

Strategies for the Efficient Dimensioning of 3G Mobile Access Networks

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Abstract

After a delay of some years, third generation mobile communication systems are beginning to be deployed. Thus, most European countries are currently involved in the installation of commercial UMTS networks based on the Release 99 set of specifications of the 3GPP¹. The main novelty of these first UMTS networks lies on the access segment, including both the radio and the fixed transmission infrastructure. Regarding the latter, Release 99 specifications establish the use of ATM, a technology largely used for the deployment of broadband backbones for multi-service networks with QoS requirements. Its use in the UMTS access network, however, is subject to optimization requirements because of the high costs associated to the transmission resources. In this paper we describe a simulation tool aimed to evaluate the performance of different network and traffic configuration alternatives that an operator may face when designing the terrestrial portion of its UMTS access network (UTRAN). In order to illustrate some of the tool features we also include and discuss a set of sample results comparing two possible traffic aggregation strategies inside the UTRAN.

Keywords: UMTS, UTRAN, ATM, Network Simulation, Quality of Service.

1. Introduction and Motivation

The general trend towards integrated networks capable of transporting any type of user applications traffic has also been observed in new generation wide area mobile networks such as UMTS (Universal Mobile Telecommunications System). These mobile networks will have to support not only voice and circuit-switched services, but also the huge set of present and potential services available through the packet-switched Internet.

The integration in traffic transport is usually associated to packet switched technologies and a group of mechanisms and techniques to assure an adequate Quality of Service (QoS) to the traffic flows that require it. The maturity of ATM (Asynchronous Transfer Mode) with respect to QoS support led to its adoption as the transport technology used

¹ Third Generation Partnership Project (www.3gpp.org)

in the terrestrial interfaces of the UTRAN (UMTS Terrestrial Radio Access Network) in its first releases (3GPP specifications Release 99 and Release 4). Later on, IP was considered [1] and specified as an alternative transport solution for the UTRAN in 3GPP Release 5 specifications [2], [3].

The work described in this paper is related to the efficient dimensioning of the most critical terrestrial interface of the UTRAN: the one between each base station (or Node-B) and its controller (or RNC – Radio Network Controller), called Iub [4]. This interface uses ATM virtual connections with AAL2 (ATM Adaptation Layer 2) [5] in the user plane. From the operator's point of view, the efficient dimensioning of the Iub interface is very important, since there can be thousands of Node-Bs in the network and their connections represent a significant part of the total network cost. Moreover, the QoS constraints for this interface are quite strict for all traffic classes, not only for real-time services [1], and this makes the dimensioning process even more difficult (see [6]).

Our study focuses on the ATM-based UTRAN, taking into account different user applications, as well as the peculiarities of the radio protocols above the transport infrastructure that modify the traffic patterns generated by the different applications. Based on the requirements that a mobile network operator installing its UMTS network may have, we have developed a simulation tool that represents with enough accuracy the Iub transport protocols and the traffic characteristics in this interface. This tool is being used to simulate different UTRAN network configurations, in order to identify the most efficient solutions for various phases of network deployment and operation. In particular, when the traffic per Node-B is low (for example in areas with few users) an adequate design can reduce the network cost significantly.

The rest of the paper is organised as follows. Section 2 presents the network scenarios considered for simulation. Section 3 describes the main characteristics of the simulator. Section 4 discusses simulation results that evaluate the statistical gain that can be achieved with different multiplexing strategies and traffic loads. The results obtained are compared with others reported in the literature. Finally, Section 5 summarizes the work done up to now, the contributions of the paper, and ongoing research activities.

2. Scenarios under Consideration

Although, from a logical perspective, the Iub interface is a point to point link between the Node-B and its RNC, nothing in the UMTS specifications prevents the operator from implementing any other physical infrastructure (see [7] and [8]). For instance, an ATM network with several links and switches can be used to implement the Iub section or part of it. Even if an ATM network is used, there can also be geographical zones in which it is convenient to arrange several Node-Bs directly in a chain or tree configuration, with its corresponding traffic concentration properties. In our study, the scenarios with an ATM network have been given priority, since this can be a quite usual situation for some UMTS operators with pre-existing ATM infrastructure.

