End-to-end UMTS Network Performance Modeling

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Abstract

Problem Statement: User-perceived application-level performance is key to the adoption and success of UMTS services and infrastructure. To predict this performance in advance, a detailed end-to-end simulation model of a UMTS network was built to include application traffic characteristics, network architecture, network element details, and protocol features. The model has been used to assess architectural alternatives, identify system bottlenecks, and validate performance requirements. The main conclusion is that end-to-end application-level performance must be designed in at all phases of the development process.

1. Introduction

This paper describes a user-plane simulation model of an end-to-end reference connection through a UMTS network. The tool models all protocol layers from the physical through the application layer and models details of the packet handling characteristics of each network element along the path. Foreground and background traffic are generated to represent specific applications running over the network. The simulation model predicts application-level performance metrics such as response time, packet loss, jitter, and throughput and has been used to assess architectural alternatives, identify performance bottlenecks, and validate performance requirements. In general, the goal is to design quality and performance into the products and solutions up front. Some highlights of the UMTS Performance Simulator are:

- Model based on the OPNET simulation tool
- Models end-to-end reference connections - ignores some air interface details
- Block Error Rate (BLER) information obtained from another tool is fed into the UMTS Simulator
- Models UMTS applications and services
- Models user-plane traffic only - not control plane
- Impacts of mobility will be approximated
- Models each Lucent network element
- Models UMTS packet flow and detailed protocol stacks

The reference architecture and connections are based on Lucent UMTS products and the UMTS application models are based on a combination of standards and published traffic characteristics; for example [1]. For the voice traffic model a mobile-to-mobile reference connection is assumed and for the web browsing, e-mail and video streaming traffic, client-server models are assumed. Using this simulator, the user can predict the performance metrics of end-to-end applications, network elements, or various protocol layer levels in the UMTS network. Key features in this model are:

- UMTS service traffic models
- RLC retransmission model
- IP and ATM end-to-end routing model
- Background traffic for key UMTS services
- QoS buffering and scheduling algorithms for network elements
- ATM adaptation layer models - AAL1, AAL2 and AAL5
- Protocol stacks models - IP, TCP, RLC, DchFP, PHY_UP, Iu_UP and GTP_U
- Network elements - UE, Node-B, RNC, CBX500, TAG, PSAX, WAG, SGSN, GGSN and Data Center

There are two types of traffic modeled in the simulator: foreground and background traffic. The foreground traffic represents the specific traffic and services that traverse a given reference connection. It is the goal of the simulator to model the performance of this traffic in detail. An important contributor to the performance of these services will be the characterization and load contributed by the background traffic at each node. In this simulation, we model background traffic at each network element by service type as if it arrived from a source and goes to a destination that is independent of the given reference connection. Thus, the background traffic at each network is independent. In this release of the simulator, detailed protocols and buffering algorithms are modeled for UE, Node-B, RNC, CBX500, TAG, SGSN, GGSN and PSAX, while slightly less detailed models are used for the remaining network elements. More detail will be added to these elements over time.

2. Network Model

The reference architecture in this simulator is based on the 3GPP UMTS Release 99 standards. Fig. 1 shows the OPNET network model for this architecture. The orange colored dotted line represents the voice traffic path and the blue colored dotted line represents the web traffic path. Background traffic generators are included in each of the network elements and affect queues as if the background traffic exists in the network element. We assume ATM transport across the backbone network for circuit-switched and packet-switched services.

