Lessons and Perspectives of Policing Mechanisms for Broadband Networks

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Abstract

Networks of today are passing through a rapid evolution. The broadband ISDN (B-ISDN) which offers a wide variety of telecommunication services is considered to be a powerful future network which can satisfy the demands of users and the network providers. The network speed and costumers request are increasing and new multimedia applications which need large bandwidth will appear in the future. For this reason control of user traffic will be very important to keep the Quality of Service (QoS) of other already established connections by detecting violations of negotiated parameters and taking appropriate actions. In this paper, we give lessons and perspectives of Policing Mechanisms (PM) for multimedia applications.

1 Introduction

Networks of today are passing through a rapid evolution. The broadband ISDN (B-ISDN) which offers a wide variety of telecommunication services is considered to be a powerful future network which can satisfy the demands of users and the network providers. In this information age, customers are requesting an ever-increasing number of new services. Each of these services will generate other requirements for the B-ISDN. This large span of requirements introduces the need for traffic control.

The network speed and costumers request are increasing and new multimedia applications which need large bandwidth will appear in the future. For this reason control of user traffic will be very important to keep the Quality of Service (QoS) of other already established connections by detecting violations of negotiated parameters and taking appropriate actions.

The parameters for monitoring source traffic characteristics are the mean bit rate, peak bit rate or 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 [1]. The control of the mean cell rate is more difficult, but is intended to improve the link utilization when it has to handle bursty traffic sources.

So far, some PMs have been proposed in literature such as Leaky Bucket Mechanism (LBM) and Window Mechanisms (WMs). But, these PMs can't efficiently monitor the mean cell rate of bursty sources [2, 3, 4]. The WMs of traditional packet switched networks are not well suited to the bursty nature of the sources that will be supported in B-ISDN, and the 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. Therefore, new PMs are needed to control efficiently the mean cell rate of bursty sources.

The uncertainties of B-ISDN traffic patterns and the complexity of the traffic control suggest a step-wise approach for defining traffic parameters and network traffic control and congestion control mechanism. Fuzzy set theory has been accepted in literature as a robust mathematical framework for dealing with certain forms of imprecision that frequently occur in decision making environments, but for which the probability calculus is inadequate. Such imprecision is inherent in diverse broadband network environments with bursty nature of sources. In practical situations the mean of the arrival rate and the mean service rate are frequently fuzzy, i.e., they can't be expressed in exact terms [5]. Many design and control problems in communication systems are well suited for analysis using fuzzy set theory. Use of intelligent algorithms based on Fuzzy Logic (FL) can prove to be efficient for traffic control in high speed networks [6, 7, 8, 9].

In this paper, we will make a comparison study of PMs for broadband networks and provide some insights how policing can be used to control multimedia applications.

The organization of this paper is as follows. In Section 2, we discuss conventional PMs. In Section 3, we make the comparison of conventional PMs. In Section 4, we give the drawbacks of conventional PMs. In Section 5, we treat flexible PMs. In Section 6, we present a FPM for still pictures. Finally, Section 7 concludes the paper.

2 Conventional Policing Mechanisms

Several PMs have been proposed so far. They are divided in two groups: LBM and WMs. The performance analysis of the conventional PMs is based on the probability theory. The assumptions about characteristics of the traffic source have a significant influence on the results. Therefore, the two-phase burst/silence model has been used for performance analysis. The bursty source model is considered as the worst-case traffic pattern. It allows the relevant parameters, namely peak bit rate, mean bit rate, and mean silence duration, to be varied independently of each other.

2.1 LBM and Its Variants

2.1.1 LBM Variant 1

This variant of the LBM consists of a counter which is incremented by 1 each time a cell is generated by the source and decremented in fixed intervals as long as the counter value is positive. If the momentary cell arrival rate exceeds the decrementation rate, the counter value starts to increase. It is assumed that the source has exceeded the admissible parameter range if the counter reaches a predefined limit, and suitable actions (e.g., discard or mark cells) are taken on all subsequently generated cells until the counter has fallen below its limit again.

The G/D/1-s delay loss system is an exact model for the violation probability of this LBM, which is identical to the packet loss probability if violating cells are discarded. This model consists of a single server with deterministic service times (D), a finite capacity queue with s waiting places, and a general arrival process (G). The service time of the model is chosen to be equal to the decrementation interval and the number of customers in the system (including server and queue) directly represents the state of the counter. Therefore, the counter limit N is equal to $(s+1)$. Solutions are known for the stationary system with negative exponential interarrival times and for Bernoulli input.

