Study of impact of network and source time scales on feedback based congestion control

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ABSTRACT

In this study, the problem of multiplexing VBR and ABR traffic is considered. VBR is uncontrollable, while ABR is provided the remaining service capacity in a controllable fashion. While in a given state, the VBR source is supposed to transmit at a fixed rate; the VBR time scale is then defined in terms of the time constant associated with the rate of change of the rate of the VBR source. ABR sources are assumed to be at some distance from the multiplexing network node; the network speed defines the network time scale which determines the distance (in network slots) between the ABR sources and the node. Finally, the minimum tolerable ABR rate (or the speed at which the ABR source can generate data units to be cellized) define the source time scale. While it is known that the increased network transmission speed (decreased network time scale) reduces the effectiveness of feedback-based adaptive rate control mechanisms due to the increased bandwidth propagation delay product, the positive impact of the VBR and ABR time scales has not been considered in the past. In this work a tractable analytical model is considered and the impact of the three time scales is investigated.

Key Words : VBR time scale, network time scale, feedback, rate control, time constant

1 INTRODUCTION

Asynchronous Transfer Mode (ATM) has been chosen as the CCITT standard for the switching and multiplexing technique of the Broadband-Integrated Services Digital Networks (B-ISDN) currently under development. ATM networks are expected to support applications with diverse traffic characteristics and Quality of Service (QoS) requirements, such as data transfer, video, voice, multi-media conference and real time control.

The ATM Forum[1] has defined four different service classes. Constant bit rate (CBR), variable bit rate (VBR), available bit rate (ABR) and unspecified bit rate (UBR). Because of the diverse traffic characteristics, these classes can represent many types of applications. Non-real time VBR, ABR and UBR service classes are intended for non-real time applications, while CBR and real time VBR are intended for real time applications.

The CBR service class is expected to accommodate real time applications which require stringent throughput and delay, such as voice and video. A fixed amount of bandwidth should be available to CBR applications in order to guarantee the required delay and throughput. Peak cell rate/cell delay variation tolerance (PCR/CDVT), cell loss ratio (CLR) and cell transfer delay/cell delay variation (CTD/CDV) are the negotiated QoS and traffic parameters for CBR applications where the CDVT information may be explicit or implicit. There is no control information for CBR service classes.

The real time VBR service class is also intended to accommodate real time applications. The difference between CBR and real time VBR is that the rate of the sources varies with time in the latter case. For real time VBR, the QoS parameters are CTD, CDV, CLR and the traffic parameters are PCR, CDVT, sustainable cell rate (SCR), maximum burst size (MBS).

The non-real time VBR service class is intended for non-real time applications which do not require stringent throughput and delay such as file transfers and electronic mail. These applications have bursty traffic characteristics and are unpredictable. If the cells reach the destination end systems as specified by the traffic contract, a very low cell loss ratio is expected. Non-real time VBR service class can also support statistical multiplexing of connections. For this service class CLR is the negotiated QoS parameter and PCR, CDVT,SCR, MBS are the traffic parameters, where CDVT information may be explicit or implicit.

The UBR service class is intended for non-real time applications without any QoS parameters. The only traffic parameters for UBR are PCR and CDVT. Neither of these parameters is subject to CAC and UPC and may be explicit or implicit. The level of network congestion is not provided to the sources explicitly but it is understood implicitly by the number of delivered or dropped cells on a connection. UBR service also supports statistical multiplexing of sources.

The ABR service class is intended for non-real time applications which can tolerate delay. This service class simply uses the remaining capacity left from VBR and CBR services and is a best effort service. The goal of this service is to use the unused network bandwidth as efficiently as possible. For ABR the only negotiated QoS parameter is the CLR and is not necessarily quantified. PCR, CDVT (may be explicit or implicit) and MCR are the traffic parameters. If the user does not request a MCR, it is set to zero by default. When MCR is specified the network guarantees that the available bandwidth for that connection will not be less than MCR or larger than PCR. It is believed that some data connections need a minimum throughput so MCR should be specified, but this idea conflicts with the available bandwidth concept. If the available bandwidth reduces to zero, then the network can not supply MCR for that connection. With ABR service class cell delay variation (CDV) is not controlled and the sustainable cell rate (SCR) and maximum burst size (MBS) are not specified.

