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CHARACTERISING THE WORST TRAFFIC PROFILE PASSING THROUGH AN ATM-UNI

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Abstract

Broadband networks (B-ISDN) based on the ATM technology are designed to support a wide variety of services characterised by heterogeneous ATM traffic descriptors and Quality of Service (QoS) parameters. According to the ATM-Forum User Network Interface Specification, an ATM connection can be characterised by four parameters, the Peak Cell Rate, the Cell Delay Variation tolerance, the Sustainable Cell Rate and the Burst tolerance. User Parameter Control and Connection Admission Control algorithms should consider all the above traffic parameters for effective network management. However, there is a large number of traffic patterns that can be characterised by the same four parameters. Supposing that no additional information is known about the traffic profiles of the incoming streams, the CAC mechanisms should consider the worst traffic profiles, so that the ATM network will be able to efficiently allocate resources and satisfy its QoS commitments.

This paper evaluates the worst traffic profile of an ATM connection which is characterised by four parameters. Such a traffic stream can pass through the Leaky Bucket policing algorithms of an ATM UNI as conformant and have the worst implications on the ATM networks performance. The mean and squared coefficient of variation of the inter-cell times of the worst traffic profile are estimated and the statistical behaviour of the traffic pattern is modelled by the Generalised Geometric distribution.

Keywords: Broadband networks, Asynchronous Transfer Mode, Performance Modelling, Peak Cell Rate, Cell Delay Variation tolerance, Sustainable Cell Rate Burst tolerance, Leaky Bucket (LB), Generalised Geometric Distribution.

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1. INTRODUCTION

Broadband ATM networks will be able to carry a variety of services. Considering the characteristics of their traffic profiles which will be included in the ATM traffic contact [1], the services can be divided into two major categories, the Constant Bit Rate (CBR) and Variable Bit rate (VBR).

The main traffic parameter of a CBR connection is the Peak Cell Rate (PCR) [1]. However, various functions of the ATM layer (e.g. cell multiplexing, insertion of OAM cells and overheads of the Physical Layer) may impose random delays on the regularly generated cells. Consequently, Usage Parameter Control (UPC) mechanisms, e.g. Leaky Bucket (LB) devices that police this reference connection, may observe that some cells arrive at a rate higher than the declared PCR. This phenomenon is called Cell Delay Variation (CDV). Therefore, the UPC function should consider a CDV tolerance so that it will not discard those cells that arrive at a higher peak rate. Several studies [3,4,5,6] have analysed the CDV introduced by different topologies (e.g. FIFO multiplexers, bus topologies, networks of multiplexers). Their results indicate that the size of CDV varies significantly and is mainly affected by the load imposed at the multiplexer. Various schemes have also been proposed [6] for limiting the effect of short-term fluctuations of the CDV.

A VBR connection will mainly be characterised by both the peak cell rate and the Sustainable Cell Rate (SCR) [2]. The PCR may also be distorted by CDV. However, it is expected that the effect of CDV on VBR connections will be less significant than on CBR streams. VBR traffic is usually called bursty traffic, which means that a service may require to transmit cells at the PCR during a given time interval. The size of such bursts of cells is indicated by the Maximum Burst Size (MBS) which will be an additional source traffic parameter for VBR connections. The burst tolerance which is associated with the MBS will be used by the LB mechanism that polices the sustainable cell rate so that it will not discard the cells of a burst which arrive at a rate higher than the SCR.

This paper specifies the Worst Traffic Profile (WTP) defined by the PCR, CDV tolerance, SCR and MBS. This traffic stream can be declared as conformant by the UPC mechanisms of an ATM-UNI and have the worst implications on the performance of a network. The WTP will be analysed, the mean and squared coefficient of variation (sqv) of the cell interarrival times will be evaluated and its traffic behaviour will be modelled by the Generalised Geometric (GGeo) distribution. The effect of CDV and MBS on the variability of the WTP will also be examined.

