Fair Queueing Wireless ATM MAC Protocols

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ABSTRACT

Wireless ATM networks, which are currently under investigation, promise to support future multimedia applications. The medium access control (MAC) protocol of such systems plays a key role in providing differentiated quality of service (QoS). A variety of proposed MAC protocols use a centrally controlled flexible allocation of time slots. In order to support differentiated QoS the base station scheduler must allow a fair sharing of the available resources depending on the requested QoS. Moreover it should be insensitive against partially outdated status information of the mobile station queues. Our proposed scheme is able to support these properties and is simple to implement.

I. INTRODUCTION

Future networks will have to support a wide variety of services with different traffic characteristics and quality of service (QoS) requirements. For the fixed network the asynchronous transfer mode (ATM) has been developed as an universal networking technology which is able to carry information originating from all kinds of multimedia services in an integrated way. Also in the wireless area, cellular networks like GSM (global system for mobile communication) are evolving to multiservice networks, but the number of available services and the transmission capacity are rather low. Therefore wireless ATM is currently under investigation and will complement future cellular networks (e.g., UMTS, universal mobile telecommunications system) in different application scenarios. As depicted in Figure 1 these include cellular networks covering small areas as e.g. the center of a city, radio local loop (RLL) maintaining access to ATM fixed networks for residential and business users, and wireless ATM LANs.

The ATM Forum has set up a wireless ATM working group which investigates the necessary extensions to current ATM protocols in order to cope with the mobility of users and terminals [9]. Besides this, the ETSI BRAN (Broadband Radio Access Network) project (former ETSI RES10 working group) cooperates with the ATM Forum and works on the standardization of the ATM based wireless access protocols [2].

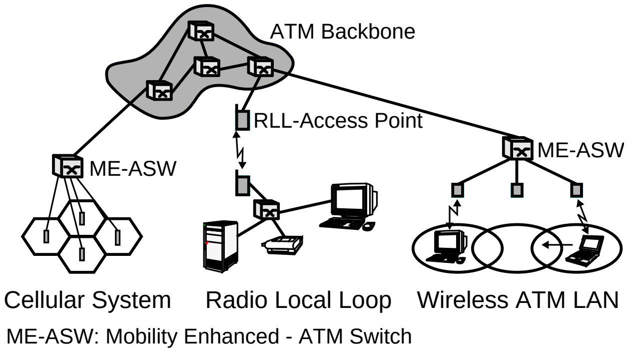

Figure 1: Wireless ATM application scenarios

In order to provide differentiated QoS for fixed networks, the ATM Forum has specified different ATM service categories (CBR, rtVBR, nrtVBR, ABR, UBR, see Table 1) and traffic management functions (e.g., UPC, CAC, traffic shaping, VP management) [1] which are able to guarantee the QoS objectives. These are expressed through a set of network performance parameters (see [4], e.g., cell loss ratio, cell transfer delay, and cell delay variation) which are negotiated upon connection set-up and contained in the traffic contract. In order to allow the seamless attachment of wireless nodes to fixed ATM networks, both must support the same service categories (Table 1).

	CBR	rt-VBR	nrt-VBR	ABR	UBR
timing	real-time		non-real-time		
cell rate	constant	variable			
QoS model	guaranteed			flexible	best effort
resource allocation	preventive			reactive	none

Table 1: Classification of ATM service categories

The remainder of the paper is organized as follows. Section II discusses the principles of wireless ATM MAC protocols which use a TDMA/TDD access schemes. Related Work is discussed in Section III. Our proposal for a fair queueing wireless ATM MAC protocol is presented in Section IV. In Section V the proposed scheme is compared to round robin scheduling by the means of computer simulations.

II. WIRELESS ATM MAC PROTOCOLS

In the protocol reference model for wireless ATM, a wireless data link control (DLC) layer and a radio (infrared) physical layer are introduced below the ATM layer (cf., [5], [6], and [8]). The DLC layer is subdivided into a media access control (MAC) sublayer which controls the access to the wireless channel and a logical link control (LLC) sublayer which deals with error control for the wireless link.

Wireless ATM MAC protocols use a centralized access scheme where a particular station (e. g. base station) controls the resource utilization. Because of the high bandwidth time division multiple access (TDMA) is considered for the MAC by the ETSI BRAN group. Moreover, in order to increase the multiplexing gain, time division duplex (TDD) is adopted, i.e. both directions of transmission (uplink and downlink) are distinguished by different time slots. Several time slots are bundled to frames of fixed or variable length. An example of such a frame is depicted in Figure 2.

