Transport Performance Evaluation of an ATM-based UMTS Access Network

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ABSTRACT: One of the challenges of the Universal Mobile Telecommunication System (UMTS) is to bring closer together the mobile and the broadband fixed networks (B-ISDN/ATM). The objective is to use the same fixed network infrastructure and to offer mobile terminal users the same services as those available to the fixed terminal users. In this context, the design of the UMTS pursues service, transport and signaling protocol integration with fixed B-ISDN. This paper focuses on the transport integration aspects. Guidelines and mechanisms towards the definition of a fixed, ATM-based, access transport system for the target UMTS are given. The evaluation of the transport architecture, considering the European Advanced TDMA (ATDMA) technology at the radio interface, demonstrates the behavior of the system under various speech traffic loads, and yields results which fall within acceptable ATM performance measures.

1. INTRODUCTION

UMTS, currently being specified within the European Telecommunications Standards Institute (ETSI), will form the basis for third generation wireless systems in Europe, and is intended to consolidate today's diverse and incompatible mobile environments into a seamless radio and fixed network infrastructure, capable of offering a wide range of telecommunication services on a global scale, [1]. Future Public Land Mobile Telecommunication System (FPLMTS), [2], is a parallel standard being developed by ITU and it is closely aligned with UMTS. The goal of UMTS is to support a large variety of constant and variable bit rate services up to 2 Mbps, designed to support a range of voice, data, video and multimedia applications.

UMTS should be developed not as a separate overlay network, but as a system that allows true integration of mobile and fixed communication into a single, advanced telecommunications infrastructure, [3]. The recognition that ATM has recently emerged as the predominant switching and transport technology for wide and local area future broadband networks implies that a desirable feature for UMTS is its service, transport and signaling protocol integration with fixed broadband networks, [4]. This paper addresses the aspects related to the UMTS transport protocol integration into B-ISDN/ATM focusing on the access network. The access part of the target UMTS will incorporate a number of different radio access interfaces (European ATDMA, [5], and CDMA, [6], wireless ATM, and second generation systems), and the mobile users would expect the same or even better Quality of Service (QoS), compared to the service quality provided by each system operating independently. In addition, UMTS should support for each radio interface at least the same features that each standalone system supports. To satisfy this requirement, a full set of transport functions has been defined for the radio access part of the UMTS in [3], [7], [8].

This paper focuses on the functions needed for the adaptation of the UMTS third generation, non ATM-based, radio transport schemes to the transport schemes of the fixed ATM network. The transport integration configurations for the ATM-based radio access interfaces (e.g., [9]) comprise a simplified subset of these functions and their study is outside the scope of this paper. The architectural and transport protocol design is quantitatively studied by simulation. The modular introduction of the radio transport functions into fixed B-ISDN/ATM transport infrastructure comprises the basic feature of the evaluation model. The obtained results, considering the European ATDMA radio access technology at the radio interface, capture the effect of the proposed transport model on the access network buffering requirements, and on the cell loss, mean cell transport delay and cell delay variation for speech services under various network loads.

The rest of this paper is organized as follows. Section 2 introduces the UMTS network configuration and presents the protocol stacks for the network elements. In Section 3, the model used to evaluate the transport architecture is presented. Section 4 discusses the obtained numerical results. Finally, Section 5 contains our concluding remarks.

2. BASIC ARCHITECTURE AND PROTOCOL STACKS

A. UMTS Network Architecture

The UMTS network configuration considered in this paper is shown in Fig. 1., [3], [4], [7], [8]. This architecture is generally compliant with the different application environments (public, business, domestic) considered for UMTS.

