Impact of Wireless Access on Traffic Management in ATM Networks

Rolf Sigle [a,b,1], Thomas Renger [a,2]

[a] *University of Stuttgart, Institute of Communication Networks and Computer Engineering, Pfaffenwaldring 47, D-70569 Stuttgart, Germany*

[b] *Daimler-Benz AG, Communication Technology, D-89013 Ulm, Germany*

Abstract

Traffic management plays an important role in providing differentiated quality of service and supporting the integration of a variety of broadband services within a common ATM network. Wireless ATM access networks are under definition in standards bodies as well as subject of various research activities and first field trials. The nature of the wireless medium requires new protocols that are able to cope with multiple access, error prone wireless channels and user mobility. When attaching a wireless ATM network to a fixed ATM network proper interaction of traffic and resource management functions throughout both networks is necessary to achieve stringent QoS objectives. In this paper the relation between mobile specific protocols and traffic management functions as well as their mutual impacts are discussed. Three key areas to enable seamless traffic management integration are identified and possible solutions are outlined.

Key words: Wireless ATM, Traffic Management, MAC Protocols, Weighted Fair Queueing

1 Introduction

Today we face two major trends in communications: broadband multimedia and mobility. Thus there is a strong demand for broadband wireless networks which support advanced multimedia applications running on a variety of terminals and in different environments. While for fixed networks technologies like ATM promise to provide differentiated Quality of Service (QoS), nowadays

[1] Corresponding author, Email: sigle@ind.uni-stuttgart.de

[2] The author is now with Mannesmann Eurokom, D-70565 Stuttgart, Germany

wireless cellular networks like GSM or IS-54 and wireless LANs like HIPERLAN1 (HIgh PErformance Radio Local Area Network) or IEEE 802.11 are mainly single service networks which are not able to meet the above mentioned future requirements.

Therefore, the wireless ATM working group of the ATM Forum is specifying various extensions to ATM protocols in order to cope with the mobility of users and wireless access [14]. Moreover, the ETSI BRAN (Broadband Radio Access Network) project (former ETSI RES10 working group) is standardizing ATM based wireless access networks as part of the HIPERLAN protocol family [2]. In parallel several companies like Olivetti [12] and NEC [15] among others as well as European R&D projects like the Magic WAND ACTS project [13] develop and investigate wireless ATM prototype systems.

In Figure 1 various application scenarios of wireless ATM are depicted. Whereas cellular wireless ATM networks may cover the area of a city its center and allow the user to roam inside this relatively large area (or to another covered area), the possible user movement within wireless ATM LANs is restricted to, e.g., a building or even only a floor. In order to support the user mobility in these scenarios mobility enhanced ATM edge switches are necessary (ME-ASW). On the other hand, if wireless ATM is used for the wireless local loop configurations, the users are only allowed to connect to their corresponding access point. Hence, no specific mobility support functions within the ATM network are required.

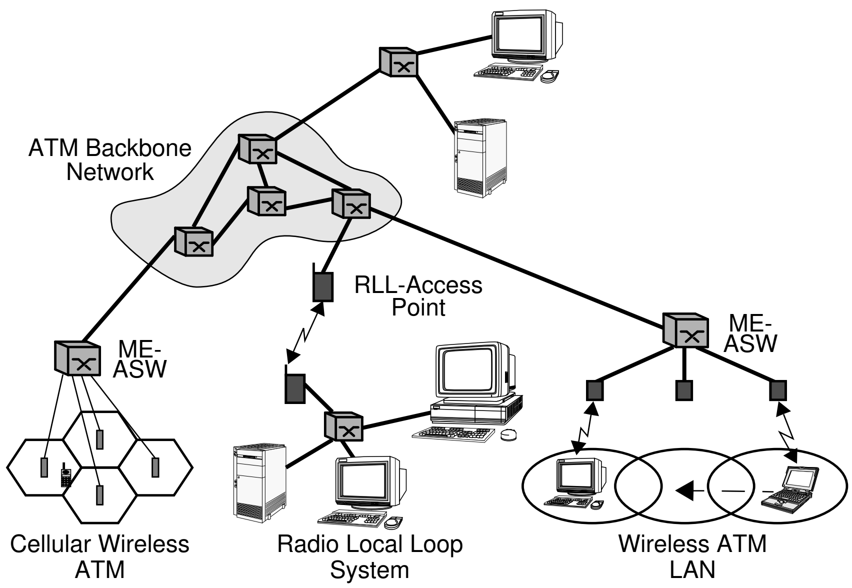


Fig. 1. Wireless ATM application scenarios

To provide differentiated QoS for fixed ATM networks the ATM Forum has specified different ATM service categories (CBR, rtVBR, nrtVBR, ABR, UBR) and traffic management functions (e.g., UPC, CAC, traffic shaping, VP management) [1]. These functions are able to guarantee the QoS objectives which are expressed through a set of network performance parameters (e.g., cell loss ratio, cell transfer delay, and cell delay variation, see [5]). These parameters are negotiated upon connection set-up and are 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. Hence, traffic management functions for both the wireless as well as the fixed network need a careful design. On the one hand, they must fulfil the specific control requirements but on the other hand they should co-operate and thereby constitute a robust and efficient overall control framework.

The remainder of this paper is organized as follows. In Section 2 we review traffic management in fixed ATM networks. Then Section 3 discusses in detail various problems that arise from wireless access to fixed ATM networks. Possible solutions are then outlined in Section 4, where specific focus is put on scheduling architectures and algorithms for an integrated wireless/wireline traffic management. Finally, we conclude by giving an outline of future work.

