A Proactive Feedback Based Flow Control Scheme for ABR Services *

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Abstract

By design, the Available Bit Rate (ABR) applications will be allocated the networking capacity which is not utilized by Variable Bit Rate (VBR) and Constant Bit Rate (CBR) applications. The ABR traffic entering the network will be controlled by a feedback based scheme. As the distance between the ABR source and the network access node increases, the feedback based flow control mechanisms become less effective due to the increased propagation delay. This is known as the bandwidth mismatch problem. In this paper, a proactive feedback based flow control scheme for the ABR service class is introduced by attempting to reduce the induced bandwidth mismatch. It also can provide for a fair rate allocation to ABR sources with different propagation delays.

1 Introduction

The Asynchronous Transfer Mode (ATM) has been selected 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, multimedia 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). These classes can cover a broad spectrum of diverse 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 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. For the ABR service class the only negotiated QoS parameter is the CLR and is not necessarily quantified. Peak Cell Rate (PCR), Cell Delay Variation Tolerance (CDVT) and Minimum Cell Rate (MCR) are the traffic parameters.

The ABR service class is different from the other service classes in many ways [2] .The available bandwidth is shared by the ABR connections and can change dynamically due to the fluctuations in the VBR and CBR traffic and it may reduce to the MCR. Since VBR and CBR traffic rates fluctuate in time, the ABR sources should adjust their rates to these fluctuations in order to efficiently utilize the entire remaining capacity or avoid cell losses. These characteristics point to the necessity of controlling the flow of the ABR traffic sources.

In rate based flow control, the sender is notified about congestion in the network with a feedback generated from the receiver or from the congested nodes. When the sender receives such a feedback, it adjusts its rate according to the flow control policy in effect.

Many different flow control policies have been proposed for the rate based flow control such as the Explicit Forward Congestion Indication (EFCI) [6], Backward Explicit Congestion Notification (BECN) [7], Proportional Rate Control Algorithm (PRCA) [8], Explicit Rate Feedback (ERF) [9] and Enhanced Proportional Rate Control Algorithm (EPRCA) [10].

Assume here that VBR/CBR rate information is available to the network access node. For the some flow control schemes, the feedback is transmitted when a rate change occurs. This type of flow control schemes are referred as the non-proactive flow control (*NPF*) schemes in this paper. When the propagation delay is non-zero, the ABR sources learn about the change in the rate of the VBR/CBR sources - that is, the current level of the available bandwidth - only after they receive the feedback information. Meanwhile, the ABR sources transmit at a rate which is based on the most recent level of available bandwidth known to them. Consequently, the effectiveness of the rate based flow control schemes decrease under non-zero propagation delays.

For the *NPF* schemes, if the propagation delay between an ABR source and the network access node is T_d and the available bandwidth changes at time t, the ABR source will learn about the change in

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bandwidth availability at time $t + T_d$. The adjusted rate from the ABR source will reach the network access node at time $t+2T_d$, assuming that the backward and forward propagation delays are equal. This can be clearly observed in Figure 1 where a network link is shared by VBR/CBR and ABR applications. Whenever the VBR/CBR sources change their rates, a bandwidth mismatch occurs for a duration of $2T_d$. When a decrease in the remaining bandwidth occurs, the link capacity is exceeded for a duration of $2T_d$ and overutilization occurs which may induce cell losses depending on the amount of buffering available. When an increase in the remaining bandwidth occurs, underutilization occurs for a duration of $2T_d$. The effects of increased propagation delay on the flow control schemes has been studied in the past [11], [12], [13]. It turns out that, as the distance between the sources and the network access node increases (propagation delay increases) more cell losses occur.

