Performance Evaluation of Medium Access Control Schemes for MBS

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Abstract: **This paper presents different approaches for the Medium Access Control (MAC) Scheme for the Mobile Broadband System (MBS), which aims to be a mobile extension of an ATM based network like B-ISDN. In order to enable the comparison of different protocols, performance parameters have been determined using the simulation tool SIMCO3++ [1], which contains realistic models for propagation, mobility and data traffic load. The simulation results are presented and compared with conventional MAC protocols.**

1 Introduction

Present cellular mobile radio networks like GSM are designed to support speech services that are characterized by constant data rates and maximum acceptable time delays. This has led to a specific kind of *Medium Access Control* (MAC) schemes on the uplink based on a TDMA structure, which are subdividing the stream of transmission slots into frames of fixed length. Every logical channel is assigned to a fixed slot position of the cyclic repeated frame, so that transmission slots are available in equidistant time intervals. This reduces the part of the channel capacity occupied by signalling messages because a previous assigned slot position will be available for the specific logical channel in all following frames without additional signalling procedures. Furthermore, none of the assignments will be lost caused by erroneous transmission.

The allocation of constant transmission capacity to logical channels is possible because the constant data rates of speech services are guaranteeing a certain amount of data at transmission time. Thus, the transmission delay can be minimized due to a specific combination of source coding and MAC scheme, so that data packets will be transmitted directly after their generation without waiting period.

It can be seen, that services with variable data rates will cause higher transmission delays and a reduction of channel throughput. The reasons for this lower performance are on the one hand the additional waiting periods for transmission slots in case of too early or too late generated packets, and on the other hand unused transmission slots, if no packets have to be transmitted caused by short-time lower data rates.

To extend service integrating fixed networks to mobile users (UMTS↔ISDN, MBS↔B-ISDN) an adaptation of the MAC schemes specialized in transmission of constant data rates of speech services to the variable and high dynamical data rates of broadband services is necessary [2, 3].

This paper presents considerations on the MAC scheme for MBS which has to be adapted to the transmission of virtual channels of ATM based networks like B-ISDN.

2 Requirements on Medium Access Control Schemes for MBS

The goal of MBS is to extend B-ISDN to mobile users. It has to be able to support most of the broadband services like video transmission, file transfer or interactive communication as well as the conventional narrowband services of ISDN like speech transmission over the air interface without a great loss of quality.

In order to reach this aim the air interface of MBS has to adapt the *Asynchronous Transfer Mode* (ATM) of B-ISDN. The basic idea of ATM is the separation of services, their data and data rates. Thus an ATM-Net does not have to make available service specific channels. Because of the great number of different services this leads to a flexible, service independent and uniform network structure [4].

ATM is a packet oriented transmission scheme. The transmission path of the packets of constant length, the so called *ATM-Cells*, will be established during connection set-up between the two end-points by assigning a virtual channel. At this time, the necessary resources are provided and the logical channels are assigned. All packets of a virtual channel are carried over the same path. The transmission capacity of a virtual channel can freely be chosen in a wide range and is characterized by the parameters *mean bit rate* and *peak bit rate* during connection set-up. ATM-Cells are generated according to the need of the data source. Thus, ATM is a very good method to meet the dynamic requirements of connections with variable data rates.

MBS will be the interface between the fixed ATM-Net at the base station side and the mobile ATM-Net at the mobile station side. Normally, the ATM-Net at the mobile station side will only consist of one end system, e.g. a handy-telephone or a HDTV camera. For every end system it is possible to operate several virtual channels with different data rates at the same time. In the case of a portable camera, there will be virtual channels for video and audio data as well as channels for computer control or speech connections between camera operator and producer.

The uplink of the MBS air interface is the critical part of the MAC scheme. As depicted in figure 1 it consists of a system of mobile stations each having a different number of virtual channels as message sources and one base station as message sink. Furthermore there is a certain number of frequency channels each having a TDMA structure with slots being the basis for ATM-Cell transmission.

