Traffic Control in an ATM Network Using Fuzzy Set Theory

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Abstract

Due to the demand for high-speed and multimedia services, ATM (asynchronous transfer mode) networks have increasingly received high attention. The multimedia services in ATM networks have diverse traffic characteristics and service requirements, appropriate traffic controls of call admission and congestion are needed so as to guarantee the required quality of service (QOS) for services. Previous studies on the traffic control were based on the results of queueing analyses. In this paper, an alternative traffic control for admission in conjunction with congestion based on fuzzy set theory are proposed for an ATM network. The performance evaluation via simulation shows the effectiveness of the proposed method in comparison with the equivalent capacity in [1]; link utilization is effectively improved by 8% while keeping the QOS contract.

1 Introduction

An ATM (asynchronous transfer mode) network must have proper traffic control capability to efficiently support a diverse mixture of voice, video and data services and must be able to meet various quality of service (QOS) as well as bandwidth requirements. The traffic control includes admission control and congestion control that should be highly correlated. In order to have an appropriate admission control, the network should have enough information about the traffic characteristics of the currently connected and newly requested users (customers). The proposed parameters for describing the source traffic characteristics are the average bit rate (ABR), peak bit rate (PBR), burstiness (=PBR/ABR) or PBR duration [2, 3, 4, 5, 6, 7].

Several admission control methods were proposed, but the methods either assumed a too simplified model or were too complicated to implement [1, 8, 9]. In [8], the authors proposed an admission control scheme based on a burst model without considering the output buffer size. In this case, the relationship between the cell loss probability and the buffer size is not clear and difficulties in the implementation of the method occur when the number of call classes is large. In [9], Saito proposed an upper bound of the cell loss probability based on the observed statistical characteristics of the new call. The QOS requirement is guaranteed under this control without assuming a cell arrival process. But the main drawback is the complexity for implementation. In [1], approximations based on both fluid-flow model and Gaussian distribution were used. An upper bound for the equivalent capacity required by the new user was estimated and the "link metric" was defined. This method is fast because it is easy to update the link metric. However, it suffers the drawback of inefficiency uses of the system resource.

Although an appropriate admission control scheme can provide a good management of network resource, due to the unpredictable fluctuations of traffic flows or fault conditions within the network, network congestion will also be caused. Previous congestion control strategies [3, 10, 11] are based on the results obtained via analytical performance evaluation, within which a queueing model is assumed and a steady-state optimal performance solution is obtained. The main drawback of these congestion control methods is that an appropriate and realistic model, which exactly describes the system behavior, is difficult to be analyzed and the analytic results have the problem of computational intractability.

In this paper, we apply the fuzzy set theory and propose a fuzzy traffic controller to deal with the traffic control problem in an ATM network. The proposed traffic control scheme is an admission control operating in conjunction with a congestion control for an ATM network. The performance of the fuzzy traffic controller is evaluated via simulation and is compared with the equivalent capacity method proposed by Guèrin [1]. The result shows that link utilization of the fuzzy control is effectively improved about 8% higher than that in [1] while keeping the QOS contract.

The organization of this paper is as follows. The system model will be given in section 2. A traffic control scheme, based on the fuzzy set theory, is proposed as well. The functional block diagram of the fuzzy traffic controller and the details about each component will be presented in section 3. In section 4, simulation results are illustrated and discussed. The concluding remarks are given in section 5.

2 System Model

As shown in Fig. 1, the system categorizes the input services into two types: real-time (type-1) and

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non-real-time (type-2). Video and voice services are examples of type-1, while data service is an example of type-2. The message from the users is cut into fixed-length packets, called "ATM cells", and is then stored in prebuffer waiting for transmission. Two separate finite buffers for type-1 and type-2 traffic are provided with size K_1 and K_2, respectively. Each buffer space can accommodate an ATM cell. When the buffer is full of cells, the new coming cells are then blocked and lost.