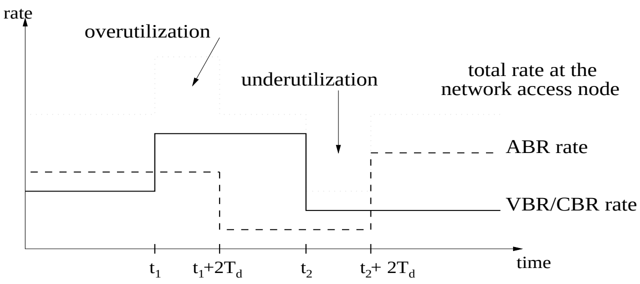

Figure 1: An example of bandwidth mismatch

In this paper, a proactive flow control scheme (*PF*) which tries to decrease the bandwidth mismatch is introduced. Since losses may occur only because of bandwidth mismatch, they will be reduced to zero if the bandwidth mismatch is completely eliminated. This can be achieved if the exact time instant of the VBR/CBR source rate change is known to the network access node and a feedback is generated $2T_d$ before that time. For example, the exact time instant of the rate change may be known for MPEG video applications which maintain a fixed rate over a frame or a group of frames. Because of jitter due to multiplexing the frame or group of frame boundaries may be randomly distributed or for certain VBR applications the actual time between two consecutive rate changes may be randomly distributed due to the employed traffic smoothing scheme and source traffic characteristics. In these cases, by estimating the time of rate change with sufficient accuracy, a feedback may be generated in advance, resulting in a reduction of the induced bandwidth mismatch below $2T_d$.

The remainder of this paper is organized as follows. In Section 2, the *PF* scheme is introduced. In Section 3, the expected amount of bandwidth mismatch for *PF* and *NPF* schemes are calculated and compared. Some numerical examples are presented in Section 4 and the paper concludes with a brief summary in section 5.

2 The *PF* (Proactive Flow Control) Scheme

Consider a transmission link shared by VBR and ABR applications. The VBR source has prioritized access to the resources and the ABR source is allocated the remaining resources. The network access node has a buffer with finite capacity B, for the temporary storage of ABR and VBR cells.

The ABR source is away from the network access node and the propagation delay between the ABR source and the network access node is T_d. It is assumed that the VBR source transmits cells with one of two different rates, s_0 and s_1, where $s_1 > s_0$.

Since the ABR applications will use the capacity not utilized by the VBR applications, the allowable transmission rates for the ABR source will be $a_1 = 1-s_0-\epsilon$ or $a_0 = 1-s_1-\epsilon$. Here, ϵ is a small positive number to ensure that the total link rate is below 1. This guarantees the stability of the system.

When a VBR rate change occurs, the allowable ABR rate changes as well. The new rate is communicated to the ABR source with a feedback generated by the network access node. Until the feedback reaches the ABR source and the adjusted ABR source rate returns back the network access node, the ABR rate at the network access node depends on the previous feedback information. Therefore, to determine the ABR source rate at the network access node, the status of the feedback is needed in addition to the VBR source rate. Let j be an indicator function which describes the status of the impact of the feedback generated by the network access node. Thus, j assumes the value of 0, if the impact of the feedback is not pending (ABR source rate has been adjusted). Otherwise, j is equal to 1.

The proposed *PF* scheme described below aims to decrease the amount of bandwidth mismatch. Under this scheme, the rate change of the VBR source is estimated before it occurs and the feedback is generated in advance ($2T_d$ before the estimated rate change instant). Figure 2 presents a realization of the bandwidth mismatch process under the *PF* scheme. Since the values of s, j and a are shown at the network access node, the total traffic at the network access node is the addition of VBR and ABR traffics (s and a).

Let t_k denote the k^{th} time instant at which a VBR rate change occurs. Let X_k denote the length of the time interval over which the VBR source maintains a constant rate. That is, $X_k = t_k - t_{k-1}$. In [14], X_k is defined as the VBR time scale. Let $\hat{X}$ denote an estimator for X_k.

Under the *PF* scheme the transmission instant of the feedback depends on t_k, X_k, $\hat{X}$ and the roundtrip propagation delay $2T_d$. Figure 3 illustrates an exam-

