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Performance evaluation of the ASR-ARQ Protocol for wireless ATM

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***Abstract* — This paper introduces an ARQ protocol to be used on the air interface of a cellular system offering a full integration of mobile ATM terminals into a fixed ATM network. The special aspects of this ARQ protocol resulting from the transmission of ATM cells are described like establishing multiple ARQ instances in order to vary the effort of error control on different VCs dependent on their QoS requirements. The protocol has been optimized to work together with a MAC protocol offering capacity on demand resulting from statistical multiplexing on the air interface.**

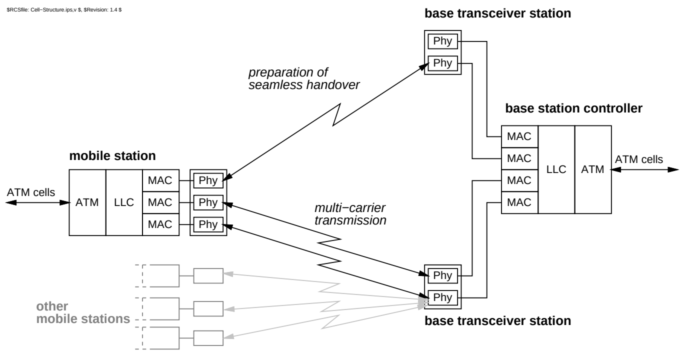

Figure 1: Structure of a MBS cell

I. Introduction

The Asynchronous-Transfer-Mode (ATM) turned out to be the transmission technique of future communication networks[1]. Following the general trend of extending services of fixed networks to mobile users, necessary network structures and protocols for a mobile extension of ATM networks are investigated within the project *Mobile Broadband System*[2] (MBS, R2067, supported by the European Commission under the RACE programme).

The goal of MBS is to allow full integration of mobile ATM terminals into a fixed ATM network. This integration should not affect the end-to-end relation of the protocols of the ATM adaption layer (AAL). The transmission of ATM cells over the air interface is to be transparent to the AAL. The resulting structure of MBS with base stations offering mobile stations access to the fixed ATM network is shown in figure 1. Several base transceiver stations are controlled by a base station controller which contains the ATM layer, and three MBS specific lower layers replacing the physical layer of the ATM network which are a LLC layer, a MAC layer with one instance of the MAC protocol for each transceiver unit and a MBS physical layer located in a transceiver of a base transceiver station.

Because of restricted transmission conditions on the air interface in comparison to a fibre link, an additional error correction scheme is necessary. This scheme consists of a hybrid combination of *forward error correction* (FEC) and *automatic repeat request* (ARQ). The FEC is included in an appropriate channel coding under responsibility of the physical layer. The ARQ protocol is executed by the LLC layer. The structure of the LLC layer is described in section II.

When developing the ARQ protocol there is a fundamental trade-off between delay caused by retransmissions and residual cell loss ratio (CLR). It is not useful and often not possible to offer CLR values which are available in fixed, fibre based networks. Instead it should be possible to adapt the amount of error control for each virtual channel according to its requirements described by the connection specific parameters *maximum delay* and *cell loss ratio* specified during connection set-up.

To meet the requirements on error correction the *Adaptive Selective Repeat Automatic Repeat reQuest* (ASR-ARQ) protocol has been developed. It is derived from conventional ARQ protocols like HDLC, ISO 8802.2 and LAP-B of ITU-T. The protocol controls the number of retransmissions in dependency of the requested QoS, taking into account the current queueing delay and channel load. It offers an advanced *Selective Repeat* (SR) algorithm using *Selective REJect* (SREJ) commands in order to force retransmissions. To avoid overflow of buffers, it is possible to discard cells, which have exceeded their maximum delay because of congestion or worst propagation conditions.

The ASR-ARQ protocol establishes one ARQ instance per VC resp. virtual path (VP). This allows to vary the effort of error control for different VCs dependent on their QoS requirements. A sophisticated multiplexing and queueing strategy based on a priority mechanism is responsible to schedule cells of parallel ARQ instances according to their instantaneous requirements. Some special aspects of the ARQ protocol resulting from the transmission of ATM cells are described in section IV.

