QoS Based ABR Service under the PF Based Flow Control Scheme *

Tamer Dağ † Ioannis Stavrakakis †

†Dept. of Electrical and Computer Engineering
Northeastern University
Boston, MA 02115
e-mail : {ioannis,tdag}@cdsp.neu.edu

Abstract

In this paper a new feedback based flow control scheme (Proactive Feedback) is introduced which can deliver better QoS to ABR applications than under the classical schemes, as well as guarantee a predefined level of QoS by setting properly the link utilization factor. The Proactive Feedback based flow control scheme can eliminate the reaction time of ABR source rate adjustments to the network bandwidth usage changes through cooperation between the VBR sources and the network nodes. In addition to supporting 'stringent' ABR applications, the PF scheme can also support UBR applications and/or co-exist with classical schemes supporting 'less stringent' (or standard) ABR applications.

1 Introduction

Among the four different service classes defined by the ATM Forum [1], the ABR (Available Bit Rate) service [2] is intended for non-real time applications which can tolerate delay. The ABR service is a best effort service and uses the bandwidth left from VBR (Variable Bit Rate) and CBR (Constant Bit Rate) applications. However, the dynamically changing bandwidth usage of VBR and CBR services necessitate the usage of feedback based flow control schemes for the ABR service.

The flow control schemes proposed for the rate based flow control [3, 4, 5, 6, 7], mainly operate on the idea of detecting congestion and responding to it by adjusting the ABR source rates. However, the cell loss probabilities occurring under these flow control schemes tend to be high because of the reaction time of the ABR sources to the bandwidth usage changes.

In this paper, a Proactive Feedback (PF) based flow control scheme which tries to eliminate the reaction time of the ABR sources is presented. By employing coordination between the VBR/CBR sources and the network node, the network node is able to transmit early feedbacks to the ABR sources so that the ABR sources can adjust their rates to the current available bandwidth immediately. As the bandwidth overutilization is prevented in the PF based flow control scheme, the loss ratios can be controlled and any required cell loss probability can be achieved for a fixed buffer size by properly selecting a target link utilization. Thus, the PF based flow control scheme can support ABR sources with stringent QoS requirements.

Because of the selected target link utilization, some amount of bandwidth remains unused under the PF based flow control scheme. Thus, in order to efficiently use the bandwidth, the excess bandwidth can be used by UBR sources with no QoS requirements or by ABR sources with very low QoS requirements. By this way, the PF based flow control scheme allows diverse applications to be supported simultaneously.

The remainder of the paper is organized as follows. In Section 2, the PF based flow control scheme is presented for a single node environment. In Section 3, the PF based flow control scheme is extended to a more general environment by introducing coordination of local and global feedbacks. In Section 4, some numerical results are presented for the PF based flow control scheme and compared with the EPRCA (Enhanced Proportional Rate Control Algorithm). In Section 5, some conclusions are made.

2 The Proactive Feedback Based Flow Control Scheme

In this section, the Proactive Feedback (PF) based flow control scheme for the ABR services is described.

Since the ABR service aims to use the remaining bandwidth left from other services such as VBR and CBR, some flow control schemes for the ABR service need to

*Research supported by the National Science Foundation under grant NCR-9628116.

be employed. However, due to the presence of propagation delays, the efficiency of the flow control schemes decrease due to the late reaction of the ABR sources to a congestion occurring in the network. The PF based flow control scheme tries to reduce (or eliminate) the amount of reaction time by employing cooperation between the VBR sources and the network node and generating early feedbacks for the ABR sources so that congestion can be prevented before it occurs.

Consider a transmission link shared by N VBR and M ABR applications as shown in Figure 1. Assume that the ABR sources are at different distances from the network node and the propagation delay between the ABR source i and the network node for each ABR source $(1 \leq i \leq M)$ is denoted by T_d^i. The network node has a finite buffer of size C, for the temporary storage of ABR and VBR cells.

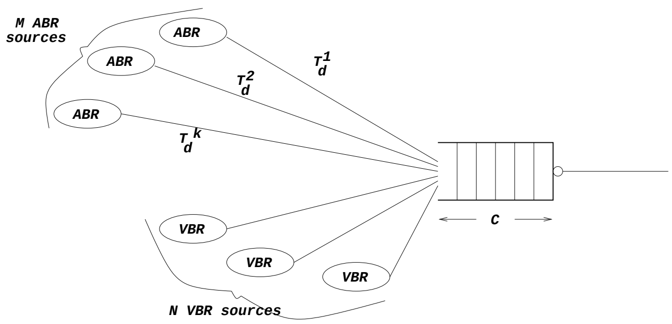

Figure 1: An example network

If the VBR sources provide information to the network node about their current rates, next rates and current time scales (interval over which the current rate will be in effect), the network node can coordinate and shape performance over finite time intervals of interest by calculating the available bandwidths left for the ABR sources and transmitting the bandwidth information to the ABR sources earlier than under the classical reactive flow control schemes.