2 Traffic Management in Fixed ATM Networks

Traffic management in fixed ATM networks is based on the concept of a service architecture and traffic contracts, which is described in the following. Afterwards, the set of traffic management functions required to realize this concept is introduced.

2.1 ATM Service Architecture

The support and integration of different services (e.g., voice, video, data) in ATM networks requires specific protocols and service models at the ATM layer. In order to support typical broadband services while at the same time providing an efficient usage of transmission resources, the ATM Forum has defined several ATM service categories [1]. These can be distinguished by properties such as timing requirements, cell rate variability, QoS model, and resource allocation strategy (see Table 1).

To provide strict network performance guarantees to constant bit rate (CBR) connections, the required resources are allocated in advance for the connection life-time. CBR connections have real-time constraints, i.e., the cell delay as well as the cell delay variation must be kept strictly bounded.

Applications with time varying bit rates are supported by the variable bit rate (VBR) service categories. During the connection establishment phase

Table 1
Classification of ATM service categories

<table>
<tr><th></th><th>CBR</th><th>rt-VBR</th><th>nrt-VBR</th><th>ABR</th><th>UBR</th></tr>
<tr><td>timing</td><td colspan="2">real-time</td><td colspan="3">non-real-time</td></tr>
<tr><td>cell rate</td><td>constant</td><td colspan="4">variable</td></tr>
<tr><td>QoS model</td><td colspan="3">guaranteed</td><td>elastic</td><td>best effort</td></tr>
<tr><td>resource allocation</td><td colspan="3">preventive</td><td>reactive</td><td>none</td></tr>
</table>

the application must be able to provide information about the mean and peak cell rates of the connection. As the VBR services have a guaranteed QoS, preventive resource allocation must be applied. The variation of the cell rates of VBR connections can be taken into account when allocating resources which may result in a more efficient resource usage. Depending on the timing requirements, VBR is further divided into real-time (rt) and non-real-time (nrt) subcategories.

For applications without real-time constraints and the possibility to adapt to currently free network resources the available bit rate (ABR) service category was defined. The ABR protocol allows fast access to spare resources. Moreover, during connection set-up a minimum guaranteed cell rate is specified. Therefore, the cell rate is composed of a guaranteed and a flexible part and is bounded by the peak cell rate.

The unspecified bit rate (UBR) service doesn't provide any guarantees to applications. UBR connections may use any spare resources which aren't in use by connections of other service categories. Usually no explicit allocation of resources is made for UBR connections. Hence, UBR connections have lowest priority for resource allocation.

A similar service architecture has been specified by the ITU-T. The ITU-T architecture is based upon so-called ATM transfer capabilities (deterministic bit rate, DBR; statistical bit rate, SBR; available bit rate, ABR; ATM block transfer, ABT). For further details about the ITU-T concept it is referred to [6]. Moreover, in the reminder of the paper we will stay with the ATM Forum notation.

In order to provide diversified ATM services, various agreements must be made during a connection set-up. These are contained in the traffic contract (see Figure 2) which is negotiated between the user and the network at the standardized user network interface (UNI) and is composed of several components which are described in the following.

The connection traffic descriptor is composed of the source traffic descriptor and the cell delay variation tolerance. The source traffic descriptor includes

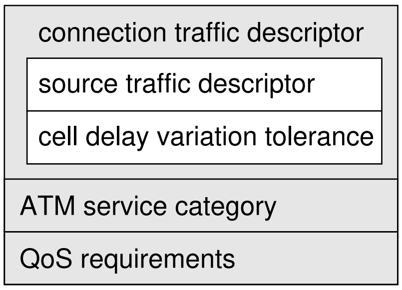


Fig. 2. Components of the traffic contract

a list of all traffic parameters and describes the characteristics of the traffic profile. These parameters must be understandable by the network as well as by the application and easily measurable. Currently the peak cell rate (PCR), sustainable cell rate (SCR), maximum burst size (MBS), and minimum cell rate (MCR) parameters are standardized [1,6]. While the PCR parameter is part of all traffic contracts, SCR and MBS are used for VBR connections only. The MBS parameter specifies the maximum number of ATM cells which may be sent at PCR. The MCR parameter is used for ABR connections and specifies the guaranteed part of the ABR cell rate. The cell delay variation tolerance (CDVT) parameter is part of the connection traffic descriptor as well. It describes how far and how long an application may exceed the declared PCR.

In addition to the connection traffic descriptor the used service category and the needed QoS must be specified in the traffic contract by means of ATM layer network performance parameters as standardized in [5]. Among others, these parameters are the cell loss ratio (CLR), cell transfer delay (CTD), and cell delay variation (CDV). The network performance objectives have to be guaranteed only for the part of the traffic which is conforming to the specified connection traffic descriptor. The treatment of non-conforming cells may be specified separately.

The traffic and network performance parameters for each ATM service category are summarized in Table 2.

Table 2
Traffic and network performance parameters

	CBR	rt-VBR	nrt-VBR	ABR	UBR
traffic parameter	PCR	PCR, SCR, MBS		PCR, MCR	(PCR)
network performance par.	CLR, CTD, CDV			—	—

2.2 Traffic Management Functions

Traffic management functions are mechanisms and protocols that directly or indirectly influence the flow of cells in an ATM network. Their task is to support the different ATM service categories (see Table 1) and to guarantee the negotiated network performance objectives with minimal network resource effort. The traffic management framework can be divided further into a traffic control and congestion control part. While traffic control functions avoid network overload situations, congestion control functions minimize the impact, intensity, duration, and spread of such situations. Overload situations are usually caused either by statistical multiplexing effects or incorrect network element operation.

