A Rate-Based Flow Control Mechanism for Avoiding Congestion

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Abstract The rate-based flow control mechanisms for the Available Bit Rate (ABR) service are used to share the available bandwidth of a bottleneck switch connected to a bottleneck link fairly and reasonably among many competitive users, and to maintain the buffer queue length of the switch at a desired level in order to avoid congestion in Asynchronous Transfer Mode (ATM) networks. In this paper, a control theoretic approach that uses a Deadbeat-Response (DR) controller to the design of a rate-based flow control mechanism is presented. The mechanism has a simple structure and is robust in the sense that its stability is not sensitive to the change of the number of active Virtual Connections (VCs). Simulation results show that this mechanism not only ensures fair share of the bandwidth for all active VCs regardless of the number of hops they traverse but also has the advantages of fast convergence, no oscillation, and high link bandwidth utilization.

Keywords ATM network, congestion prevention, flow control, control theory

1 Introduction

A major development in high-speed networking is the emergence of Broadband Integrated Service Digital Networks and Asynchronous Transfer Mode (ATM), and the basic transmission unit in ATM is a cell with 53 bytes. When the cell routes through a switch node, the Virtual Path Identifier (VPI) and the Virtual Channel Identifier (VCI) in the cell header are used for looking up switching tables to quickly decide the output VPI, VCI and port number for the completion of switching. Many VCs can be multiplexed to share a link bandwidth.

Several service classes have been defined in ATM for the support of traffic with different Quality of Service (QoS) requirements. The Available Bit Rate (ABR) service class was defined for the support of “best-effort” applications. This service class does not provide any strict guarantee. It attempts to minimize the cell loss at the expense of delay and allows applications to fully utilize the available bandwidth in the network by adjusting their instantaneous transmission rates to the available capacity. The ATM Forum Traffic Management Committee has completed the specification of a rate-based flow control framework to satisfy this objective[1]. Thus, the rate-based flow control mechanisms for the ABR service are designed not only to avoid network congestion but also to guarantee the available bandwidth to be shared fairly among all the ABR competitive users in ATM networks[1-3].

The various rate-based flow control mechanisms can be classified broadly into two categories depending on the feedback mechanism employed: binary feedback mechanism and Explicit Rate (ER) mechanism. A number of ER mechanisms have been proposed in the literature[4-6] due to their reported advantages over the binary feedback mechanism. The reported advantages of the ER mechanism include: the use of more information from the switches, such as the current queue length and its growth rate; the reaction time is substantially better; faster startup in most cases; policing can be straightforward since the entry switches can monitor returning Resource Management (RM) cells and use the rate directly in their policing algorithms; and robustness against the loss of RM cells, as the...
next correct RM cell will bring the rate to its correct value. However, the main drawback of these mechanisms is that the control schemes are based on heuristics and do not provide any formal design methodology to ensure the stability of the control loop. In [7], the authors suggested that formal methods should be applied to the design of closed loop flow control in high-speed networks. In [8], an analytical method for the design of closed loop flow controllers is developed, and the issues of stability and fairness are addressed. In addition, several control theory-based flow control mechanisms have been proposed in [9-12]. In these control mechanisms, the main characteristic is that the Round Trip Time (RTT) for every Virtual Connection (VC) is considered during the design of the mechanisms and is measured during their operations.

One of the options of the ABR framework is the Virtual Source/Virtual Destination (VS/VD) option. This option allows a switch to divide an ABR connection into two or more separately controlled ABR segments[1], and the design considerations for this option have been discussed in [13]. In effect, the end-to-end flow control is replaced by segment-by-segment flow control. One advantage of the segment-by-segment flow control is that the segments have shorter feedback loops, which can greatly reduce RTT. Thus one can ignore the impact of RTT and focus on the flow control aspect in designing the ABR ER control mechanism, such as [14, 15].

In this paper, we propose a control-theoretic ER flow mechanism that is based on a conventional Deadbeat-Response (DR) controller. Our mechanism is simple and has lower implementation complexity.

The remainder of the paper is organized as follows. In Section 2 we briefly review the specification about the ER flow control. In Section 3 we provide the details of our mechanism. In Section 4 simulation results are presented. In Section 5 conclusions are given.

2 Explicit Rate Flow Control Mechanism and Its Design Objectives

The rate-based flow control mechanism for the ABR service in ATM networks operates as follows: the source periodically sends a “Forward” Resource Management (FRM) cell to the destination every N rm data cells. This FRM cell contains several fields, mainly including the Current Cell Rate (CCR) field that is set by the source to its current Allowed Cell Rate (ACR) when it generates an FRM cell, the Congestion Indication (CI) field that is used to have a source increase or decrease its rate by some predefined amount, and the ER field that carries a 15-bit floating point number representing the explicit rate. Upon receiving the FRM cell, the destination returns it to the source with the latest network information, and this FRM becomes a “Backward” RM (BRM) cell. The network information is contained in either one or both of its CI and ER fields depending on the mode of operation of the switch.

In the ER control mechanism, a switch computes an average fair share of its available capacity for each active VC. This quantity is called explicit rate and is given directly to the source in the ER field of either FRM or BRM. The source adjusts its ACR based on the feedback information contained in the BRM cells. If the CI bit is set, the source decreases its ACR by the Rate Decrease Factor (RDF). The ACR may go down to Minimum Cell Rate (MCR) which is a rate negotiated at connection set-up. Otherwise the source increases its ACR according to the Rate Increase Factor (RIF) that is a fraction of the Peak Cell Rate (PCR) negotiated at connection set-up. Under all conditions, ACR is not larger than the ER except for the conditions that the ER is less than MCR. The ER field in the FRM cell is initially set to PCR by the source, and then the intermediate switches can only decrease it. For the details of the specification about the ER control mechanism, the reader may refer to [1].

3 Mechanism Design and Analysis

3.1 Linear Dynamic Model

The DR flow control mechanism mainly consists of ABR Source End System (SES), ABR Desti-