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Architectures for wireless ATM access

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Abstract

This paper presents a study on possible architecture design concepts for integrating wireless networks with ATM technology. We discuss four different solutions for wireless ATM access, starting with transparent cell-relaying over the air interface, thereafter focussing on ATM- and AAL-based interworking concepts, and finally discussing proxy approaches. Our analyses show that the performance benefits of higher layer interworking justify their comparatively high technical expenses.

Keywords

ATM, wireless networks, mobile computing, interworking, proxy architectures

1 INTRODUCTION

Within the past few years ATM (Asynchronous Transfer Mode) has proven its capability to serve as the future networking standard for tele- as well as data communication applications. Starting as one option for the B-ISDN backbone it was soon discovered to also meet the requirements for a wide-spread deployment in ATM local area networks and even to the user's desktop. With mobile computing a second key technology has undergone a tremendous growth over the past decade. Inspired by the success of mobile telephony people are now getting used to be able to communicate wherever they currently roam. ‘Mobile desktop’ and ‘wireless office’ are two of the popular buzzwords indicating this trend (Spaniol, 1995). Thus, ‘ATM to the mobile desktop’ seems to be just the next logical step.

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However, ATM has been developed based on two important presumptions: Firstly, the Virtual Path/Channel concept has been designed for the interconnection of fixed stations, and secondly, the ATM technology assumes an extremely reliable underlying transmission medium. Both of these assumptions are violated when integrating wireless networks with ATM technology: Users will demand uninterrupted service availability and guaranteed Quality-of-Service (QoS) even when they are 'on the move'. Since connection redirection is not supported by the static VCI/VPI concept, extensive research is currently done in the area of handover control and location management, see Fasbender (1995), Fernandes (1995). Furthermore, wireless access media are highly vulnerable to link disruptions, and show a considerably higher overall bit error rate caused for example by multipath fading and hidden stations. Hence, leaving error control to the end systems leads to (unnecessary) additional traffic on the relatively reliable fixed network due to retransmissions for which only the wireless part of the network is responsible.

Therefore, an approach meeting both high speed networking and mobile computing requirements must be carefully designed and evaluated. Starting with a short description of ATM switching concepts and future applications for mobile computing, we therefore try to systematically identify and evaluate feasible approaches for integrating ATM networks and wireless environments. We have subdivided the discussion based on different interworking layers between mobile and fixed network, starting with ATM-compatible cell relay principles on the radio link, thereafter concentrating on interworking solutions at ATM and AAL layer, respectively, and ending up with splitting up the end-to-end transport layer connection into two separately optimizable parts using a proxy approach. We will motivate the need for non-transparent interconnection solutions by evaluating their performance in terms of improved (AAL) packet error rates and thus significantly decreased retransmission traffic in the wired backbone.

1.1 ATM

The ATM technology's primary goal is the integration of traditional telecommunication services and data communications, and thus the support of a wide range of traffic types with different communication requirements. It is based on small, fixed size cells with a payload of 48 bytes, which are transported via virtual paths and circuits in a connection-oriented fashion. ATM supports fixed bandwidth traffic (constant bit rate, CBR) as well as statistically multiplexed variable bandwidth traffic (variable bit rate, VBR) and guarantees delivery within certain timing restrains. These service classes are primarily aimed at telecommunication services (voice- and videotelephony) as well as the traffic generated by modern distributed multimedia applications. Additionally service classes like ABR (available bit rate) and UBR (unspecified bit rate) for traditional data communication applications without explicit timing or bandwidth requirements will also be supported.

The ATM system architecture consists of a media dependent physical layer, the ATM layer dealing with the mapping of cells to connections, and the ATM Adaptation Layers (AAL) which handle segmentation and reassembly of user packets. The different AALs and their service characteristics are shown in Fig. 1. Call control, multiparty operations and the negotiations of QoS parameters are handled by the ATM signalling. The signalling protocol Q.2931 is based on ISDN's Q.931 signalling specification. Signalling messages are exchanged between end system and network as well as between end systems via dedicated signalling VP/VCs.