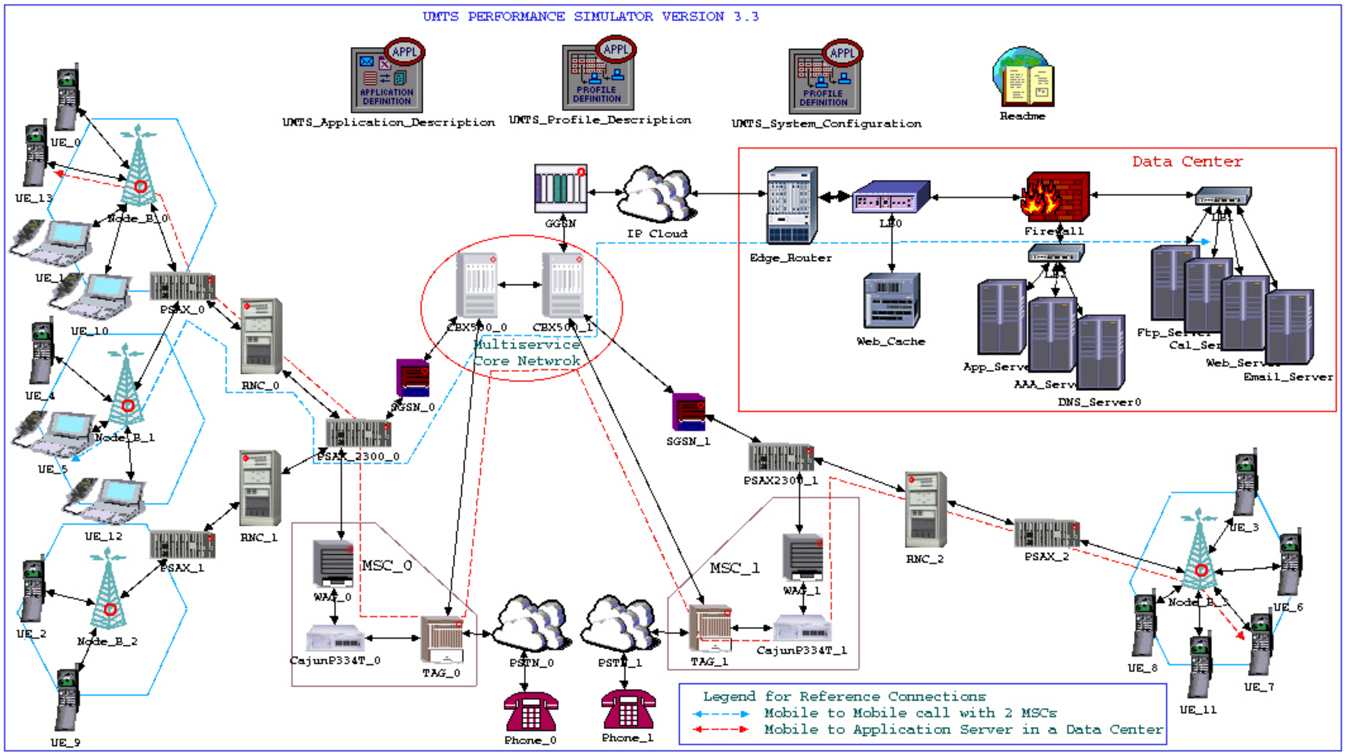


Fig. 1 Network Architecture

3. Protocol Stack Models

Protocol stacks for both circuit-switched and packet-switched services were modeled to include all packet overheads and key performance impacting actions. Fig. 2 shows the protocol stack for the transport network user plane on the Uu, Iub, Iur, Iu and Gn interfaces towards the packet-switched (PS) domain. It shows the protocol stack for the DCH transport channel for PS with separate Controlling and Serving RNC. In this case, the Iub interface is terminated in the CRNC and inter-worked with the Iur interface between RNCs. If the Controlling and Serving RNC are co-incident, simply remove the CRNC and Iur interface from Fig. 2, and connect the Iub interface from the Node-B to the SRNC.