2.1.2 LBM Variant 2

The second variant of the LBM is one found in ref. [3]. This LBM corresponds to a counter which is incremented each time a cell is generated by the source and is decremented periodically with a suitable leaky rate. A cell arriving when the counter has reached a given threshold N is dropped (or marked as an excess cell). The control parameters of the LBM are two: the leaky rate a and buffer capacity N.

This LBM can be modeled as G/D/1/N queue with finite waiting room N. No cell is actually queued and the stream of accepted cells is not altered by the LBM. The analysis for this PM are carried out considering Exact Model and Fluid Flow Approach.

2.1.3 LBM Variant 3

In Variant 1 and Variant 2 of the LBM no input buffer is provided. Variant 3 of LBM is to control the traffic flow by means of tokens [10]. The LBM Variant 3 is shown in Fig.1. An arriving cell first enters a queue. If the queue is full, cells are simply discarded. To enter the network, a cell must first obtain a token from the token pool; if there is no token, a cell must wait in the queue until a new token is generated. Tokens are generated at a fixed rate corresponding to the average bit rate declared during Call Admission Control (CAC). If the number of tokens in the token pool exceeds some predefined threshold value, token generation stops. This threshold value corresponds to the burstiness of the transmission declared at the connection

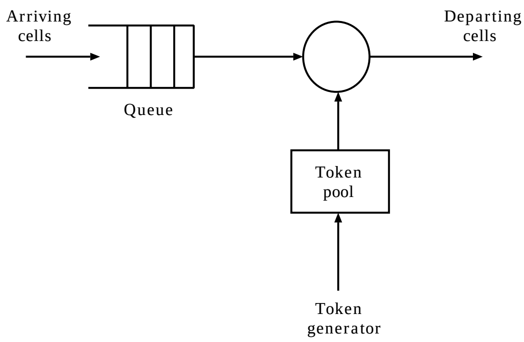

Figure 1: LBM Variant 3.

admission time. For larger threshold values, more burstiness is allowed. This method enforces the average input rate while allowing for a certain degree of burstiness. The LBM can also enforce the traffic flow of constant bit rate applications by generating tokens at a rate corresponding to the peak rate.

In this LBM, the input buffer provides control of the tradeoff between the cell waiting times and the cell loss probabilities. In an extreme case, where no input buffer is provided, incoming cells do not have to wait in the buffer, but a large number of cells may be lost since all the violating cells (i.e., cells arriving at the rate faster than that of token generation when the token pool is empty) are discarded. In the other extreme case (where an infinite input buffer is provided), no incoming cell will be lost, but cells may suffer long waiting times. By choosing an appropriate input queue size, the tradeoff between these two extremes can be controlled.

2.2 Window Mechanisms

The Window Mechanisms (WMs) utilize time windows during which the number of arriving packets is regulated according to parameters established during call set-up.

2.2.1 Jumping Window Mechanism (JWM)

The JWM limits the maximum number of cells accepted from a source within a fixed time interval (window) to a maximum number N. The new interval starts immediately at the end of the preceding interval (jumping window) and the associated counter is restarted again with an initial value of zero. Therefore, the time interval during which a specific cell is influencing the counter value varies from zero to the window width.

The probability that policing actions must be taken on a cell can be computed by using the counting process for the cell arrivals, which characterizes the number of arriving cells in an arbitrary time interval. For example, the counting process for negative-exponential interarrival time is a Poison process, whereas for the discrete-time arrival process defined by a fixed probability for a cell arrival in each time slot (Bernoulli arrivals) the counting process has a binomial distribution.

2.2.2 Triggered Jumping Window Mechanism (TJWM)

The time window is not synchronized with source activity in the JWM. To avoid the ambiguity problems arising from this fact, the "triggered jumping window" mechanism has been proposed, where the time windows are not consecutive but are triggered by the first arriving cell.

The TJWM can be analyzed in a similar way as the JWM. The only difference is that the distribution of the counting process has to be calculated under the assumption that the time interval starts with an arrival event, which is also included in the cell count.