In order to control the stability and to evaluate the performance of the developed protocols a complex simulator has been implemented. The details of the simulator are described in section V.

II. Structure of the Logical Link Control Layer

The development of the LLC layer of MBS is closely related to the development of the MAC protocol. In [3] a pro-

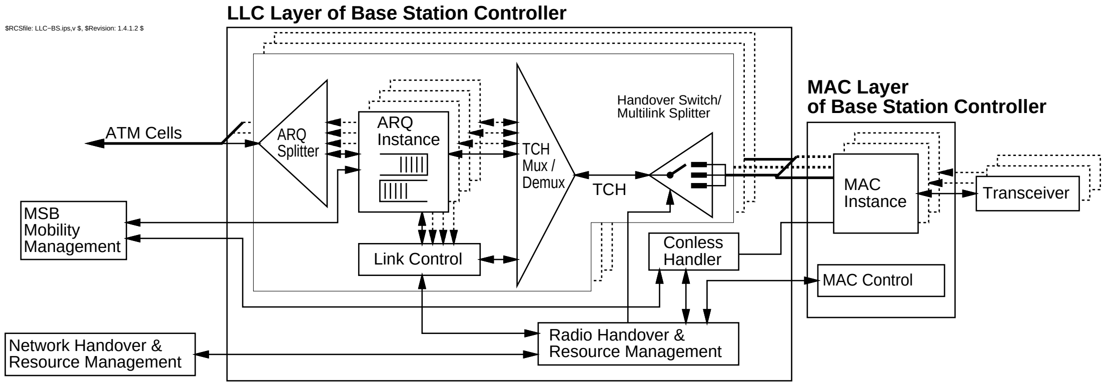

Figure 2: Structure of the LLC layer of the base station controller

posal for the MAC protocol of MBS is described. It enables the access of multiple mobile stations to the air interface by extending the statistical multiplexing from ATM multiplexers and offering capacity on demand. One instance of the MAC protocol is generated for each transceiver unit (figure 2). The generation of MAC instances is controlled by the MAC layer controller. In the mobile station the controller is responsible for the generation and update of a data base containing all available channel resources. A resource scanning algorithm is responsible for finding the paging or pilot channel of base stations. This channel resource data base is used by upper layer functions for admission control, resource management and handover. The controller in the base station is executing an algorithm for dynamic frequency selection offering low inter cell interference and high channel efficiency.

The extension of ATM networks to mobile users requires special mobility management functions. Very important for the observance of QoS requirements is the execution of *seamless handover*. As long as only one base station controller is involved in a handover (figure 1), it is executed completely within the LLC layer and the network/ATM layer is not affected. Therefore the lower sublayer of the LLC has to offer functions to prepare a seamless handover by establishing connections to alternate base stations. The execution of a handover has to be done transparently for the instances of the ARQ protocol.

Another task of the LLC layer is the execution of multi-link transmission for services requiring higher data rates than available on one carrier (figure 1). This mode is only available, if the mobile station contains multiple transceiver units for parallel transmission on several carriers. The lower sublayer of the LLC layer contains a splitting and recombining unit for multi-link transmission. The splitting takes place dynamically according to the current availability of capacity indicated by the MAC protocol.

The ARQ Splitter is splitting and recombining the stream of ATM cells delivered from the ATM layer to the belonging ARQ instances.

An ARQ instance is responsible for executing the ARQ protocol for one VC. It contains the sending and resequencing buffers. In order to reduce complexity of the LLC layer, it seems to be reasonable to possibly multiplex ABR-like VCs above ARQ, because they normally request the same very low cell loss rate and are insensitive to large delays.

PDUs generated by the ARQ instances are called frames. Frames directed to the same destination (mobile station ↔ base station controller) are multiplexed on one logical channel, the *Traffic CHannel* (TCH) (figure 2). The base station establishes one TCH for each registered mobile station.