The information that the VBR sources provide to the network nodes can be in special control cells transmitted with every VBR source rate change. These cells - referred to as parcells (parameter cells) - shall contain r_c (current cell rate), r_n (next cell rate) and T_c (current time scale) fields.

Based on a parcell received from a VBR source, the network node will conclude that the VBR source will be transmitting with rate r_c for a period of T_c slots after which the rate in effect will be r_n. Thus, the network node can calculate the available bandwidth left to the ABR sources for a time horizon allowed by the timing information contained in the parcells. The available bandwidth can then be equally shared among the ABR sources supported by the network node. Assuming that the network node knows the propagation delays between the ABR sources and itself, the network node transmits the available bandwidth information to the ABR sources a roundtrip propagation delay before a VBR rate change occurs. This way, the ABR cells transmitted with a rate adjusted to the next VBR rate change will arrive at the network node at the same time that the VBR rate changes. Thus, under the PF based flow control scheme ABR sources at different propagation distances will not suffer from losses occurring due to increased propagation delays.

In order to calculate the feedback generation instants, the network node keeps track of the parcells received from the VBR sources.

At each time slot, the network node decrements T_c^i, $1 \leq i \leq N$. Whenever T_c^i reaches the roundtrip propagation delay of an ABR source, T_d^k,$1 \leq k \leq M$, the network node generates a feedback for the ABR source with an explicit rate information calculated from the VBR parcells.

In order to calculate the rate to be transmitted with the feedback, the network node compares T_c^i with other VBR sources' time scales (T_c^j, $1 \leq j \leq N$). If $T_c^j \geq T_c^i$, then the j^{th} VBR source will be transmitting with its current rate when the ABR cells with the adjusted rate reaches the network node. Thus, r_c^j should be used for the available rate calculation. If $T_c^j < T_c^i$, then the j^{th} VBR source will have made a rate change before the ABR cells with the adjusted rate reaches the network node. Thus, r_n^j should be used for the available rate calculation.

Thus, the total VBR rate when the ABR cells with the adjusted rate reach the network node is given by the following equation,

$$r_v^{tot} = \sum_{T_c^j < T_d^k} r_n^j + \sum_{T_c^j \geq T_d^k} r_c^j.$$

The total available rate for the ABR sources is the remaining rate given by the following equation,

$$\begin{aligned} r_a^{tot} &= 1 - r_v^{tot} - \epsilon \\ &= 1 - \sum_{T_c^j < T_d^k} r_n^j - \sum_{T_c^j \geq T_d^k} r_c^j - \epsilon. \end{aligned}$$

Finally, if the total available rate is equally shared among the ABR sources, the available rate for a single ABR source can be expressed as,

$$r_a = \frac{1 - \sum_{T_c^j < T_d^k} r_n^j - \sum_{T_c^j \geq T_d^k} r_c^j - \epsilon}{M}.$$

In calculating the available ABR rate, a link utilization parameter ϵ ($\epsilon \geq 0$) is employed for stability reasons. Also, by selecting an appropriate value for ϵ, the cell loss probabilities can be controlled and any required cell loss probability can be achieved for a given buffer size. In order not to waste the remaining bandwidth left from VBR and ABR applications, UBR (Unspecified Bit Rate) service with no QoS requirements can be supported as well. However, in order not to affect the VBR and ABR performance, both VBR and ABR cells arriving at a node should have higher priority than the UBR cells. Thus, both ABR sources with stringent QoS requirements and UBR sources can be accommodated.

3 The PF Based Flow Control Scheme in a Multi-node Environment

The PF based flow control scheme described in the previous section can be applied to a more general network by employing coordination between the network nodes.

Consider a network node shown in Figure 2. The network node may have connections to upstream nodes, downstream nodes and to VBR and/or ABR endsystems. Any endsystem may use the network node for a connection if the path of the connection passes through the network node. The information flows from upstream nodes through downstream nodes or from VBR/ABR endsystems through downstream nodes. The feedback flow is in the reverse direction.