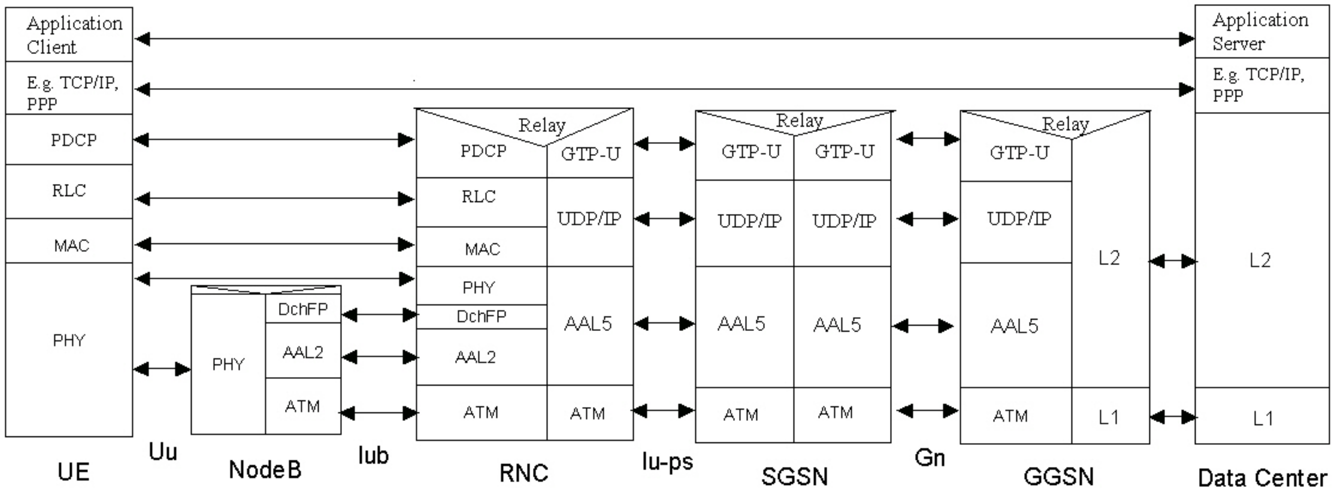


Fig. 2 Protocol Mode for PS Service Bearer Traffic

The air interface is not modeled explicitly as that would slow the simulation down too much. Instead a separate model was used to generate trace files of air interface performance as given by the Block Error Rate (BLER) under various conditions. This trace file of BLER was fed into the RLC layer for RLC acknowledge-mode operation to be modeled correctly.

4. Service Traffic Models

4.1. Foreground traffic models

Application traffic generation uses a model with a hierarchical structure. Session level traffic is defined in the Profile Configuration module and the packet level traffic specified in the Application Configuration module. An example of the design model for a web browsing service is illustrated in Fig. 3

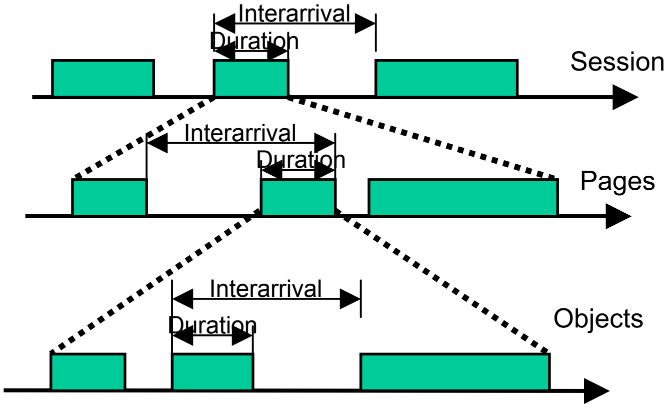


Fig. 3 **Web browsing traffic model**

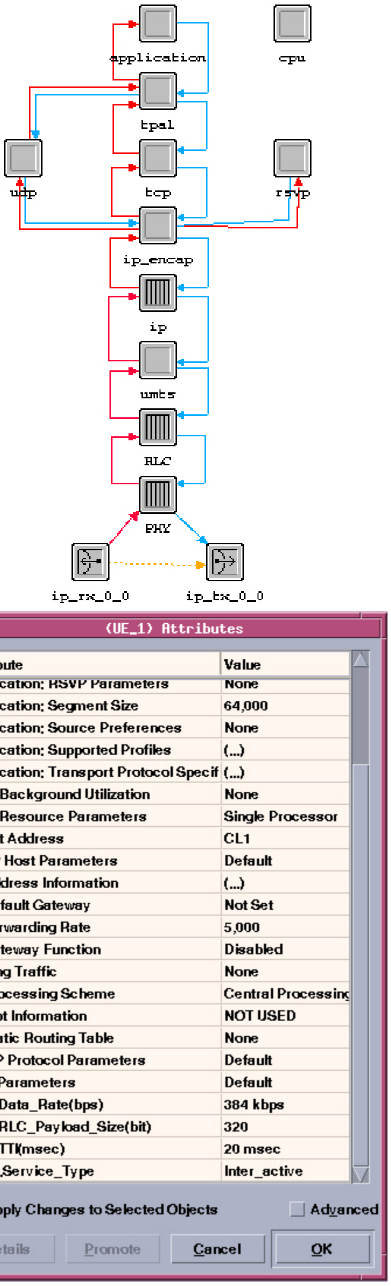
Here we model the arrival of sessions, characterize the arrival of page requests within a session, and the number of objects and their sizes for each page. Other UMTS applications of interest are modeled similarly. It is the performance of these foreground applications that the simulation model will measure in detail.