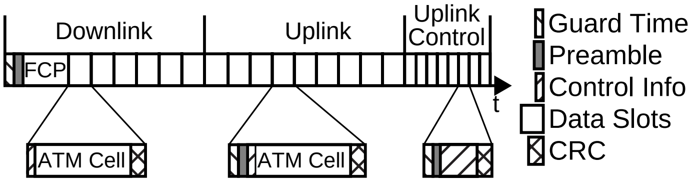

Figure 2: TDMA/TDD frame structure

While the downlink packets may be sent back to back, a guard time is needed between uplink packets and a transceiver turnaround time must be introduced between uplink and downlink phases. The time slots are allocated by the base station on a frame by frame basis. A simplified queueing model for wireless ATM MAC operation using TDMA/TDD access is depicted in Figure 3.

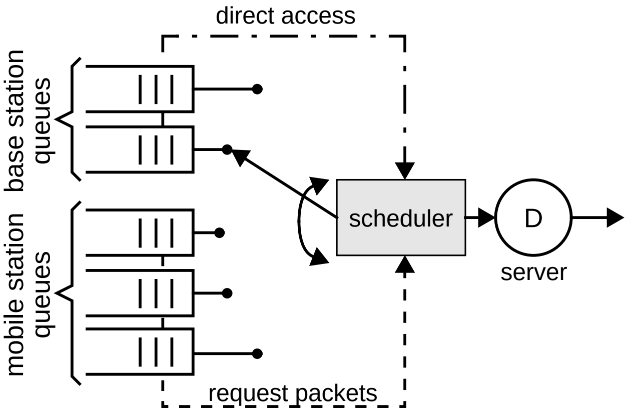

Figure 3: Queueing model of wireless MAC using TDMA/TDD

A wireless ATM MAC protocol operates as a distributed ATM multiplexer with input queues located inside the mobile stations and the base station. Depending on the available queue status information at the beginning of each frame, the scheduler inside the base station decides about the allocation of time slots for the next frame and informs the mobile stations through a frame control packet (FCP) about the allocation. In turn they send data packets in the allocated time slots. For a fair and efficient operation of the MAC protocol, the base station must have detailed information about the status of the input queues. While this is no problem for the base station queues, information about mobile station queues must be send in request packets which are either piggybacked to data slots or sent in special short control slots.

In order to support differentiated QoS in an efficient way, wireless ATM DLC protocols must provide the following properties:

1. isolation and integration of the different service categories, i.e. traffic from all service categories should be multiplexed in one network while at the same time the QoS of guaranteed services must not be violated.
2. insensitive against partially outdated queue status information
3. in case of channel error of individual connections, the QoS of other connections has to be maintained.

The key component which is responsible for the resource allocation is the scheduler inside the base station. Several scheduling strategies, which are based on generalized processor sharing and which are able to support property one, have been proposed for the fixed network. While a lot of work has been done on QoS support in fixed networks, only few investigations have been carried out in the area of wireless fair queueing which will be discussed in the following section.

III. RELATED WORK

Fair queueing service disciplines are able to provide the requested QoS of admitted connections if their input traffic is conforming to the traffic parameters negotiated during connection set up. A separate FIFO queue and a weight ϕ_i (service share) which is based on the traffic parameters is assigned to each flow. For scheduling purposes, a virtual time function is maintained and each cell is assigned a so-called service tag which depends on the service tag of the preceding cell and the virtual time. Waiting cells are served in ascending order of their service tags. Fair queueing service disciplines distribute the available bandwidth among all backlogged flows (flow with cells waiting for service in its queue) according to the allocated weights. Thus, independent of the behavior of all other flows each flow will receive at least its corresponding service share. Resources, which are not allocated to a flow or which are momentarily not used by a flow because of an empty input buffer, are automatically made available to the backlogged flows according to their weights.

In contrast to fixed networks, transmission errors occur frequently in wireless networks. Multipath fading effects cause error burst during which a mobile station cannot communicate with the base station. In [11] Lu et. al. and in [12] Ng et. al. discussed the notion of fairness in case of the existence of channel errors. They used the basic assumptions, that the channel status (error free or not) is known in advance or at least predictable. In this case, a mobile station will only be allowed to send, if the channel will likely be error-free. In the case of assumed channel error, another station may send instead of the planned one. This causes the first station to lag its error-free service and the second one to lead. After the end of the error burst a lagging flow may make up its lag by causing leading flows to give up their lead.

Lu also proposed a possible implementation of his wireless fair queueing algorithm. In this algorithm uplink and downlink slots are alternating and information on the next three slots is piggybacked to each downlink cell. In the following three mini-slots the addressed mobile stations answer if the channel condition is predicted to be good. In the forth mini-slot, the base station identifies the flow which has been chosen for transmission during the current slot.