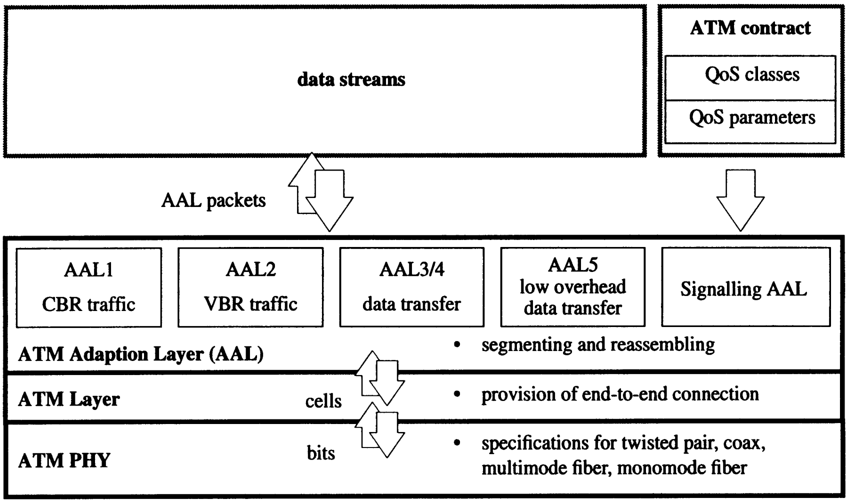

Figure 1 ATM protocol stack.

The VP/VC concept makes it clear that ATM was primarily designed for operations in fixed networks, which seems to limit ATM's applicability for mobile networks. Furthermore, the additional signalling requirements of mobile systems, in particular for mobility management, cannot be met by ATM's UNI (User Network Interface). Solutions for overcoming these limitations and for integrating mobile systems and ATM networks are the subject of this paper.

1.2 Mobile computing

Wireless and mobile access to communication services is offered in various existing networks: For example, mobile networks according to GSM (Mouly, 1992) and cordless telecommunications according to DECT (Spaniol, 1995) extend the services available for fixed telecommunication networks (e.g. ISDN services like fax) for mobile and wireless users. However, service quality in terms of available transmission capacities and bit error rates is less than it is offered by fixed networks. Therefore, third generation mobile systems like the Universal Mobile Telecommunication System (UMTS) aim at an integration of different services offered by fixed, cordless and mobile (cellular and satellite) networks, improving speech quality and the variety of data services provided (Chia, 1992). UMTS will offer at least Narrowband ISDN (N-ISDN) basic services, while B-ISDN is considered for the backbone structure.

Future mobile data and multimedia applications will cover a vast field ranging from mobile extensions of today's fixed applications (for nomadic and mobile computing) to future wireless office scenarios including wireless multimedia services with QoS comparable to fixed networks. However, the demand for mobile data services will also arise from totally different fields of applications, like telematic services for Road Transport Informatics (RTI), e.g. advanced traveller and tourist information, or Teleaction services for palmtop computers allowing applications like Teleshopping and Telebanking to go mobile. Clearly, existing mobile networks are not sufficient to realize the high bandwidth requirements for multimedia services and short response times, e.g. for interactive applications in wireless office environments (Spaniol, 1995) or for wireless access to the WWW (Kaashoek, 1994). This demand can only be met by directly accessing high performance networks such as ATM via a wireless link. In general, the access to high speed services is more and more required in local environments (Fernandes, 1995).

The requirement of terminal mobility (i.e. service availability in the whole coverage area and movement during service) leads to specific system architectures (Spaniol, 1995). The relevant tasks are radio resource management, mobility management and security management. Here we will not focus on these aspects, our main interest is the investigation of different ATM-interworking aspects in a nomadic computing environment and their consequences on end-to-end communication. With respect to the scope of our discussions we also abstract from the technical details of the radio access system of the wireless segment. Suitable air interfaces and protocols for medium access control, channel sharing and error control are currently under research and development, e.g. Fernandes (1995), IEEE 802.11 (1994), Phipps (1994). In general, we assume the existence of two types of communication (radio) channels: signalling and traffic channels. At least one of the signalling channels will be controlled in a random access fashion or by other distributed access mechanisms to enable a mobile station to initiate communications with the base station. Additionally, there are broadcast signalling channels used to inform mobile stations about network parameter and mobile terminated connection requests. A third type, point-to-point signalling channels are used to negotiate connection specific (QoS) parameter according to the ATM contract which have to be guaranteed by the base station for the assigned traffic channel(s). Thus, most of the radio resource allocation will be managed centrally.

