Modeling an ATM-Based Access Network for 3rd Generation Mobile Communication Networks

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Abstract -- In this paper we present a simulation model of an ATM-based access network for third generation mobile communication systems (UMTS/IMT-2000). As these systems will offer a variety of services (voice, data, video, WWW, etc.) with flexible, on-demand bandwidth requirements, ATM is proposed as transport medium for the access network. Additionally to the standardized ATM Adaptation Layers (AAL 1, 3/4, and 5), which are mainly used for high bitrate services like multimedia or video, the shortly standardized AAL2 is considered for efficient transport of low bit rate delay sensitive traffic (e.g. speech). For the design of the access network, we propose detailed models of its components. These models will be used in future to dimension the functional elements (e.g. buffers, switch capacity, timer) and to compare different implementation options by performance analysis through computer simulations or theoretical analysis.

I. Introduction

The Universal Mobile Telecommunications System (UMTS, standardized by ETSI [3]) like the International Mobile Telecommunications - 2000 (IMT-2000, standardized by ITU), is the third generation of mobile communication systems. They will include:

- provision of a unified presentation of services to the user in wireless and wired environment,
- mobile technology that supports a very broad mix of communication services and applications,
- on-demand flexible bandwidth allocation in a wide variety of applications.

Hence, third generation mobile communication networks will offer services that have traditionally been provided by fixed networks (up to a maximal user bandwidth of 2Mb/s). In this context not only the radio interface, but also the (fixed) access network must support on-demand, variable, bandwidth allocation. A technology which can provide this is ATM. Furthermore, ATM is expected to be a widespread technology with full country coverage in the near future. So an access network for future mobile communication systems can use already existing ATM networks for the interconnection of network components, but should also integrate existing technologies like PCM (GSM system). These ATM networks may be public MANs, WANs, or private LANs.

The support of low bandwidth and delay sensitive services (e.g. speech) in an ATM network results in some disadvantages with existing AAL layers 1, 3/4 and 5 in terms of bandwidth utilization. When the offered payload is smaller than the payload of an ATM cell, AAL1, 3/4, and 5 can only partially fill the cell or gather successive packets of the same connection into one cell, which may introduce a considerable delay. Both approaches will result in a bad performance of the system. A solution for compressed voice in cellular systems [1] led to the standardization of the new AAL2 layer [2]. It is specially designed to carry low bandwidth services with hard delay constraints. The drawback is the overhead when used with very small packets (3 byte overhead/packet). Additionally it will add more complexity to ATM components like switches (minicell switching, see section III) and to strategies like CAC and UPC which have to be performed for the AAL2 virtual connection as well as for its included connections.

AAL2 introduces minicells, also named CPS-packets in [2], which are small packets of variable size (maximum length: 45 or 64 bytes). This allows multiplexing of various small bandwidth connections into one ATM connection, whereas minicells can overlap consecutive ATM cells. Thus, it is possible to achieve higher efficiency than by using partially filled cells and cope with delay sensitive services at the same time.

UMTS/IMT-2000 may allow the possibility that a mobile station is connected to more than one base station simultaneously. This so called macroscopic diversity is necessary for soft handover in CDMA systems, but can also be useful to improve link quality [8] and increase capacity [7] in TDMA systems. The macrodiversity functionality lays an additional burden on the fixed access network in terms of increased bandwidth usage and system complexity. To study this phenomenon we introduce a macrodiversity component in the access network.

In the following we present the access network architecture based on the functional elements defined by ETSI [3] also including the new AAL2 standard and a macrodiversity functional element. We develop models for each separate functional element. As an example for these elements, we present the model of the transport relay (TR) in closer detail. As the transport relay may be extended for switching not only ATM connections, but also minicell (AAL2) connections, it is especially interesting to take a close look on its detailed model.

II. Components of the network model

The access network model (Fig. 1) which was derived from

[5] consists of the following components: Mobile Terminal (MT), Air Interface (AI), Base Transceiver Station physical (BTSp), Intermediate Unit (IU), Transport Relay (TR), Macrodiversity Unit (MDU), Interworking Unit (IWU), and ATM and other interconnection links.

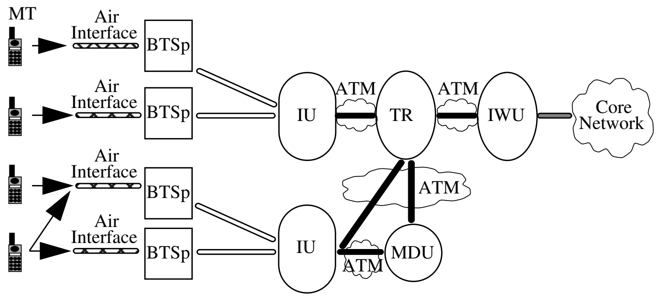

Figure 1: The components of the access network

A Functionality of the Components

The access network model is detailed further by models for each component in order to implement a simulation tool. Hence, a short description of the functionality residing in each component is given in the following.

