Camera ready version of paper submitted for

ACTS Mobile Communications Summit ’98

June 8-11, Rhodos, Greece

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Topics: SAMBA project, Wireless ATM, Dynamic Channel Allocation

Dynamic Channel Allocation in FDD based Wireless ATM Networks[1]

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***Abstract**: Wireless ATM networks are of growing interest which results in an intensive research and in demonstrators which are build up right now. Nevertheless, nearly no research has been carried out in the field of dynamic channel allocation which is an essential item for a mobile communication system. Due to the behaviour of ATM traffic (wide range of bandwidth and Quality of Service requirements), conventional dynamic channel allocation schemes cannot be used in case of wireless ATM. In this paper a dynamic channel allocation scheme for FDD based wireless ATM networks is introduced which enables the base station to allocate different capacity for up- and downlink direction and leads to a more efficient handling of asymmetric traffic.*

1. 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 develop and to integrate wireless ATM terminals into the fixed ATM network [PKH96]. Currently, many international projects are building demonstrators which will be finished during the next years [DLPZ97][BDMMP96].

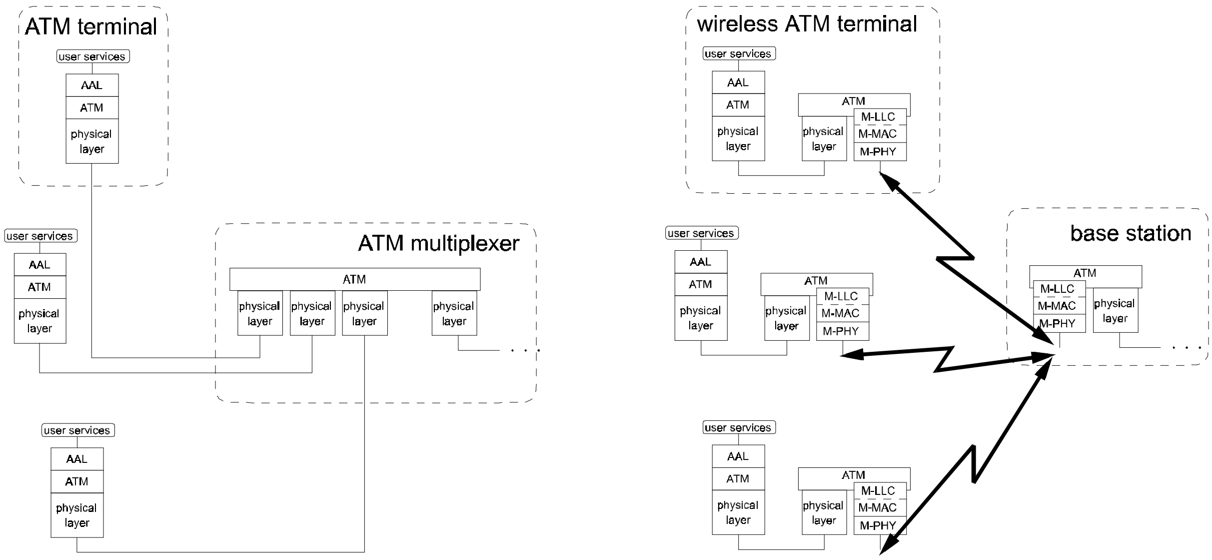

Figure 1: Correspondence between radio cell and ATM multiplexer

To fulfil the requirements of the mobile users, the ATM like statistical multiplexing has to be extended to the air interface (cf. figure 1). This can be done by using a TDMA scheme to divide the physical channel into slots which are able to carry one or several ATM cells and by using an appropriate MAC/LLC protocol. Such protocols have been developed in the last years [PKH96][BDMMP96]. In the following the key principle of such MAC protocols is explained shortly. The base station (BS) as a central instance co-ordinates the access of the wireless terminals (WTs) to

[1] This work has been partially funded by the European Union in the ACTS AC204 SAMBA project

the common physical channel. It has to share the available channel capacity fairly between the WTs according to the negotiated *Quality of Service* (QoS) parameters and their capacity requests.

