A Framework for Traffic Policing-Routing in ATM Networks Using Fuzzy Set Theory*

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Abstract

The Asynchronous Transfer Mode (ATM) has been standardized and widely accepted as a technique to support the future B-ISDN networks. With the B-ISDN/ATM goals of supporting diverse services and traffic mixes, and of efficient network resource engineering, the design of the traffic control becomes an important challenge. Two of important functions for the traffic of the ATM networks are policing and routing functions. The goal of these two functions is to guarantee the required Quality of Service (QoS). So far, all the studies have treated the policing mechanisms (PMs) and the routing policies (RPs) in a separate way. There is not a study that combines the PMs and the RPs. This combination can guarantee a better QoS and increase the network utilization. In this paper we propose a framework for traffic policing-routing in ATM networks using fuzzy set theory. We introduce the source, network and system models. After that the evaluation of the system is carried out by some simulations. Additional work is in progress to provide detailed quantitative evidence of this policing-routing framework.

1 Introduction

The Asynchronous Transfer Mode (ATM) technique has been standardized and widely accepted as a basis for transporting and switching user's traffic in the future B-ISDN networks, where user's information is packetized and carried in fixed length cells. With the B-ISDN/ATM goals of supporting diverse services and traffic mixes, and of efficient network resource engineering, the design of the traffic control becomes an important challenge. Two of important functions for the traffic of the ATM networks are policing and routing functions.

The purpose of the PMs is to act on each source before all the traffic is multiplexed, in order to guarantee the negotiated QoS. The proposed parameters for monitoring source traffic characteristics are the mean cell rate, the peak cell rate or the peak burst duration [10], [11]. Policing of the peak cell rate is generally not complex and can be achieved by using a cell spacer or other PMs [9]. Monitoring of the mean cell rate is more difficult. It is intended to improve the link utilization when it has to handle bursty traffic sources. The conventional PMs proposed in [1], [2], [6], [7], can't efficiently monitor the mean cell rate of bursty sources. The window mechanisms are not well suited to the real-time services of the speed envisaged for the B-ISDN, and the leaky policing mechanism (LBM) in the case of the mean cell rate control requires a very high counter threshold to obtain an acceptable cell loss probability. This means that very long times are necessary to detect a violation of the mean cell rate.

Routing plays also an important role to guarantee the QoS. In [15] two routing policies RP1 and RP2 are proposed. Under light and heavy loadings all routing policies perform almost the same as alternate routes are used rare. Under moderate loading conditions is better to use RP1 and RP2 than Least Loaded Routing (LLR). In [16] MDP (Markov Decision Process) routing in VP networks with reserved VP capacity is studied. They try to improve the bandwidth efficiency through adaptive routing when capacity is reserved on all VPs. Two VP capacity reservation strategies are examined : the deterministic strategy and statistical strategy. Four MDP routing policies are designed and evaluated. The MDP routing algorithms provide significantly lower network blocking probability with slightly increase the control cost.

So far, all the studies have treated the PMs and the RPs in a separate way. There is not a study that combines the PMs and the RPs. This combination is expected to give a better guarantee of the QoS and increase the network utilization.

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*ポリシングとルーチングを組み合わせたATMネットワークのファジィ・トラヒック制御

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In this paper we propose a framework for traffic policing-routing in ATM networks using fuzzy set theory. In [3], [4], [5] a fuzzy policing mechanism (FPM) to control the mean cell rate of bursty sources is proposed and the performance analysis of the FPM are carried out. The FPM has good performance characteristics and dynamic behavior characteristics and with small counter size the control results are very good. The selectivity of the FPM approach the ideal characteristic required for a PM. In the FPM the cells which are in violation with negotiated parameters are discarded. Another policing action is to mark the violation cells and send them toward the network. Considering that during the periods of low network utilization the probability of losing marked cells might be considerably reduced, and also, guided by the desire to satisfy the services requirements of diverse traffic types and high resource network utilization we propose a fuzzy policing-routing mechanism (FPRM).

The organization of this paper is as follows. The source model will be given in Section 2. The network model will be treated in Section 3. The system model will be introduced in Section 4. Some simulation results are given in Section 5. The conclusions are given in Section 6.

2 Source Model

We assume for the cell arrival process pattern, a bursty source, as is shown in Fig. 1. Each burst has a duration *mbd* (mean burst duration) random variable and a cell rate of *pcr* cell/s (peak cell rate). The duration of inactive (silence) period is the random variable *msd* (mean silence duration).

