

Internet Congestion Control Using Fuzzy Integral Controller

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Abstract: Until now, internet congestion problem cannot be completely resolved. The main cause of the internet congestion is the control mechanism for dividing network capacity does not work effectively. Thus, the amount of data through the network can exceed the network capacity. Various studies based on the control system theory have been done to overcome this problem. This paper specifically examines congestion control system based on fuzzy logic mechanism. The proposed controller is fuzzy integral controller in the router and control signal processing that resides on the user side, which is modelled by first order system. This control technique is a congestion control with explicit feedback. The control calculation result, i.e. the divided capacity of the router, which is distributed fairly among all users, is explicitly given to the user. There are three simulation scenarios to show the performance of the proposed congestion control system. From the simulation results can be concluded that the congestion control system using fuzzy integral controller has succeeded in fairly allocating capacity routers and able to prevent internet congestion by keeping the aggregate data flow through the router does not exceed the service rate of the router.

Keywords: congestion, internet, fuzzy, integral, controller, router.

1. Introduction

Today, the internet used Additive Increase Multiplicative Decrease (AIMD) techniques to control the congestion. This was developed on the basis of the packets conservation principle. New data packet cannot be sent over the network, before the old data packets out of the network. If this principle is used, it is possible there will be no internet congestion [1]. However, when considered more carefully, AIMD with feedback mechanism implicitly or explicitly does not provide accurate information about the number of data packets out of the network. Therefore, a slow start and congestion avoidance are trying to estimate the amount of data sent to the network based on the inaccurate information. These inaccuracies lead to oscillations about the desired value. It is true that the data packets conservation principle has been used to produce a stable response. However, inaccurate network information still causes oscillation problems, so that the network remains congested. This paper will examine the network congestion model and control to overcome the unknown information in the system. A number of assumptions that are taken on this paper i.e:

- All Sources are responsive.
- For unicast data flow.
- For best effort network.
- Each data flow from source to destination has one route

2. Recent Studies

On the current Internet, congestion control system structure and feedback mechanism can be seen as shown in Figure 1 below. There are three applications, i.e. on the sender (source), receiver (destination), and router (network). Application on the sender determines the number of data packets transmitted over the network, which should match with the network and receiver capacity.

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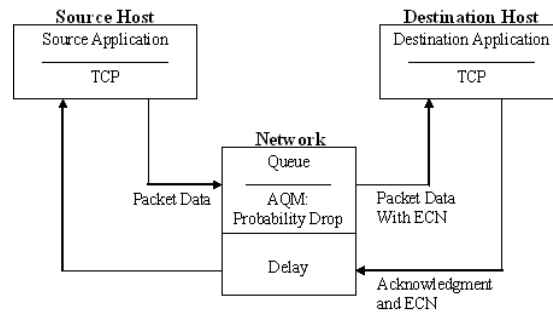


Figure 1. Congestion Control System using Explicit Congestion Notification (ECN)

Active Queue Management applications in the routers will calculate the congestion level or the allocation of the existing router capacity. By explicit feedback, congestion level or capacity allocation information is sent to the sender. It should be noted that on the travelling of data packets from the sender to the receiver and from the receiver to the sender, the data packet experienced a delay time. Especially in the router, when the routing process occurs, the delay time in router queues has non-linear characteristics. More queues in the router the delay time will be even greater. The presence of the delay time and the number of network users, which is always changing at any time makes the internet congestion very difficult to be controlled.

Network information is considered important as the parameters for congestion control. Quality of information networks has evolved along with the development of congestion control techniques. Here is a grouping based on the quality of information network [2].

1. Black box, which views the network as a black box. It is assumed that there is no any information about the network, except the binary feedback (0 means there is no congestion and 1 indicating the presence of congestion). The technique in this group based on the principles of AIMD.
2. Grey box, which use the measurements to estimate the available capacity, the contention level, or the congestion level. Because there is a possibility of measurement imprecision, the network is seen as a grey box. An example is TCP Vegas, which estimate the queuing delay time and change the WINDOW value, so that the number of packets in the queue is always constant.
3. Green box is group that has calculation in the router, with regard to inform the availability of router capacity, which can be used by the sender as network status information. Included in this group are MaxNet, Explicit Control Protocol (XCP), and Jetmax.

Above grouping can be seen as a tendency, so that the network information can be measured and fed back explicitly. With this trend, the desired congestion control can provide accurate results.