2. THE WORST TRAFFIC PROFILE

The traffic stream of an ATM connection will be controlled at the UNI by LB mechanisms which will only allow conformant cells to get into the ATM network for transmission (assuming that the cell tagging option is not used). Bursts of cells may also enter the network, depending on the distortion due to CDV and the source traffic pattern. It is apparent that connections with large bursts of cells will generally require more network resources than those with more regular traffic patterns.

2.1 Maximum Back-to-Back Burst Sizes

Consider a CBR source that generates ATM cells at PCR r and is connected with an ATM-UNI with cell transmission rate denoted by R. Let also $T(=R/r)$ denote the period of the CBR traffic stream measured in slots, where as slot is defined the time interval required for the transmission of a cell.

Due to cell multiplexing, the periodic profile of the source's stream may be distorted and the LB policing device may observe cells arriving at rate higher than r. It can actually observe cells arriving back-to-back at the line rate R. The LB may also declare all those cells as conformant, depending on the size of CDV tolerance parameter τ , which has been specified in the ATM traffic contract.

The size of the burst of cells at the line rate R , that is the Maximum Back-to-Back Burst Size (MBBS) denoted by B, is expressed by the following formula :

$$B = \left\lfloor \frac{\tau}{\frac{1}{r} - \frac{1}{R}} \right\rfloor + 1 \qquad (1)$$

This indicates that the MBBS B depends not only on CDV tolerance τ (measured in time units) but also on period T.

Consider now a VBR connection of PCR r, CDV tolerance τ, SCR s and MBS S. When a VBR source bursts it can generate up to B cells at the PCR r. During this time interval the VBR source behaves like a CBR one. The traffic stream generated by the VBR source is policed at the UNI by two LB algorithms. The first one controls the PCR and considers the CDV tolerance parameter τ and the second LB polices the SCR s and considers the burst tolerance τ_s which is given by:

$$\tau_s = (S - 1)\left(\frac{1}{s} - \frac{1}{r}\right) \qquad (2)$$

The peak rate LB policer will allow *B* back-to-back cells at the line rate *R* to pass through while the sustainable rate LB policer will allow *V* back-to-back cells to pass through as conformant, where *V* is given by the following expression:

$$V = \left\lfloor \tau_s' * \frac{T_s}{T_s - 1} \right\rfloor + 1 \tag{3}$$

where T_s *(=R/s)* is the average period of the cells of the VBR source measured in slots, and the burst tolerance $\tau_s' = \tau_s * s$. Since the traffic stream passes through both the LB policing devices , the maximum number of back-to-back cells at the line rate R that can actually get into the ATM network will be:

$$L = \min \{B, V\} \tag{4}$$

It is generally expected that the traffic stream submitted by VBR data type services (e.g. Frame Relay, LAN Emulation) will be characterised by relatively large MBS *S* values, so that the resulting MBBS *V* value will be larger than the MBBS *B* value associated with the CDV tolerance parameter τ. This implies that the MBBS that can enter the network will be that which can pass through the PCR LB policer as conformant, i.e. *L=B*.

2.2 Evaluation of the Worst Traffic Profile (WTP)

The traffic stream submitted by a VBR connection into the network will be characterised by the above four traffic parameters. However, there is a large number of traffic patterns that can satisfy them, and each is characterised by a unique cell interarrival time distribution. The traffic patterns that can satisfy all the four parameters will have the same long-term rate equal to *s* and, equivalently, the same mean cell interarrival time equal to T_s. slots, but different variability.

Therefore, we define as the Worst Traffic Profile (WTP) among those with the same mean interarrival time to be that with the largest variation. Let D denote a set containing the interarrival times of a reference traffic pattern, $D=\{d_1, d_2, ..., d_{j-1}, d_j\}$ and without loss of generality let $d_j = \max\{ d_i \}$, $i=1,...j$. It has been shown [7, 8] that the set of interarrival times with the greatest variability is of the following form :

$$D_{\max} = \{1,1,...,1, [\textstyle\sum_{i=1}^{j-1} (d_i - 1)] \} \tag{5}$$

This means that the set of the cell interarrival times of the WTP should have as many cell interarrival times equal to one slot as possible. This means that the traffic stream should have as many bursts of back-to-back cells at the link rate *R* as possible. Based on the above burst analysis, the MBBS that can enter the network is L. The interval between successive bursts and the maximum number of burst that can be transmitted according to this pattern depends on the relation among the parameters B, S, V and L.