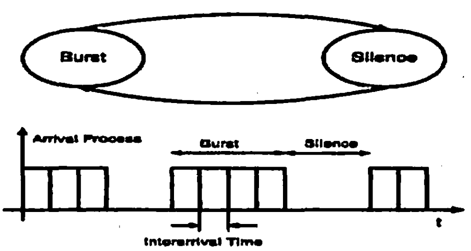

Figure 1: **Source model.**

The source is characterized by the following set of parameters:

- the peak (burst) cell rate [*pcr*]
- the mean burst duration [*mbd*]
- the mean silence duration [*msd*]
- the source burstiness [*sb = (mbd+msd)/mbd*]
- the mean burst length in cells (or burst cell number) [*bcn = pcr * mbd*]
- the mean source cell rate [*m = bcn / (mbd + msd)*]
- the mean cycle duration [*mcd = mbd + msd*].

3 ATM Network Model

We consider a VP based ATM network. The VPs concept has an important role in the cost-effective management of the network resources. The VP is a group of Virtual Connections (VCs). The capacity in ATM network is reserved on the Virtual Path Connection (VPC), thus the Virtual Channel Connections (VCCs) can be established by executing simple control function at the end-points of the VPC, so no call processing is required at the transit nodes (TN). The number of VPs to form a connection between a source node (SN) and a destination node (DN) pairs is restricted to two. Routing allowing connections with more than two VPs may be effective when the network load is sufficiently low. When the load is heavy, routing allowing connection with more than two VPs results in performance degradation because of delays in the transmitted cells and the excessive network resources.

The ATM network model is shown in Fig. 2.

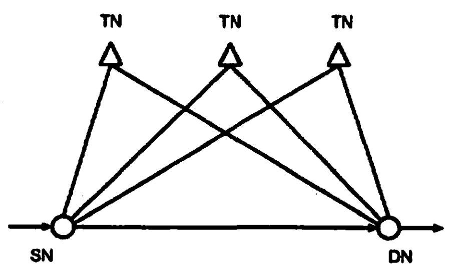

Figure 2: **ATM Network model.**

4 System Model

The FLC is the major component in the proposed FPRM. The basic components of the FLC are shown if Fig. 3. They are the fuzzifier, the inference engine, the fuzzy rule base (FRB) and the defuzzifier.

We use for membership functions the triangular shape function, because it is easy to tune the membership functions and the second the error is smaller compare with the other membership function shapes. The function $f(x, x_0, a_0, a_1)$ for triangular shape is defined (see Fig. 4) as follows:

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

where x_0 is the center of triangular function and a_j is the right/left width of the monotonic part of triangular function ($j = 0/1$).

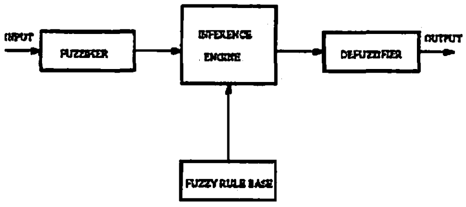

Figure 3: Fuzzy logic controller.

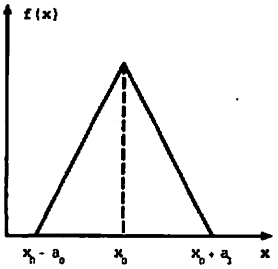

Figure 4: Triangular membership function.

The system model has three parts. They are the FPM, the direct path fuzzy controller (DPFC) and the fuzzy routing mechanism (FRM). We will describe each of them in follows.

4.1 FPM

The input linguistic parameters of the FPM are: the burst cell number *bcn*, the mean silence duration *msd* and the counter state *cs*. The output linguistic parameter is the controlled cell rate *ccr* that enters in the counter. The FPM model is shown in Fig. 5.

The term sets of *bcn, msd, cs* are defined respectively as:

$$T(bcn) = \{small, medium, big\} = \{sm, me, bi\};$$
$$T(msd) = \{SHORT, MIDDLE, LONG\} = \{SHO, MI, LO\};$$
$$T(cs) = \{SMALL, MEDIUM, BIG\} = \{S, M, B\}.$$

The set of the membership functions associated with terms in the term set of *bcn*, $T(bcn) = \{sm, me, bi\}$, are denoted by $M(bcn) = \{\mu_{sm}, \mu_{me}, \mu_{bi}\}$, where $\mu_{sm}, \mu_{me}, \mu_{bi}$ are the membership functions for *sm, me, bi,* respectively. They are given by:

$$\mu_{sm}(bcn) = f(bcn, sm_c, sm_{w0}, sm_{w1});$$
$$\mu_{me}(bcn) = f(bcn, me_c, me_{w0}, me_{w1});$$
$$\mu_{bi}(bcn) = f(bcn, bi_c, bi_{w0}, bi_{w1}).$$

$M(msd) = \{\mu_{SHO}, \mu_{MI}, \mu_{LO}\}$ are the membership functions for term set of *msd*. The membership functions μ_{SHO}, μ_{MI} and μ_{LO} are given by:

