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Recommended Paper

An Integrated Fuzzy Policing-Routing Mechanism for ATM Networks Using Violation Tagging Function

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In Asynchronous Transfer Mode (ATM) networks, the traffic control design becomes an important challenge, because of the diverse services support and the need for an efficient network resource engineering. Two of important functions for traffic control in ATM networks are policing and routing. The goal of these two functions is to guarantee the required quality of service and increase the network utilization. All previous studies have treated policing and routing in a separate way. A combination of policing and routing can guarantee a better quality of service and network utilization. So far, many network control strategies have been proposed, but they are not well suited for high speed networks. To cope with rapidly changing network conditions, the traffic control methods for high speed networks must be adaptive, flexible, and intelligent for efficient network management. Use of intelligent algorithms based on fuzzy logic, neural networks and genetic algorithms can prove to be efficient for traffic control in ATM networks. In this paper, we propose an intelligent policing-routing mechanism which is based on fuzzy logic. Performance evaluation via simulations shows that the proposed mechanism performs better than conventional policing mechanisms. Furthermore, by using tagging function and handling the traffic of violation cells the network utilization is improved.

1. Introduction

The Asynchronous Transfer Mode (ATM) networks has been standardized and widely accepted as a technique to support 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 traffic control becomes an important challenge. Two of important functions for traffic control of ATM networks are Policing Mechanisms (PMs) and Routing Algorithms (RAs).

All previous studies[1)~9)], have treated policing and routing in a separate way. A combination of policing and routing can guarantee a better Quality of Service (QoS) and network utilization.

The purpose of PMs is to act on each source before all the traffic is multiplexed, in order to guarantee the negotiated QoS. The proposed parameters for source policing are the mean cell rate, the peak cell rate or the peak burst duration. Policing of the peak cell rate is generally not complex and can be achieved by using a cell spacer or other PMs[4)]. Monitoring of the mean cell rate is more difficult, but is intended to improve the link utilization when it has to handle "bursty" traffic sources. The conventional PMs proposed in Refs. 1)–4), can't efficiently monitor the mean cell rate of bursty sources. The Window Mechanisms (WMs) are not well suited to the real-time services of the speed envisaged for B-ISDN, and the Leaky Bucket Mechanism (LBM) in the case of 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 the violation of mean cell rate.

High speed transmission rates bring forward their specific issues influencing the RAs design. The RAs should be adaptive to cope with traffic changes in ATM networks. The conventional Table-Based Routing (TBR) algorithms, which use routing tables, are computationally expensive and require a substantial amount of bookkeeping and periodic transmission of status information among the nodes. Also, the table size increases with the network size and can be large for a network with many nodes[6)].

The conventional PMs and RAs suffer from serious shortcomings. Some are simple but include many approximations and assumptions

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that are hard to justify. Others include complicated mathematical solutions that may not be feasible for real time implementation. Traditional network control strategies, which use queuing models for analytical evaluation, may not be effective because only the network steady state is assumed in queuing models. Therefore, to cope with rapidly changing network conditions, the network traffic methods must be adaptive, flexible, and intelligent for efficient network management[12)].

Use of intelligent algorithms based on Fuzzy Logic (FL), Neural Networks (NN) and Genetic Algorithms (GA) can prove to be efficient for traffic control in high speed networks[8)~13)]. In Refs. 8) and 9), the FL is used to build a fuzzy policer, performance of which is better than conventional PMs and very close to ideal behavior of a PM. Bonde and Ghosh[10)] use a fuzzy threshold function for queue management in high-speed networks. The results show that, the FL provides a flexible and high performance solutions to queue management in cell-switching networks. Cheng and Chang[11)] present a fuzzy traffic controller that simultaneously manages congestion control and call admission control in ATM networks. The fuzzy traffic controller is a fuzzy implementation of two-threshold congestion control method and the equivalent capacity admission control method. The fuzzy control improves system utilization by 11% compared with conventional method. Some NN applications for traffic control in ATM networks are proposed in Ref. 12). The NN are well suited to applications in the control of communications networks due to their adaptability and high speed. They can achieve an efficient adaptive control through the use of adaptive learning capabilities. A GA based routing method is proposed in Ref. 13). The proposed routing algorithm has a fast decision and shows an adaptive behavior based on GA.