The dynamics of ATM traffic flows range from cell level (microseconds) to hourly or even seasonally fluctuations. Hence, different traffic management functions operating at different time scales exist. All functions together constitute a hierarchical traffic management framework where long-term control functions are based on short-term control functions (see Figure 3). Most of the depicted functions are specified in a generic form, leaving the implementation of algorithms and protocols open [1,6]. Only the algorithms for the usage parameter control (UPC) and the protocols for ABR are standardized. Moreover, only the UPC function and the connection admission control (CAC) function are mandatory, all others are optional.

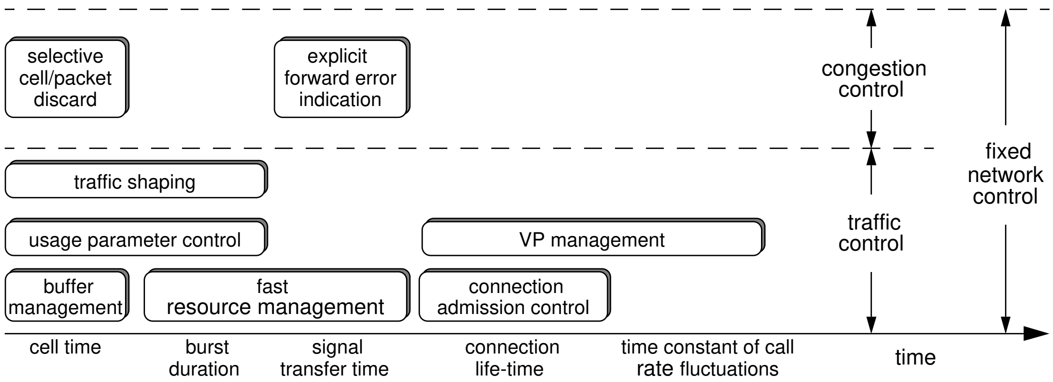


Fig. 3. Classification of traffic management functions [9]

The CAC is a central part of the traffic management framework. Based on the traffic parameters, the selected service category, and the QoS requirements it decides whether a new connection may be set up or not. A very simple version of the CAC is based on the peak cell rate allocation which is used for CBR connections. Obviously this strategy is very inefficient for VBR connections as the potential statistical multiplexing gain cannot be exploited. Especially for very bursty traffic this causes a waste of valuable network resources. Therefore, an equivalent cell rate [4] can be calculated which is bounded by the SCR and PCR parameters. This must take into account the traffic and network performance parameters of all existing as well as the new connection. Obviously there exists a trade-off between a high statistical multiplexing gain and a low cell loss ratio. For ABR connections only resources for the MCR must be allocated while for UBR no resources have to be reserved.

If an application sends traffic which is not conforming to the connection traffic descriptor, the network may not be able to provide the QoS guarantees of other conforming traffic multiplexed within the same network. Hence, the traffic parameters of all connections must be monitored which is done using the generic cell rate algorithm (GCRA) [1,6]. The GCRA is based on the leaky bucket mechanism which allows to monitor a rate parameter together with its tolerance value. By this means PCR and CDVT as well as SCR and MBS parameters are monitored together by one GCRA, respectively. Non-conforming cells may either be discarded or given a lower priority. The traffic parameters are monitored at the UNI or network node interface (NNI). The corresponding functions are therefore denoted usage parameter control (UPC) and network parameter control (NPC), respectively.

Traffic shaping can be used at the UNI or NNI interface to change the profile of the cell flow. A subscriber may not know in advance the exact traffic parameters of the cell flow generated by his applications. As he doesn't want to pay more by reserving too much bandwidth he may ask for a PCR which is too small for some periods of time during the connection. Traffic shaping may be used to delay non-conforming cells until they become conforming to the traffic contract. This function can be located at the user or network side of the UNI. Inside the network traffic shaping may be used to eliminate changes of the traffic profile caused by asynchronous multiplexing.

Buffer management plays an important role in supporting and integrating different service categories. It includes all functions to partition and reserve buffer space and to handle the cells inside the buffer queues. Different strategies based on weighted fair queueing are discussed in the ATM community as possible approaches for the integration of ATM service categories [16]. In order to avoid overload, cell buffers may set a bit in the ATM cell header and thereby indicate that the applications should lower their rates (explicit forward error indication). Moreover, special cell and packet discard schemes can be used in order to improve network throughput.

Data traffic is usually characterized by very high cell rate variations and hence very bursty traffic. Furthermore, it tolerates higher transfer delay and delay variation but demands very low error rates because errors lead to retransmissions of data packets. Therefore, it is not feasible to use the same service categories as for guaranteed services. In order to support the specific needs of data traffic different protocols for fast resource management (FRM) were developed. The basic idea is to reserve resources for a connection only when it really needs them and to return them to other connections when it doesn't need them. During connection set-up only the route through the network is determined. By sending special resource management (RM) cells the sender reserves buffer space and/or bandwidth in the network nodes along the selected route. Depending on the used protocol the reservation may change during connection life-time. An adaptive mechanism that allows a fast and continuous adaptation of the sending rate is the ABR protocol specified by the ATM Forum. In this protocol the sender periodically inserts RM cells with the allowed cell rate (ACR). In a control loop all nodes on the way to the receiver may lower this rate and send the RM cell back to the sender. Another FRM protocol is ABT which has been standardized by the ITU-T [6].

The concept of virtual paths (VP) allows the logical separation of different service categories and can simplify CAC. The major drawback is the lower achievable multiplexing gain, e.g., one VP is fully loaded and therefore new connection requests on this VP must be rejected although there is spare capacity on the link the VP belongs to. In order to avoid such situations and to increase the overall throughput, VP management tries to optimize the capacity assigned to each VP and to adapt the VP network configuration according to the current traffic load.

