Influence of Dynamic Channel Allocation on the Transmission Delay in Wireless ATM Networks*

Andreas Krämling, Markus Scheibenbogen

Communication Networks, Aachen Univ. of Technology
Kopernikusstr. 16, 52074 Aachen, Germany
E-Mail: {akr|msc}@comnets.rwth-aachen.de
WWW: http://www.comnets.rwth-aachen.de/~{akr|msc}

Abstract — **During the last few years extensive research has been carried out to extend fixed ATM networks to the mobile user. Several access protocols have been developed [1, 2] and international projects are building the first wireless ATM (WATM) demonstrators. Up to now nearly no research has been done in the area of dynamic channel allocation for WATM networks, which is an essential issue for a future communication system. In case of a WATM system two different aspects have to be combined: on the one side the ATM like statistical multiplexing leads to a very dynamic assignment of capacity – on the other side dynamic channel allocation requires a steady behaviour. Due to these opposing requirements, a new allocation scheme is required which has been introduced in [3]. This paper focuses on the influence on the transmission delay via the ATM air interface caused by this allocation scheme.**

I. Introduction

After the success of the *asynchronous transfer mode* (ATM) in the area of multimedia networks during the last years, a lot of research has been carried out to integrate wireless ATM terminals into the ATM network. All research which has been carried out is only focused on a Medium Access Control (MAC) protocol without taking into account aspects of Dynamic Channel Allocation (DCA) which is essential for a future cellular system.

The general approach is a full integration of the mobile user into the fixed ATM networks [1, 4]. The ATM cells have to be transmitted over the air interface in such a way that the ATM adaptation layer (AAL) is not involved and that the Quality of Service (QoS) requirements of the mobile users can be fulfilled. This means that the air interface has to be integrated transparently into the fixed ATM network. Thus, the protocol stack at the ATM air interface has to behave like a usual ATM multiplexer with an internal air interface. This *virtual* ATM multiplexer has to co-ordinate the access on the shared radio channel in such a way that the requirements of the established virtual connections are fulfilled.

In cellular ATM networks the statistical multiplexing of the terminals on the shared physical channel is co-ordinated by the base station (BS). The BS assigns capacity to the terminals on a slot to slot basis. Simulations have shown that this leads to a most efficient usage of the available channel capacity and to lowest transmission delays. Nevertheless, due to the statistical multiplexing no prediction of the capacity assignments for the terminals is possible.

In case of wireless ATM it is likely that systems of different providers are working in the same frequency band and therefore decentralised dynamic channel allocation schemes seem to be most promising. These schemes allocate channels based on measurements. Thus, a certain steadiness is required which is contradictory to the statistical multiplexing of WATM.

A new DCA scheme for WATM was introduced in [3] which enables the statistical multiplexing and provides the required steadiness for a DCA algorithm.

The paper is structured as follows: To understand the influence on the transmission delay caused by the proposed DCA scheme, a understanding of the used MAC protocol is required which is presented in section II. Afterwards the DCA scheme is introduced in section III. The resulting influence on the transmission delay was evaluated by simulations which are presented in section IV.

II. Medium Access Control for Wireless ATM

A wide range of applications should be served by wireless ATM networks. This means that different QoS requirements (e.g. transmission delay, error ratio, ...) have to be fulfilled. A synchronous air-interface (fixed capacity is assigned to a terminal/connection) would lead either to an inefficient usage of the available channel capacity or to difficulties in fulfilling the QoS requirements. Therefore the ATM like statistical multiplexing has to be extended over the air interface to provide an efficient usage of the radio resources and to be able to guarantee the QoS requirements. Several MAC protocols have been developed during the last years which are based on the same principle [1, 2].

The access on the physical channel is co-ordinated by the BS as a central instance. It assigns capacity to its wireless terminals (WT) on a slot to slot basis according to the current capacity requirements. The BS informs its WTs about these assignments by transmitting a *Downlink Signalling PDU* (DownSig-PDU), which contains several reservation messages. These messages together with the DownSig-PDU form the so called *signalling period* which is shown in figure 1. A terminal has to inform the BS about its capacity requirements, which can be done piggy-backed with uplink ATM cells

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or in special uplink signalling slots.