The following are studies that have been done using the controller based on fuzzy logic (FL). At the first fuzzy paper, Fuzzy Controller is used to deal with a non-linear and dynamic problem in the Internet. In this model there are two inputs, i.e. Traffic Intensity and Available Link Bandwidth, which are denoted by Trafint and AVbw respectively. The Traffic Intensity and Available Link Bandwidth Trafint and AVbw are classified into 3 linguistic variables: {Low, Medium, High} which is represented as {L, M, H}. Output function of Queue limit-Qlim is classified into five linguistic variables: {Very_Low, Low, Medium, High, Very_High}. This FL based methods show improvement in increased in throughput, reduction in delays, and packet loss [4].

The second paper proposed a modified TCP delay-based congestion avoidance mechanism which is based on traditional TCP-Africa algorithm. This fuzzy controller uses queue delay and link capacity as input linguistic variables. The fuzzy controller output is the window size to which the sending window must be adjusted. The proposed mechanism will be quite robust in

dealing with steady scenarios, where abrupt changes are not too frequent, for instance a lossy channel. However, different scenarios and more elaborate inference models have to be checked to render this system even more generic [5].

The third paper proposed a mechanism to control congestion in streaming media applications using fuzzy logic. Fuzzy logic is very easy, simple and effective way to solve the congestion problem [6]. For controlling congestion, this work use rules as follows:

1. If (available bandwidth is low) and (change rate is decreasing) then (send rate is low).
2. If (available bandwidth is low) and (change rate is decreasing) then (send rate is high).
3. If (TCP response is low) then (send rate is low).
4. If (available bandwidth is high) and (TCP response is high) then (send rate is high).
5. If (available bandwidth is high) then (send rate is high).
6. If (available bandwidth is low) then (send rate is low).

The inputs used in this system are TCP response, change rate, and available bandwidth. While, the output is send rate. This article featuring ease of designing controllers based on fuzzy. Unfortunately, the simulation results are not displayed. Thus, the results cannot be compared with others fuzzy logic controller performance.

The fourth paper proposed a perturbed Takagi-Sugeno fuzzy model to overcome the number of transmission control protocol sessions that usually varies from time to time. This paper reveals the modelling, the design of fuzzy control system based on Lyapunov stability theory and numerical verification using Iterative Linear Matrix Inequality (ILMI) algorithm. The simulation results showed that the proposed fuzzy controller has successfully provided robust performance when the number of TCP sessions varies from time to time [7]. The window size and queue length as the controller performance can be seen in Figure 2 and Figure 3 below.

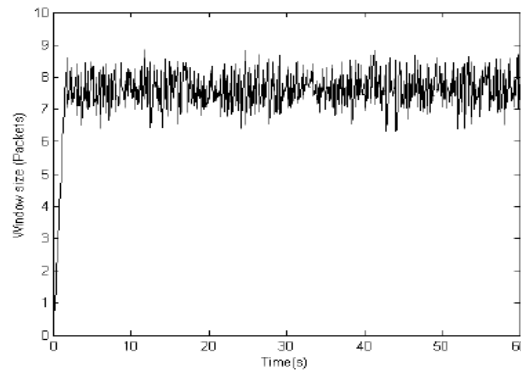


Figure 2. Window Size $W(t)$

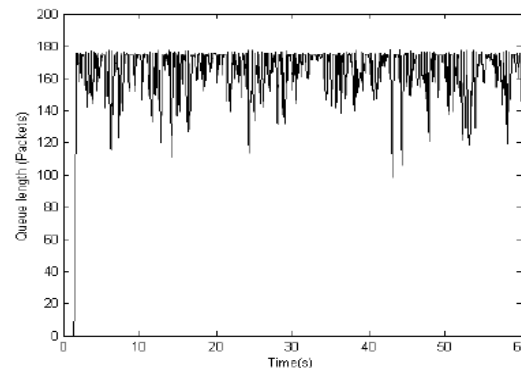


Figure 3. Queue Length $q(t)$

3. Proposed Control System

A. Basic Idea

Congestion that occurs in the router is caused by the number of data packets that are likely to increase exceeding the router service rate. To solve the congestion problem completely, the controller in the router should be able to control aggregate rate of arrival data packets. So, it does not exceed the router service rate. Thus, the architecture of congestion controls system can be defined as follow. The router service rate becomes the controller set point and the aggregate rate of arrival data packets as the controlled variable. The result of the control calculation is the capacity of the router, which is equally distributed to all users. Users obtain explicit feedback control signal and the smooth rate of actual users data transmission will be calculated based on the value of the control signal. With this mechanism, the aggregate rate of user arrival data packets is guaranteed not to exceed the router service rate. Thus, congestion can be overcome.