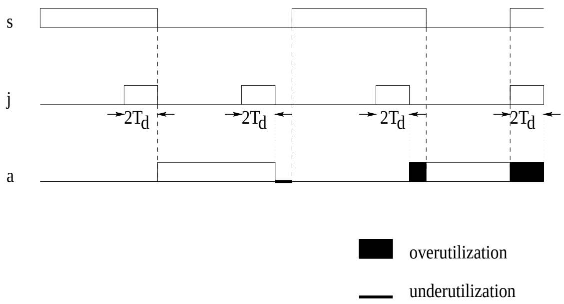

Figure 2: Bandwidth mismatch example under *PF* Scheme

ple of feedback transmission instants. Let f_k denote the time instant that the k^{th} feedback is transmitted. If $X_k > \hat{X} - 2T_d$, the network access node transmits the feedback to the ABR source at time $t_{k-1} + \hat{X} - 2T_d$. If $X_k < \hat{X} - 2T_d$, the feedback is transmitted at $t_{k-1} + X_k$ like the *NPF* schemes. Therefore,

$$f_k = t_{k-1} + min\{X_k, \hat{X} - 2T_d\}$$

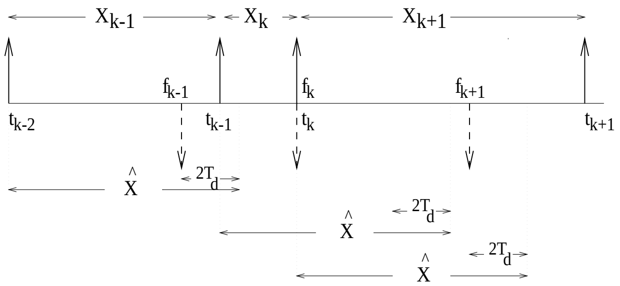

Figure 3: A realization of feedback transmission instants

Since the roundtrip propagation delay is $2T_d$, the adjusted ABR rate reaches the network access node at $f_k + 2T_d$.

3 Evaluation of the effectiveness of the *PF* Scheme

In order to compare the effectiveness of the *PF* scheme with *NPF* schemes, the magnitude of the induced bandwidth mismatch is considered. Since, the ABR cell losses are mainly caused by the overutilization periods, which are captured by the bandwidth mismatch, the expected bandwidth mismatch would reflect the efficiency of a feedback based flow control scheme in terms of the induced cell losses.

Under the *NPF* schemes, feedback is transmitted when a VBR rate change is detected. Thus, the induced bandwidth mismatch will always be equal to the roundtrip propagation delay, $2T_d$. Thus, the expected value of the amount of bandwidth mismatch induced is $2T_d$. Let C_{NPF} be equal to this amount, thus $C_{NPF} = 2T_d$.

Let C_{PF} be the expected value of the amount of bandwidth mismatch induced and W_{PF} be a random variable indicating the amount of bandwidth mismatch under the *PF* scheme. Thus, $C_{PF} = E\{W_{PF}\}$. Under the proposed *PF* scheme W_{PF} will be equal to,

$$\begin{aligned} W_{PF} &= |t_k - (f_k + 2T_d)| \\ &= |X_k - min\{X_k, \hat{X} - 2T_d\} - 2T_d| \\ &= \begin{cases} 2T_d & \text{if } X_k \leq \hat{X} - 2T_d \\ \hat{X} - X_k & \text{if } \hat{X} - 2T_d + 1 \leq X_k < \hat{X} \\ 0 & \text{if } X_k = \hat{X} \\ X_k - \hat{X} & \text{if } X_k > \hat{X} \end{cases} \end{aligned}$$

Let $f(X_k)$ denote the distribution of X_k (the VBR time scale). An example distribution is shown in Figure 4. Let $\hat{X}$ be the estimate of X_k.

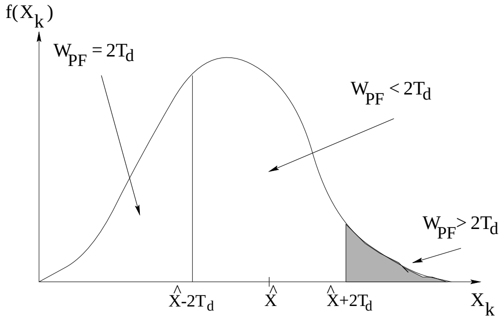

Figure 4: An example distribution of X_k

If X_k is in the region $1 \leq X_k \leq \hat{X} + 2T_d$, then the bandwidth mismatch is always equal to or less than the the roundtrip propagation delay. Therefore, in this region $W_{PF} <= W_{NPF} = 2T_d$. The only region in which the *PF* scheme may lead to more bandwidth mismatch than the *NPF* scheme is $X_k > \hat{X} + 2T_d$. Since, only in this region the bandwidth mismatch is greater than the roundtrip propagation delay. Therefore, the effectiveness of the *PF* scheme depends on the tail of the distribution of X_k. If the estimator chosen can decrease the probability of entering into this region while increasing the probability of entering into the low bandwidth mismatch region the effectiveness of the *PF* scheme can be increased.