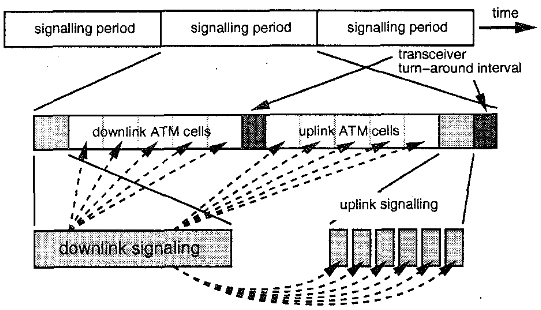

Figure 1: Structure of the signalling period

In general, the signalling period consists of four parts:

DownSig-PDU: The DownSig-PDU is transmitted from the BS to the WTs and contains all required reservation messages for the new signalling period. It also contains additional signalling information (for collision resolution, LLC signalling,...).

Downlink Slots: The downlink slots are used to transmit ATM cells together with additional signalling messages from the BS to a dedicated terminal.

Uplink Slots: The uplink slots are used to transmit ATM cells together with capacity requests and additional signalling messages from the WT to the BS. These slots are assigned to a dedicated terminal and therefore the transmission is contention free.

Uplink Signalling: The uplink signalling slots are shorter than normal uplink slots (ratio r=1/3...1/6) and are only used to transmit signalling information from the terminal to the base station. The access on the uplink signalling slots can be contention based or contention free – it was shown in [1] that a combination of both leads to the best performance.

The length of the signalling period as well as the length of each part varies over the time. This means that the downlink and uplink capacity can be adapted to the requirements of the terminals and is therefore able to deal with asymmetric load most efficiently.

III. Dynamic Channel Allocation for Wireless ATM

The DCA scheme introduced in [3] enables the base station to allocate capacity stepwise with a stepsize much smaller than the capacity offered by one frequency. The remaining capacity can be used by other BSs which results in an efficient usage of the available bandwidth. This is done by dividing one frequency into time periods of equal length which are called *containers*. The containers are generated using a TDMA scheme. Several containers build a frame which is repeated periodically (Fig. 2).

The BS is able to allocate several containers according to the capacity requested of its WTs. The same

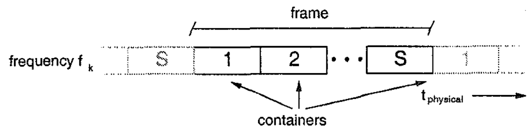

Figure 2: Frame and container structure on a physical channel

containers are used in each frame and hold for a relatively long time which results in synchronous channels (Fig. 3) and provides the required steadiness for the DCA.

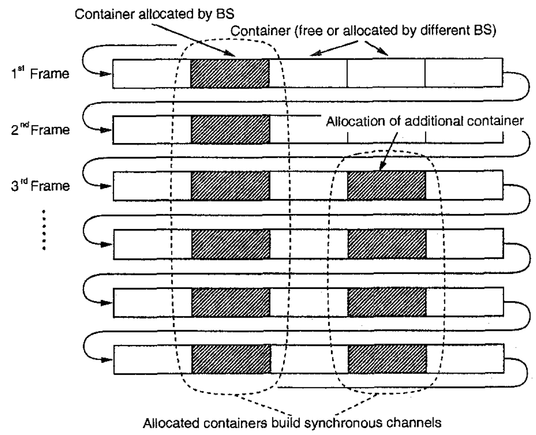

Figure 3: Resulting synchronous channels

Inside the allocated container-channels, the access of the BS and the WTs on the physical channel is coordinated using a *standard* MAC protocol as described in section II. The signalling periods of the MAC protocol are mapped on the allocated containers (cf. Fig. 4). It has to be pointed out, that there is no fixed relation between a signalling period and a container – a signalling period may consists of several containers.

