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# A MODEL FOR PREVENTIVE CONGESTION CONTROL MECHANISM IN ATM NETWORKS

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*ABSTRACT*

***Maximizing bandwidth utilization and providing performance guarantees, in the context of multimedia networking, are two incompatible goals. Heterogeneity of the multimedia sources calls for effective traffic control schemes to satisfy their diverse Quality of Service (QoS) requirement. These include admission control at connection set up, traffic control at the source ends and efficient scheduling schemes at the switches. The emphasis in this paper is on traffic control at both connection set up and source end. A model for the Connection Admission Control (CAC) is proposed using probabilistic technique. Mathematical formulas are derived for Cell Loss Probability (CLP), violation probability ($P_v$) and cell throughput ($T_c$). The performances of two UPC models (fluid flow and flow approximation) are investigated using the Leaky Bucket (LB) algorithm. The CLP, $P_v$ and $T_c$ as a function of increase in the normalized negotiated peak rate for these models are presented. Simulations are performed for different traffic sources which are characterized by their mean bit rate, peak bit rate and average number of bits generated during the burst. The results of the simulation show that the model for the Connection Admission Control (CAC) performs satisfactorily well for different traffic sources. Also, both models for the Leaky Bucket are almost coincident in policing the peak rate and mean rate of the source. Hence, policing effect is improved considerably using the proposed model.***

**Keywords:** Asynchronous Transfer Mode, Leaky Bucket algorithm, Cell Loss Probability, Connection Admission Control, Usage Parameter Control

## INTRODUCTION.

Asynchronous Transfer Mode (ATM) is the basis for future high-speed telecommunication networks [Kalevi, 1994]. The principle of ATM has proved usable in a wide range of networks from small local specialized networks to huge global integrated networks. The strength of ATM lies in its superior flexibility, which enables a wide variety of services and applications to be efficiently integrated in one network.

At an early stage of development, ATM was called Asynchronous Time-Division. This name clarifies a basic principle of ATM: all services or connections can share network resources in an asynchronous manner without any fixed reservation. Each connection can use the capacity of links, switches and buffers exactly when needed, and if for a while there is no information to be transferred, all capacity is left to other connections. On the other hand, when a number of applications compete for the same resources, the competition needs fair and efficient rules [ITU-T, 1997; Prycker, 1995].

ATM has a feature, which guarantees its success, namely the possibility to transport any service, irrespective of its characteristics such as the bit rate, its quality requirements or its bursty nature, etc. This big advantage was one of the main motivations for CCITT (now ITU-T) to decide that ATM will be the transfer mode for the future B-ISDN.

The Asynchronous Transfer Mode (ATM) is the transport model for the Broadband-ISDN (B-ISDN). ATM is capable of multiplexing a large number of connections providing services like voice, data, TV, video and others. Due to complex traffic characteristics in ATM-networks a wide range of problems must be resolved before such networks can be effectively managed. These problems include many performance issues that have been attacked by advanced mathematical techniques [Butto, et al, 1991; ITU-T, 1997]. One of the main topics in ATM networks is traffic management that has to provide for effective congestion control to prevent the network becoming a bottleneck. The congestion control techniques proposed for ATM cover a wide range of time scales, including the (re) definition of virtual paths, traffic shaping by buffering cells to reduce the peak rate, call admission and bandwidth allocation, and usage parameter control or traffic policing.

Figure 1 sketches some features of the ATM-concept within a multi-service environment comprising different traffic sources like voice, data, video conferencing and TV. The channel is a resource shared among many users by a time multiplexing scheme.

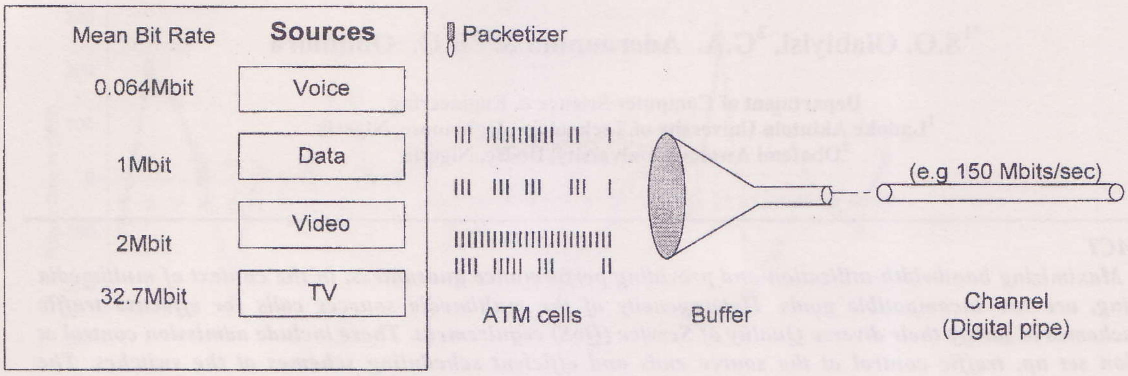


**Figure 1: Traffic sources, packetizing and digital pipe.**

The bit streams generated by the sources are divided into cells which have a length of 48 byte supplemented by a 5 byte header. The ATM-header fields carry information concerning flow control, load type, priority, error control, and identifiers for virtual paths and virtual channels. Note that a virtual path (VP) is a collection of virtual (VCs) between two nodes. Hence the length of the data part of a cell in bits is cell = 48*8 =384 and a bit rate of e.g. IM /bits/sec/ yields a net cell rate of $2^{20}$/384=2730.6/cells/sec/.