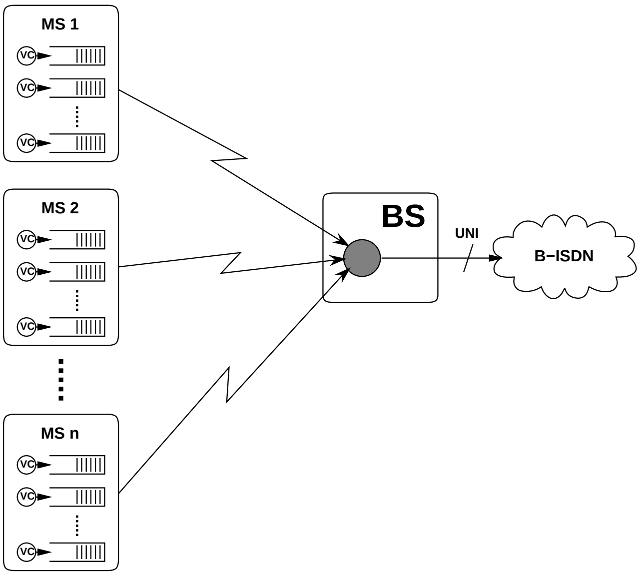

Figure 1: VC queuing in mobile stations

The generation times of ATM-Cells of virtual channels can only be estimated by using stochastic processes characterized by the above mentioned parameters *mean bit rate* and *peak bit rate*. Unlike GSM the cells will not be generated synchronously to the transmission slots, so that they have to be buffered in queues. But it is not advisable to buffer the cells of all virtual channels of a mobile station together in one queue because they have to be handled with different priorities due to their different data rates. Thus, there has to be a separate queue for each virtual channel as shown in figure 1.

Within the above described structure of the uplink it is the task of the MAC scheme to assign transmission slots to the virtual channels in such a way that the *Quality of Services* (QoS) parameter of the ATM-Net and the desired transmission rates of the virtual channels are guaranteed. Within an ATM-Net, cells with a delay greater than a specific limit will be removed, so that first of all, the MAC scheme has to keep the delays at a minimum. As well, it has to maximize the throughput because of the limited channel capacity. Within most of the MAC protocols there is an exchange between throughput and transmission delay, so that it is necessary to find the optimum ratio between these two parameters in an iterative way to reach the QoS parameters as close as possible.

Due to the variable cell generation rates the MAC scheme has to adjust the allocated transmission capacity to the varying short-term requirements. In the following sections, an examination of two different protocols, *Cyclic Slot Allocation* and *Dynamic Slot Assignment*, is presented.

3 Cyclic Slot Allocation

The *Cyclic Slot Allocation* (CSA) protocol is based on MAC schemes of conventional cellular mobile radio networks as described in section 1. The virtual channels are assigned to specific slot positions within the frames, so that cyclic repeated slots are available for transmission. The CSA protocol allows efficient transmission of services with variable data rates by dynamically adapting the number of assigned slot positions to the current requirements of the virtual channels. In order to meet this dynamic requirements fast signalling procedures are necessary. A short-term increase of the cell generation rate is handled by buffering the cells in queues. If the waiting period of cells reaches a certain limit, additional slot positions are requested. Decreasing generation rates are causing unused slots. If the number of unused slots reaches a limit, the number of slot positions assigned to the virtual channel is reduced so that the unused slots are given free. A combination of the CSA protocol with a *Dynamic Channel Allocation* algorithm has been presented in [5].

The CSA protocol operates most efficiently with services of high and relative constant data rates, so that several slot positions are occupied at the same time (e.g. video applications). A problem are the additional waiting times cased by buffering in case of short-term increased generation rates. As well, for virtual channels with only one assigned slot position long waiting periods can result from new packets generated just after the last transmission slot, which have to wait about approximately one frame for the next slot.

4 Dynamic Slot Assignment

A minimum transmission delay in combination with maximum throughput will be reached, if the assignment of transmission slots to virtual channels is controlled by a central instance with knowledge of all current transmission requirements. For the determination of the slot assignments, the central instance has to take into account the connection specific parameters like mean data rate and peak data rate (static parameters) as well as the short term and dynamically changing parameters like current queue length and waiting period of the first cell in a queue (dynamic parameters) [6].