The BS assigns these slots to the WTs on a slot to slot basis and informs the WTs by transmitting reservation messages in a special signalling burst (Downlink Signalling PDU=DSig-PDU). The assigned slots build together with the *DSig-PDU* the so called signalling period. Its length is variable and varies over the time. Since for each reservation message a short terminal Id has to be transmitted, the maximum length is given by the capacity of the *DSig-PDU*, while the minimum length results mainly from the processing delay. The principle of the resulting signalling scheme in case of frequency division duplexing (FDD) is shown in figure 2. In case that not enough capacity has been requested by the terminals empty slots are insert in the signalling period.

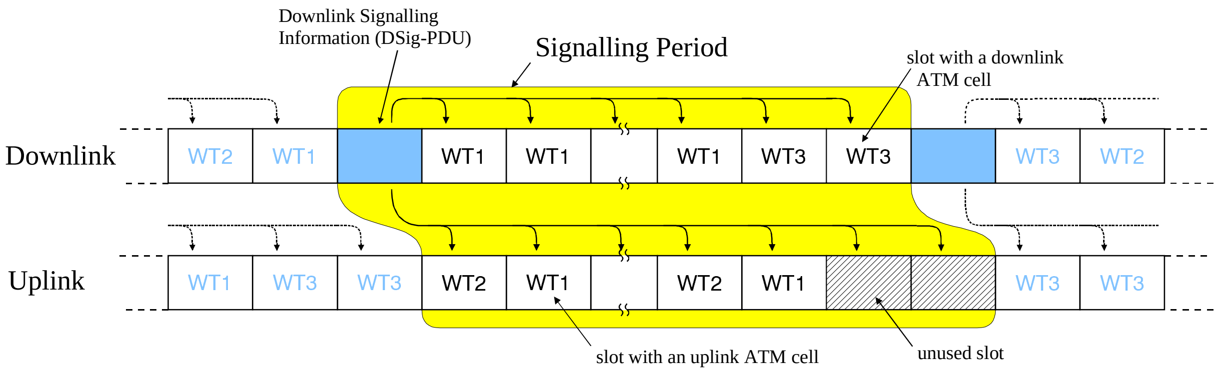

Figure 2: Structure of the signalling period in a FDD system

The statistical multiplexing which is performed via the air interface leads to a very dynamic assignment of capacity to the terminals. Since the capacity assignments change from period to period according to the current capacity needs, no prediction of future slot assignments is possible.
On the other side, dynamic channel allocation schemes typically used for circuit switched connections measure the current channel situation and predict, based on these measurements, the future usability. Therefore dynamic channel allocation schemes are only able to work effectively, if there is a certain steadiness in the allocated channels. Due to the limited radio resource (limited number of frequencies) an efficient usage of the available resources is essential for a future mobile broadband communication system.
This means that a dynamic channel allocation (DCA) scheme for WATM networks has to support the statistic multiplexing to fulfil the QoS requirements of different traffic types and to provide the required steadiness. These requirements will be fulfilled by our approach.
This paper is organised as follows. In section 2 the concept for dynamic channel allocation for WATM networks is explained. The following section describes the necessary adaptation of the existing MAC protocols. Section 4 gives a description of the simulation model and in the next section the simulation results are discussed.

2. Dynamic Channel Allocation for Wireless ATM

In [KSL98] a scheme for dynamic channel allocation in wireless ATM in case of time division duplex (TDD) has been presented. The scheme allows a base station (BS) to allocated the bandwidth which is required to serve its terminals.
A continuous allocation of capacity is difficult to realise in a distributed system, but a stepwise allocation can be realised with a stepsize much smaller than the capacity offered by one physical frequency. This means that the capacity has to be divided into small parts, which are called *containers* in the following. The containers are generated by using a TDMA scheme. A fixed number of containers build a frame which is repeated periodically (cf. figure 3).