3 Impact of Wireless Access

Most of the existing proposals for wireless ATM access (cf., [7,8,11–13,15]) introduce a wireless data link control (DLC) layer below the ATM layer that uses a centralized access protocol in which the base station acts as an ATM multiplexer with distributed input queues located inside the mobile stations. The protocol reference model for a wireless ATM access network is depicted in Figure 4. As shown there, the radio resource management on the wireless channel cooperates with the resource management in the mobility enhanced ATM switch and the wireless DLC (MAC and LLC) layer. In cellular networks, in addition to special wireless DLC protocols specific support of terminal and personal mobility must be added to the wireless ATM access network. If a user moves from one radio cell to another while connections are established, a handover protocol takes care of the continuation of the connections.

Like the traffic management functions these wireless control functions operate at different time scales (see Figure 5). While the wireless medium access control (MAC) as well as the wireless logical link control (LLC) protocols operate on the cell and burst level, handover becomes effective on longer time scales up to the connection life-time. Therefore, different ATM traffic management functions are influenced by wireless DLC and handover protocols. These mutual influences are discussed in the following two subsections.

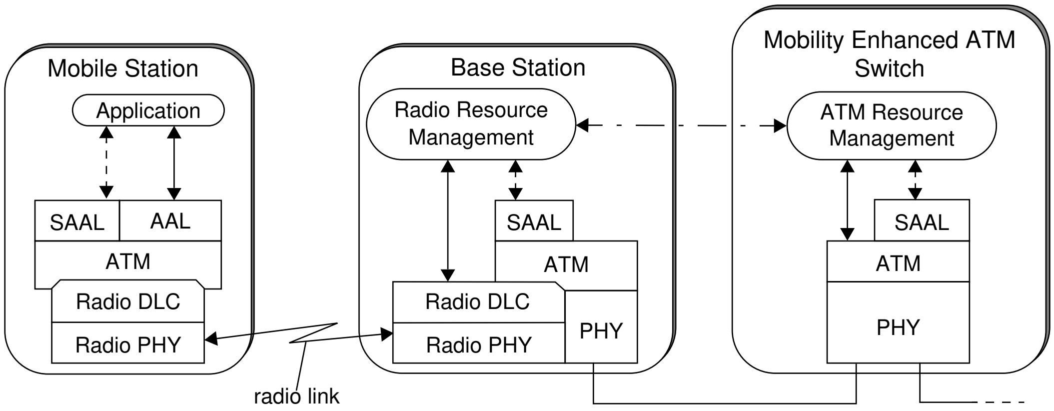


Fig. 4. Wireless ATM reference model

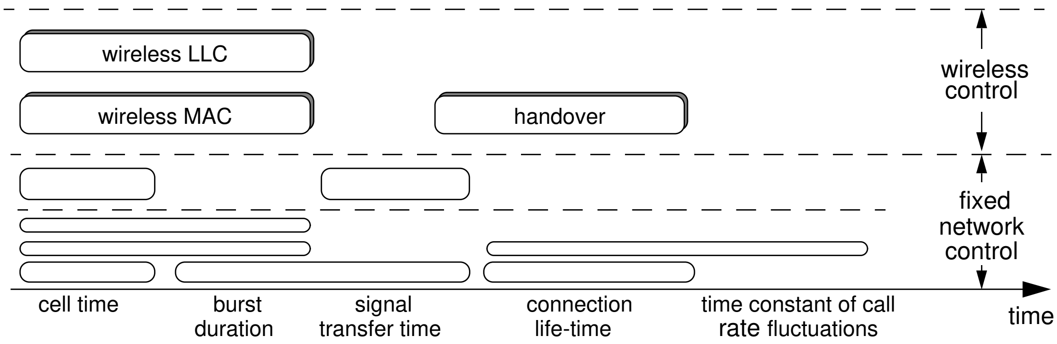


Fig. 5. Relation between traffic management functions and wireless control functions

3.1 Short-term Effects

As mentioned above the wireless MAC protocol in the DLC layer works like a distributed ATM multiplexer with a scheduler inside the base station and input queues located in the mobile station. Additional input queues are located at the base station if time division duplex (TDD) is used, i.e., uplink and downlink share the same frequency band and are separated by different time slots.

In most of the existing proposals for wireless ATM MAC protocols only input queues with queue lengths greater than zero are served in order to allow a work conserving scheduling and to fully exploit the available bandwidth. In order to guarantee a fair and efficient operation of the protocol, the scheduler inside the base station needs accurate information about the status of the input queues. Obviously this is not a problem concerning queues located in the base station but for the queues within the mobile terminals an additional mechanism is needed to update status information. This can be done with special request packets (usually shorter than data packets) sent either piggy-backed to a data packet or in special time slots.

The access policy on these request time slots may be based on polling, random access, or a combination of both. Depending on the used mechanism, the content of the request packets, and the used scheduling discipline, the queue status informations available at the base station scheduler may be inaccurate and partially outdated. Furthermore, the information updates consume valuable transmission capacity which could otherwise be used for sending data packets.

Obviously a trade-off exists between the update frequency and the accuracy of the status information at the base station. Therefore this mechanisms and the scheduling algorithm heavily influence the ATM cell transfer delay and change the profile of the incoming source traffic (e.g., enlarged cell delay variation). Hence, traffic which is conforming to the traffic contract at the terminal side may be altered to non-conforming traffic through the wireless MAC protocol. Inside the ATM network (e.g., at the first ATM switch) UPC and/or NPC functions may therefore discard ATM cells if no special precautions are foreseen. A similar problem can be found in MAC protocols for passive optical networks [10] and other access network technologies.