B. Model

Congestion control system consists of three sub-systems that can be seen in Figure 4, i.e.

1. Internet users or the sender, which the number is always changing time to time and sends data packets with a certain amount and speed.
2. Delay in data transmission process, routing, and sending control signals from router back to the sender.
3. Control mechanism in the router to control the amount of data through internet.

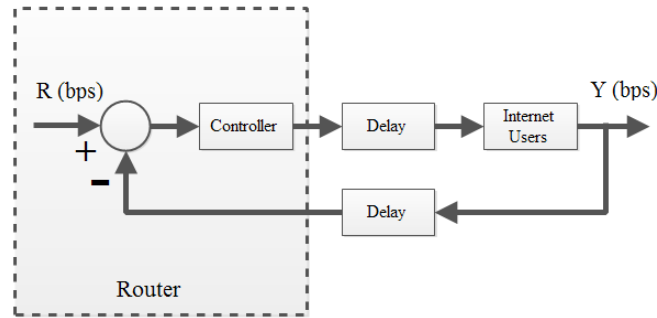


Figure 4. Congestion Control System

Where, R is router service rate as set point, Y is aggregate arrival rate.

The router acts as the controller of the aggregate arrival rate of all data users through the router. The router service rate will be defined as the set point of the controller. Error, which is the difference between the set point and the aggregate arrival rate, becomes the input of the controller. This controller determine the control signal in the form of capacity which is distributed to all users, whose the data packets through the router.

When the router has determined the capacity allocation, the sender needs to adjust the data packet rate, in accordance with this capacity allocation. Therefore, the process selected for each user in the form of first-order systems, which can be seen in equation (1) below [8]. With the characteristics of first-order systems, the data transmission rate from the user will always follow the control signal from the router [10].

$$G_{User}(s) = N \frac{K_1}{s + K_1} \quad (1)$$

Where, a constant value of K_1 will be determined later in the simulation. s is the Laplace operator and N is a constant, which represents the aggregate amount of data from all users.

For simulation purposes, the model used first order delay with Pade approximation [9]. The model can be seen in equation (2) below.

$$G_{Delay}(s) = \frac{(1 - \frac{sT}{2})}{(1 + \frac{sT}{2})} \quad (2)$$

Where, T is delay constant, which is assumed deterministic.

The simulation structure using Matlab-Simulink can be seen in Figure 5 below.