The multiplexing is executed by the TCH mux/demux which is responsible for controlling the order of access from ARQ instances on the TCH. It contains a priority controlled mechanism for determining ARQ instances, which are allowed to transmit the next frames. The priorities for the ARQ instances are calculated based on following parameters:

residual lifetime Difference between maximum delay and queueing period of buffered ATM cells

queue length Number of buffered ATM cells

exception situations Necessity of transmitting supervisory frames, e.g. *Receive Ready* in case of a closed window (too much pending acknowledgements)

III. Advantages of multiple ARQ Instances

Because of the requirements on short delays of ATM cells of real-time oriented services it is useful to handle such VCs with higher priority than VCs with high maximum delay. This results in a changed sequence of ATM cells which do not belong to the same VC but keeps the sequence of cells of the same VC in order.

Therefore in contrast to traditional LLC protocols the ASR-ARQ protocol establishes one ARQ instance per VC resp. virtual path (VP). This allows the adaptation of the amount of error correction for each VC according to the required QoS. Furthermore the transmission capacity offered by the MAC layer can be assigned to the ARQ instances according to their priority.

There is another advantage of using multiple ARQ instances leading to shorter delays. If all ATM cells would be processed by only one ARQ instance, situations will occur, in which ATM cells have to wait for the retransmission of missing cells although not necessary: In case of an incorrect transmission of a cell, cells with "higher" sequence numbers than the missing one have to be buffered in the receiving ARQ instance until the missing cell is retransmitted correctly. But if the rejected ATM cell belongs to a different VC than the waiting ones, the delaying of these cells would not be necessary. Forwarding the buffered cells to the upper layer would have been possible before, if the belonging of cells to VCs is known by the receiver. This lack of knowledge is avoided by using multiple ARQ instances.

A. Separation of acknowledgement and information

As shown in figure 3 an ARQ frame consists of several control fields with a type of frame, several counters and addresses and an information field, containing an ATM cell. The type of frame defines the type of acknowledgement (e.g. positive, negative) used in a particular frame. Thus acknowledgements are piggybacked on information frames. Without ATM cells being available on a specific VC, acknowledgements are transmitted with empty information field. This type of frame is called pure supervisory frame. Asymmetrical traffic on several VCs in both directions normally leads to an overhead of pure supervisory frames, because ARQ instances have to deliver acknowledgements without being able to piggyback them on information frames. Even with a more symmetrical traffic, acknowledgements stick to their payload. ARQ instances are unable to deliver highly recommended acknowledgements without getting high priority for their ATM cells. The priority algorithm selecting frames to be sent is oriented to the requirements of transmitting payload and not acknowledgements. It is obvious, that the separation of VCs delivering acknowledgements from those delivering information for the generation of a frame to be transmitted solves this problem. Combining messages of two VCs in one frame, it is necessary to add a second ARQ-Id, identifying the VC associated with the acknowledgement.

The separation of acknowledgement and information requires two independent algorithms, one for selecting the ARQ instance delivering the acknowledge message and the other delivering the information. Parameters for determining the ARQ instance with the highest prioritized acknowledgement are:

type of acknowledgements Three types are used:
- **Receive Ready (RR)** Acknowledgement for the receipt of one or more information frames up to number N(R)
- **SREJ** Forcing retransmission of frame N(R)
- **Delay** Signalling the delay of frame N(R) (see section IV.)

No. frames Number of frames being received since the last acknowledgement has been transmitted

delay time Time passed by since occurrence of an event causing the necessity for an acknowledgement, e.g. receipt of a frame

In case of lack of any information cells in one direction it is possible to combine the acknowledgements of multiple VCs in one frame.

IV. Advanced Selective Repeat Algorithm

The ASR-ARQ protocol is based on a HDLC–like window algorithm and has been adapted to the special needs of wireless ATM transmission. The buffer length of an ARQ instance will be adapted to the QoS requirements of the associated VC. The queueing delay of every buffered ATM cell is stored in order to automatically adapt the number of retransmission to the maximum delay, the maximum cell loss rate and the current channel load. ATM cells, which exceed their maximum delay, will be treated in a special way explained in section B.