Claim : If the maximum value that X_k can achieve is finite, a value of $\hat{X}$ (estimator for *PF* Scheme) can be found such that $C_{PF} \leq C_{NPF}$.

Proof: Let X_{max} denote the maximum value of X_k. Since a bandwidth mismatch larger than $2T_d$ may occur only in the region $X_k > \hat{X} + 2T_d$, $\hat{X}$ can be chosen such that $\hat{X} + 2T_d \geq X_{max}$. Therefore, $X_k > \hat{X} + 2T_d \geq X_{max}$ will never occur and the bandwidth mismatch will never exceed $2T_d$. Since for $X_k \leq \hat{X} + 2T_d$, bandwidth mismatch is less than or equal to $2T_d$, $C_{ESF} \leq C_0 = 2T_d$.

4 Numerical Results

In this section, in order to illustrate the effectiveness of the *PF* scheme with respect to the *NPF* scheme, the expected amount of bandwidth mismatch is calculated for both schemes and some simulation results are presented in terms of loss probabilities. For this section, it is assumed that the maximum length for X_k is 100 slots.

Figure 5 shows the C_{PF} and C_{NPF} when X_k has a binomial distribution with parameters 100 and 0.5, thus $X_k \sim Bin(100, 0.5)$. For this distribution, it turns out that the C_{PF} reaches its minimum when $\hat{X} = 50$ (the mean of the binomial distribution).

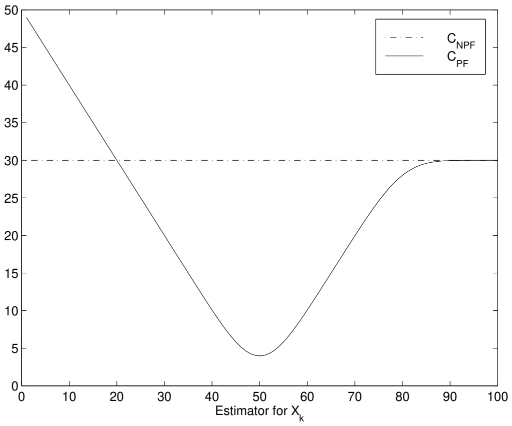

Figure 5: Comparison of C_{NPF} and C_{PF} for $X_k \sim Bin(100, 0.5)$

Figure 6 illustrates the C_{PF} as a function of the variance of the binomial distribution ($\sigma^2 = 100p(1-p)$). The estimator used for each value of p is the mean of the distribution ($\mu = 100p$). The variance of the binomial distribution is maximum when $p = 0.5$ ($\sigma^2 = 25$) and the expected amount of bandwidth mismatch reaches its maximum at this point. Because, when the variance increases the distribution becomes less concentrated around its mean and the probability of entering the high bandwidth mismatch regions increase.

These figures illustrated the expected amount of bandwidth mismatch under the *NPF* and *PF* schemes. Since the overutilization periods of the bandwidth mismatch may induce cell losses, a decrease in the cell losses is also expected under the *PF* scheme. To illustrate this, some simulation results are presented next. For the simulations the following values are assumed. The buffer at the network access node has a capacity of 30. The VBR source rates are 0.8 and 0.4 cells/slot and the ABR source rates are 0.167 and 0.5 cells/slot.

In Figure 7, the ABR cell loss probabilities for the *PF* scheme and for the *NPF* scheme are plotted for $2T_d = 20$ and $2T_d = 30$. As expected, the best estimator for X_k is around the mean of the distribution. Once a good estimator for X_k is chosen, there is a significant gain in terms of losses. Also, the losses become very close around the mean for different propagation delays. If $\hat{X}$ is close to X_{max}, the loss probabilities under the *PF* scheme converge to those induced by the *NPF* schemes. Since in this case feedback is transmitted mostly at the instants of rate changes (as opposed to earlier).