2 WIRELESS ATM ACCESS

The simplified network structure we consider for studying schemes for wireless ATM access comprises Mobile Stations (MSs), a wireless access network with the Base Stations responsible for the wireless link to the MSs on the one hand and connected to the wired ATM backbone on the other, as illustrated in Fig. 2. A number of possible approaches for wireless ATM access have been recently discussed in the literature: Raychaudhuri (1994) adopted the cell-relay paradigm to the wireless transport architecture as an 'early architectural view' for future personal communication networks. The Mobile Broadband System (MBS) design philosophy (Fernandes, 1995) as well as two proposals for ATM-based wireless local area networks, see Eng (1995), Porter (1994), already make use of encapsulating one or more ATM cells into wireless MAC frames and employing error control mechanisms at the air interface. With this approach a radio link specific cell format may be used (e.g., including sequence numbers), while the redundant transmission of ATM cell headers can be omitted. A variety of other, non-ATM-specific solutions achieve interworking at or above the transport layer, see Caceres (1995) and Yavatkar (1994). These approaches can of course easily be adopted to an ATM-based wired switching network. In the rest of this section we will focus on performability issues of all of the named concepts, and we will introduce a solution 'in-between', where convergence between wired and wireless part of the network is attained at AAL.

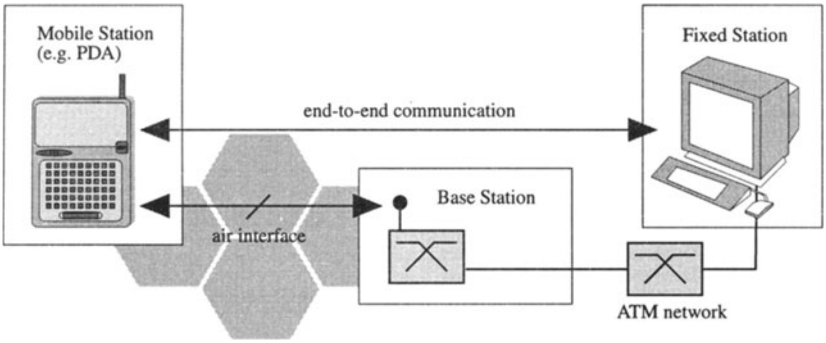

Figure 2 Assumed simplified network structure.

2.1 Transparent solution

The starting point of this study is the basic approach 'ATM on the air': ATM cells are transmitted to the mobile device and interworking between wireless and fixed network is achieved at the ATM layer, with the wireless channel serving as a simple link between the end system's ATM interface and the base station (see Fig. 3). This **access transparency** has the advantage of being easily introducable into a market that already supports ATM in the end systems. The reliability of the wireless link can be increased by applying FEC mechanisms. However, the transparent transmission of ATM cells over the wireless link introduces unnecessary overhead (ATM header transmission), and, as we will motivate, the support of VBR applications becomes hardly feasible. Furthermore, due to the limited reliability of the

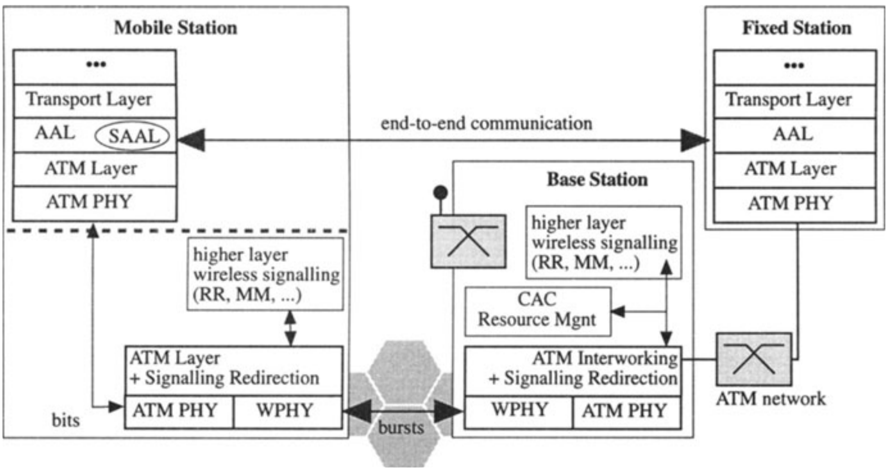

Figure 3 Interworking at ATM layer using standard ATM equipment with mobile add-on.