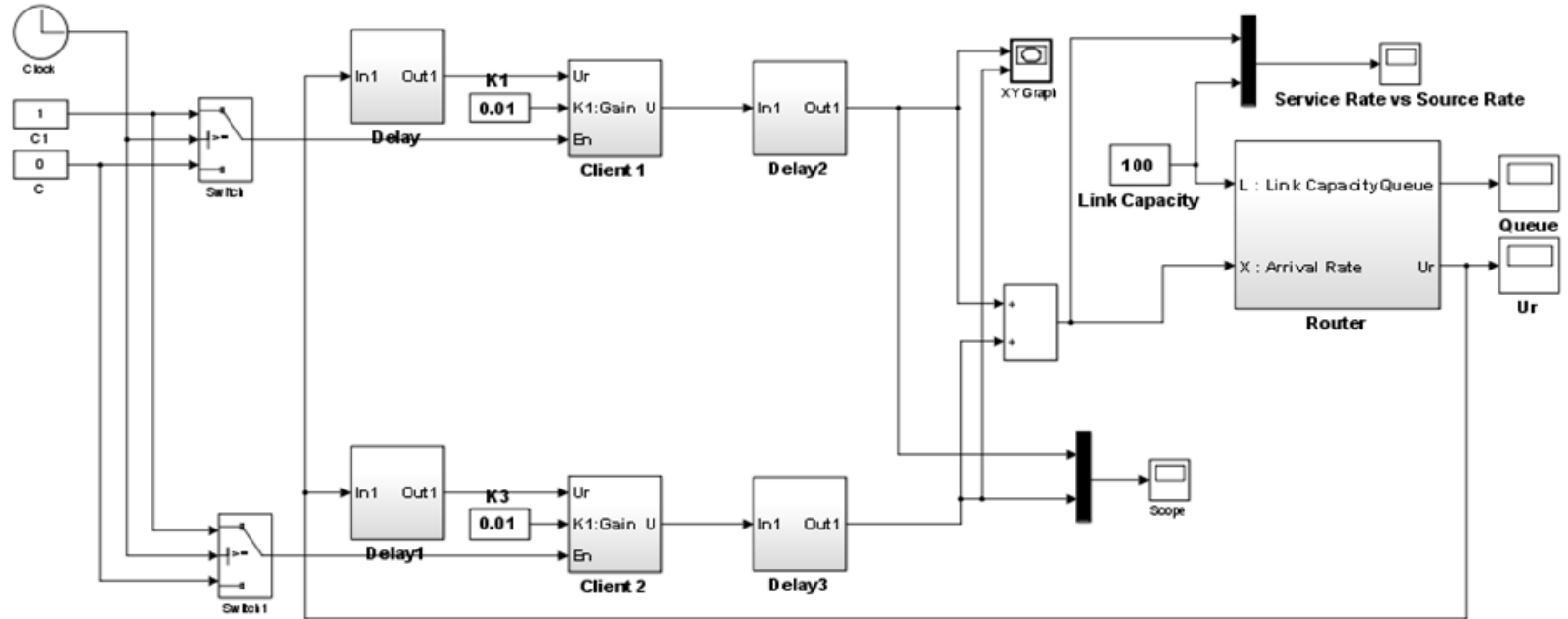


Figure 5. Simulation Structure

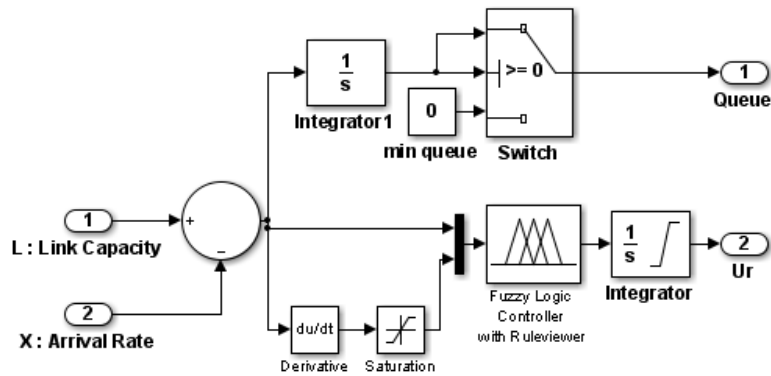


Figure 6. Fuzzy Integral Controller

Figure 6 shows fuzzy integral controller and queue structure. The fuzzy controller has two input, i.e. the error between link capacity/router service rate and aggregate arrival rate and first derivative of the error. The fuzzy controller output is connected to the integral with saturation. So, the resulting control signal is network capacity, which is distributed fairly among all users.

C. Performance Spesification

The system response is expected without overshoot and the steady state error is zero. The system response without overshoot will ensure that there will be no queue at all. Meanwhile, the zero steady state error will ensure maximum network capacity utilization. With this specification, the expected fuzzy integral controller can divide the network capacity fairly among all users and can limit the amount of data transmitted over the network below or equal network capacity. Thus, the internet congestion can be avoided.

D. Fuzzy Integral Controller

The design of fuzzy integral controller is carried out with fuzzy toolbox in Matlab. Fuzzy integral controller has two inputs, namely error and first derivative of error, which can be seen in Figure 7 and Figure 8. The error has three membership functions i.e. [neg, posSmall, posBig]. Meanwhile, the first derivative of error has two membership functions i.e. [decreasing, increasing]. Fuzzy controller outputs can be seen in Figure 9. The final outcome of the fuzzy controller is the change rate, which has three membership functions i.e. [neg, posSmall, posBig].

