2nd IFIP Workshop on Personal Wireless Communications - Wireless Local Acces,
Frankfurt, Germany, 10-12 December 1996

Assessment of Edge Devices with Error Control Mechanisms for ATM Networks with Wireless Local Loop

Georg Carle
Elmar Dorner

Institute of Telematics
University of Karlsruhe (TH)
76128 Karlsruhe
Germany
[carle|dorner]@telematik.informatik.uni-karlsruhe.de

Abstract

The growing market of both wired ATM networks and wireless Personal Communication Networks leads towards the problem of how to achieve the integration of wireless with wired networks. Although wireless technology will allow the implementation of a large number of new services, several significant problems still need to be solved for widespread use.

A key difference between wireless and wireline systems is link reliability. The error characteristics of wireless links and wired links differ in some fundamental ways, such as error probability and correlation properties of bit errors. Therefore, the common approach of end-to-end error control for reliable services in wired networks may lead to severe performance degradations when used in communication scenarios involving a wireless local loop.

In this paper, we investigate error control strategies for hybrid networks consisting of a high speed wide-area wired ATM network and a wireless local loop with significantly higher error rates. In order to perform error control efficiently, we propose to perform error recovery not only in the end systems, but also in specific edge devices at crossing from wireless to the ATM cloud.

We present results of a performance evaluation by analysis and by simulation of conventional end-to-end error control, and error control including edge devices. We compare performance results for different retransmission strategies. A key result of our investigation is that the deployment of edge devices allows for a significant increase of throughput and significant reduction of mean delay and delay variance.

1 Introduction

In the telecommunication field today two major trends can be seen: evolution towards fixed broadband networks and the breakthrough of mobile communications. The next trend is expected to be the merging of these two lines of evolution [1]. Integration of mobile hosts into existing internetworking consisting mostly of stationary hosts gives rise to some peculiar problems because of the special requirements of small, low power mobile hosts, and also because of the special characteristics of wireless links. There is a growing need for new protocols to accommodate the specific needs of a wireless link in an efficient way.

In this paper, section 2 gives an overview on related protocols for error recovery. In section 3 the proposed edge device is presented. Section 4 presents an analytical performance evaluation and describes simulations we performed. Section 5 closes the paper with a conclusion of our work.

2 Motivation

With the growing acceptance of ATM as the standard for broadband networking, it has become appropriate to consider the feasibility of extending ATM capabilities to portable wireless platforms. Early technical results in this area indicate that it is indeed possible to use standard ATM protocols to support seamless wired and wireless networking [2], [3].

In such a hybrid networking infrastructure the network characteristics differ in many aspects. For the fixed part we can assume a very low bit error rate and a high path capacity. On the other hand, because of the effects of fading, interference and mobility, the error rate incurred in a wireless link is often very high. This leads to problems in end-to-end error control, because protocols which are well designed for high speed networks are often not well suited for the wireless part of such a hybrid network [4], [5].

Considering that a mobile host has only limited power and a smaller processing capability than a stationery host leads towards the perception that the majority of processing, e. g. of error control mechanisms, should be done in the wired part of a hybrid network. Fig. 1 shows a hybrid network scenario with the newly introduced transport level edge device. This device, which processes transport layer protocol functions, is part of the wired network and is connected to a wireless host via a base station. It is not necessary for the edge device and the base station to be in different locations. Where appropriate they can be combined.