Mobile Terminal

The mobile terminal (MT) combines the terminal equipment (TE) and terminal adaptation (TA) functions. In the simulation model it represents the traffic source (uplink) or sink (downlink). Several traffic sources may be simulated by the MT depending on the demanded service (voice, data, video, etc.). MTs may roam according to a mobility model.

Air Interface

In 3rd generation mobile systems several air interfaces (AI) may exist. We model the influences of the AI on data transmission independent of any specific technology. These influences are: the segmentation of source data into air interface frames, the delay of frames due to medium access control and radio propagation, and the introduction of errors due to the mobile radio channel. Of course, the parameters will depend on the chosen radio technology. Note that the notion of air interface frames (further simply called AI frames) exists in all digital AI technologies, whether it is a packet or circuit oriented system. The AI frame is the data unit (of fixed or variable size) used to transfer information over the air. It may be a data packet as well as the output block of a speech or video coder.

Base Transceiver Station

The base transceiver station (BTSp) terminates the physical radio layer. It contains the basic functionality necessary for radio transmission. If macrodiversity is applied, the BTSp adds quality information to each received AI frame derived from signal strength measurements or bit error rate calculations. This quality information is necessary for the combining process in the macrodiversity unit. In upstream direction the AI frames are transformed to the transport medium used for the interconnection of BTSp and Intermediate Unit (IU), and vice versa for the downlink. The transport medium between the BTSp and the IU is not considered further in this paper.

Intermediate Unit

This unit contains the "intelligence" of the access network. It controls one or more BTSp and runs the MAC and the RLC protocols of the air interface. Furthermore mobility management functions are located in the IU. For handovers the IU can serve as an anchor point. On the transport plane the IU may include the functions of mapping AI frames into ATM cells as shown in Fig. 2 or, in the case of AAL2, into minicells, which then, in turn, are multiplexed into ATM cells.

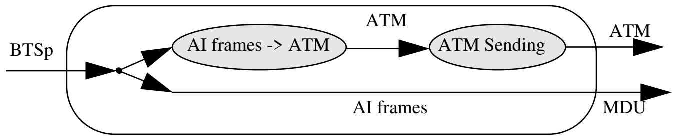

Figure 2: General model of the Intermediate Unit

Macrodiversity Unit

When operating in macrodiversity mode, a MT is connected to more than one base transceiver station. The same information is transmitted to several BTSp. In upstream direction, each BTSp transmits the received AI frame complemented with quality information to the macrodiversity unit (MDU). The MDU combines the frames to one resulting frame (block level combining, see Fig. 3). Downstream, the MDU generates duplicates of the arriving data and sends them to the corresponding IUs.

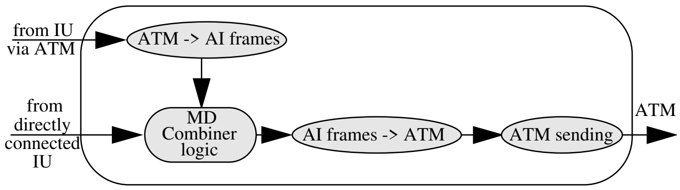

Figure 3: General model for the uplink macrodiversity unit

Macrodiversity can be used in any mobile communication system to improve speech and data quality by reducing the influence of shadowing [7]. It can increase capacity or coverage range [8] and simplifies handover, but has a strong impact on the access network too. More bandwidth is needed in the access network to support the additional traffic and the network components become more complex by adding macrodiversity functionality.

Interworking Unit and Core Network

The Interworking Unit (IWU) represents the gateway from the access network to the core network. The IWU includes the functional entities for protocol and data conversion. The UMTS core network will mainly evolve from existing GSM networks. However, other networks (e.g. N-ISDN, B-ISDN, or the Internet) may be connected to the access network. The exact structure of these two components are not part of this study. Hence, the IWU simply terminates the simulation model.

ATM network

The IU, MDU, TR and the IWU are interconnected by an ATM network in which all transported cells are subject to variable queueing delays and loss. The exact influence of these parameters on one specific ATM connection depend on the topology of the network, the traffic sent through the network, and even the switch architectures. As we do not want to suppose any specific ATM network architecture, we model the ATM connection by a more general approach. Each ATM cell suffers from the sum of constant propagation and processing delay, and from a variable queueing delay (Fig. 4). Moreover it can be randomly lost (with very low probability). This model is based on experimental studies in real ATM networks [4]. A theoretical analysis is presented in [6].

