Enhanced QoS and QoE Support in UMTS Cellular Architectures Based on Application Requirements and Core Network Capabilities

An Autonomic Resource Management Perspective

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Abstract—**The goal of this paper is to propose a solution in order to enhance the quality of services support inside the Internet Protocol-based packet switched domain of an Universal Mobile Telecommunications System architecture. The originality of this approach lies in the perspective of an integrated functionality defined at the conjunction of the service requests with the network capabilities. Objective quality of services and quality of experience analysis will highlight the benefits of the autonomic resource management in terms of average end-to-end delay, jitter and mean opinion score.**

Keywords-UMTS; QoS support; QoE perception; autonomic management.

I. INTRODUCTION

The success of the Internet Protocol (IP) technology, as evidenced by the variety of many types of applications and network architectures, has proven its centrality through the way it has influenced, and often determined the daily life.

Continuous user demands for traffic capacity determined the operators and infrastructure providers to identify and to offer end-to-end solutions including carefully-managed connections and high-quality user services and experience. In this context, Internet's ubiquity has revealed a number of shortcomings that the current architecture cannot solve.

Hence a multitude of solutions have been developed to approach problems such as addressing, routing, congestion, resource management or traffic precedence.

In a sustained effort to improve resource management for mobile network environments, our previous work was focused on the benefits offered by an integrated Quality of Services (QoS) support inside the Universal Mobile Telecommunications System (UMTS) IP packet switched (PS) part of the Core Network (CN) domain [1]. Introducing a realistic radio access network modeling, the work presented in this paper completes over the quality of delivered services.

In this way, we demonstrate the need for a correlation between the application request and the network context as the basic background of an integrated autonomic resource management.

A similar solution that considers the needs for built in quality control functions needed by many applications, addresses the resource management issue by combining a routing procedure and an information model for the representation of connection properties [2].

Two major trends can be distinguished in the way the scientific community understood solving this set of problems, namely: the complete remodeling of the Internet architecture (i.e., 4WARD [3], AUTOI [4], 4D [5], GENI [6]), and the gradual improvement of functionalities in the existing architecture [7] (i.e., Self-NET [8]).

The complete remodeling of the Internet architecture offers a purist approach, a clean slate kind of modeling the new architectural elements. On the other hand, the gradual development of network architecture, ruled by a pluralistic approach, considers that the leap towards a new Internet architecture is impossible independently of the existing technologies.

Promoting the functionality promised by a clean slate approach (flexibility, reliability, fault-tolerance, autonomy and manageability), the authors of this paper believe however that passing to an architecture that will integrate all these features is progressive, at least for two reasons: the perspective of operators and Internet service providers on radical changes in the network and the difficulty in testing, evaluating and validating the proposed new architectural elements.

Beyond the need for new legislative and normative agreements between Internet service providers and network operators, agreements required by fundamental architectural changes. Therefore, a major issue in the revolutionary innovation of the Internet architecture is the difficulty of assessing the new concepts in real experimental scenarios.

In [9], Peterson disputes the promotion of new architectural ideas, calling the scientific community to test the proposed solutions in the experimental "M-Lab" test-bed site [10], a validation site completely different from what means the evaluation by simulation or emulation.

Although the reality of testing on an experimental platform is undeniable, the risk is to focus the proposed solutions on an single extremely narrow issue.

Therefore, the authors of this paper believe that prior to a live testing phase there are several steps that must be completed by simulation and emulation, namely: monitoring and highlighting critical situations to identify network problems, testing the effect of local parametric adjustments on the whole system, development and gradual integration of scalable features in a new architecture. Therefore, stepping towards a revolutionary architecture is a matter of time; the new capabilities added to the existing architectural elements represent the prerequisites for success in this matter. Because of this, we believe that it is impossible to jump towards an architecture, which is independent of the existing technologies, the argument of this statement being found in the evolutionary pluralist concept.

Starting from these premises, which combine the requirements of a clean slate paradigm with current technological reality, the paper aims to investigate and test the benefits of integrating autonomic resource management capabilities into the UMTS CN architectural domain to enhance the QoS support.

In addition to analyzing QoS parameters such as average end-to-end delay, throughput or average jitter experienced by time-critical applications in the UMTS radio access network domain (UMTS RAN) [11], this paper enhances and extends the QoS / Quality of Experience (QoE) support even to the UMTS IP PS domain by integrating an autonomic resource management through network virtualization.

As the native UMTS QoS support is based only on service level classification in the Radio Access Network (RAN) domain, by describing, transmitting and correlating particular requirements of the source application with the context of IP PS domain, an optimal end-to-end performance could be offered through network virtualization in the CN.

In the context of this paper, by a native UMTS QoS support we consider a UMTS system offering QoS traffic differentiation by default. It is worth mentioning that the UMTS traffic classification covers only a certain part of the system and is closer to the physical connection (the RAN part), and therefore always has more stringent requirements in terms of QoS parameters.

Section II of the paper describes the radio access techniques, the architectural elements and the capabilities of the UMTS network domains that support various QoS traffic classes.

A holistic view of the quality of delivered services through the UMTS QoS support is completed by a QoE perspective. The QoE concept, the evaluation models and the parameters involved in the QoS objective analysis are presented in Section III.

Section IV presents the system model calibration for UMTS RAN in terms of Cumulative Distribution Function (CDF) of the Signal-to-Noise Interference level (SINR) for users in one cell that maximize the performances of the UMTS air interface. The UMTS RAN system model parameters that guarantee an optimal dimensioning of the network (transmission power, accepted co-channel interference levels, radio range and cell capacity) are determined. Then, the performances of QoS/QoE support traffic classes for applications that have stringent requirements concerning the time component are evaluated.