On the customer side, we assume that cells generated by a video coder belong to one of the two motion states (low motion for interframe and high motion for intraframe)[12]. Here we divide the rate of the intraframe coding into two parts. The first has the same rate as the interframe coding and the second, called difference coding, is the difference rate between intraframe coding and interframe coding. Let $\lambda_a(t)$, $\lambda_r(t)$, and $\lambda'_a(t)$, denote the number of cells generated from the video coder for intraframe coding, interframe coding, and difference coding at time t, respectively. Then

$$\lambda_a(t) = \lambda_r(t) + \lambda'_a(t),$$

The interframe coding and the difference coding are all modeled as discrete-state Markov processes with basic rates A_r and A_a, respectively. The level transition diagram for the bit rate process of $\lambda_r(t)$ and $\lambda'_a(t)$ are shown in Fig.s 2(a) and 2(b), where label $m_r A_r$ $(0 \leq m_r \leq M_r)$ in each level indicates the source rate due to interframe coding. And, $m_a A_a$ $(0 \leq m_a \leq M_a)$ in each level indicates the additional rate due to intraframe coding. The video source will alternate between interframe and intraframe as shown in Fig. 2(c), and it depends on the video source activity factor c and d. The value of γ, ω, M_r, A_r, Φ, Ψ, M_a, A_a, c, and d in Fig. 2 can be obtained according to the source characteristic such as peak rate, mean rate, etc. [13]-[16].

For the voice source, there is a strong correlation to the alternation between talkspurt and silence. The correlation can be modeled by a two-state Markov chain, as shown in Fig. 2(d). During the ON (talk spurt) state, voice cells are generated at a fixed rate A_v; while during the OFF (silence) state, no cells are generated [16, 17]. For the data source, the generation of cell is characterized by a bursty arrival process. We denote the probability of i arrival cells per frame by $P_d(i)$.

On the network side, a higher service priority is assigned to type-1 traffic. Type-2 traffic can only be served when the queue of the type-1 is empty. For this reason, connection admission control strategy is only provided for type-1 traffic. New user can enter the network and be served after negotiation with the fuzzy traffic controller in the call set-up phase. Three linguistic traffic parameters – peak bit rate (R_p), average bit rate (R_m) and peak rate duration (T_p) – should be provided. According to these parameters, the required capacity of the new customer is estimated by a fuzzy logic controller and then is used for acceptance decision. Another three linguistic parameters – queue length q, the change rate of the queue length Δq, and the cell loss probability p – are fed to the fuzzy traffic controller to indicate the occurrence of congestion and generate the coding rate control signal to relieve congestion. According to the coding rate control signal, less significant cells are selectively discarded in the prebuffer. For type-2 traffic, a threshold value L_2 of the queue length is used to indicate congestion and, a transmission rate manager generates a transmission rate control signal to determine the transmission rate of type-2 traffic when the congestion occurs or releases. The details about our control algorithm and the design of the fuzzy traffic controller are described in the next section.

3 Fuzzy Traffic Controller

The functional block diagram of the fuzzy traffic controller is shown in Fig. 3. Basic functions of each component in the fuzzy traffic controller and the way to implement the fuzzy traffic controller are described in the following.

- *Usage Parameter Estimator:* The usage parameter estimator observes the system performance parameters of queue length q, change rate of queue length Δq and the cell loss probability p for type-1 traffic. The estimator feeds these parameters to a fuzzy congestion controller.

- *Fuzzy Congestion Controller:* The fuzzy congestion controller is a fuzzy logic controller that deals with the congestion control related procedure. The control action y is determined according to a set of linguistic variables (q, Δq and p) and a set of fuzzy control rules. The control rules are predefined in a rule base on the basis of our knowledge about the congestion control strategy. The control action y is an availability indication of the network resource. If y is positive, it indicates that the resource is available; either a new customer has a good chance to enter the network or the already established customers can retain their negotiated QOS. If y is negative, it denotes a certain degree of network congestion; no new customers can be accepted and the selective discarding procedure should be performed.

- *Decision Block:* The block makes a decision under the congestion control action y and the current QOS. Accordingly, the control action y is fed to the fuzzy admission controller if the QOSs for the already served customers are satisfied and the value of y is positive. Otherwise, y is fed to the coding rate manager.

- *Coding Rate Manager:* The coding rate manager performs a "selective discard" function for type-1 traffic at the prebuffer under the control action y.

- *Traffic Negotiator:* The traffic negotiator is a fuzzy logic controller. It gives an estimation of the capacity requirement for the new user according to the source traffic parameters provided at the call set-up phase. The traffic parameters used here are the peak bit rate (R_p), average bit rate (R_m), and the peak rate duration (T_p). A set of fuzzy control rules, as obtained from our knowledge about the bandwidth assignment (or equivalent capacity assignment) for a new user, is used to give an appropriate estimation of the required equivalent capacity C_e. The C_e provides the bandwidth information for the new coming customer to the fuzzy admission controller.