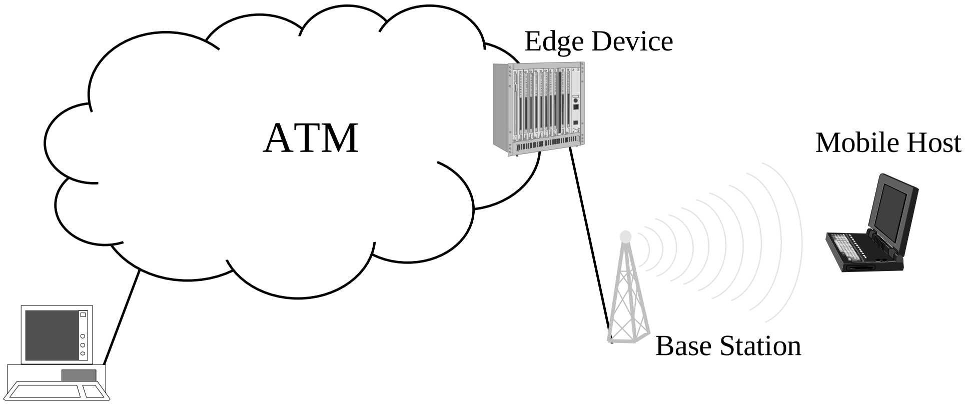

Figure 1: ATM network with Edge Device and wireless link

2.1 Related work

Previous research work in the areas related to low speed links and error correction can be found in [6], [7]. Since bandwidth is expensive in such a scenario it is necessary to minimize the amount of retransmissions. On the other hand, when the error rate on a wireless link is relatively high, it may be desirable to perform redundant transmissions with the assumption that the probability of a packet being delivered correctly is higher if it is transmitted more than once. Based on these considerations, the design of an asymmetric link-layer protocol is presented in [6] which uses a combination of adaptive Forward Error Correction (FEC) and retransmission mechanisms.

In [7] the aspect of multicast messages in networks with mobile hosts is discussed. The aim is to extend the existing protocols for network-layer multicast with static hosts to support transparent host mobility on the transport layer and above. The work also presents a framework for structuring protocols for the reliable delivery of multicast messages to mobile hosts.

In [4] the acknowledgement and retransmission policies in TCP and XTP are investigated in scenarios with high-speed wireless links. TCP was selected because it is one of the mostly used transport protocols. XTP offers certain protocol functions with policies that are more tailored towards high speed networks. The concept of a mobile hub is introduced in order to subdivide the end-to-end communication path into mobile subpaths and fixed subpaths. Different protocol policies may be applied over both sorts of subpaths. The simulation experiments showed the advantage of the mobile hub concept, especially considering end-to-end throughput.

3 ATM edge devices with error control

Figure 2 presents a network scenario with multicast mechanisms in the transport component of end systems and in dedicated servers. The term Group Communication Server (GCS) describes an edge device with multicast error control capability which is attached to a wired ATM network, and also to a base station for a wireless local loop. The Group Communication Server may integrate a number of mechanisms that can be grouped into three main tasks [8]:

- Provision of high-quality reliable services with efficient use of network resources;
- Provision of processing support for transmitters;
- Support of heterogeneous communication scenarios.

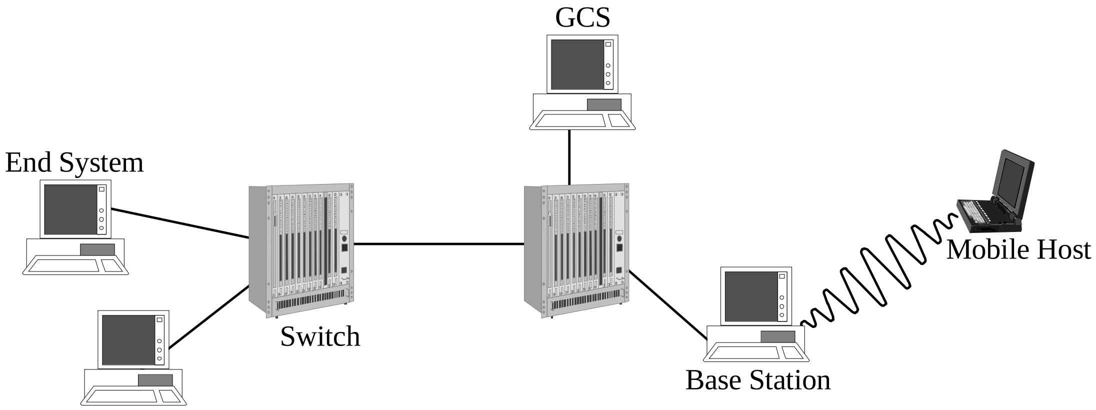

Figure 2: Error control in Group Communication Servers and end systems

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, as shown in Figure 3, avoids unnecessary retransmissions over wired sections of the network. In order to ensure low delay, the server does not guarantee an in-sequence forwarding of packets. Instead, it will forward every packet to the receivers as soon as possible. Low delay is ensured by allowing the server to detect losses prior to the receiver and to immediately initiate a retransmission by the sender.