wireless link frequent cell losses will lead to reduced performance and increased network load due to end-to-end retransmissions. The network load is further increased by the fact that cell losses in *outgoing* connections (from the mobile to the fixed network) lead to the transmission of invalid AAL packets across the network to the destination end system, which will discard these packets on arrival. While this is a problem of ATM systems in general its effects will be drastically enhanced by the lower reliability of the wireless link.

The base station, which is basically an ATM switch, handles the interworking between mobile and fixed network on cell level. Outgoing cells are collected in a queue and forwarded to the next ATM switch. If the base station has access to several ATM switches it also performs VC/VP based cell routing. If on the other hand the base station is connected to a single ATM switch there is no need for reassembling outgoing cells in the base-station. Incoming cells have to be reassembled to identify the appropriate wireless channel, since such a channel is assigned to each individual ATM connection. Traffic is thus processed by retrieving connection information from a local database (which is updated during signalling phase). To realize this mapping between available channels and connections and for signalling support and resource management in general, the base station has to be aware of the ATM signalling traffic in order to perform admission control and resource allocation on the wireless link. For inbound traffic (fixed network to mobile station) this means that all connection setup messages have to be intercepted and their QoS demands have to be matched against the available resources on the air interface.

For outgoing traffic the situation is slightly more complicated. If a mobile station wishes to establish an ATM connection, it first has to forward its QoS demands to the base station which in turn performs the necessary connection admission control (CAC) and resource allocation. This additional signalling traffic is sent via a dedicated wireless signalling channel. Since ATM signalling is protected against packet loss via a dedicated transport protocol (the Service Specific Connection Oriented Protocol, SSCOP) and to keep signalling costs low, this dedicated channel can be realised as random access channel which is shared among all mobile stations in the domain of a base station.

To facilitate this additional signalling certain modifications in the mobile station are necessary to intercept signalling messages and forward these to the base station via the signalling channel. This can either be realized by enhancing the functionality of the mobile station's Signalling AAL in that from, that the SAAL will transmit signalling requests not via the ATM stack but via a dedicated data path to the wireless device, which then forwards these to the base station (Fig. 4). A common WPHY reduces the complexity of the mobile station, but requires dedicated equipment because PHY and ATM layer are usually integrated in a single device. If standard end-system equipment is used, as shown in Fig. 3, the wireless device could be modified to intercept signalling messages on the ATM signalling VP/VC, to reassemble these message and to propagate connection setup requests to the base station. While this approach does not necessitate any changes in the end system it requires more expensive hardware.

The shared medium characteristics of the wireless segment lead to problems not known from the exclusive usability of high capacity end system links in fixed environments. Variable Bit Rate (VBR) channels thus can only be mapped onto wireless links, if the base stations may perform channel allocation adaptively on a per-station basis. However, this demand-oriented spectrum division would traditionally be solved at MAC rather than WPHY level, leading to non-transparent solutions as discussed in the next chapters. Constant Bit Rate channels with

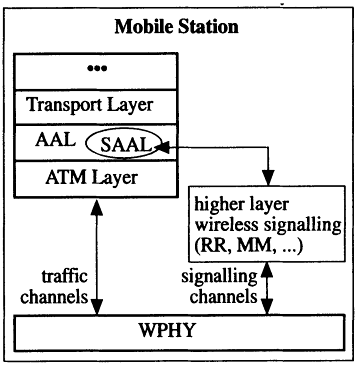

Figure 4 Mobile Station architecture when using a dedicated WPHY.