- *Network Resource Estimator:* To deal with the connection admission control problem, we should provide not only the traffic characteristic of the new user but also the current available network capacity. The initial value of the C_a is set to 1 because no capacity is used. When a new customer is accepted by the fuzzy admission controller, a portion C_e of the total capacity is virtually assigned to this new customer and C_a should be updated. On the other hand, when a connected customer ends his service, another C_e is virtually released by this old customer and C_a is also updated.
- *Fuzzy Admission Controller:* The fuzzy admission controller is a fuzzy logic controller that deals with the admission control related procedure. The control action z is determined by a set of linguistic variables y, C_e, and C_a obtained from the the fuzzy congestion controller, traffic negotiator, and the network resource estimator, respectively. A set of fuzzy control rules are designed in this block so as to make a proper decision on acceptance or rejection of a new call. The final control action z is fed into the traffic negotiator for informing the new user to accept or reject the call request.

As described above, the fuzzy logic controller is the major component in our fuzzy traffic controller. As shown in Fig. 4, the basic functions of components in the fuzzy logic controller are described in the following.

- *Fuzzifier :* The fuzzifier converts the input system performance parameters X into suitable linguistic values which are needed in the inference engine.
- *Fuzzy Rule Base :* The fuzzy rule base contains a set of fuzzy control rules, defined in a linguistic way, to describe the control policy.
- *Inference Engine :* The inference engine infers the fuzzy control action under the fuzzy control rules and the related input linguistic parameters.
- *Defuzzifier :* The defuzzifier converts the inferred fuzzy control action into a nonfuzzy control action Y under a defuzzification strategy.

At first, we are concerned about the design of a fuzzy logic controller for congestion control. As shown in Fig. 3, the input linguistic parameters are chosen here to be the performance parameters of (q), (Δq), and (p). The output linguistic parameter, denoted by y, is to indicate the discarding amount of type-1 cells at the prebuffer.

In the fuzzifier, we determine term sets at the right level of granularity for describing the values of linguistic parameters. The number of terms in a term set is selected as a compromise between the complexity and the controlled performance. We assign more terms to the term set of q than to the term sets of Δq and p because we expect that q contains more information than Δq and p. Accordingly, the term sets of q, Δq, and p are defined respectively as $T(q)$ = {Short, Medium, Long} = {S, M, L}, $T(\Delta q)$ = {Negative, Positive} = {N, P}, and $T(p)$ = {Safe, Danger} = {Sa, Da}.

Next, we define a membership function M for each term set. The main task is to choose a function with proper shape and position. As in most applications, here we use the shape of triangular and trapezoidal functions [18]. Two functions $f(x, x_0, a_0, a_1)$ and $g(x, x_0, x_1, a_0, a_1)$ for the triangular and trapezoidal shapes are defined respectively (see Fig. 5) below.

$$f(x, x_0, a_0, a_1) = \begin{cases} \frac{x-x_0}{a_0} + 1 & \text{for } x_0 - a_0 < x \le x_0 \\ \frac{x_0-x}{a_1} + 1 & \text{for } x_0 < x \le x_0 + a_1 \\ 0 & \text{otherwise} \end{cases}$$

$$g(x, x_0, x_1, a_0, a_1) = \begin{cases} \frac{x-x_0}{a_0} + 1 & \text{for } x_0 - a_0 < x \le x_0 \\ 1 & \text{for } x_0 < x \le x_1 \\ \frac{x_1-x_0}{a_1} & \text{for } x_1 < x \le x_1 + a_1 \\ 0 & \text{otherwise} \end{cases}$$

where x_i is the center of the triangular function ($i = 0$) or the right/left edge of the trapezoidal function (i=0/1), and a_j is the right/left width of the monotonic part of the triangular or the trapezoidal function (j=0/1). In our application, the center (or the edge) and the width of the triangular or trapezoidal functions for each term set of q and Δq will be initially specified based on our knowledge about the system, while those for each term belonging to the term set of p are initially specified according to the QOS requirement.

The set of the membership functions associated with terms in the term set of q, $T(q)$ = {S, M, L}, are denoted by $M(q) = \{\mu_S, \mu_M, \mu_L\}$, where μ_S, μ_M, and μ_L are the membership functions for S, M, and L, respectively. They are given by (see Fig. 6(a))

$$\mu_S(q) = g(q, 0, S_e, 0, S_w)$$

$$\mu_M(q) = f(q, M_c, M_{w0}, M_{w1})$$

and

$$\mu_L(q) = g(q, L_e, K_1, L_w, 0)$$

where S_e (S_w) is the right edge (right width) of the membership function for *Short*; M_c (M_{wj}, j=0/1) is the center (right/left width) of the membership function for *Medium*; and L_e (L_w) is the left edge (left width) of the membership function for *Long*.