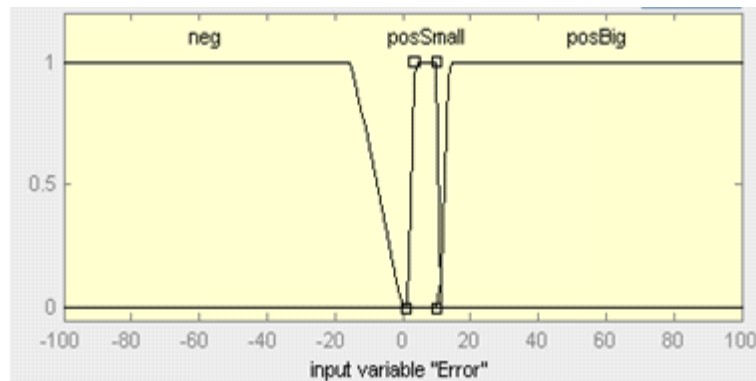


Figure 7. Input "Error" Membership Function

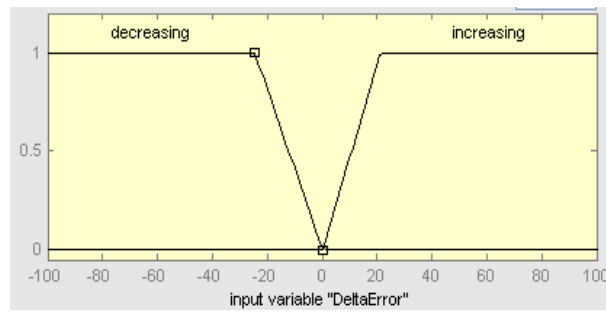


Figure 8. Input "DeltaError" Membership Function

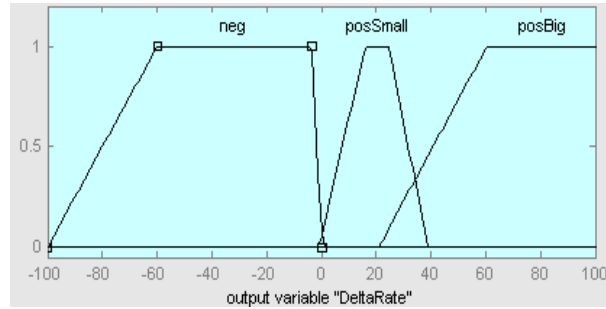


Figure 9. Output "DeltaRate" Membership Function

Fuzzy rules are designed as follows:

1. If (Error is posBig) then (DeltaRate is posBig)
2. If (Error is posSmall) and (DeltaError is increasing)) then (DeltaRate is posSmall)
3. If (Error is posSmall) and (DeltaError is decreasing)) then (DeltaRate is posSmall)
4. If (Error is neg) then (DeltaRate is neg)

Integral sub-systems with saturation are needed to accumulate the fuzzy controller output with a minimum value is zero and a maximum value equal to the router service rate.

4. Simulation Scenarios

To analyze the performance of the congestion control system, the proposed system is simulated with the following 3 scenarios.

1st Scenario

This 1st scenario uses topology in Figure10 and simulation stages on table 1.

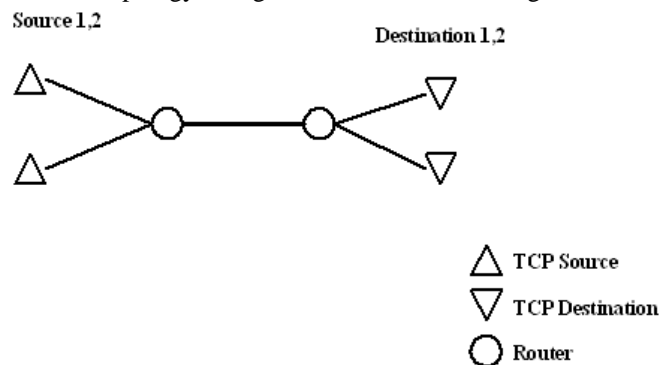


Figure 10. 1st Topology

Assumption:

Source 1:2 send data to Destination 1:2.

Link Capacity is 100 Mbps

Source/destination maximum capacity 100Mbps

RTT: 50 mS

Table 1. Simulation Stages

Iteration	Stages
0	S1 to D1 ON
500	S2 to D2 ON

2nd Scenario

This 2nd Scenario uses topology in Figure 11.

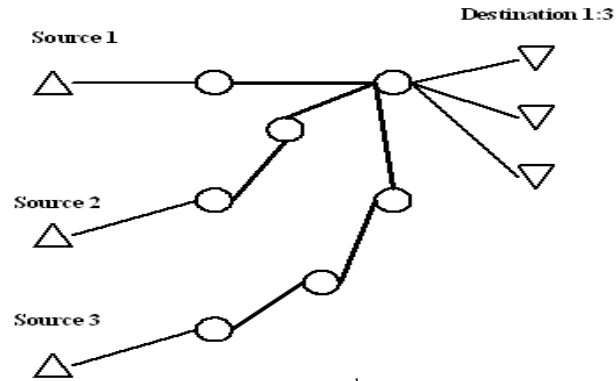


Figure 11. 2nd Topology

Assumption:

Link Capacity is 100 Mbps

Source/destination maximum capacity is 100Mbps.