The ABR service class is different from the other service classes in many ways[2] . The available bandwidth will be shared by the ABR connections and will change dynamically due to the fluctuations in the VBR and CBR traffic. The bandwidth for each ABR connection may reduce to the minimum cell rate (MCR). Since VBR and CBR traffic rates will fluctuate in time, the ABR sources should adjust their rates to these fluctuations in order to utilize the entire remaining capacity or avoid cell losses. As a consequence, a feedback based control scheme should be employed. The ABR sources will learn about the change in the rate of the VBR/CBR sources - that is, their available bandwidth - only after they have received the feedback information. As a result there will always be a bandwidth mismatch, if the feedback propagation delay is nonzero. When the VBR/CBR sources decrease (increase) their rates, the bandwidth mismatch will cause throughput (cell) loss. The rate based[3] ,[4] ,[5] traffic control has been adopted by the ATM forum. Credit based[6] or combination of credit and rate based[7] approaches have also been considered.

A binary feedback scheme was first introduced in[8] . For the window size adaptation increase/decrease algorithms[9] were used and it was shown that for feasibility and optimal convergence to fairness, the increase policy should be additive and decrease policy should be multiplicative. Later, these algorithms were translated into rate adaptation[4] instead of window adaptation. Explicit forward congestion indication (EFCI), proportional rate control algorithm (PRCA), explicit rate feedback[10] and enhanced proportional rate control algorithm (EPRCA) are the main rate control schemes and they are generally enhanced versions of their previous scheme.

As the network systems began to span large geographic areas, the propagation delay and its effect on the rate control schemes became very important. In[11] , the effect of segmenting end-to-end control loops into smaller loops was examined. With unequal propagation delays, an adaptive control scheme was studied in[12] .

This paper is focused on the effects of the network time scales and source time scales on the performance of an explicit rate congestion control system where the network time scale determines the distance between the source and the node, the VBR source time scale determines the frequency of rate changes of the VBR sources and the ABR source time scale is speed at which the ABR source can generate data units.

The rest of the paper is organized as follows: In section 2, the system model considered in this work is desribed. In section 3, the system is analyzed and the induced cell loss probability is evaluated. In section 4 some numerical results are presented and the effects of the network and source time scales on the effectiveness of the feedback based control scheme is discussed.

2 DESCRIPTION OF THE SYSTEM

Consider a transmission link shared by variable bit rate (VBR) and available bit rate (ABR) applications. The VBR sources are provided prioritized access to the resources and ABR sources are allocated the remaining resources. In order to simplify the analysis and facilitate the understanding of the impact of the various time scales, a system with one VBR source and one ABR source is considered. Each of these sources will deliver at most one cell per slot according to the rate in effect.

The ABR traffic source is assumed to be away from the network access node and thus the propagation delay between the ABR source and the network access node is non-negligible. The distance between the VBR source and the network access node is not important in this work since no control is applied on the VBR source. Based on the current VBR source rate, an appropriate transmission rate is determined by the network access node for the ABR traffic source and it is fed back to the ABR source. This rate for the ABR source is in effect until the next rate change for the VBR traffic source is detected by the network access node.

The network access node is assumed to have a buffer of capacity C to temporarily store the ABR cells when the transmission link (server) attends to the VBR traffic. A queuing model of the network access node is shown in Figure 1. The serving policy is assumed to be work conserving and at most one VBR cell arrival per slot is provided head of line (HoL) priority. ABR cells are served according to the first come first served (FCFS) policy. Cell departures are assumed to occur before cell arrivals. Since the one service per slot will be available to the VBR cell upon its arrival to the network access node, a buffer of capacity 1 is sufficient for the VBR queue.

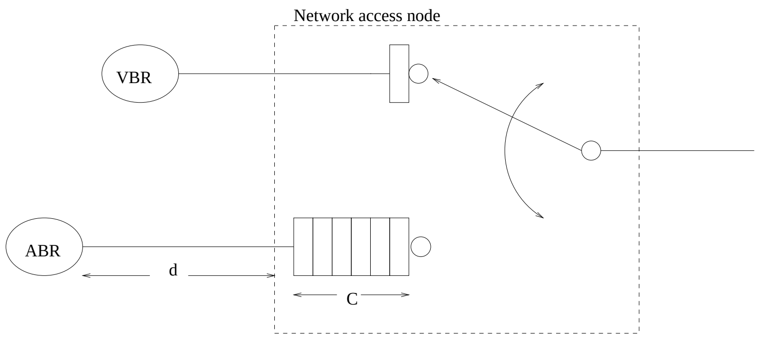

Figure 1: The queuing model of the network access node

Because of the large distance d between the ABR traffic source and the network access node, bandwidth mismatch will occur when VBR traffic rate changes occur. A change in the VBR rate at time t will be detected by the ABR source at time $t + T_d$ and the adjusted ABR rate will reach the network access node at time $t + 2T_d$.