The UMTS RAN dimensioning is performed by using Matlab, while the end-to-end system performance evaluation is performed by using QualNet 5.1 network simulator [12].

In Section V, the premises for an autonomic resource management that ensures a higher quality support in the UMTS CN are investigated in terms of QoS/QoE support.

This fact is accomplished by the ability of the application to select an alternative route between UMTS CN entities, the Serving GPRS Support Node (SGSN) and the Gateway GPRS Support Node (GGSN), based on its knowledge of the source requirements.

Finally, Section IV presents the conclusions of the conducted study by showing the perspective of an autonomic management of network resources that is based on the conjunction of application requirements and network context.

II. AN OVERVIEW OF THE UMTS CELLULAR SYSTEM

We will present the radio access techniques, the architectural elements and capabilities of the UMTS network domains that support various QoS traffic classes.

A. *UMTS Radio Access Techniques*

The Universal Mobile Telecommunications System is one of the third generation (3G) cellular system technologies. It uses Wideband Code Division Multiple Access (WCDMA), a direct-sequence spread spectrum access technology developed by NTT DoCoMo [13].

NTT DoCoMo submitted WCDMA specification to the International Telecommunication Union (ITU) as a proposal for the air interfaces of the ITU IMT-2000 family of 3G Standards. Therefore WCDMA was selected as an air interface for UMTS system, the 3G successor to Global System for Mobile Communications (GSM).

Since it is GSM down-compatible, some of the UTMS key features include the two basic multiplexing modes, Time Division Duplexing (TDD) and Frequency Division Duplexing (FDD). The advantages offered by the use of WCDMA, a time-frequency space multiplexing technique were reflected in extended network coverage and increased cell capacity. This is a direct consequence of the accepted cell interference vs. number of mobile users in the system compromise. The benefits of using WCDMA over other multiple access techniques also reflect on adaptive power control, variable transmission rates and inherent QoS support.

B. *UMTS Network Architecture*

The UMTS network architecture consists of three interacting parts: the User Equipment (UE) or Mobile Equipment (ME), the UMTS Terrestrial Radio Access Network (UTRAN) and the Core Network (CN). Due to its various radio access supported methods, the UMTS UE is capable of working in three modes: Circuit Switching (CS), Packet Switching (PS) and hybrid CS/PS mode [14].

The RAN part consists of the Base Stations (BSs) or Node Bs and Radio Network Controllers (RNCs). The main functions of the BS are air interface transmission / reception, signal modulation / demodulation, while major functions of the RNC are power control, admission control, channel allocation, radio resource control / management, data multiplexing / demultiplexing.

The CN part provides data switching, routing and handles the user traffic. It also contains the network user registries or databases and the network management functions. Offering both CS and PS, the CN is divided in two domains: CS domain and PS domain. The CS domain network elements are the Mobile Services Switching Centre (MSC), Visitor Location Register (VLR) and Gateway MSC (GMSC). The PS elements are the SGSN and the GGSN. Network operational and maintenace elements like HLR, VLR, Equipament Identifier (EIR) and Authentificantion Center (AuC) are shared by both domains.

Concluding, we have to note that the UMTS CN part is based on the GSM network architecture with General Packet Radio Service (GPRS) support.

In order to achieve a certain QoS support, UMTS network has defined a so-called "Bearer Service". A bearer service includes all aspects needed to enable the provision of a contracted QoS, including the control signaling, user plane transport and QoS management functionality.

C. *UMTS QoS Support*

Various types of bearer service were established between different parts of UMTS network. In addition, each bearer service on a specific layer offers its individual services using services provided by the layers below.

It is worth mentioning that bearers that cover only a certain part of a system and are closer to the physical connection always have more stringent QoS requirements.

In order to solve the QoS problem, UMTS defines four types of traffic classes: Conversational (CO) Class, Streaming (ST) Class, Interactive (IN) Class and Background (BK) Class [15]. The main difference between these QoS classes is the transfer delay value. Conversational QoS Class includes real-time applications that require stringent limits for delay value, while Background QoS Class is the most delay insensitive traffic class.

Table I shows the main characteristics of the above-mentioned QoS classes and examples of corresponding applications.

TABLE I. MAIN CHARACTERISTICS OF UMTS QOS CLASSES

Traffic classes	**Characteristics**	**Application**
Conversational (CO) Class	low delay, low jitter, symmetric traffic, no buffering	speech, voice over IP (VoIP), video, video gaming
Streaming (ST) Class	moderate delay, moderate jitter, asymmetric traffic, buffering allowed	multimedia, video streaming, audio streaming, video on demand
Interactive (IN) Class	moderate jitter, asymmetric traffic, buffering allowed, request response pattern	web browsing, network gaming, databases access
Background (BK) Class	destination doesn't expect data within a certain time, preserve payload content, asymmetric traffic, buffering allowed	email, file downloading, fax, short message services (SMS)

In order to define the traffic characteristics, the UMTS network architecture introduces a set of QoS attributes. It must be mentioned that a particular type of traffic class is itself a QoS attribute.

There are attributes specific to all classes (i.e., maximum bit rate, delivery order, maximum SDU (Service Data Unit) size) and some attributes that are applied only to a specific class (i.e., transfer delay is applied only to conversational and streaming classes; traffic handling priority is applied only to interactive class).

