FUZZY LOGIC CONTROL IN ATM NETWORK

Weng Tat Lau, K. K. Phang, Mashkuri Yaacob, T. C. Ling
Faculty of Computer Science and
Information Technology
University of Malaya
50603 Kuala Lumpur, Malaysia
email: mc98lwt@siswazah.fsktm.um.edu.my
{phang, mashkuri, tchaw}@fsktm.um.edu.my

ABSTRACT

Due to the unpredictable behavior of the traffic and various traffic characteristics, it has become a great challenge for ATM networks to effectively control traffic and congestion while at the same time provide the desired quality of service. In this paper, a fuzzy logic traffic controller is proposed to perform traffic and congestion control functions. Simulation results showed the feasibility of utilizing fuzzy logic control in an ATM network.

Keywords: ***ATM, Fuzzy Logic Control, Usage Parameter Control***

1.0 INTRODUCTION

The Asynchronous Transfer Mode (ATM) network offers a high-speed transport network capable of supporting various types of traffic with different quality of service (QoS) requirements [1, 2, 3]. ATM networks use statistical multiplexing to efficiently share transmission resources and to improve on effective throughput. Thus, proper traffic management is needed to ensure fairness and efficient operation of the networks. The first line of defense is Connection Admission Control (CAC). Its task is to evaluate and determine whether a connection should be accepted or rejected. Decision is made based on the information in the traffic contract and the condition of the network. After the connection is accepted, congestion may still occur because a connection can potentially exceed the negotiated values in the traffic contract during CAC setup. Thus, the Usage Parameter Control (UPC) function is introduced to monitor existing connections in the network.

However, both the CAC and UPC suffer from some limitations. Firstly, it is difficult for a network to acquire complete statistics of the input traffic accurately [4]. Some of the characteristics of the traffic may not be known with required accuracy during connection setup and some may be modified before the cells reach the UPC function. Furthermore, the UPC function depends on monitoring traffic parameters such as peak cell rate, mean cell rate and burst size which are insufficient to completely describe the behavior of all ATM sources. Coupled with less then satisfactory accuracy, these uncertainties result in a significant probability that the UPC makes a wrong decision and discard cells originating from a compliant source. This will affect overall network performance and jeopardize the QoS requested by users. In short, the network is forced to make a decision based on incomplete information and thus the decision process is full of uncertainties. A fuzzy logic based traffic controller is proposed in this paper to perform traffic and congestion control functions. It is a type of fuzzy logic controllers (FLC) [5] that incorporates the experience of human experts in making appropriate decisions to control traffic and congestion. This paper is organized as follows: Section 2 presents the basic principles of a fuzzy logic controller. Next, the proposed fuzzy logic traffic controller is discussed in detail in Section 3. Section 4 presents the simulation results obtained while the conclusion is given in Section 5.

2.0 FUZZY LOGIC CONTROLLER

The idea of fuzzy control is to convert and translate all the expertise of the human operator and incorporate into a controller [5]. The basic architecture of a fuzzy logic controller consists of 3 components: a fuzzifier, a fuzzy inference engine, and a defuzzifier [6, 7, 8]. Currently, a lot of work has already been done to utilize the FLC in congestion control. Papers have been published that produce some favorable results when compared with conventional methods [4, 9-11]. In [4], two existing policing mechanisms are incorporated into a Fuzzy Rule-Based System. They are the *Modified Leaky Bucket* mechanism and the *Moving Window* mechanism.

The fuzzy policer proposed in [9] is a window-based control mechanism, in which the maximum number of cells that can be accepted in a specific window of certain length, is a threshold that is dynamically updated by inference rules. The fuzzy policer's task is to ensure that the source complies with negotiated mean rate over the duration of the connection. In [10], a fuzzy thresholding function is utilized to deliberately block or refuse entry to a fraction of incoming cells from other switches. The fuzzy thresholding function is a continuous function of the current buffer occupancy level, and it offers a more robust queue management scheme than conventional fixed threshold approach.

A fuzzy-based policer is proposed in [11] as an alternative to the leaky bucket algorithm. The fuzzy policer is designed to simultaneously monitor mean rate and reject bursts. It then decides whether to pass or discard cells based on the compliance/violation level of the two parameters.

3.0 PROPOSED FUZZY LOGIC BASED TRAFFIC CONTROLLER

Fig. 1 depicts the proposed Fuzzy Logic based Traffic Controller for an ATM network. It consists of two parts:

a) Fuzzy Policer (FP)
b) Fuzzy Congestion Controller (FCC)

The Fuzzy Policer (FP) is proposed as an alternative to the leaky bucket policing scheme. The FP goal is to simultaneously police mean rate and reject bursts. Its function is similar to the generic function performed by UPC. Cells are passed or dropped based on an evaluation of conformance to the traffic contract and negotiated traffic parameters.

