ELSEVIER

Computer Communications 23 (2000) 802–815

computer communications

www.elsevier.com/locate/comcom

Performance of TCP applications over ATM networks with ABR and UBR services—a simulation analysis

D.B. Hoang*, Z. Wang

Basser Department of Computer Science, University of Sydney, NSW 2006, Australia

Received 24 September 1999; received in revised form 16 November 1999; accepted 16 November 1999

Abstract

This paper aims to present a comparative simulation study of the performance of TCP traffic over ATM networks with UBR and ABR services; to identify weaknesses of currently most promising ATM congestion control schemes; and to indicate the requirements for a fairer, simpler and more robust congestion control mechanism. Variety of congestion control schemes under various network configurations and traffic patterns are simulated for a comprehensive analysis. Simulation results show that Early Packet Discard (EPD) wastes buffer capacity and has no provision for fairness, Intelligent Marking [K.Y. Siu, H.Y. Tzeng, Computer Communication Review 24 (5) (1995) 81–106] does not provide adequate fairness among competitive connections, and ERICA + [R. Jain, S. Kalyanaraman, Y. Goyal, S. Fahmy, R. Viswanathan, ERICA switch algorithm: a complete description, ATM Forum Contribution 96-1172, 1996] is too restrictive and unnecessarily complicated. The paper also indicates that TCP flow control and ATM congestion control do not cooperate well when buffer overflows and retransmission occurs, necessitating further control mechanisms for improving performance.

Keywords: TCP-ATM flow control; Rate-based congestion control; Available bit rate service

1. Introduction

Asynchronous Transfer Mode (ATM) has emerged as the most promising technology in supporting future broadband multimedia communication services, and the driving force behind this technology is increasingly coming from data networking applications. Since most data applications cannot predict their own bandwidth requirements, they usually require a service that dynamically shares the available bandwidth among all active users. In ATM networks, Unspecified Bit Rate (UBR) service and Available Bit Rate (ABR) service are designed to support traditional data traffic applications, as opposed to voice or video. With UBR, the network only makes available unused network capacity and no commitment is made to UBR source. No feedback concerning congestion is provided. Both delays and variable losses are possible. The ABR is designed to improve the service provided to bursty sources that would otherwise use UBR. An application using ABR can specify a Peak Cell Rate (PCR) that it uses and a Minimum Cell Rate (MCR) that it requires. The network allocates resources so that all ABR applications receive at least their MCR capacity. Any unused capacity is then shared fairly among all ABR sources. The main practical difference between ABR and UBR is that, in the case of ABR, the network provides congestion information to the sources, enabling them to adjust the sending rate to avoid congestion and to achieve high throughput. For ATM to succeed, it needs to support the huge legacy of existing data applications, which invariably employ Transmission Control Protocol (TCP) as the transport layer protocol over the Internet. It is thus of paramount importance to study the performance of data transport protocols TCP over ATM networks with UBR service and ABR service.

For data traffic, whose traffic patterns are often highly bursty and unpredictable, congestion control poses a challenging problem for stable and efficient operations. TCP provides a reliable transfer of data using a window-based flow control and error control algorithm. Since the UBR service does not include flow control, it has to rely on TCP's congestion control mechanism when UBR service is employed to carry TCP traffic. However, this TCP/UBR combination is not very effective in terms of resource usage. The main reason is that a TCP segment is often much longer than the length of an ATM cell, and has to be segmented into multiple cells. Even if only one cell of the segment is lost, the

* Corresponding author. Tel.: + 61-2-9351-3423; fax: + 61-2-29351-3838.

E-mail address: doan@cs.usyd.edu.au (D.B. Hoang).