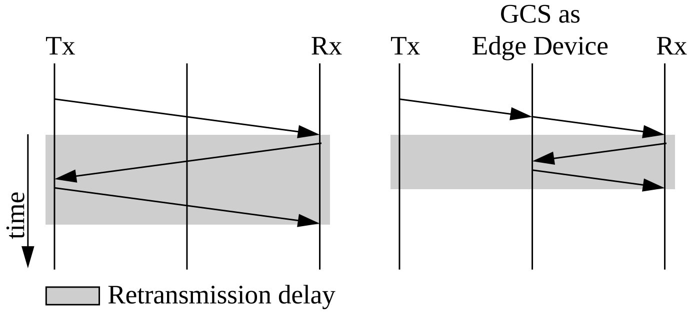

Figure 3: End-to-end error control versus error control involving edge devices

For the second task, the GCS releases the burden of a transmitter that may deal 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 processing support for high performance error control in a server allows better usage of dedicated resources such as coprocessors and buffers. For end systems, it is not required to have high error control processing capabilities. It will be sufficient to have access to a GCS for participation in a high performance point-to-point or point-to-multipoint communication over long distances. Then, the error control mechanisms of individual end systems have only negligible influence on the overall performance, as simple error control mechanisms are sufficient for communication with a local GCS.

For the third task, a GCS may use the potential of diversifying outgoing data streams, allowing support of different qualities of service for individual servers or subgroups. Furthermore it may apply filtering functions for specific data streams and support different subnetworks, where a different set of protocol parameters, or different error control schemes such as Go-Back-N (GBN) and Selective Repeat (SR), may be appropriate.

4 Performance Evaluation

4.1 System Model

Figure 5 shows the analytic model for the scenario studied in this work. The model consists of a transmitter, a wired link, a group communication server, a wireless link, and a receiver. The parameter λ indicates the rate of arrival from the source. The rate of arrival is the mean number of cells arrived within a specified time unit. As can be seen from the Figure, the transmitter and the group communication server have a buffer that is divided into two sections B1 and B2. The cells arriving from the source are stored in the FIFO buffer B1. After transmitting a cell, the cell is removed from buffer section B1 and stored in buffer section B2 until an ACK message confirms that the cell has been received correctly. After waiting in the buffer for transmission, the cells are delayed by a certain transmission delay indicated by a white circle.

For the following analysis, a system model was applied based on time slots T for the transmission of a single ATM cell. The transmission delay (T_t) is defined as the cell size in bits (N=384; ATM cell payload) divided by the link bit rate (R) in bits per second. The propagation delay (T_P), depicted by grey circles in the Figure, is defined as the physical separation in meters (D) divided by the velocity of the propagation of the signal in meters per seconds. The normalized path capacity S represents the number cells that may be stored on the links and in buffers of multiplexing equipment between the transmitter and a receiver. The assumptions used for the model in Figure 5 are as follows:

- The transmission delay for ACK/NACK cells are negligible;
- The ACK/NACK messages are sent on error-free channel;
- The buffers in the transmitter are infinitely large;
- The mean arrival rate is less than the mean service time;
- The receiver buffer for selective repeat has the size *Si* cells;
- The processing times in receiver, GCS, and transmitter are set to 0;
- The cells from buffer B2 have priority for transmission over cells in buffer B1.