Another problem induced by the wireless channel is the relatively high bit error probability. In order to guarantee fixed ATM network like cell loss and cell error probabilities, forward error correction (FEC), automatic repeat request (ARQ), or hybrid schemes are used at the LLC and physical layers. Due to the asynchronous nature of transmission interleaving over several data packets cannot be adopted in combination with FEC. Hence, the ATM cell transmission is vulnerable by burst errors which are common in wireless communications. If the LLC layer recognizes an error by means of an error detection code the ATM cell must be retransmitted.

In order to guarantee the cell sequence integrity all other ATM cells of the same ATM connection, which are correctly received later, must be delayed until the correct reception the erroneous cell leading to an additional delay and delay variation. Cells may even be sent back to back. Depending on the ARQ protocol positive or negative acknowledgments for single or several ATM cells of each connection or mobile terminal must be exchanged between the mobile station and the base station. Again the uplink direction is the more critical part. Like request packets ARQ information may be piggy-backed on data packets or sent separately.

While FEC (adopted to a single data packet) doesn't introduce additional cell transfer delay or delay variation ARQ schemes even further change the traffic profile. Furthermore, transmission capacity needed for retransmissions is not available for other data transmission which causes a reduction of the effectively available bandwidth. During high error probability phases retransmissions in one connection sent at high priority may even reduce the QoS of other connections.

In addition to these short-term effects introduced by wireless DLC protocols long-term effects caused by the movement of terminals must be considered during the development of wireless ATM networks. Changes of the radio cell while connections are established must be handled by new handover protocols. In order to allow a seamless transition into the new radio cell the handover protocol must be able to guarantee the cell sequence integrity and a low cell loss probability during handover. Moreover, a mandatory prerequisite for a successful handover is the availability of enough resources at the air interface of the new radio cell as well as within the fixed part of the access network. In contrast to nowadays cellular networks a single user in future wireless ATM networks will be able to claim a significant portion of the overall available bandwidth. Therefore, simple concepts that reserve channels for handover purposes without considering the current situation of the network (e.g., active connections and the location of the active terminals) will fail.

In Figure 6 a handover example is given. While a successful handover of the notebook terminal to the radio cell on the upper right is possible, a transition to the right will lead to dropping its connections because most resources are already allocated to other terminals. In order to guarantee (at least to a certain extent) the continuation of connections after handover the CAC of the fixed network should consider the movement of the users.

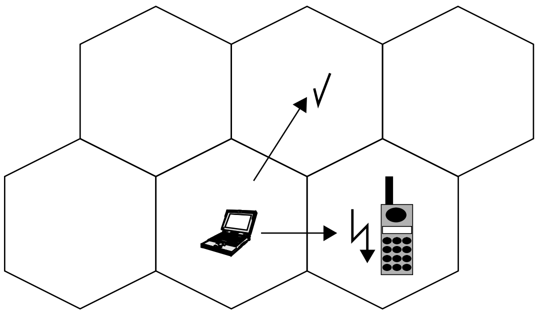


Fig. 6. Example for successful and unsuccessful handover

In order to provide low connection blocking probabilities enough capacity to set up new connections must be made available. The amount of needed resources depends heavily on the spatial user density which may change with time. While people stay at work during the day they tend to stay at home during the night. Furthermore, there are hot spots with varying user density in space and time dimension. These situations may occur periodically (e.g., once a week) or just once. This variability must be taken into account for resource reservation at the air interface and in the fixed network.

4 Integrated Traffic Management

As described in Section 3 and depicted in Figure 5 several relations exist between the wireless control protocols and traffic management functions defined for fixed ATM networks. In order to constitute a robust and efficient overall traffic management framework for wireless ATM networks, the interactions between the different protocols have to be taken into account during the system design. Moreover, new protocols should be designed to co-operate with already existing mechanisms. In this section we propose and discuss approaches for traffic control integration, enforcement of UPC conformance and handover support.

4.1 Traffic Control Integration

The ETSI BRAN project group is currently investigating MAC protocols which are based on time division multiple access/time division duplex (TDMA/TDD), i.e., different connections as well as uplink and downlink directions are distinguished by different time slots. Several time slots are bundled to frames of fixed or variable length. A simplified model for wireless ATM MAC operation using TDMA/TDD access is depicted in Figure 7.

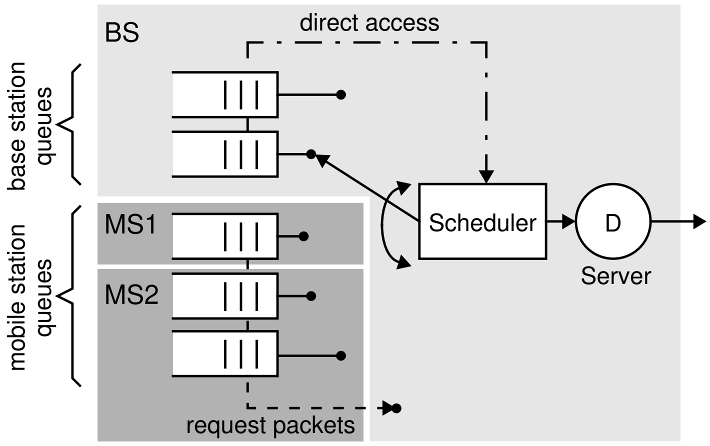


Fig. 7. Model of wireless MAC using TDMA/TDD

The time slots are allocated on a frame by frame basis by the base station (BS) scheduler. Depending on the available queue status information at the beginning of a frame, the scheduler decides about the allocation of time slots for the next frame and informs the mobile stations (MS) about the allocation by broadcasting a frame control packet. In return they send a data packet in the allocated time slot. The server (D) models the constant service time of an ATM cell on the radio link.