The characterization and modeling of sources is one of the central topics in high-speed network performance.

The trend to describe sources with a minimum set of parameters leads to these four parameters, which are widely used:

* Peak arrival rate of the ATM cells when source is at the on-state: p
* Mean arrival rate of ATM cells: m
* The average duration of the on-state (peak duration): $t_{on}$
* Traffic burstiness (β=p/m) β

Some proposed traffic characteristics [Akimaru, and Kwashina, 1993; Butto, et al, 1991; Sykas, et al. 1992] of the future B-ISDN that are used in this paper are shown in Table 1.

Table 1: Traffic Characteristics of some B-ISDN Services

| Source | p | m | $t_{on}$ | β = p/m |
|---|---|---|---|---|
| Packet Voice | 32 kbit/s | 11.2 kbit/s | 352ms | 2.85 |
| Broadband Ser. | 10 Mbit/s | 2 Mbit/s | 5ms | 5 |

**Connection Admission Control and Usage Parameter Control**

The design of a suitable ATM traffic control is the most important challenge for the success of an ATM based B-ISDN. Therefore, it has been the subject of vigorous research over recent years.

The objectives of ATM layer traffic control for B-ISDN can be summarized as follows:

- *Flexibility:* It should support a set of ATM layer QoS classes sufficient for all existing and foreseeable services.
- Simplicity: The challenge is to design a simple ATM layer traffic control mechanism, which minimizes network equipment complexity while maximizing network utilization.
- *Robustness:* The requirement of achieving high resource efficiency under any traffic circumstance while maintaining simple control functions.

To meet the above objectives, the following two functions are prerequisite in ATM networks: Connection Admission Control (CAC) and Usage Parameter Control (UPC). The locations of these functions in ATM networks are shown in Figure 2.

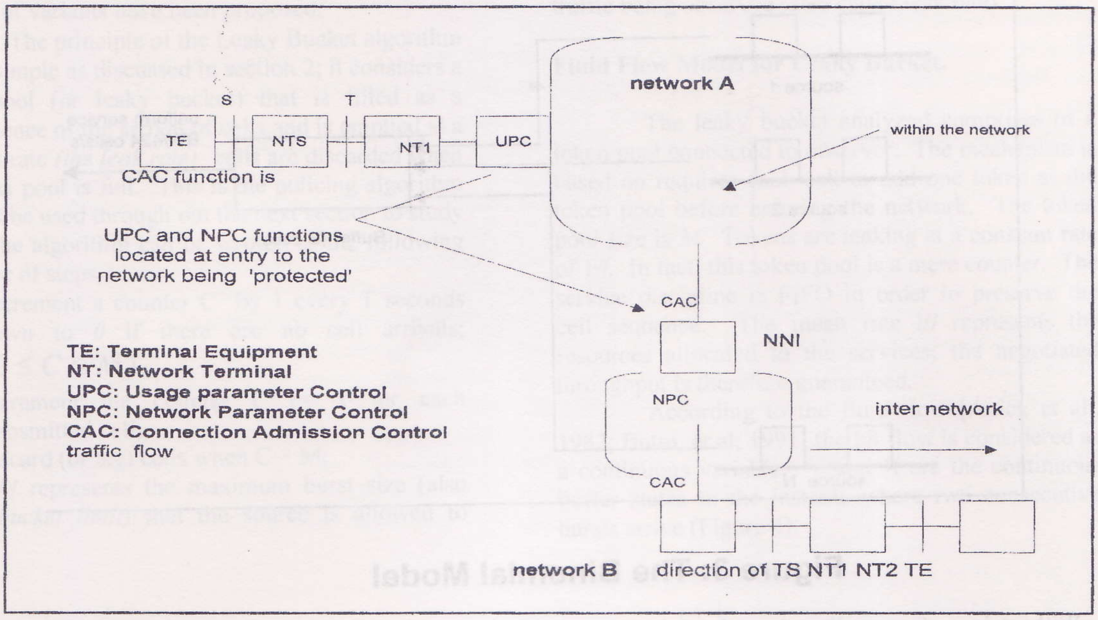


**Figure 2: Location of traffic control functions.**

The concept of traffic control in ATM networks is simple. Users declare the traffic characteristics of their communication when they set up a connection, and the network assigns the resources necessary for this communication. If the assignment is impossible the connection is rejected. During communication, the network monitors the conformity between the declared traffic characteristics and the characteristics of the actual cell steam at the entrance of the network. If the network finds disconformities it imposes a penalty on the user. The control assigning resources and judging rejection or acceptance is called *Connection Admission Control* (CAC), and the control monitoring the cell stream and imposing penalties is called *Usage Parameter Control* (UPC) [Olabiyisi, 2003].