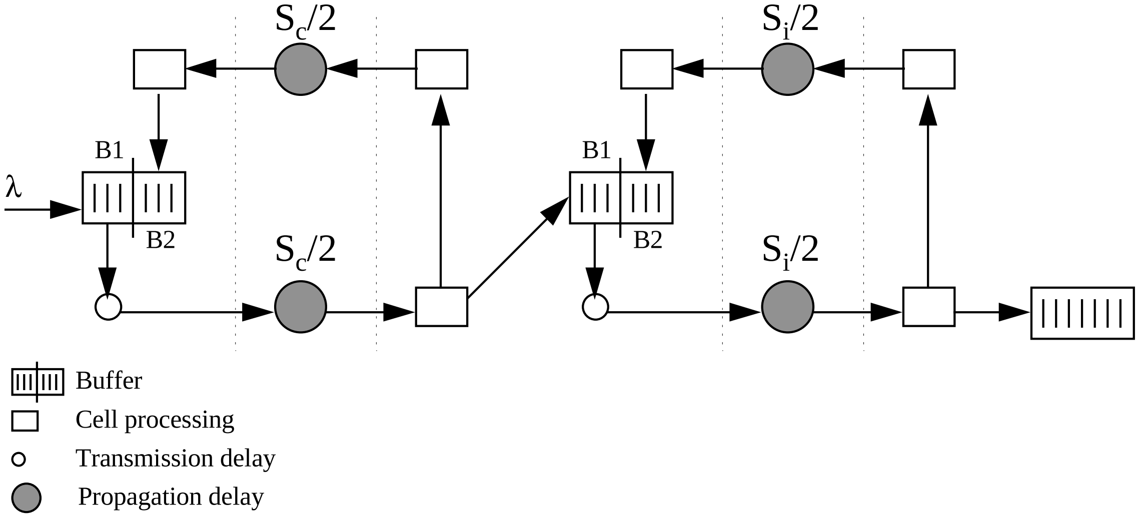

Figure 4: Model for the investigated scenario

For generating an analytically solvable model, we consider only those elements of the previous model which introduce delay: waiting time in buffers, transmission delay, and propagation delay. By evaluating the mean number of retransmissions in a point-to-point link for loss probability *q*, the mean delivery delay for this model can be obtained:

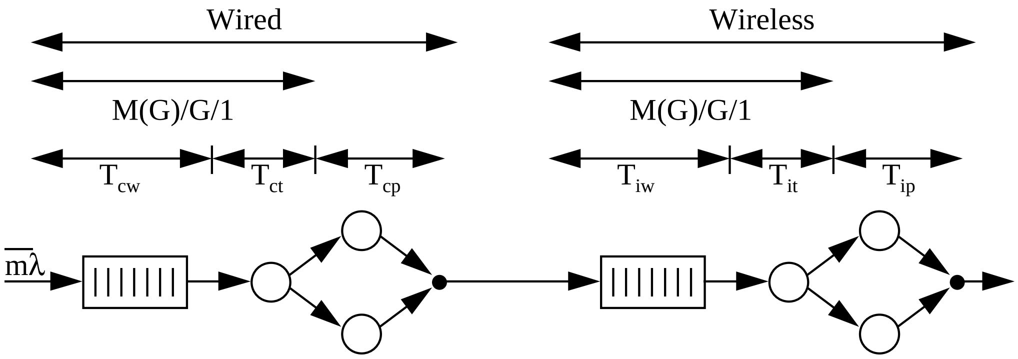

Figure 5: Simplified model for the hybrid system

Parameters used in this model are:

- T_{cw} Mean waiting time spent in buffer B1 for wired link;
- T_{ct} Mean transmission delay for wired link;
- T_{cp} Mean propagation delay for wired link;
- T_{iw} Mean waiting time spent in buffer B1 for wireless link;
- T_{it} Mean transmission delay for wireless link;
- T_{ip} Mean propagation delay for wireless link.

For a cell loss probability of zero and a Poisson distributed source the buffer and the transmission delay part form an M/G/1 or M/D/1 system (see Figure 5). With a cell loss probability higher than 0 the cells that need to be retransmitted are added to the Poisson flow . With a very high cell loss probability this part of the system behaves no longer as M/G/1 but rather as G/G/1. The variance of the arrival process is now larger, and the mean time spent in the buffer will therefore increase. However, with a cell loss probability studied in this work (typically less than 10^{-2}), it is reasonable to approximate this part to be equal to M/G/1.