III. QUALITY OF EXPERIENCE

QoE is defined by the ITU-T as "the overall acceptability of an application or service, as perceived subjectively by the end-user" [16], thus it measures the performance expectations of the user. It is also stated that QoE includes "the complete end-to-end system effects", meaning that the source quality, the effects of the network, protocols, source codecs, terminals equipments etc. are reflected in the quality perception at the end-user.

Although it may seem that it overlaps with the QoS notion, QoE is not limited to the performances of the network. The end-user perception is also influenced by non-technical aspects such as environmental, sociological, and psychological factors, and thus it would be more accurate to say that QoE augments QoS by linking the performance of the system and the user's expectations.

As expected, due to the fact that it reflects the user's opinion regarding the quality of the transmission, QoE cannot be easily evaluated. However, two types of evaluation methods are usually approached: the subjective and the objective one.

In order to evaluate the quality of a transmission from a subjective perspective, different tests and experiments have to be conducted using human subjects. This tests directly ask the participants to rate their experience regarding a certain service. Although this method is the only way of assessing the psychological and sociological impacts on QoE, it is expensive and time consuming [17]. Consequently, the second evaluation method is used in order to implement several models that associate the network performance with the user's level of satisfaction.

As described in [18], in the process of developing such a model, three main steps have to be considered: (1) analyze key QoS parameters that have an impact on the performance perceived by the user (e.g. delay, jitter or packet loss [19]) and identify the relationship between them and QoE, (2) measure the parameters considered in the first step and (3) use mapping metrics to rate the QoE based on the QoS measured parameters.

A. *Objective QoE Analysis: The E-model*

The most popular model used to predict the quality of a voice application is the E-model [20]. It is an objective method used to compute the performances of an end-to-end voice transmission and thus anticipate the quality perceived by the end-user taking into account the network impairment parameters like packet loss and delay.

The primary outcome of the E-model is the Rating Factor R as in (1)

$$R = R_0 - I_s - I_d - I_{e-eff} + A, \qquad (1)$$

where R_0 is the Signal to Noise Ratio, I_s represents the impairments that occur at the same time as the voice signal, I_d represents the impairments caused by the delay, I_{e-eff} is the effective equipment impairment factor (caused by the low rate codecs), and A is the advantage factor, which may compensate for some of the impairment factors assuming that there are other advantages of access to the user [21].

By processing the R factor, an estimation of the user's opinion can be obtained.

B. Mean Opinion Score

The Mean Opinion Score (MOS) is the most used QoE metric and is defined in [16] as “the value on a predefined scale that a subject assigns to his opinion of the performance of the telephone transmission system used either for conversation or only for listening to spoken material”.

Although this definition reffers to the telephone transmission system, the MOS is used in the evaluation of voice and video applications too. MOS is expressed as a number between 1 and 5, from the lowest to the highest perceived quality.

Table II presents the correspondence between the absolute value of MOS, the perceived quality descriptor and the degradation of the transmission as perceived by the user.

TABLE II. MOS CORRESPONDENCE TABLE

MOS	**Quality descriptor**	**Degradation**
5	Excellent	Imperceptible
4	Good	Perceptible
3	Fair	Slightly annoying
2	Poor	Annoying
1	Bad	Very annoying

A correspondence between the value of the R factor and MOS [20] is given in (2):

$$\begin{aligned} &R < 0,\ MOS = 1, \\ &0 < R < 100,\ MOS = 1 + 0.035R + R(R-60)(100-R)7 \cdot 10^{-6}, \qquad (2) \\ &R > 100,\ MOS = 4.5. \end{aligned}$$

C. QualNet 5.1 implementation of MOS

In addition to describing the subjective opinion, MOS is also used for scores that originate from objective models, like the one implemented by Scalable Networks for QualNet 5.1 simulator.

QualNet Simulator provides several parameters describing the performances of the network in the simulated scenarios. Among the usual objective parameters, MOS is also computed, based on the ITU-T E-model presented earlier.

The R factor is computed in a simplified manner as in (3)

$$R = 93.2 - I_d - I_{ef}, \qquad (3)$$

where I_d represents the impairment factor due to the delay in the network expressed by (4)

$$I_d = 0.024d + 0.11(d - 177.3)H(d - 177.3). \qquad (4)$$

Parameter d is the one-way delay (including coding, network and de-jitter delay) and I_{ef} (5) is the impairment caused by the low bit rate

$$I_{ef} = 30\ln(1+15e)H(0.04-e) + 19\ln(1+70e)H(e-0.04), \qquad (5)$$

where e is the error probability and $H(x) = 0$ for $x < 0$ and $H(x) = 1$ for $x \geq 0$ [12]. The formulae for computing MOS by means of the R factor are presented in (2).

IV. UMTS RAN SYSTEM MODEL AND NATIVE UMTS QOS SUPPORT EVALUATION

In this section, the system model calibration for UMTS RAN in terms of CDF of the SINR level for users in one cell that maximize the performances of the UMTS air interface is determined. Then, the performances of QoS/QoE support traffic classes for applications that have stringent requirements concerning the time component are evaluated.

A. Radio Access System Model Parameter Calibration

The air interface calibration scenario considered in this paper consists of a 1.4 x 1.4km^2 area, in which a UMTS RAN has been deployed.

The UMTS RAN calibration system model considers seven Node Bs deployed, each of them having three-sector antennas. The Inter-Site Distance (ISD) is considered to be 500m, as for a typical urban environment. Furthermore, the NodeBs transmit powers are set to 20W.

The radio propagation model considered in the simulations consists of a log-distance path loss model with fixed and exponential coefficients taken from [21].