As discussed in Section II a transceiver turn-around time must be introduced between each uplink and downlink packet which is necessary because of transmission and processing delays. In Lu's proposal, four turn-around times and two guard times (between uplink mini-slots) are needed for each period, i.e. one downlink and one uplink cell. Considering a DLC layer bandwidth of 30 Mbit/s, 5µs turn-around time, and 1µs guard time, this leads to an overhead of 660 bits which corresponds to 1.6 ATM cells. In addition to this relative large overhead the exchange of information bits during the negotiation phase must be considered, leading to a rather inefficient and complicated protocol. Moreover, frame sizes greater than one are not considered in their work which would have great impact on the accuracy of the channel status prediction.

IV. FAIR QUEUEING MAC PROTOCOLS

In our approach we do not assume any knowledge about the status of the wireless channel. Moreover, we consider the wireless ATM MAC principles described in Section II, i.e. TDMA/TDD access scheme with centrally controlled resource allocation. The self clocked fair queueing (SCFQ) [3] service strategy is adopted in the base station scheduler. With SCFQ the service tag of a cell arriving at a non-empty queue can directly be derived from the service tag of the preceding cell. Moreover, the virtual time function is independent of the set of backlogged flows. Therefore, the exact arrival time of a cell is not important and the scheduler must only maintain one service tag per backlogged flow. Moreover, a mobile station does not have to send an request packet in the uplink control slots but will send the new queue length information piggybacked on its next data packet. If a new cell arrives at a previously empty queue, the mobile station sends a request packet in an uplink control slot. Access to these slots is contention based.

At the end of each frame the base station determines the allocation of slots for the next frame based on the currently available information. Thus, cells arriving during a frame can earliest be considered for transmission in the next frame. The base station scheduler stores the number of waiting cells of each flow and maintains an ordered list containing a service tag for the first element of all backlogged flows. Scheduling is done in two steps:

1 Up to a maximum number of iterations (maximum frame length) or until all queue length counters are zero the scheduler removes the first element of its service tag list, generates a transmission permit, decreases the corresponding queue length counters by one, and, if it is not zero, a new service tag is calculated and inserted into the service tag list.

2 Permits are then separated into uplink and downlink permits and included in the frame header. Note, that this separation is necessary to limit the overhead due to transceiver turn-around and guard times.

In parallel, the virtual time is updated according to the service tag of the cell currently in service.

A mobile station (MS) running multimedia applications on high speed networks may very likely use several connections in parallel. If these connections have different QoS requirements, they cannot simply be multiplexed into a common MS FIFO queue. Hence, a scheduler must determine the service order. In wireless ATM MAC protocols connections of one mobile station may be treated either separately by the scheduling mechanism in the base station or several connections may be pooled and handled as one flow by the central scheduler. In order to realize the second approach an additional scheduler is needed in the mobile station. This hierarchical scheduling approach is described in detail in [10]. It reduces the amount of exchanged status information and the base station complexity. Furthermore, even if the base station doesn't know about the arrival of an urgent cell at the mobile station this cell can still overtake other cells at the mobile station and be transmitted in the next mobile station data slot. Depending on the terminal requirements the scheduler in the mobile station may use different scheduling strategies, it may use the same as the base station scheduler or a different one, e.g. a simple priority based scheduling or round-robin. In the remainder we assume that the base station scheduler serves the base station queues as well as the mobile station queues on a per connection basis.

In case of channel errors, the corresponding flow will get a credit and free resources are additionally allocated to the corresponding flow. If several flows are facing bad channel conditions, the free resources are shared among them according to their service weights. As only free resources are distributed among flows which are in error, the QoS of error free flows is not affected. Up to now, this mechanism has not been included in the simulation environment and therefore only the error-free case is investigated in Section V.

V. SIMULATION RESULTS

By means of simulation studies we compared two different scheduling mechanisms for wireless ATM MAC protocols, SCFQ scheduling and the round robin strategy where all connections are served separately by the base station scheduler. We considered two multimedia scenarios with five mobile stations and one base station. All mobile stations have established several bidirectional CBR, VBR, and UBR connections. For the VBR connections ATM cells are generated according to the well-known on-off source model. Poisson sources generate background UBR traffic.

In the first scenario each mobile station has set up five connections in either direction. Two bidirectional CBR and VBR connections and one UBR connection. The selected values for the source parameters as well as their corresponding service weights ϕ_i are depicted in Table 2. A small weight was allocated to the Poisson background traffic in order to guarantee a minimum QoS for this service. In the second scenario we have replaced the two VBR connections of the first mobile station by one with doubled mean and peak rate as well as weight ϕ_i.