The current UPC functions are majority performed by the leaky bucket algorithm. There are reasons for proposing a fuzzy alternative to perform UPC functions. The performance of the leaky bucket algorithm has been extensively studied in [12–14]. Previous works have shown that the leaky bucket algorithm has some disadvantages with respect to mean cell rate policing [4] and mean burst length policing [12]. This has encouraged the search for a better algorithm and method to overcome these inefficiencies. In addition, considerable works have been done on utilizing fuzzy based approach in other areas of traffic and congestion control functions. For example, applying fuzzy systems to estimate effective bandwidth for CAC functions has been done in [15]. Another example is the use of fuzzy system to estimate cell loss ratio for applications in CAC functions [16].

The Fuzzy Congestion Controller (FCC) is a FLC that can prevent or relieve network congestion. The FCC is a fuzzy implementation of the two-threshold congestion control method [17-18]. The current implementation of two-threshold congestion control method has the difficulty of determining the effective thresholds under various bursty traffic conditions in ATM networks. Therefore, a fuzzy based approach is proposed as a solution to control congestion. A model of the Fuzzy Logic Traffic Controller is presented in Fig. 1.

3.1 Fuzzy Policer (FP)

The proposed FP is an enhancement over the fuzzy policer suggested in [11]. The FP in this paper is an extension over the original fuzzy policer. The original fuzzy policer is a two-input, nine-rule, one-output system. In contrast, the FP presented in this paper is a three-input, eighteen-rule, one-output system. The reason for the extension is to provide the FP with more information thus helping it in making more accurate decisions on passing or dropping cells.

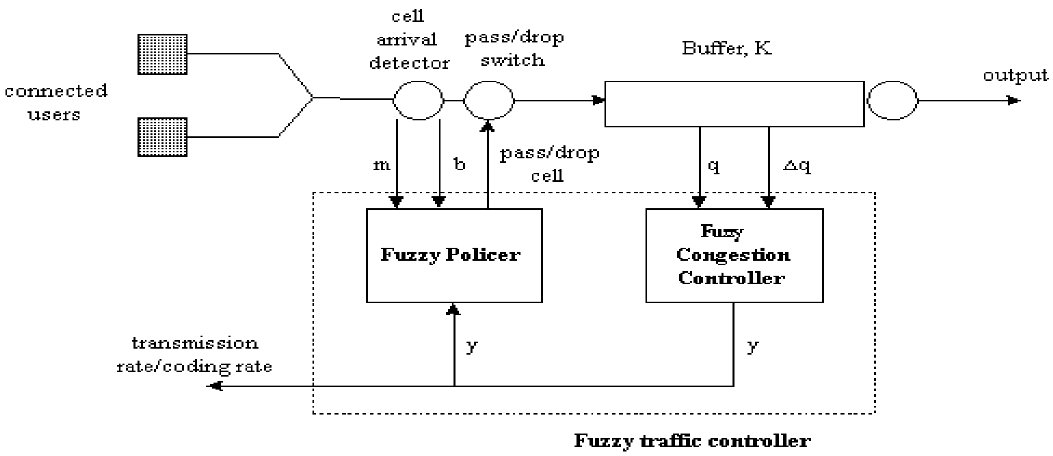

Fig. 1: Model of the Fuzzy Logic Traffic Controller

The objective of the FP is to police the mean rate and reject bursts. The FP performs its job by continuously evaluating the compliance/violation level of two parameters; i.e. the ratio of up-to-date mean bit rate to negotiated mean bit rate and ratio of up-to-date mean burst length to negotiated mean burst length. It then decides on the drop rate to be imposed on the cells based on the collective evaluation of the compliance/violation level of the two parameters. When policing mean rate, cells are discarded or tagged when the mean rate is above the negotiated mean rate. However, dealing with violation of burst length requires more information. When policing the burst length, the FP needs to acquire the mean rate together with the burst type before taking actions on discarding cells. For example, when the mean rate is below negotiated values but the burst length is slightly above the negotiated values, violation of burst length in this situation may need to be excused. This is to minimize reduction in the throughput capacities of the mean rate. Therefore, the FP has to evaluate the violation level of both the mean rate and burst length to decide on a proper action.

The proposed FP in this paper adds another parameter as input to provide more information in making decisions. The parameter serves an indicator of the state of the network. It informs the FP on whether the network is in a congested state or not. If the network is expecting congestion or is congested, then discarding cells is more favorable to reduce the intensity and prevent the spread of congestion. Looking back at the situation above, where the mean rate is below negotiated rate and burst length slightly above negotiated values, passing cells may minimize the reduction in throughput. However, if the network is congested, then passing cells will only lead to more cells being dropped due to buffer overflow and worsen the congestion. In the end, the throughput will drop as well. Hence, discarding some fraction of cells during congestion period is more appropriate. Therefore, the proposed FP has the advantage of acquiring more information about the input traffic and the state of the network before making any decisions. If congestion occurs, the FP will impose a heavier penalty than during congestion free, depending on the violation level of the parameters. Equipped with these information, the proposed FP is able to reduce uncertainties and thus make more accurate decisions in policing cells.