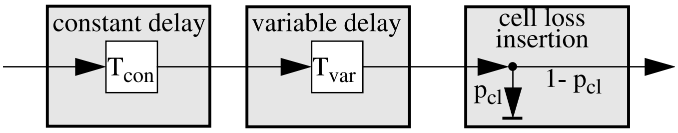

Figure 4: Detailed model of ATM connection

Transport Relay

The transport relay (TR) contains the switching functionality (see Fig. 5). In the context of a mobile communication access network, the support of AAL2 for the efficient transport of speech may be important. Hence, the model for the TR should include both ATM cell (Fig. 5, upper switch) and minicell switching (lower switch) capabilities. In chapter III we therefore propose a combined ATM and minicell switch.

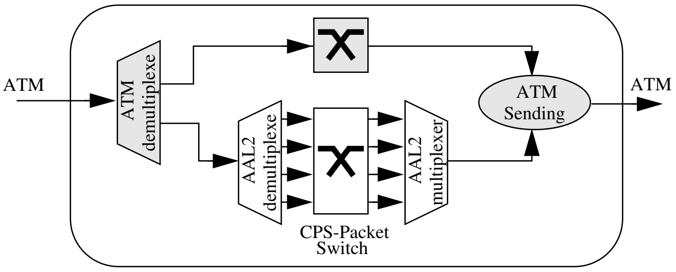

Figure 5: Generic model for the transport relay

B Application Scenario

In order to clarify how to apply the generic access network model to real application scenarios, we will present an example in this section. The functional elements of the generic access network model are mapped onto network elements for the rural and urban environment.

Fig. 6 depicts a possible access network architecture. On the left hand side an architecture adapted for a rural environment and on the right hand side an adapted architecture for an urban environment is presented [5].

Urban areas are characterized by high traffic density and small cells, so that the number of base stations can become quite elevated. This drives to a solution with cost-efficient base stations BS_u. These base stations only terminate the physical radio layer and relay the datastreams to the control unit. The radio link control as well as the medium access control layers are terminated in the IU which resides in the radio network controller (RNC_u). The RNC_u combines the functionality of the IU, the MDU, and the TR. One RNC_u controls several BS_u.

In rural areas with low traffic and user density, large cells (so-called macro-cells) will be in use. The base stations (BS_r) will be scarcely distributed in the landscape. In such an environment the base stations may contain additionally to the previous scenario the functionality of the intermediate unit. The RNC_r then contains the functionality of the transport relay and the macrodiversity unit.

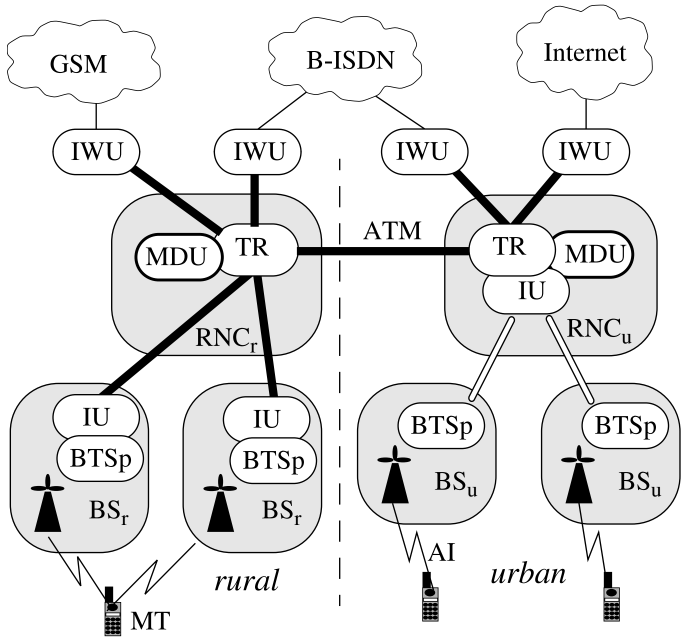

Figure 6: Example physical architecture of an access network

As UMTS may evolve from current GSM networks, migration scenarios must be considered. For example, it is conceivable that the connection between the BS and the RNC is a PCM link as used in the GSM system (see Fig. 6, urban scenario). In contrast to the transport of cells on the ATM part of the access network, data is transported as a bit stream on a PCM link. Hence, packetizing and depacketizing units have to be installed.