Source	peak rate [Mbit/s]	mean burst size [cells]	mean rate [kbit/s]	ϕ_i
VBR 1-2	2	10	300	1.0
CBR 1-2	0.3	-	300	1.0
UBR	-	-	500	0.2
VBR of MS 1	4	10	600	2.0

Table 2: Source parameters and service weights

For the MAC protocol we assume a raw data rate of 30 Mbit/s including all overhead. We used a variable frame length with a maximum of 20 data slots and an adaptive number of request slots according to the identifier splitting algorithm described in [7] which polls individual terminals if they collided twice. Hence, it guarantees the successful transmission of the queue status information at latest after three frames. The frame header consists of a fixed part and a variable part which depends on the number of permits granted for this frame. The guard time between uplink slots was set to 1µs and the transceiver turnaround time between uplink and downlink phases was chosen as 5µs. The size of the uplink and downlink data slots were set to 60 Bytes including preamble and control information. The size of request packets is 9 Bytes. Assuming a maximum frame length of 20 data slots and three request slots this results in a gross system rate of 23 Mbit/s (including ATM and AAL header overhead). The system load was chosen as 74%, i.e. 17 Mbit/s.

The results for the round robin scheduler are shown in Figure 4, Figure 5, and Table 3. The first diagram shows the complementary delay distribution function of the downlink connections in the first scenario (symmetric load). As can be seen there, the UBR connections perform better than the VBR connections which is not desirable for best effort services. Figure 5 shows the results for the second scenario with asymmetric load. Because of the same overall load, the performance of the unchanged connections remains about the same but the performance of the high rate VBR connection of mobile station 1 shows even worse performance. The same can be seen for the mean transfer time shown together with 95% confidence intervals in Table 3. The slight differences in the performance between the two VBR and CBR sources respectively can be attributed to the frame based allocation of time slots.

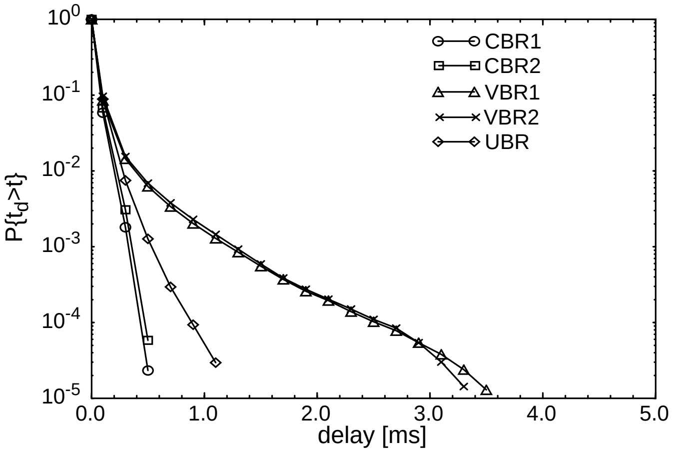

Figure 4: Round robin scheduler, downlink direction, symmetric scenario

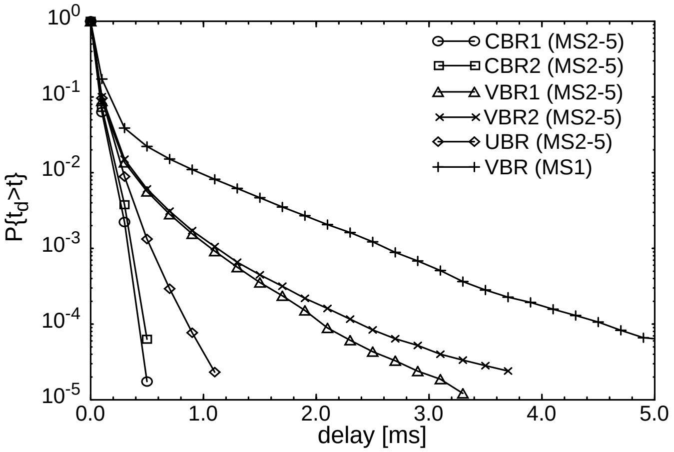

Figure 5: Round robin scheduler, downlink direction, asymmetric scenario

Source	sym. scenario	asym. scenario
VBR 1	0.095 +- 0.001	0.095 +- 0.001
VBR 2	0.100 +- 0.001	0.100 +- 0.001
CBR 1	0.081 +- 0.001	0.083 +- 0.002
CBR 2	0.086 +- 0.001	0.087 +- 0.001
UBR	0.096 +- 0.001	0.097 +- 0.001
VBR of MS 1		0.143 +- 0.002

Table 3: Mean transfer time [ms] for round robin

In summary, the round robin scheduling discipline provides no means for discriminating between different services and QoS requirements and therefore leads to a poor MAC protocol performance.

