

Performance evaluation of rate based congestion control schemes for ATM networks

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Abstract

Asynchronous Transfer Mode (ATM) has emerged as most promising technology in supporting broadband multimedia communications. Congestion control plays important role in the effective and stable operation of ATM networks. In this paper, we described several existing rate based congestion control schemes namely, Explicit Forward Congestion Indication (EFCI), Enhanced Proportional Rate Control Algorithm (EPRCA) and Explicit Rate Indication Congestion Avoidance (ERICA) for ATM networks. These rate based congestion control schemes were implemented for a network configuration using NIST ATM Network Simulator. Through simulation results, we show some drawbacks of the rate based congestion control schemes. We then propose a new enhanced scheme to overcome the problems with existing rate based schemes.

Keywords

ATM Networks, Congestion, EFCI, EPRCA, ERICA, NIST ATM Network Simulator.

1. Introduction

Broadband Integrated Services Digital Networks (B-ISDN) will provide text, image, audio, and video transmission services to the users. B-ISDN uses Asynchronous Transfer Mode (ATM) [10] technique, which transmits all information in small, fixed size packet called cells. ATM networks are able to transport integrated traffic with a wide range of characteristics and Quality of Service (QoS) requirements.

Congestion control [1,3,6] mechanisms are essential for the support of ABR service to provide efficient and fair bandwidth allocation among ABR applications. Among congestion schemes, rate based congestion control promises effective traffic management for data communication in ATM networks. In the rate based congestion control mechanism, cell emission rate of each source end system is regulated according to congestion information returned by the network.

In this paper, we considered two rate based congestion control algorithms, Explicit Forward Congestion Indication

(EFCI) and Explicit Rate Indication Congestion Avoidance (ERICA) for ATM networks. These schemes were implemented for a network configuration using NIST ATM simulator and results were presented and compared. This paper is organized as follows. Congestion control schemes for ATM networks were presented in section 2. The various rate based congestion control schemes for ATM networks were presented section 3. The simulation environment and results for three rate based schemes are presented in section 4. The proposed enhancement to ERICA scheme and benefits of this scheme over other schemes are presented in section 5. Finally the paper is concluded in section 6.

2. congestion control schemes

Congestion control lies in the heart of general problem of traffic management for ATM networks. In general, congestion arises when incoming traffic to specific link is more than outgoing link capacity. The primary function of congestion control is to ensure good throughput and delay performance while maintaining a fair allocation of network resources to users.

There are two main schemes for controlling congestion in ATM networks: credit based and rate based schemes.

2.1 Credit-based Congestion Control

The credit based [6] solution is essentially a dynamic sliding window protocol. Each link in the network runs the flow control mechanism. In this scheme, a certain number of cell buffers are reserved for each virtual connection at the receiving end of each link. This reservation is given in the form of a credit balance. A credit balance is maintained at the sending end of each link. Each unit of credit represents one empty buffer at the receiving end. A connection is allowed to continue cell transmission as long as it gains credits from the receiving end, as shown in fig 1 (a). When each cell is transmitted by the sending end, the

credit balance for that connection is decremented. If a virtual connection runs out of credit on a particular link, it will stop sending cells. As each cell is removed from the buffer at the receiving end, a credit is returned to the sending end of each virtual connection. This link (virtual connection) by link feedback mechanism can relieve congestion effectively, and no cell loss occurs caused by congestion, because the connection has to wait for credit before it can send cells. These are some reasons against adoption of credit based schemes, because link-by-link flow control requires complex hardware at the switches. Transmission delay may be too long with credit based schemes.

2.2 Rate-based Congestion Control

Rate based control schemes are end-to-end feedback mechanisms. They have one source and one destination for each feedback loop. As shown in fig 1.(b), the destination

end alerts the source end to slow transmission where congestion occurs. If there are ATM switches between source and destination, these devices simply forward and augment the flow-control information moving between the destination and source.