4.2 Delivery delay

The total mean delivery delay is found by adding the different parts of the solvable analytic model. The delivery delay is the time difference between the time a cell is correctly received by the receiver and the arrival time at buffer B1.

It should be noted that the delivery delay does not include the waiting time in the receiver buffer. Selective repeat must also include a receiver buffer of size *s*. For ARQ schemes without receiver buffer (e.g. go-back-N) the delivery delay extends until the cells are delivered to the layer on top. In such schemes, cells are approved and delivered to the next layer simultaneously. The mean delivery delay is given by:

$$E(V)= T_{cw}+ T_{ct}+ T_{cp}+ T_{iw}+ T_{it}+ T_{ip} \tag{1}$$

Mean Waiting Time In Buffer B1: The formula for the waiting time in buffer B1 for a M/G/1 system is given by:

$$E(W) = \frac{\overline{m}\lambda\overline{m^2}}{2(1-\overline{m}\overline{m}\lambda)} \tag{2}$$

with E(W): mean waiting time in queue, $\overline{m}\lambda$: arrival rate, $\overline{m}$: first moment of the number of retransmissions, and $\overline{m^2}$: second moment of the number of retransmissions.

Mean Transmission Delay: The mean transmission delay is the mean number of transmission for each cell multiplied with the time it takes to transmit a cell once. One cell time unit is the time it takes to transmit one cell once. This gives the formula for the mean transmission delay:

$$T_t = \overline{m} \tag{3}$$

Mean Propagation Delay: The mean propagation time is the time in cell unit times that the cell propagates in the data channel added to the time the NACK propagates in the ACK/NACK channel. The parameter *s* denotes the number of cells that can be sent during one round trip delay. From Figure 5 it can be seen that the propagation delay is the sum of the propagation delay for data cells and the propagation delay for the NACK cells:

$$T_t = \overline{m}\frac{s}{2} + (\overline{m} - 1)\frac{s}{2} = 2\overline{m}\frac{s}{2} - \frac{s}{2} = (\overline{m} - \frac{1}{2})s \tag{4}$$

Total Delivery Delay With GCS: The total delivery delay for the scenario in Figure 6 is evaluated in this section. There is one ARQ scheme between the transmitter and the GCS (wired link) and one ARQ scheme between the GCS and the receiver (wireless link).

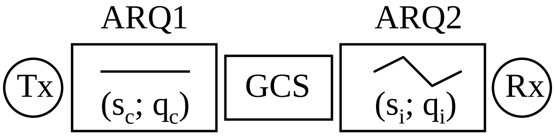

Figure 6: Simple model of the scenario with GCS.

The bitrates of the wired and the wireless link are assumed to be equal in the model. This means that the transmission time units are also the same. If $\overline{m_{ARQ1}}$ and $\overline{m^2_{ARQ2}}$ denote $\overline{m}$ and $\overline{m^2}$ for the common link, they can be calculated as functions of cell loss rate q_c and capacity s_c for the common link, allowing for the derivation of the total delivery delay including a GCS to:

$$\overline{V}_{ARQ1} = \frac{\overline{m_{ARQ1}}\lambda\overline{m^2_{ARQ1}}}{2(1 - \overline{m_{ARQ1}}\,\overline{m_{ARQ1}}\lambda)} + \overline{m_{ARQ1}} + (\overline{m_{ARQ1}} - \frac{1}{2})s_{ct} \tag{5}$$

Using a similar calculation for the delay of the wireless link, the total delivery delay is then:

$$\overline{V} = \overline{V_{ARQ1}} + \overline{V_{ARQ2}} \tag{6}$$

Links With Different Data Rates: As the wireless link has lower data rates than the wired link, the transmission time units for the links have to be different in order to use the derived formulas. We define the transmission unit factor k as the transmission rate for wired (R_c) divided by the transmission rate for the wireless link (R_i) :

$$k = R_c/R_i \tag{7}$$

The mean total delivery delay for the system shown is then:

$$\overline{V} = \overline{V_{ARQ1}} + k\overline{V_{ARQ2}} \tag{8}$$

4.3 Numerical Results: Delay Profile

A study of the profile of the delivery delay provides a better understanding of the characteristics of the system. One may see from Figure 7 showing the delay profile for GBN, the propagation delay for the wired link, the waiting time in buffer for the wireless link, and the transmission time also for the wireless link have the strongest influence on the total delivery delay. The propagation delay is the dominant delay factor for the wired part because the wired part has a high transmission rate (leading to a low transmission delay and a low waiting time in buffer) and the distance is large (leading to a high propagation delay). The characteristics for the wireless part make the waiting time in buffer and the transmission delay the dominant parts of the delivery delay. The Figure also shows that the waiting time in buffer for the wireless link increases most rapidly with increasing cell loss rate.

In this analysis, it has been shown that the waiting time in buffer for the wireless part is the delay part which is most sensitive to increased load and increased cell loss rate. The waiting time in buffer is therefore a critical point for this system. A more bursty source will increase the waiting time in the buffer. Correlated losses will decrease the waiting time in the buffer, as uncorrelated losses with the same overall loss probability lead to the highest delay in GBN and SR ARQ schemes.

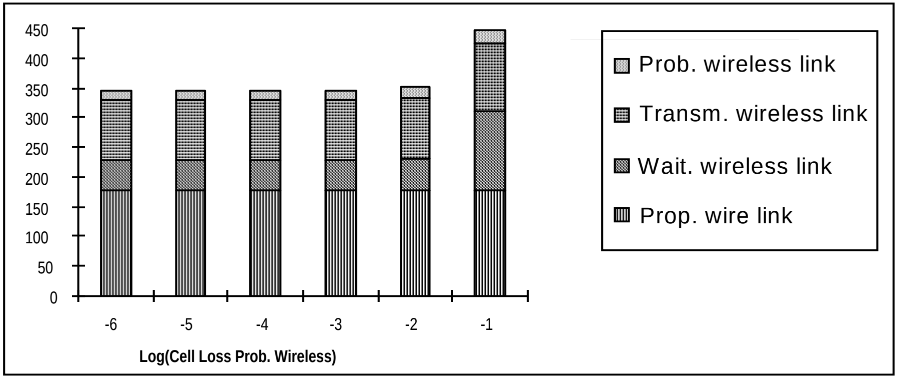

Figure 7: Delay profile for GBN.

4.4 Simulation

Taking the analytical model as a basis, we built a simulation model was built. This enabled us to perform various simulation runs for different system parameters. In our simulation we can set the bit rate, cell loss probability, and the distance for the wireless and wired link. Additional parameters are buffer size of the GCS and mean interarrival time for the transmitter. A simulation model also has the advantage of allowing refinements to closer fit a target system, where an analytical model becomes too difficult to solve.

As simulation tool we used BONeS/DESIGNER [9,10], a software package for modeling and simulating event-driven systems. It provides a graphical environment for modeling a system’s structure and function. The system model is hierarchically and graphically constructed by selecting blocks from a collection of library blocks. The tool performs an event-driven Monte Carlo simulation, measures performance, and displays the results graphically.

In Figure 8 the block hierarchy of the selective repeat simulation is illustrated. To obtain the simulation model for the GBN model, the blocks with SR in their label must be replaced with the correspondent GBN block. Furthermore the "GBN Nack Handler" contains an additional "Compute # Retransmission" block.