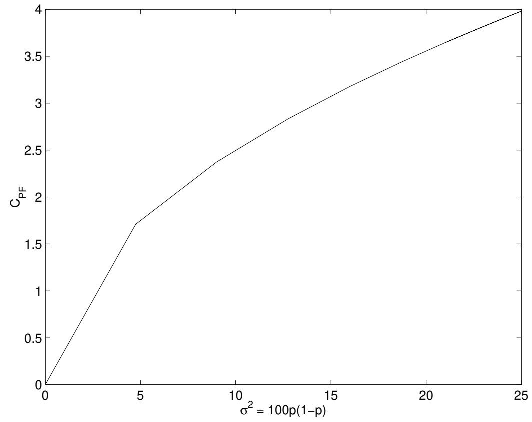

Figure 6: The bandwidth mismatch as a function of variance for $X_k \sim Bin(100, p)$

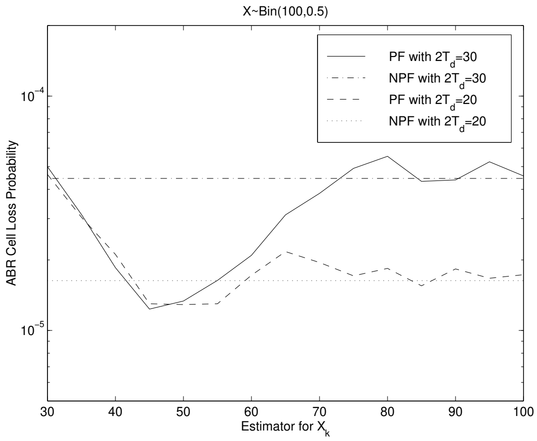

Figure 7: ABR Cell Loss Probability vs. $\hat{X}$

Figure 8 shows the ABR cell loss probabilities under both schemes as a function of p for $2T_d = 20$ and $2T_d = 30$. The gain in terms of losses under the *PF* scheme is larger with the increased propagation delay. But, in addition to this, the gain increases as the variance of the distribution decreases (p increases). When the variance decreases, $\hat{X}$ estimates X_k more accurately since X_k becomes more concentrated around its mean.

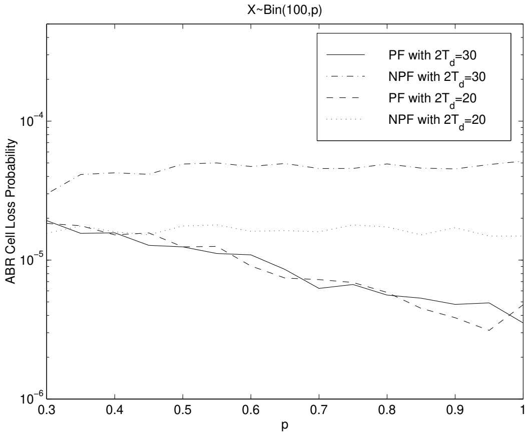

Figure 8: ABR Cell Loss Probability vs. p

5 Summary

In this paper, a proactive feedback based flow control scheme (*PF*) is introduced and compared with non-proactive flow control (*NPF*) schemes. Under an *NPF* scheme, the network access node transmits a feedback to the ABR source (to adjust its rate to the current available rate), when it detects a VBR source rate change. But, under the proposed *PF* scheme, the feedback is transmitted to the ABR source before the VBR rate change occurs. Under the *PF scheme* , if the exact time instant of a rate change is known, the feedback is transmitted a roundtrip propagation delay time ($2T_d$) before the rate change occurs. This totally eliminates the bandwidth mismatch which induces cell losses. If the rate change instants are not known, they can be estimated and the feedbacks can be transmitted according to the estimated time instants. The *PF* scheme guarantees to be at least as efficient as the *NPF* scheme by choosing a suitable estimator. In addition, it can provide for a fair rate allocation to ABR sources with different propagation delays, as the bandwidth mismatch is mostly dependent on the chosen estimator value under the *PF* scheme. However, bandwidth mismatch depends directly on the propagation delay under an *NPF* scheme. Thus, under the *PF* scheme ABR sources at different distances do not suffer losses due to their distances.

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