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Error Control for Reliable Multipoint Communication in ATM Networks

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Abstract

A new framework for support of reliable multipoint communication in ATM networks is presented. It is based on a new adaptation layer type, called the Reliable Multicast ATM Adaptation Layer (RMC-AAL), and on a new network element, called the Group Communication Server (GCS). A set of error control mechanisms tailored for multipoint communication are integrated into RMC-AAL and GCS. Error control is based on ARQ and FEC schemes, allowing to select the mechanism that is most suitable for the application requirements in a specific communication scenario. The functionality of adaptation layer and group communication server are described, a basic implementation architecture is presented, and results of a performance evaluation are given.

1 Introduction

Upcoming applications, for example distributed multimedia systems, computer-supported co-operative work (CSCW) applications, and virtual shared memory systems require high performance multipoint communication services. The provision of a multicast service with a specific quality of service (QoS) in terms of throughput, delay and reliability is of growing importance.

Various issues need to be addressed in order to provide group communication services in ATM networks [1, 2]. Switches need to incorporate a copy function for support of 1:N virtual channels (VCs). Signaling must be capable of managing multipoint connections, and group management functions need to be provided for administration of members joining and leaving a group. Procedures for routing and call admission control (CAC) need to be adapted for multicast communication. Another key problem that must be solved to provide a reliable multipoint service is the recovery from cell losses due to congestion in the switches. Short periods of congestion may occur due to statistical correlations among variable bit rate traffic sources, resulting in buffer overflow. The probability for cell loss may vary over a wide range, depending on the strategy for usage parameter control (UPC) and call admission control which is applied. Cell losses do not occur randomly distributed, but in bursts and show a highly correlated characteristic [3]. If a reliable service in ATM networks is based on traditional transport protocols like TCP, severe performance degradations may be observed [4]. Additional problems occur for the provision of a reliable multipoint service, where transmitters need to deal with many receivers and where cell losses occur more frequently.

This paper focuses on suitable error control mechanisms for correction of cell losses. Section 2 gives an overview on related protocols for error recovery. In section 3, the proposed framework for reliable multicast communication is presented. Section 4 presents performance results of different error control schemes.

2 Error Control Protocols

2.1 Adaptation Layer Protocols

According to the B-ISDN protocol reference model, mechanisms for error recovery may be integrated into the Service Specific Convergence Sublayer (SSCS) of the adaptation layer [5] for provision of an assured mode service [6]. Up to now, only two SSCS-Protocols that offer error control mechanisms are specified in the B-ISDN recommendations. The Service Specific Connection Oriented Protocol (SSCOP) is subject of standardisation for a SSCS that offers assured mode service for signaling. The protocol provides end-to-end flow control and retransmission of lost or corrupted data frames by operating in either selective repeat or go-back-N mode. However, SSCOP does not support assured mode multicast connections. For AAL1, a SSCS with FEC is proposed [6], based on a Reed-Solomon-Code applied on blocks of 128 cells that allows the regeneration of up to four missing cells.

2.2 Transport Protocols

Transport protocols that are suitable for a connectionless network layer, as for example TCP, TP4 and XTP, provide more functionality than the functionality that is required for a SSCS protocol. These transport protocols need to tolerate packets delivered out of sequence by the network layer. A

SSCS protocol for a reliable service may be simpler, as it may use sequence number gaps for error detection. The TP++ transport protocol [7] is designed for a heterogeneous internetwork with large bandwidth-delay products and is suitable for ATM networks. TP++ uses a type I hybrid ARQ scheme and is at present the only transport protocol for high speed networks with FEC. It is only capable of unicast communication. Up to now, no hybrid ARQ protocol was presented for multicast communication in ATM networks.

2.3 Protocol Implementation

While transmission capacity was growing enormously over the last years, protocol processing and system functions in the transport component turned out to be a performance bottleneck. High performance communication subsystems, based on parallel protocol processing, and hybrid architectures with hardware components for time-critical operations [8] are required for provision of a service with high throughput and low latency. For highest performance, complete VLSI implementations of transport subsystems are planned [9]. The performance bottleneck of the transport component that can be observed for point-to-point-communication is even more crucial for reliable multipoint connections. For a growing number of receivers, processing of a growing number of control packets and management of a large amount of status information needs to be performed.

2.4 Selection of Protocol Mechanisms

In order to offer a wide range of services to the applications for various network parameters, several concepts of flexible communication subsystems are under development. The parallel transport system PATROCLOS [8] is a parallel implementation of a high performance transport system, offering a wide range of protocol mechanisms that may be selected according to the needs of an application. The Flexible Communication SubSystem (FCSS) [10] is a configurable, function-based transport system. It allows protocol configuration and the reservation of resources in order to provide applications with a specific service quality.