Figure 1 shows examples of physical configurations of interest. It is important to note that the ATM network is not necessarily dedicated exclusively to Iub traffic. It can also transport traffic pertaining to other UTRAN interfaces (e.g. the Iur interface between RNCs) or even to non-UMTS services. This scenario raises two main aspects to be considered in the dimensioning process, as described in the following paragraphs.

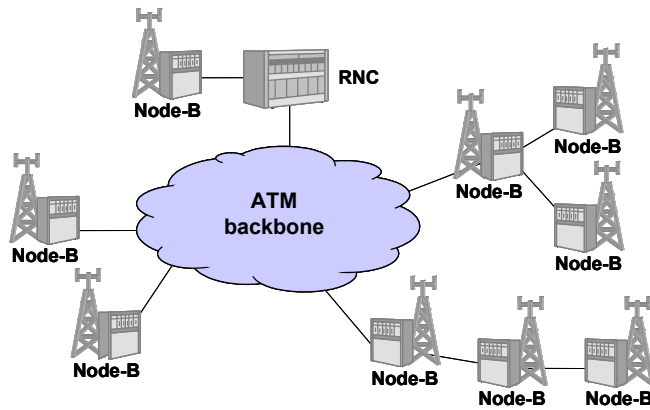


Figure 1: Physical configuration examples for the Iub interface

Firstly, the traffic flows of several Node-Bs should be statistically multiplexed for efficient transport in the ATM network. This multiplexing may be done at the AAL2 layer by using AAL2 switching [8], or at the ATM layer by using conventional ATM switches. Each alternative has its advantages and drawbacks, as discussed in detail in Section 4. Since the generated traffic will correspond to diverse types of applications (e.g. voice, web, etc.), it is also necessary to consider whether traffic flows of different types are multiplexed together or not.

Secondly, the efficiency requirement may suggest using variable bit rate (VBR) service categories instead of the more straightforward constant bit rate (CBR) category, since this involves an increase in statistical multiplexing gain inside the network. However, the dimensioning of VBR channels is more complex because it includes more degrees of freedom (i.e. more parameters to determine).

The traffic that RNCs and Node-Bs insert into the network may need to be limited in order to avoid interferences with other traffic carried by the ATM network. This means that the traffic parameters relevant for the selected service category (CBR, VBR) are policed by the UPC (Usage Parameter Control) at network entry points. Consequently, RNCs and Node-Bs must include a traffic shaping functionality that guarantees that the traffic sent to the network conforms to the specified parameter values (e.g. peak cell rate) and is accepted by the UPC.

The complexity associated to these scenarios has led us to use simulation techniques instead of analytical models. The next section describes the simulator developed for this study. Then, Section 4 presents the results that have been obtained for the first alternative mentioned above, that is, multiplexing at the AAL2 layer vs. multiplexing at the ATM layer.

3. Description of the Simulator

The simulator models the Transport Network Layer (TNL) of the Iub interface. This TNL is based on the establishment of an AAL2 connection for each user flow (whether packet-switched or circuit-switched). Several AAL2 connections will usually share the same ATM VCC (Virtual Channel Connection). Above AAL2 we find the radio protocols (see [9]), whose peculiarities (e.g. pseudo-periodicity in frame generation) are included in the simulation traffic sources, together with the relevant end-applications characteristics.

This tool has been developed to run on a commercial simulation platform: OPNET Modeler [10]. This software gives enough flexibility to create new models (or to adapt existing ones) while providing the developer and the user with a graphical environment to configure simulations and network topologies.

Simulation scenarios are formed with three main components, which can be interconnected by ATM links of any capacity (see Figure 2).

- Source node: it represents the radio network controller, and includes both the traffic sources (for downlink traffic²) and the AAL2 and ATM multiplexers.
- Destination node: it models the Node-B, responsible of performing the ATM and AAL2 de-multiplexing as well as the traffic sink functions (among them, the QoS statistics calculation).
- ATM switch: inside the ATM network, it models the switching of ATM virtual channel or path connections.