As for the leaky bucket algorithm, previous works have shown that it has problems in policing mean cell rate and mean burst length. The reason for less than satisfactory results in policing mean cell rate is that the characteristics of the source must be estimated on the basis of relatively short sample. This causes a certain probability of incorrect policing decision [4]. In addition, the leaky bucket algorithm is ineffective in policing bursty traffic [11]. The proposed FP offers a solution to the first problem by utilizing up-to-date value of the mean rate and burst length. The up-to-date value is calculated by taking into account all the values for each parameter (mean rate and burst length) respectively thus extending the sampling size. This enables more accurate information and reduces probability of incorrect policing decisions. As for bursty traffic, the proposed FP collectively evaluates the compliance/violation level of both the mean rate and burst length before making policing decisions. Therefore, the FP is able to make a better decision under different bursty situation. Furthermore, the FP also considers the state of the network which is an important piece of information when making policing decisions.

The three-input values to the FP are:

a) ratio of up-to-date mean bit rate to negotiated mean bit rate (A_1) (1)
b) ratio of up-to-date mean burst length to negotiated burst length (A_2)
c) state of the network (y)

(1) mean cell rate can also be used

The up-to-date value is calculated by averaging all previous values up to the most current value. For example, if we have m_1, m_2, m_3, …. m_i as the values of actual mean rate, then

$$\text{up-to-date mean rate} = \frac{1}{i}\sum_{1}^{i} m_i$$

The two ratios serve as indication of the compliance/ violation level of the two parameters. For example, a higher value of the ratio shows a greater violation of the up-to-date value over the negotiated value. A lower ratio, having a value of less than or equal to one, shows full compliance with the negotiated value. The value of input y, which represents the state of the network, may be positive or negative. If y is a negative value, then it indicates that there is congestion. On the other hand, a positive value of y implies congestion free environment.

The output value of the FP is the drop rate (c). Its value is within the range of [0, 1] whereby 0 denotes total drop of all cells and 1 denotes total pass of all cells.

The three inputs are first fuzzified, then fed to the rule base in the inference engine, and later defuzzified to produce a crisp output action c, which dictates the drop rate to be performed on the cells. The proposed FP will continuously evaluate the compliance/violation levels of the two inputs and the state of the network, which is provided by the third input to calculate the drop rate. The third input is generated by the FCC. The drop rate value is then sent to a pass/drop switch. The switch should have enough memory to store incoming cells before a decision is made. The switch will then either pass or drop a fraction of the cells in the memory based on the values of the drop rate.

The term sets used to describe each input parameter and the output drop rate are defined as follows:

Term set for A_1, $T(A_1)$ = { Violate (V), Sort of Comply (SC), Comply (C) }
Term set for A_2, $T(A_2)$ = { Violate (V), Sort of Comply (SC), Comply (C) }
Term set for y, T(y) = { Negative (N), Positive (P) }
Term set for drop rate c, T(c) = {Drop (D), Between Pass & Drop (B), Pass (P)}

The shape of the membership functions used is triangular or trapezoidal functions because these functions are suitable for real time operation [8]. The membership functions for the term set $T(A_1)$ and $T(A_2)$ are identical. Fig. 2 below illustrates the membership functions for the term set $T(A_1)$

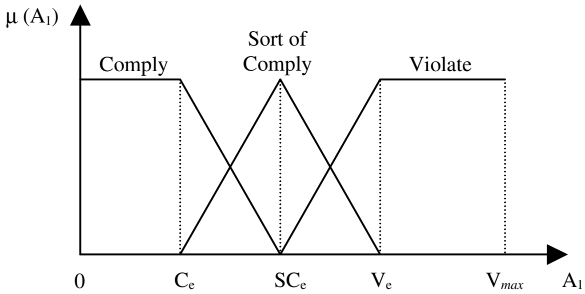

Fig. 2: The membership functions for the term set $T(A_1)$

C_e represents the maximum ratio value of the parameter (A_1 ,A_2) that can still be considered to be compliant. SC_e provides a soft transition value between compliance and violation. V_e is the ratio value that is considered to be in violation while V_{max} represents the largest possible violation ratio.

The membership functions for the term set T(y) are illustrated in Fig. 3.

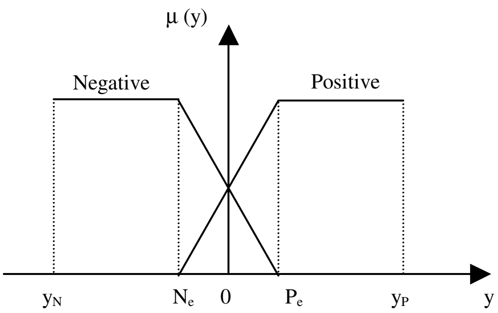

Fig. 3: The membership functions for the term set T(y)

A negative value of y indicates congestion while a positive value shows no congestion. y_N represents the maximum negative value that y can take, whereas y_P represents the maximum positive value for y. The value between N_e and P_e provides a soft transition between congestion and congestion free state.