The amplitude change caused by shadowing is modelled using a log-normal distribution with a standard deviation according to the log-distance model. The shadow fading maps were generated based on the method in [22] with the standard deviation parameters taken from [21]. The summary of the full range of parameters used in the simulations is presented in Table III.

TABLE III. UMTS RAN SIMULATION PARAMETERS

Path loss	Path-loss is modelled as 11.81+ 38.63 $\log_{10}(d)$ for network users, where d is the distance from the base station in meters.
Shadow fading	Shadow fading is modelled as spatially correlated random process with log-normal distribution (6dB standard deviation), spatial correlation $r(x) = e^{x/20}$ for distance x.
Receiver noise power	The receiver noise power is modelled as 10 $\log_{10}$ ($kT\ NF\ W$) where the effective noise bandwidth is given as W = 3.84 × 10^6Hz, and kT = 1.3804 × 10^{-23} × 290W/Hz. The noise figure at the UE is $NF_{[dB]} = 7$dB.
Base station antenna gain	The base station antenna gain is calculated as $G(\theta)dB = G_{\max} - \min\left[12\left(\frac{\theta}{\beta}\right)^2, G_s\right], \quad -\pi \le \theta \le \pi$ with $\beta = 70\pi/180$ angle where gain pattern is 3dB down from peak G_s = 20dB sidelobe gain level in dB $G_{\max}$ = 16dB maximum gain level in dB

Radio system simulations were carried out in order to investigate the performances of the UMTS mobile network. The simulation parameters were taken from Table III, and if not otherwise mentioned they will be the same for all the simulations carried out in the paper.

The received signal strength on the downlink direction is calculated as in (6)

$$P_{Rx} = P_{tx} + P_{loss} + P_{shadow} + P_{antenna} , \qquad (6)$$

where P_{tx} is the transmit power of the base station; P_{loss} is the path loss component calculated according to Table III; P_{shadow} is the shadow fading component at the user location defined by the parameters in Table III; $P_{antenna}$ is the antenna gain component specific for the three sector antenna used at the Node B transmitter.

In order to have a general view of the system model, Figure 1 presents the level of the received signal strength throughout the environment. The levels for the received signal are calculated according to equation (6). For a better understanding and clarity of the figure, the values of the signal displayed in Figure 1 are calculated without considering any shadow fading.

The values of the received signal strength are given in dBm, according to the colour bar on the right hand side of the figure. The resolution of the map is 2m.

Figure 1 presents the general view of the system model, but in order to understand the performances of the network we need to analyse it cell-wise. In order to do this, we will further concentrate on one of the three hexagonal cells of the centre base station.

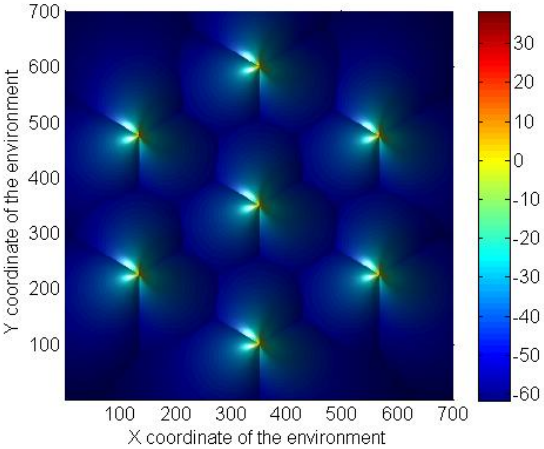

Figure 1. Received signal strength level for the considered environment

The analyzed parameter in this case will be the signal to interference plus noise ratio (SINR), defined as in (7)

$$SINR = P_{Rx\_\max} - (P_{\text{int}\,erference} + P_{noise}) , \qquad (7)$$

where $P_{Rx\_\max}$ is the received signal strength from the best server; $P_{\text{int}\,erference}$ is the sum of the contributions of all the other base stations; P_{noise} is the receiver noise power defined according to Table III.

Using (6), the SINR level will be calculated for all the positions in the environment with the same location resolution. Because the level of the noise power at the user location is -101.13dBm, as calculated from the relations in Table III, the receiver sensitivity considered in the scenario needs to be above this threshold.

One factor, which has a great impact upon the obtained SINR value, is the shadow fading. This phenomenon occurs when an obstacle is situated between the transmitter and the receiver, in our case base station and mobile terminal, respectively. In order to better understand the influence of the shadow fading component upon the level of the obtained SINR, we will vary the value of the shadow fading standard deviation. The analysis we conducted led us to the results presented in Figure 3, which illustrates the CDF of the obtained SINR value for all the user positions in one of the hexagonal centre cells.

The results are calculated for the instances when we have no shadow fading, shadow fading with standard deviation 4, 6, 8 and 10, respectively.

The analysis reveals that the shadow fading has a negative impact upon the obtained SINR value, directly proportional to the increase of the standard deviation.

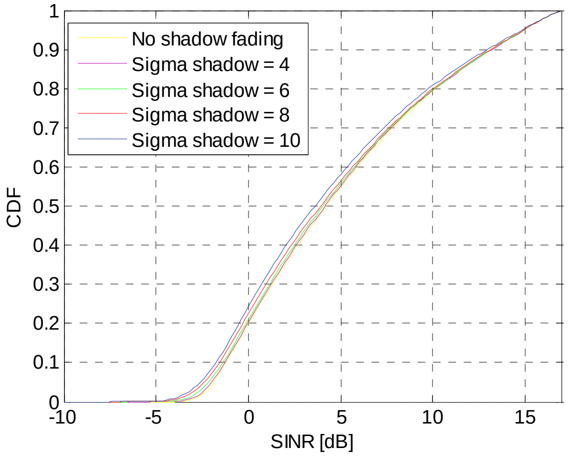

Figure 2. CDF of SINR for users in one cell

Because in our scenario we consider a minimum threshold value of the SINR of -6.5dB, the worst case that fulfils this condition is that of using a standard deviation of 6. The minimum value of -6.5dB for the SINR, corresponds to a user throughput of 500kbps.