In this paper, we propose an integrated Fuzzy Policing-Routing Mechanism (FPRM) for ATM networks. The proposed mechanism has four elements the Fuzzy Policing Mechanism (FPM), Tagging Switch (TS), Direct Path Fuzzy Controller (DPFC), and Fuzzy Routing Mechanism (FRM). The performance evaluation via simulations shows that the FPM has a better behavior than traditional Leaky Bucket Mechanism (LBM), the DPFC decision characteristic is very close to the ideal one, and the FRM can increase the network utilization.

The organization of this paper is as follows. In the next Section, we will give a brief introduction of FL. The source and network models will be treated in Section 3. The system model will be introduced in Section 4. The simulation results will be discussed in Section 5. Finally, the conclusions will be given in Section 6.

2. FL

The concept of a fuzzy set deals with the representation of classes whose boundaries are not determined. It uses a characteristic function, taking values usually in the interval $[0, 1]$. The fuzzy sets are used for representing linguistical labels. This can be viewed as expressing an uncertainty about the clear-cut meaning of the label. But important point is that the valuation set is supposed to be common to the various linguistic labels that are involved in the given problem[15)].

The fuzzy set theory uses the membership function to encode a preference among the possible interpretations of the corresponding label. A fuzzy set can be defined by examplification, ranking elements according to their typicality with respect to the concept underlying the fuzzy set[16)]. The prototypical element receives the greater membership grade. Fuzzy set naturally appears in non-strict specification. It may be soft constraints or flexible requirements for which slight violations can be tolerated (e.g., the dead line is today, but tomorrow is still acceptable although less good), or elastic classes of objects, approximate descriptions of types of situation to which a given procedure can be applied, or even procedures with fuzzy stated instructions.

The ability of fuzzy sets to model gradual properties or soft constraints whose satisfaction is matter of degree, as well as information pervaded with imprecision and uncertainty, makes them useful in a great variety of applications. The most popular area of application is fuzzy control. In fuzzy control systems, expert knowledge is encoded in the form of fuzzy rules, which describe recommended actions for different classes of situations represented by fuzzy sets. An interpolation mechanism provided by the fuzzy control methodology is then at work. A fuzzy control unit can do the same work as a Proportional Integral Differential (PID) controller, since it implicitly defines a numerical function tying the control variables and the ob-

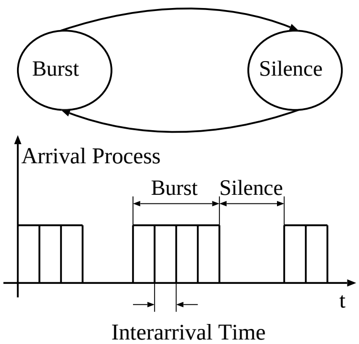

Fig. 1 Source model.

served control variables together. However, by PID controllers only linear control laws can be attained, while the FL controller may capture non-liner laws, which may explain the success of the FL controllers over PID controllers. In fact, any kind of control law can be modeled by the FL control methodology, provided that this law is expressible in terms of "if ... then ..." rules, just like in the case of expert systems. However, FL diverges from the standard expert system approach by providing an interpolation mechanism from several rules. In the contents of complex processes, it may turn out to be more practical to get knowledge from an expert operator than to calculate an optimal control, due to modeling costs or because a model is out of reach[17),18)].

3. Source and Network Models

3.1 Source Model

We assume for the cell arrival process pattern a bursty source as 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).

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) $[bcn = pcr \cdot mbd]$;
- the mean source cell rate $[m = bcn/(mbd + msd)]$;
- the mean cycle duration $[mcd = mbd + msd]$.