### The Leaky Bucket

The leak bucket is generally agreed to achieve the best performance compromise of the mechanisms studied for policing. It was first introduced in [Yin and Micheal, 1991]. Since then a number of variants have been proposed. The basic idea behind this approach is that each incoming cell adds one token to the leaky bucket if there is at least one token space available. Token 'leak' at a constant rate out of the bucket. The size of the bucket imposes an upper bound on the burst length and determines the number of cells that can be transmitted back to back, controlling the burst length. Provided that the burst is short, the bucket will not fill and no action will be taken against the cell stream. However, if a long burst of higher-rate cells arrives, the bucket will overflow and the UPC function will take actions against cells in that burst. The tolerance allowed for the connection depends on the size of the bucket (M) and the leaky rate (l), which are also the parameters of the leaky bucket.

### THE BINOMIAL MODEL FOR THE CAC

In the model, a buffer receives cell from a finite number of statistically independent and identical traffic sources that asynchronously alternate between exponentially distributed periods in the 'on' and 'off' states. In the on state the source transmits at a uniform rate. The buffer depletes uniformly with the allocated bandwidth rate of *BW* bits/s. This model is shown in Figure 3.

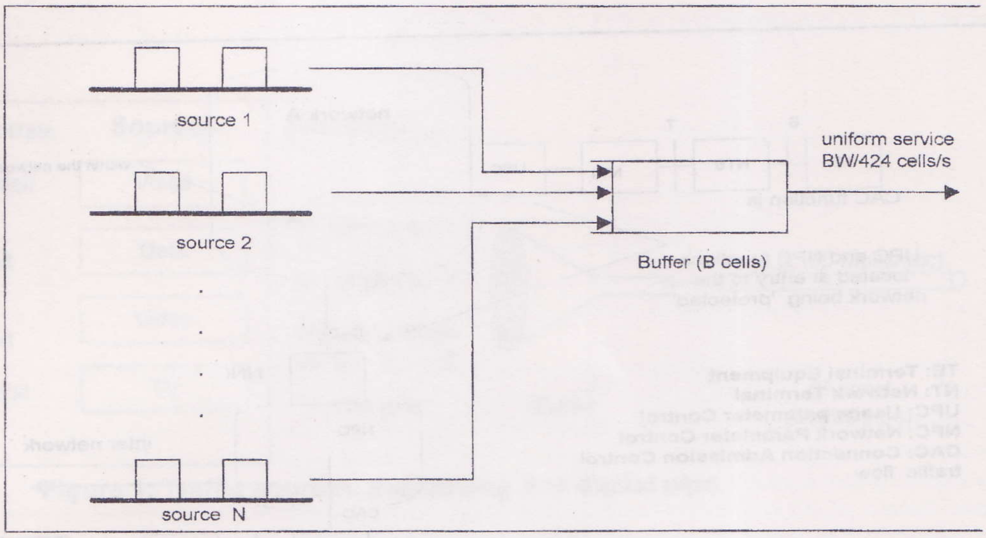


**Figure 3: The Binomial Model**

Without loss of generality, the unit of time is selected to be the average on period ($t_{off}$). With this unit of time, the average off period is denoted by $1/\lambda$. That means

$t_{off} = t_{on}/\lambda$.

$\lambda = \alpha/(1-\alpha)$

where $\alpha=1/\beta = m/p = t_{off}/(t_{on-} t_{off})$ denotes the on-state time fraction. Note that $p$ is the peak arrival rate of the ATM cells when source is at the on - state, $\beta$ is the traffic burstness and m is the mean arrival rate of ATM cells. Again without loss of generality, the unit of information is chosen to be the amount generated by a source in an average on period. Thus, at the on state, the source transmits at the uniform rate of 1 unit of information per unit of time. The output link capacity is $C = BW / p$ units of information per unit of time.

If $BW$ is the transfer rate of the output link, then the maximum number of identical sources which is acceptable to be in the on state without any cell losses is:

$$C = BW/p \tag{1}$$

As the number of the on state sources becomes larger than C, the output link is not able to carry the requested bandwidth and losses of cells occur. If $i$ sources are in the on state then the cell loss is approximated:

$$CLP = I*p-BW \tag{2}$$

The probability for a particular number of sources to be at the on-state is binomially distributed with parameters $N$ and $\alpha=1/\beta$. The probability of having i sources in the on state is equal to:

$$\Pr(i \text{ sources at the on state}) = \text{bin}(N, i, \alpha) \tag{3}$$

Using these formulas the total rate of the lost ATM cells due to the lack of available bandwidth can be calculated. Dividing the rate of ATM lost cells with the maximum number of the generated cells $Np\alpha$, the ATM cell loss probability is then given by:

$$CLP = \frac{\sum_{I=C+1}^{N}(i-c)bin(N,i,\alpha)}{N\alpha} \tag{4}$$

This is the cell loss probability where each expression has been divided by the peak rate p, where

$$bin(N,i,\alpha) = \binom{N}{i}\alpha^{i}(1-\alpha)^{N-i} \tag{5}$$

The above model implies that cell loss will occur in case of an overload situation (input flow is greater than BW). Measures of minor interest are the violation probability ($P_v$)

$$P_v = \frac{CLP}{p} \tag{6}$$

And the cell through put ($T_c$)

$$T_c = P.(1-P_v) \tag{7}$$

In order to investigate the binomial model, the model is simulated, the result of the simulation for different source characteristics are presented in the appendix.