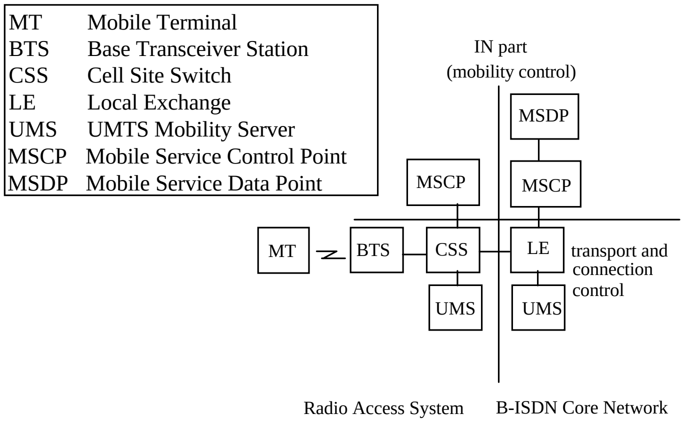


Figure 1 - Generic UMTS Network Architecture

In this configuration, the Mobile Terminal (MT) comprises all the call, connection and mobility control, and transport functionality required from the user side in order to support the mobile users in the UMTS network. The Radio Access System (RAS) implements the radio related functions required to connect the MT to the fixed B-ISDN. The Base Transceiver Station (BTS) includes the radio link management functions, while the Cell Site Switch (CSS) provides the basic switching functionality in the UMTS access network. The B-ISDN core network provides the switching and transmission functions required by UMTS, and represents the existing network infrastructure used for fixed communications. The Intelligent Network (IN) part of Fig. 1 (MSCP, MSDP) provides additional service and control logic required to support mobile users (location update, handover etc.).

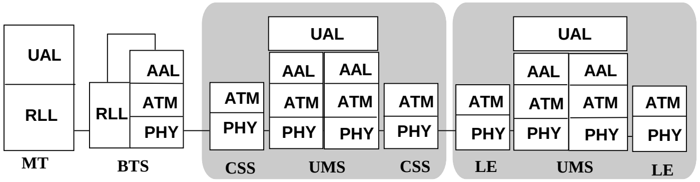
A considerable constraint in developing UMTS is to reuse the existing ATM switching infrastructure without modifying it. This means that all the UMTS-specific functions, which are not realized in the B-ISDN/ATM fixed network, have to be implemented in additional, enhanced, network elements to minimize the changes to the transport functionality of the B-ISDN components. The UMTS Mobility Server (UMS), [7], [8], shown in Fig. 1, provides the required special transport functions, which cannot be easily provided within a standard ATM switching network. In this way, the switching elements of the access part (LE, CSS) do not have to be modified to satisfy the service and transport protocol integration requirements.

B. Access Network Transport Chain

The efficient support of a variety of services across a network, which is composed of a fixed B-ISDN as a core network and a non-ATM radio access interface, necessitates the introduction of certain interworking functions. The need for such functions is dictated by the differences in functionality in the mobile access part and the fixed part of the UMTS core network. The purpose of these functions is to terminate all UMTS-dependent transport functions, and to attain adequate performance within the technological constraints imposed by the adopted radio interface. Based on the generic UMTS network configuration, a radio transmission model for European ATDMA and CDMA radio interfaces has been introduced in [3], [7], [8], for the access part of UMTS. This model identifies the following transport functions:

- The combining/multicasting function, related to the support of macrodiversity (i.e., the transport of the same information along a number of uncorrelated paths between the MT and a predetermined point of the fixed network).
- The transcoding function needed to support voice communication between mobile terminals, or between mobile and fixed terminals that use different speech coding schemes. For data traffic the transcoding function is null.
- Other interworking functions, such as segmentation/ reassembly (for splitting high bit rate connections, e.g. multimedia, that cannot be directly established on the radio interface), and ARQ functions for error control.

The user-plane (U-plane) protocol stack of the transport model considered is given in Fig. 2.



RLL: RADIO LOWER LAYERS

UAL:COMBINING/MULTICASTING , SEGMENTATION/REASSEMBLY, ARQ,
SOURCE CODING (FOR SPEECH SERVICES), TRANSCODING (FOR SPEECH SERVICES)

Figure 2 - U-plane protocol stack

The MT implements the radio access technology-dependent protocol stack, which includes all the radio transmission/reception functions and the transport functions described above. The UMTS Adaptation Layer (UAL), sitting on top of the radio lower layers, realizes most the transport functions, depending on the radio access scheme. Since our design objective is to define a generic transport architecture that is independent of the underlying radio technology, the study of the radio interface details for each radio access technique is beyond the scope of this paper.