During the above round-trip propagation delay $2T_d$, the network may either be underutilized or overutilized inducing cell losses.

Cell losses are very important for ATM networks because of segmentation. A packet is segmented into many ATM cells and the entire packet is considered to be lost in most cases if any of these ATM cells is lost. For example if a data packet is segmented into N cells and the probability of losing an ATM cell is p, the packet loss probability is Np for very small p^2 .The remaining cells of the packet which are not lost become useless and their presence within the network may induce further losses.

The maximum allowable ABR traffic source rate can be calculated from the current VBR traffic source rate. If the latter is equal to r_v, then the maximum allowable ABR traffic rate will be $1 - r_v$. The ABR source can transmit one cell at the first slot of a subframe of length T slots, where T is the ABR source time scale and it is given in terms of $1 - r_v$ by $T = \lfloor \frac{1}{1-r_v} - \epsilon \rfloor$ where $\lfloor () \rfloor$ denotes the largest integer smaller than $()$ and ϵ is an arbitrarily small positive number determined by the desirable load at the network access node. The ABR source will continue to transmit one cell at the first slot of each subframe of length T until another rate change for the VBR traffic occurs. Then the new value for T is calculated and applied. It is assumed that the ABR source can transmit at the maximum allowable rate selected for it by the network access node (heavy ABR traffic assumption). Under this assumption the worst case performance for the ABR source cells will be derived.

Although the activity level of the VBR traffic source can change in principle at any slot, it will be assumed that such changes occur at subframe boundaries for analysis tractability. Let $\{S_k\}_{k\geq 1}$ be a 2-state underlying Markov chain with state space $\overline{S} = \{0, 1\}$ embedded at subframe boundaries $\{t_k\}_{k\geq 1}$ of length T_k, where T_k is equal to the period of the ABR traffic as determined by the perceived remaining capacity. Let $p_s(s_k)$ denote the probability that S_k changes state at the end of the current subframe at the beginning of which it was in state s_k. Let $r_v(s_k)$ denote the rate of the VBR source over T_k. The VBR cell arrival process will be modeled as a Bernoulli process.

Since the VBR traffic is provided prioritized service and the VBR queue is allocated a buffer of size 1, VBR cells will never be lost and the analysis will focus on the behavior of the ABR queue. The ABR queue subsystem is shown in Figure 2. The server takes vacation over the slot in which a VBR cell arrives and it attends to the ABR queue otherwise.

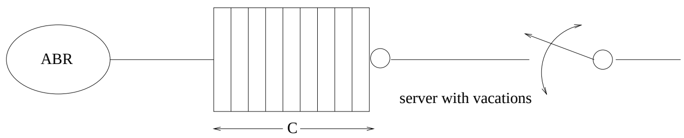

Figure 2: The ABR queue subsystem

The behavior of the ABR queue is affected by the activity in the VBR queue. Fortunately, the coupling between the two queues is not very tight. There is only a unidirectional interference on the ABR queue coming from the VBR queue; on the other hand, the behavior of the VBR queue is independent from the activity in the ABR queue. This observation allows the modeling of the interference from the VBR queue on the ABR queue as an independent process.

The behavior of the ABR queue subsystem shown in Figure 2 can be studied by considering the equivalent queuing model shown in Figure 3. Instead of considering the server vacations, the server keeps attending to the ABR queue which is now fed by an additional interfering Bernoulli traffic which receives HoL priority and keeps the server busy when it would be on vacation in the original system (Figure 2). Clearly, the ABR losses in the original system will be identical to the losses of the system in Figure 3.