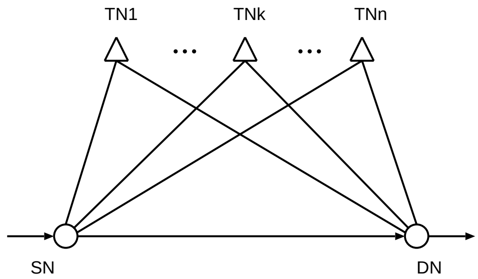

Fig. 2 ATM network model.

3.2 Network Model

We consider a Virtual Path (VP) based ATM network as is shown in **Fig. 2**. The VP 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 endpoints 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 a connection with more than two VPs results in performance degradation because of delays in the transmitted cells and the excessive network resources[6),7)].

4. System Model

The system model is shown in **Fig. 3**. The FPRM has four components: FPM, TS, DPFC and FRM.

The Fuzzy Logic Controller (FLC) is the major component in the proposed FPRM. The basic components of the FLC are shown in **Fig. 4**. They are the fuzzifier, inference engine, Fuzzy Rule Base (FRB) and defuzzifier.

In the design of the FLC, the triangular shape function is used because it is easy to tune the membership functions. The function $f(x, x_0, a_0, a_1)$ (see **Fig. 5**) is defined 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 $(j = 0/1)$.

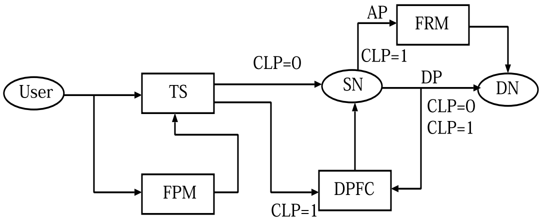

Fig. 3 FPRM model.

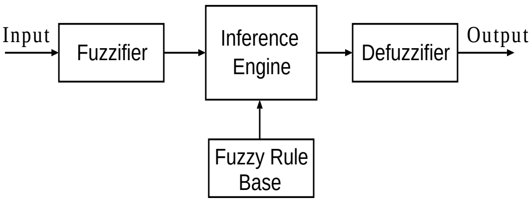

Fig. 4 FLC structure.

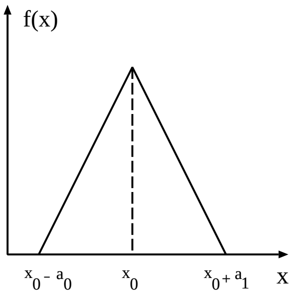

Fig. 5 Triangular membership function.

4.1 FPM

In high-speed networks, because of the unpredictable and often bursty real-time characteristics of traffic, network resources must be designed for average utilization. Therefore, the FPM is designed to control the mean cell rate of packet voice source. The input linguistic parameters of the FPM are: burst cell number *bcn*, mean silence duration *msd* and counter state *cs*. The output linguistic parameter is the controlled cell rate *ccr* which enters into subtractor. The FPM model is shown in **Fig. 6**. Whereas, the membership functions for input and output linguistic parameters are shown in **Fig. 7**. The term sets of *bcn, msd, cs* are defined 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 $\mu_{sm}, \mu_{me}, \mu_{bi}$

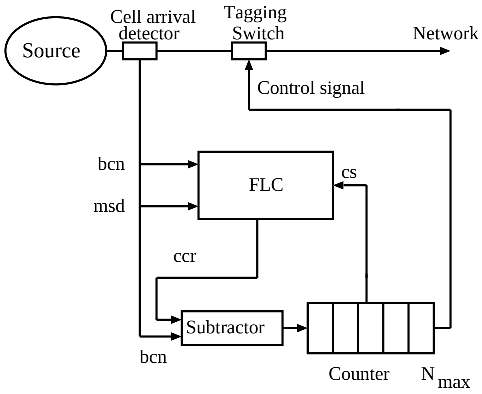

Fig. 6 FPM model.