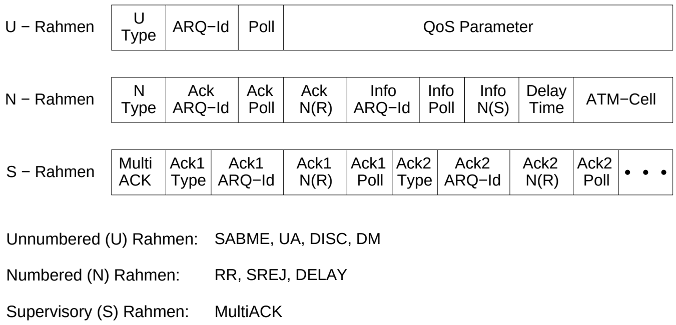

Figure 3: Structure of ARQ frames

Figure 3 shows the structure of the frames with the various counters and parameters in the control field, using two ARQ-Ids and two P/F bits, one for acknowledgement (Ack) and one for information (Info) each.

A. Resequencing hazards and their avoidance

The ARQ instance in the receiving station is responsible for the resequencing of received ATM cells according to their *frame sequence number*. If the interference of a burst was too high for the FEC to decode it correctly, the information frame that was included in the interfered burst will be missing in the sequence and has to be requested for retransmission. The protocol makes use of SREJ (N(R)), which orders retransmission of the information frame marked with the *receive sequence number* N(R). If the received sequence is complete, the receiver acknowledges the transmitted data by sending a RR (N(R)) command with N(R) being the sequence number of the next I frame to be awaited.

As described in the literature [4], *Selective Repeat ARQ* (SR-ARQ) protocols only allows to make use of $m/2$ as the maximum window size, where m is the modulus coding the sequence numbers. Using a larger window than $m/2$, resequencing hazards may occur. In this case the receiver has no chance to distinguish between reception of a retransmitted frame and a new frame. There are two strategies to deal with these hazards, defined as follows:

conservative: reducing the maximum window size down to $m/2$ as described above

progressive: introducing an ignore timer, enlarging the maximum window size up to $m-1$

The *conservative* strategy allows to repeat the transmission of previously sent, but still unacknowledged frames, when the sending station is polling for an acknowledgement. This type of frame is sent, when the transmitting station has reached the end of its transmission window.

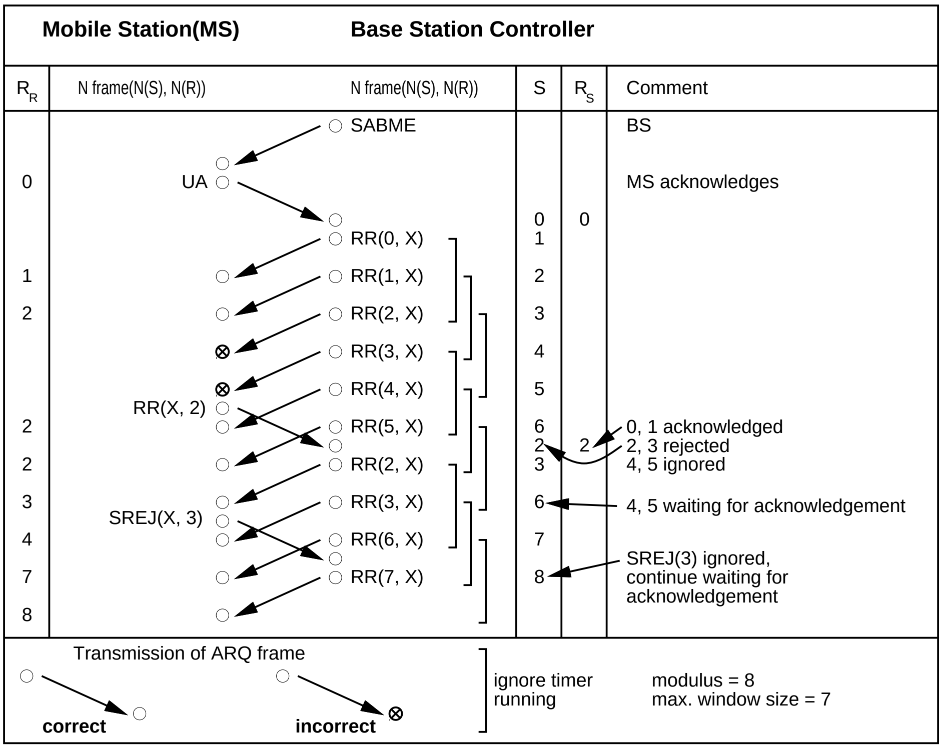

Figure 4: Usage of the ignore timer

Because acknowledgements of the receiver are missing, the sender is not able to shift its transmission window in time. Because of the constant slot length, designed to carry N frames with an ATM cell as payload, pure S (Supervisory) frames without a payload lead to wasted capacity and hence are not useful. Therefore the usage of the empty information field for retransmission of not requested N frames makes sense, even if they were already received and not the reason for the pending acknowledgement.