The membership functions for the term set T(c) are illustrated in Fig. 4 below:

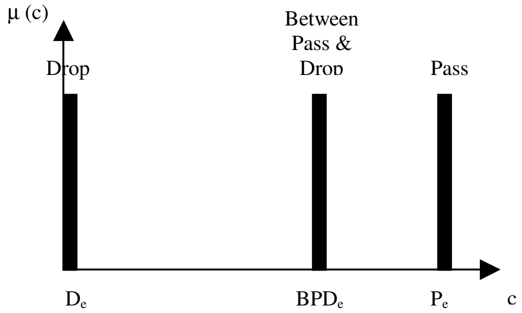

Fig. 4: The membership functions for the term set T(c)

D_e , BPD_e , P_e represents the drop rate imposed on the cells. D_e would be set to 0 for total drop of all cells, BPD_e to a value within [0, 1] but closer to 1 for dropping a fraction of the cells, and P_e is set to 1 for passing all cells.

The FP decides on the drop rate c, according to the set of linguistic variables of parameters A_1 and A_2, state of the network y generated by the FCC, and a set of built in fuzzy control rules. The rule base is constructed on the basis of knowledge from policing experts. The eighteen–rule structure for the FP is presented in Table 1 above. The rule base consists of a set of linguistics rules in the form of "if – then" statement. The rules are read as follows:

IF A_1 is C **and** A_2 is C **and** *y* is P **THEN** *c* is P

The proposed FP uses the max-min inference method [8] for the inference engine because it is designed for real time operation. As for the defuzzification process, the FP uses the Tsukamoto's Defuzzification Method because of its simplicity in computation. The defuzzification process produces a crisp value of the drop rate, which indicates the number of cells to pass/drop.

3.2 Fuzzy Congestion Controller (FCC)

The proposed Fuzzy Congestion Controller (FCC) aims to prevent or relieve network congestion. It is a two-input, four-rule, one-output system. The two-input values to the FCC are:

a) queue length of buffer (q)
b) queue-length change rate (Δq)

Table 1: Rule Structure for the Fuzzy Policer (FP)

Rule	A_1	A_2	y	c	Rule	A_1	A_2	Y	c	Rule	A_1	A_2	y	c
1	C	C	P	P	7	V	C	P	D	13	SC	C	N	D
2	C	SC	P	B	8	V	SC	P	D	14	SC	SC	N	D
3	C	V	P	D	9	V	V	P	D	15	SC	V	N	D
4	SC	C	P	B	10	C	C	N	P	16	V	C	N	D
5	SC	SC	P	B	11	C	SC	N	B	17	V	SC	N	D
6	SC	V	P	D	12	C	V	N	D	18	V	V	N	D

The FCC will continuously monitor the queue length of the buffer to check whether the queue length has exceeded the threshold values or not. Two threshold values are determined, one for the high threshold and the other for the low threshold. These threshold values are used to determine the onset and the relief of congestion. If the queue length exceeds the high threshold value, it means that the system is experiencing congestion. On the other hand, if the queue length drops below the low threshold, it means that the system is congestion free or has just recovered from congestion. The FCC also takes into account the queue-length change rate as an extra indicator of the congestion state of the system. By evaluating the buffer queue length and the queue-length change rate, the FCC offers a more accurate view of the state of the system.

The output value of the FCC is the rate control (y), which is sent to the source. It acts as a signal to notify the source to adjust its current transmission (cell) rates based on the congestion state of the system. If the system is experiencing congestion, the FCC will sent a negative value of y to inform the source to decrease its current rate. The source can then decrease its current rates by reducing transmission rates or selectively discarding cells. If the system is congestion free, then a positive value of y is sent, so that the source can restore to its original rate. This step is necessary to improve throughput.

The term sets used to describe each input parameter and the output control rate are defined as follows:

Term set for queue length T(q) = { Empty (E), Full (F) }
Term set for queue-length change rate T(Δq) = { Negative (N), Positive (P) }
Term set for rate control T(y) = { Decrease (DC), No Change (NC), Increase (I) }

The terms Empty and Full are used to describe the queue length. As for the queue-length change rate, the term Negative indicates that the occupancy of the queue is reducing while the term Positive shows that the occupancy is increasing. The terms Decrease, No Change and Increase are used to describe the rate control action generated by the FCC.