Similarly, $M(\Delta q) = \{\mu_N, \mu_P\}$ are the membership functions for the term set of Δq, $T(\Delta q)$={N,P}, and μ_N and μ_P are given by (see Fig. 6(b))

$$\mu_N(\Delta q) = g(\Delta q, -K_1, N_e, 0, N_w)$$

and

$$\mu_P(\Delta q) = g(\Delta q, P_e, K_1, P_w, 0)$$

where N_e (N_w) is the right edge (right width) of the membership function for *Negative*; and P_e (P_w) is the left edge (left width) of the membership function for *Positive*.

And $M(p) = \{\mu_{Sa}, \mu_{Da}\}$ are the membership functions for the term set of p, $T(p) = \{\text{Sa,Da}\}$, and μ_{Sa} and μ_{Da} are given by (see Fig. 6(c))

$$\mu_{Sa}(p) = g(p, 0, Sa_e, 0, Sa_w)$$

and

$$\mu_{Da}(p) = g(p, Da_e, 1, Da_w, 0)$$

where Sa_e (Sa_w) is the right edge (right width) of the membership function for *Safe* (i.e. the QOS requirement); and Da_e (Da_w) is the left edge (left width) of the membership function for *Danger* (i.e. the unacceptable cell loss probability).

We also define the term set of the output control action y as $T(y) = \{$Decrease More, Decrease Slightly, No Control, Increase Slightly, Increase More$\}$ = $\{$DM,DS,NC,IS,IM$\}$. The set of the membership functions associated with $T(y) = \{$DM,DS,NC,IS,IM$\}$ are denoted by $M(y) = \{\mu_{DM}, \mu_{DS}, \mu_{NC}, \mu_{IS}, \mu_{IM}\}$, which are given by (see Fig. 6(d))

$$\mu_{DM}(y) = f(y, DM_c, 0, 0),$$

$$\mu_{DS}(y) = f(y, DS_c, 0, 0),$$

$$\mu_{NC}(y) = f(y, NC_c, 0, 0),$$

$$\mu_{IS}(y) = f(y, IS_c, 0, 0),$$

$$\mu_{IM}(y) = f(y, IM_c, 0, 0),$$

where DM_c, DS_c, NC_c, IS_c, and IM_c are the center of the membership functions for *Decrease More*, *Decrease Slightly*, *No Control*, *Increase Slightly*, and *Increase More*, respectively.

After these, a fuzzy rule base, based on the above linguistic description of the main input performance parameters, is developed. According to the fuzzy set theory, the fuzzy rule base forms a fuzzy set of dimension $|T(q)| \times |T(\Delta q)| \times |T(p)|$ (note that $|T(x)|$ is the number of terms in $T(x)$). So there are at most a total of 12 inference rules in our fuzzy rule base. We initially design the fuzzy control rules for congestion control given by

Rule	q	Δq	p	y	Rule	q	Δq	p	y
1	S	N	Sa	IM	7	M	P	Sa	DS
2	S	N	Da	IM	8	M	P	Da	NC
3	S	P	Sa	IS	9	L	N	Sa	NC
4	S	P	Da	IM	10	L	N	Da	NC
5	M	N	Sa	IS	11	L	P	Sa	DS
6	M	N	Da	IS	12	L	P	Da	DM

In the next section, we will use Genetic algorithms (GAs) to find the optimal rules.

We use the max-min inference method [19, p. 182] in the inference engine. One example of our inference method is shown in Fig. 7, where rule 1 leads to the control action *Increase More*, so the height of the output membership function for $\mu_{IM}(y)$ is obtained by cutting the degree of membership values for the corresponding premise – $\mu_S(q_0)$, $\mu_N(\Delta q_0)$, and $\mu_{Sa}(p_0)$. Since rules 1, 2, and 4 have the same control action, they are combined by "max" operator, so the final output membership value (called the firing strength) for $\mu_{IM}(y)$ is the maximum of the three rules' output membership values.

We also use the Tsukamoto's method [20, p. 77] as our defuzzification strategy. The defuzzification strategy combines all the fuzzy logic rules' output membership functions into a crisp output control action according to the firing strength of the five control actions. After the defuzzification operation, the coding rate manager generates a signal of coding rate control. It is used to throttle the incoming traffic by selectively discarding less significant cells of the type-1 traffic according to the crisp output value y_0.