In this end-to-end rate based scheme, a resource management cell (an RM cell) is used, which is a standard 53 byte ATM cell used to transmit flow control information. This RM cell carries information over the virtual circuit and is therefore allowed to flow all the way to the destination /source end station. The destination reflects or issues the RM cell, with an indicator to show the status of the traffic. The intermediate switches then simply forward or mark down the rate in the RM cell if needed. The source end system then uses this information in the RM cells for subsequent transmissions until a new resource management cell is received.

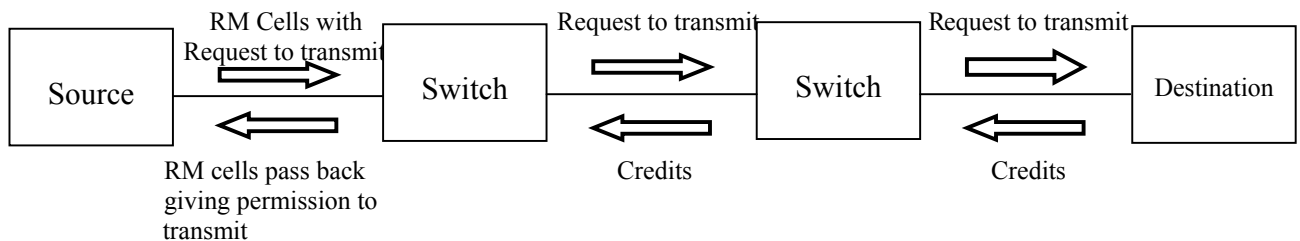


Fig 1.a Credit Based Scheme

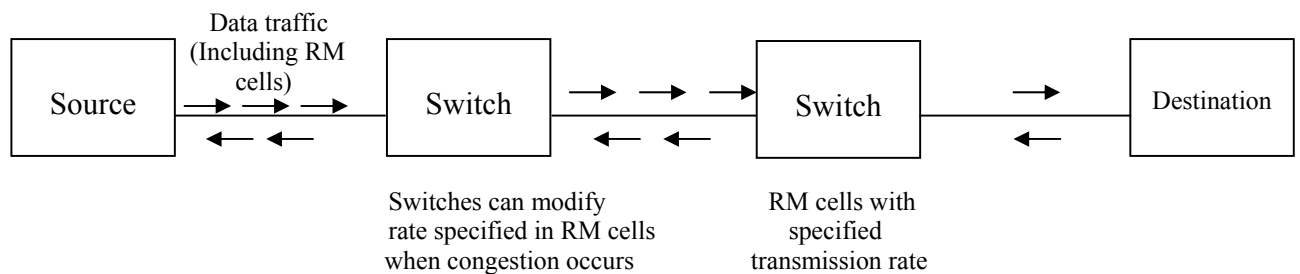


Fig 1.b Rate Based Scheme

3. Rate-based congestion control schemes

We will describe a few rate based congestion control schemes developed by ATM forum in this section.

3.1 EFCI Scheme

Explicit Forward Congestion Indication (EFCI)[3] is an end-to-end rate based scheme in which most of the control complexity resides in the end systems. An Allowed Cell

Rate (ACR) at the source is adjusted according to the congestion status of the network. The congestion is detected at each intermediate switch by monitoring the queue length of switch. If the queue length exceeds the threshold value of switch, then the switch is said to be congested.

To indicate congestion, the switch will mark an Explicit Forward Congestion Indication (EFCI) bit in the header of all passing data cells on the path in forward direction. When the destination end system receives a data cell in which the EFCI bit is marked, it will generate a Resource Management (RM) cell. This RM cell is sent back to the

source end system along the backward path. Once the source receives an RM cell, it must decrease its ACR by a rate decrease factor, but not less than MCR :

$$ACR = \max(ACR * DF, MCR)$$

Where, DF is the rate decrease factor, and MCR is the minimum allowed cell rate. A time interval is defined at the destination end systems. Only one RM cell is allowed to be sent back in an RM time interval. Also there is an interval timer in the source end system. The source recognizes no congestion in the network without receiving an RM cell after an interval time. Then the source will increase ACR:

$$ACR = \min(ACR * IF, PCR)$$

Where, IF is the rate increase factor and PCR is the peak cell rate of this connection