With the *progressive* strategy unrequested retransmissions are prohibited. But this strategy has to deal with another hazard, occurring during the coincidence of receiving an N frame and transmitting a SREJ frame with the same *sequence number* (figure 4). Now it may happen that the sending ARQ instance repeats the already successfully transmitted N frame. In this case the receiver has no chance to distinguish between retransmission and new frame missing other frames with "lower" numbers. The solution is to ignore retransmission requests during the period of coincidence. In MBS the processing time measured from the generation of a frame to its delivery to the resequencing buffer is deterministic. The reason is, that LLC frames are generated immediately before transmission and not buffered inside the MAC layer. Additionally the delay of the physical channel is deterministic because of the constant slot length in MBS. Setting the ignore time twice the processing time (for transmission of an N frame and receiving the acknowledgement), the protocol is able to deal with retransmission hazards.

But the introduction of the ignore timer does not only ignore the SREJ command for the just transmitted frame, on further investigation it leads to a more precise interpretation of all kinds of acknowledgements. Taking advantage of the ignore timer the ARQ instances are able to treat a positive RR command as a negative REJ (REJect) command, as shown in figure 4. The reception of a RR command not only acknowledges "lower" frames but also offers the information that all "upper" frames with expired ignore timer are lost. The ARQ instance in the sender is able to retransmit these "upper" frames without receiving a repeat request. At this moment the receiver might not even know that there are frames lost so that it has not been able to send a retransmission request. This behaviour reduces the average delay.

Note that without using the ignore time it is not possible to get the benefit of unrequested retransmissions, since the ARQ instance would start to "stutter"[4]. That means repeating just sent frames without delay. This produces heaps of useless repetitions.

The protocol sequence shown in figure 4 demonstrates the above mentioned features with an example of an asymmetric data transmission from base station to mobile station.

The N frames with the *send sequence numbers* $N(S) = 2$ and $N(S) = 3$ have not been received by the mobile station. Acknowledging the two successfully received frames with the *send sequence numbers* $N(S) = 0$ and $N(S) = 1$ the RR command is being sent without knowing about the loss of two frames. During this transmission two more frames are received correctly. On the receipt of the RR command the base station acknowledges all frames with "lower" sequence numbers than 2. At this time the ignore timers of frame 2 and 3 are expired, so that these frames are rejected and marked for retransmission. Since the timers of frame 4 and 5 are still active these frames will not be marked for retransmission because at this time no information about their state is available. Repetition of the two lost frames leads to the correct sequence order. Going on with the fol-