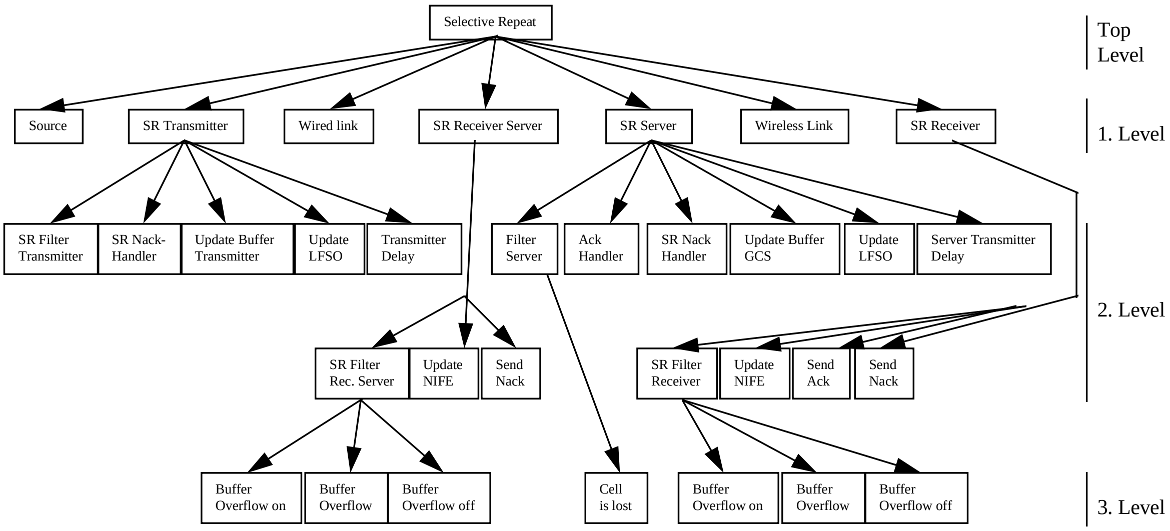

Figure 8: Block hierarchy of simulation model

4.5 Comparison of results from analysis and simulation

By the analysis in the section above it has been proven that the waiting time in buffer for the wireless part is that delay part which is most sensitive to increased load and increased cell loss rate. The waiting time in buffer is therefore a critical point for this system. The burstiness of the source and the loss correlation properties will affect the waiting time in the buffer. An analytical investigation of this influence is difficult. Simulations were therefore performed to investigate the waiting time in buffer for a correlated loss model. The stochastic variance of arriving cells will increase with a bursty source. Fig. 9 shows the simulation results for a parameter set defining a 150Mbit/s, 100km wired link combined with a 1.5Mbit/s, 10km wireless link.

Fig. 10 compares the analytical results with the results found by simulation. The parameters are the same as for the waiting time in buffer, except that the cell loss rate for the wired link is 10^{-6} and the arrival rate is 750kbit/s (half of the transmission rate for the wireless link). As predicted, using a GCS in selective ARQ mode presents the best performance. However, one has to take into account that this solution requires comparatively complex protocol processing and an extra buffer in the receiver. For lower cell loss probabilities, GBN and SR have almost equal performances. The conformity between the analytical results and the simulations for lower cell loss probabilities is very good. Only for atypical high cell loss rates, analytical and simulation results for SR differ considerably (not shown in Figure 9/10).