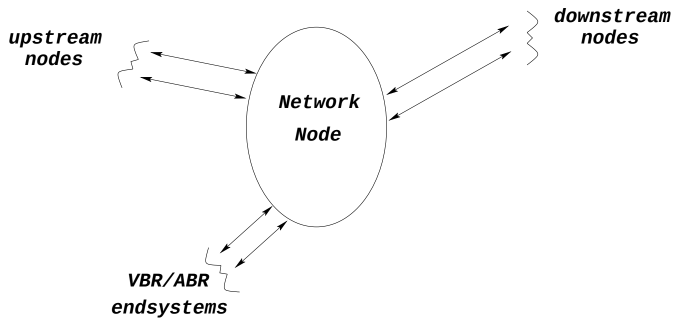

Figure 2: A model of the network node

Each node has a table which shows the active connections and the parcells received from the VBR sources. Thus, the PF based flow control scheme can be applied at each node by using the algorithm given in the previous section. However, in addition to the locally generated feedbacks at the network node, there may be feedbacks coming from the upstream nodes.

Let r_{f_k} denote the available rate that is calculated by the network node using the parcell information and f_k be the time instant that this rate should be transmitted to the ABR sources. Let r_{g_l} denote the available rate calculated by a downstream node and reached the network node at time g_l.

If the network access node transmits all the feedbacks (thus all r_{f_k} and r_{g_l}), then the PF scheme which was shown to be very efficient in a single node environment can fail in a multi-node environment. As the network node transmits the requests of all downstream nodes without any constraints, the ABR sources replies can cause congestion in the network. Therefore, the network node should coordinate r_{f_k} and r_{g_l} for an efficient PF based flow control scheme operation.

Let r_G denote the most recent value of r_{g_l} transmitted from a downstream node. r_G may or may not be transmitted according to the policy described below. Let G denote the transmission time (transmitted or not) of r_G at the network node. Let r_F denote the most recent *transmitted* feedback value. It may be equal to either r_{f_k} or r_{g_l}. Let F denote the transmission time of r_F at the network node.

With these definitions a possible policy to transmit feedbacks without causing bandwidth overutilization can be as follows.

The policy to transmit r_{f_k}:

- If $r_{f_k} < r_F$, then r_{f_k} will be transmitted as ignoring it would cause a bandwidth overutilization in the amount of $r_f - r_{f_k}$. When, r_{f_k} is transmitted $r_F \leftarrow r_{f_k}$.
- If $r_{f_k} \geq r_F$, then a comparison between r_{f_k} and r_G will be made.
  - If $r_{f_k} > r_G$, then the feedback will be ignored, because a downstream node is probably in congestion and the ABR source rates should not be increased.
  - If $r_{f_k} \leq r_G$, then the feedback will be transmitted. Thus $r_F \leftarrow r_{f_k}$.

The policy to transmit r_{g_l}:

- If $r_{g_l} < r_F$, then r_{g_l} will be transmitted because ignoring it would cause a bandwidth overutilization in the amount of $r_F - r_{g_l}$ at a downstream node. Thus, $r_F \leftarrow r_{g_l}$ and $r_G \leftarrow r_{g_l}$.
- If $r_{g_l} \geq r_F$, then r_{g_l} will be ignored. But, $r_G \leftarrow r_{g_l}$.

In a multi-node environment the PF based flow control scheme can still guarantee the stringent QoS requirements of the ABR sources. But, a bottlenecked node may limit the utilization of some ABR sources which do not experience congestion elsewhere in the network. In that case, some additional traffic (e.g. UBR applications, ABR applications with lower QoS requirements) may be used to fill up the excess bandwidth left from VBR and ABR sources. Since UBR applications do not have any QoS requirements, they have lower priority than VBR and ABR source cells. At a network node, the VBR and ABR cells have both space and service priority to the UBR cells. If a VBR/ABR cell arriving at a network node finds the buffer full, it takes place of a UBR cell waiting in the buffer (if there is) and the UBR cell is lost instead of the arriving high priority cell. In addition, the UBR cells are served only when there are no VBR/ABR cells present in the buffer. Thus, the loss ratio of the UBR service is expected to be higher than the loss ratio of the ABR service. As a result, the PF based flow control scheme allows diversification of traffic supported by a network node.

4 Numerical Results

In this section, some simulation results for the PF based flow control scheme are presented for a single node and a multi-node network. Also, the performances of the PF based flow control scheme and EPRCA are compared.