The membership functions for the term set T(q) are illustrated in Fig. 5 below:

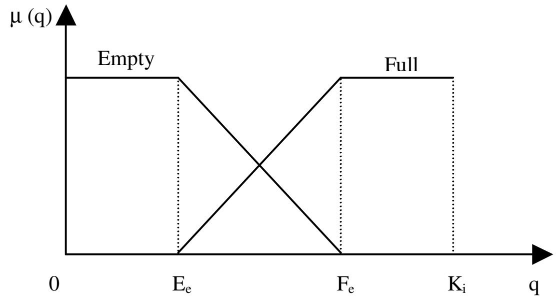

Fig. 5: The membership functions for the term set T(q)

The values at E_e and F_e represent the low threshold and high threshold values respectively, as used in the two-threshold congestion control method. A value of q below low threshold indicates a congestion free state while a value of q above the high threshold implies congestion. K_i represents the total buffer size.

The membership functions for the term set T(Δq) are illustrated in Fig. 6 below:

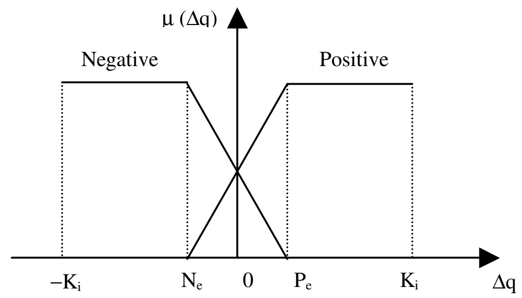

Fig. 6: The membership functions for the term set T(Δq)

$-K_i$ represents the maximum possible value that Δq can take during congestion free period, whereas K_i represents the maximum value for Δq during congestion.

The membership functions for the term set T(y) are illustrated in Fig. 7 below:

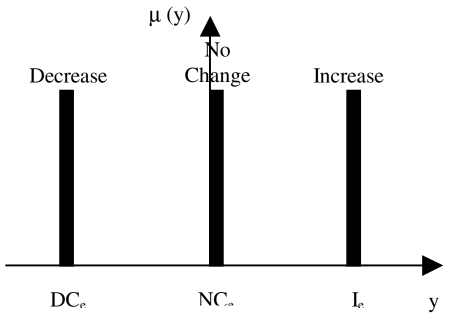

Fig. 7: The membership functions for the term set T(y)

DC_e , NC_e , I_e represent the rate control sent to the source. NC_e would be set to 0, DC_e and I_e are set to a negative and positive value respectively. They would be set to the same magnitude for symmetry.

The FCC generates the rate control action y, according to the set of linguistic variables of queue length q and queue-length change rate Δq, and a set of built in fuzzy control rules. The rule base is constructed on the basis of knowledge of the two-threshold congestion control method. The rule structure for the FCC is presented in Table 2 below. The rules are read as follows:

IF q is E **and** Δq is N **THEN** y is I

Table 2: Rule Structure for the Fuzzy Congestion Controller (FCC)

Rule	q	Δq	y
1	E	N	I
2	E	P	I
3	F	N	D
4	F	P	D

The proposed FCC also uses the max-min inference method for the inference engine, and the Tsukamoto's Defuzzification Method for the defuzzification process. Finally, a crisp rate control value is produced and sent to the source. The source will then adjust its transmission (cell) rate accordingly to prevent or to relieve congestion.

3.3 Operation of the Fuzzy Logic Traffic Controller

A cell arrival detector measures the mean bit rate (m) and mean burst length (b) of incoming traffic from connected users. These two measurements serve as inputs to the FP. The FP also accepts an input from the FCC that depicts the congestion state of the network (y). The output decision from the FP will then be sent to the pass/drop switch. The FCC accepts the queue length (q), and queue-length change rate (Δq) of the buffer as inputs and outputs a rate control action (y) to the traffic sources. In short, the Fuzzy Traffic Controller's goal is to simultaneously monitor mean rate and reject bursts while at the same time prevent and relieve congestion.

4.0 SIMULATION RESULTS

A simulation was carried out to analyze the performance of the FP and FCC in policing and controlling traffic flow within virtual channel connections (VCCs) passing through a network node. Comparison is made between the proposed FP and FCC, with existing schemes to evaluate any performance gain. The FP and FCC schemes are included into the simulation model to measure their performance in policing cell rates and preventing congestion. The leaky bucket algorithm is also included for comparison. The model simulates the traffic consisting of ATM cells flowing within the VCCs. Appropriate traffic source model is used to generate different types of traffic streams within the VCCs.

The traffic model, which is widely used for the characterization of ATM sources, is the on-off source model. This model has been successfully used to realistically model packetized voice, still picture and interactive data services [4, 12]. Using the on-off model, the ATM cell stream from a single source is modeled as a sequence of alternating burst periods and silence periods. During the "on" state, which is the burst state, the source will generate a stream of cells that are equally spaced at its peak rate. When it is in the "off" state, during the silence period, it generates no cells at all. Two traffic generating models can be used to generate the traffic stream. In the first, both the burst and silence periods are exponentially distributed. In the second model, the number of cells generated during a burst follows the geometrical distribution, while the silence period is exponentially distributed. In this simulation, the second model was used to generate the traffic stream.