The BTS acts as an interworking unit between the radio interface and the fixed ATM; it receives and extracts the radio packets and puts them in ATM cells to be forwarded higher into the fixed network. CSS and LE realize the typical ATM switching functionality. Both the UMSs (at CSS and LE level) implement the full ATM U-plane protocol stack and provide for the special transport functions of the UMTS access network that cannot be provided by the standard ATM switching infrastructure. The processing for all the transport functions (combining/multicasting, transcoding, etc.) in the UMS is performed above the ATM Adaptation Layer (AAL) at the UAL.

3. PERFORMANCE EVALUATION MODEL

In this section, the architectural and transport model presented above is quantitatively studied by simulation. The objective is to study the behavior of the system in terms of buffering, cell loss, mean transport delay and Cell Delay Variation (CDV) for speech services under various traffic loads. The configuration of the UMTS access network model used for performance evaluation purposes is shown in Fig. 3; it consists of 1 LE, 2 CSSs attached to the LE and 2 BTSs per CSS. The European ATDMA radio access technology, [5], is adopted at the radio interface.

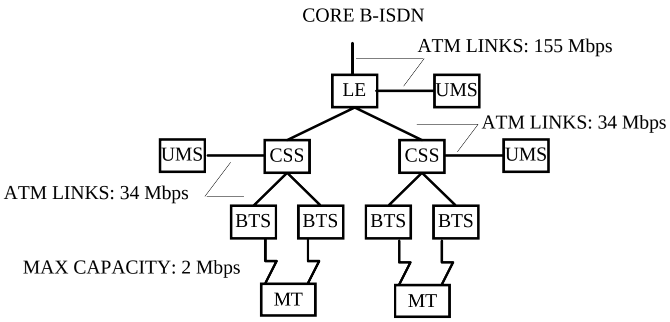


Figure 3 - Evaluated Network Architecture

A constant number of 4 voice terminals has been assigned to each BTS. For these MTs macrodiversity is used in the way shown in Fig. 3. However, in order to represent a system operating under real traffic conditions, the simulation model uses "background voice traffic" that enters the access system at the BTS, CSS and LE level and contributes to the total traffic loading of the system. This traffic emulates the overall traffic that comes from other MTs attached to the BTSs of Fig. 3, and from constellations of BTSs and CSSs that may form part of a real UMTS access network.

At the uplink, we consider only one level of combining. Traffic coming from the BTS-to-CSS links is subjected to combining at CSS level. "Background traffic" entering the UMS at CSS level does not undergo combining processing and represents non-macrodiversity traffic. In addition, the overall traffic coming from the CSSs towards LE is subjected to transcoding processing at UMS (LE) level. The "background traffic" entering the LE simply contributes to the traffic loading, and models communication between terminals that use the same speech encoding scheme.

The interface between the ports of the switching elements (CSS, LE) and the UMSs consists of separate ATM links for the UMS-incoming, uplink streams and of a single ATM link for the UMS-outgoing (towards the switch), uplink stream. This means that there is a need for traffic buffering within the UMS, since it implicitly acts as a traffic concentrator. The transmission rates for these links are shown in Fig. 3. The evaluation model takes into account the processing delays of the "Layer 3" and some of the upper "Layer 2" operations. These procedures are assumed to be executed by a single processor within each network node. Delays introduced by the lower layers processing are not taken into account. The propagation delays at the radio interface and on each fixed link between access network nodes have been taken equal to 4 μsec and 100 μsec, respectively. Switching times at the switches (CSS and LE) are assumed of nsec order, and as such they have been ignored. The simulation tool used for this performance evaluation is the OPNET 2.5A, [10].

The MTs are modelled as ATDMA voice terminals. According to the ATDMA technology, the MT speech source coder (implemented at Layer 3, the so-called UAL) provides a 9.6 Kbps bit rate (10ms speech frames of 96 bits each). The channel coder, which forms part of the Layer 2 (Radio Link Layer - RLL) functionality, codes 130 bits every 10 ms resulting in a 13Kbps total bit rate. The processing time for these functions has been taken equal to 1 ms. A diagonal interleaving technique is performed (part of RLL), resulting in a total delay of 15 ms. The MAC and radio propagation features that comprise the lower functions of Layer 2 and Layer 1 (Physical Link Layer - PLL), respectively, have not been taken into account.