As seen in this application example, various implementation options for the access network are possible. Before building a real system, different options must be evaluated. Moreover, the exact design parameters (buffer length, switching capacity, etc.) of each functional element must be determined already in the network design phase. Therefore analytical studies or computer simulations are necessary. In order to perform these studies we developed detailed queueing models of each functional element.

III. Model of the Transport Relay

The job of the transport relay is switching user connections. Several options exist for its implementation. As discussed before, AAL2 technology may be used for low bitrate services in future UMTS/IMT-2000 access networks. Herein several minicell connections are multiplexed within one ATM connection (we refer to this as an AAL2 trunk).

Minicell switching functionality should be included in the transport relay for efficiency and handover reasons. In contrast to conventional ATM switches a minicell switch must process functions of the AAL layer, e.g. minicells of overlapping ATM cells must be reassembled (see Fig. 7). Then reassembled minicells are switched according to the connection identifier in the minicell header. Afterwards the minicells are packed into ATM cells again.

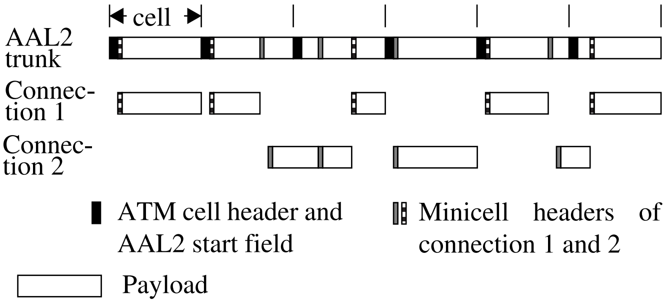

Figure 7: AAL2 Reassembly

Our model, depicted in Fig. 5, is composed of a demultiplexer, two switching blocks, pre- (AAL2 demultiplexer) and post processing (AAL2 multiplexer) units for minicells, and an output unit. ATM cells arriving at the incoming ATM links are demultiplexed either to the ATM cell switching or minicell switching part (lower part of Fig. 5).

In the minicell switching part first the minicells are reassembled. The minicells are then directly passed to a special variable length minicell switch. After switching the minicells must be packed into ATM cells. Moreover the new minicell channel identifiers are inserted in the minicell header. Then the ATM cells are passed to the output link unit, where they are scheduled for delivery (depending on the connection parameters).

In addition to reassembly and segmentation of minicells, address mapping between AAL2 channel identifier and ATM VPI/VCIs must be executed in the pre- and postprocessing part of the minicell switching unit

As can be seen from Fig. 7, the size of the minicells is variable up to a maximal length. For this maximal length two different proposals exist: 45 Bytes or 64 Bytes minicell payload.

If the maximal length of the minicell will be chosen to 64 bytes (motivated by the 6 bit length field in the minicell header), new switching hardware would be needed that can deal with either variable length minicells or constant length packets with a maximal size of 67 byte (64 bytes payload plus 3 bytes header).

By choosing the maximal length of a minicell to 45 Byte any minicell would completely fit within the payload of an ATM cell. Thus, for the implementation of a minicell switch a switching fabric of a conventional ATM switch complemented by a pre- and post processing unit could be used. This would lead to small additional development costs. As shown in Fig. 8 we can even spare one switching fabric compared to Fig. 5.

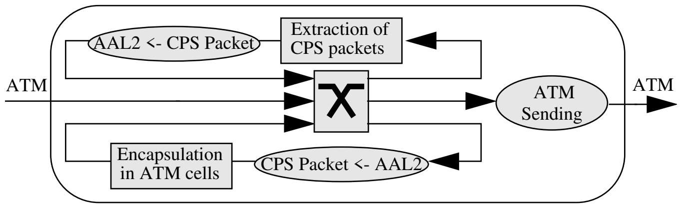

Figure 8: ATM switch extended to minicell switching

IV. Conclusions

We presented a simulation model of an ATM based access network for third generation mobile communication systems (UMTS/IMT-2000). It is capable to handle macrodiversity and the new AAL2 technology additionally to the other AALs. We developed models for the functional elements of the access network. Since AAL2 is new and only used for AAL2 trunking so far, we focus on the realization of AAL2 switching.

In further studies, the models will be used in order to examine different access network implementations for characteristic application scenarios. The advantages and disadvantages of these different implementations and scenarios (e.g. AAL2 trunking vs. switching) for the access network will be investigated. Moreover, design parameters (e.g. buffer sizes, switch capacity, and link bandwidth) for the network components will be determined.

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