3 Conceptual Framework for Reliable Multipoint Communication in ATM Networks

A conceptual framework was developed based on error control mechanisms in the adaptation layer of ATM end systems and in dedicated servers. For large groups, the servers may be used hierarchically.

3.1 Reliable Multicast ATM Adaptation Layer

In order to offer a reliable and efficient high performance multicast service, the concept of a Reliable Multicast ATM Adaptation Layer (RMC-AAL) was developed. Its ideas are based on the proposal of a configurable extended adaptation layer [11], on the parallel transport system PATROCLOS and on the flexible communication subsystem FCSS.

RMC-AAL extends basic functions of AAL5 by selectable error control mechanisms. Error recovery is based on three schemes: pure ARQ, type I hybrid ARQ and pure FEC. A fully reliable service and a service that assures delivery to K out of N receivers are offered. Retransmissions may be sent by multicast or by unicast in selective repeat or go-back-N mode. It can be selected if retransmissions are frame-based or cell-based (by retransmission of frame fragments). When FEC is used, h redundant cells are generated for $l \cdot h$ information cells, based on XOR-operations and matrix interleaving. Frames are distinguished using the ‘end-of-message’ identifier of AAL5 in the payload type field of the cell header. Frames are identified by a sequence number (with frame sequence numbers of 24 bit) and carry the payload length (16 bit) in the frame header. Cell sequence numbers (6 bit) are provided for detection of missing cells. Two options are available for additional frame-based error detection. The payload of a frame may be protected by the cyclic redundancy check CRC-32 of AAL5 for a minimum Hamming distance of four when applied to a payload with up to 11454 bytes. For cell-based retransmissions, the payload may be protected by a weighted sum code of 32 bit (WSC-2 of [7]). This alternative error detection method requires a more complex processing unit, but allows to evaluate the code for payload protection in any order. For links with a high bit error probability, the per-cell cyclic redundancy check CRC-10 of AAL3/4 may be applied for a minimum Hamming distance of four. Receivers send acknowledgements periodically, after reception of a frame in which an ‘immediate acknowledgement’ bit is set, and after detection of cell loss. Receivers may use cumulative positive acknowledgements by sending the frame sequence number of their lower window edge. Additionally, they may use bit maps (with a length of 32 byte) for selective acknowledgement of frames and of individual cells. For retransmissions of frame fragments, the first cell of a retransmission frame carries a bit map that identifies retransmitted cells. For flow control, acknowledgements contain the upper window edge of the receiver buffer section reserved for the multipoint connection. Selection of acknowledgement mode, retransmission mode, and time-out periods of RMC-AAL is performed using control frames.

3.2 Group Communication Server

The presented reliable multicast adaptation layer represents an important step towards a high performance reliable multicast service. Further improvements of performance and efficiency may be achieved by the deployment of dedicated servers in the network that provide support for group communication. In many cases of multicasting, the achievable throughput degrades fast for growing group sizes. A significant advantage can be achieved if a hierarchical approach for multicast error control is chosen. The proposed Group Communication Server (GCS) integrates a range of mechanisms that can be grouped into the following tasks: provision of a high-quality multipoint service with efficient use of network resources; provision of processing support for multicast transmitters; support of heterogeneous hierarchical multicasting; multiplexing support for groups with multiple transmitters.

For the first task, performing error control in the server permits to increase network efficiency and to reduce delays introduced by retransmissions. Allowing retransmissions originating from the server avoids unnecessary retransmissions over common branches of a multicast tree. The integration of FEC mechanisms into the GCS allows regeneration of lost cells and reinsertion of additional redundancy for adjusting the FEC coding scheme according to the needs of subsequent hops.

For the second task, the GCS releases the burden of a transmitter that deals with a large number of receivers, providing scalability. Instead of communicating with all receivers of a group simultaneously, it is possible for a sender to communicate with a small number of GCSs, where each of them provides reliable delivery to a subset of the receivers. Integrating support for reliable high performance multipoint communication into a server allows better use of such dedicated resources.

For the third task, a GCS may use the potential of diversifying outgoing data streams, allowing conversion of different error control schemes and support of different qualities of service for individual servers or subgroups. A group communication server may offer the full range of error control mechanisms of RMC-AAL. However, it is not required to implement the full functionality of RMC-AAL in every end system. Instead, it will be sufficient for end systems to have access to a local GCS for participation in a high performance multipoint communication over long distances, as simple error control mechanisms are sufficient for communication with a local GCS. If a priority field is used in the frame format, the server is able to distinguish frames of different importance. One example application would be hierarchically coded video. For information of different importance, different FEC codes may be applied for the same VC, and specific frames may be suppressed for certain outgoing links.

For the fourth task, the GCS provides support for multiplexing of AAL5 frames onto a single point-to-multipoint connection [15]. It may be selected if the GCS operates in reassembly or in streaming mode.