different bandwidth requirements can be realized by reserving certain resources for a single connection, e.g. time slots in TDM. Available Bit Rate (ABR) connections can be set up with a certain guaranteed minimum bandwidth using the same mechanism as with VBR and CBR. Additional capacity may be granted to specific connections if medium is not saturated by sharing all free link capacity (in a fair fashion) among all current ABR connections (although not by statistical multiplexing but by dividing the bandwidth). A new connection as well as the termination of an existing one lead to a redistribution of this 'excess' bandwidth. In this sense, ABR is practically an adaptable peak rate allocation. Buffering of cells before transmission (to reduce traffic peaks) may facilitate mean bandwidth allocation and thus a VBR-like service, but will introduce an additional delay. Again, such mechanisms would be easier handled on MAC level. One advantage of the transparent approach is the possibility of using standard or near-standard ATM equipment in the mobile station. On the other hand, the scarce radio resource is not utilized efficiently, since the transmission of ATM cell headers is redundant in this approach: Connections are not identified by VC/VPs but by their transmission channel(s). Although the quality of the wireless link can be improved by employing FEC mechanisms this can only be realised by sacrificing a large percentage of the available bandwidth. Cell retransmissions are not possible in this approach due to the transparency of the wireless link.

2.2 Interworking at ATM layer

Moving up one layer in the ATM reference model a 'wireless ATM layer', encapsulating ATM cells on the air, is a solution currently discussed in the literature, e.g. Eng (1995), Porter (1994). Interworking is still achieved at ATM layer (see Fig. 5), but the transmission of ATM headers on the wireless link can be avoided. Moreover, this **link transparency** enables cell based retransmissions on the last hop, which drastically reduces the amount of wasted bandwidth in the reliable backbone network. However, additional (but compared to the ATM header size much smaller) overhead for sequence numbers is introduced in this solution. Nevertheless, the transmission of corrupted AAL5 packets to the end systems results in an unnecessary load at the transport layer. In addition, the real drawback seems to be that retransmissions are part of the connection's reserved bandwidth and therefore lead to a violation of the connection's traffic

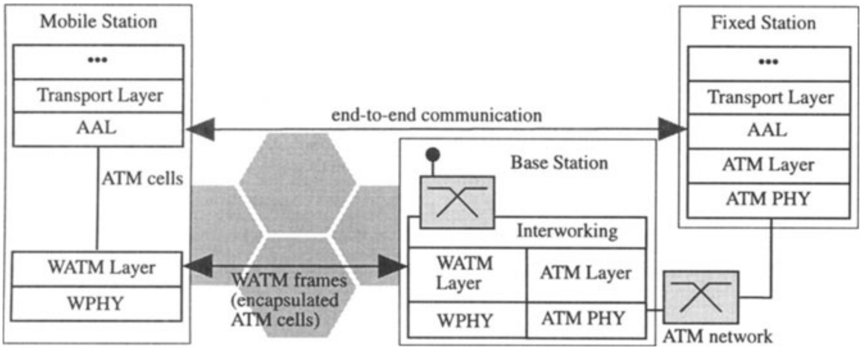

Figure 5 Interworking at ATM layer.

contract. Thus, it is compulsory that the number of retransmissions has to be kept in a limited range, e.g. at most once per MAC frame.

Based on a simple modelling approach the following results estimate the performance benefits of the ATM cell encapsulation solution compared to the transparent solution. Realizing that the sojourn times in error states of a wireless link (e.g. 'low BER', 'high BER', 'no connection') are high compared to the cell transmission times (for a 155 mbps ATM link some 380.000 cells may arrive at the base station in just a second), we assume stochastically independent bit errors at the air interface. The performance is evaluated for different bit error rates. ATM cells are encapsulated in MAC frames of size 1 and 10 cells, respectively, and we allow one retransmission per MAC frame.