4.2. Background Traffic Models

The background traffic characteristics must be representative of the applications that are being run over the network so that their impact on the foreground traffic is accurately accounted for. However, the impact on the simulation run time precludes detailed application-level models. After reviewing an enormous number of different methods, such as statistical models for data traffic (long range dependant type)[2],[3] and traffic analysis and synthesis [4], [5], we decide to use a traffic trace file to get the effect of the background traffic. The first step is to collect a detailed packet trace for 1000 simultaneous sessions for each application using the simulator. This trace file is then scaled to match the desired mean rate for a given application. Using this trace file approach to generate the background load at each network element improved simulation run-time performance, but was still too slow. Thus we used the trace file to simulate a virtual packet load by calculating the delay effect in the buffer instead of generating background traffic packet by packet. We use Lindley's Recursion, extended to account for the impact of multiple queues and the queue scheduling discipline used, to calculate the packet delay effect.

5. Network Element Models

A detailed OPNET model was created for each of the network elements in the reference architecture. We give an example of the User Equipment (UE) model and the pre-defined user parameters, which should be set prior to the simulation in each network elements. The upper figure of Fig. 4 represents the OPNET Node-level model. Each box in that figure represents a function that is modeled by a finite-state machine with C-code describing each state. It can be seen that each layer of the protocol stack is modeled.



(UE_1) Attributes

Attribute	Value
Application: RSVP Parameters	None
Application: Segment Size	64,000
Application: Source Preferences	None
Application: Supported Profiles	(...)
Application: Transport Protocol Specif	(...)
CPU Background Utilization	None
CPU Resource Parameters	Single Processor
Client Address	CL1
IGMP Host Parameters	Default
IP Address Information	(...)
IP Default Gateway	Not Set
IP Forwarding Rate	5,000
IP Gateway Function	Disabled
IP Ping Traffic	None
IP Processing Scheme	Central Processing
IP Slot Information	NOT USED
IP Static Routing Table	None
RSVP Protocol Parameters	Default
TCP Parameters	Default
RLC.Data_Rate(bps)	384 kbps
RLC.RLC_Payload_Size(bit)	320
RLC.TTI(msec)	20 msec
umts.Service_Type	Inter_active

Fig. 4 Node model and User Interface of UE

The lower figure of Fig. 4 illustrates the user parameters that may be set. These include specification of the application data characteristics originating at that UE as well as network element configuration parameters.

6. Sample Performance Results

6.1. Simulation Results

We now show some simulation runs that illustrate the types of results that can be generated. Fig. 5 shows a simulation of the 12.2Kbps AMR voice service. The X-axis represents simulation time and we run the simulation for 35 minutes. The top graph shows goodput (bits/sec) on the application layer of 12.2Kbps AMR voice service. By goodput we mean the user payload excluding any protocol or other overhead. The red (or light) colored line represents average of goodput. The 12.2Kbps voice traffic generates 244 bits during an active period frame while it generates 39 bits comfort noise frame during a silence period [6]. End-to-end packet delay and delay jitter are shown in the middle and bottom graphs. Average end-to-end packet delay is about 200 msec and delay jitter is very small (the scale is 10^{-5}) since there is low background traffic on the network in this scenario and there is a 20 ms jitter buffer that absorbs most of the delay variation. As the background load is increased, the results would show, not only increased delay, but also greatly increased delay jitter. This model is able to quantify the impact explicitly.