B. *Performance Evaluation of UMTS QoS/QoE Support*

In order to evaluate the QoS support implicitly provided by a UMTS network, a scenario including a PLMN (Public Land Mobile Network) was simulated using QualNet 5.1 network simulator, a widely used platform in the defense and telecommunication network design and evaluation [12].

Global parameters configured at the physical UMTS RAN level of the simulation are given in Table IV.

TABLE IV. PHY LAYER CONFIGURATION PARAMETERS

Parameter	Value
Terrain dimensions	1.4 x 1.4 km^2
Up-link channel frequency	1.95 GHz
Down-link channel frequency	2.15 GHz
Shadowing Mean	6 dB
Node B transmission power	20 W
Simulation time	200 s

The system model parameters previously determined guarantee an optimal dimensioning of the network in terms of signal distribution vs. system capacity. It should be noticed that two different radio channels were used in order to access the network resources. The frequency values of these channels were chosen accordingly with European 3G bands for UMTS 2100 recommendations [23].

The UMTS RAN network scenario includes eight UE nodes: four source nodes (UE nodes 6, 8, 10, and 12) and four destination nodes (UE nodes 7, 9, 11, and 13), as presented in Figure 3.

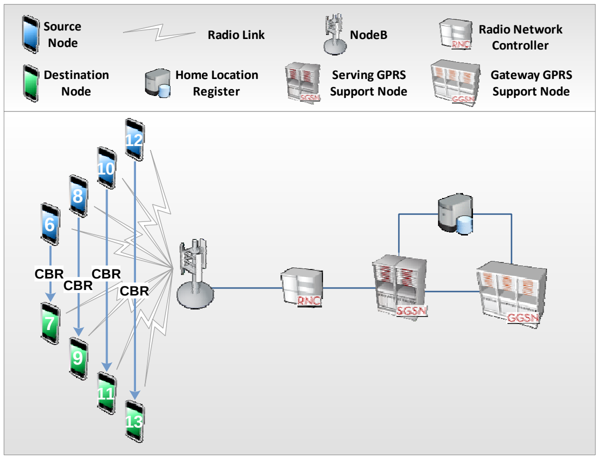

Figure 3. UMTS evaluation scenario

Between the source nodes (SN) and destination nodes (DN), four CBR (Constant Bit Rate) applications, each of them corresponding to one QoS class defined by the UMTS network, were considered. The characteristics of all applications are summarized in Table V.

TABLE V. CORRESPONDING QOS CLASS FOR EACH CBR APPLICATION USED IN THE EVALUATION SCENARIO

Application Type	SN	DN	Items to Send	Item Size (bytes)	Interval (s)	QoS Class
CBR	6	7	1000	40	0.1	BK
	8	9				IN
	10	11				ST
	12	13				CO

The results of the simulations concerning the average end-to-end delay, the average jitter and average MOS for each QoS supported class are presented in Figure 4, Figure 5 and Figure 6 respectively.

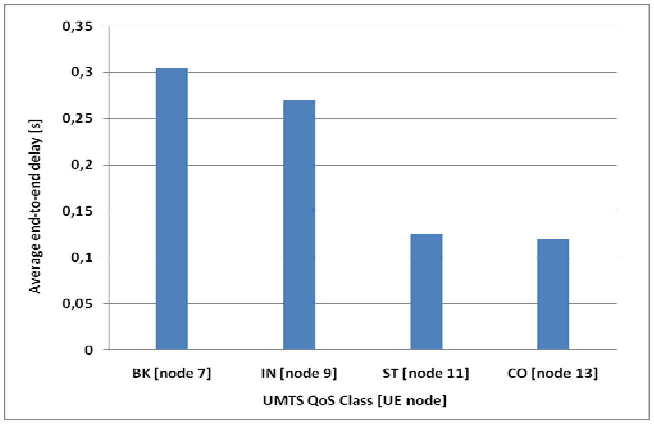

Figure 4. Average end-to-end delay experienced by the test applications in each QoS support class

In analyzing the obtained results, it can be noticed that application, which corresponds to the Conversational and

Streaming QoS class, is characterized by the lowest value of average end-to-end delay and jitter delay, as expected for the type of application corresponding to this class (speech, VoIP, video or audio streaming).

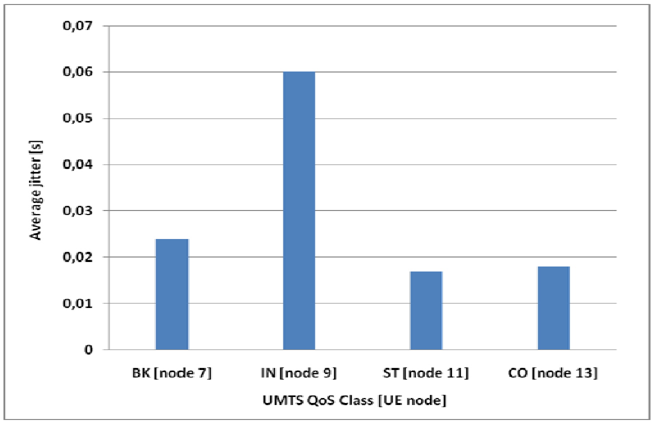

Figure 5. Average jitter experienced by the test applications in each QoS support class

Summarizing, the network complies with the priority level imposed on the test applications that were modeled by CBR-type traffic sources, and this is reflected in the average values of the end-to-end transmission delays and in the jitter for each QoS priority class.