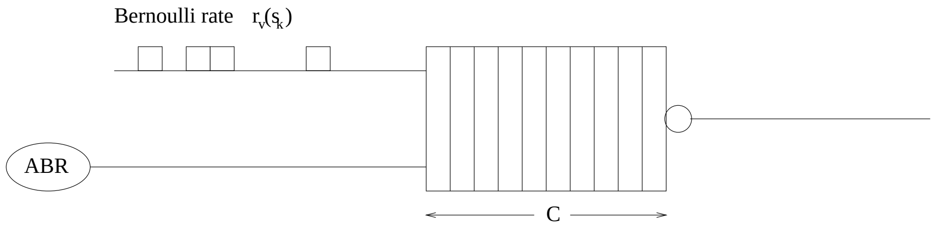

Figure 3: The equivalent queuing model

3 ANALYSIS OF THE SYSTEM

In this section a proper Markov chain describing the evolution of the system shown in Figure 3 is derived.

Let $\{S_k, Q_k\}_{k\geq 1}$ be a 2-dimensional process embedded on $\{t_k\}_{k\geq 1}$ where Q_k is a random variable describing the buffer occupancy at t_k. By definition, S_k determines completely the interfering (or VBR) arrival process. If $T_d = 0$, then S_k determines the ABR arrival process as well which is equal to $\frac{1}{T_k} = 1 - r_v(s_k) - \epsilon$, where $\epsilon > 0$ is fixed and it is selected based on the desirable maximum load at the network access node. Clearly, $\{S_k, Q_k\}_{k\geq 1}$ is a Markov chain embedded on $\{t_k\}_{k\geq 1}$ when $T_d = 0$.

When $T_d > 0$, the ABR rate is given by $\frac{1}{T_k} = 1 - r_v(s'_k) - \epsilon$ where s'_k is the VBR state $2T_d$ time units earlier. As a consequence, the current state S_k does not determine the arrival process and thus $\{S_k, Q_k\}_{k\geq 1}$ is not a Markov chain. Although a Markov chain can be costructed to describe the evolution of the system under fixed and non-zero rountrip propagation delay, a simplifying assumption is made by assuming that the round-trip propagation delay is random and geometrically distributed with mean $\frac{1}{p_f}$. In this case, a VBR source rate change will arrive at the ABR source in the next subframe boundary with probability p_f.

Let J_k be an indicator function which assumes the value 1 if a feedback carrying a VBR rate change is pending at t_k. The ABR traffic rate $\frac{1}{T_k}$ (or subframe T_k) will be completely determined by (S_k, J_k) and it is given by $\frac{1}{T_k} = 1 - r_v(s_k \oplus j_k) - \epsilon$ where $\oplus$ denotes the modulo 2 addition, provided that more than one pending VBR rate changes are not possible. The latter approximation holds true if $max\{p_s(s_k)\} \ll p_f$; that is, if the VBR source time constant is much larger than the propagation delay.

Under the above assumptions it is easy to establish that the stochastic process $\{S_k, J_k, Q_k\}$ embedded at subframe boundaries is a Markov chain with state space $\{(s_k, j_k, q_k) : 0 \leq s_k \leq 1, 0 \leq j_k \leq 1, 0 \leq q_k \leq C\}$.

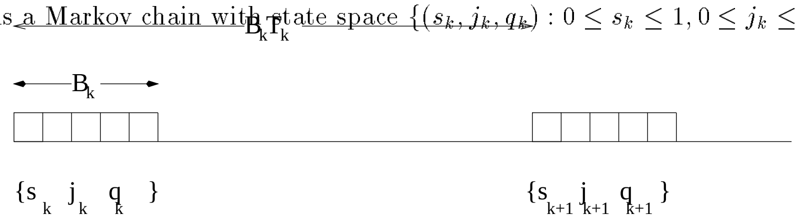

Figure 4: The ABR cell arrival process

Let $P(s_k j_k q_k; s_{k+1} j_{k+1} q_{k+1})$ be the probability that the Markov chain $\{S_k, J_k, Q_k\}$ moves from state (s_k, j_k, q_k) at time t_k to state $(s_{k+1} j_{k+1} q_{k+1})$ at time t_{k+1}. From the description of the system model it can be seen that

(s_{k+1}, j_{k+1}) evolves independently from the queue occupancy q_k and thus;

$$P(s_k j_k q_k; s_{k+1} j_{k+1} q_{k+1}) = P(s_k j_k; s_{k+1} j_{k+1}) P(q_{k+1}/s_k j_k q_k) \tag{1}$$

The probabilities on the right side of equation 1 can be calculated separately as shown below. Note that $P(s_k j_k; s_{k+1} j_{k+1})$ is the probability of passing from (s_k, j_k) to (s_{k+1}, j_{k+1}) and $P(q_{k+1}/s_k j_k q_k)$ is the probability of being at queue occupancy q_{k+1} at the beginning of the next subframe given the current subframe parameters.