For the single node example as shown in Figure 1, it is assumed that a transmission link is shared by 3 ABR and 2 VBR applications where the ABR sources are at different propagation distances from the network node (5,10 and 15 slots respectively). The VBR sources are represented by two-state Markov chains with source rates of (0.3 - 0.5) cells/slot for the first VBR source and (0.1 - 0.4) cells/slot for the second VBR source. The average time scales for the VBR sources are 200 slots and 350 slots respectively. Heavy traffic assumption is made for the ABR sources.

Figure 3 illustrates the ABR cell loss probabilities at the network node as a function of ϵ for a buffer size C=50. As ϵ increases the cell loss probabilities decrease as expected. Therefore, given a fixed buffer size, by selecting an appropriate value of ϵ the required cell loss probability can be obtained. For example, if a cell loss probability of 10^{-4} is required for a buffer size C=50, ϵ should be larger than 0.05.

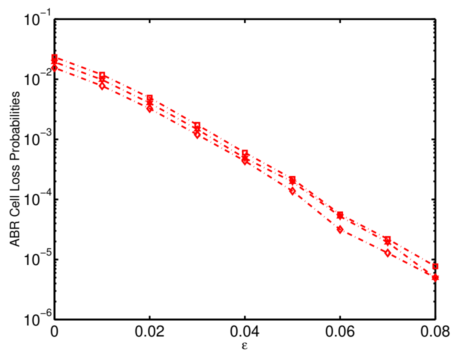

Figure 3: Cell Loss Probability vs. ϵ

Figure 4 compares the cell loss probabilities of PF based flow control scheme and EPRCA when the link distance varies. For this figure, the average VBR time scales are equal to 400 slots and 350 slots respectively. The buffer size C=50 and the buffer threshold for EPRCA is 15 where the best performance is obtained. As the link distance increases, the time to react to bandwidth availability changes increase for the EPRCA. Thus, the cell loss probabilities increase. But, for the PF based flow control scheme, the cell loss probabilities remain constant as long as the VBR time scale is larger than the roundtrip propagation delay. Thus, a lower constant cell loss ratio is observed for the PF based flow control scheme.

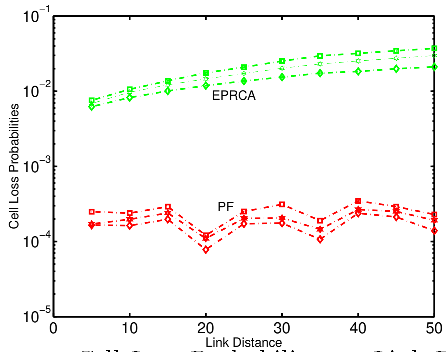

Figure 4: Cell Loss Probability vs. Link Distances

To measure the performance of the PF based flow control scheme in a multi-node environment, the network in Figure 5 is used. The network has 2 VBR sources and an ABR source where the VBR source characteristics are similar to the single node example.

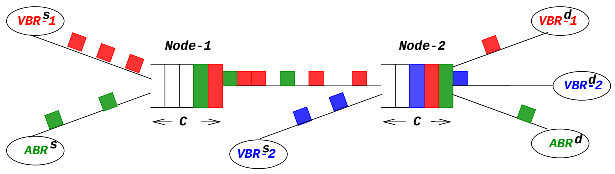

Figure 5: Simulated Network

When the ABR source has approximately equal utilization under both the PF based and EPRCA flow control schemes as shown in Figure 6, the PF based flow control scheme has a better performance than the EPRCA for cell loss probabilities. Because of the coordination between the VBR sources and the network nodes, the network nodes are able to prevent congestion before it occurs under the PF based flow control scheme and thus the cell losses occurring are less than cell losses occurring under the EPRCA scheme.

To see the effects of adding UBR traffic to the network, a UBR source is added to the network of Figure 5 such that the UBR source cells shares both network nodes 1 and 2 like the ABR source.