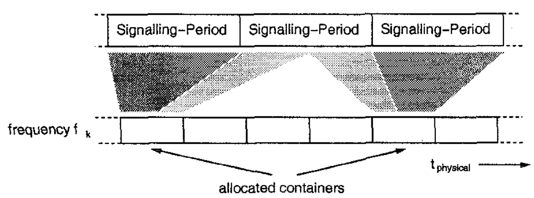

Figure 4: Mapping of signalling periods on containers

This leads to a two level multiplexing. Inside the allocated container-channels the BS performs a multiplexing of the traffic of its WTs, which results in a very dynamical capacity assignment to the WTs. The multiplexing of BSs (the use of different containers by different BSs) on the same physical channel happens with reduced dynamic, since the capacity requirements of a BS are steadier.

If a simple scheme is used to mark allocated containers (e.g. energy signals at the beginning of a container), it would even be possible to run different systems of different providers in the same frequency band.

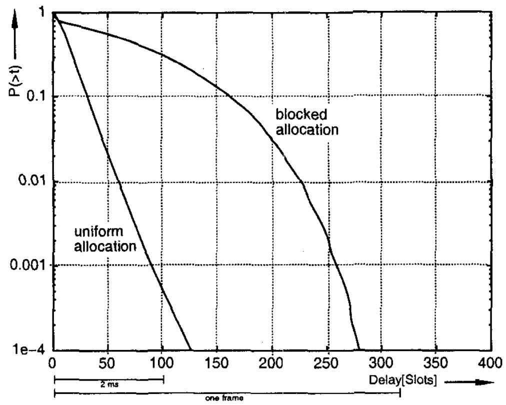

Figure 5: Influence of the container distribution within a frame on the transmission delay

IV. Simulation Results

In this section the influence on the transmission delay caused by dynamic channel allocation is evaluated. Transmission delay means the time required to transmit ATM cells from the BS to the WT and vice versa.

To evaluate the behaviour of the system simulations with the following parameters were performed if not stated otherwise.

slot length	20 μs
max. period length	15 slots
container length	200 μs = 10 slots
container per frame	32
frame length	6.4 ms
source model	Poisson
number of terminals per cell	50
one cell simulation	section A,B,C, one frequency
19-cell simulation	section D, four frequencies

Each terminal was modelled as a two state machine. During the active state the terminal generates ATM cells using a Poisson arrival process with a mean rate of 5% (referred to the capacity offered by one physical channel) equally distributed between 4% and 6%, while during the passive state no cells were generated at all.

A. Container Distribution

When a new container is allocated, not only the container quality (Radio Strength Signal Indicator, RSSI) but also the distribution of the containers within a frame has to be considered. Two extreme cases can be distinguished:

blocked allocation: the BS allocates consecutive containers

uniform allocation: the allocated containers a distributed uniformly within a frame

In figure 5 the complementary distribution function of the transmission delay is shown. It can be seen that uniform allocation decreases the transmission delay since the capacity is distributed more homogeneous within a frame. Therefore, in all following simulations the BS tries to achieve an uniform container distribution. Whenever several containers have the same RSSI value, the BS chooses the container which leads to more uniform distribution.

B. Influence of the Load

This section deals with the influence of the BS's load situation on the transmission delay. Whenever a new connection is established the BS determines the required capacity. When the capacity of the allocated container channels is not sufficient, new channels are allocated.

A simple approach to determine the required capacity would be to allocated the mean rate of the connection plus a certain percentage (e.g. mean+25%). These simulation results are shown in figure 7 and it can be seen that the transmission delay depends highly on the load situation of the base station. Since the multiplexing gain increases with higher load of the BS the transmission delay decreases with increasing load, which is unusual for a communication system.