By using the on-off burst silence model, the peak rate, mean burst size and the silence period are sufficient to completely describe the traffic statistics behavior of a source [4, 12, 13]. The peak rate is the cell rate during a burst. Therefore, the cell inter-arrival time during a burst can be derived from the peak rate. The mean burst size is the average number of cells in a single burst. For a review of other traffic models, please refer to [19].

4.1 Results for the FP

In this simulation, the performance of the FP is compared to the leaky bucket algorithm. Both the FP and leaky bucket algorithm are performed on a per VCC basis. The result is based on the policing functions performed by both schemes on the same VCC. Identical sets of traffic pattern are fed to both the FP and the leaky bucket algorithm. The system performance is then measured in terms of cell loss ratio for the traffic in the VCC.

The simulation is based on bursty traffic sources with geometrically distributed burst size and exponentially distributed silence period. The FP is tested in parallel with the leaky bucket algorithm. Two leaky buckets are used for comparison, both dimensioned to monitor mean cell rate:

1) leaky rate close to mean rate with a very large bucket size (Leaky Bucket 1)
2) leaky rate much greater than mean rate with a very small bucket size (Leaky Bucket 2)

Two traffic types are considered: packetized voice and still images. The traffic characteristics for this type of sources are based on data from [4], [12] and are shown in Table 3 below:

Table 3: Traffic Characteristics of Packetized Voice and still images

Source Parameter	Packetized Voice	Still Images
Peak rate, *p*	32 Kbps	2 Mbps
Mean rate, *m*	11.2 Kbps	87 Kbps
Burst Size, *b*	26 cells	2358 cells
Silence period, μ	0.65 s	11 s
Burstiness, β	2.85	23

Testing is performed on both violation of the mean bit rate and violation of the mean burst size. The simulation results obtained are shown in Fig. 8 – 11.

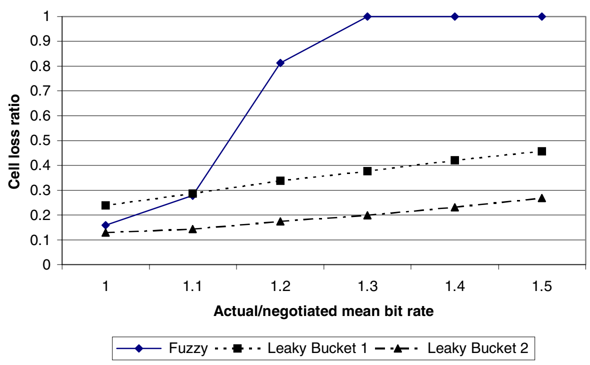

Fig. 8: Violation of mean bit rate for packetized voice

From the simulation results, it can be seen that the proposed FP outperforms the leaky bucket algorithm in both violations of the mean bit rate and the mean burst size. The FP performs extremely well on the policing of mean bit rate when compared to the leaky bucket algorithm. When the violation level is increasing, the FP is able to detect the situation and take appropriate action to discard and shut off sources that violate the negotiated values. In the policing of burst size, the FP once again outperforms the leaky bucket algorithm. The leaky bucket algorithm is found to be less effective in policing burst size as compare to the FP. The FP is able to detect violation of burst size very efficiently thus dropping cells when necessary to ensure fairness and protect the network from severe congestion.