Because of the limited transmission capacity of the air interface, this ideal system can only be implemented with reduced performance. The informing of the base station (as central instance) about the changing of the mobile station's internal states can only be done by transmission of the dynamic parameters at discrete moments. Thus the ideal system can be approximated by implementation of efficient algorithms for the exchange of information between mobile stations and base stations in order to update the dynamic parameters, and by interpolation of the dynamic parameters during the update events. The algorithms have to solve the following problems:

- Broadcasting of slot assignment messages of every single slot by the base station. The frame structure is not longer used.
- Broadcasting of the transmission state of the last slot as acknowledgement. Because of possible *hidden stations* only the base station can measure the state of the uplink.
- Informing the base station about the dynamic parameters of the queues inside the mobile stations.
- Calculation of dynamic slot assignments dependent on static and dynamic parameters for every single slot.

The assignment and acknowledge messages can be transmitted in every single slot on the downlink. The slots on uplink and downlink are transmitted synchronously. Thus the mobile stations are informed in time about the state of the next slot on the uplink. On the downlink no guard time for the compensation of asynchronisms between mobile stations in different distances to the base station is necessary. These additional bits can be used for the transmission of the short signalling messages. The position of these additional bits is depicted in figure 2.

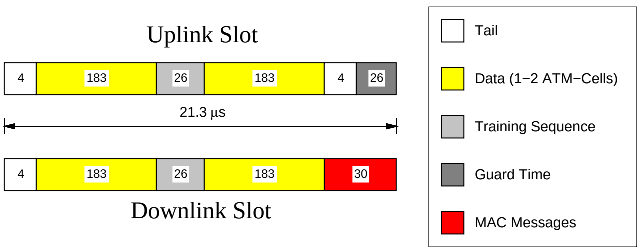

Figure 2: Structure of slots on Uplink and Downlink

Ideally, the transmission of the dynamic parameters should happen after every change of a queue. Because of efficiency reasons this is impossible. But the transmission can easily be done during transmitting a cell of the corresponding queue. The transmission slot can contain information about the current queue length and the waiting period of the next cell in the queue. Although in this way the base station is informed with some delay from the occurrence of a new cell in the mobile station's queue, it is possible to estimate the urgency for a slot assignment to the corresponding virtual channel.

As long as a transmitted cell informs the base station about the existence of further waiting cells, the base station will further assign enough transmission capacity to the corresponding virtual channel. But whenever the last cell of a queue is transmitted, the base station cannot be informed about the arrival of the next cell. For such queues there has to be another way to transmit the dynamic parameters. In principle there are two possible methods:

- The base station queries the dynamic parameters of the virtual channels (polling)
- Transmission of the dynamic parameters on demand over special slots offering random access (random access slots)

The method which offers the shortest delay depends on the current system load. Therefore the best results can be expected with adaptive algorithms choosing the currently optimal method.

The above considerations show, that a virtual channel can stay in one of two possible modes, either *reservation mode* or *contention mode*. In reservation mode the base station is informed about the existence of further waiting cells in the corresponding queue. The transmission of a cell in an assigned slot is guaranteed. This is not the case with virtual channels in contention mode.

The development and refinement of the MAC scheme now subdivides into two steps:

1. Development of an algorithm for the calculation of dynamic slot assignments
2. Development of a protocol for transmission of messages over the random access slots

4.1 Calculation of dynamic slot assignments

The calculation of the virtual channel, to which the next slot should be assigned, can easily be done with a priority algorithm. This algorithm calculates a dynamic priority for every virtual channel, taking into account its static and dynamic parameters. Then the next slot will be assigned to the virtual channel with the highest priority.

The priority algorithm is responsible for the observance of the Quality of Service (QoS) parameters. Furthermore it determines, in which relation the different QoS parameters are reached. Section 5 presents results of simulation based performance evaluations using a heuristically created algorithm.

The static and dynamic parameters, that are used to calculate the priorities are listed in table 1.

static parameters	
stat_mean:	mean data rate (Connection specific (set-up) parameter)
stat_peak:	peak data rate (Connection specific (set-up) parameter)
dynamic parameters	
dyn_mean:	mean data rate in last n frames
waiting_time:	waiting period of first ATM-Cell in queue
idle_time:	idle time (No. slots since last transmitted successful ATM-Cell)
queue_length:	last transmitted queue length

Table 1: Static and dynamic parameter used by dynamic slot assignment algorithm

4.2 Transmission of the dynamic parameters in contention mode

A certain number of random access slots have to be included on the uplink in order to enable the transmission of the dynamic parameters of virtual channels in contention mode. The stream of random access slots forms a *Random Access Channel* (RAC). On this RAC every protocol for random access can be used, especially the ALOHA protocols. The priority controlled slot assignment allows to adapt dynamically the transmission capacity of the RAC to the current requirements. Thus fast collision resolution is possible, resulting in short transmission delay. For stabilisation, splitting algorithms as described in [7] can be used.