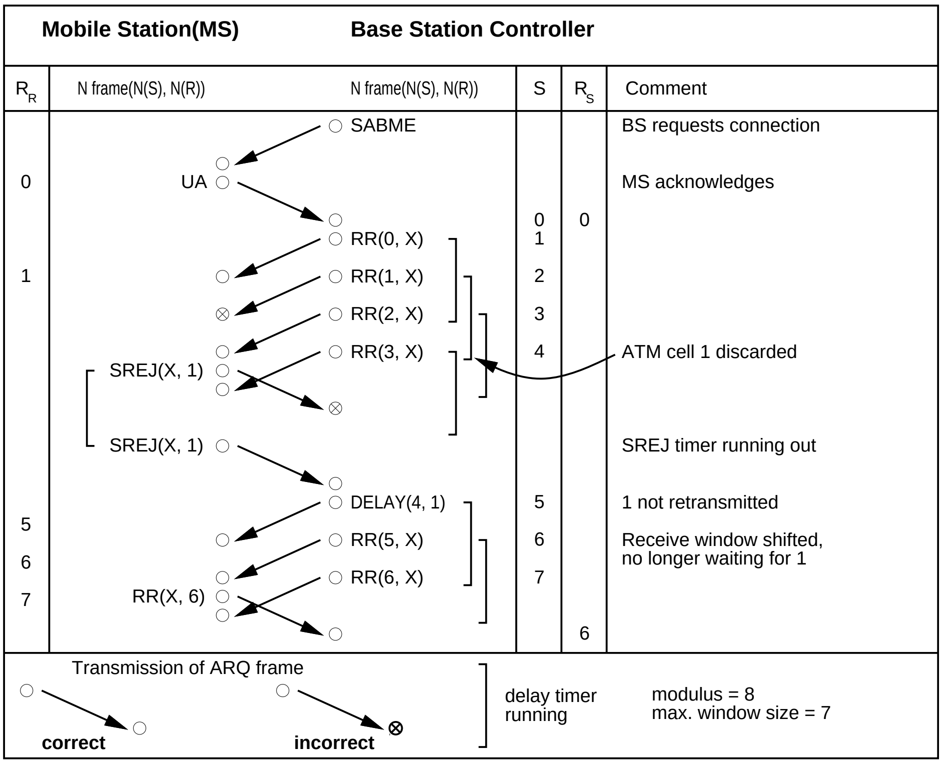

Figure 5: Treatment of discarded ATM cells

lowing frames 6 and 7 and ignoring the SREJ command this protocol is able to keep the right sequence order without waiting for retransmission requests.

Note that these retransmission are not really unrequested because only frames which are definitely lost will be repeated.

B. Treatment of delayed ATM cells

The sending station has the possibility to discard cells, which have reached their maximum allowed delay. If discarded cells have not been involved into the transmission process until the moment of their discardance, the receiver does not have to be informed about the discardance. A different situation occurs if the receiving station has requested the discarded cell for being retransmitted. In this case the sender has to signal that the rejected cell will not be sent again. This is done by the Delay command which is treated as an acknowledgement generated by the sender and delivered to the receiver. The *receive sequence number N(R)* in this frame is set to the *sequence number* of the discarded and requested cell. Like normal acknowledgements the Delay command can be transmitted piggyback on an N frame. Delay commands should not have higher priority than acknowledgements of the same ARQ instance in order not to displace them resulting in a deadlock situation.

The protocol sequence shown in figure 5 illustrates the treatment of delayed ATM cells with an example of an asymmetric data transmission from base station to mobile station.

The N frame with the *send sequence number* $N(S) = 1$ has not been received by the mobile station. Receiving the N frame with $N(S) = 2$, the receiver generates a SREJ(1) to force the sender to retransmit the lost frame 1. This request is being lost. When the delay timer 0 expires, the sender discards this cell and signals the discardance to the receiver by transmitting a Delay(0) frame with empty Info field in the lack of ATM cells to be transmitted. When the SREJ timer in the mobile station expires it repeats its retransmission request SREJ(1). Receiving this, the base station transmits an N_Delay frame with the meanwhile arrived ATM cell 4, informing the mobile station, not to wait for frame 1 because this has been discarded. Receiving the N_Delay(4,1) frame successfully, the receiver is able to shift its window, no longer waiting for frame 1. Acknowledging the reception of frames 2–5 with an RR(6) frame the protocol returns to normal condition.

V. Performance Evaluations and Simulation

For performance evaluations the ASR-ARQ protocol has been implemented in an event driven simulator. It is based on the SIMCO3++ tool developed at the chair of communication networks [5]. The simulator contains models for propagation, mobility and traffic generation enabling the validation of the protocol under realistic environmental conditions. Because the MAC protocol of MBS has been implemented in the same tool [3] it is possible to study the behaviour of the ASR-ARQ protocol under the situation of competition of multiple mobile stations with statistical multiplexing on the air interface resulting in capacity on demand.