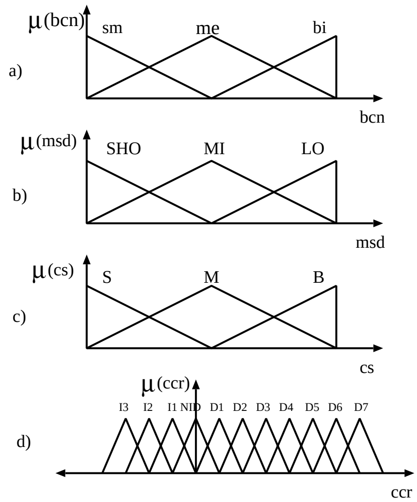

Fig. 7 Membership functions.

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:

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

The membership functions for term set cs are $M(cs) = \{\mu_S, \mu_M, \mu_B\}$, and μ_S, μ_M, 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 $T(ccr)$ as {Increase

3, Increase 2, Increase 1, Not Increase Not Decrease, Decrease 1, Decrease 2, Decrease 3, Decrease 4, Decrease 5, Decrease 6, Decrease 7}. We write for short as $\{I3, I2, I1, NID, D1, D2, D3, D4, D5, D6, D7\}$, where $I2$ increases more than $I1$ and $D2$ decreases more than $D1$ and so on.

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

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

Based on the above linguistic description of input and output parameters a FRB is constructed. The FRB forms a fuzzy set of dimensions $|T(bcn)| \times |T(msd)| \times |T(cs)|$, where $|T(x)|$ is the number of terms on $T(x)$. So, there are 27 rules in the FRB 1, which are shown in **Table 1**. The control rules have the following form: IF "conditions" THEN "control action". The conditions are the input linguistic parameters and the control action is the output linguistic parameter. Statements on conditions go like "the *bcn* is small" or "the *msd* is long". Likewise, statements on control action may be "increase the *ccr*" or "decrease the *ccr*".

The FPM works in the following way. The detector counts the number of cells going to the network and at the same time going to the FLC and 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 input parameters, the FLC gives an appropriate output value, which enters into subtractor. The subtractor carries out the operation $[bcn - ccr]$. If the *ccr* value is positive, the number of cells entering the counter decreases. On the other hand, if the *ccr* value is negative, the number of cells entering the counter increases. The state of the counter is expressed as $[cs = cs_0 + bcn - ccr]$, where cs_0 is the initial counter state, *bcn* is the number of cells in a burst, and *ccr* is the FLC output which indicates the number of cells that the counter state should be changed. If the number of cells entering the counter exceeds the maximum value of the counter a control signal will go to the TS, so the violation cells will be tagged. At the same time, the counter value starts from zero.

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*	*NID*
11	*me*	*SHO*	*B*	*D2*
12	*me*	*MI*	*S*	*NID*
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*

Fig. 8 TS operation scheme.

4.2 TS Operation

The TS operation scheme is shown in **Fig. 8**. The 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 path if the network is congested. The 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

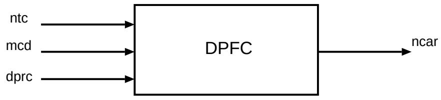

Fig. 9 DPFC scheme.

impact of traffic uncertainty. By traffic policing and traffic violation tagging the total CLP=0 traffic can be handled and network utilization can be improved by CLP=1 traffic.

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 DPFC scheme is shown in **Fig. 9**. The DPFC handles the CLP=1 stream using the membership functions described in following.

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

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}, 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 $T(ncar)$ as {Reject 6, Reject 5, Reject 4, Reject 3, Reject 2, Reject 1, Not Reject Not Accept, Accept 1, Accept 2, Accept 3, Accept 4, Accept 5, Accept 6, Accept 7}. We write for short as $\{R6, R5, R4, R3, R2, R1, NRA, A1, A2, A3, A4, A5, A6, A7\}$.