3.2 eprca scheme

The Enhanced Proportional Rate Control Algorithm (EPRCA) [7,9] is a rate based congestion control scheme for ATM networks. This scheme is simply described as follows:

- The source send n data cells then send a Resource Management (RM) cell, and then proportionately and continuously decrease their Allowed Cell Rate (ACR). The RM cells contain the source's current cell rate (CCR) and minimum cell rate (MCR). The RM cells also have several fields that can be used by the switches to provide feedback to the sources. These fields are: Explicit Rate (ER), Congestion Indication (CI) flag, No Increase (NI) flag.
- The switch computes a Mean Allowed Cell Rate (MACR) after receive forward RM cell by $MACR = (1 - AV) * MACR + AV * CCR$, Where AV is the Average Ratio.
- If the switch receive a backward RM cell, it will set Explicit Rate $ER = \min(ER, 7/8 * MACR)$ if it is congested.
- If the source receives a RM feedback, then set $ACR = \min(ACR + AIR, ER, PCR)$ for $CI = 0$, where AIR is Additive Increase Rate, PCR is Peak Cell Rate and CI is Congestion Indication.

3.3. ERICA Scheme

The ERICA algorithm [4, 5] operates at each output port (or a link) of switch. The switch periodically monitors the load on each link and determines a load factor, z , the ABR capacity, and the number of currently active VCs (Virtual Channels or Virtual Circuits). In every averaging (measuring) interval (the interval between two RM cells), these quantities will be updated. Further, the switch gives no or one new feedback per source in any averaging interval.

The load factor is calculated as the ratio of the measured input rate at the port to the target capacity of the output link.

$$z \leftarrow \frac{ABR \text{ Input Rate}}{ABR \text{ Capacity}}$$

Where, $ABR \text{ capacity} \leftarrow \text{Target Utilization (U)} \times \text{Link Bandwidth}$

The load factor, z , is an indicator of the congestion level of the link. High overload values are undesirable because excessive congestion; so are low overload values which indicate link underutilization. The optimal operating point is at an overload value equal to one. The goal of the switch is to maintain the network at unit overload.

The fair share of each VC, Fair Share, is also computed as follows:

$$FairShare \leftarrow \frac{ABR \text{ Capacity}}{\text{Number of Active sources}}$$

The above steps are executed at the end of switch averaging interval.

The switch allows each source sending at a rate below the FairShare to rise to FairShare every time it sends a feedback to the source. If the source does not use all of its FairShare, then the switch fairly allocates the remaining capacity to the sources which can use it. For this purpose, the switch calculates the quantity of VCShare:

$$VCShare \leftarrow \frac{CCR}{z}$$

If all VCs changed their rate to their VCShare values then, in the next cycle, the switch would experience unit overload (z equals one). Hence VCShare aims at bringing the system to an efficient operating point, which may not necessarily be fair, and FairShare allocation aims at ensuring fairness, possibly leading to overload (inefficient operation). A combination of these two quantities is used to rapidly reach optimal operations as follows:

$$ER \leftarrow \max(FairShare, VCShare)$$

ER can not be greater than ABR capacity. So if the calculated ER value is greater than ABR capacity, our new ER value will be computed as follows:

$$ER \leftarrow \min(ER \text{ Calculated}, ABR \text{ capacity})$$

Source are allowed to send at a rate of at least FairShare within the first round-trip. This ensures minimum fairness between sources. If the VCShare value is greater than the FairShare value, the source is allowed to send at VCShare, so that the link is not underutilized

Each switch computes the minimum of the ER it has calculated as above and the ER value in the RM cell. This value is inserted in the ER field of the RM cell.

$$ER \text{ in RM cell} \leftarrow \min(ER \text{ in RM cell}, ER)$$

4. Simulation Environment and Results

4.1 Simulation Environment

The EFCI, EPRCA and ERICA schemes described in previous section were implemented using NIST ATM Network Simulator [8] for a network configuration shown in fig 2. The NIST ATM Network simulator was developed by National Institute of Standards and Technology (NIST) for studying and evaluating performance of ATM networks.