The simulator contains a graphical interactive user interface for illustrating the functionality of the protocol. This *protocol debugger* allows to display the state of internal variables like the sending and resequencing buffer in

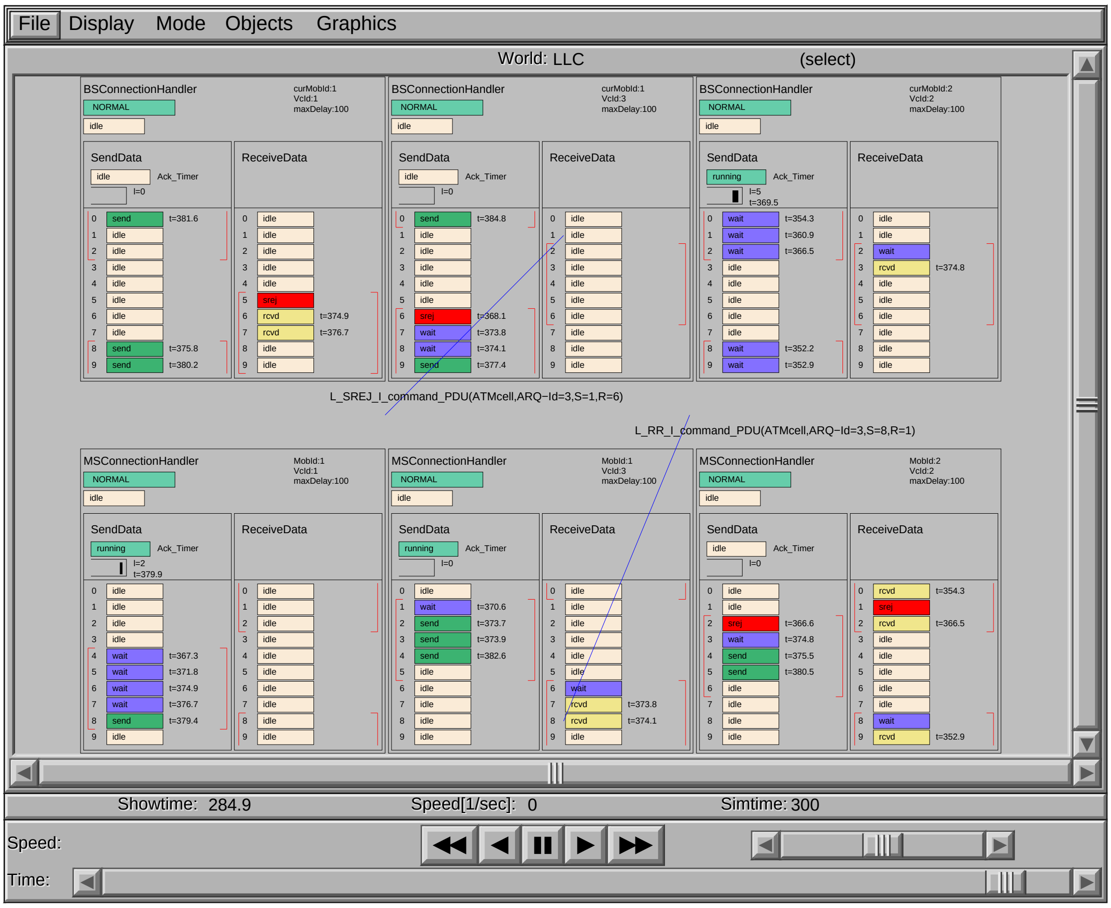

Figure 6: Screen dump of the protocol debugger

the ARQ instances. Furthermore it is possible to illustrate sequences in the protocol execution together with the produced events step-by-step. Figure 6 shows a screen dump of the debugger with a scenario consisting of the ARQ instances of three VCs in base station (top) and mobile stations (bottom).

Simulation runs with the protocol debugger have lead to the concept of several procedures described above which are able to increase the performance of the protocol by leading to shorter delays resulting in lower cell loss rate.

With future extensive simulation runs the influence of the various parameters of the priority algorithms described above will be investigated. Furthermore a well balanced cooperation between LLC layer and MAC layer has to be established.

VI. Conclusions

The new ASR-ARQ protocol has been introduced which is adapted to the requirements on error correction in a cellular system offering a full integration of mobile ATM terminals into a fixed ATM network. An advanced SR algorithm has been described that is able to reduce the average delay of ATM cells. This is essential for the transmission of ATM cells of real-time oriented services.

Further studies are dealing with the analysis and optimization of algorithms for scheduling of ATM cell and acknowledgement transmissions.

VII. Acknowledgements

The author would like to thank the members of the MBS project for their suggestions. Furthermore this work would not have been possible without the hard work and enthusiasm of the students working on their diploma thesis.

VIII. References

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