The set of the membership functions for $ncar$, $T(ncar)$, are denoted by $M(ncar)$. They are written as $\{\mu_{R6}, \mu_{R5}, \mu_{R4}, \mu_{R3}, \mu_{R2}, \mu_{R1}, \mu_{NRA}, \mu_{A1}, \mu_{A2}, \mu_{A3}, \mu_{A4}, \mu_{A5}, \mu_{A6}, \mu_{A7}\}$ and are given by:

$$\mu_{R6}(ncar) = f(ncar, R6_c, R6_{w0}, R6_{w1});$$
$$\mu_{R5}(ncar) = f(ncar, R5_c, R5_{w0}, R5_{w1});$$
$$\mu_{R4}(ncar) = f(ncar, R4_c, R4_{w0}, R4_{w1});$$
$$\mu_{R3}(ncar) = f(ncar, R3_c, R3_{w0}, R3_{w1});$$
$$\mu_{R2}(ncar) = f(ncar, R2_c, R2_{w0}, R2_{w1});$$
$$\mu_{R1}(ncar) = f(ncar, R1_c, R1_{w0}, R1_{w1});$$
$$\mu_{NRA}(ncar) = f(ncar, NRA_c, NRA_{w0}, NRA_{w1});$$
$$\mu_{A1}(ncar) = f(ncar, A1_c, A1_{w0}, A1_{w1});$$
$$\mu_{A2}(ncar) = f(ncar, A2_c, A2_{w0}, A2_{w1});$$
$$\mu_{A3}(ncar) = f(ncar, A3_c, A3_{w0}, A3_{w1});$$
$$\mu_{A4}(ncar) = f(ncar, A4_c, A4_{w0}, A4_{w1});$$
$$\mu_{A5}(ncar) = f(ncar, A5_c, A5_{w0}, A5_{w1});$$
$$\mu_{A6}(ncar) = f(ncar, A6_c, A6_{w0}, A6_{w1});$$
$$\mu_{A7}(ncar) = f(ncar, A7_c, A7_{w0}, A7_{w1}).$$

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 FRM is activated when the DPFC doesn't find enough available resources at the DP. The FRM scheme is shown in **Fig. 10**. The FRM tries to find an Alternate Path (AP) based on the following design.

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 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:

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

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 func-

Table 2 FRB 2.

Rule	*ntc*	*mcd*	*dprc*	*ncar*
0	*sm*	*sho*	*vs*	*R*4
1	*sm*	*sho*	*sl*	*A*1
2	*sm*	*sho*	*md*	*A*4
3	*sm*	*sho*	*bg*	*A*6
4	*sm*	*mi*	*vs*	*R*1
5	*sm*	*mi*	*sl*	*A*4
6	*sm*	*mi*	*md*	*A*5
7	*sm*	*mi*	*bg*	*A*7
8	*sm*	*lo*	*vs*	*NRA*
9	*sm*	*lo*	*sl*	*A*4
10	*sm*	*lo*	*md*	*A*5
11	*sm*	*lo*	*bg*	*A*7
12	*me*	*sho*	*vs*	*R*5
13	*me*	*sho*	*sl*	*R*2
14	*me*	*sho*	*md*	*A*4
15	*me*	*sho*	*bg*	*A*6
16	*me*	*mi*	*vs*	*R*3
17	*me*	*mi*	*sl*	*A*1
18	*me*	*mi*	*md*	*A*5
19	*me*	*mi*	*bg*	*A*7
20	*me*	*lo*	*vs*	*R*2
21	*me*	*lo*	*sl*	*A*1
22	*me*	*lo*	*md*	*A*5
23	*me*	*lo*	*bg*	*A*7
24	*bi*	*sho*	*vs*	*R*6
25	*bi*	*sho*	*sl*	*R*4
26	*bi*	*sho*	*md*	*A*3
27	*bi*	*sho*	*bg*	*A*5
28	*bi*	*mi*	*vs*	*R*3
29	*bi*	*mi*	*sl*	*A*1
30	*bi*	*mi*	*md*	*A*4
31	*bi*	*mi*	*bg*	*A*7
32	*bi*	*lo*	*vs*	*R*3
33	*bi*	*lo*	*sl*	*A*2
34	*bi*	*lo*	*md*	*A*5
35	*bi*	*lo*	*bg*	*A*7