As shown in Figure 7, the scheduler has direct access to the status information of the base station queues but request packets are necessary to update the status of the mobile stations' queues. The request packets may either be sent piggy-backed to data packets or in special control slots. The transmission of request packets consumes valuable bandwidth which could otherwise be used for data transmission. Therefore, their frequency should be kept as low as possible.

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

(1) isolation and integration of the different service categories, i.e., traffic from all service categories should be multiplexed into 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 to provide these properties is the scheduler. Several scheduling strategies, which are based on generalized processor sharing and which are able to support property 1, have been proposed for the fixed network. With these mechanisms, a weight is assigned to each connection which corresponds to a guaranteed service rate. It has been found, that out of this family of scheduling disciplines self clocked fair queueing (SCFQ) [3] is especially suited for WATM MAC protocols.

If SCFQ is used for the MAC protocol the scheduler needs information about the number of cells waiting in the queues, i.e., the mobile stations send the queue length together with the corresponding connection indicator to the base station. This information is used to update the queue length counter in the connection table which also includes the weights of the connections (see Figure 8). For scheduling purposes, a service tag (st) is assigned to the first cell of each active queue according to the SCFQ algorithm. In addition to the connection table, a sorted list of service tags is maintained at the base station scheduler. This list includes one element for each currently backlogged connection (i.e., connections with queue length greater than zero). Scheduling is done in two steps:

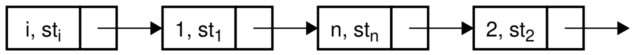
(1) The scheduler removes the first element of its service tag list, generates a transmission permit, decrements the corresponding queue length counter by one, and, if it is not zero, a new service tag is calculated and inserted into the service tag list. This is repeated until the maximum number of slots in a frame is reached or all queue length counters are zero.
(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 (introduced between

uplink and downlink phases) and guard times (introduced between uplink slots).

Connection Table

Conn. ID (i)	F_i	queue length (QL_i)	service tag (st_i)
1	0.1	3	3.2
2	0.3	0	3.5
...			
n	0.2	12	3.3

Sorted List of Service Tags



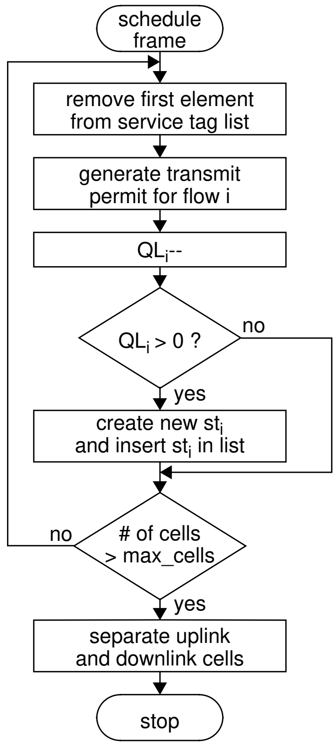


Fig. 8. Scheduling algorithm

While this mechanism is quite simple it has several advantages. If the queue length is greater than zero, service tag values of newly arriving ATM cells can be directly derived from the service tag of the preceding cell in the queue. Hence, the exact arrival time of a cell is not important and there is no need to transmit other queue status information in addition to the queue length. Moreover, as request packets are piggy-backed to data packets, mobile stations only have to send a request packet via random access, if new cells arrive at a previously empty queue. The size of the queue length information field can be limited to the maximum number of slots in a frame which is the absolute maximum number of cells which can be served within one frame.

Results from performance evaluations of the protocol outlined above can be found in [18]. It can be shown that SCFQ is able to guarantee the QoS of traffic that is conforming to the GCRA, independent of other connections even if another terminal tries to send more than it is allowed to. Spare capacity is fairly shared among all active connections according to their corresponding rates. The service rates for CBR and VBR connections are directly derived from the CAC parameters, for ABR connections these are calculated from RM cell information. In order to provide at least a minimum QoS to UBR connections, a provider may also decide to reserve some bandwidth for them and to assign a small service rate to these connections. To improve the performance of UBR service, cell and packet discard schemes could additionally be included in the MAC protocol.

If the radio channel between the base station and one mobile station currently has a high error rate and therefore causes lots of (high priority) retransmissions, additional bandwidth is needed which cannot be used for other connections. With our approach a service rate is also assigned for retransmission purposes. It is used by connections suffering from bad radio channel conditions. If all mobile stations experience good channel conditions this capacity is fairly shared among the active connections. By reserving bandwidth for retransmissions the QoS of all connections with good channel conditions can still be maintained.

In a multimedia scenario a mobile station may very likely run several connections in parallel. If these connections have different QoS requirements they cannot be simply multiplexed into a common buffer, i.e., a scheduler must decide on the service sequence. In an extension of the above mechanism, several connections of a mobile station may be pooled and handled as one flow by the base station scheduler. I order to meet the QoS requirements of all connections an additional scheduler inside the mobile station is necessary (see Figure 9).

A detailed description together with results from a performance evaluation of this hierarchical scheduling approach can be found in [17]. 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 a different scheduling strategy than the base station scheduler, e.g., a simple priority based scheduling or round-robin.