We apply similar procedures to design the traffic negotiator and the fuzzy admission controller. The membership functions and fuzzy control rules for traffic negotiator are designed as:

- Input linguistic variables: R_p, R_m, and T_p.
- Term sets of the input linguistic variables:
  $T(R_p) = \{\text{Small,Medium,Large}\} = \{S, M, L\}$.
  $T(R_m) = \{\text{Low,High}\} = \{\text{Lo,Hi}\}$.
  $T(T_p) = \{\text{Short,Medium,Long}\} = \{Sh, Me, Lg\}$.
- Membership functions for $T(R_p)$:

$$\mu_S(R_p) = g(log(\frac{R_p}{K_1}), -10, 0, S_e, S_w)$$

$$\mu_M(R_p) = f(log(\frac{R_p}{K_1}), M_e, M_{w0}, M_{w1})$$

and

$$\mu_L(R_p) = g(log(\frac{R_p}{K_1}), L_e, 10, L_w, 0)$$

- Membership functions for $T(R_m)$:

$$\mu_{Lo}(R_m) = g(\frac{R_m}{R_p}, 0, Lo_e, 0, Lo_w)$$

and

$$\mu_{Hi}(R_m) = g(\frac{R_m}{R_p}, Hi_e, 1, Hi_w, 0)$$

- Membership functions for $T(T_p)$:

$$\mu_{Sh}(T_p) = g(log(\frac{T_p}{K_1}), -10, Sh_e, 0, Sh_w)$$

$$\mu_{Me}(T_p) = f(log(\frac{T_p}{K_1}), Me_e, Me_{w0}, Me_{w1})$$

and

$$\mu_{Lg}(T_p) = g(log(\frac{T_p}{K_1}), Lg_e, 10, Lg_w, 0)$$

- Output linguistic variable: C_e.
- Term set of the output linguistic variable: Here, we roughly divide the estimated capacity into six types. $T(C_e) = \{C_1, C_2, C_3, C_4, C_5, C_6\}$, where C_i $(i = 1 \ldots 6)$ denotes different amount of capacity that we estimate.
- Membership functions for $T(C_e)$:

$$\mu_{C_1}(C_e) = f(C_e, C_{1,e}, 0, 0),$$
$$\mu_{C_2}(C_e) = f(C_e, C_{2,e}, 0, 0),$$
$$\mu_{C_3}(C_e) = f(C_e, C_{3,e}, 0, 0),$$
$$\mu_{C_4}(C_e) = f(C_e, C_{4,e}, 0, 0),$$
$$\mu_{C_5}(C_e) = f(C_e, C_{5,e}, 0, 0),$$
$$\mu_{C_6}(C_e) = f(C_e, C_{6,e}, 0, 0),$$

where $C_{i,e}, i = 1 \ldots 6$ is the edge of the estimated capacity C_i and

$$\begin{aligned} C_{1,e} &= R_m \\ C_{6,e} &= R_p \\ C_{i,e} &= C_{i-1,e} + \Delta R, \text{ where } i = 2 \ldots 5, \\ &\text{and } \Delta R \equiv \frac{(R_p - R_m)}{5} \end{aligned}$$

- Fuzzy control rules:

Rule	R_p	R_m	T_p	C_e	Rule	R_p	R_m	T_p	C_e
1	S	Lo	Sh	C_1	10	M	Hi	Sh	C_1
2	S	Lo	Me	C_2	11	M	Hi	Me	C_2
3	S	Lo	Lg	C_5	12	M	Hi	Lg	C_5
4	S	Hi	Sh	C_1	13	L	Lo	Sh	C_4
5	S	Hi	Me	C_1	14	L	Lo	Me	C_6
6	S	Hi	Lg	C_4	15	L	Lo	Lg	C_6
7	M	Lo	Sh	C_1	16	L	Hi	Sh	C_3
8	M	Lo	Me	C_3	17	L	Hi	Me	C_5
9	M	Lo	Lg	C_6	18	L	Hi	Lg	C_6

And the membership functions and fuzzy control rules for admission controller are designed as:

- Input linguistic variable: C_a, and y.
- Term sets of the input linguistic variables:
  $T(C_a) = \{\text{Enough,Not Enough}\} = \{\text{E,NE}\}$.
  $T(y) = \{\text{Low,High}\} = \{\text{L,H}\}$.
- Membership functions for $T(C_a)$:

$$\mu_E(C_a) = g(C_a, 0, S_e, 0, S_w)$$

and

$$\mu_N E(C_a) = g(C_a, L_e, 1, L_w, 0)$$

- Membership functions for $T(y)$:

$$\mu_L(y) = g(y, 0, L_e, 0, L_w)$$

and

$$\mu_H(y) = g(y, H_e, y_{max}, H_w, 0)$$

- Output linguistic variable: z.
- Term set of the output linguistic variable:

$$\begin{aligned} T(z) &= \{\text{Accept,Weak Accept,} \\ &\quad \text{Weak Reject,Reject}\} \\ &= \{\text{A,WA,WR,R}\}. \end{aligned}$$