Let us, for example, consider probably the most common case where the burst tolerance will be greater than the CDV tolerance. Evaluating formulae (1)-(4), we can observe that the following relations will be satisfied :

$$B < S, \quad B < V \quad and \quad L = B \tag{6}$$

Accordingly, the maximum burst length at the link rate R that can enter the network will be $L=B$. This means that the depth of the peak rate LB policer will reach its greatest value and the CDV tolerance τ will be exhausted. The next burst of size L can arrive after an interval which is necessary for the LB to get completely relaxed and its depth to reach its minimum value, that is zero. This time interval is $\{L*T-L+1\}$ slots long. The number of successive burst of size L that can follow this pattern is equal to $\{ S/L \}$ and the total interval will be $(S/L)*(L*T)$ time slots long. During this period S cells will pass through the UNI with an average rate equal to the PCR. This means that the depth of the LB algorithm that polices the SCR of this ATM connection will have reached its highest value or, equivalently, the burst tolerance τ_s will be exhausted. The next sequence can be repeated after the SCR LB having completely been relaxed and its depth reached its minimum value that is zero. The latter relaxation interval will be equal to $S*(T_s-T)+L*(T-1)+1$.

The cell arriving pattern described above satisfies the characteristics of the profile expressed by (5) (i.e. has the largest variability) and also considers the maximum cell bursts that can be tolerated by both the peak and sustainable cell rate LB policing mechanisms. Therefore, it is the Worst Traffic Profile that can pass through an ATM-UNI as compliant and enter the ATM network.

Figure 1 below illustrates the worst traffic profile by using a simple example. Consider an ATM VBR connection of PCR $r=(75/424)Mcells/sec$ and SCR $s=(50/424)Mcells/sec$ which is connected with an ATM-UNI of transmission rate $R=(150/424)Mcells/sec$. Let the declared CDV tolerance be $\tau=5.6\mu sec$ and the MBS $S=6$ *cells*. Translating those raw input parameters of the ATM traffic contract we have that: $T=2$ *slots*, $T_s=3$ *slots*, $B=3$ *cells*, $S=6$ *cells* and $L=3$ *cells*, where a slot equals $(424/150M)\mu sec$.

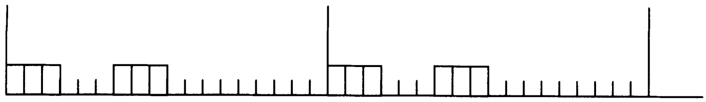


Figure 1 The Worst Traffic Profile passing through an ATM-UNI

A worst traffic profile sequence consists of *S/L=2* bursts of cells each of them having *L=min{B,S}=3* cells which arrive at the line rate *R*. The interval between the first cells of two successive burst measures *L*T=6 slots* while the interval between the last cell of the last burst of a WTP sequence and the first cell of the first burst of the successive WTP sequence is *10 slots*. The overall interval of a WTP sequence is $S^*T_s=18$ *slots*.

The size of the interarrival times and their frequency that can occur during a WTP sequence is shown in the table 1 below.

Table 1 Cell interarrival times in the Worst Traffic Profile

Size of interarrival time (in slots)	Frequency occurred
1	*S - S/L*
*L*T-L+1*	*S/L - 1*
$S^*(T_s-T)+L^*(T-1)+1$	*1*

Based on the above results, we can easily evaluate the first two moments of the interarrival time distribution of the WTP which can pass through an ATM-UNI. Therefore, the mean and squared coefficient of variation, denoted by m_a and C_a^2, respectively, are expressed by the following formulae:

$$m_a = T_s \tag{7}$$

$$C_a^2 = \frac{S(T_s - T)^2 + 2T_s\left(L(T-1)+1\right) - \left(L\left(T^2-1\right)+1\right)}{T_s^2} - 1 \tag{8}$$

Note, that if the conditions shown in (6) are different, the quantities shown in Table 1 and consequently the formulae (7), (8) may change accordingly.