2.2.3 Exponentially Weighted Moving Average Mechanism (EWMAM)

The EWMAM uses fixed consecutive-time windows like the JWM. The difference is that the maximum number of accepted cells in the $i-th$ window (N_i) is a function of the allowed mean number of cells per interval N and an exponentially weighted sum of the number of accepted cells in the preceding intervals (X_i) according to the rule:

$$N_i = \frac{N - \gamma S_{i-1}}{1-\gamma}, \quad 0 \leq \gamma < 1 \tag{1}$$

with,

$$S_{i-1} = (1-\gamma)X_{i-1} + \gamma S_{i-2}. \tag{2}$$

In other words, N_i is given by:

$$N_i = \frac{N - (1-\gamma)(\gamma X_{i-1} + \cdots + \gamma^{i-1}X_1) - \gamma^{i+1}S_0}{1-\gamma} \tag{3}$$

where S_0 is the initial value of the EWMAM measurement. The constant γ reflects the flexibility of the algorithm with respect to traffic burstiness. If $\gamma = 0$, the EWMAM becomes identical to the JWM. A value of γ greater than 0 allows more variable source behavior.

2.2.4 Moving Window Mechanism (MWM)

Similar to the JWM, the maximum number of cell arrivals within a given time interval T is limited by this mechanism. The difference is that each cell is remembered for exactly one window width. That is, the arrival time of each cell is stored and a counter is incremented by one for each arrival. Exactly T time units after the arrival of an accepted cell the counter is decremented by one again. This mechanism can be interpreted as a window, which is steadily moving along the time axis. This mechanism requires that the arrival times of up to N cells are stored for the duration of one window.

The MWM can be modeled by a multiple server loss system, where the deterministic service times reflect the window width T and the number of servers is defined by the maximum allowed number N of cells in the interval. For poison arrivals, the violation probability of the MWM can be readily calculated by using Erlang's loss formula, which is valid for general (including deterministic) service time distributions.

3 Comparison of the Conventional PMs

For the JWM, EWMAM, and MWM, the ratio of the maximum accepted number of cells per interval N and window width T gives the long-term average cell rate λ_p that is controlled by the mechanism, while for the TJWM, this ratio is an upper limit for the controlled mean cell rate. For the LBM Variant 1, the controlled average cell rate λ_p is given by the reciprocal of the decrementation interval D. To allow more flexibility in dimensioning the mechanisms, an over dimensioning factor $c \geq 1$ is introduced, giving the ratio of the policed cell rate λ_p to the actual mean cell rate of the source λ. With a choice of:

$$T = \frac{N}{\lambda C} = \frac{N}{\lambda_p}, \quad and \quad D = \frac{1}{\lambda C} = \frac{1}{\lambda_p}, \tag{4}$$

all the mechanisms are dimensioned to control the same mean cell rate λ_p, which is equal to the mean cell rate of the source for $C = 1$.

Nondeterministic traffic sources will violate the policing criterion with a certain probability because of their short-term statistical fluctuation, even if they respect the long term average. This probability can be decreased for a given policed cell rate λ_p by increasing the counter limit N for the LBM. The same reasoning applies to all the WMs if the ratio of N and the window width T is kept constant. For the EWMAM, the factor γ can be also increased for this purpose. On the other hand, increasing N (and γ) also increases the reaction time of the mechanisms. Decreasing the violation probability by using the factor $C > 1$ will decrease the ability of the mechanism to detect real long-term parameter violation.

For a choice $N = 1$ and $D = T$, the LBM, MWM, and TJWM are identical and can be used to police the maximum cell rate of a source if the jitter of this cell rate is negligible. The time windows in the JWM and EWMAM are not synchronized with the cell arrivals and, therefore, these mechanisms are not able to enforce a minimum spacing between cells with the dimensioning described above.

Fig. 2 shows the behavior of the mechanisms for $N = 2$ and the mean cell rate $\frac{\lambda}{2}$ arrivals for time unit. With a factor $C = 1$, the dimensioning results in a window width of $T = 4$ time units for the WMs and in a decrementation interval of $D = 2$ time units for the LBM Variant 1.

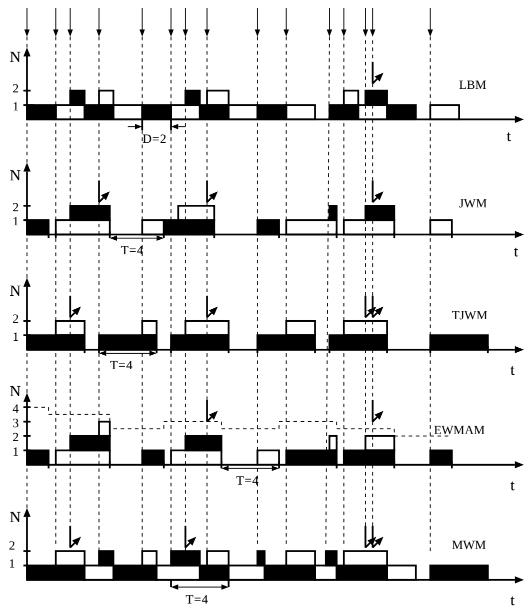

Figure 2: Comparison of conventional PMs.