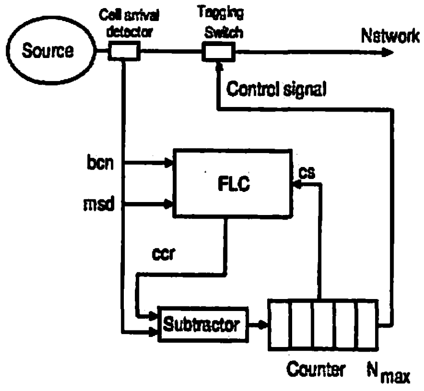

Figure 5: FPM model.

$$\mu_{SHO}(msd) = f(msd, SHO_c, SHO_{w0}, SHO_{w1});$$
$$\mu_{MI}(msd) = f(msd, MI_c, MI_{w0}, MI_{w1});$$
$$\mu_{LO}(msd) = f(msd, LO_c, LO_{w0}, LO_{w1}).$$

The membership functions for term set *cs* is $M(cs) = \{\mu_S, \mu_M, \mu_B\}$, and μ_S, μ_M and μ_B are given by:

$$\mu_S(cs) = f(cs, S_c, S_{w0}, S_{w1});$$
$$\mu_M(cs) = f(cs, M_c, M_{w0}, M_{w1});$$
$$\mu_B(cs) = f(cs, B_c, B_{w0}, B_{w1}).$$

We define the term set of the output linguistic parameter $T(ccr) = \{Increase3,\ Increase2,\ Increase1, Not\ Increase\ Not\ Decrease,\ Decrease1, Decrease2, Decrease3, Decrease4, Decrease5, Decrease6, Decrease7\} = \{I3,\ I2,\ I1,\ NIND,\ D1, D2, D3, D4, D5, D6, D7\}$, where I2 increase more than I1 and D2 decrease more than D1 and so on.

The term set of the output membership functions, are denoted by $M(ccr) = \{\mu_{I3}, \mu_{I2}, \mu_{I1}, \mu_{NIND}, \mu_{D1}, \mu_{D2}, \mu_{D3}, \mu_{D4}, \mu_{D5}, \mu_{D6}, \mu_{D7}\}$, and are given by:

$$\mu_{I3}(ccr) = f(ccr, I3_c, I3_{w0}, I3_{w1});$$
$$\mu_{I2}(ccr) = f(ccr, I2_c, I2_{w0}, I2_{w1});$$
$$\mu_{I1}(ccr) = f(ccr, I1_c, I1_{w0}, I1_{w1}); \mu_{NIND}(ccr) = f(ccr, NIND_c, NIND_{w0}, NIND_{w1});$$
$$\mu_{D1}(ccr) = f(ccr, D1_c, D1_{w0}, D1_{w1});$$
$$\mu_{D2}(ccr) = f(ccr, D2_c, D2_{w0}, D2_{w1});$$
$$\mu_{D3}(ccr) = f(ccr, D3_c, D3_{w0}, D3_{w1});$$
$$\mu_{D4}(ccr) = f(ccr, D4_c, D4_{w0}, D4_{w1});$$
$$\mu_{D5}(ccr) = f(ccr, D5_c, D5_{w0}, D5_{w1});$$
$$\mu_{D6}(ccr) = f(ccr, D6_c, D6_{w0}, D6_{w1});$$
$$\mu_{D7}(ccr) = f(ccr, D7_c, D7_{w0}, D7_{w1});$$

Based on the above linguistic description of the input and output parameters we make a FRB. The FRB forms a fuzzy set of dimensions $|T(bcn)| \times |T(sd)| \times |T(cs)|$, where $|T(x)|$ is the number of terms on T(x). So, there are a total number of 27 rules in the FRB. The FRB 1 is shown in Table 1.

The FPM works in this way : the detector counts the number of cells going to the network

Table 1: FRB 1.

Rule	bcn	msd	cs	ccr
0	sm	SHO	S	I3
1	sm	SHO	M	I2
2	sm	SHO	B	D2
3	sm	MI	S	D1
4	sm	MI	M	D2
5	sm	MI	B	D3
6	sm	LO	S	D1
7	sm	LO	M	D3
8	sm	LO	B	D4
9	me	SHO	S	I2
10	me	SHO	M	NIND
11	me	SHO	B	D2
12	me	MI	S	NIND
13	me	MI	M	D2
14	me	MI	B	D3
15	me	LO	S	D2
16	me	LO	M	D4
17	me	LO	B	D5
18	bi	SHO	S	I1
19	bi	SHO	M	D1
20	bi	SHO	B	D2
21	bi	MI	S	D2
22	bi	MI	M	D4
23	bi	MI	B	D5
24	bi	LO	S	D4
25	bi	LO	M	D6
26	bi	LO	B	D7

and at the same time going to the FLC and the subtractor. The parameters of the controlled source *bcn*, *msd* and the counter state parameter *cs* are the input parameters for the FLC. Based on the values of the input parameters, the FLC gives an appropriate output value, which enters to the subtractor. The subtractor carries out the operation *bcn* - *ccr*. If the *ccr* value is positive, the number of the cells entering the counter decrease, on the other hand, if the *ccr* value is negative, the number of the cells entering the counter increase. The state of the counter is expressed by the formula $[cs = cs_0 + bcn - ccr]$, where cs_0 is the starting state of the counter, *bcn* is the number of the cell in a burst and *ccr* is the output of the FLC. If the number of cells entering the counter exceed the maximum value of the counter a control signal will go to the tagging switch and the value of the counter starts from zero.