Round Trip Time (RTT):

RTT S1 to D1: 50 mS

RTT S2 to D2: 250 mS

RTT S3 to D3: 1000 mS

3rd Scenario

This 3rd Scenario uses topology in Figure 12 and simulation stages on table 2.

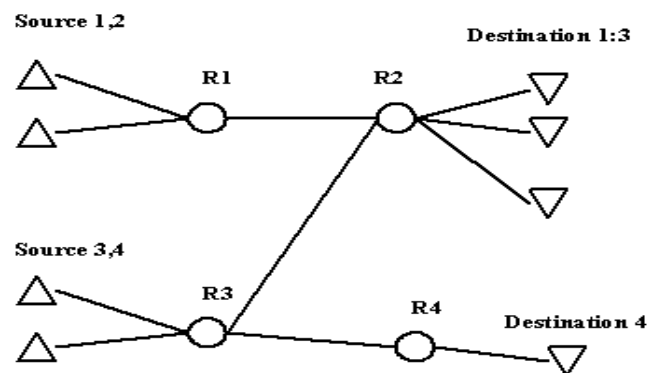


Figure 12. 3rd Topology

Table 2. Simulation Stages

Iteration	Stages
0	S1 to D1 ON
100	S4 to D4 ON
400	S2 to D2 ON
2000	S3 to D3 ON
3500	S3 to D3 OFF
4250	S2 to D2 OFF

Note:

Si: Source i

Di: Destination i

5. Simulation Results

First scenario simulation results are shown in Figure 13 to Figure 17 below. In Figure 13 and Figure 15 are shown at the beginning there is source 1 which first began to use the network. It can be seen in Figure 16, the controller gives all of the capacity to source 1. After 500th iterations, source 2 start using the network, and the controller immediately reduced divided capacity to zero. So that, the source 1 rate immediately lowered and there is no overshoot in the aggregate arrival rate, which can be seen in Figure 14. Decreased rate of source 1 immediately followed by the increase rate of source 2, until both have same rate at 50 Mbps at 1000th iteration. It can be seen in Figure 15.

With these responses, in which the aggregate arrival rate can be controlled below or equal the router capacity, it is possible there is no data packets queue. This is shown in Figure 17. Each data packet that arrives to the router directly served. This result guaranteed that there will be no congestion in the router.