## THE UPC MODELS

Usage Parameter Control (UPC) was described in section 2 as a mechanism that monitors the traffic accepted to a network, in order to protect the network from malicious or unintentional misbehaviour of the sources generating traffic and therefore ensure that QoS of well-behaved sources is not affected. When the UPC finds traffic that is violating its traffic contract (i.e. the contract established at call set-up to be used by the CAC function), actions are taken on that traffic that can result in either the discarding or tagging of violating cells. The leaky bucket is generally agreed to achieve the best performance compromise of the mechanisms studied for policing. It was first introduced in [Yin and Micheal, 1991], since then a number of variants have been proposed.

The principle of the Leaky Bucket algorithm is very simple as discussed in section 2; it considers a token pool (or leaky bucket) that is filled as a consequence of the arrival of cells and is emptied at a constant rate *(the leak rate);* cells are discarded when the token pool is full. This is the policing algorithm that will be used through out the next section to study UPC. The algorithm can be written as the following sequence of steps,

1. decrement a counter C by 1 every T seconds down to *0* if there are no cell arrivals; $(0 \leq C \leq M)$
2. increment the counter *C* by 1 for each transmitted cell;
3. discard (or tag) cells when C = M;

where *M* represents the maximum burst size (also called *bucket limit)* that the source is allowed to present and the reciprocal of *T* is the peak rate of the traffic being observed (also called leak rate).

**Fluid Flow Model for Leaky Bucket.**

The leaky bucket analyzed comprises of a token pool connected to observer. The mechanism is based on requires each cell to add one token to the token pool before entering the network. The token pool size is *M*. Tokens are leaking at a constant rate of 1/*l*. In fact, this token pool is a mere counter. The service discipline is FIFO in order to preserve the cell sequence. The mean rate i// represents the resources allocated to the services; the negotiated throughput is therefore guaranteed.

According to the fluid flow [Anick et al., 1982; Butto, et al, 1991] the bit flow is considered as a continuous variable. Y and X are the continuous buffer states in the instants where two consecutive bursts arrive (Figure 4).

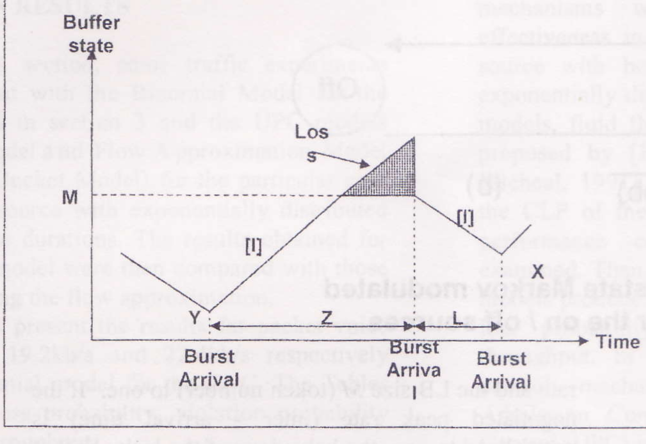


**Figure 4: The Fluid Flow Model**

During the burst, whose duration is Z, the buffer state grows at rate: b =p-l bits/s
After the burst, during the inactivity period of duration L, the buffer state decreases at the rate l bits/s.
At the instant a burst begins, the buffer state is a Markov chain. described by the equation:
X = Y = b*Z – l*L
We assumed that l<p, otherwise the buffer state is always empty.

The calculations to obtain the model for the cell loss probability (8) can be found in [Butto, et al, 1991]. The source model used for the calculations is the on-off model.

$$CLP = \frac{P-A}{P} \cdot \frac{\lambda_1 - \lambda_2}{\lambda_1 e^{(\lambda_1-\lambda_2)M} - \lambda_2} \qquad (8)$$

$$\lambda_1 = \frac{1}{t_{on}.b} \qquad \lambda_2 = \frac{1}{t_{off}.a}$$

P: peak arrival rate of the ATM cells when source is at the on-state
l: leaky rate
M: leaky bucket size
$t_{on}$: the average duration of the on-state (peak duration)
$t_{off}$: the average duration of the off-state (silence duration)

## FLOW APPROXIMATION MODEL OF LEAKY BUCKET

A flow approximation model introduced in [Yin and Micheal, 1991] analyses the leaky Bucket algorithm for an On/Off modeled traffic source (with exponentially distributed *On* and *Off* state durations) that is characterized by its average and peak rates as well as by its average burst length. The Leaky Bucket algorithm uses a fictitious queue to model the behaviour of the mechanism and the analysis can be applied both in the case of buffered and unbuffered Leaky Bucket. In this environment, the analysis described by [Yin and Micheal, 1991] then gives closed -form expressions for the cell discarding / marking probability and queuing delay (in the case of a buffered Leaky Bucket). The description of the flow approximation analysis given here merely indicates the model developed in [Yin and Micheal, 1991] that is used in this work.