3. MODELLING OF THE WORST TRAFFIC PROFILE

The mean and squared coefficient of variation of the interarrival times will be used to model the WTP distribution. Figure 2 below illustrates the UPC mechanisms for traffic

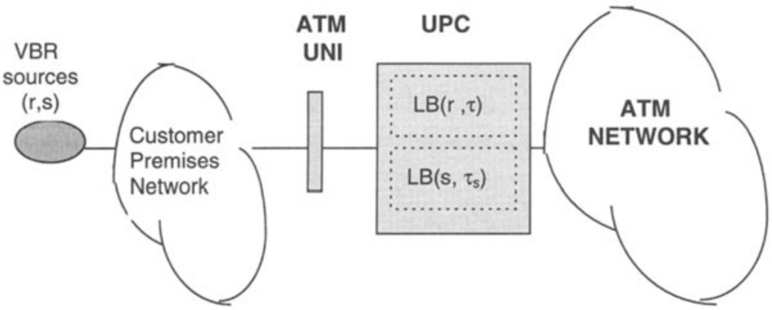


Figure 2 UPC mechanisms at the ATM-UNI

submitted by ATM connections. A set of LB algorithms will control the cell arrivals by using the declared rates and the associated tolerances. Each traffic stream will be characterised by the WTP whose statistical behaviour will be modelled by the Generalised Geometric distribution.

3.1 The Generalised Geometric distribution

The Generalised Geometric, denoted by $GGeo(\lambda, C^2)$, is a discrete time distribution [6], defined by the first two moments, the mean $1/\lambda$ and the squared coefficient of variation C^2 of the interevent times. The GGeo distribution is of the following form:

$$f_n = \Pr(W = n) = \begin{cases} 1 - \omega, & n = 0 \\ \omega\sigma(1-\sigma)^{n-1}, & n \geq 1 \end{cases} \qquad (9)$$

where W is the random variable of the interevent time, $\omega = 2/(C^2+\lambda+1)$ and $\sigma = \omega\lambda$. Figure 3 below depicts the operation of a GGeo distribution.

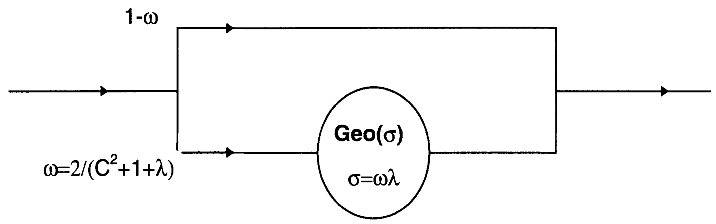


Figure 3 The GGeo(λ,C^2) distributional model

The GGeo is a two-phase distribution which implies a bulk interevent pattern according to a Bernoulli process at rate σ ($0 \leq \sigma \leq 1$) while the number of events in a slot is geometrically distributed with mean $1/\omega$. The GGeo distribution is versatile and possesses the following very interesting properties which make the solution of queueing systems tractable [6].

a) *Pseudo-Memoryless Property*: The remaining interevent time of a *GGeo(λ,C^2)* distribution is geometrically distributed with parameter σ.

b) *Extremal Property*: The *GGeo(λ,C^2)*, is the extremal case of a two-parallel-phase distribution. At one of the phases the rate bursts to ($+\infty$) and at the other the random variable is geometrically distributed with parameter $\lambda\omega$.

c) *Compound Binomial Property* : The underlying renewal process of a *GGeo(λ,C^2)*, distribution that counts the total number of events in *n* consecutive slots is a Compound Binomial distribution with parameters *(n,ω,σ)*.

The GGeo is stochastically a true probability distribution if $|1-\lambda| \leq C^2$. Outside that range it is a pseudo-distributional function and it may be interpreted as a heuristic flow model approximation of a stochastic model [6]. It has also been shown that GGeo is the distribution that maximises the entropy [10,11,12] (i.e. the most unbiased distribution) of the GGeo/G/1 queueing system when the GGeo is used to characterise the general G service time distribution of the model.