The proposed SCFQ wireless ATM MAC protocol has been evaluated using the same scenarios. The results obtained from this investigation are depicted in Figure 6, Figure 7, and Table 4. In contrast to the round robin scheduling, the SCFQ scheduling is able to control the QoS. As expected, the performance of the

UBR service is worse than in the round robin case. As a result, the CBR and VBR services gain slightly. Moreover, the performance of the VBR connection of mobile station one in the asymmetric scenario (see Figure 7) is similar to the performance of the VBR connections of the other mobile stations. Compared to the symmetric scenario although, the CBR and VBR connections of mobile stations 2-5 face a minor decrease of their performance. This is caused by the assignment of the weight for the high rate VBR connection of mobile station 1 and the very bursty nature of the corresponding source in the asymmetric scenario. This effect could be reduced but not eliminated by a better assignments of the weights.

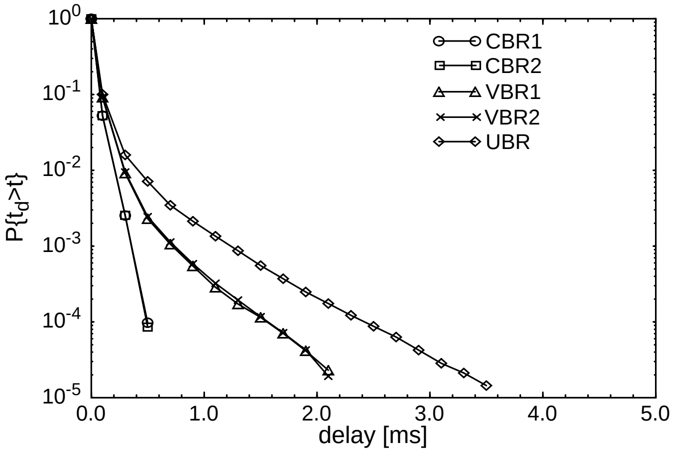

Figure 6: SCFQ scheduler, downlink direction, symmetric scenario

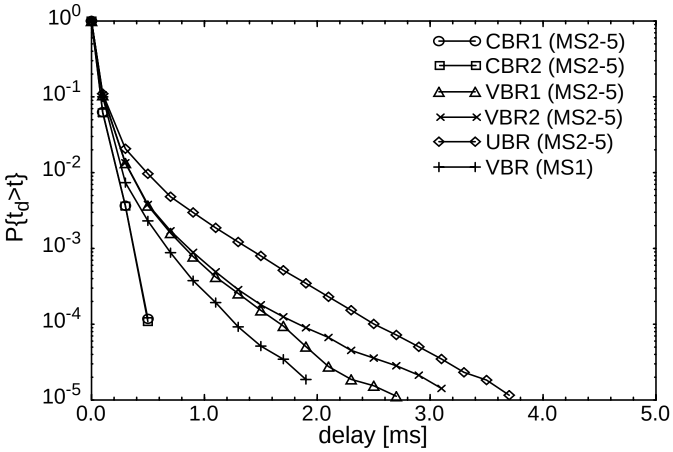

Figure 7: SCFQ scheduler, downlink direction, asymmetric scenario

Source	sym. scenario	asym. scenario
VBR 1	0.095 +- 0.001	0.100 +- 0.001
VBR 2	0.096 +- 0.001	0.100 +- 0.001
CBR 1	0.078 +- 0.001	0.081 +- 0.001
CBR 2	0.078 +- 0.001	0.081 +- 0.001
UBR	0.105 +- 0.001	0.109 +- 0.001
VBR of MS 1		0.098 +- 0.001

Table 4: Mean transfer time [ms] for SCFQ

VI. CONCLUSIONS

In this paper we have proposed the application of fair queueing strategies (SCFQ) to TDMA/TDD wireless ATM MAC protocols. Moreover, the proposed mechanism was evaluated by means of computer simulations and compared to the round robin scheduling strategy. While our approach is simple to implement it allows to control the performance of each individual connection and therefore is able to support differentiated QoS. Currently, we are investigating the use of a hierarchical scheduling strategy with different queueing strategies in the mobile station. This approach will be compared with MAC protocols known from the literature. Moreover, channel errors will be considered.

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