The performance of a web browsing service is plotted in Fig. 6. The top graph shows the received web traffic (bytes/sec) in the client application layer and it represents the application layer goodput for single user web browsing session. The middle and bottom graphs present the object and page response times respectively. The average page response time is about 5 second between UE_1 and Web_Server. We assumed that the RLC data rate is 64 kbps for the uplink and 384 kbps for the downlink in this scenario.

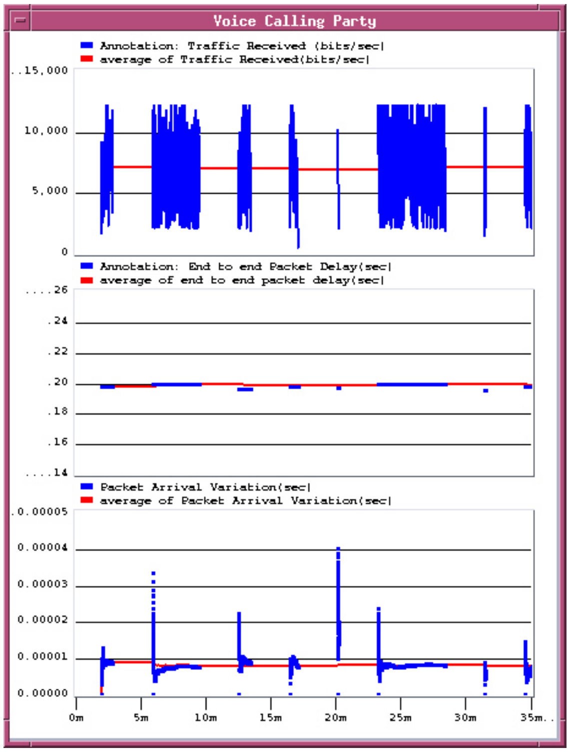


Fig. 5 Performance results of voice service

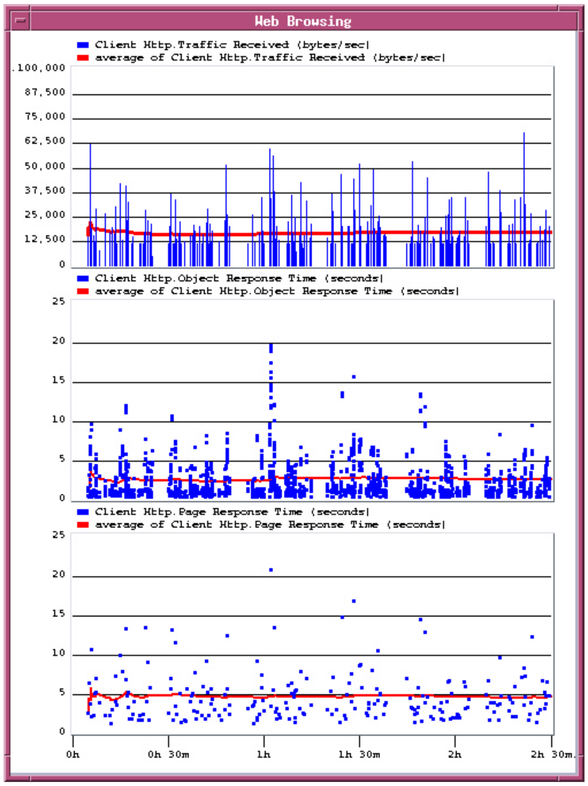


Fig. 6 Performance results of web browsing service

Fig. 7 shows the web browsing traffic goodput (bits/sec), TCP/IP and ATM protocol overhead. UMTS release 99 uses ATM transport in the UTRAN so it results in ATM protocol overhead in the application packets. The bottom curve shows the web browsing downlink (from server to client) goodput. The middle curve represents link throughput measured on the link from IP cloud to GGSN and it includes TCP/IP overhead. TCP/IP overhead is about 10% of the application layer goodput. The top curve shows link throughput from GGSN to CBX500 and it includes GTP_U, UDP, IP and ATM (AAL5) protocol overhead. It adds about 42% protocol overhead to the application goodput.