The throughput of the RAC can be improved by splitting the random access slots into sub-slots [8, 9]. Then only the dynamic parameters are transmitted in order to switch the virtual channel in reservation mode. In case of collisions, no longer the whole slot is lost but only the sub-slot.

When analysing the protocol, the additional slots for the transmission of the cells have to be taken into account, what is not necessary with ALOHA protocols. Furthermore it has to be considered, that the acknowledgments for all sub-slots of a random access slot are transmitted together in one message.

If a slot is divided in C sub-slots and n transmissions have taken place in a slot, equally distributed over all sub-slots, then the probability for a successful transmission of a sub-slots is:

$$\overline{p}_C(n) = \left(1 - \frac{1}{C}\right)^{(n-1)}$$

The throughput of this *Sub-Slotted-ALOHA Protocol* has been analysed in [9]. Under the assumption of negativ exponential distributed arrival intervals and equal arrival rates of all virtual channels, the maximum throughput can be calculated by:

$$\lambda_{\max} = \begin{cases} \frac{C\,(N-1)^{N-1}}{N^{N-1}+C(N-1)^{N-1}} & \text{for} \quad C \leq N \\ \frac{N\,(C-1)^{N-1}}{C^{N-1}+N(C-1)^{N-1}} & \text{for} \quad C > N \end{cases}$$

C: No. sub-slots in random access slot
N: No. virtual channels

Figure 3 shows the maximum throughput dependent on the number of sub-slots C and the number of virtual channels N.

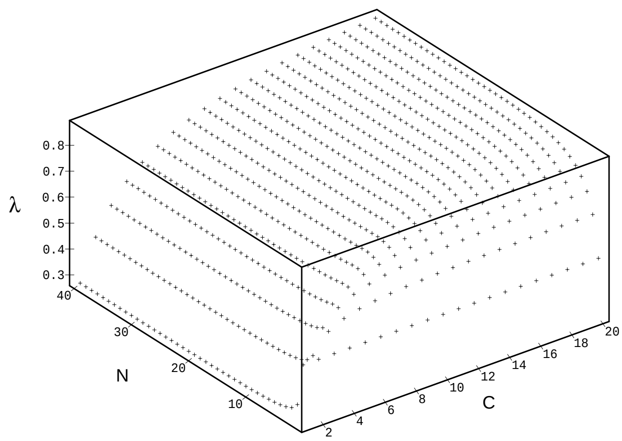

Figure 3: Maximum throughput on Random Access Channel dependent on No. Sub-slots and No. Virtual Channels

The dynamic slot assignment algorithm adjusts the transmission capacity of the RAC to the current requirements so that it is always working to capacity. In this case the maximum throughput is much higher than in Slotted-ALOHA ($\lambda_{\text{S-ALOHA}\max} = 0.37$).

The transmission delay has been examined by simulations. The results of measurements with $C = 4$ and $N = 4$ are shown in figure 4. For comparison the values for Slotted-ALOHA are also shown.

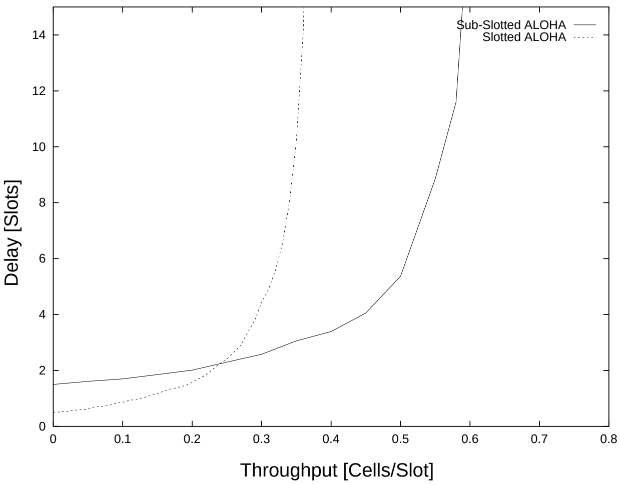

Figure 4: Delay of Slotted-ALOHA and Sub-Slotted-ALOHA ($C = 4$, $N = 4$)