The factor γ for the EWMAM has been set to 0.5 and the actual counter limit is indicated by the dotted line. The MWM strictly limits the number of accepted cells within any possible interval, because every cell is remembered for exactly 4 time units. The other mechanisms allow intervals of 4 time units with more than two accepted cells. Therefore, assuming the same traffic source and the same dimensioning, the MWM has a generally higher violation probability than the other WMs. The clipping of inactive periods of the source between successive time windows in the TJWM results in a violation probability which is greater than the one of the JWM. The EWMAM, on the other hand, tolerates more short-term fluctuations in the cell rate and yields a lower violation probability than the JWM if γ is set greater than zero (for $\gamma = 0$, the JWM and EWMAM are identical). In general, it can be stated that, under identical conditions, the following inequality holds :

$$P_{viol}^{MWM} \geq P_{viol}^{TJWM} \geq P_{viol}^{JWM} \geq P_{viol}^{EWMAM}. \quad (5)$$

4 Drawbacks of Conventional PMs

The proposed conventional PMs have the following drawbacks.

- **WMs.**

  The WMs are not well suited to the real-time services of the speed envisaged for the B-ISDN.

- **LBM Variant 1.** This variant of the LBM is more sensitive to static overload than the WMs, but it uses a fixed decrementation rate, thus it is not flexible enough to cope with the bursty nature traffic supported by broadband networks.

- **LBM Variant 2.** The LBM Variant 2 is a more flexible PM than the LBM Variant 1. But the number of states grows strongly when the service is very bursty or the leaky rate approaches to the mean cell rate of the source. So, for numerical reasons, the exact model can't be used for evaluating the performance of the LBM, in the case of very bursty services or for low leaky rates.

  The fluid flow approximation give inaccurate results only when the burst and silence periods include very few cells. The control of the mean cell rate requires a leaky rate near the source mean rate. That means a very higher counter threshold is necessary to control the mean cell rate of the bursty sources. This implies that very long times are necessary to detect the violation of the mean cell rate.

- **LBM Variant 3.**

  One disadvantage of the LBM Variant 3 is that the bandwidth enforcement introduced by the token pool is in effect even when the network load is light and there is no need for enforcement. Another disadvantage of this LBM is that it may mistake non-violating cells for violating cells. When traffic is bursty, a large number of cells may be generated in a short period of time, that conform to the traffic descriptor values claimed at the time the connection was established. In such situations, none of these cells should be considering violating cells. Yet in actual practice, this LBM may erroneously identify such cells as being in violation of admission parameters.

  For example, consider a case in which a large burst arrives and seizes all the tokens in the token pool. Even if the long-term average cell rate of the connection remains at the rate specified during CAC, the next cell will be not able to appropriate another token. It will either be dropped if no buffer is provided, resulting in loss, or buffered, resulting in delay.

5 Flexible PMs

5.1 Need for Flexible PMs

The broadband networks can transport different services with different bandwidth requirements in an integrated manner. They also provide the potential to obtain improved bandwidth efficiency by statistical multiplexing

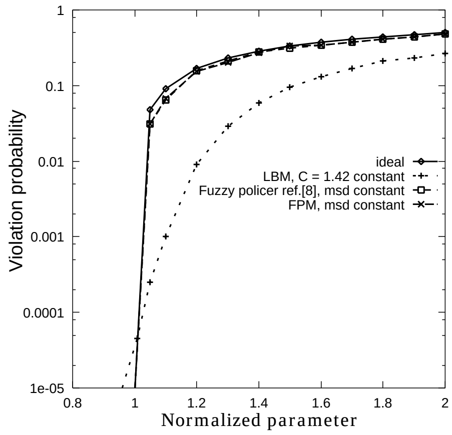

Figure 3: Performance comparison of PMs.

of the bursty traffic streams. Statistical multiplexing of different types of services with different correlations and burstiness properties, and different QoS requirements, require elaborate traffic control mechanisms in order to avoid excessive loss of information. This problem is complicated by the fact that most of these multimedia services have poorly understood traffic characteristics. Also, some new services (e.g. VBR video) exhibit sudden changes in their arrival rate process, which might lead to significant changes in the network's work-load, thus adding another degree of complexity to the problem. This has lead many researchers to believe that new traffic PMs, with some adaptive intelligent capability, are required to meet such new challenges.