The state diagram for the $\{S_k, J_k\}$ process is shown in Figure 5. Notice that not all state transitions are possible because of the constraint on j_k and the requirement of generating a feedback only when the VBR rate changes. Let $s_k j_k \longrightarrow s_{k+1} j_{k+1}$ denote a state transition from $(s_k j_k)$ to $(s_{k+1} j_{k+1})$. A $00 \longrightarrow 10$ transition is impossible, because a pending feedback has to be generated when a VBR rate change occurs. This transition may be possible only if the feedback delay is zero. Similarly, a transition from $11 \longrightarrow 01$ is impossible since $p_s(1) \ll p_f$, since another VBR rate change can not occur before the pending feedback arrives at the ABR source.

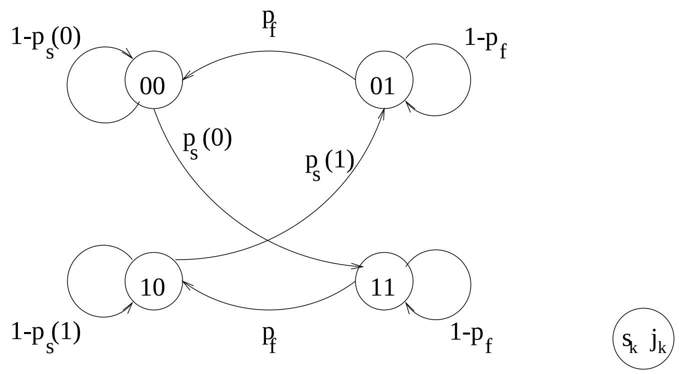

Figure 5: The state diagram of the $\{S_k, J_k\}$ process

Let $q_{k,i}$ denote the queue occupancy at the end of the i^{th} slot of the k^{th} subframe. As shown in Figure 4, an ABR cell arrival occurs only in the first slot while VBR cells may arrive in any slot. Let $P_A(q_{k,i+1}/s_k j_k q_{k,i})$ denote the one slot transition probability from $q_{k,i}$ to $q_{k,i+1}$ when arrivals are possible from both sources and let $P_B(q_{k,i+1}/s_k j_k q_{k,i})$ denote the one slot transition probability when only VBR arrivals are possible. Thus,

$$P(q_{k+1}/s_k j_k q_k) = \sum_{q_{k,1}=0}^{C} P_A(q_{k,1}/s_k j_k q_k) P_B(q_{k+1}/s_k j_k q_{k,1}) \tag{2}$$

$P_A(q_{k,i+1}/s_k j_k q_{k,i})$ can be calculated as follows where $1 \leq i \leq T_k$.

For $q_{k,i} = 0$, $0 \leq q_{k,i+1} \leq C - 1$: $q_{k,i+1} = A(s_k) + 1$ where $A(s_k)$ denotes the number of arrivals from the VBR traffic source in one slot. Thus,

$$P_A(q_{k,i+1}/s_k j_k q_{k,i} = 0) = P\{A(s_k) = q_{k,i+1} - 1\} \tag{3}$$

For $1 \leq q_{k,i} \leq C$, $0 \leq q_{k,i+1} \leq C-1 : q_{k,i+1} = q_{k,i} + A(s_k)$. Thus,

$$P_A(q_{k,i+1}/s_k j_k q_{k,i}) = P\{A(s_k) = q_{k,i+1} - q_{k,i}\} \tag{4}$$

For $0 \leq q_{k,i} \leq C$, $q_{k,i+1} = C : C = q_{k,i} + A(s_k)$. If $A(s_k) > C - q_{k,i}$, $A(s_k) - C + q_{k,i}$ cells will be lost. Thus,

$$P_A(q_{k,i+1} = C/s_k j_k q_{k,i}) = \sum_{m=0}^{m_{max}} P\{A(s_k) = C - q_{k,i} + m\} \tag{5}$$

where $m_{max} = 1 - C + q_{k,i}$

Similarly, $P_B(q_{k,i+1}/s_k j_k q_{k,i})$ can be calculated as follows.