4.3 Improvements

If multiple virtual channels are associated to one mobile station, then usually a part of them is in reservation mode and the rest in contention mode. In this case virtual channels in reservation mode can transmit the dynamic parameters of channels in contention mode in order to switch them into reservation mode and minimize the traffic on the RAC. This leads to a further reduction of the mean transmission delay.

5 Development of a Simulator

The development of the MAC protocols is supported by a simulation tool used for debugging and performance evaluation. The simulator is based on the SIMCO3++ tool [1] (Simulation of Mobile and Communication), which is currently under development at COMNETS for performance evaluation of both cellular type as well as short-range communication networks. This tool is based on CNCL (Communication Network Class Library), which is a C++ library consisting of all necessary classes for an event driven simulation. SIMCO3++ offers all basic mobile communication modules for channel model, medium access control, data traffic generation, environment scenarios and mobility of stations. Furthermore, SIMCO3++ contains the tool GIST (Graphical Interactiv Simulation Result Tool), which allows the interactive control of simulation as well as the presentation of simulation results during and after simulation in a graphical manner.

The structure of the simulator together with the information flow between the various modules is depict in figure 5. The graphical user interface is given in figure 6. It allows to control the execution of a protocol by single-stepping through the sequence of events in order to validate the functionality.

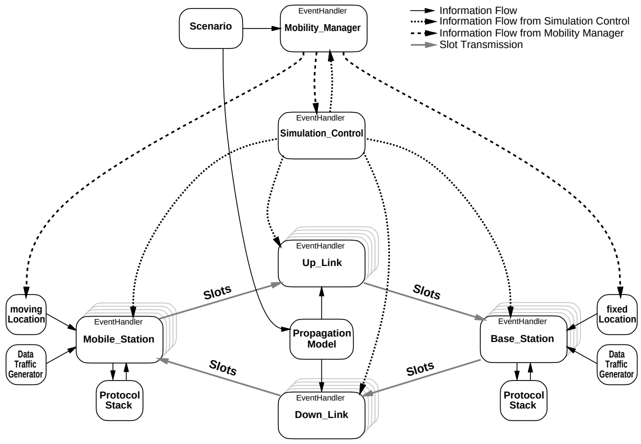

Figure 5: Information flow between the modules of the simulator

5.1 Measurements of transmission delay

Among the throughput, the transmission delay is one of the most critical QoS parameters, that has to be considered when designing the MAC scheme of MBS. Therefore, some computer simulations have been done to measure the transmission delay produced by the previous described MAC protocols. For the comparison of the results, also considerations on the best and worst case have been done.

The lowest values of transmission delay can be expected, if an ideal system is assumed, transmitting the cells in the order of their arrival time. This system can be modeled as a time discrete M/D/1/FCFS node. The worst case in relation to transmission delays is the allocation of constant transmission capacity, as with the CSA protocol of section 3 without adaptive adjustment of the allocated slot positions. In this case, an extra amount of transmission capacity has to be added to the mean data rate of a virtual channel in order to avoid overflow of the queue.

Simulations have been executed for all three scenarios. The transmission delay $\overline{\tau}$ (in No. slots) has been measured dependent on the overall cell generation rate of all virtual channels $\lambda = \sum_{i=1}^{n} \lambda_i$. Every single virtual channel has a cell generation rate of 0.1 cells per slot. The measurements have been done for all possible numbers of concurrently existing virtual channels. The results are depict in figure 7.

Scenario 1—DSA: The DSA protocol with a simple algorithm for calculation of dynamic slot assignments is used. A non adapting ALOHA protocol is used on the random access slots, so that the delays can further be reduced by more sophisticated algorithms.