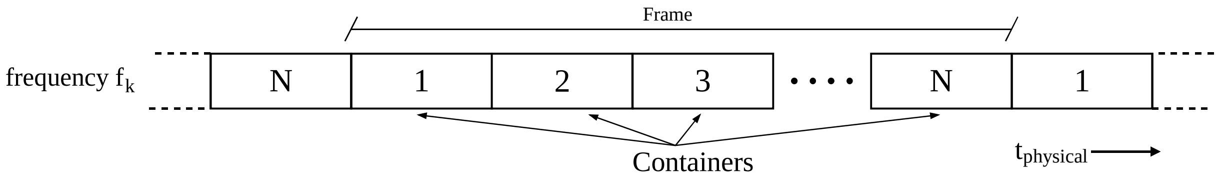

Figure 3: Frame and container structure on a physical channel

The BS is able to allocate one or several containers according to the capacity requested by all its WTs. These containers are hold for a relatively long time (using the same container over many frames) to provide the required steadiness for the DCA. Therefore a container can be seen as a channel which is allocated by the BS. Inside the allocated containers, the access of the BS and the WTs on the physical channel is co-ordinated using a MAC protocol as shortly explained in the introduction (cf. figure 2). This scheme offers a high variety of parameters like container length, container per frame, etc., which have been examined in [KSL98]. There it was shown, that a higher number of containers per frame increases the overall load which can be carried by the system.
The proposed scheme results in a two level multiplexing: within the allocated containers the BS performs a multiplexing of the traffic of its WTs, which results in a very dynamic capacity assignment to the WTs. The multiplexing of BSs (the use of different containers by different BSs) on the same physical frequency is executed with a reduced dynamic, since the capacity requirements of a BS are steadier.
In case of a frequency division duplex system the downlink and uplink frequencies are divided into containers (cf. figure 4) which are allocated by the BS.

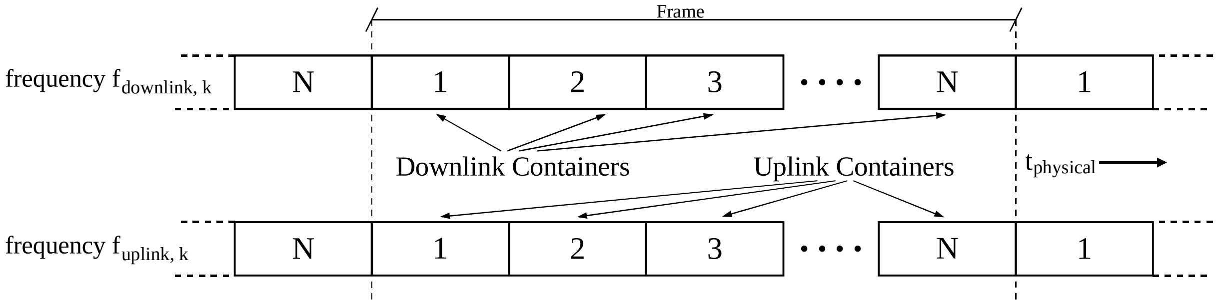

Figure 4: Frame and container structure in a FDD system

In principle, it is possible to allocated the up- and downlink containers symmetrically or asymmetrically. Symmetrically means that the same containers are allocated for both transmission directions and therefore the BS has the same capacity for up- and downlink. In case of asymmetric load always the maximum of the required capacity in up-/downlink direction has to be allocated which results in an inefficient usage of the radio resources.
On the other side, the BS may allocate container asymmetrically: different number of containers for each transmission direction are allocated, depending on the current traffic situation. In case of higher uplink traffic the BS allocates more uplink container and the other way round. This enables the BS to cope with asymmetric load more efficiently, since only the required capacity for each direction is allocated. This requires a modification of the MAC signalling scheme which is introduced in section 3.2.

