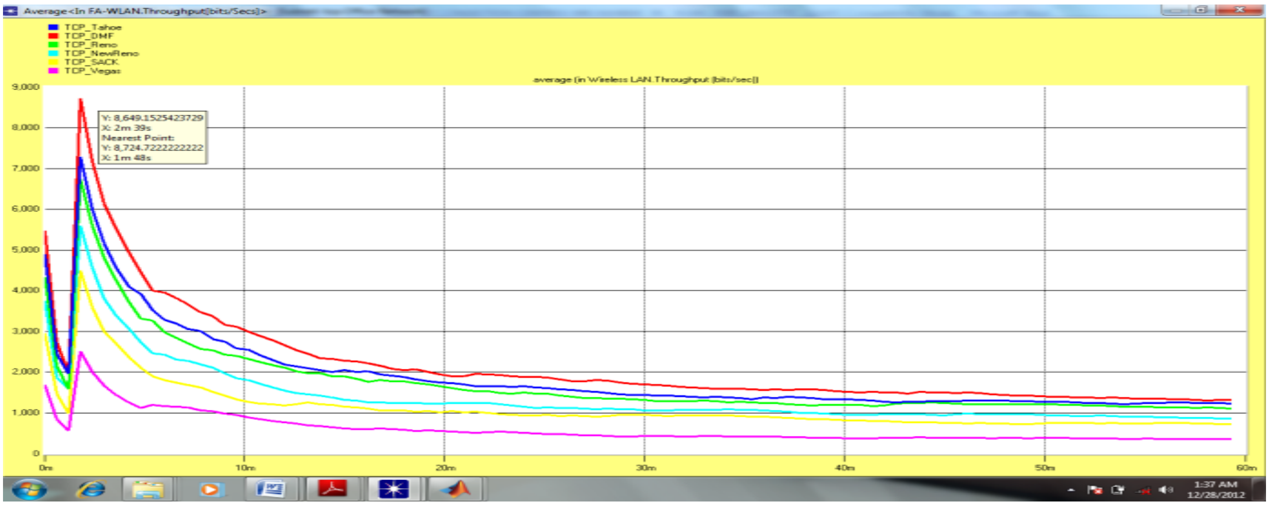

Fig 12: A throughput Plot of TCP-TRONVs Vs Proposed fizzy layer-4 DMF algorithm

iii. Buffer Utilization Response

Figure 13 shows the buffer utilization Plot of TCP-TRONVs with the proposed layer-4 DMF algorithm. At the core AP base station and mobile stations, the output buffer was set to hold a maximum of 2048Kbps bytes.

Essentially, the buffer sizes were varied starting from 64kb packets to 2028 packets for various realistic load sources. From Fig 13, it was observed that with the proposed fuzzy layer-4 DMF algorithm, there was a fairly assumed peak exponential rise in buffer utilization with time due to congestive load effects.

Traffic flows shows an enhanced throughput as the buffer sizes were increased. The buffer utilization curves are on top of each other with gradual transitions giving way to higher and efficient throughputs. From a buffer size of about 2000kb packets and above, throughput of bulk traffic TCP DMF was significantly high. This guarantees a fair allocation in the congested link. Thus, an increase in buffer size leads to a better performance network considering the various load intensities. This also means that a better buffer size utilization accounts for less packet drops in a congestive wireless link.

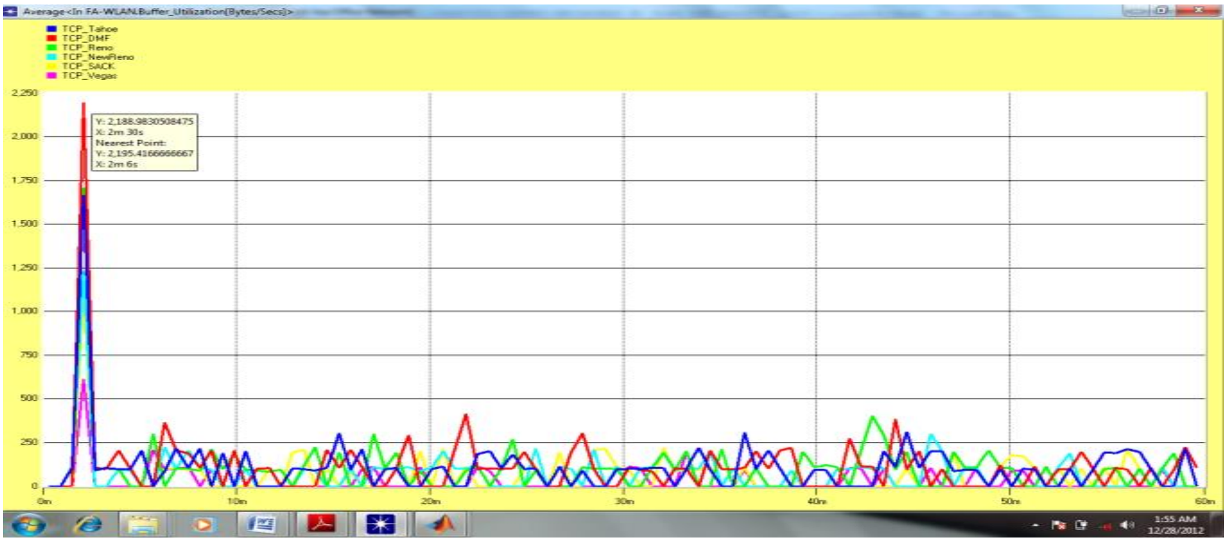

Figure 13: Buffer utilization Plot of TCP-TRONVs Vs the Proposed fizzy layer-4 DMF