3.2 Modelling of the WTP by the GGeo distribution

Those interesting analytic properties and the ability to capture the variability of traffic patterns make the GGeo distributional model suitable for the approximation of the statistical behaviour of the WTP that can pass through an ATM-UNI. This approximation is conservative because the back-to-back cells of a burst of a WTP sequence will be modelled by multiple arrivals per slots, which are allowed by the GGeo.

Let r_i, τ_i, s_i, S_i denote the PCR, CDV tolerance, SCR and MBS parameters in the ATM traffic contract of the *i*th VBR connection which is served by an ATM-UNI of R transmission cell rate. The behaviour of the WTP can be approximated by the $GGeo(\lambda_i, C^2_{a,i})$, distribution with $1/\lambda_i$ and $C^2_{a,i}$ the mean and squared coefficient of variation of the cell interarrival distribution. The moments can be evaluated according to the analysis of the previous section. Therefore,

$$\lambda_i = r_i \tag{10}$$

$$C^2_{a,i} = \frac{S_i(T_{s,i} - T_i)^2 + 2T_{s,i}\left(L_i\left(T_i - 1\right) + 1\right) - \left(L_i\left(T_i^2 - 1\right) + 1\right)}{T^2_{s,i}} - 1 \tag{11}$$

where $T_{s,i} = R/s_i$, $T_i = R/r_i$, and L_i can be evaluated by expression (6).

4. THE VARIABILITY OF THE WORST TRAFFIC PROFILE

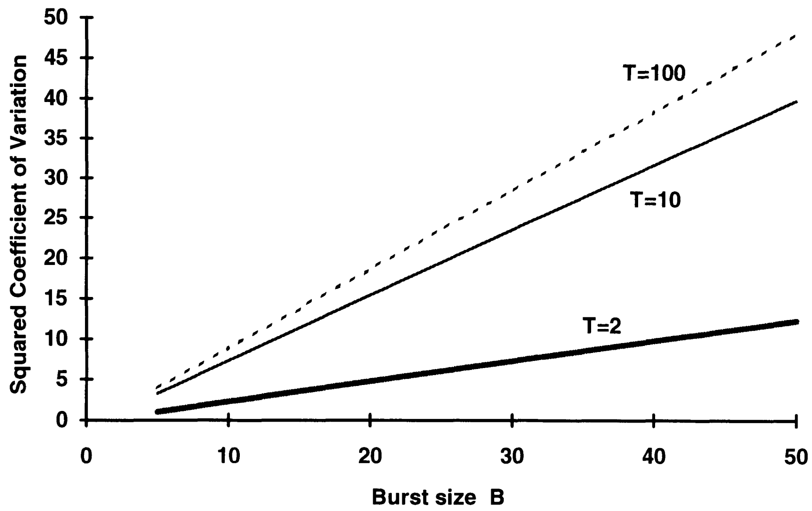
This section examines the effect of the ATM traffic parameters on the variability of the WTP which is measured by the squared coefficient of variation. It is expected that traffic streams with high variability will need more resources to satisfy their short term high bandwidth requirements. Consequently, the utilisation of the network components may be low.

4.1 The effect of CDV on the variability of the WTP

Graph 1 below illustrates the effect of CDV tolerance parameter τ on the squared coefficient of variation of the WTP for three different peak cell rates. For comparison purposes CBR connections are considered (i.e. PCR=SCR).

The CDV tolerance τ is measured by the MBBS B and their relation is expressed by formula (1). For example, if the transmission cell rate of the interface is $R=(150/424)$*Mcells/sec* the periods $T=2$, $T=10$ and $T=100$ correspond to peak cell rates of $(75/424)$*Mcells/sec*, $(15/424)$*Mcells/sec* and $(1.5/424)$*Mcells/sec* , respectively. A value of $B=50$ *cells* also corresponds to CDV tolerance $\tau=140\mu sec$, *1.25 msec* and *14 msec*, respectively.