For $q_{k,i} = 0$, $0 \leq q_{k,i+1} \leq C : q_{k,i+1} = A(s_k)$. Thus,

$$P_B(q_{k,i+1}/s_k j_k q_{k,i}) = P\{A(s_k) = q_{k,i+1}\} \tag{6}$$

For $1 \leq q_{k,i} \leq C$, $0 \leq q_{k,i+1} \leq C : q_{k,i+1} = q_{k,i} + A(s_k) - 1$ where -1 accounts for the served cell. Thus,

$$P_B(q_{k,i+1}/s_k j_k q_k) = P\{A(s_k) = q_{k,i+1} - q_{k,i} + 1\} \tag{7}$$

The $T_k - 1$ slot transition probability $P_B(q_{k+1}/s_k j_k q_{k,1})$ can be derived recursively using $T_k - 2$ and 1 slot transition probabilities.

$$P_B(q_{k+1}/s_k j_k q_{k,1}) = \sum_{q_{k,T_k-1}} P_B(q_{k,T_k-1}/s_k j_k q_{k,1}) P_B(q_{k+1}/s_k j_k q_{k,T_k-1}) \tag{8}$$

After finding the transition probabilities $P(s_k j_k q_k; s_{k+1} j_{k+1} q_{k+1})$, the steady state probability distribution $\Pi(s_k, j_k, q_k)$ can be derived from the following matrix equations.

$$\Pi = \Pi P \tag{9}$$

$$\sum_i \Pi_i = 1 \tag{10}$$

where the state transition matrix P is a $4(C+1) \times 4(C+1)$ sparse matrix.

Let $L(s_k, j_k, q_k)$ be the number of cells lost over the subframe starting with $\{s_k, j_k, q_k\}$ and $\overline{L}(s_k, j_k, q_k)$ be the expected value of $L(s_k, j_k, q_k)$. Let $I(s_k, j_k, q_k; i)$ denote the number of cells lost at the i^{th} slot of the subframe and $R(s_k, j_k, q_k; i)$ denote the number of cells arrived at the i^{th} slot of the subframe; $1 \leq i \leq T_k$. The number of cell arrivals $R(s_k, j_k, q_k; i)$ does not depend on the queue occupancy and is a function of s_k, j_k and i. Thus,

$$R(s_k, j_k; i) = \begin{cases} A(s_k) & \text{if } i \neq 1 \\ A(s_k) + 1 & \text{if } i = 1 \end{cases} \tag{11}$$

The number of lost cells can be found by considering the number of arrivals, the buffer occupancy in the previous slot and the buffer capacity C.

$$I(s_k, j_k, q_k; i) = \begin{cases} k & \text{if } R(s_k, j_k; n) = C + 1 - q_{k,i-1} + k \\ 0 & \text{otherwise} \end{cases} \tag{12}$$

The total number of cells lost over the entire subframe will be

$$L(s_k, j_k, q_k) = \sum_{i=1}^{T_k} I(s_k, j_k, q_k; i) \tag{13}$$

Taking the expectation of both sides

$$\begin{aligned} \overline{L}(s_k, j_k, q_k) &= E \textstyle\sum_{i=1}^{T_k} I(s_k, j_k, q_k; i) \\ &= \textstyle\sum_{i=1}^{T_k} E\{I(s_k, j_k, q_k; i)\} \\ &= \textstyle\sum_{i=1}^{T_k} \sum_k kP\{A(s_k) = C + 1 - q_{k,i-1} + k / q_{k,0} = q_k, s = s_k, j = j_k\} \\ &= \textstyle\sum_{i=1}^{T_k} \sum_{l=0}^{C} \sum_k kP\{A(s_k) = C + 1 - l + k / q_{k,0} = q_k, s = s_k, j = j_k\} P\{q_{k,i-1} = l / q_{k,0} = q_k\} \\ &= \textstyle\sum_{l=0}^{C} \sum_k kP\{A(s_k) = C - l + k / q_{k,0} = q_k, s = s_k, j = j_k\} 1_{\{q_k = l\}} \\ &\quad + \textstyle\sum_{i=2}^{T_k} \sum_{l=0}^{C} \sum_k kP\{A(s_k) = C + 1 - l + k / q_{k,0} = q_k, s = s_k, j = j_k\} P\{q_{k,i-1} = l / q_{k,0} = q_k\} \end{aligned}$$

Only the first slot of each subframe can cause cell losses, since on other subframes there can be at most 1 arrivals. So,

$$\overline{L}(s_k, j_k, q_k) = \sum_{l=0}^{C} \sum_{k=0}^{kmax} kP\{A(s_k) = C - l + k\} 1_{\{q_k = l\}} \tag{14}$$

Since the cell departures are assumed to occur before cell arrivals are counted, the upper limit of k, i.e $kmax$ can be found as follows.