Correlating end-to-end transmission delays with the transmission flow rate and with the time interval between transmitted packets one can notice the increased flow rate in the case of Background class, which is due to transmitting a reduced total number of packets in a very short transmission time interval.

If MOS values are compared, it can be seen that the application from Conversational QoS class has the highest value of this parameter, which corresponds to the lowest value for the average end-to-end delay and the average jitter.

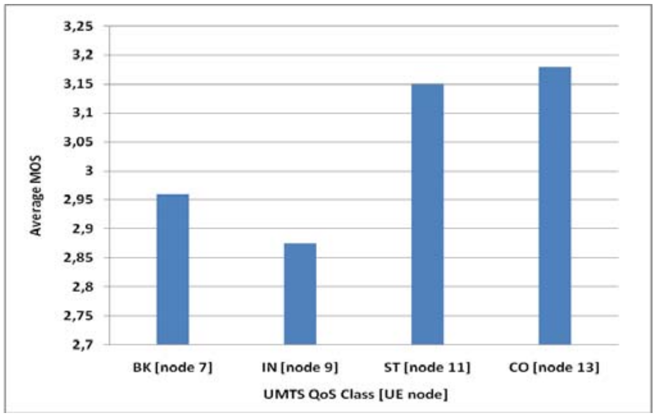

Figure 6. Average MOS experienced by the test applications in each QoS support class

Note that the QualNet simulator offers the possibility to mark the traffic flows by setting the appropriate IP Precedence field. In this way, the applications are identified, classified and scheduled in the corresponding queues.

V. Perspectives towards an Autonomic Resource Management in a UMTS Network

Developed within the 3rd Generation Partnership Project (3GPP), the 3G standard suggests an end-to-end QoS support based on a policy management system (Policy-Based Network Management) [15].

The network architecture presented by the first 3GPP public versions has evolved to an architectural model System Architecture Evolution (SAE) [24], which ensures the convergence of different access network categories such as UMTS, 3GPP, Wireless Local Area Network (WLAN) or any other non-3GPP radio access technology.

The latest public 3GPP version considers the IP Multimedia Subsystem (IMS) [23] network architecture to be completely separated from the access technology, having the specific access functions isolated from the core network. By eliminating the hierarchical dependence between the Serving RNC (SRNC) and the corresponding SGSN, a more efficient resource allocation was offered.

In order to manage QoS resources, the SAE architecture integrates an informational QoS Information Function (QIF) function that interacts with all individual network models included within the IMS platform. This QoS resource management solution is an external part of the network, based on the use and interaction between a central entity and periferic elements.

Although in the clean slate approach the resource management and the QoS support are considered an integrated part of communications networks, this fact is not reflected in the characteristics of current systems or by the UMTS network architecture.

Therefore, the perspective of an autonomic resource management in a UMTS network proposed in this paper suggests the necessity of adding additional information at the level of the central UMTS network elements using virtualization technique.

Network virtualization represents a high level abstraction process that overlaps the implementation and physical network configuration details. Allowing co-existence of multiple virtual architectures overlaid on a common substrate physically shared, network virtualization promises flexibility and security, promoting diversity and increased management capacity [24].

In this way, UMTS core network nodes act autonomously, being able to sense the environment, to perceive the changes, to understand internal changes and to react in an intelligent manner by selecting the optimal path according to application requirements.

To demonstrate this, native UMTS QoS support is analyzed in comparison to the potential of the autonomic management offered through network virtualization, using QualNet network simulator [12]. Thus, in the case of an autonomic management system, the proposed analysis scenarios highlight the ability of selecting the best route according to the source application constraints in terms of maximum acceptable end-to-end delay.

A. *Scenario description*

According to [13], it is possible for an UMTS network to have multiple SGSNs and GGSNs entities, which can be co-located or can be interconnected via an IP subnetwork in order to increase the geographical area served by an operator.

Considering the second approach, an evaluation scenario was developed, in which the SGSN and the GGSN are interconnected via a simple IP sub-network that consists of seven generic routers denoted R1 to R7, as depicted in Figure 7.

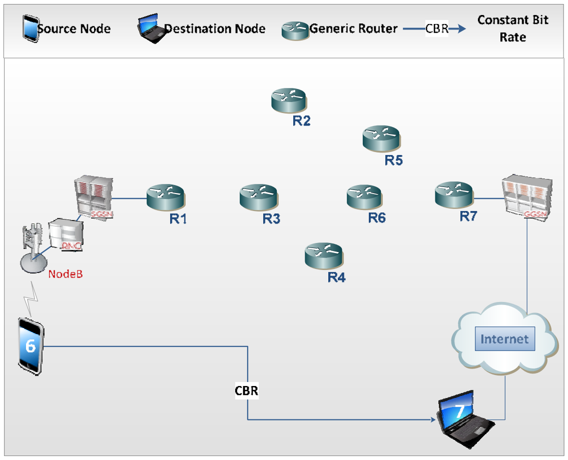

Figure 7. The architecture of the evaluation scenario

Obviously, a real-life UMTS IP sub-network would be more complex, the motivation for this topology was to better illustrate the problems that may arise and the proposed solution.