Graph 1
The Effect of CDV tolerance on the Variability of the WTP



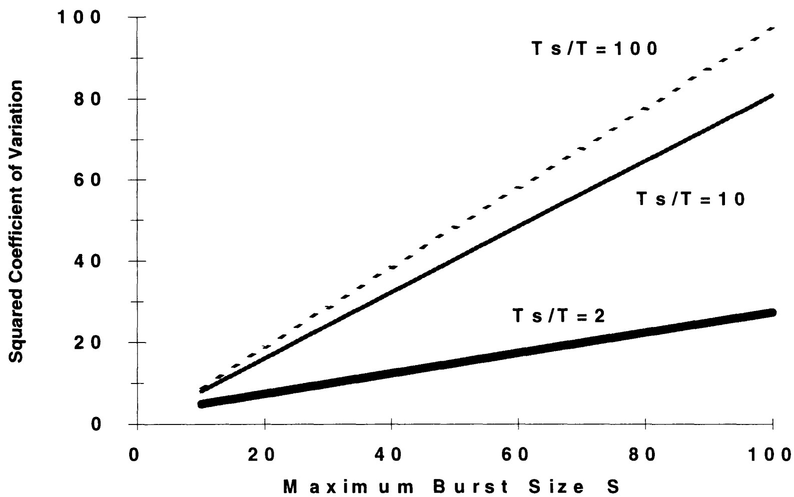
Graph 1 shows that the variability of the WTP increases as the MBBS *B* and the PCR increases. Burst size of 50 cells back-to-back at the line rate will result in sqv equal to 12, 40 and 50, respectively. These values can be compared with unity, which is the sqv of the exponential interarrival distribution, or the cell stream of a Poisson traffic profile. It becomes apparent that the WTP of a stream, which has originally been generated by a CBR source, been distorted by CDV and, finally, entered the network, can be much worse than a Poissonian traffic stream.

4.2 The effect of MBS on the variability of the WTP

The effect of the MBS traffic parameter *S*, which is declared on the ATM traffic contact of VBR connections, on the variability of the WTP is illustrated in Graph 2 below. Three different cases are examined, where the peak cell rate is 2, 10 and 100 times greater than the sustainable cell rate. In particular, they have the same PCR *r=(30/424)Mcells/sec* and CDV MBBS *B=L=5*, and pass through an ATM-UNI of transmission cell rate *R=(150/424)Mcells/sec*. Their SCRs are *(15/424)Mcells/sec*, *(3/424)Mcells/sec* and

(0.3/424)Mcells/sec, respectively. The above parameters mean that the connections have *T=5* slots and T_s */T=2,10* and *100*.

Graph 2
The effect of MBS on the WTP Variability



Graph 2 shows that the variability of the WTP increases as the MBS increases and the sustainable cell rate in relation to the peak cell rate increases. For example, the WTP sqv of VBR connections with the above traffic characteristics and with MBS *S=100* is equal to 30, 80 and 100, respectively. Comparison of those values with unity measures the difference between the variability of the WTP and a Poissonian traffic profile.

5. CONCLUSIONS

This paper evaluated the WTP of a VBR connection that can pass through the UPC mechanisms of an ATM-UNI as conforming. The VBR connection is characterised by four traffic parameters, the PCR, the CDV tolerance, the SCR and the MBS.

The traffic profile that satisfies all four parameters and has the largest variability of the intercell times was presented. The first two moments of the WTP were also evaluated and the Generalised Geometric distribution was used to approximate its statistical behaviour. The effect of CDV tolerance and MBS on the variability of the WTP was also illustrated. High values of CDV tolerance and MBS may result in ATM traffic streams with variability much higher than that of a Poissonian traffic pattern.

High variability implies high requirements for allocated bandwidth and, consequently, low utilisation of the network resources. Future work will evaluate the accuracy of approximating the WTP by the GGeo distribution for various values of the ATM traffic contract parameters. It will also be focused on examining the effect of the WTP on connection admission control algorithms and bandwidth allocation mechanisms.

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