$k_{max} = A_{tmax} - C - 1 + l$ where A_{tmax} is the maximum number of VBR and ABR cell arrivals in a slot. So, $k_{max} = l - C + 1$.

Let L denote the probability that a cell is lost

L = E$\left\{ \frac{Average\ \ number\ \ of\ \ cells\ \ lost\ \ in\ \ subframe\ \ (s_k j_k q_k)}{Average\ \ number\ \ of\ \ cells\ \ arrived\ \ in\ \ subframe\ \ (s_k j_k q_k)} \right\}$

$$L = \{\frac{\overline{L}(s_k, j_k, q_k)}{1 + r_v(s_k)T_k}\} \tag{15}$$

$$= \sum_{s_k=0}^{1} \sum_{j_k=0}^{1} \sum_{q_k=0}^{C} \frac{\overline{L}(s_k, j_k, q_k)}{1 + r_v(s_k)T_k} \Pi(s_k, j_k, q_k) \tag{16}$$

4 NUMERICAL RESULTS

In this section the impact of the network and source time scales on feedback based congestion control for the proposed policy is evaluated.

The performance of the queuing system in terms of cell loss probability for the ABR source is illustrated in Figure 6. The loss probability is plotted as a function of p_f, where $\frac{1}{p_f}$ represents the expected distance of the ABR source from the network access node measured in short subframes (p_f was adjusted properly under large subframe operation so that the mean propagation delay under both large and short subframe operation be the same in slots). For example for $p_f = 0.1$, the mean distance between the ABR source and the network access node is equal to 10 short subframes. As p_f increases, the distance between the ABR source and network access node decreases. The results of Figure 6 are derived for a buffer capacity C of 40 and VBR source rates of 0.4 and 0.8 cells/slot. As the propagation delay decreases, the amount of time that it takes for the ABR source to respond to the VBR source rate changes decreases. As a consequence, the duration of bandwidth mismatch decreases, causing a decrease in the ABR loss probability. $\frac{1}{p_s}$ indicates the VBR time scale and as p_s increases VBR source rate changes occur more frequently. As a result, more bandwidth mismatch cycles are initiated resulting in more losses. Figure 6 shows ABR loss probability for $p_s = 0.005$, $p_s = 0.001$, $p_s = 0.0005$, $p_s = 0.0001$ where $p_s = p_s(0) = p_s(1)$. Note that p_s is kept below 0.005 due to the requirement that it should be much less than p_f in order for the assumption of no multiple feedbacks to be reasonably accurate.

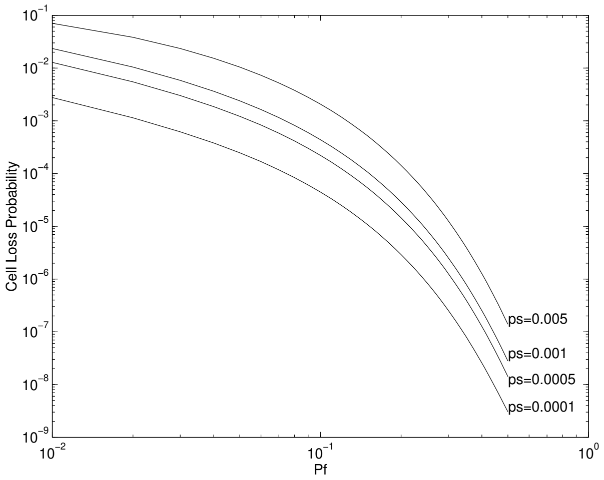

Figure 6: ABR cell loss probability vs. p_f for various p_s

Figure 7 illustrates the loss probability for the ABR source cells as a function of p_f for $C = 2$, $C = 4$, $C = 8$, $C = 16$, $C = 32$, $C = 64$. This result is derived for VBR source rates of 0.4 and 0.8 cells/slot and $p_s = p_s(0) = p_s(1) = 0.001$. As the buffer capacity increases, the loss probability for a given p_f decreases. The amount of decrease becomes more significant as the distance between the ABR source and the network access node becomes smaller (as p_f increases).