Figure 7 illustrates the cell loss probabilities of ABR and UBR sources for varying buffer size C when $\epsilon = 0.05$. As expected, increasing the buffer size improves the performance of the ABR and UBR sources. To make a comparison between the loss probabilities occurring under the EPRCA and PF based flow control scheme, the ABR cell loss probability occurring under the EPRCA scheme is also plotted when the utilization of the ABR_{EPRCA} is equal to the utilization of ABR_{PF} (U(ABR_{EPRCA}) =

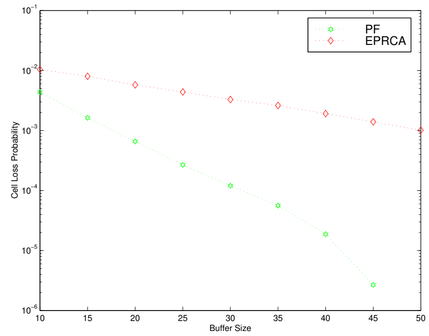

Figure 6: Comparison of PF and EPRCA

U(ABR_{PF})) and when the utilization of the ABR_{EPRCA} is equal to the sum of the utilization of ABR_{PF} and UBR_{PF} (U(ABR_{EPRCA}) = U(ABR_{PF}) + U(UBR_{PF})). The cell loss probability of ABR_{PF} is always less than the cell loss probability of ABR_{EPRCA} even when an additional UBR traffic is added to the network.

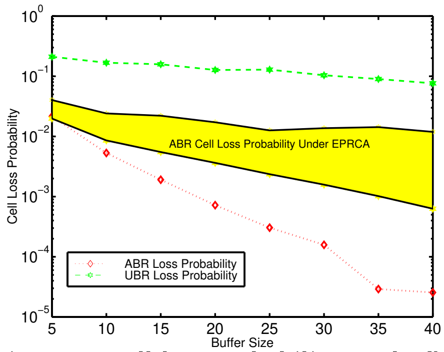

Figure 7: Cell loss probability vs. buffer size

Figure 8 illustrates the cell loss probabilities of ABR and UBR sources for varying ϵ for two cases of buffer sizes ($C = 20$ and $C = 40$). As ϵ increases both ABR and UBR cell loss probabilities decrease. Thus, PF based flow control scheme can work in a multi-node environment by allowing additional traffic with diversified QoS.

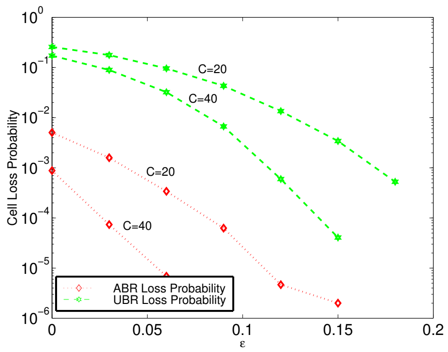

Figure 8: Cell loss probability vs. ϵ

5 Conclusions

In this paper, the PF (Proactive Feedback) based flow control scheme for the ABR services is introduced. Under the proposed PF based flow control scheme, early feedbacks are generated at the network nodes for the ABR sources by using the parcell information received from the VBR sources. ABR sources at different propagation distances from the network node can have their fair rate allocation and they do not suffer from cell losses affected by their propagation distances as the PF based flow control scheme eliminates the reaction time of the ABR sources to changing bandwidth usage.

Losses occurring under the PF based flow control scheme is lower than those occurring under other schemes. In addition, the PF based flow control scheme can provide any required cell loss probability for a given buffer size by changing the link utilization parameter, ϵ.

The excess bandwidth left from VBR/CBR and ABR sources can be used by UBR sources with no QoS requirements. In addition, ABR applications controlled by the classical EPRCA scheme can be simultaneously supported receiving a lower level of QoS compared to than under the proposed PF scheme. Thus, in principle, three classes on non-real time applications can be effectively accommodated provided that certain level of class separation is possible at the nodes: 'stringent' ABR, ABR and UBR.

References

[1] ATM Forum, "Traffic Management Specification Version 4.0", *ATM Forum/95-0013R10*, Feb. 1995.

[2] T. Chen et al. , "The Available Bit Rate Service for Data in ATM Networks", *IEEE Communications Magazine*, pp. 56-71, May 1996.

[3] N. Yin and M. G. Hluchjy, "On Closed-Loop Rate Control for ATM Cell Relay Networks," *INFOCOM'94*, pp.99-108, Toronto, 1994.

[4] R. Beraldi and S. Morano, "Selective BECN Schemes for Congestion Control of ABR traffic in ATM LAN," *ICC'96*, pp. 503-507, 1996.

[5] A. Barnhart, "Baseline Performance Using PRCA Rate Control," *ATM Forum/94-0597*, July 1994.

[6] A. Charny et al., "Congestion Control with Explicit Rate Indications," *ICC'95*, pp. 1954-1963, Seattle, 1995.

[7] L. Roberts, "Enhanced PRCA," *ATM Forum/94-0735R1*, Aug. 1994.

[8] Mischwa Schwarz," Broadband Integrated Networks ", *Prentice Hall*, 1996.