4.2 Operation of the Tagging Switch

The tagging switch (TS) is implemented via a single indicator in the ATM cell header, termed the "cell loss priority" (CLP) indicator. When this indicator is set CLP=1, it signifies that the cell may be discarded in any network element along the VC/VP path if the network is congested. This CLP indicator serves a dual purpose: a setting of the CLP indicator of a cell to 1 by the TS signify that the cell carries nonessential information, so this cell is discardable under congestion condition; getting of the indicator CLP=1 at the access to the network it is judged by the network that the cell is in violation of the traffic limits agreed to in the negotiated contract.

The TS can be viewed as a throughput burstiness filter which separates the source information into nonviolation traffic CLP=0 and violation traffic CLP=1. Thus, the TS reduces the impact of traffic uncertainty. In this way, by traffic policing and traffic violation tagging we can ensure that the total CLP=0 traffic can be handled. The TS operation scheme is shown in Fig. 6.

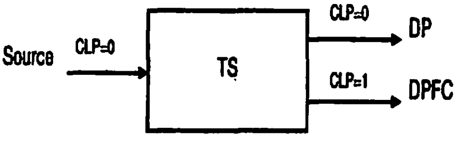

Figure 6: TS operation scheme.

4.3 DPFC

The SN sends the CLP=0 stream via the direct path (DP) to the DN. The stream CLP=1 goes to the DPFC. The design of the DPFC is described in follows.

The input linguistic parameters for the DPFC are the number of tagging cells *ntc*, the mean cycle duration *mcd* and the direct path remained capacity *dprc*. The output linguistic parameter is the number of cells accepted or rejected to/from the DP *ncar*.

The term sets of *ntc*, *mcd* and *dprc* are defined respectively as :

$$T(ntc) = \{small, medium, big\} = \{sm, me, bi\};$$
$$T(mcd) = \{short, middle, long\} = \{sho, mi, lo\};$$
$$T(dprc) = \{verysmall, small, medium, big\} = \{vs, sl, md, bg\}.$$

The set of the membership functions associated with terms in the term set of *ntc*, $T(ntc) = \{sm, me, bi\}$, are denoted by $M(ntc) = \{\mu_{sm}, \mu_{me}, \mu_{bi}\}$, where $\mu_{sm}, \mu_{me}, \mu_{bi}$ are the membership functions for *sm*, *me*, *bi* respectively. They are given by:

$$\mu_{sm}(ntc) = f(ntc, sm_c, sm_{w0}, sm_{w1});$$
$$\mu_{me}(ntc) = f(ntc, me_c, me_{w0}, me_{w1});$$
$$\mu_{bi}(ntc) = f(ntc, bi_c, bi_{w0}, bi_{w1}).$$

$M(mcd) = \{\mu_{sho}, \mu_{mi}, \mu_{lo}\}$ are the membership functions for the term set of *mcd*. The membership functions μ_{sho}, μ_{mi} and μ_{lo} are given by:

$$\mu_{sho}(mcd) = f(mcd, sho_c, sho_{w0}, sho_{w1});$$
$$\mu_{mi}(mcd) = f(mcd, mi_c, mi_{w0}, mi_{w1});$$
$$\mu_{lo}(mcd) = f(mcd, lo_c, lo_{w0}, lo_{w1}).$$

The membership functions for the term set *dprc* are $M(dprc) = \{\mu_{vs}, \mu_{sl}, \mu_{md}, \mu_{bg}\}$, and μ_{vs}, μ_{sl}, μ_{md} and μ_{bg} are given by:

$$\mu_{vs}(dprc) = f(dprc, vs_c, vs_{w0}, vs_{w1});$$
$$\mu_{sl}(dprc) = f(dprc, sl_c, sl_{w0}, sl_{w1});$$
$$\mu_{md}(dprc) = f(dprc, md_c, md_{w0}, md_{w1});$$
$$\mu_{bg}(dprc) = f(dprc, bg_c, bg_{w0}, bg_{w1}).$$

We define the term set of the output linguistic parameter as $T(ncar)$ = {Reject 5, Reject4, Reject 3, Reject 2, Reject 1, Not Reject Not Accept, Accept 1, Accept 2, Accept 3, Accept 4, Accept 5, Accept 6, Accept 7}= {R5, R4, R3, R2, R1, NRNA, A1, A2, A3, A4, A5, A6, A7}.