The following definitions need to be taken into account in the calculation of the cell discarding/marking probability:

P = source peak bit rate
l = permit generation rate or leak rate of the Leaky Bucket (also called sustainable cell rate)
M = maximum bucket size
abl = average burst length (in bits)
mbr = average (or mean) source bit ratee
e_prob = equilibrum probability in the on state (i.e., the source utilization)
lb_load = Leaky Bucket load.

*The Leaky Bucket load and equilibrium probability in the on state can be written as*

$$lb\_load = \frac{mbr}{l} \quad \text{and} \quad e\_prob = \frac{mbr}{p} \quad (9)$$

[Yin and Micheal, 1991] then derives an expression for the probability of the fictitious queue being full by considering the On/Off source modeled by a two - state Markov chain, as shown in figure 5. Therefore, the analysis only considers the situation where the Leaky Bucket load (given by lb_load) is greater than the source utilization (given by e_prob). In the opposite case, the leaky Bucket "queue" would always remain empty and no traffic would be discarded or tagged.

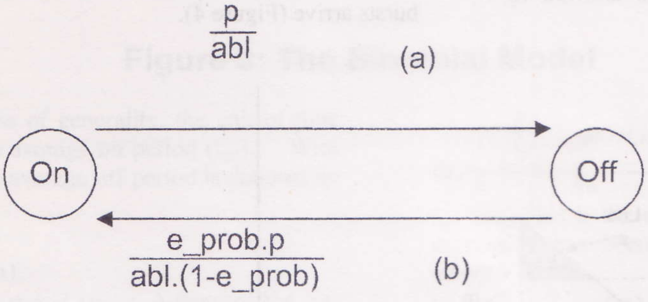


**Figure 5: The two-state Markov modulated rate process for the on / off sources**

The cell loss probability (CLP) (and similarly for the case of the cell marking probability) is a function of both the probability of the fictitious queue being full and the rate at which traffic is discarded when the fictitious queue is full; in mathematical notation.

$$CLP = \frac{p-l}{mbr}.prob \ \{\text{fictitious queue being full}\}$$

$$= \frac{(lb\_load - e\_prob).(1-e\_prob)e^{\varepsilon M}}{ib\_load.(1-e\_prob).\left(1-\frac{ib\_load-e\_prob}{1-e\_prob}.e^{\varepsilon M}\right)} \quad (10)$$

Where $\varepsilon$ is the non-zero system eigenvalue of the matrix that specifies the differential equations for the system [Yin and Micheal, 1991] and it is given by the expression,

$$\varepsilon = \frac{ib\_load.(ib\_load-1)}{abl.(1-e\_prob).(ib\_load-e\_prob)}, \text{ for ib\_load} < 1 \quad (11)$$

## CONTROL OF THE PEAK RATE

As mentioned in previous section, the ITU - T has recommended only to control the peak rate. and the other traffic parameters remain unstandardised. The interarrival time of the cells during the burst is 1/p. The peak rate is easily controlled by setting the leaky rate equal to the peak rate and the LB size *M* (token number) to one. If the negotiated peak rate (inter - arrival time) is normalized to one, the behaviour of the leaky bucket can be investigated for violation of the negotiated (normalized) peak rate.

Let Y be the factor of increase in the normalized negotiated peak rate.

Actual Peak Rate = Y * Negotiated Peak Rate.

## CONTROL OF THE MEAN RATE

Although, the peak rate was effectively and simply controlled by setting the leaky rate to the peak rate, it is not effective controlling the mean rate by setting the leaky rate equal to the mean rate. This is due to the fact that cells arrive at peak rate during the burst. Calculations and simulation results show that the leaky rate must be higher than the mean bit rate in order to achieve the required QoS.

Expressing the leaky rate in symbols yields:

Leaky rate (l) = E* Mean Bit Rate

Where E > 1. The question now becomes: which value of E and *M* (token number) should be used in order for a well-behaved source to experience a loss probability of the same order as its QoS. Due to the oversize factor E, it is expected that some sources may exceed the declared mean rate and yet go undetected.

## SIMULATION RESULTS AND ANALYSIS OF RESULTS

The central issues in the design, implementation, and operation of communication networks are performance evaluation and trade off analysis. The performance measures used to evaluate communication network vary, depending on the type of network being analyzed and the application. For this paper, performance in terms of cell loss probability, violation probability and cell throughput are investigated.

Simulation programs are developed using the Turbo C language produced by Borland. The C programming language offer unique capabilities especially in the area of its suitability for numeric computation.