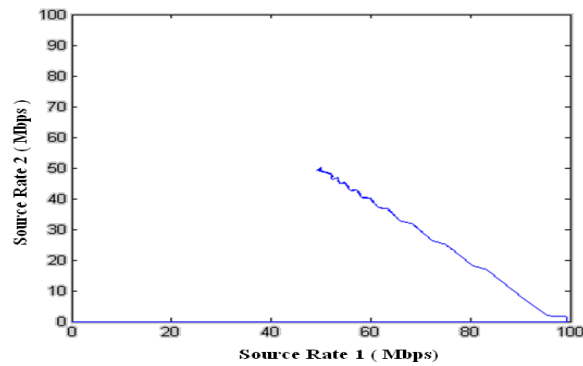


Figure 13. Source Rate 1 vs Source Rate 2

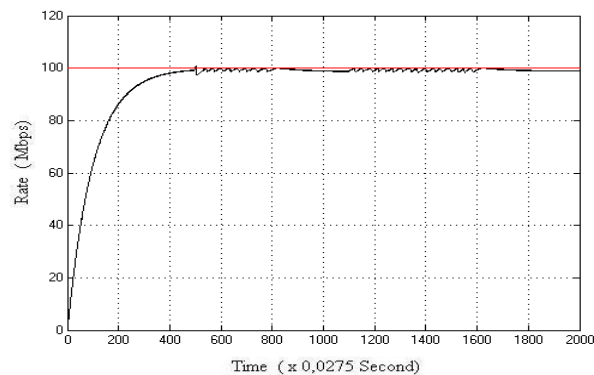


Figure 14. Service Rate and Aggregate Arrival Rate

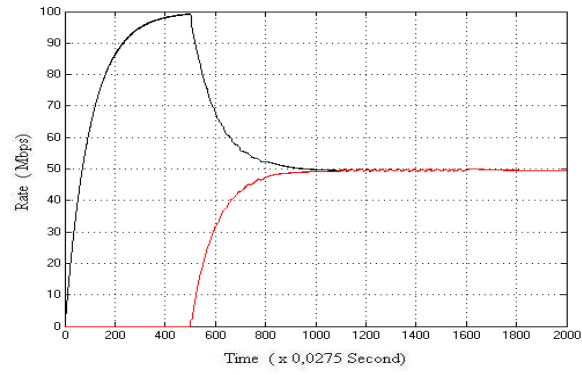


Figure 15. Source Rate 1 and Source Rate 2

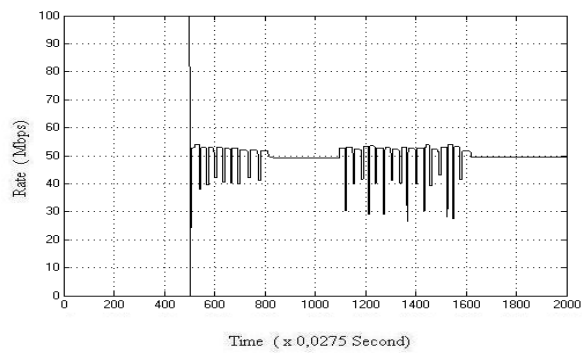


Figure 16. Control Signal (Shared Rate)

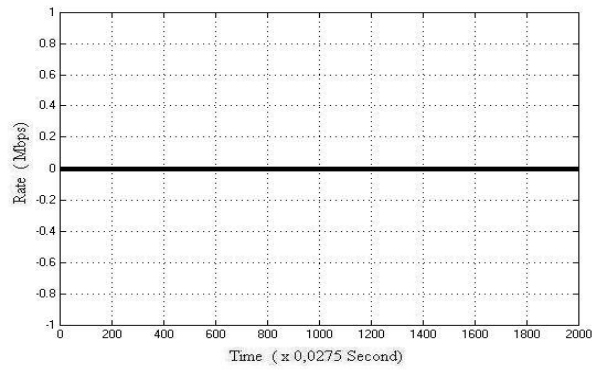


Figure 17. Zero Queue Simulation results of scenario 2 are shown in Figure 18 to Figure 20 below.

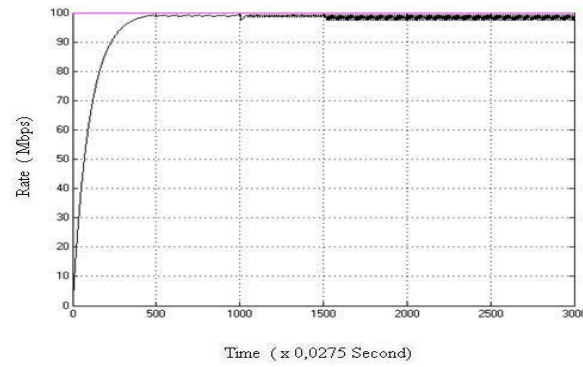


Figure 18. Service Rate and Aggregate Arrival Rate

It can be seen in Figure 18 above, there is no overshoot in the aggregate arrival rate response. Router capacity can be divided to all users fairly, which is shown in Figure 19 below.

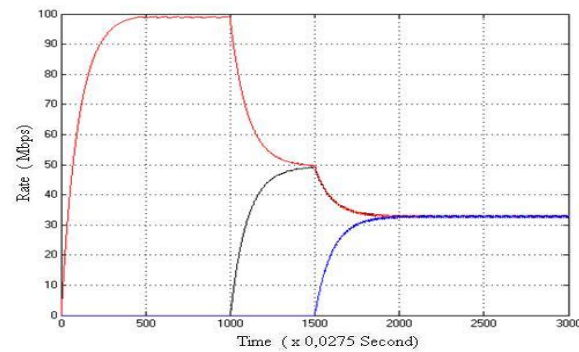


Figure 19. Users Source Rate

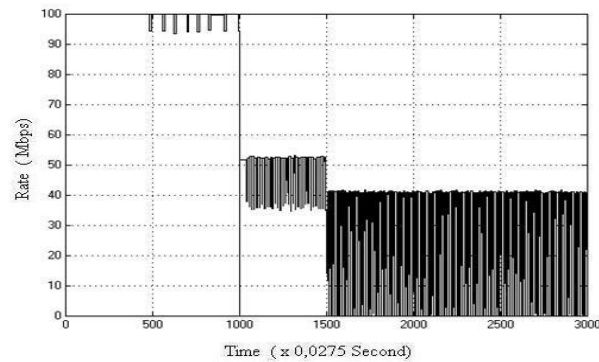


Figure 20. Control Signal as Divided Router Capacity

In the 2nd scenario, although there are differences in the Round Trip Time (RTT) of three sources, all sources can be controlled. So, aggregate arrival rate does not exceed the service rate. Source with greater RTT will take longer time to respond to the divided rate from the controller. This delay variation result oscillation in control signal (divided rate), which is shown in Figure 20. Also, there is a small oscillation in the steady state aggregate arrival rate in Figure 18.

