ABSTRACT

We study both correctness and performance of the source/destination protocol of the Available Bit Rate (ABR) service in Asynchronous Transfer Mode (ATM) networks. Although the basic source/destination protocol for congestion management is relatively simple, the protocol specification has to cope with several "real-world" cases such as failures and delayed/lost feedback which may introduce complexity. Rigorous proofs of the correct functioning of the protocol based on a formal specification is necessary. We use a formal Extended Finite State Machine (EFSM) model to show that the ABR source/destination protocol is free of live-locks, so that under all conditions both Resource Management (RM) and data cells will be transmitted. We also show that the network options of Explicit Forward Congestion Indication (EFCI) and Explicit Rate (ER) interoperate correctly.

While ensuring the correct functioning of the protocol, it is essential that pathological situations do not result in abysmal performance, which is another form of incorrect operation. We use the understanding of the informal English description of the source/destination behavior and of our EFSM model to derive conditions that ensure that the source transmission rate is stable in the presence of delayed or lost feedback RM cells, especially under the operation of a source rule that requires the reduction of the source rate under these conditions. We arrive at bounds on the number of consecutive RM cell losses tolerated while the rate remains stable.

It is also of vital importance that the delay for feedback of network state is well understood. There are two components of this delay contributed by the source/destination protocol: the source delay for sending out the probe Forward RM cells and the destination delay to turn-around the Backward RM cell. We provide a worst-case analysis of the delay in turning around RM cells at the destination station and the worst-case inter-departure time of Forward RM cells from the source.

1. INTRODUCTION

The Available Bit Rate (ABR) service class for Asynchronous Transfer Mode (ATM) networks uses a rate control scheme to manage congestion. Sources adjust their rates such that the aggregate load on the network does not exceed the capacity of the network [ATM]. The protocol specification for the source and destination behavior to achieve overall congestion avoidance and control is specified using a relatively informal specification described in [ATM]. Many of the aspects of the protocol have been designed based on extensive performance analysis through simulation. Simulation has been used especially to determine correct parameter settings. There is little work in the literature that rigorously analyzes the performance and examines the correctness of the ABR protocol.

Some of the properties of the protocol, such as whether it is correct or not, are difficult to show using simulation. A formal specification is necessary for this purpose. Correctness relates to whether the specified protocol is free of any undesirable properties. We model the ABR protocol by an Extended Finite State Machine (EFSM) and show that the ABR protocol is live-lock free in terms of transmitting data cells and Resource Management (RM) cells, which act as source probes of the network conditions.

In addition, the ABR congestion management specification accommodates at least two different modes in which switches in the network may operate. The source/destination policies (the main focus of the specification) are designed to smoothly operate with any intermix of the two types of switches in the network - these are the Explicit Forward Congestion Indication (EFCI) and Explicit Rate (ER) switches. EFCI switches use a single bit to communicate congestion [RI] when a queue threshold is exceeded. ER switches on the other hand compute a max-min fair rate [CCJ, CR] and communicate this rate to the sources. The source and destination use a common ABR protocol to interface to both types of switches. We examine whether the specification correctly inter-operates with both types of switches, using the formal specification we have developed.

Rate based flow control mechanisms also need some form of protection against failures. For example, when the feedback from the network is not provided in a timely manner or is lost, it is desirable that the source reduces its rate so that the network is not overloaded by the source transmitting at an incorrectly high rate. ATM's ABR service also permits sources to start at a high initial rate so that higher layer protocols and applications such as Remote Procedure Calls (RPC) may transmit a short burst without a start-up delay of a full round-trip time for feedback from the network (Source Rule 6 in [ATM]). To avoid using this potentially high rate for too long, and thus exceeding the buffering in the network, the source rules specify a proportionate reduction in the rate in the absence of feedback from the network. This rate reduction may also be triggered in certain cases when the current transmission rate of RM cells by the source is mismatched with the rate at which RM cells return from the network, especially subsequent to a source rate increase. If the parameters are set inappropriately, this may...