## SIMULATION RESULTS

In this section, some traffic experiments were carried out with the Binomial Model for the CAC described in section 3 and the UPC models (Fluid flow Model and Flow Approximation Model for the Leaky Bucket Model) for the particular case of one on/off source with exponentially distributed on and off state durations. The results obtained for the fluid flow model were then compared with those obtained by using the flow approximation. Tables 2 and 3 present the results for packet voice Bandwidth of 19.2kb/s and 22.4kb/s respectively using the Binomial model for the CAC. The Tables give the cell loss probability, violation probability and the Cell Throughput.

While Tables 4 and 5 present the simulation results for Broadband source using the fluid flow model and flow approximation model, respectively.

### Result Analysis

Graphs depicting the ATM cell loss probability violation probability and cell throughput (Tc) are represented for the analysis of the results. Figures 6, 7 and 8 present the Binomial Model Cell Loss Probability (CLP) against number of sources (N) for BW = 19.2 kbs and BW = 22.4kbs; violation probability Pv against number of sources (N) for BW = 19.2kbs and BW= 22.4kbs and cell throughput against number of sources (N) for BW = 19.2kbs and BW= 22.4kbs respectively. Figure 6 shows that cell loss probability is higher in packet voice with BW = 22.4 kbs than that of BW = 19.2 kbs. Similar analysis can be given to figure 7 but in Figure 8, the source with lower Bandwidth has larger cell throughput. Which shows that for a source to meet the require QoS, the effective BW must not exceed the BW assigned to each source.

Figures 9, 10 and 11 compare the cell loss probability (CLP), violation probability (Pv) and Cell throughput (Tc) as a function of y (factors of increase in the negotiated peak rate P ) respectively or the fluid flow and flow approximation model. The models (Fluid flow and Flow approximation) produce almost coincident result for the cell loss probability, violation probability and cell throughput of the Broadband source.

## CONCLUSION

The CAC model for the calculation of the ATM cell loss probability has been presented and measures of minor interest such as violation probability and cell throughput are also presented. The binomial model, which takes into account the number of sources (N) and $\alpha$ = 1/burstiness of the ATM source performed very satisfactorily for different traffic source as it has been proved in section 5.

The Leaky Bucket (LB), which is generally agreed to achieve the best performance of the UPC mechanisms was analyzed to determine its effectiveness in policing source parameters. For a source with both the burst and silence duration exponentially distributed (on/off source model), two models, fluid flow and flow approximation models proposed by [Butto, et al, 1991] and [Yin and Micheal, 1991], respectively, for the simulation of the CLP of the LB mechanism are described and performance comparison of these models is examined. Then, on the basis of this comparison, the models produce almost coincident results for the cell loss probability, violation probability and cell throughput. In conclusion, a complete preventive control mechanism, consisting of Connection Admission Control (CAC) and Usage Parameter Control (UPC) has been defined by the results.

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## APPENDIX

Table 2: Binomial Model Result for Packet Voice BW=19.2kb/s

| N | CLP | PV | TC |
|---|---|---|---|
| 5 | 0.6962427 | 0.02177888 | 31.30307579 |
| 10 | 0.85344428 | 0.02667013 | 31.14655495 |
| 15 | 0.0006064 | 0.00001895 | 31.99939346 |
| 20 | 0.43790802 | 0.01368463 | 31.56209183 |
| 25 | 0.00000442 | 0.00000014 | 31.99999619 |
| 30 | 0.29194087 | 0.00912315 | 31.70805931 |

Table 3: Binomial Model Result for Packet Voice BW=22.4kb/s

| N | CLP | PV | TC |
|---|---|---|---|
| 5 | 0.64641166 | 0.02020036 | 31.3535881 |
| 10 | 1.67851508 | 0.0524536 | 30.32148552 |
| 15 | 0.00060761 | 0.00001899 | 31.99939156 |
| 20 | 0.85021389 | 0.02656918 | 31.149786 |
| 25 | 0.00000452 | 0.00000014 | 31.99999619 |
| 30 | 0.56681132 | 0.01771285 | 31.43318939 |

Table 4: Fluid Flow Model Result for Broadband Source

| Y | CLP | PV | TC |
|---|---|---|---|
| 1.02 | 0 | 0 | 1.01999998 |
| 1.04 | 0.00000064 | 0.00000061 | 1.03999937 |
| 1.06 | 0.00000493 | 0.00000465 | 1.05999506 |
| 1.08 | 0.00001477 | 0.00001368 | 1.07998526 |
| 1.1 | 0.00002974 | 0.00002704 | 1.09997034 |
| 1.12 | 0.00004867 | 0.00004346 | 1.11995137 |
| 1.14 | 0.00007042 | 0.00006177 | 1.13992953 |
| 1.16 | 0.000094 | 0.00008109 | 1.15660591 |
| 1.18 | 0.00011891 | 0.00010077 | 1.1798811 |
| 1.2 | 0.00014443 | 0.00012036 | 1.19985557 |
| 1.22 | 0.00017024 | 0.00013954 | 1.2198298 |
| 1.24 | 0.00019606 | 0.00015811 | 1.23980391 |