3. Adaptation of MAC Protocol

In both cases (symmetric or asymmetric allocation), the MAC protocol has to be adapted to the container structure on the air interface. In general, it can be seen as a mapping of the signalling periods to the allocated container – only in case of asymmetric allocation, the mapping is more difficult.

The influence on the structure of the signalling period is shown in the following subsections by an example for each case. For both examples it is assumed, that one container contains 10 slots and that the capacity of the *DSig-PDU* is limited to 11 reservation messages.

3.1. Symmetric Allocation of Capacity

Symmetric allocation means that always the same containers in up- and downlink direction are allocated. The allocated containers can be seen as a channel with a reduced bandwidth compared to a physical channel. Since always the same containers in each transmission direction are allocated, the signalling periods are mapped on the allocated containers.

Figure 5 shows a sequence of three containers (three in uplink and three in downlink direction). Two containers are allocated by a BS in each transmission direction. It can be seen, that the 1st and the 3rd signalling period of figure 5 looks equal to the signalling period shown in figure 2. Only the 2nd signalling period is stretched, since it has to bridge the unallocated container. Nevertheless it can be seen that the signalling periods are simply mapped to the container structure.

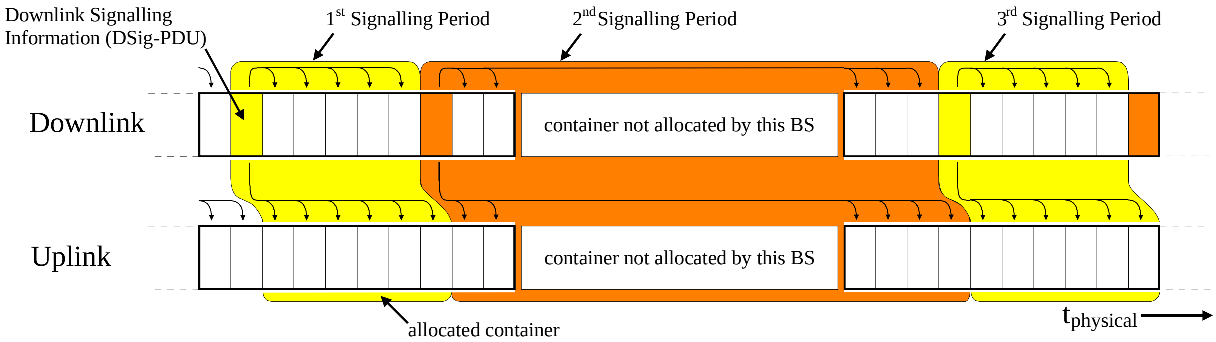

Figure 5: Symmetric allocation of containers

3.2. Asymmetric Allocation of Capacity

Asymmetric allocation means that different numbers of containers and therefore also containers at different positions within a frame are allocated for each transmission direction. It has to be considered that an allocated uplink container has to be covered by reservation messages, even if the corresponding downlink container is not allocated. In this case, it might be necessary to insert additional *DSig-PDU*s to achieve the required number of reservation messages.

Figure 6 shows again a sequence of three containers (three in uplink and three in downlink direction). Two are allocated in downlink direction and three in uplink direction. For the 1st signalling period nothing has to be changed compared to figure 5, since up- and downlink containers are allocated by the BS. Since at the second container position only an uplink container is allocated, an additional *DSig-PDU* is required which is inserted at the end of the first downlink container to provide the required number of reservation messages to bridge the uplink container. The second signalling period covers the remaining part of the first downlink container and most of the second uplink container. The third signalling period covers the remaining slots of the second uplink container and the first part of the third container in up- and downlink direction.