Many design and control problems in communication systems are well suited for analysis using fuzzy set theory. Fuzzy logic has proven effective in a number of applications such as intelligent control and decision making, especially where system behavior is difficult to characterize and has strict implementation constraints. In broadband networks which will support diverse services that have a multiple performance criteria, fuzzy logic is a robust method to deal with control problems.

5.2 Intelligent PMs

In this section, we will present two intelligent PMs reported in refs. [8, 9]. Some studies proposed so far [2, 3] show that the LBM has a better performance compared with the other conventional PMs. However, in ref. [4] it is shown that the LBM has performance limitation for user parameter control in high-speed 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 proposed FPM in ref. [9] 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. 3. 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.

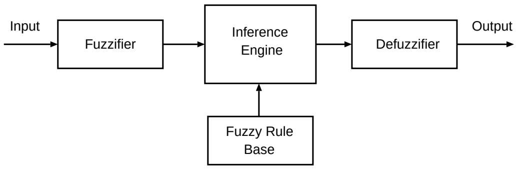

Figure 4: FLC structure.

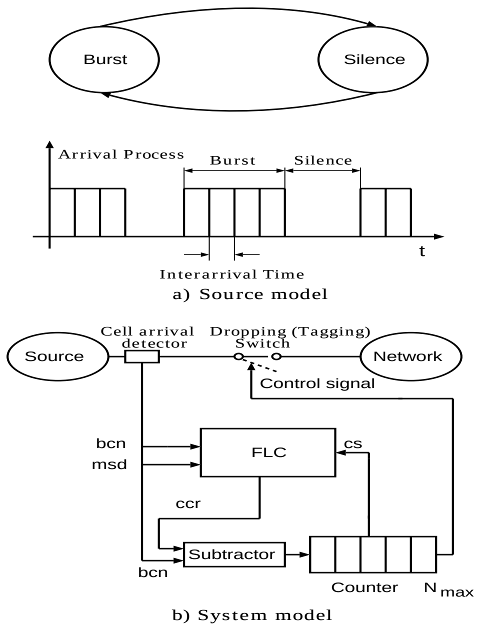

Figure 5: Source and system models. a) Source model b) System model.

6 FPM for Still Picture

The difficulty of characterizing a policer accurately, if conventional methods and models are used, led us to explore alternative solutions based on soft computing techniques. In this section, we introduce an intelligent PM for still picture based on FL. The Fuzzy Logic Controller (FLC) is the major component in the proposed FPM, whose main function is to control the short-term behavior of the source. The FLC structure is shown in Fig.4.

We assume for the cell arrival process pattern, a bursty source, as is shown in Fig. 5(a). 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 system model is shown in Fig. 5(b). The counter's main function is to control the long-term behavior of the source. If the cell arrival number exceed a predefined number (the maximum value of the counter) the mechanism will act and will discard or tag the exceeded cells.

The state of the counter is expressed by the formula:

$$cs = cs_0 + bcn - ccr \tag{6}$$

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.

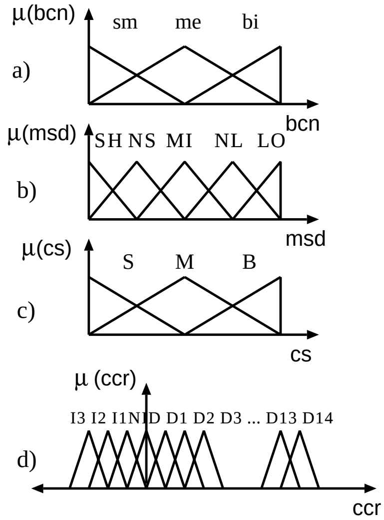

Figure 6: Membership functions.

The main task in the FPM design is to choose a function with proper shape and position and to determine the values of linguistic parameters at an appropriate level of granularity. During a lot of experiments we found that the triangular membership function is more appropriate for our system. First, because it is easy to tune the membership functions and the second the error is smaller compare with the other membership function shapes.

The input linguistic parameters 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 enter in the counter (see Fig. 5(b)). The term sets of bcn, msd, cs are defined respectively as:

$$T(bcn) = \{small, medium, big\} = \{sm, me, bi\};$$
$$T(msd) = \{short, notshort, middle, notlong, long\} = \{SHO, NSH, MI, NL, LO\};$$
$$T(cs) = \{Small, Medium, Big\} = \{S, M, B\}.$$

We define the term set of the output linguistic parameter T(ccr) = {Increase 3, Increase 2, Increase 1, Not Increase Not Decrease, Decrease 1, Decrease 2, ..., Decrease 13, Decrease 14} = {I3, I2, I1, NIND, D1, D2, ..., D13, D14}, where I2 increase more than I1 and D2 decrease more than D1 and so on. The membership functions are shown in Fig. 6.