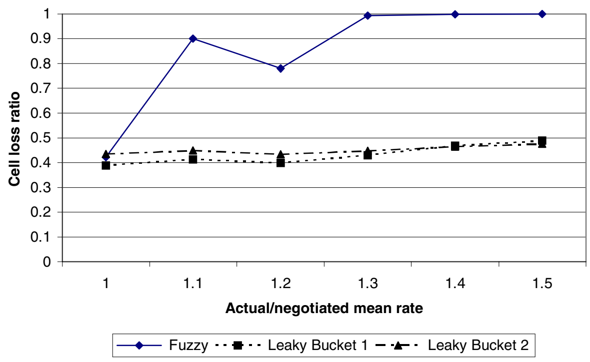

Fig. 9: Violation of mean bit rate for still images

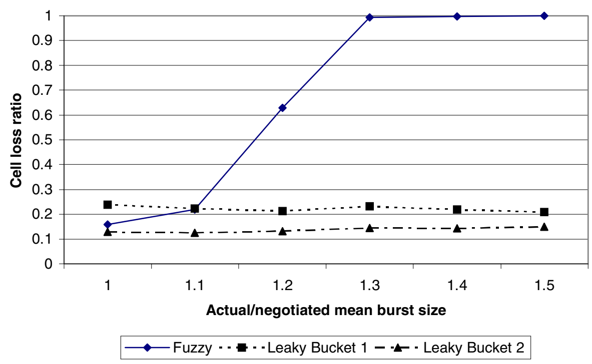

Fig. 10: Violation of mean burst size for packetized voice

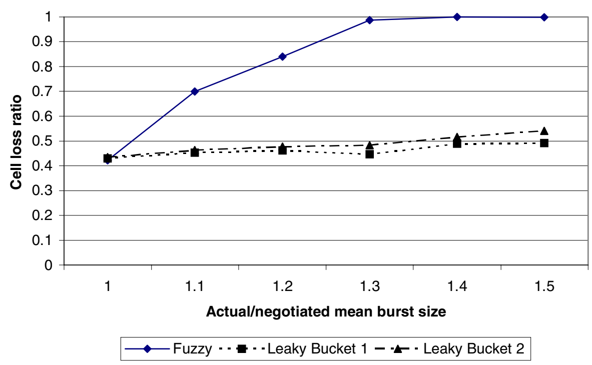

Fig. 11: Violation of mean burst size for still images

In Fig. 8 and Fig. 10, it is found that the Leaky Bucket 1 seemed to perform better within the range of 1 to 1.1 (actual/negotiated values) when compared to the FP. The Leaky Bucket 1 is able to detect slight violation (between 1 to 1.1) and begin discarding cells. However, the objective of the FP is to tolerate a slight violation of the negotiated values (e.g. mean rate) when the other parameters (e.g. burst size) are below negotiated values. The purpose is to minimize reduction in throughput when cells are discarded. Therefore, the performance of FP within this region (1 to 1.1) is more desirable. Furthermore, the FP control parameters can be adjusted to enforce a stronger action when the violation level is within this range. The simulation results have demonstrated that the proposed FP can outperform the leaky bucket algorithm by substantial margin and the FP is very suitable for policing bursty traffic.

4.2 Results for the FCC

In this simulation, performance of the FCC is compared to the one that does not utilize fuzzy logic control. By comparing the cell loss ratio for both of them, the performance of the FCC can be analyzed. The FCC, after evaluating the current buffer utilization, will send a rate control signal to notify the source to adjust its transmission/cell rate. When the system is relieved from congestion, the transmission/cell rate will be restored to its original value to improve overall throughput and performance of the system.

The simulation is based on bursty traffic sources with geometrically distributed burst size and exponentially distributed silence duration. The FCC is put into test under different traffic environment. To accomplish this, traffic sources with different load conditions are used in the simulation. This is done by varying the traffic parameters, i.e. peak rate, mean burst size and the mean silence duration. Cell inter-arrival time during bursts can be derived from the peak rate. The source parameters used are:

mean inter-arrival time = 5 ms
mean burst size = 50 cells
mean silence duration = 500 ms

and the number of connections = 10

The parameters for the output link (network node) in the simulation are:

mean inter-arrival time = 1 ms
mean burst size = 100 cells
mean silence duration = 200 ms

The simulation results obtained are presented in Fig. 12 to Fig. 15 below.

From the simulation results, it is evident that the proposed FCC provides significant reduction of cell loss due to congestion and buffer overflow under various traffic load environments. If there is congestion, the FCC will notify the source to reduce its current rate. However, when the system is relieved from congestion, the transmission/cell rate will be restored to its original value. This is to improve overall throughput and performance of the system.