- Membership functions for $T(z)$:

$$\mu_A(z) = f(z, A_e, 0, 0),$$
$$\mu_{WA}(z) = f(z, WA_e, 0, 0),$$
$$\mu_{WR}(z) = f(z, WR_e, 0, 0),$$
$$\mu_R(z) = f(z, R_e, 0, 0),$$

- Fuzzy control rules:

Rule	C_a	y	z	Rule	C_a	y	z
1	E	L	WA	3	NE	L	R
2	E	H	A	4	NE	H	WR

4 Simulation Results

Since there are two kinds of cell loss for type-i traffic, the source loss $P_{S,i}$ and the node loss $P_{N,i}$, we define the cell loss probability for type-i traffic as

$$P_i = \kappa P_{S,i} + P_{N,i} \quad i = 1, 2$$

where κ is a weighting factor of the source loss over the node loss. As mentioned above, the source loss will have a less effect on the information retrieval, and κ is assigned to 0.8 in the simulation analysis. We also define a combined cell loss probability P_c as

$$P_c = \zeta P_1 + (1 - \zeta) P_2 \tag{1}$$

where ζ is used to distinguish the importance between these two types of traffic. In our case, the effect of type-2 loss is less significant because it can be retransmitted. Therefore, a value of 0.8 is assigned to ζ. The buffer capacity for type-1 (K_1) and type-2 (K_2) are given as $K_1 = K_2 = 100$. The initial value for L_2 is 90. The link capacity is assumed to be 150Mbps. For video source, $M_r = M_a = 20$, $Ar = 1.34 \times 10^{-3}$, $A_a = 3.15 \times 10^{-4}$, $\gamma = 3.77 \times 10^{-6}$, $\omega = 5.65 \times 10^{-6}$, $\Phi = \Psi = 2.83 \times 10^{-5}$, $c = 5.65 \times 10^{-6}$, and $d = 5.09 \times 10^{-5}$. For voice traffic, $\alpha = 1.71 \times 10^{-6}$, and $\beta = 2.09 \times 10^{-6}$. The T_p for video and voice are 1.35 sec. and 0.5 sec., respectively. Mean holding time for video and voice source is 60 minutes and 3 minutes, respectively. The maximum allowable customers for video and voice are limited to 50 and 1000, respectively.

In our fuzzy congestion controller, there are still several design parameters that should be determined, such as those parameters related with the control rules and the membership functions. According to our knowledge about the system, we heuristically give an initial setting for these parameters as: for the queue length q, $S_e = 80$, $M_c = 90$, $L_e = 95$, $S_w = 10$,

$M_{w0} = M_{w1} = 5$, and $L_w = 5$; for the change rate of queue length Δq, $N_e = -1$, $P_e = 1$, and $N_w = P_w = 2$; for cell loss probability p, $Sa_e = 10^{-4}$, $Da_e = 2 \times 10^{-4}$, $Sa_w = Da_w = 10^{-4}$; for the control action y $DM_c = -0.2$, $DS_c = -0.2/3$, $NC_c = 0$, $IS_c = 0.2/3$, and $IM_c = 0.2$. In order to have a better control result, we apply optimization algorithm here to give a fine tune of these parameters. And, superfluous rules could be eliminated if the result shows that they have no notable effect on the system performance. Here we use the Genetic algorithms (GAs) to find that the optimal fuzzy control rules (called the optimal structure) and the optimal position of the membership function (called optimal parameters) in the design of fuzzy congestion controller.

In this paper, the objective function [21] is the combined cell loss probability P_c in (1). The structure and the parameters are coded into a binary string. The GA_{UCSD} 1.4 [22] is utilized here. According to the searched result, we find that the term M in the term set $T(q)$ has little effect on the system performance and may be eliminated. The new congestion control rules are

Rule	q	Δq	p	y	Rule	q	Δq	p	y
1	S	N	Sa	IS	5	L	N	Sa	IM
2	S	N	Da	IS	6	L	N	Da	IM
3	S	P	Sa	IM	7	L	P	Sa	DS
4	S	P	Da	DS	8	L	P	Da	NC

The optimal parameters for $T(q)$ are found as $S_c = 81$, $L_e = 98$, $S_w = 17$, and $L_w = 17$. Parameter search for $T(\Delta q)$ and $T(p)$ is not performed because the former is easy to define and the latter should be defined according to the QOS requirement.