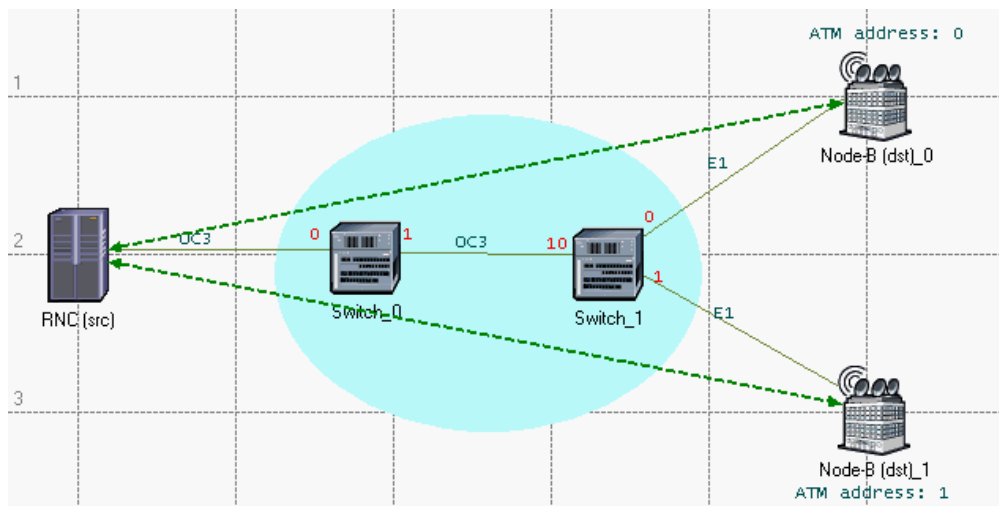


Figure 2: Graphical configuration of a sample scenario

Each individual user session (packet or circuit switched) in the model represents an active user (for instance, during a telephone conversation) and it makes use of a dedicated transport channel (DCH). This is consistent with the decision adopted by most UMTS operators for initial deployment. The resulting DCH Frame Protocol (DCH FP) frames are carried by an AAL2 connection across Iub. Each source is a two-state generator, which alternates between High and Low states. These states are directly associated with two allowed rates of the corresponding Radio Access Bearer.

Due to the semi-periodical characteristics of the radio protocols (and also DCH) frame generation, during each of the two defined states (High and Low) constant-sized frames are generated with an interarrival time equal to the TTI (Transmission Timing Interval) of the bearer. The frame sizes and the TTI values are deduced from the Radio Access Bearer characteristics [11]. See examples in Table 1.

The statistical characterization of the state durations depends on the application characteristics (size of the files the user is downloading, activity factor of speech, etc.).

² In the case of symmetrical applications (e.g. voice), considering downlink (DL) traffic instead of uplink (UL) does not imply any loss of generality. For asymmetrical applications (e.g. web) downlink traffic will be typically more voluminous than uplink traffic.

The simulation tool allows defining as many groups of identical sources (with the characteristics explained above) as needed. An individual source may generate its traffic with a stochastic offset with respect to the rest of sources inside the same group.

Table 1. Voice and web traffic parameters

	Voice AMR	Web
Radio bearer (kbit/s max. UL/DL)	Conversational, CS (12.2 / 12.2)	Interactive or background, PS (64 / 64)
TTI (ms)	20	20
High/Low State	active speech / silence description	file download / reading time
Selected DL rates (kbit/s High/Low)	12.2 / 1.95	64 / 0
Frame sizes (bytes High/Low)	const (40) / const (13)	const (174) / -
State duration (seconds High/Low)	exp (mean:3) / exp (mean:3)	pareto (shape:1.1, scale:0.23) / exp (mean:12)

For more information on the physical meaning of these parameters see [6]. Some distributions and parameter values have been extracted or derived from the recommendations given by 3GPP for simulation studies (see [1], annex A).

The simulator has been designed to be flexible regarding ATM configuration. It is possible to establish Virtual Channel Connections (VCCs) or Virtual Path Connections (VPCs) of any ATM service category between RNC and Node-Bs, and decide which sources share the same connection. These connections can traverse an ATM network with switches and links disposed following the topology chosen by the user. At the entry ATM switch (the one directly connected to the RNC) the UPC function can be activated if necessary. And, accordingly, inside the RNC, traffic shaping can be applied both for CBR and VBR categories.