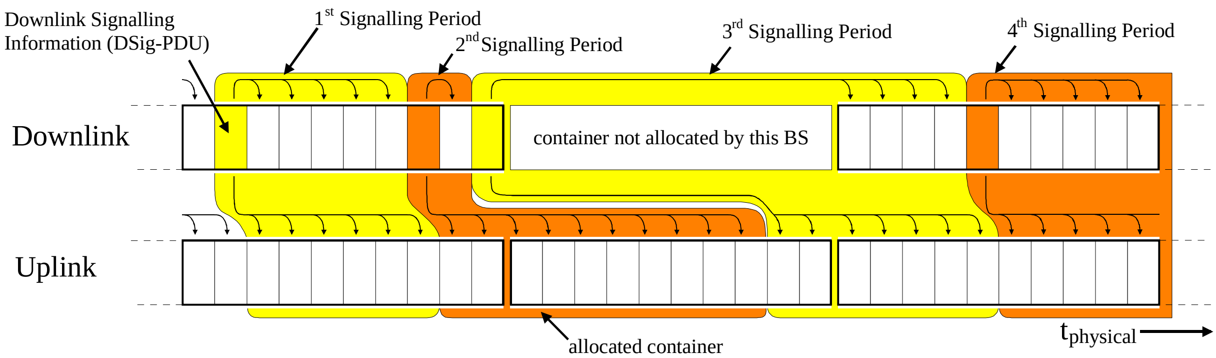

Figure 6: Asymmetric allocation of containers

4. Simulation Scenario

The performance of the DCA scheme and the advantage of asymmetric compared to symmetric allocation was evaluated by simulations using a scenario consisting of 19 radio cells of which the inner 7 cells were evaluated to reduce the border effects (cf. figure 7). Within each radio cell 50 wireless terminals were uniformly distributed. Half of the terminals generated mainly uplink traffic and a second half mainly downlink traffic.

Each terminal was modelled by a two state machine. During the passive state no ATM cells were generated at all, while during the active state the mean rate was 5% referred to the capacity offered by one physical channel. The rate μ was chosen so that the terminal stays with a mean of *10s* in the active state, while the duration of the passive state was adjusted to receive a certain load.

It was assumed that all BSs/WTs were equipped with omni-directional antennas with no additional antenna gain. The pathloss was calculated by the following formula:

$$L = -40(1+\log_{10}D)$$

where *D* is the distance between the sender and receiver. The carrier-to-interference ratio was calculated for each slot with all stations (BS/WT) sending on the same frequency. A simple DCA algorithm was used which chooses the most quite container as long as the noise power was below -105 dBm. When a Further details can be found in [KSL98].

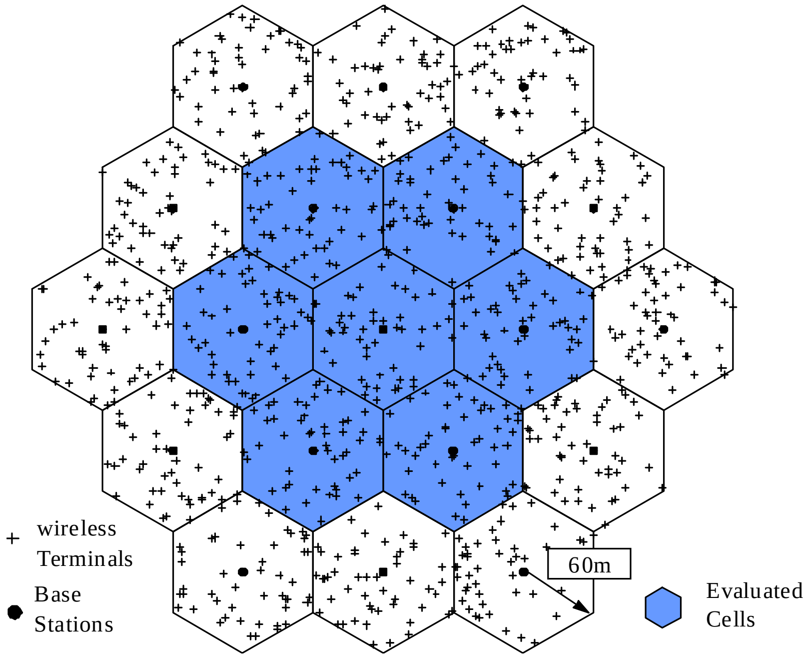

Figure 7: Simulation scenario

The simulations were performed with 16 containers per frame and 10 slots per container.