For the traffic negotiator, a simulation based on Guèrin's [1] method is studied and used to help us to find the appropriate structure and parameters. For the fuzzy admission controller, because of its simple structure, the structure and parameters can be specified within our knowledge about admission control. The parameters for traffic negotiator are assigned as: for R_p, $S_e = -1$, $M_c = 0$, $L_e = 1$, $S_w = 0.9$, $M_{w0} = M_{w1} = 1$, and $L_w = 0.9$; for R_m, $Lo_e = 0.6$, $Hi_e = 0.75$, $Lo_w = 0.15$, and $Hi_w = 0.1$; for T_p, $Sh_e = -3$, $Me_c = -2$, and $Lg_e = -1$, $Sh_w = 0.7$, $Me_{w0} = Me_{w1} = 0.8$, and $Lg_w = 0.7$. As for the fuzzy admission controller, the parameters are assigned as: for C_a, $NE_e = 0.1$, $E_e = 0.2$, and $NE_w = E_w = 0.1$; for y, $y_{max} = 0.2$, $L_e = 0.04$, $H_e = 0.1$, and $L_w = H_w = 0.04$.

In the following, we show some simulation examples to illustrate the performance of our fuzzy traffic controller. We compare the performance of admission controller with that obtained by Guèrin in [1], where he proposed analytical methods to estimate the equivalent capacity for a customer based on the traffic parameters.

In Fig. 8, the call acceptance probability and the number of connected calls of our fuzzy traffic control scheme and Guèrin's control scheme are shown. In Fig.s 8(a) and 8(b), it shows that our fuzzy traffic control scheme accommodates more voice and video customers' traffic than Guèrin's scheme. From Fig.s 8(c) and 8(d), we find that our fuzzy traffic control scheme achieves better system utilization for video and voice sources over the whole simulation interval. We also find that the overall system utilization is effectively improved by 8%, where the overall system utilization is defined as the sum of system utilization in Fig.s 8(c) and 8(d).

5 Concluding Remarks

In this paper, we propose a traffic control scheme based on the fuzzy set theory for an ATM network. The major components in the fuzzy traffic controller are the fuzzy congestion controller, the traffic negotiator, and the fuzzy admission controller. All of them are fuzzy logic controllers.

Up to now, there is no exact accounts about the service features of ATM networks. As a result, it is still difficult to construct the fuzzy traffic controller. Therefore, an optimization algorithm is applied to help us design the fuzzy congestion controller. We adapt GAs to find the proper rules and the related parameters for fuzzy congestion controller. According to the simulation results, better performance is achieved and less control rules are needed.

The performance of our traffic control scheme is compared with the method proposed by Guèrin. According to the simulation results, we can find that a substantial overestimate of the required capacity is obtained with both methods. However, our method provides a higher link utilization and lower call rejection ratio. Under the operation of the two traffic control schemes, the negotiated QOS are all guaranteed. Performance evaluation via simulation shows that the link utilization is effectively improved by 8% with fuzzy traffic control scheme. To sum up, our fuzzy traffic controller can provide a more efficient use of network resource and has the capability to handle the network congestion. The operation speed is fast because only simple "min", "max" operations are used. It is a promising candidate that can be implemented in a real system.

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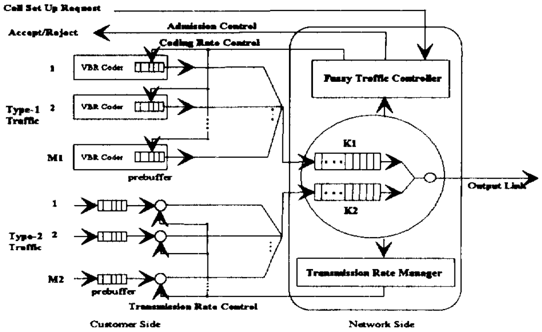

Figure 1: A block diagram for our system model.

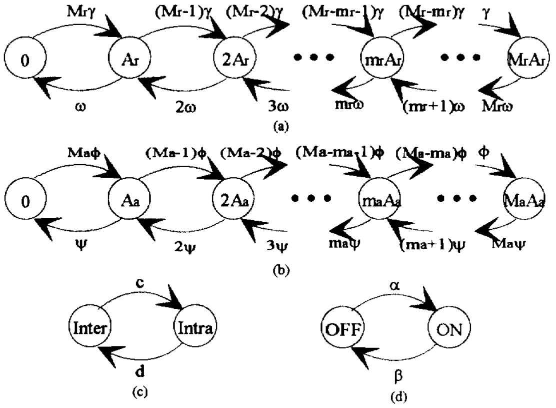

Figure 2: Level transition diagram for (a) interframe coding $\lambda_r(t)$ (b) difference state $\lambda'_a(t)$ (c)interframe and intraframe alternate model (d)voice source.