In the BTS, the received packets are de-interleaved and channel decoded. Actual data is put in partially filled ATM cells at a rate of 1 cell every 10 ms. The information elements of the AAL payload (17 bytes) for the ATDMA speech service include 12 bytes of speech data, 1 byte Quality Measure (QM), i.e., hard decision estimates, delivered by the channel decoder, 1 byte indicating the source coding mode, 2 bytes timing control information for the time alignment of the transcoder, and 1 byte for CRC. The processing time for each packet at the BTS (after de-interleaving) is taken equal to 1 ms.

In the UMS at the CSS level, packets belonging to different streams that undergo macrodiversity are subjected to hard combining based on the QM information. Since the radio propagation features have not been taken into account, the QM for each packet is assigned randomly. The combining function is performed above the AAL layer. The new AAL payload is similar to that of the BTS, with the difference that the new packets do not include the QM field, thus resulting in a total length of 128 bits. These packets are also put in partially filled ATM cells to be forwarded to the LE. The processing time for AAL packetization and hard combining is assumed equal to 1 ms. The second UMS at LE level performs transcoding and terminates all UMTS-specific functions. Packets received in the UMS at LE level are source decoded, and the transcoder generates 64 Kbps speech, changing in this way the information rate. The output is delivered to AAL assuming that two blocks of 5 ms speech are put into two partially filled ATM cells. The overall processing time for AAL packetization and transcoding is taken equal to 1 ms. Processing times in the downlink direction are considered equal to those in the uplink direction.

4. NUMERICAL RESULTS

In the first part of the simulation results, all buffers in the BTS and UMS at CSS and LE level are assumed to have infinite capacity, so that no cell loss occurs in the access network. Figs. 4 and 5 give the maximum number of buffered packets and the mean buffer occupancy, respectively, at the BTS and UMSs versus the link utilization. Link utilization is measured at the 2 Mbps radio interface, the UMS-to-CSS outgoing link and the UMS-to-LE outgoing link. The system is tested by gradually increasing the background traffic entering the system at different levels, in order to reach each time the desired link utilization at each access network level. The traffic parameters used are shown in Table I. From these figures we observe that, with the proposed design, most of the traffic buffering is performed within the UMSs at CSS and LE levels.

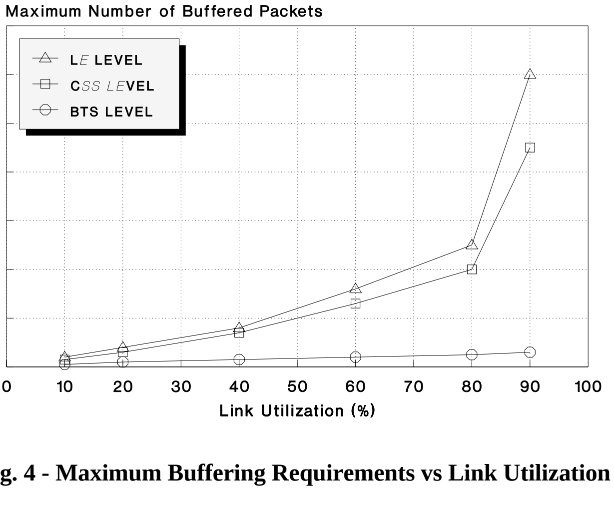


Fig. 4 - Maximum Buffering Requirements vs Link Utilization

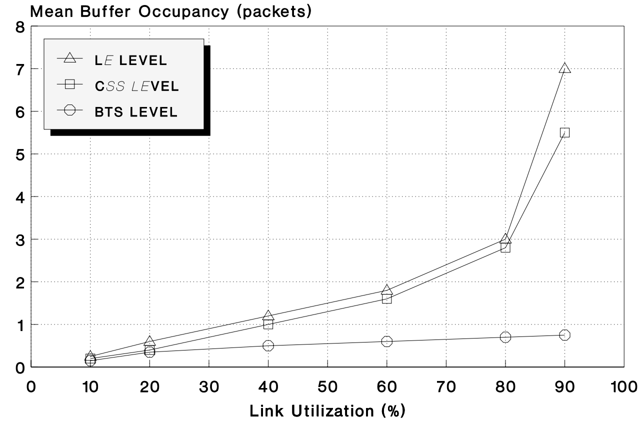


Fig. 5 - Mean Buffer Occupancy vs Link Utilization

Parameter	**Value**
Voice Service	9.6 Kbps (CBR)
Mean Call Duration (Exponentially distributed)	3 min
Mean Call Arrival/MT/hr (Poisson Arrivals)	10