0140-3664/00/$ - see front matter
PII: S0140-3664(00)00157-2

Nomenclature

ABR	Available Bit Rate
ACR	Allowed Cell Rate
AAL5	ATM Adaptive Layer
ATM	Asynchronous Transfer Mode
CCR	Current Cell Rate
EPD	Early Packet Discard
ER	Explicit Rate
ERICA	Explicit Rate Indication Congestion Avoidance
IM	Intelligent Marking
MACR	Mean Allowed Cell Rate
MCR	Minimum Cell Rate
PCR	Peak Cell Rate
RM	Resource Management
TCP	Transmission Control Protocol
UBR	Unspecified Bit Rate

entire segment is considered lost and has to be retransmitted because ATM does not provide the cell retransmission function for error recovery. Early Packet Discard (EPD) is introduced to alleviate this problem. With this approach, the switch is equipped with a function to identify and discard cells belonging to the same upper-layer packet in order to protect other packets from corruption. The mechanism is expected to provide considerable throughput improvements when compared with TCP over plain UBR service.

Explicit Rate (ER) feedback mechanism has been proven effective for congestion control for high-speed networks [1–4] that it has been adopted for ABR traffic management by the ATM Forum [5]. The function of the mechanism is to control the cell emission rate of each source end system using feedback information from the network. If a switch in the network becomes congested, it sends congestion indication to the source end systems. Each source end system then decreases its cell emission rate to avoid buffer overflow at the congested switch. After congestion is relieved, the transmission rate is increased. When TCP uses the ABR service to carry its data, two distinct control algorithm mechanisms exist: the TCP window-based congestion control mechanism controlling the end-to-end loop between TCP components, and the ATM congestion control mechanism controlling the ATM networks. These two mechanisms are independent from each other. It is expected that some form of cooperation between the two mechanisms would help to control traffic flow more effectively. Several efforts have been made to study the performance of TCP over ATM networks. Some of them studied TCP over UBR, some studied TCP over ABR with a particular congestion control scheme. Romanow and Floyd [6] investigated the performance of TCP connections over ATM networks with UBR service, and compared it to the performance of TCP over packet-based networks. The simulation results showed that the effective throughput of TCP over ATM could be quite low when cells are dropped at the congested ATM switch. The low throughput was due to wasted bandwidth as the congested link transmitted cells from corrupted packets. They investigated two packet discard strategies, where Partial Packet Discard improves performance to some extent and Early Packet Discard prevents fragmentation and restored throughput to maximum levels.

Simulation of TCP over ATM with ABR service was presented in [7]. The results suggested that the performance of data applications could be severely degraded when the available bandwidth in the ATM network is drastically varied between a maximum and a minimum. Although the performance can be improved to a certain level by deploying large buffers at the ATM switch.

Hasegawa et al. [8] evaluated performance of three methods: TCP over UBR, TCP over EPD and TCP over ABR. The simulation experiments showed that TCP over ABR can outperform the other two methods in terms of fairness and throughput if the control parameters of rate-based congestion control algorithm were chosen carefully. However, the simulation also indicates that if the parameter set of the rate-based congestion control was not appropriately used, the congestion would be recognized at TCP level due to packet drops and TCP unnecessarily throttled its window size. The authors pointed out that some modification of TCP might be necessary for further performance improvement.

Because most applications use the congestion control provided by TCP, it is important to determine the benefit of using ABR congestion control at the subnetwork layer.

Most previous studies on the TCP traffic over ATM emphasize on particular congestion control schemes, employ particular network configurations and use different simulation tools from each other. It is difficult to draw comparative conclusions related to performance under various conditions.

This paper presents a comparative simulation study of the performance of TCP traffic over ATM network with UBR and ABR service. A comprehensive set of simulation experiments are performed, employing various congestion control schemes, network configurations, and traffic patterns. TCP effective throughput, packet delay and fairness are used as performance measures for comparison. The paper is organized as follows. Section 1 introduces the background information and issues under study. Section 2 presents a brief review of various congestion control schemes analysed in the paper. Section 3 presents the simulation model and its parameters. Section 4 presents simulation results and analysis. Section 5 points out strengths and weaknesses of the two most promising schemes. Section 6 concludes the paper by indicating the requirements for a fairer, simpler and more effective congestion control scheme.

2. Review of mechanisms

In this section we briefly describe various mechanisms that were employed in our comparative performance study.