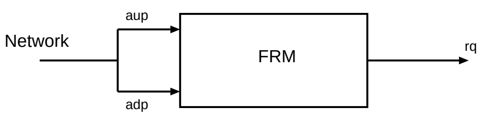

Fig. 10 FRM scheme.

tions 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$\} = \{U, B, F, G, E\}$.

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:

$$\mu_U(rq) = f(rq, U_c, U_{w0}, U_{w1});$$
$$\mu_B(rq) = f(rq, B_c, B_{w0}, B_{w1});$$

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*

$$\mu_F(rq) = f(rq, F_c, F_{w0}, F_{w1});$$
$$\mu_G(rq) = f(rq, G_c, G_{w0}, G_{w1});$$
$$\mu_E(rq) = f(rq, E_c, E_{w0}, E_{w1}).$$

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

5. Simulation Results

For the simulations, we make the following assumptions:

- the source is directly connected to the ATM network;
- the source peak cell rate is controlled separately by a PM.

We generate the burst and the silence period in an independent way. The distribution functions are exponential and the density functions f(.) are expressed as: $f_B(b) = 1/mbd * \exp^{-mbd*b}$ and $f_S(s) = 1/msd * \exp^{-msd*s}$, for the burst and silence, respectively. In Ref. 9), we evaluated the FPM for still picture source. In this paper, we will use for simulation the packet voice source, which is considered a worst case traffic pattern[1]).

The packed voice parameters are as follows:

$$pcr0 = 32\,\text{kb/s} \approx 62\,\text{cell/s},$$
$$mbd0 = 352\,\text{ms},$$
$$msd0 = 650\,\text{ms},$$
$$m = 11.2\,\text{kb/s} \approx 22\,\text{cell/s}.$$

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 order to gain from the statistical multiplexing, the bandwidth for the VCCs is assigned based on the equivalent bandwidth concept[14]. The traffic descriptors in this case can be given by:

$$T_s = \{\rho_s, b_s, (R_{peak})_s\} \quad (1)$$

where ρ_s is the utilization, b_s is the mean burst period, and $(R_{peak})_s$ is the peak rate. We choose the buffer size $x = 20\,\text{kb/s}$, $\epsilon = 10^{-5}$, and the utilization $\rho_s = 0.352$. Thus, the equivalent capacity is about 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:

$$N = \frac{C}{\hat{c}} \quad (2)$$

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

The dynamic behavior of the FPM is evaluated for different burst and silence durations. The FPM selectivity is measured as the violation probability V_p, that the PM will detect a cell as excessive which is considered as a violating cell. The ideal behavior will be for V_p to be zero when the mean cell rate is up to nominal one, and $V_p = (\gamma - 1)/\gamma$ for $\gamma > 1$, where γ is the long term actual mean cell rate of the source normalized to the negotiated mean cell rate.

Figure 11 shows the characteristic of violation probability as a function of the number of emitted cells. We keep the *msd* constant. The increase in the mean cell rate has been achieved by increasing the *mbd* (or *bcn*). For *msd* 0.65 s (second), 1 s and 1.5 s, the violation probability is zero until the number of emitted cells are less than 50, 105 and 275 cells, respectively. This implies that the mean cell rate is 22 cell/s to these points. After these points, the FPM starts to tag the violation cells. The characteristics increase gradually as the number of emitted cells increase. The violation probability is higher for *msd* 0.65 s. This happens because with decreasing the *msd* the violation probability value increases.