Table I - Traffic Parameters

The mean delay observed for the speech packets across the access network is shown in Fig. 6, while the mean CDV is given in Fig. 7. Note that the delay performance results in Figs. 6 and 7 refer only to the traffic coming from the MTs, and not to the background traffic entering the system at different levels. As expected, as the traffic load increases there is a straightforward increase of the performance measures. Both the mean packet delay and mean CDV for speech services are kept within acceptable levels according to the results reported in [11], [12]. However, it has to be noted that if the presence of the lower layer processing had been taken into account (as in a real UMTS system), the delay measures would have been higher.

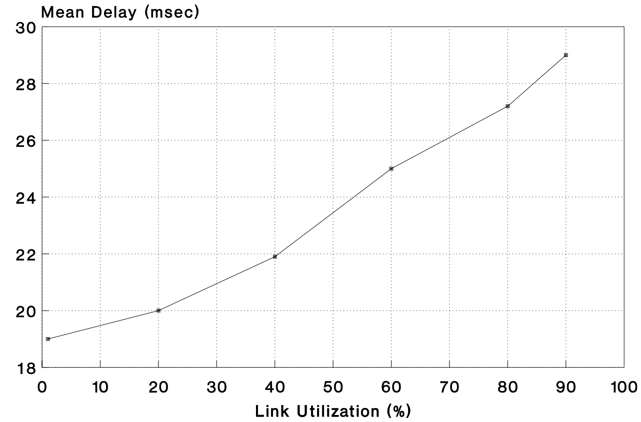


Fig. 6 - Mean Packet Delay vs Link Utilization

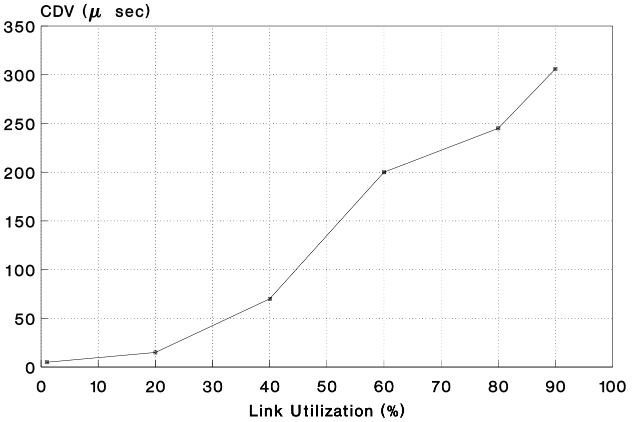


Fig. 7 - Mean CDV vs Link Utilization

The second part of simulation results shows the effect of cell losses on cell buffering and cell delay requirements, assuming 60%, 80%, and 90% link utilization. Figs. 8 and 9 show the maximum buffer size at the UMSs for different values of cell loss probabilities. A buffer size of 3 packets has been used in the BTS to avoid packet losses at BTS level according to the results given in Fig. 4. From these results the maximum UMS buffer size for optimum cell loss performance (order of 10^{-6}) can be obtained. However, the adjustment of the buffer sizes at CSS and LE level to meet a desired level of cell loss under different traffic loads of the access network is subject to the minimum cell delay and cell delay variation requirements. Figs. 10 and 11 give the corresponding delay performance measures versus the cell loss probability for various traffic loads. Note that as the cell loss probability increases the delay decreases, especially when the traffic load is high (90%). This implies that for voice services it would be preferable to use shorter buffers, in order to keep the mean transport delay and mean CDV at lower values, while maintaining an acceptable level of cell loss probability (order of 10^{-3}).