Figure 1 shows a proposed implementation architecture for a Group Communication Server. Main focus of the design was to achieve a high degree of pipelining. Acknowledgement processing for a large number of receivers is a potential bottleneck. Therefore, dedicated hardware support is provided for generation, filtering and processing of acknowledgements, and for managing the status information of the group and of individual receivers. The unit performing this functionality is called *ARQ manager*. The *send manger* unit schedules between ordinary transmissions, retransmissions and acknowledgements. A component of the *ARQ manager* generates multicast flow control information required by the *send manager*. The *connection manager* unit schedules between different connections and is also responsible for rate control and spacing. Additional hardware components are required for CRC, FEC, buffer management, list and timer management. For cell demultiplexing at the receiving side, a content addressable memory (CAM) is used to map the large VPI/VCI address space on smaller internal identifiers.

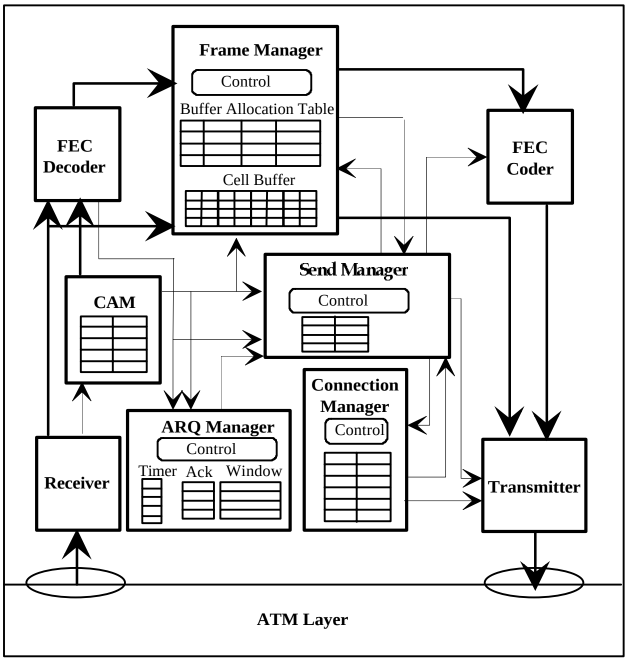

Figure 1: Architecture for the Group Communication Server

4 Performance Evaluation

It is important to know which error control scheme is best suited for a given situation. For some multicast scenarios, the achievable performance of the proposed error control schemes was evaluated by simulation and by analysis. For modelling of the correlation properties of lost cells, a two state Markov model (Gilbert Model) was applied. Based on the worst case observations of [3], a probability of 0.3 was used for a cell discard following a cell discard. This is equivalent to cell losses with a mean burst length of 1.428 cells. Using this error model, four different error control schemes were simulated in a point-to-multipoint scenario with four receivers. A multicast tree with one common link and four individual links was assumed, and the same error model was applied to all links. A data rate of 100 Mbit/s, a distance of 100 km, and a frame length of 50 cells was used. The first scheme used selective retransmissions of frames, the second scheme allowed selective retransmission of missing cells. In the third scheme, FEC with 5 redundant cells was combined with selective retransmission of frames, while the same FEC with selective retransmission of missing cells was combined in the fourth scheme. Figure 2 shows the efficiency (relation of usable cells to total number of transmitted cells) of the four schemes for different cell loss probabilities. Figure 3 shows mean delays that were observed. Maximum efficiency may be achieved by the ARQ scheme with cell-based retransmission. If only complete frames are retransmitted, a part of the efficiency is wasted by cells that were already successfully transmitted. For the two FEC schemes, the redundancy of 10% limits the achievable efficiency to 0.9. This disadvantage is traded off by the fact that the delay remains constant over a wide range of cell loss probabilities. Figure 3 also shows a constant delay of 0.4 ms caused by FEC. For the distance and data rate of the simulation, this constant delay is a significant part of the round trip time. Therefore, the mean delay of the ARQ schemes is lower than the mean delay of the hybrid schemes up to a cell loss rate of 10^{-4}. However, for equivalent mean delays the ARQ scheme causes already a large jitter. For longer distances and larger groups, FEC will show an even higher advantage.