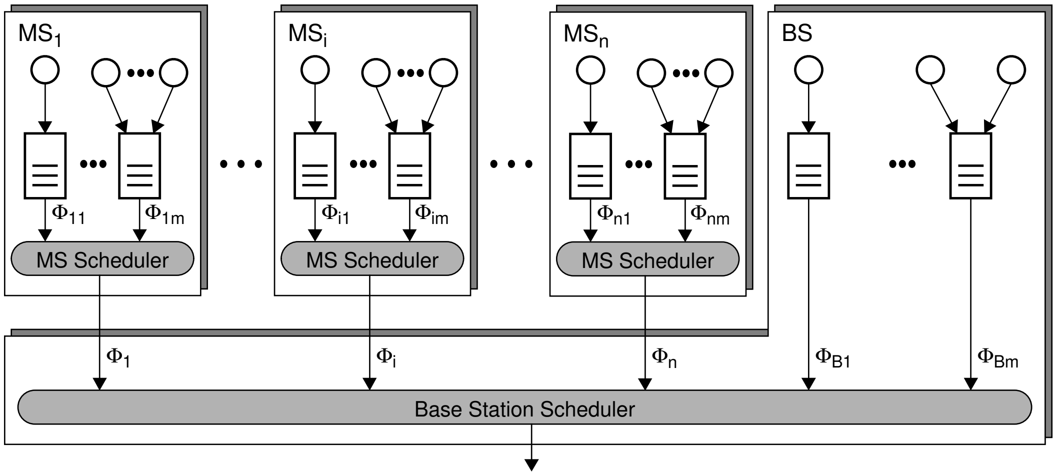


Fig. 9. Principle of hierarchical scheduling

4.2 UPC Conformance

As described in Section 3.1, wireless ATM DLC protocols change the profile of the traffic. Hence, traffic conforming to the traffic contract at the mobile station may be altered to non-conforming traffic which may therefore cause cell discards by the UPC. One way to deal with this problem is to adapt the MAC algorithm to the conformance definition of the UPC function, i.e., the GCRA. With this approach the conformance of the resulting traffic can be enforced but it still cannot remove the changes of the traffic profile caused by ARQ protocols. Hence, clumping of ATM cells may still occur.

Two other approaches to support the conformance of traffic to the UPC/NPC functions are depicted in Figure 10. In the first approach, a traffic shaper (TS) at the output of the base station or at the input of the ATM access switch may be used to enforce conformance. The major drawback of this approach is the additional delay introduced by shaping. A different approach to deal with changes in the traffic profile is to negotiate during connection set-up more tolerant UPC/NPC parameters, especially a higher CDVT value. While this method can easily be applied it also reduces the achievable multiplexing gain and therefore results in higher connection costs and less efficient use of resources. Moreover, it cannot guarantee UPC conformance but only lower the probability of cell discards by the UPC. In order to improve this approach, temporal changes of the UPC/NPC parameters for wireless ATM access networks could be envisaged, i.e., depending on the current radio link quality and load the parameters of all UPC functions are continuously adjusted. This may be very costly, especially if the service is provided by more than one network provider.

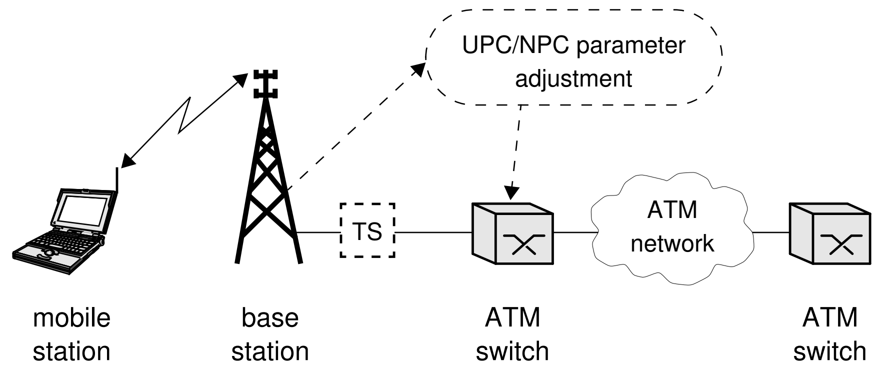


Fig. 10. UPC conformance support

4.3 Handover Support

To guarantee the continuation of connections during handover, resources must be reserved in neighboring radio cells and the access network in advance. These resources cannot be used for other guaranteed services in the neighboring radio cells. Therefore, additional resources should be allocated sparsely. In order to support an efficient operation of this mechanism a new element describing the movement class (static, slow, fast) should be added to the traffic contract. Of course each movement class would be charged differently by a public provider as there are big differences in the required resources. Furthermore, through mobile station tracking the direction of the movement could be predicted and the amount of allocated resources can be adapted accordingly. If not enough resources are available in the new radio cell and therefore the QoS cannot be guaranteed, the connection may be renegotiated again and new traffic parameters may be chosen. Therefore, additional parameters like renegotiation properties may be added to the traffic contract.

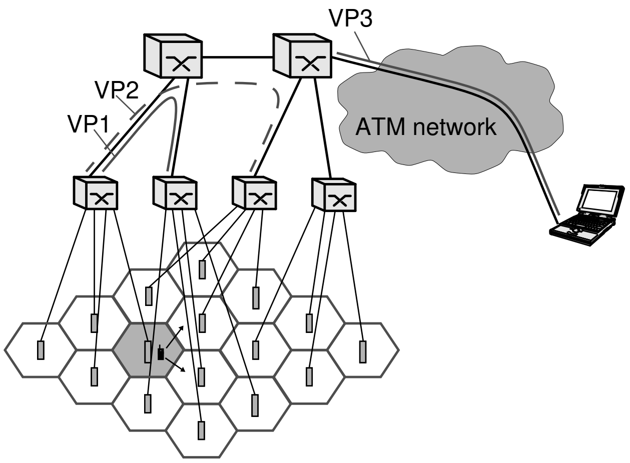


Fig. 11. VP management operations for handover support

Additional bandwidth must also be allocated inside the fixed network. In Figure 11 an access network for wireless ATM is depicted. In this example the mobile terminal within the shaded cell will move to one of the cells to its right which are connected to different access switches. For simple and fast handover the route of the mobile terminals' connections can be extended to the next access switch using the old one as anchor point. This handover mechanism can very much benefit from the concept of VPs. In order to prepare for a handover, VPs between access switches of neighboring cells may be set up in advance (VP1, VP2). Through these VPs the access switches are in a logical sense directly connected even if the VP traverses several switches (VP2). Hence, switching over of connections during handover is handled by the access switches and doesn't affect switches on the next higher network hierarchy level. The assignment of connections to VPs in other parts of the network (VP3) are not affected at all by the movement.