Fig. 6 shows the results of the analysis for bit error rates of 10^{-4} and 10^{-8}, respectively. As expected it can be observed that the amount of erroneous AAL packets, and thus the percentage of end-to-end retransmissions at AAL level, can be drastically reduced by ARQ schemes. The

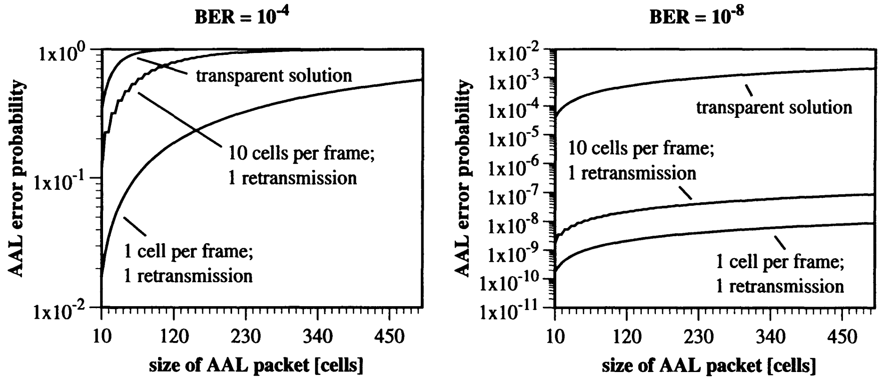

Figure 6 Performance of ATM encapsulation.

percentage of additional traffic at the radio interface is in the order of the cell error rate, e.g. 4 per cent in the case of BER = 10^{-4} and only $4 \cdot 10^{-6}$ per cent at BER = 10^{-8}.

2.3 Interworking at AAL

The third solution additionally includes knowledge of the wireless medium at the AAL level by introducing a 'wireless AAL' responsible for the transmission between mobile station and base station, as illustrated by Fig. 7. Thus, interworking is done at AAL, resulting in a **service transparency**, solving the problem of forwarding corrupted AAL5 packets and enabling the implementation of intelligent caching and filtering schemes at the interworking unit. Instead of AAL packets small, repeatable packets are (transparently) exchanged between mobile unit and base station. These small packets are temporarily stored in the base station for retransmission purposes until the base station has successfully assembled a complete AAL packet which is then transmitted to the peer entity via the ATM infrastructure. This avoids the unnecessary transmission of corrupted ATM cells on the ATM fixed network and thus reduces the traffic load on the fixed network.

If the buffer of the base station fills up for incoming traffic (e.g., due to down times of the link) packets will be lost. This will then trigger the congestion and error control mechanisms of the Transport Protocol on an end-to-end level, leading to additional traffic on the fixed network and, depending on the transport protocol, to sub-optimal end-to-end performance. Additionally, even occasional retransmissions lead to a slow build-up of buffered packets in the base station, since the channel capacity on both networks is equal and there is no notification scheme that would order the sender to temporarily reduce its transmission rate. This would only be feasible if interworking is done at transport layer as described in the following section.

For some real-time applications such as audio and video there is no need to store packets in the base stations for retransmissions. The system will benefit from the approach of a WAAL layer even for real time traffic: If cells get destroyed only these data elements (and not the whole AAL frame) are lost for the receiver. In this scheme the lost data could be substituted by artificial data to ensure that the user still receives a 'complete' AAL frame. Thus, loss tolerant applications can benefit from interworking at AAL by passing all correctly received cells within

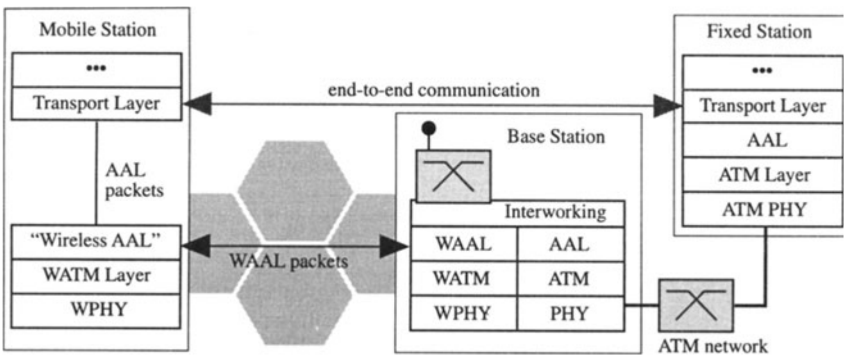

Figure 7 Interworking at ATM Adaption Layer.