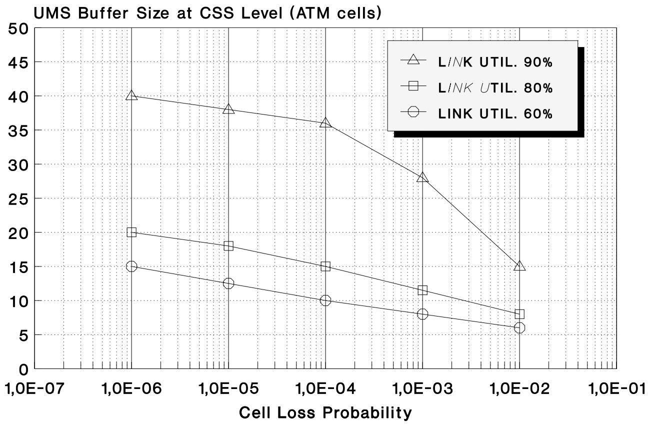


Fig. 8 - Buffering Requirements at CSS Level

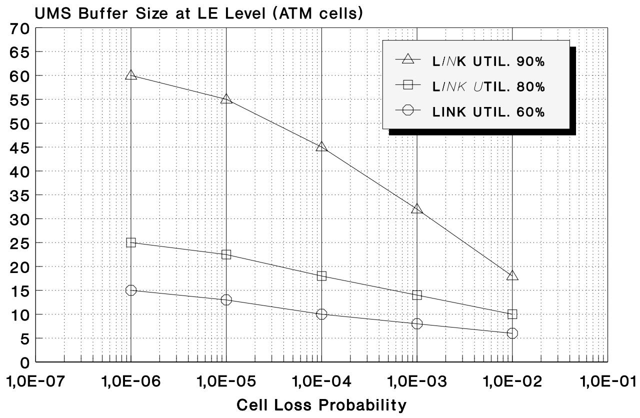


Fig. 9 - Buffering Requirements at LE Level

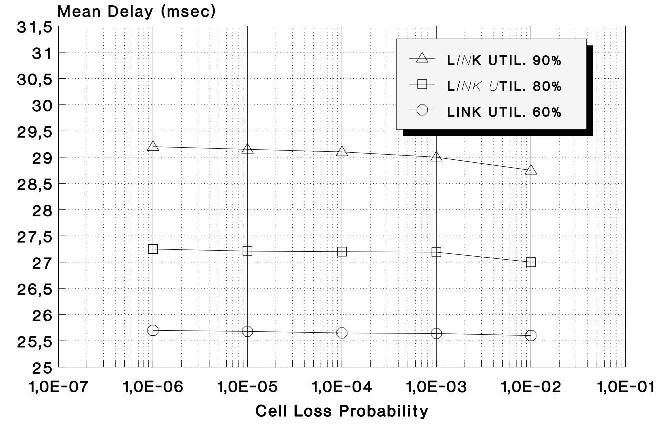


Fig. 10 - Mean Packet Delay Performance vs Cell Loss Probability

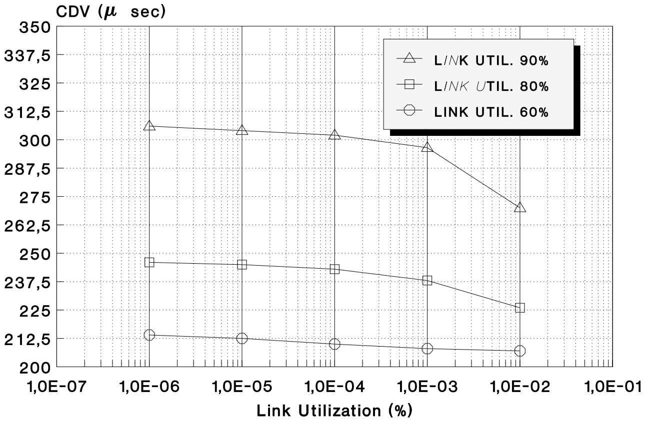


Fig. 11 - Mean CDV Performance vs Cell Loss Probability

5. CONCLUSIONS

The key problem addressed in this paper is the integration of transport functionality between UMTS and B-ISDN. The way in which ATM technology can be used to support transport interworking requirements between fixed broadband network and the various radio interfaces in UMTS has been discussed. The architectural and transport design offers a modular introduction of UMTS into fixed B-ISDN/ATM, without changing the existing B-ISDN transport infrastructure. A simulation model has been used to quantify the impact of this transport design on voice performance. The obtained results indicate that the system can satisfy the quality of service requirements for speech traffic.

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