Through the introduction of appropriate VP management functions which allow for a fast and flexible capacity reservation on VP level, powerful handover procedures can be combined with efficient resource utilization.

5 Conclusions

Wireless ATM networks will have to support the same ATM service categories as defined for fixed ATM networks. Various problems that arise through wireless access and the mobility of users were discussed and approaches for the integration of wireless ATM protocols and traffic management functions of the fixed network were outlined. These include traffic control integration, UPC conformance, and handover support. The proposed MAC protocol for traffic control integration shows good performance and especially with the hierarchical scheduling extension reduces the implementation complexity of the base station. Therefore, this scheduling architecture can be regarded as a key component for traffic management integration. Further studies will be needed for fine tuning and to identify methods for parameter settings. Moreover, the integration of ARQ schemes and the interworking with Internet Protocols (e.g., TCP) will be studied.

References

[1] ATM Forum, "Traffic Management Specification Version 4.0," *AF-TM-0056, ATM Forum Technical Committee*, April 1996.

[2] ETSI BRAN project (former ETSI RES 10 working group), "HIgh PErformance Radio Local Area Networks (HIPERLANs): Requirements and Architecture," *Working Document no. 10-07*, January 1997.

[3] S. J. Golestani, "A Self-Clocked Fair Queueing Scheme for Broadband Applications," *Proceedings Infocom'94*, Toronto, Canada, June 1994, pp. 636–646.

[4] R. Guérin, H. Ahmadi, M. Naghshineh, "Equivalent Capacity and its Application to Resource Allocation in High-Speed Networks," *IEEE Journal on Selected Areas in Communications*, vol. 9, no. 7, September 1991, pp. 968–981.

[5] ITU-T, "B-ISDN ATM Layer Cell Transfer Performance," *Recommendation I.356*, Geneva, Switzerland, October 1996.

[6] ITU-T, "Traffic Control and Congestion Control in B-ISDN," *Recommendation I.371*, Geneva, Switzerland, August 1996.

[7] M. J. Karol, Z. Liu, K. Y. Eng, "Distributed-Queueing Request Update Multiple Access (DQRUMA) for Wireless Packet (ATM) Networks," *Proceedings IEEE International Conference on Communications (ICC'95)*, Seattle, USA, June 1995, pp. 1224–1231.

[8] A. Krämling, G. Seidel, M. Radimirsch, W. Detlefsen, "Performance Evaluation of MAC Schemes for Wireless ATM Systems with Centralized Control Considering Processing Delays," *The Second European Personal Mobile Communications Conference (EPMCC'97)*, Bonn, Germany, September 1997, pp. 173–180.

[9] H. Kröner, P. J. Kühn, T. Renger, "Management von ATM-Netzen," *Informationstechnik und technische Informatik (it+ti)*, vol. 39, no. 1, February 1997, pp. 5–14, in German.

[10] F. Panken, C. Blondia, O. Casals, J. Garcia, "A MAC Protocol for ATM PONs Supporting Different Service Categories," *Proceedings of the 15th International Teletraffic Congress (ITC'15)*, Washington, DC, USA, June 1997, pp. 925–834.

[11] D. Petras, A. Krämling, A. Hettich, "MAC Protocol for Wireless ATM: Contention Free Versus Contention Based Transmission of Reservation Requests," *Proceedings International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'96)*, Taipei, Taiwan, October 1996, pp. 903–907.

[12] J. Porter, A. Hopper, D. Gilmurray, O. Mason, J. Naylon, A. Jones, "The ORL Radio ATM System, Architecture and Implementation," *ORL Technical Report No. 96.5 (ftp.orl.co.uk:/pub/docs/ORL/tr.96.5.ps.Z)*, 1995.

[13] N. Pronios, I. Dravopoulos, et al, "Wireless ATM MAC Overall Description," *CEC Deliverable No. 3D1 of the Magic WAND ACTS project*, 1996.

[14] K. Rauhala, et al, "Baseline Text for Wireless ATM Specification," *WATM working group of the ATM Forum*, Version 1.07, April 1998.

[15] D. Raychaudhuri, "WATMnet: A Prototype Wireless ATM System for Multimedia Personal Communication," *IEEE Journal on Selected Areas in Communications*, vol. 15, no. 1, January 97, pp. 83–95.

[16] J. Roberts, "Virtual Spacing for Flexible Traffic Control," *International Journal of Communication Systems*, vol. 7, 1994, pp. 307–318.

[17] R. Sigle, T. Renger, "Hierarchical Scheduling for Wireless ATM MAC Protocols," *Proceedings Personal Wireless Communications (PWC'98)*, Tokio, Japan, April 1998, pp. 175–182.

[18] R. Sigle, T. Renger, "Fair Queueing Wireless ATM MAC Protocols," *Proceedings Personal, Indoor and Mobile Radio Communications (PIMRC'98)*, Boston, USA, September 1998, pp. 55–59.