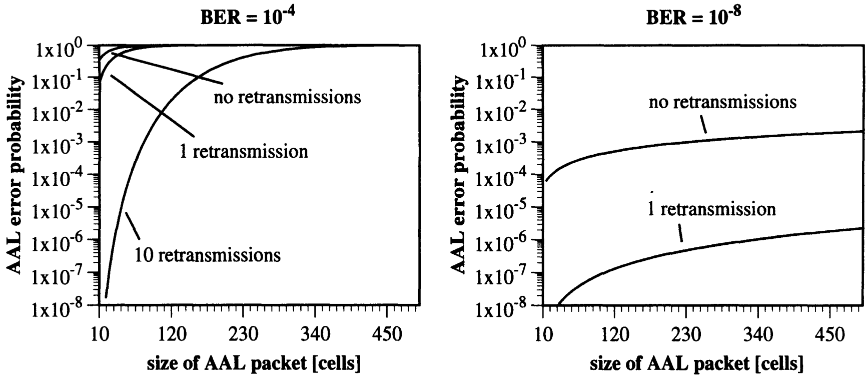

Figure 8 Performance of AAL interworking.

AAL packets to the applications instead of dropping complete AAL frames in case of cell losses.

In Fig. 8 the AAL interworking approach is evaluated against the transparent solution, again using the two bit error rate extremes and varying the number of possible cell retransmissions per AAL packet (for comparability reasons we assume that the frame size equals one ATM cell size, although a hybrid approach encapsulating two or more ATM cells in a MAC frame would further improve the AAL error probabilities). Since we allow only a fixed number of MAC frame retransmissions for each AAL frame, this solution performs slightly worse than ATM level interworking with an equal number of retransmissions per cell (compare Fig. 6 for the case of 1 retransmission). However, our approach leads to a much smaller additional overhead at the air interface. It should be noted that AAL error rates for the case of 10 retransmissions at a bit error rate of 10^{-8} vary between 10^{-19} and 10^{-17} and are therefore not included in the figure.

2.4 Interworking at transport layer

The performance optimization at transport level is not addressed sufficiently by the above approaches. Recent research indicates that due to the inherent differences of mobile and fixed links the end-to-end transport paradigm cannot be maintained, see Karabek (1995 a), Karabek (1995 b), Caceres (1995). Therefore, the basic idea is to use a proxy approach achieving a **transport transparency** (Fig. 9), where interworking is done at the transport layer, and the transport layer connection is terminated on both sides of the base station. This solution was for example suggested to improve the TCP performance of a wireless Internet access (Yavatkar, 1994). Dedicated equipment is used for the last hop to and from the mobile station, and the base station is in charge of the protocol stack conversion. This solution enables the optimization of transport protocol parameters such as window size, packet size and retransmission time-outs on both the wireless and the wired part of a connection, and hence provides a most throughput efficient communication between end systems.

The proxy approach will also yield a better performance in case of buffer overflow in the base station, since dedicated transport level mechanisms can be introduced to deal with such situations (e.g. stop and go mechanisms in case of imminent buffer overflow (threshold)), see

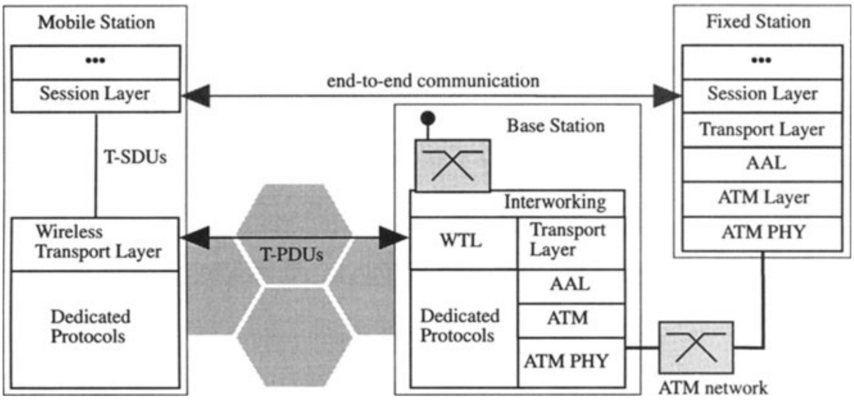

Figure 9 Interworking at transport layer.

for example Caceres (1995), (Yavatkar, 1994). The process of QoS negotation of the end-to-end communication is controlled by the base station's interworking unit, which has the role of a fixed network agent of the mobile station and handles all transport layer issues on behalf of the mobile station.