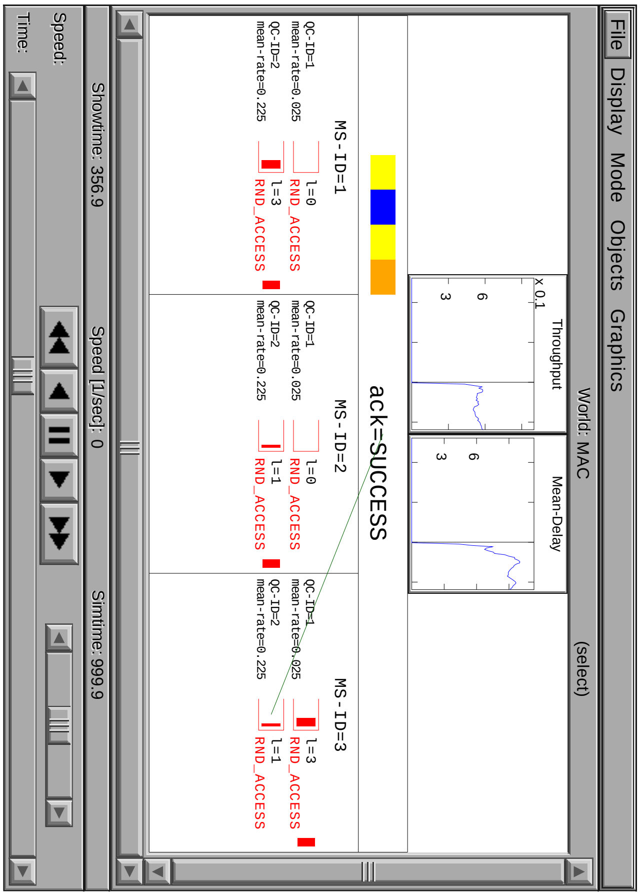

Figure 6: Screen dump of the interactive user interface

Scenario 2—M/D/1/FCFS: The lower boundary for transmission delays is formed by a time discrete M/D/1/FCFS node.

Scenario 3—CSA: A constant transmission capacity is allocated by a virtual channel. In order to reduce the waiting period, a virtual channel with a mean rate of 0.1 cells per slot has allocated every 8th slot. This results in a channel efficiency of 80%. Only eight virtual channels can coexist at the same time.

When examining the results, the necessity for a dynamic slot assignment is obvious. Although the delays of the DSA protocol can further be reduced by more sophisticated algorithms, they are much lower than the delays of the CSA protocol, despite of the low channel efficiency of 80%.

6 Conclusions

The basic idea of ATM to support different services with an uniform network structure, requires new approaches for MAC schemes of future cellular mobile radio networks like MBS. Todays cellular mobile radio networks like GSM, which are mainly designed to support speech services, offer physical channels adapted to the constant data rates of speech services. This is not longer possible in MBS. Instead of this the statistical multiplexing of ATM-Nets has to be expanded on the air interface by allowing as much as possible services to access to the same physical channel at the same time. This requires new algorithms for dynamic slot assignments. The DSA protocol which has been presented in this paper seems to meet the required QoS in a sufficient way, but still offers some possibilities for improvements. Because of the new physical channel structure sophisticated algorithms for *dynamic channel allocation* as used in DECT can not be reused. New concepts have do be developed for combining the new MAC schemes with algorithms for channel allocations in order to reach a high channel efficiency.

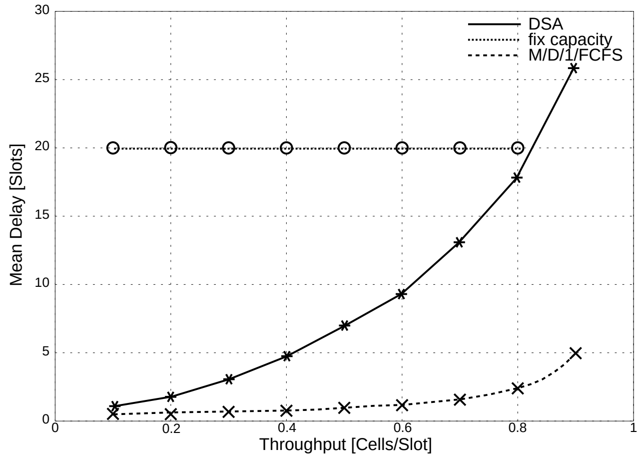

Figure 7: Mean delay for the different examined MAC protocols

7 References

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