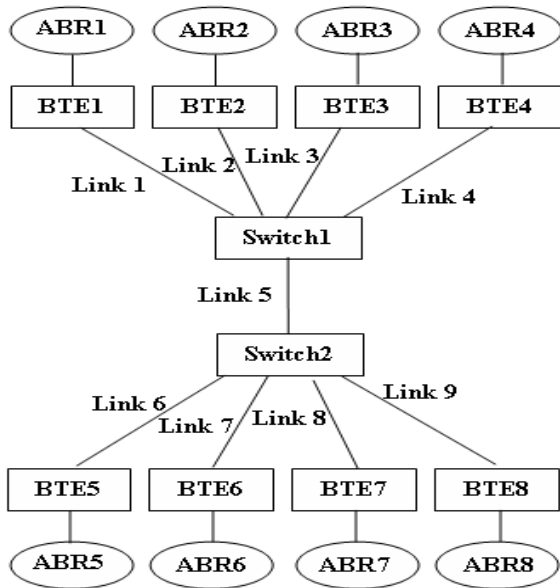


Fig.2 A Sample Network Configuration

In the network, there are two switches, four source end systems (Broadband Terminal Equipment BTE1 to BTE4), four destination systems (BTE5 to BTE8), links (link1 to link9) and ABR applications (ABR1 to ABR8). The ABR applications are attached to source and destination terminals for sending and receiving data. There are four virtual channels in the network. The first Virtual Channel (VC1) is passing through BTE1, Switch1, Switch2 and BTE5. The second Virtual Channel (VC2) is passing through BTE2, Switch1, Switch2, and BTE 6. The third Virtual Channel (VC3) is passing through BTE3, Switch1, Switch2, and BTE7. The fourth Virtual Channel (VC4) is passing through BTE4, Switch1, Switch2, and BTE 8. The network parameters are as follows: Link speed = 155 Mbps, Source end terminals (BTEs): Initial Cell Rate =7.49 Mbps, Minimum Cell Rate = 1.49 Mbps, Peak Cell Rate =149.76 Mbps, Switch parameters: Low threshold (cells)= 600, High threshold (cells)= 800 , Very Congested Queue Threshold (DQT) = 900. A switch is said to be congested when queue length of switch larger than predefined threshold.

4.2 Results Analysis

Initially, We implemented EFCI scheme and the results are presented in the form of graphs.

1. Graph of Allowed Cell Rate in Mbps over time for source terminal.
2. Graph of % cell drop over time at the switch1.

The graphs for ACR Vs. Time for source BTE , and the percentage of Cell Drop Vs. Time at Switch1 are shown in fig. 3 and 4 respectively.