The proxy approach with its independency from ATM specific transfer and signalling on the wireless link also yields the feasibility of disconnected operations, which may be realized by the interworking unit associated to the base station in cooperation under the control of dedicated session or application layer protocols. Moreover, this technique is very promising as a first step towards the 'all ATM scenario', see Karabek (1995 b) and Armbrüster (1995), since it just implements convergence devices between existing networks, which may be rapidly introduced to the market.

3 SUMMARY

Architectures for wireless access to ATM depend on the desired level of conformance to the ATM reference model and therefore differ in the interworking scheme between wireless and fixed part of the network. It was shown that wireless ATM access can be provided on all layers of the ATM reference model. However, in addition to the differing technical complexity of the presented solutions, performance investigations indicate that ATM interworking should be placed on AAL level or higher. Especially the proxy approach solves several problems of end-to-end communication via wireless links and enables disconnected operations, which will be an important feature to realize distributed systems with wireless components and in particular to introduce wireless office applications.

4 ACKNOWLEDGEMENTS

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5 REFERENCES

Armbrüster H. (1995) The Flexibility of ATM: Supporting Future Multimedia and Mobile Communications. *IEEE Communications Magazine*, February, 76–84.

Caceres R., Iftode L. (1995) Improving the Performance of Reliable Transport Protocols in Mobile Computing Environments. *IEEE Journal on Selected Areas in Communications*, June, 850–7.

Chia S. (1992) The Universal Mobile Telecommunication System. *IEEE Communications Magazine*, December, 54–62.

Eng K.Y., Karol M.J., Veeraraghavan M., Ayanoglu E., Woodworth C.B., Pancha P., Valenzuela R.A. (1995) A Wireless Broadband Ad-hoc ATM Local-Area Network. *Wireless Networks*, July, 161–74.

Fasbender A., Hoff S., Pietschmann M. (1995) Mobility Management in Third Generation Mobile Networks. *IFIP TC6 Workshop on Personal Wireless Communications.*

Fernandes L. (1995) Developing a System Concept and Technologies for Mobile Broadband Communications. *IEEE Personal Communications*, February 54 –9.

IEEE 802.11 (1994) Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications. Draft Standard.

Kaashoek F., Pinkney T., Tauber J. (1994) Dynamic Documents: Mobile Wireless Access to the WWW. *Workshop on Mobile Computing - Systems and Applications.*

Karabek R., Reinhardt W. (1995 a) Future Hypermedia Retrieval Systems and their Impact on Transfer Systems. *Bringing Telecommunication Services to the People - IS&N '95*, Lecture Notes in Computer Science 998, Springer.

Karabek R. (1995 b) A high performance transport service for ATM LANs. *Proceedings of the Broadband Islands conference.*

Mouly M., Pautet M.-B. (1992) The GSM System for Mobile Communications. *Published by the Authors*, Paris.

Phipps T. (1994) HIPERLAN Medium Access Control. *Proceedings of the 5th Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC '94)*, 870–4.

Porter J., Hopper A. (1994) An ATM based Protocol for Wireless LANs. *Technical Report 94.2, Olivetti Research Limited*, (available via: `ftp.cam-orl.co.uk/pub/docs/ORL/tr.94.2.ps.Z`).

Raychaudhuri D., Wilson N.D. (1994) ATM-based Transport Architecture for Multiservices Wireless Personal Communication Networks. *IEEE Journal on Selected Areas in Communications*, October, 1401–14.

Spaniol O., Fasbender A., Hoff S., Kaltwasser J., Kassubek J. (1995) Impacts of Mobility on Telecommunication and Data Communication Networks. *IEEE Personal Communications*, October, 20–33.

Yavatkar R., Bhagwat N. (1994) Improving End-to-End Performance of TCP over Mobile Internetworks. *Mobile 94, Workshop on Mobile Computing Systems and Applications.*

6 BIOGRAPHY

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