The third scenario simulation results can be seen in Figure 21 below. At the beginning, the source 1 and source 4 use the entire capacity of the router because there is no other source packet data that passes through the same router. On the 400th iteration, source 2 starts using the network and the controller at the router 1 and router 2 simultaneously divides its capacity to both sources. Thus, both source rates reach the same value at 50 Mbps. At 2000th iteration, source 3 uses network, which result increased aggregate arrival rate at router 2 and router 3. Controllers on the router 2, divide the capacity fairly among 3 sources. Thus, all three sources have same rate at 33.3 Mbps. Because the distributed capacity of the controllers in the router 2 is smaller than router 3, source 3 take distributed capacity of the router 2 as a reference to change the data transmission rate. Remaining capacity of the router 3 is given entirely to the source 4. At 3500th and 4250th iteration respectively, source 2 and source 3 stop using the network. Thus, source 1 and source 4 re-use all capacity of the router.

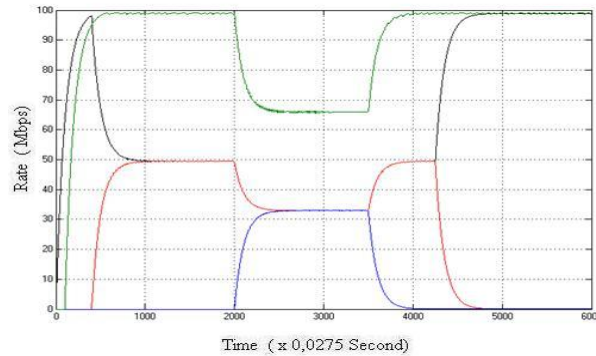


Figure 21. Users Sources Rate Dynamic

6. Performance Comparison

The stability of the Internet congestion control system related to the amount of data over the internet. From the BIBO stability perspective, the amount of data over the Internet will never exceed the capacity of data storage on the Internet. When the amount of data exceeds the capacity of the network, the data packet will be dropped. Thus, from this perspective the Internet congestion control system will always have a stable response, i.e. the amount of data over the Internet will always be limited.

Table 3. Performance Comparison

Performance	Shilpa and Madhu [4]	Deepa and Mudholkar [5]	Yogini, et al [6]	Wen, et al [7]	Proposed Control System
BIBO Stable	Stable	Stable	Stable	Stable	Stable
Asymptotically Stable	Not explained	Not explained	Not explained	Stable	Described by simulation
Queue	Exist	Exist	Exist	Exist	Zero
Packet Loss	Exist	Exist	Exist	Zero	Zero
Smooth Response	No	No	No	No	Yes

The stability of congestion control system can also be viewed as the stability of the equilibrium point of the system. Equilibrium point represents each state in the system. This state may represent the response of each user who sends the data through a router. To obtain exponentially stable equilibrium point can be done by Lyapunov theory [11], as was done by Wen et al [7]. Asymptotically stability of the proposed system has not been analyzed theoretically. However, from the simulation can be shown in Figure 15, 19, and 21 when there

is a change in the number of users, the response will always reach a new stable equilibrium point.

In addition to stability, performance comparison of the proposed control system with other methods can be seen in Table 3 above.

7. Conclusions

The proposed control system has advantages over previous methods, which have a smooth response, zero packet loss, and zero queue. However, asymptotically stability analysis is required in order to obtain guarantees when there is a change in the dynamics of the system the equilibrium point will always reach a new stable point.

The proposed fuzzy integral congestion controller can keep the amount of data transmitted over the network below or equal the network capacity, by dividing the network capacity fairly among all users. The result of this congestion control mechanism is a system response without overshoot. Though, there is a small oscillation about steady state response value. So, the steady state error is very close to zero. By controlling the rate of arrival aggregate data, the capacity of the router is enough for all users and it can be guaranteed that there are no queues in the routers. So, loss of data due to queue exceeds the data storage capacity in the router can be avoided.

The design of the fuzzy integral controller has been performed with the minimal use of variable, with 2 inputs, one output, 2-3 membership functions, and 4 rules. Thus, the realization of this integral fuzzy control algorithm will also require minimal resources of the router.

The fuzzy integral congestion control system successfully meets the desired specifications with these data assumptions. It can control user sending rate to avoid the internet congestion and divide the router capacity fairly to all users.

8. References

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