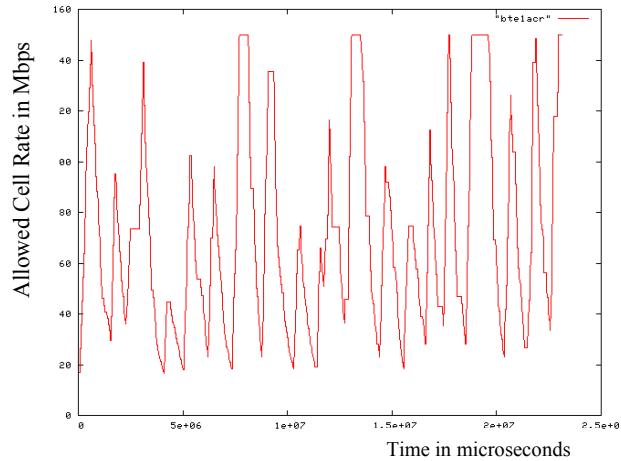


Fig.3. BTE1 ACR Vs Time

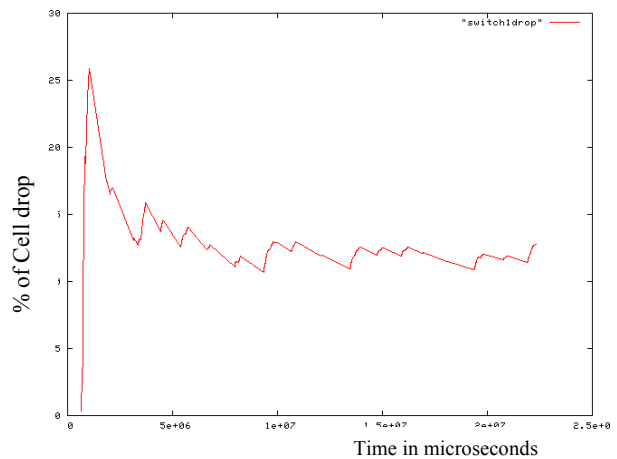


Fig.4: Percentage of Cell drop Vs Time at Switch1

From the above graphs, we can observe that, Allowed Cell Rate (ACR) of source terminals will continuously increases until source terminals receives RM cell from destination terminal. Then it decreases ACR until it receives no RM cell within time interval. We can also observe that, higher percentage of cell drop at switch1 have taken place.

Later we implemented EPRCA scheme for the same network configuration shown in fig 2. The graphs are ACR Vs. Time for source BTE and % of cell drop at Switch 1 are shown in figs 5 and 6 respectively.

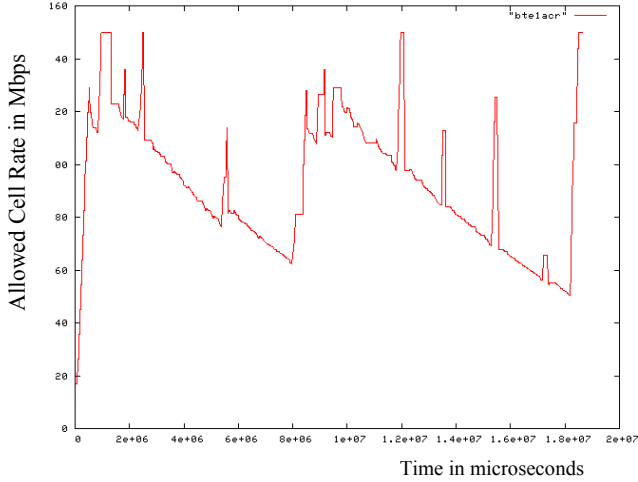


Fig5. BTE1 ACR Vs Time

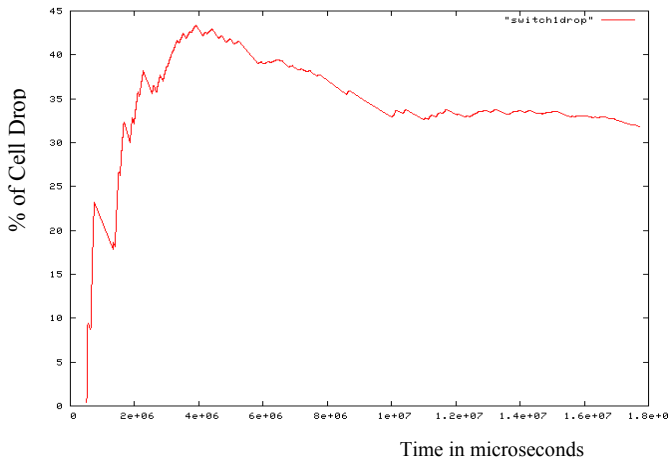


Fig.4 Percentage of Cell drop Vs Time at Switch1

From the above graphs, we can observe that, Allowed Cell Rate (ACR) of source terminals will continuously increases when no congestion information received from network. We can also observe that, higher percentage of cell drop at switch 1 have taken place.