The set of the membership functions for $ncar$, $T(ncar)$, are denoted by $M(ncar) = \{\mu_{R5}, \mu_{R4}, \mu_{R3}, \mu_{R2}, \mu_{R1}, \mu_{NRNA}, \mu_{A1}, \mu_{A2}, \mu_{A3}, \mu_{A4}, \mu_{A5}, \mu_{A6}, \mu_{A7}\}$, which are given by:

$$\mu_{R5}(ncar) = f(ncar, R5_c, R5_{w0}, R5_{w1});$$
$$\mu_{R4}(ncar) = f(ncar, R4_c, R4_{w0}, R4_{w1});$$
$$\mu_{R3}(ncar) = f(ncar, R3_c, R3_{w0}, R3_{w1});$$
$$\mu_{R2}(ncar) = f(ncar, R2_c, R2_{w0}, R2_{w1});$$
$$\mu_{R1}(ncar) = f(ncar, R1_c, R1_{w0}, R1_{w1});$$
$$\mu_{NRNA}(ncar) = f(ncar, NRNA_c, NRNA_{w0}, NRNA_{w1});$$
$$\mu_{A1}(ncar) = f(ncar, A1_c, A1_{w0}, A1_{w1});$$
$$\mu_{A2}(ncar) = f(ncar, A2_c, A2_{w0}, A2_{w1});$$
$$\mu_{A3}(ncar) = f(ncar, A3_c, A3_{w0}, A3_{w1});$$
$$\mu_{A4}(ncar) = f(ncar, A4_c, A4_{w0}, A4_{w1});$$
$$\mu_{A5}(ncar) = f(ncar, A5_c, A5_{w0}, A5_{w1});$$
$$\mu_{A6}(ncar) = f(ncar, A6_c, A6_{w0}, A6_{w1});$$
$$\mu_{A7}(ncar) = f(ncar, A7_c, A7_{w0}, A7_{w1}).$$

The DPFC scheme is shown in Fig. 7.

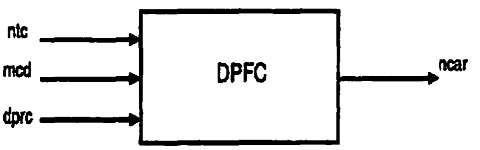

Figure 7: **DPFC scheme.**

Based on the above linguistic description of the input and output parameters the FRB has 36 rules. The FRB 2 is shown in Table 2.

4.4 FRM

The input linguistic parameters for the FRM are the availability of upward paths $aup(i)$ and the availability of downward paths $adp(i)$. The output linguistic parameter is the route quality $rq(i)$. The i varies from 1 to 3.

The term sets of aup and adp are defined as follows.

$$T(aup) = \{null, verysmall, small, medium, large\} = \{n, v, s, m, l\};$$
$$T(adp) = \{null, verysmall, small, medium, large\} = \{nl, vl, sl, md, la\}.$$

The set of the membership functions for the term set of aup, $T(aup) = \{n, v, s, m, l\}$, are denoted by $M(aup) = \{\mu_n, \mu_v, \mu_s, \mu_m, \mu_l\}$, where $\mu_n, \mu_v, \mu_s, \mu_m, \mu_l$ are the membership functions for n, v, s, m, l, respectively. They are given by:

Table 2: **FRB 2.**

Rule	ntc	mcd	dprc	ccr
0	sm	sho	vs	R4
1	sm	sho	sl	A1
2	sm	sho	md	A5
3	sm	sho	bg	A6
4	sm	mi	vs	R1
5	sm	mi	sl	A4
6	sm	mi	md	A5
7	sm	mi	bg	A7
8	sm	lo	vs	NRNA
9	sm	lo	sl	A4
10	sm	lo	md	A6
11	sm	lo	bg	A7
12	me	sho	vs	R6
13	me	sho	sl	NRNA
14	me	sho	md	A5
15	me	sho	bg	A6
16	me	mi	vs	R6
17	me	mi	sl	A2
18	me	mi	md	A5
19	me	mi	bg	A7
20	me	lo	vs	R3
21	me	lo	sl	A3
22	me	lo	md	A5
23	bi	lo	bg	A7
24	bi	sho	vs	R6
25	bi	sho	sl	R1
26	bi	sho	md	A3
27	bi	sho	bg	A6
28	bi	mi	vs	R6
29	bi	mi	sl	A2
30	bi	mi	md	A5
31	bi	mi	bg	A7
32	bi	lo	vs	R5
33	bi	lo	sl	A2
34	bi	lo	md	A5
35	bi	lo	bg	A7

$$\mu_n(aup) = f(aup, n_c, n_{w0}, n_{w1});$$
$$\mu_v(aup) = f(aup, v_c, v_{w0}, v_{w1});$$
$$\mu_s(aup) = f(aup, s_c, s_{w0}, s_{w1});$$
$$\mu_m(aup) = f(aup, m_c, m_{w0}, m_{w1});$$
$$\mu_l(aup) = f(aup, l_c, l_{w0}, l_{w1}).$$