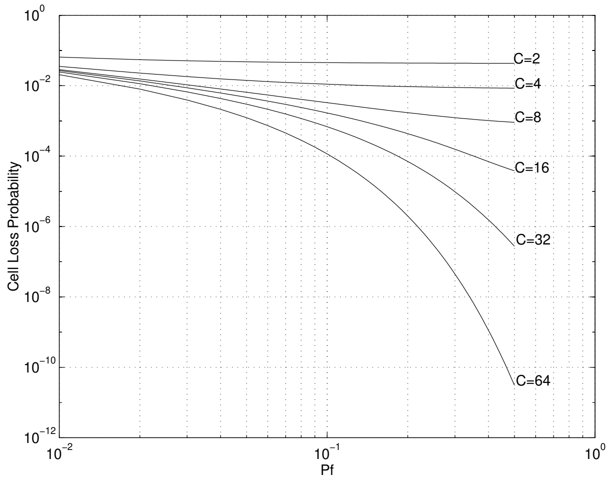

Figure 7: ABR cell loss probability vs. p_f for various C

The impact of the VBR time constant and the propagation delay is further investigated in Figure 8, where $C = 40$ and the VBR source rates are 0.4 and 0.8. As p_s increases, the ABR cell loss probability increases as expected. The effect of p_f on the loss probability is also observed for $p_f = 0.001$, $p_f = 0.005$, $p_f = 0.01$, $p_f = 0.05$, $p_f = 0.1$ and $p_f = 0.5$. As the propagation delay increases for a given p_s, the loss probability increases.

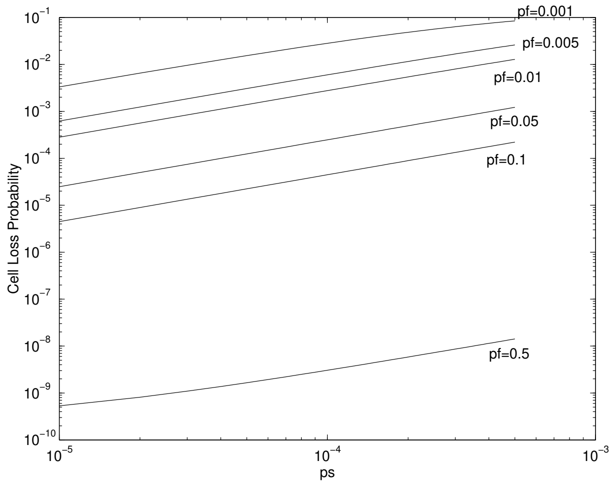

Figure 8: ABR cell loss probability vs. p_s for various p_f

In Figure 9, the effect of the VBR source rates on the loss probability is examined. The mean VBR arrival rate is the same in the three cases which are investigated. It can be seen that as the VBR arrival rates become closer for a given value of p_s, the loss probability decreases. For the case with $r_v(0) = 0.3$ and $r_v(1) = 0.9$, when a bandwidth mismatch occurs the total rate on the link can increase up to 1.6 causing many losses. Also in this case when the VBR source rate drops from 0.9 to 0.3, the total rate in the link decreases to 0.4 causing excessive underutilization. However when VBR rates are 0.5 and 0.7, during a bandwidth mismatch the total rate on the link will be at most 1.2 or at least 0.8 causing a more stable operation and a much better performance.

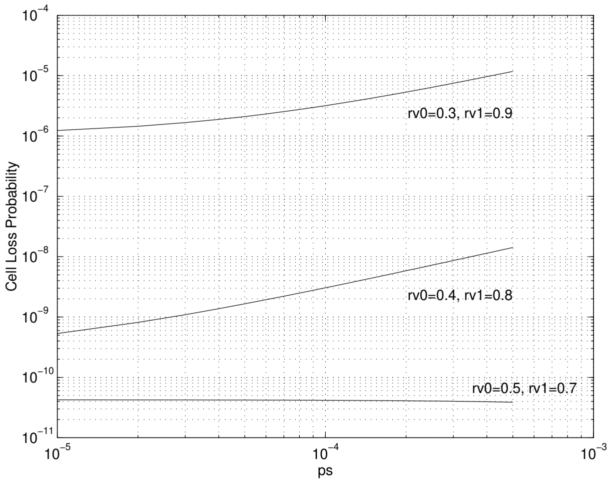

Figure 9: ABR cell loss probability vs. p_s for various VBR arrival rates

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