The statistics offered by the tool can be grouped in two categories:

- Traffic statistics comprise peak traffic rates and sustained traffic rates for ATM cells and source frames collected wherever they have significance (in any link, ATM virtual connection, network node or the global values for the entire network). Traffic rate statistics at source level (i.e. the user of AAL2 level) are available also in a per-group-of-sources basis.
- QoS statistics include loss rates, delays and delay variations for ATM cells and source frames. Again, statistics can be collected at any point in the ATM network where they are significant (for instance, nodes, links or the entire network), and statistics for the source frames are presented individually for each group of sources.

All these characteristics make the simulation tool a very useful aid for the operator when determining the most convenient network configuration and parameters, given the expected number of users and their traffic profiles.

4. Simulation Results

In the Iub interface, each user flow is carried in one AAL2 connection (or “AAL2 channel”) between RNC and Node-B. Several AAL2 connections belonging to users of the same Node-B are multiplexed in one ATM Virtual Channel Connection (VCC) that terminates in that Node-B. In this way, variable-length AAL2 packets carrying information of different users are concatenated and sent within the fixed-length ATM cells of the VCC. When an ATM cell is partially filled and there are no more pending AAL2 packets, the sender times out, completes the ATM cell with padding octets, and sends it immediately in order to avoid long delays [5].

In a second step, the traffic flows of a group of Node-Bs may be statistically multiplexed to increase the transport efficiency in the ATM network. As introduced in Section 2, this function may be done at the AAL2 layer or at the ATM layer.

In the first case, one or several nodes with AAL2 switching functionality are included between the Node-Bs and the RNC. Each AAL2 switch terminates the VCCs that come from the Node-B side, and the VCC that comes from the RNC side. In uplink direction and for each Node-B, the AAL2 switch extracts the AAL2 connections from the corresponding VCC. Then, all the AAL2 connections for all the Node-Bs in the group are multiplexed together in the same VCC towards the RNC. (The inverse process takes place in downlink direction.) See Figure 3.

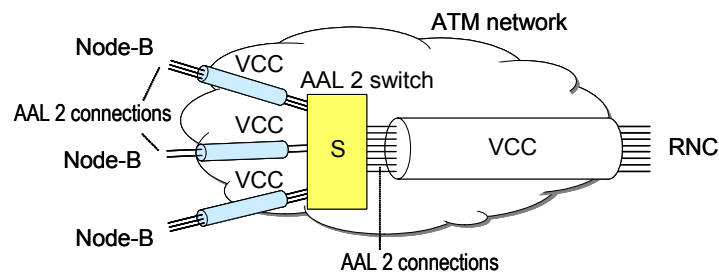


Figure 3. Multiplexing traffic to/from several Node-Bs in one VCC with an AAL2 switch

In terms of data units, this means that AAL2 packets belonging to *different users in different Node-Bs* (not only to different users in *the same Node-B*) are concatenated by the RNC (downlink direction) and the AAL2 switch (uplink direction) inside the ATM cells of a single VCC between both nodes. This reduces the number of partially filled cells (due to timeouts) that are transmitted, and therefore increases the efficiency. The improvement is greater when there are many Node-Bs, each with a low traffic load. A detailed study of this multiplexing strategy is reported in [8].

However, the efficiency gains of AAL2 switching are obtained at the cost of increased complexity in the network nodes, and extra delay due to the process of extracting and repacking AAL2 packets from and into ATM cells of different VCCs.

This section also investigates a simpler alternative which consists in multiplexing the traffic of different Node-Bs at the ATM layer by using conventional ATM switches without AAL2 switching functionality. In this case, the VCCs associated to a group of Node-Bs are statistically multiplexed inside an ATM Virtual Path Connection (VPC) established between the switching point and the RNC. See Figure 4.

With this solution there is also a multiplexing gain, since the capacity of the VPC may be smaller than the sum of capacities of the VCCs. The VCCs are end-to-end between the RNC and each Node-B, and each AAL2 packet travels from one to the other in the

same ATM cell, without waiting in intermediate AAL2 switches. The only disadvantage is that the amount of padding octets carried in partially filled cells between the switching point and the RNC will be bigger than with AAL2 switching.