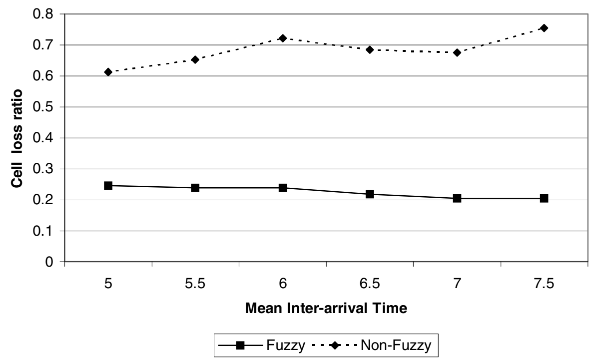

Fig. 12: Variation of mean inter-arrival time

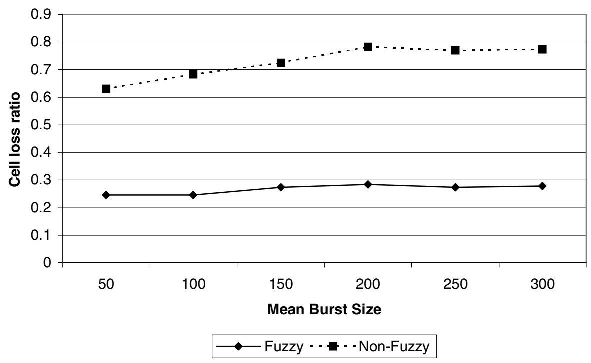

Fig. 13: Variation of mean burst size

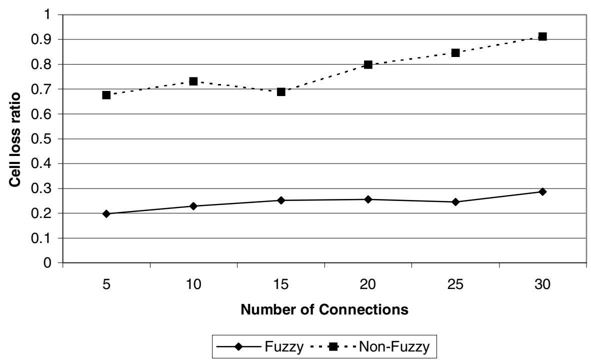

Fig. 14: Variation of number of connections

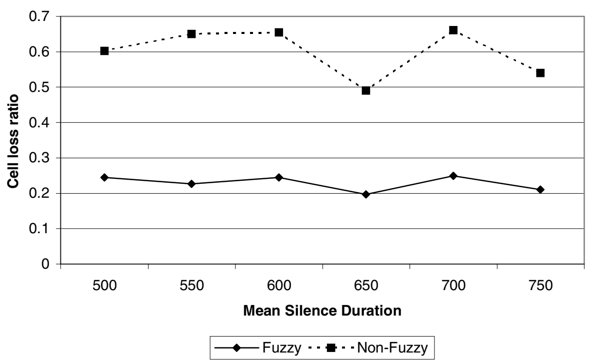

Fig. 15: Variation of mean silence duration

In Fig. 12, the peak rate of the sources is varied to create different load conditions on the network node. Congestion occurs when the buffer at the network node overflows and cells are dropped. The cell loss ratio for the FCC scheme is compared to the one without any control. The results showed that the FCC performed very well in minimizing the occurrence of congestion at the network node. This is accomplished by giving feedback to the sources to adjust their transmission/cell rate. Thus, the FCC provides a significant reduction in cell loss ratio.

The average burst size for all connections (sources) are varied to test the performance of the FCC under different load environments. The results in Fig. 13 once again showed the superiority of the FCC in minimizing the occurrences of congestion. The cell loss ratio for the FCC is much lower compared to the one without any fuzzy control. The number of cells lost due to buffer overflow is decreased sharply with the use of the FCC.

Congestion sometimes occurs when the number of connections going through a network node increases. This may be due to new users entering the network to transmit data. Therefore, a simulation is performed whereby the number of connections is increased. The results in Fig. 14 clearly showed that the FCC achieved substantial reduction in cell loss ratio when compared to the one without any control.

Finally, the mean silence duration for all the sources is varied to create different load environments on the network node. Once again, the cell loss ratio is used as a performance measure to determine the effectiveness of the FCC. Fig. 15 illustrates the results obtained from the simulation. It has been found that the FCC reduces the number of cells lost due to congestion and buffer overflow, as shown by the low cell loss ratio obtained.

5.0 CONCLUSION

This paper has presented the design of a Fuzzy Logic Traffic Controller that monitors the mean rate and reject bursts, while at the same time prevent or relieve congestion. By utilizing fuzzy logic approach and fuzzy control rule base, the proposed design is able to mimic experts' knowledge and experience in making traffic control and policing decisions. Simulation results showed that the proposed fuzzy implementation reduces cell loss ratio by substantial margin when compared to conventional schemes. The results indicate the feasibility of utilizing fuzzy logic control in ATM networks.

Future work may be directed to expanding the fuzzy controller to other areas of traffic and congestion control functions. For example, a combination of fuzzy controllers can be implemented to perform both the CAC and UPC functions together. This may provide a broader solution to the traffic and congestion problem. Also, recently neural networks have been applied in fuzzy logic controllers. The idea is to develop a fuzzy controller that learns to adjust its performance using a neural network structure. Hence, the fuzzy controller has the ability to learn and adapt to the environment by accumulating experiences. Therefore, the application of neural networks in designing fuzzy traffic controllers is worthy of further study.

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BIOGRAPHY

Lau Weng Tat is currently a Master in Computer Science student in University of Malaya. His major is in Data Communication and Networking. He obtained his Bachelor Degree in Information Technology from the National University of Malaysia in 1998.

K. K. Phang is a lecturer in the Faculty of Computer Science and Information Technology, University of Malaya, Malaysia. His current research interests include fuzzy logic and computer networks.

Mashkuri Yaacob is Professor of Computer Science and Dean of the Faculty of Computer Science and Information Technology, University of Malaya. He joined the University of Malaya in 1976. He has published over 130 research papers and presented papers at both local and international conferences. He is a member of the IASTED Conference Organising Committee and IEEE Computer Society. His research interests are software engineering, and computer architecture which includes ATM network architecture, virtual circuit management performance, and others.

T. C. Ling is a lecturer in the Faculty of Computer Science and Information Technology, University of Malaya, Malaysia. His current research interests include distributed systems and high speed computer networks