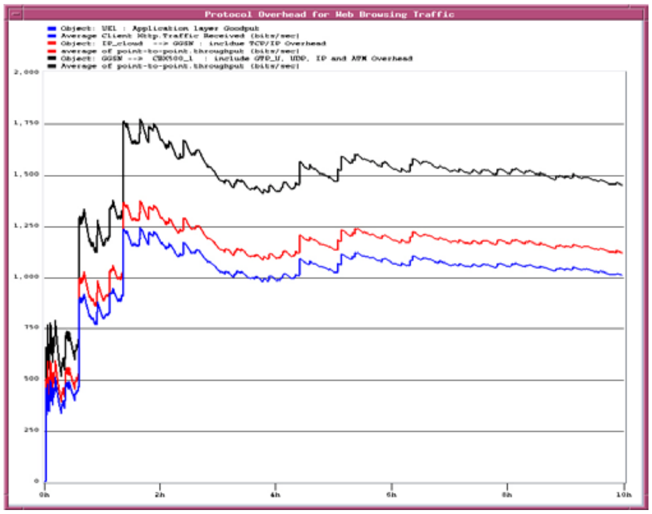


Fig. 7 Protocol overhead of Web browsing traffic

6.2. Simulation Performance

The run-time performance of the simulation can be defined in terms of number of events and processing time per event. The simulation run-time performance is always an important issue, but is especially so for network simulations where the number of events can be extremely large. As mentioned previously, we have separated the traffic into foreground and background traffic and developed specialized techniques for handling each to improve the simulation efficiency.

To quantify the UMTS Simulator performance, we modeled FTP applications with varying numbers of users: The ftp application was a 1Mbyte file download over the 64 Kbps data rate and Table 6.2.1 shows some of the simulation run times. The simulation takes 120 sec for a single user and file and the simulation time increased linearly when the number of concurrent ftp sessions were added. It clearly shows that the simulation performance is not feasible when the number of concurrent application sessions is large. However, the last two rows of Table

6.2.1 shows that the simulation performance is improved when additional ftp sessions are modeled as background traffic. For this test, 124 Mbps and 147 Mbps traffic on the average, which is about 80% and 95% of STM-1, was generated in all of the nodes along the reference connection (excluding application server) and one foreground ftp session was created.

Table 6.2.1 Simulation Run Time with and without Background traffic model

Number of Foreground Users	Number of background Users	Download File size	Simulation Time (sec)
1	0	1 Mbytes	120 sec
2	0	1 Mbytes	237 sec
3	0	1 Mbytes	355 sec
4	0	1 Mbytes	478 sec
5	0	1 Mbytes	596 sec
1	1400	1 Mbytes	190 sec
1	1670	1 Mbytes	205 sec

There are two types of traffic modeled in the simulator: foreground and background traffic as discussed in section 4. The foreground traffic represents the specific traffic and services that traverse a given reference connection. The background traffic would be used for the overloading condition simulations. It is the goal of the simulator to model the performance of the foreground traffic in detail. An important contributor to the performance of these services will be the characterization and load contributed by the background traffic at each node. In the simulation, background traffic is modeled at each network element by service type as if it arrived from a source and goes to a destination that is independent of the given reference connection.

7. Conclusions

This paper describes a user-plane simulation model of an end-to-end reference connection through a UMTS network. We used OPNET simulation tools 8.0 to build detailed end-to-end network elements and UMTS reference connections. Due to the restrictions of generic OPNET models, such as no static routing for ATM transport, we have built our own transport layer model. We have modeled all of the protocol layers shown in Fig. 2 from the application layer to the physical layer except the air interface and modeled 4 types of the UMTS service classes. We also have run 1000 concurrent application sessions and captured traffic for the background traffic load for each service. We used Lindley recursion method to obtain background traffic impact on the each interface in each network elements so that it reduced the number of simulation events and saved simulation run time. We also built detail network element models such as UE, Node-B, RNC, CBX500, TAG, PSAX, WAG, SGSN, GGSN and Data Center. The UMTS Performance Simulator presented in this paper has been used to predict and quantify the performance of UMTS applications, services, and network architectures.

8. Literature

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