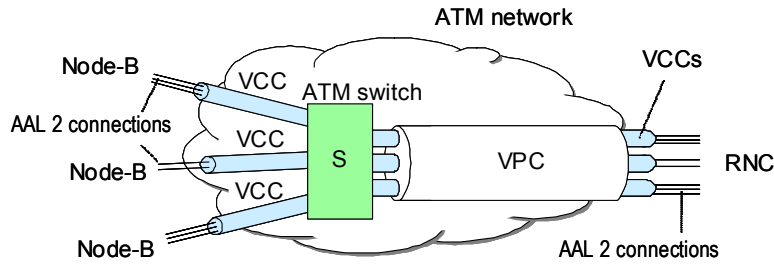


Figure 4. Multiplexing traffic to/from several Node-Bs in one VPC with an ATM switch

The simulation results shown below compare the efficiency of both Node-B traffic multiplexing alternatives (labelled “AAL2 switching” and “ATM switching” in the graphs). Except for the cases with a small number of users per Node-B, the simpler ATM switching alternative performs almost as well as AAL2 switching. For example, with 10 users per Node-B the difference between the two options is below 7%; with 20 users per Node-B the difference is below 4%.

The simulated scenarios include a variable number of both Node-Bs (N), and users per Node-B (n) with voice traffic only. Each active user generates traffic with a two-state model that represents alternating voice and silence periods within a conversation. (See details in Section 3.) Each Node-B is assumed to be equally loaded.

With AAL2 switching, $N \cdot n$ AAL2 connections are multiplexed in 1 VCC between the AAL2 switch located at point S in Figure 3 and the RNC. With ATM switching, N VCCs (carrying n AAL2 connections each) are multiplexed in 1 VPC between the same point S, which now is a conventional ATM switch, and the RNC. See Figure 4. Comparing both figures, it can be seen that the transport section between the Node-Bs and the switch S is the same in both cases, thus the simulation study focuses on the transport efficiency between S and the RNC.

Figure 5 compares the traffic load generated with AAL2 switching and with ATM switching in the section S – RNC as discussed above. Two different traffic loads per Node-B are shown.

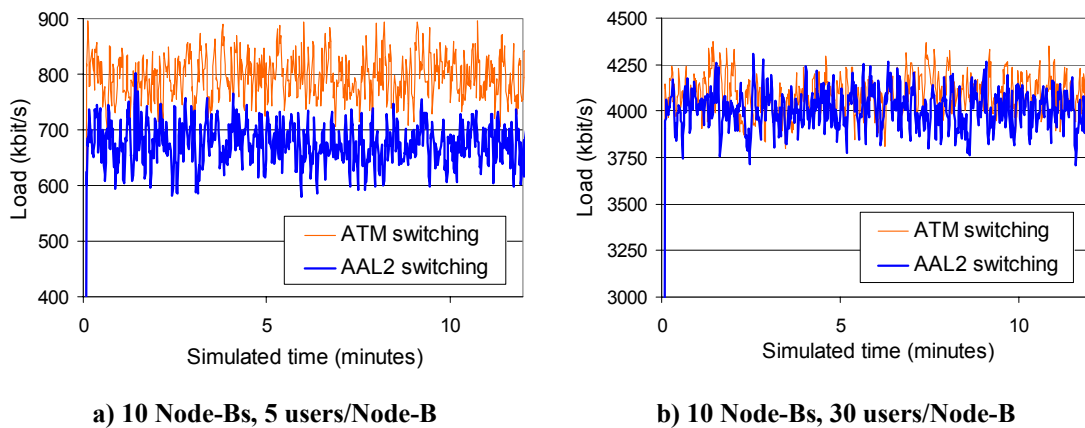


Figure 5. Comparison of traffic traces with low load (a) and high load (b)

As expected, the first option generates less traffic due to the reduced number of partially filled cells, but the difference becomes negligible when the number of users increases. This indicates that the network capacity required will be similar with and without AAL2 switches.