The set of the membership functions for adp, $T(adp) = \{nl, vl, sl, md, la\}$, are denoted by $M(adp) = \{\mu_{nl}, \mu_{vl}, \mu_{sl}, \mu_{md}, \mu_{la}\}$, where $\mu_{nl}, \mu_{vl}, \mu_{sl}, \mu_{md}, \mu_{la}$ are the membership functions for nl, vl, sl, md, la, respectively. They are given by:

$$\mu_{nl}(adp) = f(adp, nl_c, nl_{w0}, nl_{w1});$$
$$\mu_{vl}(adp) = f(adp, vl_c, vl_{w0}, vl_{w1});$$
$$\mu_{sl}(adp) = f(adp, sl_c, sl_{w0}, sl_{w1});$$
$$\mu_{md}(adp) = f(adp, md_c, md_{w0}, md_{w1});$$
$$\mu_{la}(adp) = f(adp, la_c, la_{w0}, la_{w1}).$$

We define the term set of the output linguistic parameter as $T(rq)$ = {Unavailable, Bad, Fair, Good, Excellent} = { U, B, F, G, E}.

Table 3: FRB 3.

Rule	aup	adp	rq
0	n	nl	U
1	n	vl	U
2	n	sl	U
3	n	md	U
4	n	la	U
5	v	nl	U
6	v	vl	B
7	v	sl	B
8	v	md	B
9	v	la	B
10	s	nl	U
11	s	vl	B
12	s	sl	B
13	s	md	F
14	s	la	F
15	m	nl	U
16	m	vl	B
17	m	sl	F
18	m	md	G
19	m	la	E
20	l	nl	U
21	l	vl	B
22	l	sl	F
23	l	md	E
24	l	la	E

The set of the membership functions associated with term set of rq, $T(rq)$, are denoted by $M(rq) = \{\mu_U, \mu_B, \mu_F, \mu_G, \mu_E\}$, which are given by:

$$\mu_U(rq) = f(rq, U_c, U_{w0}, U_{w1});$$
$$\mu_B(rq) = f(rq, B_c, B_{w0}, B_{w1});$$
$$\mu_F(rq) = f(rq, F_c, F_{w0}, F_{w1});$$
$$\mu_G(rq) = f(rq, G_c, G_{w0}, G_{w1});$$
$$\mu_E(rq) = f(rq, E_c, E_{w0}, E_{w1});$$

Based on the above linguistic description the FRB has 25 rules. The FRB 3 is shown in Table 3.

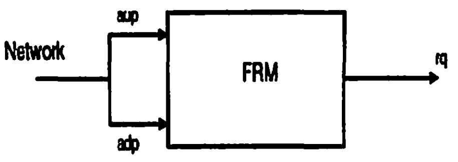

Figure 8: **FLC scheme for FRM.**

The FLC for the FRM is shown in Fig. 8. The FRM execute the procedure three times to decide the rq for the three paths. After that a sorting algorithm sorts the rq in a descending order. The best rq is choosed to route the rejected cells from the DP. This procedure is carried out for each cycle.

5 Simulation Results

For the FPM we make the following assumptions:

- The source is directly connected to the ATM network.
- The peak cell rate of the source is controlled separately by a PM and is never violated.
- The delay jitter, eventually introduced by a possible multiplexing of sources inside the customer premises doesn't exist.

We generate the burst and the silence period in an independent way. The distribution function is exponential and the density function f(.) is expressed as follows :

$$f_B(b) = 1/mbd * \exp^{-mbd*b} \quad (1)$$

$$f_S(s) = 1/msd * \exp^{-msd*s} \quad (2)$$

for the burst and the silence respectively.

Our approach is based on statistical multiplexing of traffic within a traffic class by using a VP for the class and the deterministic multiplexing of the different VPs. In this way the VCs of the similar traffic characteristics and the QoS requirements are statistically multiplexed on a VP. This simplifies the routing problem. In the follows we will carry out the simulations only for the packet voice source. For other types of sources the procedure it is the same, but the dimensioning of the FLC is different based on the source parameters. The packet voice source is a prototype of an off-on source and is considered as the worst case traffic pattern.

The packed voice parameters are as follows:

bcr0 = 32 kb/s = 62 cell/s, mbd0 = 352 ms,
msd0 = 650 ms, m = 11.2 kb/s = 22 cell/s,
minimum intercell time = 16 ms.