Later we implemented ERICA scheme for the same network configuration shown in fig 2. The graphs are ACR vs. Time for source BTEs and % of cell drop at Switch 1 are shown in figs 5 and 6 respectively.

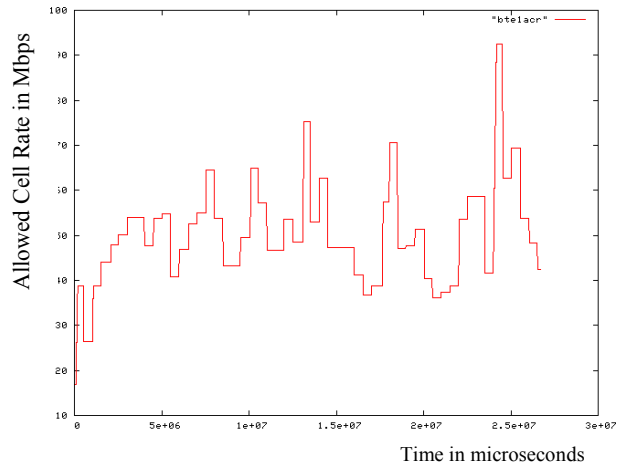


Fig.6. BTE1 ACR Vs Time

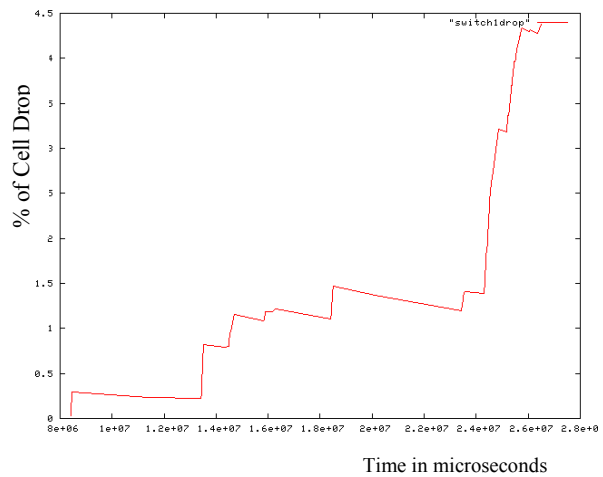


Fig.6: Percentage of Cell drop Vs Time at Switch1

From the above graphs, we can observe that, Allowed Cell Rate (ACR) of source terminals will continuously increases when no congestion information received from network. we can also observe that, fewer percentage of cell drop at switch 1 have taken place.

The above schemes have major drawback, which is cell drop at switch for bursty traffic in the network. The percentage of cell drop taken place for various schemes shown in table 1.

Table 1. Percentage of cell drop at switch1

Sl. No.	Schme	Total % of cell drop at switch1
1	EFCI	13%
2	EPRCA	15%
3	ERICA	4.4 %

The ERICA scheme has lower percentage of cell drop than other schemes and this scheme can be enhanced to further reduce that % of cell drop problem.

5. enhancement to erica scheme

Most congestion control schemes provide the netwo administrator with a number of parameters that can be set adapt the behavior of the schemes to their needs. A go scheme must provide a small number of parameters th offer the desired level of control.

ERICA provides a few parameters which are easy to s because the tradeoffs between their values are we understood. Our simulation results have shown that slig mistuning of parameters does not significantly degrade tl performance of the scheme.

The Target Utilization determines the link utilization during steady state conditions. If the Input rate is greater than Target Utilization × Link Capacity, then the switch asks source to decrease their rates to bring the total input rate to the desired fraction.

In ERICA, the target utilization is set to 95%, the remaining 5% used for draining the queue when the input rate is more than the capacity. Thus, the main difference between a system with 95% target utilization and another with 85% target utilization is that in the latter case, the queues due to overload are drained out quickly. Lower target utilization leads to faster response to overloads.