In this evaluation scenario a CBR test application corresponding to Conversational QoS class (highest priority QoS class) was considered. The main parameters that describe the characteristics for the tested application are indicated in Table VI.

TABLE VI. CHARCTERISTICS OF THE MODELED APPLICATION

Application Type	**SN**	**DN**	**Items to Send**	**Item Size [bytes]**	**Interval [s]**	**QoS Class**
CBR	6	7	1000	40	0.1	CO

As we have already mentioned, the motivation behind this evaluation is to highlight the benefits of the autonomic management offered through a network virtualization process.

In our case, the virtualization process could be illustrated by controlling, through the configuration files, the parametric values that characterize network architectural elements.

Knowing the values of these parameters, it is possible to indicate a dedicated virtual network that offers the best path from source to destination in terms of minimum average end-to-end delay, maximum throughput, packet loss rate on selected route or other stringent requirements specific to a certain type of application.

B. *Performance Evaluation*

In order to emphasize the path selection mechanism between SGSN and GGSN, core nodes of UMTS IP sub-network, two different cases were evaluated: a native UMTS QoS support selection compared to QoS network support provided by an autonomic network management selection, as a result of dedicated virtual network generation.

When it defines the links between two intermediate generic routers in the UMTS IP sub-network, the simulator allows the association of specific transmission throughput and delay on each link, as presented in Figure 8.

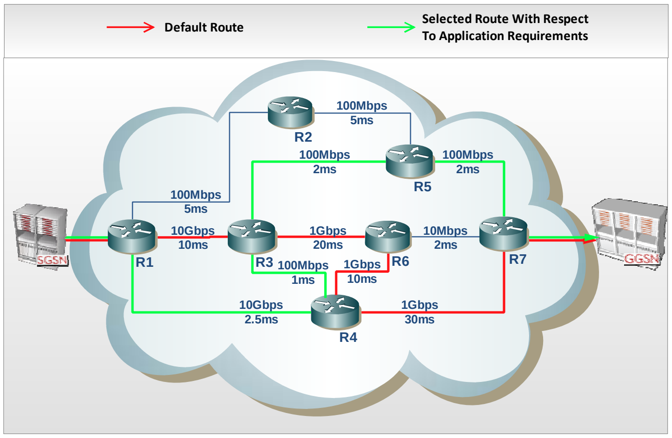

Figure 8. UMTS IP sub-network path selection

Sending the test application scheduled in Conversational Class by the native UMTS QoS support in the RAN domain, the path from router R1 to router R7 in the IP PS sub-network was selected via routers R3, R6 and R4, as illustrated in Figure 7. The path selection was based only on the use of OSPFv2 routing protocol. However, independently of the used routing protocol (e.g., Bellman Ford or RIP), simulation results indicates that there is no correlation between the application requirements and the network selected path. Therefore, the determined path remains the same in case of using default QoS support.

An autonomic network management QoS support should consider and accommodate both differentiated application requirements and dynamic network context. This mandatory integrated capability of the Future Internet (FI) network elements is implemented by means of network virtualization.

The objective of network virtualization process is to generate virtual networks and make each of these virtual networks appear to the user as a dedicated network infrastructure, with dedicated resources and services available for application requests. Therefore, the network virtualization process invokes a mode of selecting the virtual network that best integrates and satisfies the application requests at the physical network level.

It must be mentioned that for the generated virtual network, in our case, only the values of average end-to-end delay and jitter (as a consecutive delay difference) are considered as critical parameters for the source application.

Results of the simulations validate a virtual path from the router R1 to router R7 via routers R4, R3, and R5, a corresponding physical network infrastructure that offers best performances in terms of requested average end-to end delay and jitter.

Parametric results of the average end-to-end delay, the average jitter, and the average MOS, both for native UMTS QoS support and autonomic resource management QoS support in the IP PS domain, are summarized in Table VII.

TABLE VII. PARAMETRIC EVALUATION OF QOS/QOE SUPPORT

Selected path between ingress-egress nodes in UMTS PS domain	**Average end-to-end delay (s)**	**Average jitter (s)**	**Average MOS (score)**
Native QoS support in the UMTS radio access network			
R1 → R3 → → R6 → R4 → R7	0.109	0.022	3.186
Autonomic resource management based on network virtualization in UMTS IP PS domain			
R1 → R4 → → R3 → R5 → R7	0.045	0.022	3.264

As illustrated in Figure 9 and Figure 10, the UMTS IP PS domain decisively influences the applications performances in terms of average end-to-end delay, jitter and MOS.

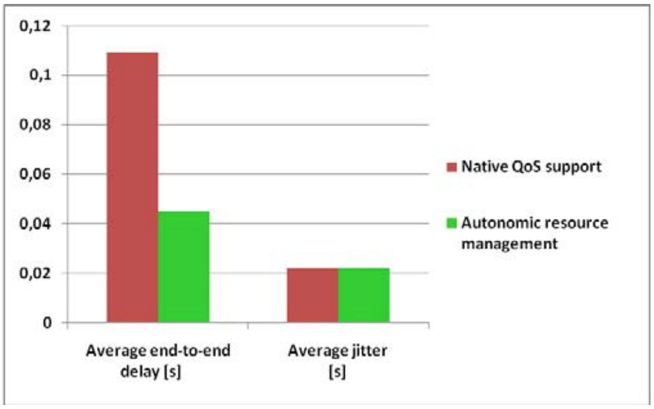

Figure 9. Comparative results of the average end-to-end delay and average jitter based on different path selection between ingress-egress nodes in the UMTS IP PS domain