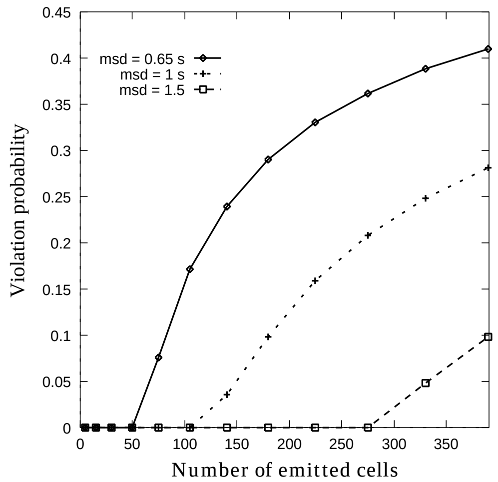

Fig. 11 Violation probability versus the number of emitted cells for different *msd* values.

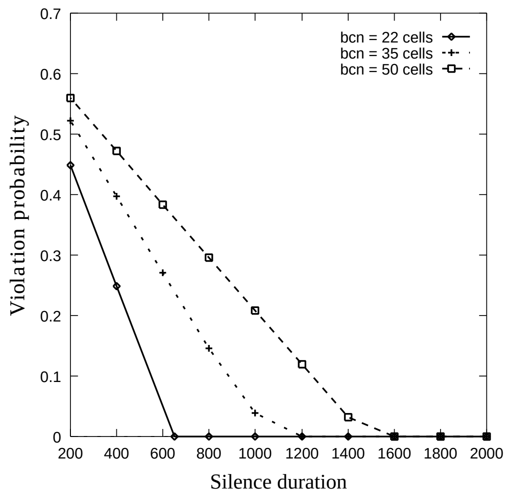

Fig. 12 Violation probability versus the silence duration for different *bcn* values.

The characteristic of violation probability versus the silence duration is shown in **Fig. 12**. We keep the *bcn* constant. The increase in the mean cell rate has been achieved by decreasing the *msd*. The mean cell rate is well policed, because the violation probability is zero until the *msd* values are 650 ms (milliseconds), 1200 ms and 1600 ms, for *bcn* 22, 35 and 50 cells, respectively. This implies that the mean cell rate is 22 cell/s to these points. The violation probability increases with increasing *bcn* and is higher for *bcn* 50 cells.

Some studies proposed so far[1),2)] show that the LBM has a better performance compared with the other conventional PMs. However, in

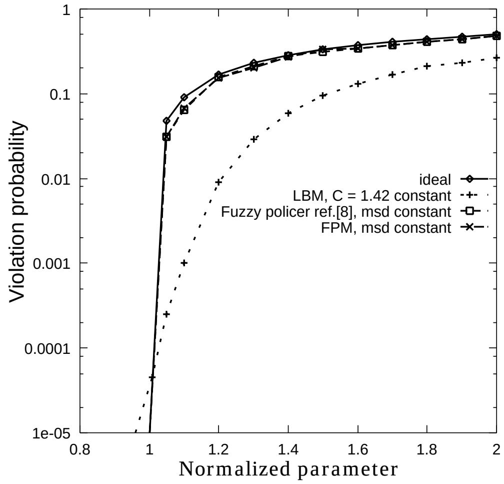

Fig. 13 Performance comparison of PMs.

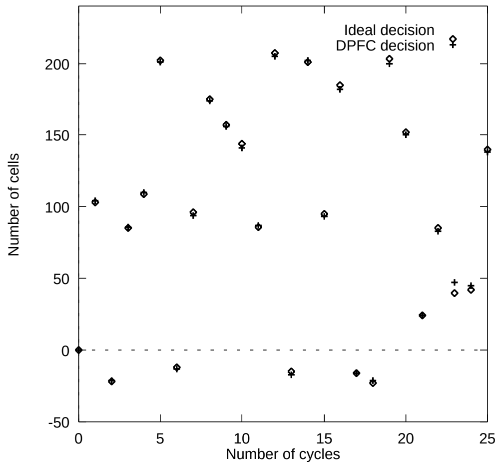

Fig. 14 Ideal and DPFC decisions.