For gained from the statistical multiplexing we assign the bandwidth for the VCCs based on the equivalent bandwidth concept. The traffic descriptors in this case can be given by:

$$T_s = \{\rho_s, b_s, (R_{peak})_s\} \quad (3)$$

where ρ_s is the utilization, b_s is the mean burst period, and $(R_{peak})_s$ is the peak rate [13]. We choose the buffer size $x = 20kb/s$, $\epsilon = 10^{-5}$, and the utilization $\rho_s = 0.352$. Thus, the equivalent capacity is 54 cell/s. We suppose that in one VP are multiplexed 25 VCCs. Based on the fluid - flow approximation technique, the maximum number of the sources that can be multiplexed onto the link without violating the QoS constraint is given by:

$$N = \frac{C}{\hat{c}} \qquad (4)$$

where $\hat{c}$ is the equivalent capacity and C is the link capacity.

For the FPM we choose the maximum burst duration 1 second and the maximum silence duration 2 second. The counter size is choosed 30 cells. For the DPFC we choose mean cycle duration 3 second. For the *dprc* linguistic parameter the maximal number of remained VCCs is choosed 6. The availability for the FRM vary from zero up to 100 %.

In Fig.9 we show a comparison performance of the FPM and the LBM. The FPM is policing the mean cell rate of the packet voice source. The policed mean cell rate of the LBM is $C \cdot mcr$, where C is the over dimensioning factor of the LBM. In this case $C = 1.42$. The performance characteristic of the FPM is closer to the ideal characteristic compare with the LBM, so the selectivity of the FPM is better than the selectivity of the LBM. The FPM starts to discard the cell when the mean cell rate is more than 22 cell/s, while the LBM starts to discard the cell before the mean cell rate is 22 cell/s that means the FPM has a good responsiveness to parameter violation compare with the LBM.

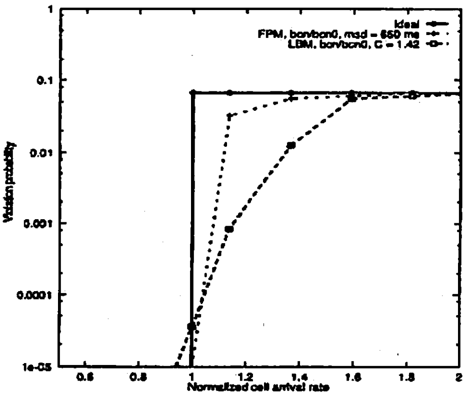

Figure 9: Comparison performance between the FPM and the LBM.

In Table 4 are shown some results of the DPFC. The *rb* parameter means remained capacity, the *tct* parameter means tagged cell throughputs, and the *ncar* parameter means number of cells accepted or rejected to/from the DP. When the *ncar* value is positive, these cells should be accepted to the DP, while the *ncar* value is negative, these cells should be rejected from the DP. The FRPM shows a good dynamic behavior for deciding the number of cells which should be accepted or rejected to/from the DP. The FPRM is a flexible mechanism, therefore we expect to increase the network utilization and to guarantee a better QoS.

Table 4: **Results of the DPFC.**

Cycle	rb	tct	ncar
1	108	4.8	104
2	0	21.4	-21
3	108	12.4	86
4	216	6.3	110
5	216	13.9	201
6	0	11.9	-13
7	108	11.7	94
8	216	38.8	174
9	162	5.2	156
10	162	17.5	141
11	108	22	87
12	216	6.1	205
13	0	15.2	-17
14	216	15.3	202
15	108	10.8	93
16	216	27.2	180
17	0	16.2	-16
18	0	23.3	-21
19	216	8.7	199
20	162	10.2	149
21	54	30.2	24
22	108	21.3	83
23	54	14.3	37
24	162	12.5	45
25	162	21.9	138

6 Conclusions

In this paper, we proposed a framework for traffic policing-routing in ATM networks using fuzzy set theory. First, we introduced the source model and network model. Next, we described the system model. After that, the simulation procedure and some results are described.

The FRPM has a good dynamic behavior and it is a flexible mechanism. The FRPM as a combination of PMs and RPs is expected to increase the network utilization and to guarantee a better QoS.

Additional work is in progress to provide detailed quantitative evidence of this policing-routing framework.

References

[1] E.Rathgeb, *"Modeling and Performance Comparison of Policing Mechanism for ATM Networks"*, IEEE J. Select. Areas Commun., vol. 9, no. 3, pp. 325-334, April 1991.

[2] M.Butto', E.Cavallero, and A.Tonietti, *"Effectiveness of "Leaky Bucket" Policing Mechanism in ATM Networks"*, IEEE J. Select. Areas Commun., vol. 9, no. 3, pp. 335-342 April 1991.

[3] L.Barolli, and K.Tanno, *"A Fuzzy Approach for Source Policing in ATM Networks"*, in Proc. ICOIN'96 (International Conference on

Information Networking), pp. 482-490, January 1996, Kyung-ju, Korea.