Figure 6 (a) shows the percentage of average load reduction that can be obtained with AAL2 switching with respect to ATM switching for several combinations of N and n . Except for $n < 10$, the percentage of reduction in all examined cases is below 7%. Figure 6 (b) shows the percentage of peak load reduction (peak load is defined as the maximum of the load averages computed during periods of 1 second). The variability of the results is bigger than before, but the same trend can be observed when n increases. In both graphs, the impact of the number of Node-Bs (N) is of little significance when $n > 10$.

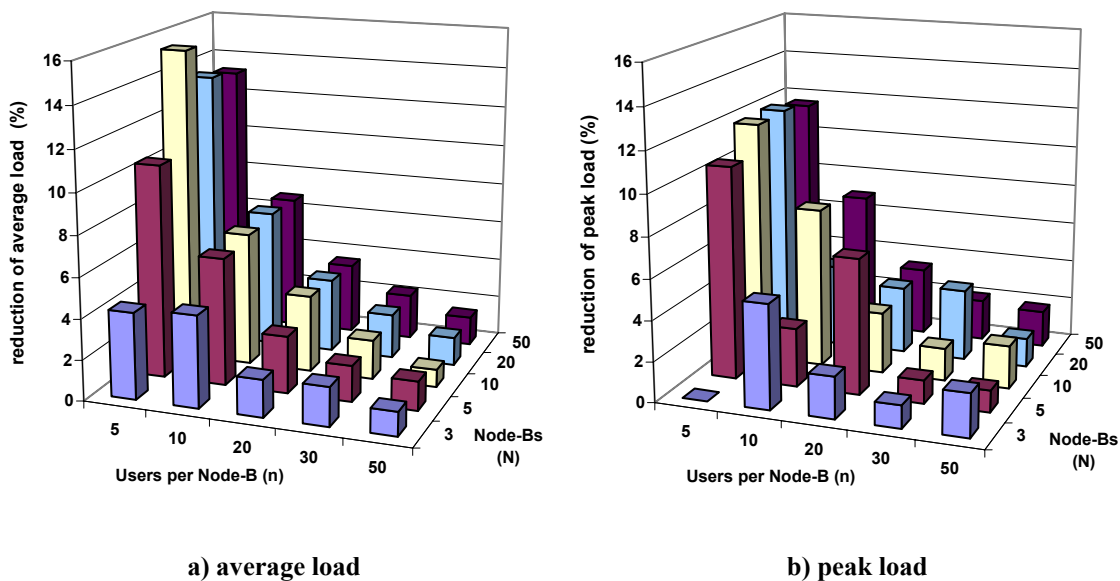


Figure 6. Load reduction for different numbers of Node-Bs and users

5. Conclusions and Future Work

The UMTS radio access network must connect a high number of Node-Bs and transport different types of traffic with strict QoS requirements in a cost-efficient way. Following 3GPP specifications, ATM and AAL2 are used as the basic transport protocols in the UTRAN, in particular in the Iub interface between each Node-B and the RNC.

This paper identifies relevant design options that affect the efficiency of ATM transport in this scenario, and describes a flexible simulation tool that can be used by network operators in order to compare these options in different network configurations (number of nodes, user profiles, traffic loads, etc.). To give an example of the simulator capabilities, the paper compares in more detail two mechanisms for traffic aggregation in the Iub interface: a more efficient, but also more complex alternative based on network nodes with AAL2 switching functionality, versus a simpler alternative based on ATM switching only, which minimizes delay at the cost of an inferior efficiency. The type of simulation results shown in the preceding section can be used to compare both alternatives in the network scenarios of interest for an operator, and determine in

which cases AAL2 switching provides significant efficiency gains, or in which cases ATM switching is enough.

The study of ATM transport in the UTRAN addresses the current needs of operators that are deploying UMTS networks based on existing ATM infrastructure. However, IP and MPLS (Multiprotocol Label Switching) are also potential alternatives for transport in the UTRAN that may allow additional savings in network cost, provided that the QoS constraints mentioned above are still satisfied. We have extended the simulator described in the paper with additional models of IP/MPLS transport protocol stacks, and compared them with AAL2/ATM in terms of efficiency for voice and data traffic. The initial results of this study can be found in [12].

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