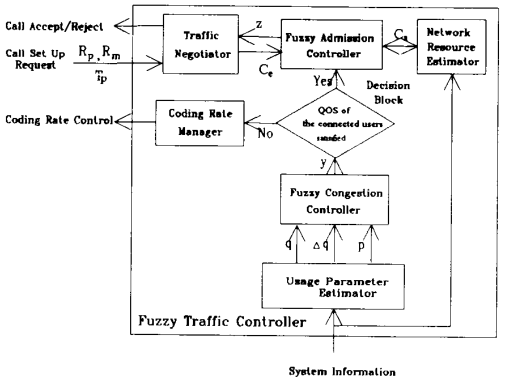

Figure 3: A functional block diagram for the fuzzy traffic controller.

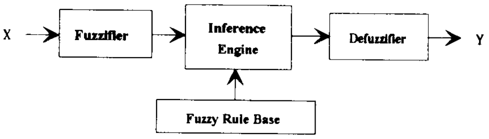

Figure 4: The basic structure of a fuzzy logic controller (FLC)

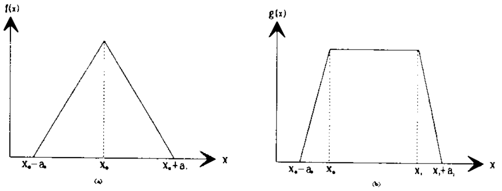

Figure 5: The definition for function $f(\cdot)$ and $g(\cdot)$

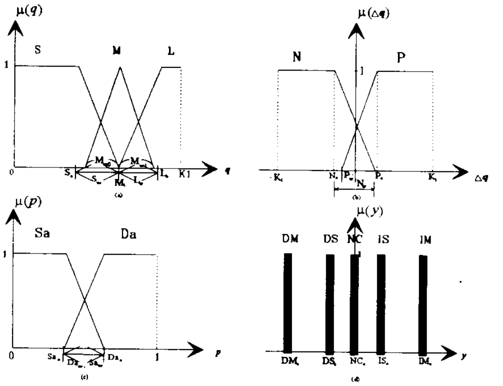

Figure 6: The membership function of the term set (a)$T(q)$ (b)$T(\Delta q)$ (c)$T(p)$ (d)$T(y)$

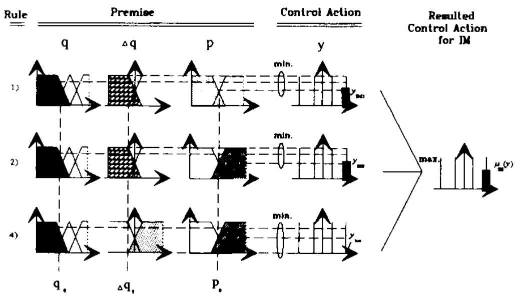

Figure 7: The max-min inference method

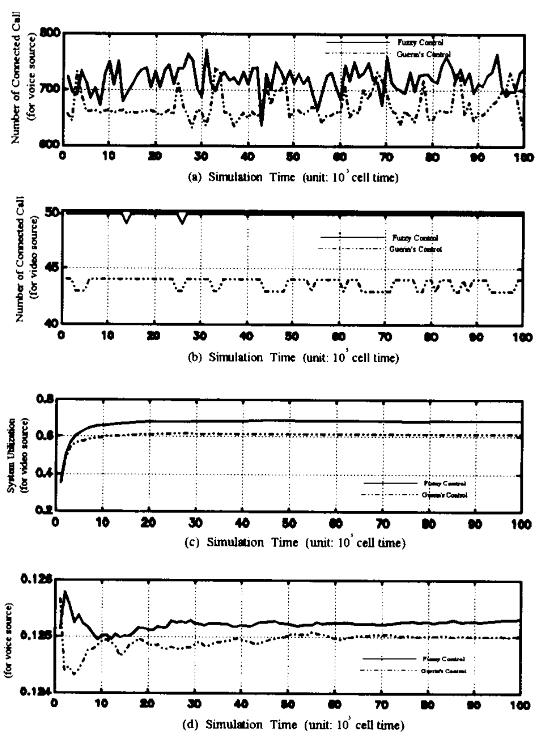

Figure 8: Simulation result of our fuzzy admission control