Excessively high values of Target Utilization are undesirable because they lead to long queues and packet loss, while low Target Utilization values lead to link underutilization.

The main problem with lower target utilization is under steady state (when there is no overload), a larger fraction of the capacity is left unused. Thus there is a tradeoff between steady state and transient operation.

We can enhance ERICA scheme by varying the target rate dynamically. During steady state target rate is 100% while it is lower during transient overloads.

Target rate = fn(queue length, link rate)

The “fn” above has to be decreasing the function of queue length.

The pseudo code for setting target rate :

```

If queue length > DQT
    Target rate = link rate * 0.75
Else
    If queue length > High threshold
        Target rate = link rate * 0.85
    Else
        If queue length < low threshold
            Target rate = link rate * 1.00
    
```

The above scheme has been implemented by using NIST ATM Network simulator and it has overcome the problem of % of cell drop at switch. The graphs for Allowed Cell Rate Vs. Time at source BTE and % cell drop at switch are shown in fig. 7 and fig. 8 respectively.

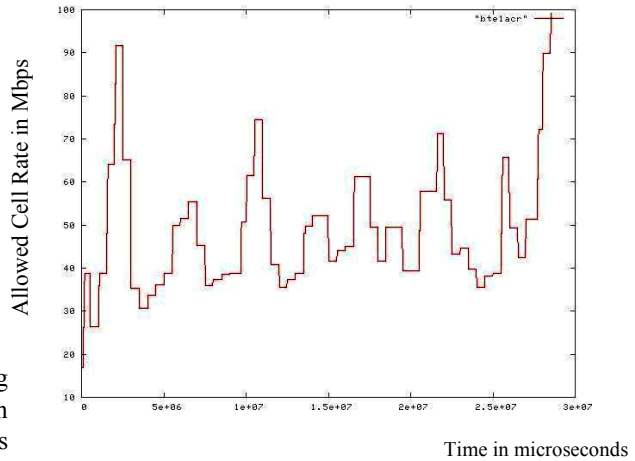


Fig.7. BTE1 ACR Vs Time

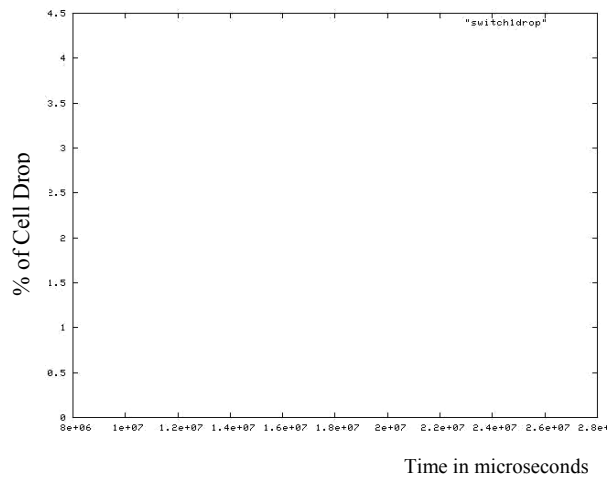


Fig.8: Percentage of Cell drop Vs Time at Switch1

The proposed enhanced ERICA gives better results than other scheme, where we can find no cell drop at switch1. So we can conclude that proposed enhanced ERICA scheme is better than other rate based schemes like EFCI, EPRCA, and ERICA schemes.

6. Conclusion

EFCI, EPRCA and ERICA rate based congestion control schemes for ATM networks were described. These schemes were implemented for a network configuration using NIST ATM Network simulator. From the results on

implementation of these schemes, we can cell drop problem at switch. The EPRCA has high % cell drop, while ERICA scheme has lower % cell drop. The proposed ERICA scheme over cell drop problem. We can conclude that enhanced ERICA scheme is better than other rate based schemes like EFCI, EPRCA, and ERICA.

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