[4] L.Barolli, and K.Tanno, *"A Fuzzy Policing Mechanism for Still Picture in ATM Networks"*, accepted, 21st Local Computer Network Conference, 13-16 October, Minneapolis, MN, USA.

[5] L.Barolli, and K.Tanno, *"A Fuzzy Policing Mechanism for Packet Voice in ATM Networks"*, accepted, IEEE ICCS'96 / ISPACS'96, 25 - 29 November 1996, Singapore.

[6] C.Rosenberg, and B.Laguë, *"A Heuristic Framework for Source Policing in ATM Networks"*, IEEE/ACM Trans. Networking, vol. 2, no. 4, August 1994.

[7] B.J.Vickers, J.B.Kim, T.Suda, D.P.Hong, *"Congestion Control and Resource Management in Diverse ATM Environments"*, Trans. IEICE (B-I), vol. J76-B-I, no. 11, pp. 759-774, November 1993.

[8] ITU Recommendation I.371, *"Traffic Control and Congestion Control in B-ISDN"*, Frozen Issue-Geneva, November 1994.

[9] F.Guillemin, P.Boyer, A.Dupis,L.Romoeuf, *"Peak Rate Enforcement in ATM Networks"*, Proc. IEEE INFOCOM'92, pp. 6A.1.1-6A.1.6, 1992.

[10] M.De Prycer, *"Asynchronous Transfer Mode. Solution for Broadband ISDN"*, Ellis Horwood, Second Edition, 1993.

[11] R.Händel, M.N.Huber, S.Schröder, *"ATM Networks. Concepts, Protocols, Applications"*, Addison - Wesley, Second Edition, 1994.

[12] A.E.Eckberg, B.T.Doshi, and R.Zoccolillo *"Controlling Congestion in B-ISDN/ATM : Issues and Strategies"*, IEEE Commun. Mag., pp. 64-70, September 1991.

[13] R.Guärin, H.Ahmadi and M.Naghshineh, *"Equivalent Capacity and Its Application to Bandwidth Allocation in High - Speed Networks"*, IEEE J on Select. areas in Commun., pp. 968-981, September 1991.

[14] Y.Sato, and K.Sato, *"Virtual Path and Link Capacity Design for ATM Networks"*, IEEE J on Select. areas in Commun., pp. 104-111, January 1991.

[15] S.Gupta, K.W.Ross, and M. El Zarki, *"Routing in Virtual Path Based ATM Networks"*, Proc. IEEE CLOBECOM'92 , pp. 571-575, December 1992.

[16] R.H.Hwang, J.F. Kurose and D.Towsley, *"MDP Routing in ATM Networks Using Virtual Path Concept"*, Proc. IEEE INFOCOM'94 , pp. 1509-1517, 1994.

[17] D.Medhi, *"Multi-Hour, Multi-Traffic Class Network Design for Virtual Path - Based Dynamically Reconfigurable Wide-Area ATM Networks"*, IEEE/ACM Trans. Networking, vol. 3, no. 6, pp. 809-818, December 1995.

[18] Y.Tanaka, K.Miyakoshi, and M.Akiyama, *"Revenue Maximization Control of a Communication Network by the Use of Hierarchical Fuzzy System"*, IEICE Trans. Commun., Part 1, vol. 74, no. 4, 1991.

[19] C.Jin, R.Park, and S.Kim, *"Communication Network Design Problems Using The Fuzzy Set Approach"*, Fifth IFSA World Congress 1993, pp. 1334-1337.

[20] A.R.Bonde, and S.Ghosh, *"A Comparative Study of Fuzzy Versus "Fixed" Thresholds for Robust Queue Management in Cell-Switching Networks"*, IEEE/ACM Trans. Networking, vol. 2, no. 4, August 1994.

[21] C.Chang, and R.Cheng, *"Traffic Control in a ATM Network Using Fuzzy Set Theory"*, Proc. INFOCOM'94, pp. 9c.1.1-9c.1.8, 1994.

[22] J.Khalfet, and P.Chemouil, *"Application of Fuzzy Control to Adaptive Traffic Routing in Telephone Networks"*, Information and Decision Tech.,vol. 19, no. 4, pp. 339-348, 1994.

[23] H.J.Zimmermann, *"Fuzzy Set Theory-and Its Applications."*, Kluwer Academic Publishers, Second, Revised Edition, 1991.

[24] H.R.Berenji, *"Fuzzy Logic Controllers"*, An Introduction To Fuzzy Logic Applications In Intelligent Systems. Edited by R.R.Yager and L.A.Zadeh, Kluwer Academic Publishers, pp. 69-96. 1992.

[25] K.Hirota, *"Industrial Applications of Fuzzy Technology."*, Springer-Verlag, 1993.

[26] A.Kandel, G.Langhholz *"Fuzzy Control Systems "*, CRC Press, 1994.