To provide the same transmission delay more independent from the load situation of the base station, the current situation of the base station has to be considered. This is done by using a M/D/1-model as a simplified model for the air interface. Based on this model a simple Call Admission Control (CAC) was used to obtain the required capacity. It has to be pointed out that it was not in the scope of our research to develop a CAC for wireless ATM-systems. In fig. 8 the same simulation as in fig. 7 is shown but with the CAC. The remaining differences in the delay are explained in fig. 6. Due to the different number of allocated containers the time span between two containers is varying in different load situations and therefore also the delay.

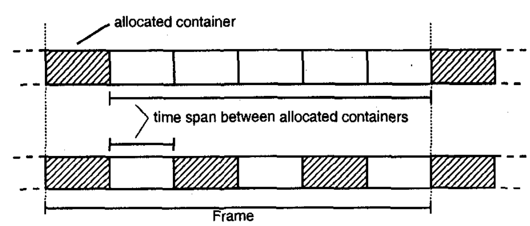

Figure 6: Time span between allocated container in different load situations

C. Blocking Probability

In the simulation environment we used 50 terminals per BS each had an average load of 5% of the capacity of one frequency. Taking into account the overhead due to the DownSig-PDU and taking into account the CAC only 16 contemporaneous connections can be accepted. Therefore the blocking probability can be calculated with the Engset formula. The curve in figure 9 is calculated with a number of sources of 50 and an activity of one source of 0.25, which results in an average offered traffic of 50%. On the x-axis the number of connections (resp. the used capacity in % of one frequency) is displayed and on the y-axis the probability is shown. In figure 10 the blocking probability for different activities of the terminals (resp. offered traffic load) is calculated and compared with simulation results. The differences between simulation and theory results form the distribution of the offered traffic of one terminal. In the analytical formula it was assumed that each terminal has exact 5% of one frequency. In the simulation the terminals offer traffic equal distributed between 4% and 6%.

For comparision also the blocking probability is shown in case that each BS allocates a complete frequency.

D. Container Length

The container length influences the frame length and it is obvious that this also influences the transmission delay over the air interface. From this point of view it seems to be advantageous to decrease the container length as much as possible. But regarding a real system a guard interval between single container is required to cover the transmission delay between different BS. Since this interval is independent from the container length, shorter container increases the overhead per container and reduces the available bandwidth.

In the simulation it was assumed that the guard interval between two containers is $0.5 \cdot slots = 10\mu s$. Figure 11 shows the simulation results and it can be seen that shorter container leads to shorter transmission delays but that on the other side also the maximum system load is reduced.

V. CONCLUSION

In this paper we evaluated the transmission delay over the air interface when a DCA algorithm is used. It was shown that a uniform distribution of the allocated containers inside the frame reduces the transmssion delay significantly. The influence of the BS's load situation can be reduced by using a non-linear capacity allocation. In real system a guard time between containers is required. We examined its influence on the transmission delay and on the blocking probabilty.

VI. REFERENCES

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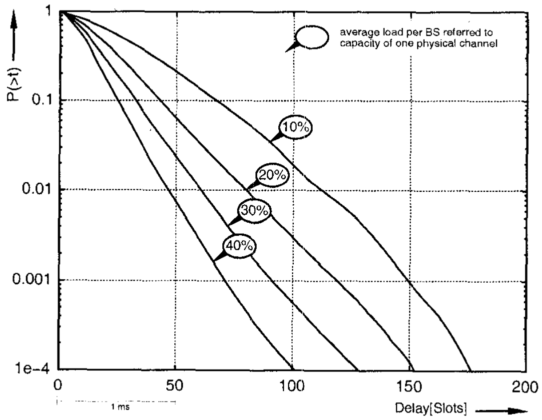


Figure 7: Influence of the load carried by a BS on the delay (allocated capacity: mean + 25%)