Table 5: Flow Approximation Model Result for Broadband Source

| Y | CLP | PV | TC |
|---|---|---|---|
| 1.02 | 1.02000002 | 0 | 1.033 |
| 1.04 | 0.0000074 | 0.0000024 | 1.054 |
| 1.06 | 0.000017 | 0.0000089 | 1.08 |
| 1.08 | 0.0000281 | 0.00002 | 1.112 |
| 1.1 | 0.0000473 | 0.0000341 | 1.166 |
| 1.12 | 0.000068 | 0.0000527 | 1.207 |
| 1.14 | 0.0000925 | 0.0000712 | 1.234 |
| 1.16 | 0.000117 | 0.0000941 | 1.274 |
| 1.18 | 0.000156 | 0.0001184 | 1.328 |
| 1.2 | 0.0001953 | 0.0001395 | 1.372 |
| 1.22 | 0.0002485 | 0.0001631 | 1.45 |
| 1.24 | 0.0002973 | 0.0001873 | 1.594 |

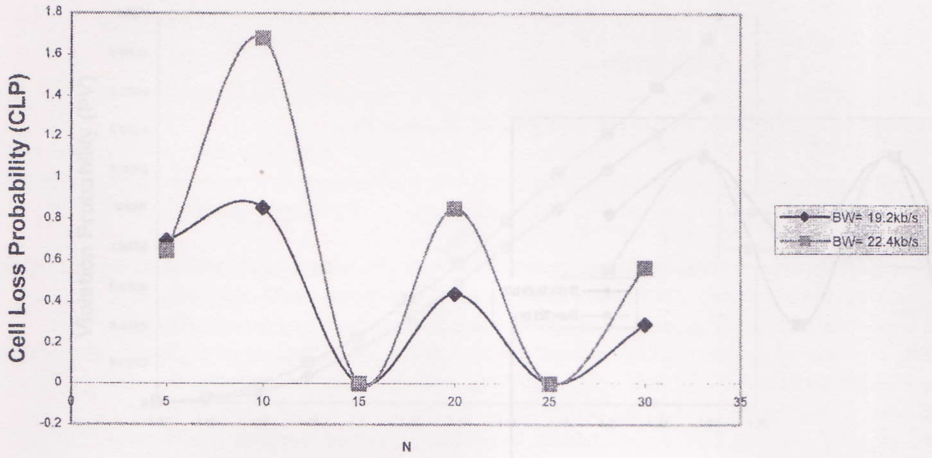