Analytical methods were applied in order to evaluate the achievable performance of RMC-AAL in selective repeat (SR) and go-back-N (GBN) mode and to evaluate the potential gain by deployment of GCSs. Figure 4 shows the efficiency of the two retransmission modes in three different scenarios. Scenario 1 represents a basic 1:N multicast without GCS. Scenario 2 represents 1:N multicasting with a GCS that performs multicast retransmissions. In scenario 3, the GCS uses individual VCs for retransmission. The analysis is based on the following assumptions: protocol processing times may be neglected, acknowledgements are transmitted over a reliable connection, and buffers are sufficiently large. Figure 4 is based on a group of 100 receivers, a data rate of 622 Mbit/s, and an overall distance of 1000 km (with common and individual links of 500 km). The analysis shows that in all cases, the efficiency is increased significantly by the GCS. Highest efficiency may be achieved for scenario 3 and selective repeat. Go-back-N retransmissions show acceptable performance only for moderate loss probabilities. Regarding efficiency, scenario 3 and selective repeat should be selected. However, this solution requires the highest implementation complexity for end systems and GCS.

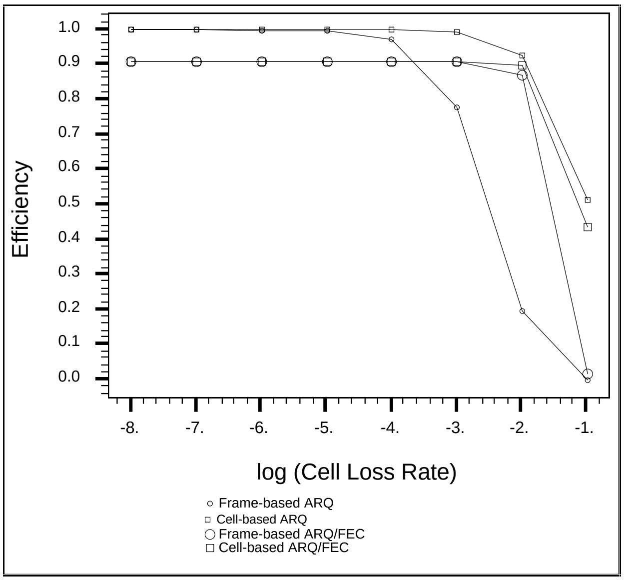

Figure 2: Simulation results for efficiency

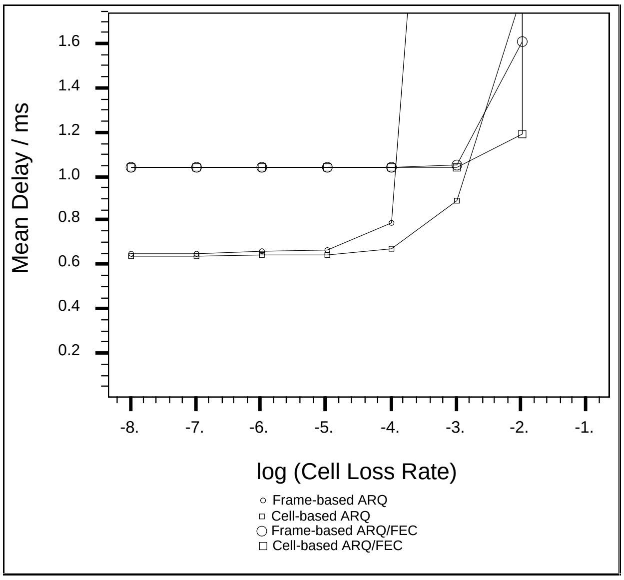

Figure 3: Simulation results for mean delay

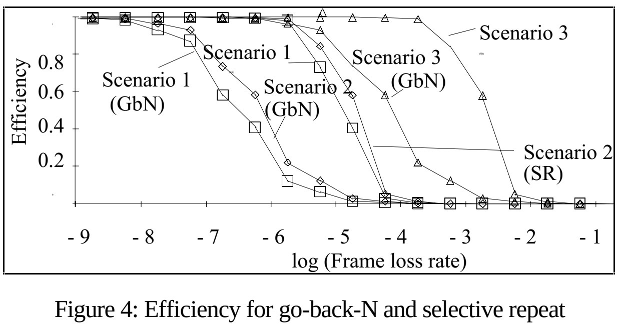

Figure 4: Efficiency for go-back-N and selective repeat

5 Conclusions

It was pointed out that existing strategies do not allow the provision of an efficient and reliable high performance multipoint service in ATM networks. A new concept was presented which has the potential to fulfil the requirements of upcoming distributed applications. It is based on the integration of multicast ARQ and FEC error control schemes into a new adaptation layer type called the Reliable Multicast ATM Adaptation Layer (RMC-AAL) and into a new network element called the Group Communication Server (GCS). A first performance evaluation is given which shows the differences of the alternative error control schemes onto service quality of multipoint connections, and potential improvements if GCSs are integrated into the network. Subject of ongoing work is a more detailed evaluation of the achievable performance, including investigation of the influence of processing times and of limited buffers. Implementation complexity will be evaluated to allow a better comparison of the alternative approaches. This should allow to derive guidelines for the deployment of GCSs and for the selection of the error control scheme best suited for a given situation.

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