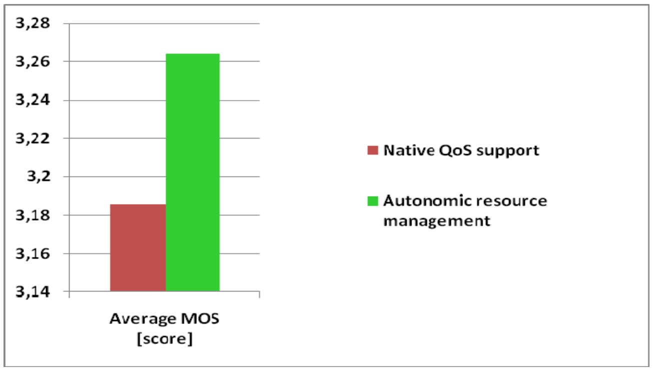

Figure 10. Comparative results of the aveage MOS based on different path selection between ingress-egress nodes in the UMTS IP PS domain

If the application requests are expressed in terms of a maximum accepted delay [26], the results illustrated in Figure 11 show that the autonomic resource management could satisfy these requests by offering an optimal path inside the UMTS IP PS domain.

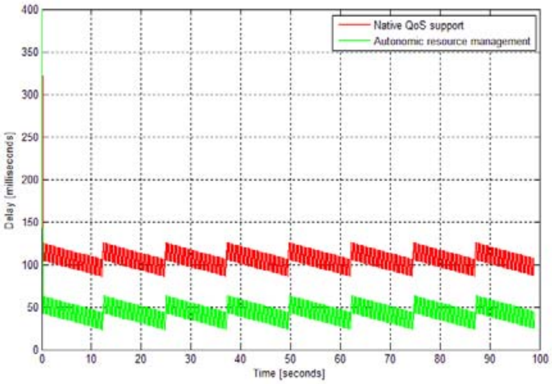

Figure 11. Delay variation over the simulation time based on different path selection between ingress-egress nodes in the UMTS IP PS domain

The QoE objective analysis based on MOS evaluation presented in Figure 12 shows that the user perception of the quality of the delivered service is enhanced by the use of an autonomic resource management support in the UMTS IP PS domain.

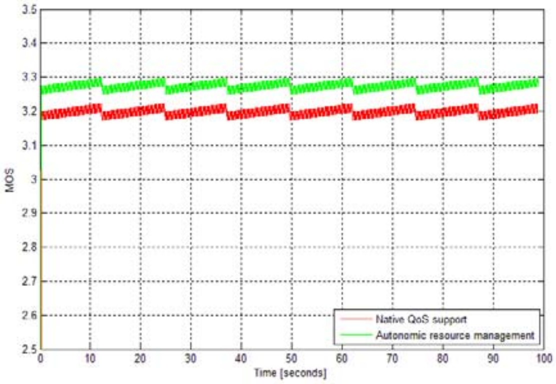

Figure 12. MOS variation over the simulation time based on different path selection between ingress-egress nodes in the UMTS IP PS domain

Therefore, simulation results support the perspective towards an autonomic resource management QoS support that makes the conjunction between the application's requests and the network context by choosing an alternate route in a virtualized environment.

The potential of the autonomic resource management is reflected by the capacity to identify an optimal path between the source node and the destination node, according to the imposed QoS constraints (for example, maximum accepted delay, minimum accepted packet loss, maximum accepted jitter or minimum requested throughput).

Some critical conditions or cost constrains could limit the resource optimization while using the native QoS support on the UMTS radio access network.

These situations request the adaptation of the source application parameters to the network available resources in order to still broadcast the information on the channel.

An implemented and tested solution (i.e., virtualization algorithm, virtualized parameters, in-network message flow, and source adaptation) for the network virtualization concept is offered in [27]. The conjunction between the source application requests and the network context is achieved through the QoS profiles message exchange and it represents the process of network virtualization.

As in [27], the paper assumes the network overflow by probing each UMTS IP PS network link. Nevertheless, the potential of the autonomic resource management is reflected by lower average end-to-end delay and lower jitter.

In order to impose the selected network elements on the virtual path, we used the Multiprotocol Label Switching (MPLS). As the proposed QoS support uses MPLS for route maintenance, it can be applied only in the UMTS IP PS network domain. Therefore, it cannot offer an end-to-end QoS support because RAN domain of the UMTS network does not have implemented the IP protocol.

VI. CONCLUSIONS AND FUTURE WORK

Considering a realistic UMTS RAN domain modeling, the paper aims to investigate the potential benefits that could reside from the integration of the autonomic resource management based on the virtualization process in current UMTS IP PS network domain architecture.

Based on an objective QoS/QoE performance analysis, the upper limit of native UMTS QoS support was analyzed, in a first stage, in terms of average end-to-end delay, average jitter and average MOS. The ability of the UMTS traffic classes to offer quality support for constant bit rate time critical applications was compared with the QoS support resulted from the usage of autonomic resource management.

The obtained results suggest that, since it is closer to the application needs and considering the network context, such an autonomic resource management could improve the native UMTS QoS support. Thus, the enhanced QoS/QoE support would overcome the situations in which the existent QoS mechanism would not even accept the service itself.

As a part of the further work, the authors intend to extend this solution also for the radio access part of the cellular networks. Moreover, future investigation will validate the simulation results through emulation on an experimental test-bet. This investigation will use the EXata emulation server (running the QualNet scenarios) and two operational hosts corresponding to the source and to the destination nodes (transmitting real-time traffic). In this way, a realistic experience of handling live traffic flows will be offered.

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