Ref. 3) it is shown that the LBM has performance limitation for user parameter control in ATM networks. To deal with these limitations, in Ref. 8), a fuzzy policer is proposed to control the mean cell rate of the bursty sources. The difference between the fuzzy policer and our FPM is that the fuzzy policer is a window-based PM, while FPM is a leaky-bucket-based PM. The performance of the PMs is shown in **Fig. 13**. All PMs are 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. The performance characteristic of fuzzy policer and FPM is almost the same and very closed to the ideal characteristic compared with the LBM. This means, they have a better selectivity characteristic than the LBM. The fuzzy policer and FPM start to tag (discard) the cells when the mean cell rate is more than 22 cell/s, while the LBM starts to discard the cells before the mean cell rate is 22 cell/s. This show that the fuzzy-based PMs have a good responsiveness to parameter violation compared with the LBM.

A snapshot of measured decisions for the ideal and DPFC decisions is shown in **Fig. 14**. The measurement considers the remained capacity parameter *rb*, the tagged cell throughputs parameter *tct*, and the number of cells accepted/rejected to/from the DP parameter *ncar*. When the number of cells parameter *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 DPFC shows a good dynamic behavior for deciding the number of cells which should be accepted/rejected to/from the DP. The DPFC decision points are very close with the ideal ones.

Table 4 Simulation results for DPFC and FRM.

DP RB	APs AB	DPFC	FPM
24%	0–100%	31%	54%

We carried out some simulations in order to evaluate the performance of the DPFC and FRM. We considered the case of VP traffic where 25 VCCs are multiplexed. The Remained Bandwidth (RB) of DP we considered 24%. Also, the Available Bandwidth (AB) of the APs was generated in the random way from zero to 100%. We ran the simulations for 500 cycles and then calculated the average number of tagged cells that the mechanism was able to send to the DN. First, the DPFC checked the RB of DP. If the DP had enough bandwidth, all the tagged cells were sent to DN, otherwise a part of tagged cells were sent to the DN and the remained tagged cells were routed by FRM via APs to the DN. The FRM selected a path which had the highest AB. If the bandwidth of the selected path was enough to send the remained tagged cells to the DN, all cells were sent to the DN, otherwise the cells were discarded. The simulation results are shown in **Table 4**. The DPFC could send to the DN 31% of the tagged cells and the FRM sent to the DN 54% of remained tagged cells. From the simulation results, we conclude that the FRM efficiently uses the available resources when the load of the network changes. The flexibility of the FRM allows quick response to rapid changes in network loading and maximizes the utilization of available resources.

6. Conclusions

In this paper, we proposed an integrated Fuzzy Policing-Routing Mechanism (FPRM) for ATM networks. After giving a brief introduction of FL, we treated the source and network models. Next, we described the system model and its elements. Finally, the simulation results were discussed. The behavior of FPM, DPFC and FRM was investigated by simulations. From the simulations results, we conclude:

- the FPM efficiently monitors the mean cell rate of the packet voice source;
- the FPM has a good dynamic responsiveness to parameter variations;
- the selectivity characteristic of the FPM approaches very close to the ideal characteristic required for a PM and is better than the LBM;
- the DPFC shows almost an ideal behavior for deciding the number of cells which should be accepted/rejected to/from the DP;
- the FRM is an adaptive routing mechanism and its flexibility allows quick response to rapid changes in network loading and maximizes the utilization of available resources;
- the inferential system which describes the FPRM is simple and can be implemented in hardware, thus improving both the cost and processing speed.

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Editer's Recommendation

The authors propose a novel mechanism

where the routing ways of messages are dynamically changed so as to improve the performance of the high-speed network like ATM ones. The route of a message is decided based on fuzzy logic. The authors evaluate the proposed mechanism by using the simulation and show how much the performance of the network can be improved. This mechanism is able to be adopted to next-generation highspeed networks. (Chairman of SIGDPS Makoto Takizawa)

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