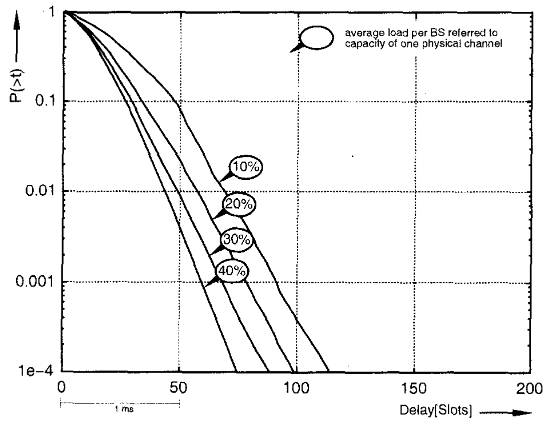


Figure 8: Influence of the load carried by a BS on the delay (with CAC; non linear overbooking)

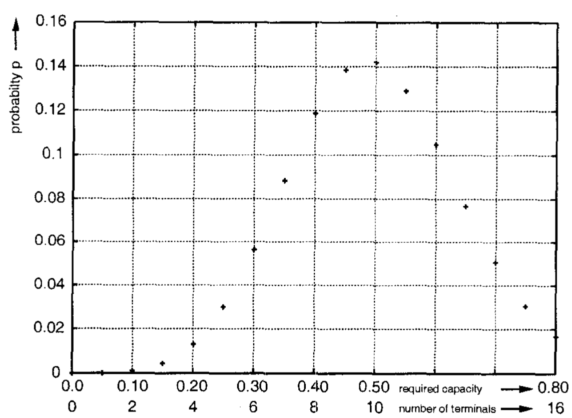


Figure 9: Distribution of the required capacity (50% average load)

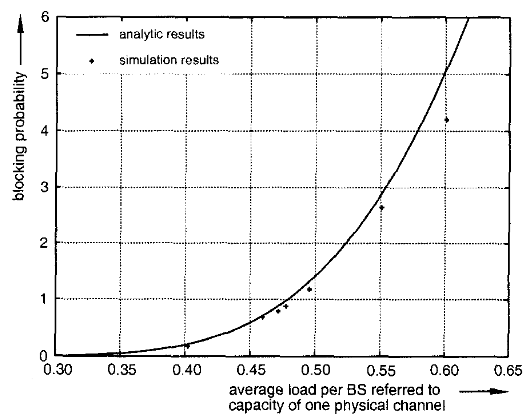
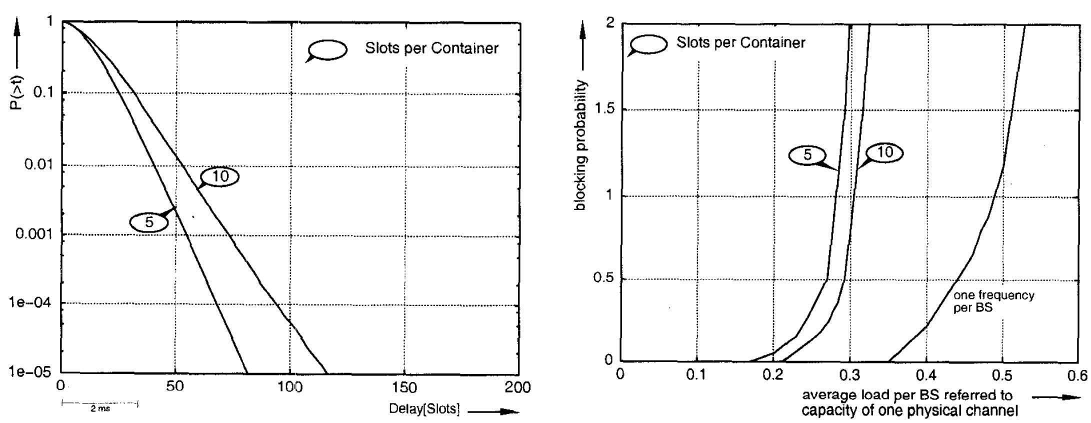


Figure 10: Resulting blocking probability



Transmission delay

Blocking probability

Figure 11: Influence of the container length