iv. Packet Loss Ratio

Fig 14 depicts a plot of Packet Loss Ratio (PLR) of TCP-TRONVs with the proposed fuzzy layer-4 DMF algorithm. As observed from the plot, the proposed layer-4 DMF algorithm has a relatively good packet loss ratio as a result of its enhanced throughput behaviour while TCP Vegas which has a comparatively better Packet Loss Ratio behaviour under congestive scenario. From the plot, TCP Vegas is demonstrates the least PLR while TCP Tahoe depicts the highest PLR.

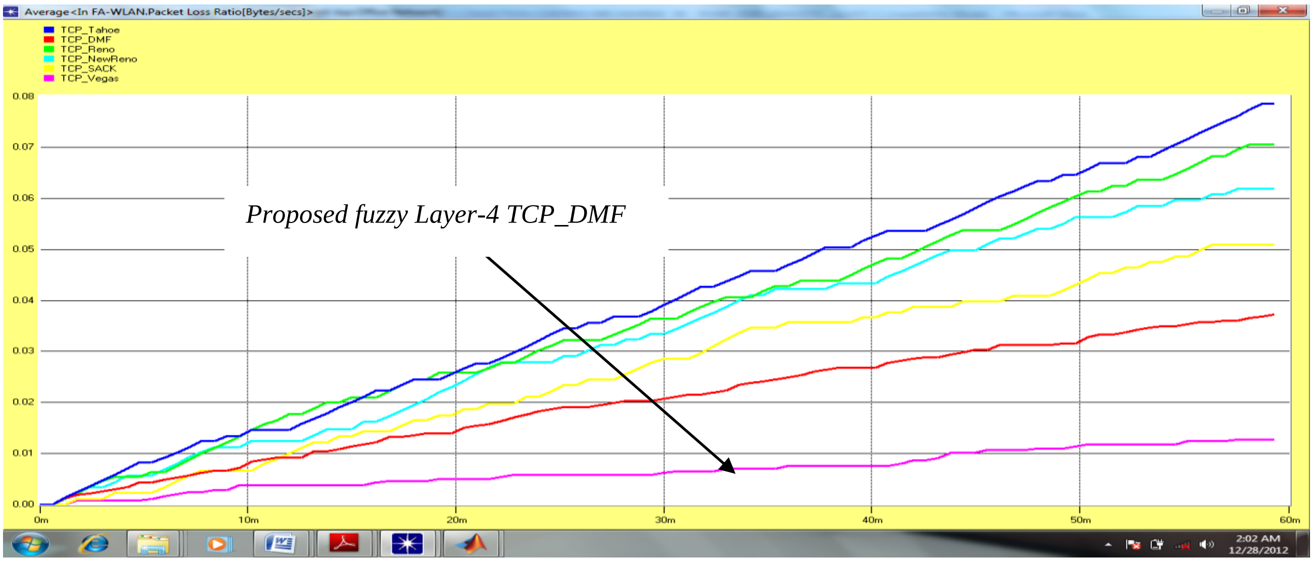

Fig. 14: Packet Loss Ratio Plot of TCP-TRONVs Vs Proposed Fuzzy layer-4 DMF algorithm

V. CONCLUSION

Data congestion in wireless network was carefully studied and evaluated in this paper. Since this is a serious consideration on today's networks, intelligent techniques that can dynamically control bandwidth capacity will be coveted. The work has evaluated a fuzzy technique for mitigating congestion in wireless domain. The fuzzy logic approach to congestion mitigation in TCP oriented network using UNN as a case study offered few observations. Using a deductive study mechanism, an intelligent fuzzy-based algorithm for the congestion management was achieved while showing a validation analysis plot of the proposed scheme in relation to other TCP variants. From the proposed scheme, it was observed that a significant improvement in the Quality of service (QoS) metrics can be realized with this scheme.

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This finding holds because a successful wireless transmission requires both the sender and receiver to be contention-free with respect to both the wireless channel and queue space. Implementing a fuzzy adaptive control policy results in substantial improvements to fairness. Low cost access points and other internal network devices can now adopt fuzzy cores.

Secondly, even when the implementation of fuzzy DMF relies on overhearing (fuzzification), an alternate implementation is possible with the use of hop-by-hop flow control and link-level acknowledgments to indicate congestion state. These were not investigated in the design point; however, they can be analysed in a future work.

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