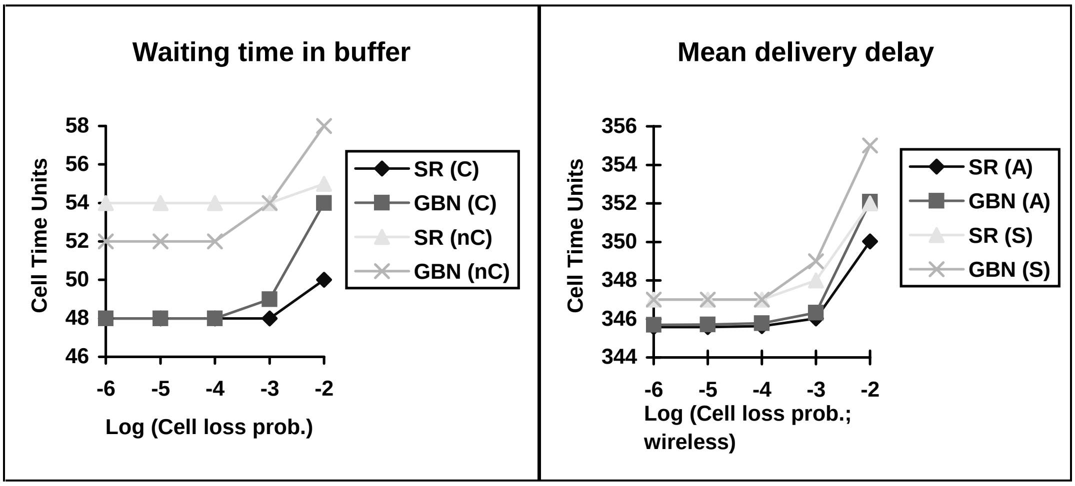

Figure 9/10: Waiting time in buffer / mean delivery delay

5 Conclusions

This paper assessed error control strategies for hybrid networks, consisting of a high-speed wide-area ATM network and a wireless local loop. An analytical model and a simulation model have been presented. Analytical results and simulation results showed a good conformity.

It was shown that the improvement achieved by the deployment of a GCS as edge device is fairly significant for a hybrid system. In the scenarios investigated, it turned out that the selective retransmission strategy shows only a marginally better performance than the significantly simpler GBN strategy. The following parameters have the strongest influence on this difference between the two re-transmission strategies: cell loss probabilities, path capacity, and load. For wireless loops with a path capacity significantly lower than in the wired section of the network, the proposed edge devices allow a significant increase in throughput, and a significant reduction of mean delay and delay variance.

An important issue that has not been discussed in this paper is the evaluation of the cost of the different alternatives. Does the improved performance using a GCS justify the extra cost of implementing the system and the cost of the extra network resources? SR requires an extra receiver buffer for re-sequencing cells and more complex logic than GBN. The cost for SR is therefore higher than for the GBN strategy. An increased buffer size will increase both the performance and the cost of the system. An investigation of the performance improvement of SR with increased receiver buffer size is the subject of ongoing work.

Acknowledgement

The authors gratefully acknowledge the support by Kurt Iben Kristiansen for his implementation of the simulation model and provision of simulation results.

References

[1] H. Hansén: *Connection management functions of a private wireless ATM network*, Master thesis, Helsinki University of Technology, March 1996.

[2] D. Raychaudhuri, N. Wilson: *ATM Based Transport Architecture for Multiservices Wireless Personal Communication Networks*, IEEE Journal on Selected Areas in Communication, Oct. 1994.

[3] L. Wei: *An Implementational Framework for Wireless Mobile ATM*, Proc. of Workshop for Information Visualization and Mobile Computing, Rostock, Germany, Feb. 26-27, 1996.

[4] M. Zitterbart, A. Fieger: *End-to-End Communication Across Hybrid Networks*, Chapter in Book: "High-Speed Networks for Multimedia Applications", W. Effelsberg, O. Spaniol, A. Danthine, D. Ferrari (Eds.), Kluwer Academic Publishers, Boston/Dordrecht/London, 1996.

[5] R. Cáceres, L. Iftode: *Improving the Performance of Reliable Transport Protocols in Mobile Computing Environments*, IEEE Journal on Selected Areas in Communications, vol.13, no. 5, june 1995.

[6] S. Paul, E. Ayanoglu, T. F. La Porta, K-W. H. Chen, K. K. Sabnani, R. D. Gitlin: *An Asymmetric Protocol for Digital Cellular Communications*.

[7] A. Acharya, B. R. Badrinath: *A framework for delivering multicast messages in networks with mobile hosts.*

[8] Georg Carle, Jochen Schiller: *Enabling High-Bandwidth Applications by High-Performance Multicast Transfer Protocol Processing*, 6th IFIP Conference on Performance of Computer Networks, Istanbul, Turkey, October 23-26, 1995, in S. Fdida, R. Onvural (Eds.): "Data Communications and their Performance", Chapman&Hall 1996, pp. 82-96.

[9] Alta Group: *Block Oriented Network Simulator*^{TM} *(BONeS*^{TM}*) User's Guide*, The Alta Group of Cadence Design Systems, Inc., U.S.A., 1995

[10] Kurt Iben Kristiansen: *Simulations and Analysis of Error Control Mechanisms for Wireless ATM Networks*, Master Thesis by Kurt Iben Kristiansen, performed at the Institute of Telematics, University of Karlsruhe, Germany, March 1996