Figure 6: Binomial Model for Packet Voice BW=19.2kb/s versus BW=22.4kb/s

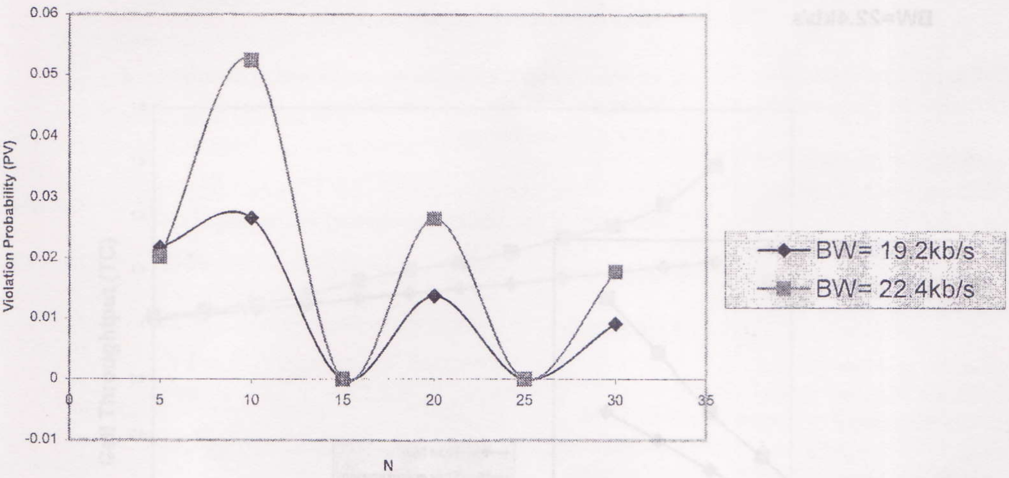


Figure 7: Binomial Model for Packet Voice BW=19.2kb/s versus BW=22.4kb/s

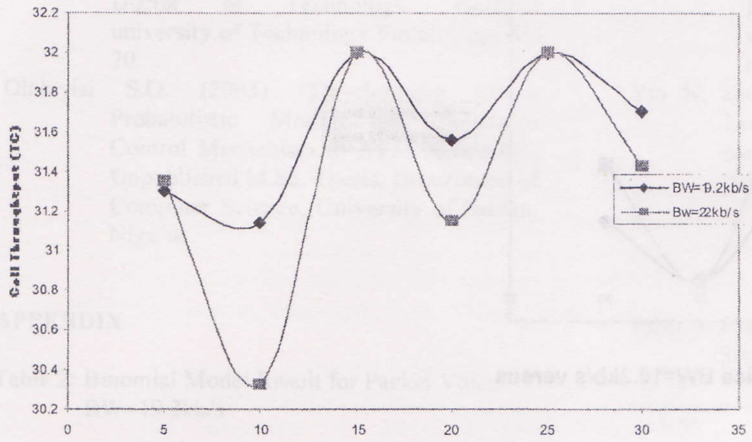


**Figure 8: Binomial Model for Packet Voice BW=19.2kb/s versus BW=22.4kb/s**

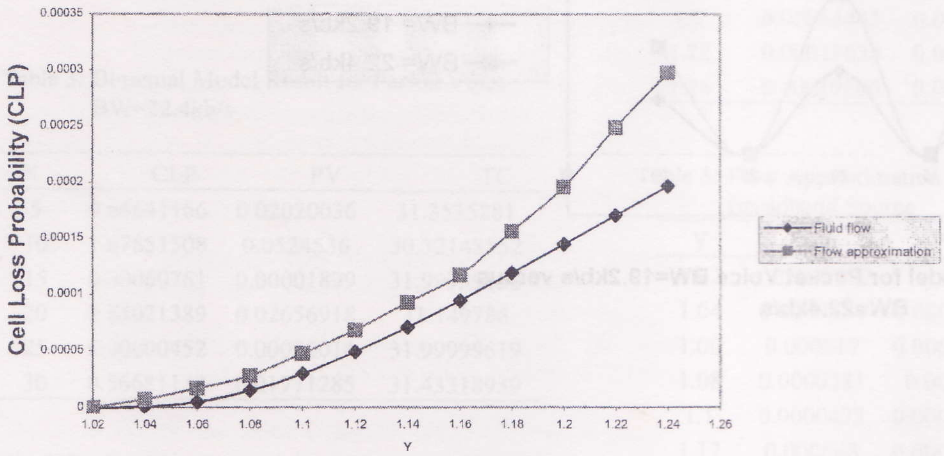


**Figure 9: Fluid flow versus Flow Approximation for Broad band source**

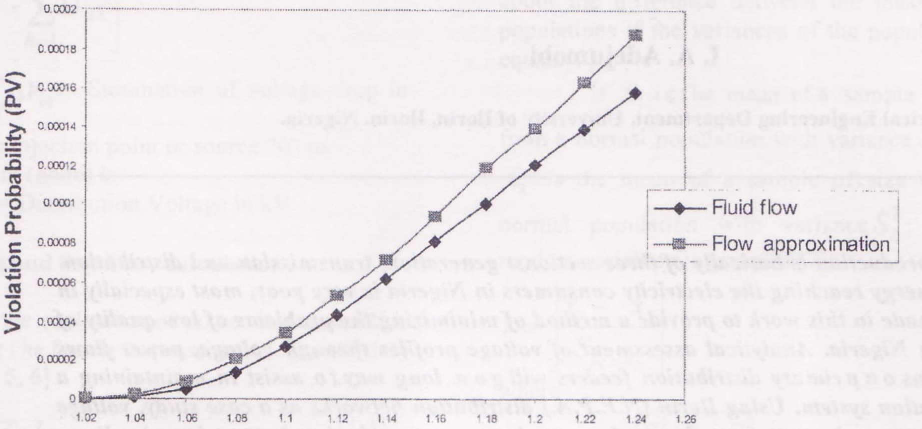


**Figure 10: Fluid flow versus Flow Approximation for Broad band source**

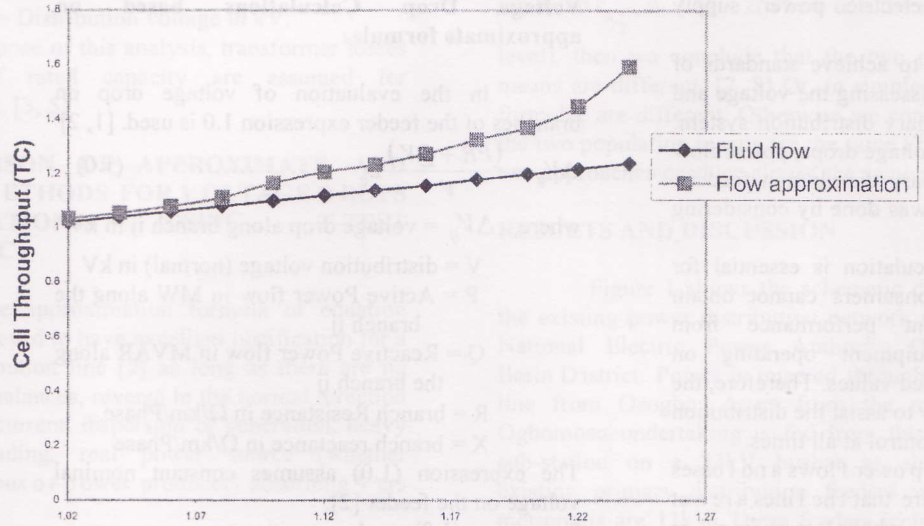


**Figure 11: Fluid flow versus Flow Approximation for Broad band source**