Based on the above linguistic description of the input and output parameters we make a Fuzzy Rule Base (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 45 rules in the FRB. The FRB is shown in Table 1.

7 Conclusions

In this paper, we described the conventional PMs and gave their drawbacks. We compared by an example their performance and showed that LBM has better behavior than WMs. We presented our FPM for controlling still picture source. In the future work, we will evaluate the performance of FPM by computer simulations. We also would like to extend the study for policing video source.

Table 1: FRB.

Rule	bcn	msd	cs	ccr
0	sm	SHO	S	I2
1	sm	SHO	M	NIND
2	sm	SHO	B	D1
3	sm	NSH	S	D2
4	sm	NSH	M	D3
5	sm	NSH	B	D4
6	sm	MI	S	D3
7	sm	MI	M	D4
8	sm	MI	B	D5
9	sm	NL	S	D4
10	sm	NL	M	D5
11	sm	NL	B	D6
12	sm	LO	S	D5
13	sm	LO	M	D6
14	sm	LO	B	D7
15	me	SHO	S	I2
16	me	SHO	M	I1
17	me	SHO	B	NIND
18	me	NSH	S	D2
19	me	NSH	M	D3
20	me	NSH	B	D3
21	me	MI	S	D5
22	me	MI	M	D6
23	me	MI	B	D7
24	me	NL	S	D8
25	me	NL	M	D9
26	me	NL	B	D10
27	me	LO	S	D9
28	me	LO	M	D10
29	me	LO	B	D11
30	bi	SHO	S	I1
31	bi	SHO	M	NIND
32	bi	SHO	B	D1
33	bi	NSH	S	D2
34	bi	NSH	M	D3
35	bi	NSH	B	D4
36	bi	MI	S	D5
37	bi	MI	M	D6
38	bi	MI	B	D6
39	bi	NL	S	D10
40	bi	NL	M	D10
41	bi	NL	B	D11
42	bi	LO	S	D11
43	bi	LO	M	D13
44	bi	LO	B	D14

References

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

[2] E.Rathgeb, "Modeling and Performance Comparison of Policing Mechanisms for ATM Networks," IEEE J. Select. Areas Commun., Vol. 9, No. 3, pp. 325-334, April 1991.

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

[4] N.Yamanaka, Y.Sato, and K.Sato, "Performance Limitation of the Leaky Bucket Algorithm for ATM Networks," IEEE Trans. on Comm., Vol. 43, No. 8, pp. 2298–2300, 1995.

[5] D.Dubois, H.Prade, and R.Yager (editors), *Fuzzy Sets for Intelligent Systems*, Morgan Kaufman Publishers Inc., 1993.

[6] L.Barolli, and K.Tanno, "A Fuzzy Approach for Source Policing in ATM Networks," Proc. of ICOIN'96 (Korea), pp. 482-490, Jan. 1996.

[7] L.Barolli, and K.Tanno, "A Fuzzy Policing Mechanism for Packet Voice in ATM Networks," Proc. of IEEE ICCS'96/ISPACS'96 (Singapore), pp. 124-128, Nov. 1996.

[8] V.Catania, G.Ficili, S.Palazzo, and D.Panno, "A Comparative Analysis of Fuzzy Versus Conventional Policing Mechanisms for ATM Networks", *IEEE/ACM Trans. on Networking*, Vol.4, No.3, pp. 449-459, June 1996.

[9] L. Barolli, and K. Tanno, "Policing Mechanism in ATM Networks Using Fuzzy Set Theory," Trans. on Inf. Process. Soc. of Japan (IPSJ), Vol.38, No.6, pp. 1103-1115, June 1997.

[10] B.J.Vickers, J.B.Kim, T.Suda, D.P.Hong, "Congestion Control and Resource Management in Diverse ATM Environments," Trans. IEICE, Vol. J76-B-I, No. 11, pp. 759-774, Nov. 1993.

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

[12] V.Catania, and G. Ascia, "A VLSI Parallel Architecture For Fuzzy Expert Systems," International J. of Pat. Recogn. and AI, Vol. 9, No. 2, pp. 421–447, 1995.