5. Simulation Results

For the given scenario the influence of symmetric and asymmetric allocation of capacity was evaluated by simulations. The *Grade of Service* (GoS)[ETSI96] was used to determine the maximum load which can be carried. A small value of the GoS means a good grade of service for the system. A GoS of less than 1% seems to be acceptable for a mobile communication system.

$$\text{GoS} = \frac{\text{blocked setup trails} + 10 \cdot \text{lost calls}}{\text{total number of calls}}$$

Figure 9 shows the probability that a certain difference between allocated downlink and uplink container occurs. Negative values mean that more uplink containers than downlink containers were allocated. Of course, in case of symmetric allocation always the same number of containers were allocated. But in case of asymmetric allocation the distribution function shows that even in case of a symmetric scenario (same average load in up- and downlink direction) the probability that the same number of containers are required was around 17%. Regarding the distribution function, it can be seen, that slightly more downlink than uplink containers were allocated, caused by the additional capacity required by the *DSig-PDU*. In figure 10 the GoS for symmetric and asymmetric allocation is shown. Since in case of asymmetric allocation only the required capacity is allocated and the remaining capacity can be used by other BSs, the load which can be carried is increased by more than 10% in the chosen scenario.

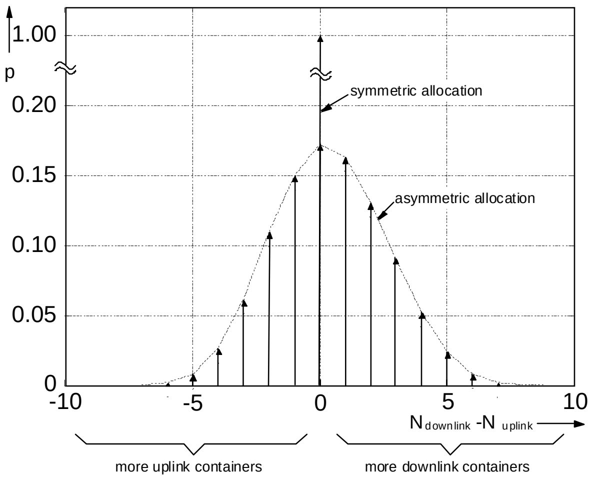

Figure 9: Comparison between allocated downlink and uplink containers

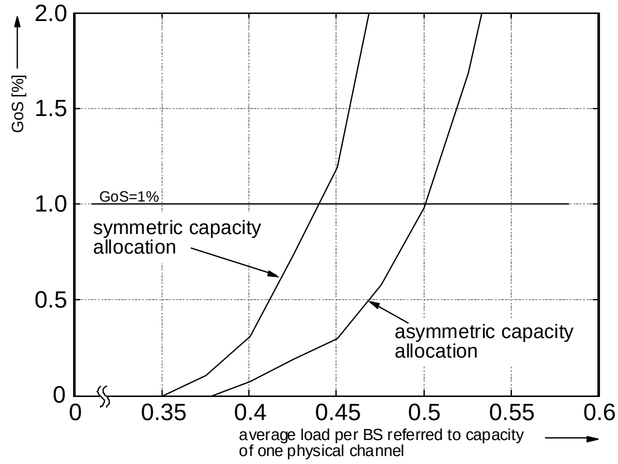

Figure 10: GoS in case of symmetric and asymmetric allocation

6. Conclusion

In this paper a dynamic channel allocation scheme for FDD based wireless ATM systems has been introduced which allows the BSs to share the available bandwidth among each other. It enables the use of circuit switched dynamic channel allocation schemes like DCS [ETS] or ARP [Ka92] by introducing steady channels into the system. Symmetric allocation of capacity results in a mapping of the signalling periods to the container structure. Asymmetric capacity allocation requires a slight adaptation of the MAC protocols, but leads to a significant increase of the load which can be carried by the system.

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