A QoE-aware IMS Infrastrusture for Multimedia Services

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***Abstract*— This paper presents the architecture and the experimental evaluation of a novel QoE-aware Mobile IPTV and VoIP infrastructure based on the IMS framework. The paper shows that the proposed management system (i.e. MCMS) provides efficiently QoE enhancement in the provision of mobile VoIP and IPTV services in case that network-related problems occur.**

Keywords-IMS; QoE; IPTV; VoIP; MCMS.

I. Introduction

The convergence of multimedia services with mobile/fixed networks and broadcast-interactive applications is creating new demands for high quality and user-responsive service provision management. To face the challenges of defining and developing the next generation of ubiquitous and converged network, together with the respective service infrastructures for communication, computing and media, the industry has launched various initiatives in order to design the reference network architecture and standardize the various modules/interfaces that are necessary for delivering the expected services, such as Voice over IP (VoIP) (e.g. voice/video call) and Internet Protocol TV (IPTV) (e.g. Live multicast IPTV or Video-on-demand).

However, this strong commercial interest may be hindered by the lack of efficient user-centric network management mechanisms, which will dynamically adapt/optimize network traffic policy to maximize perceived user satisfaction. One of the visions of future mobile communication networks is that services will be sold in a consumer mass market based on the provision of content that meets various perceptual quality requirements (e.g. video and/or voice quality). There are numerous approaches to this marketing model, but the most important is the Quality of Experience (QoE) concept because it provides a direct link to user-satisfaction. The QoE requirements for multimedia services and applications with differing bandwidth demands should provide the user with a wide range of potential quality choices, including for example cases of low, medium or high perceptual levels, and an indication of service availability and cost. However, existing IMS infrastructures do not provide any QoE-aware management mechanism within its service provision control system.

Given the need for QoE provisioning, it is expected that the success of new business opportunities and innovative multimedia services within the new convergent environment will be significantly based on novel user-centric network management solutions that employ cross-layer adaptive techniques in order to (a) compensate for network impairments (Network QoS - NQoS) according to the time varying conditions of the network delivery chain, (b) perform a content dependent optimization of the encoding and/or streaming parameters, and to (c) improve the end user experience/satisfaction by maximizing the delivered QoE level.

This paper proposes an innovative IMS-compatible Multimedia Content Management System (MCMS) [1] focused on performing a dynamic cross layer adaptation for the optimization of the user experience in terms of the delivered QoE level for IPTV and VoIP services– two of the most important multimedia services with the potential to create significant wealth for Europe. This multimodal management system makes use of the current IMS management functions by providing necessary perceptual awareness capability.

The proposed architecture has been built as a fully operational small-scale prototype in order to demonstrate the added value of MCMS in terms of both QoS and QoE enhancement. The rest of the paper is organized as follows: Section 2 presents the overall architecture. In Section 3 the small scale prototype evaluation is proposed, and finally Section 4 concludes the paper.

II. The Proposed QoE-aware IMS Architecture

A. *The Overall Architecture*

Figure 1 depicts the overall architecture, which comprises of:

- The MCMS Module [2], which is the main project entity and focuses on monitoring the network statistics (i.e. core, access, terminal), the service generation (i.e. Media Server Resource Function (MSRF), VoIP terminals) and the service perceptual level at the end-user terminal in order to define and apply an optimal cross layer adaptation action across the delivery network chain and media lifecycle (i.e. service generation node, core network, access network and end-user terminal) for maximizing the user satisfaction.

- The Multimedia Server and Resource Function (MSRF), which is an IMS-based MRF module with an additional fourfold responsibility:
  - The IPTV service generation, session management and service streaming.
  - The VoIP service session management and signaling.
  - The monitoring of the spatial and/or temporal content dynamics along with the selected encoding/streaming parameters

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- The adaptation, according to the MCMS commands, of the IPTV encoding parameters.

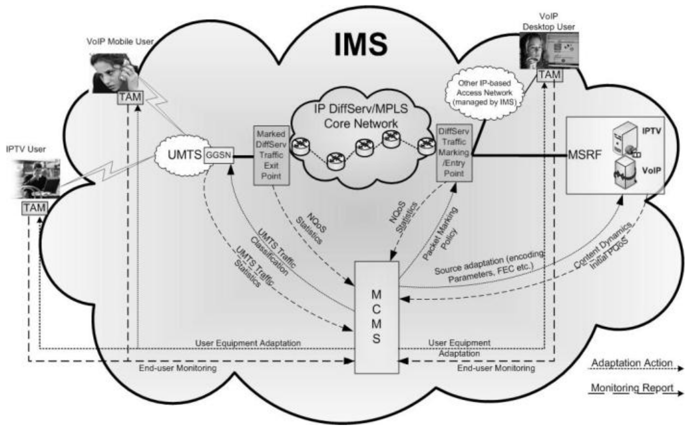

Figure 1. The overall proposed QoE-aware IMS architecture.

- An IP Core – DiffServ/MPLS Compatible Transport Network

In the proposed architecture it is considered a DiffServ/MPLS-enabled core network for the delivery of the requested multimedia service. IMS and MCMS compatible modules and interfaces are considered for the packet marking and traffic monitoring at the edges of the DiffServ/MPLS traffic network.

- The Access Network

At the access side a wireless access network is considered (e.g. UMTS), which provides service/bearer classification mechanisms for providing QoS constraints on the delivered service type (e.g. video, voice, data, etc).

- The Terminal Adaptation Module (TAM).

At the QoE-enabled user terminals (e.g. 3G mobile handset, SIP voice/video phone (hardphone or softphone), PDA) a TAM will be integrated, which enables the terminal's interaction with the appropriate interfaces/modules of the MCMS.

B. The proposed MCMS and NGN IMS interaction

According to Figure 2, the IMS Application Servers (AS) for IPTV and VoIP applications are hosted within the Media Resource Function (MRF), which executes IMS applications and services by manipulating SIP and SDP signaling for interfacing with other systems. The proposed architecture considers that MRF and AS modules are combined into a single entity, which will be called as Media Server Resource Function (MSRF). The MSRF, besides being a media server, provides mechanisms for bearer-related services such as conferencing or bearer transcoding, through a controller (MRFC) and a processor (MRFP) in compliance with the MCMS decisions.

The HSS (Home Subscriber Server) is the master user database that supports the IMS network entities that are actually exploited by the CSCF modules for handling the calls/sessions. The HSS contains the subscription-related information (user profiles), performs authentication and authorization of the user, and can provide information about the physical location of user.

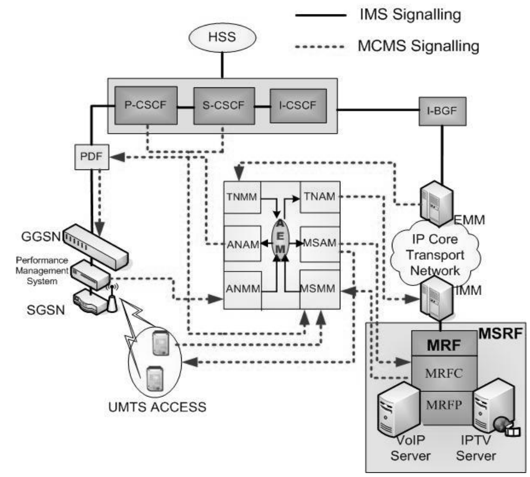

Figure 2. The proposed MCMS and NGN IMS interaction

The control layer of the IMS infrastructure consists of nodes for managing call establishment, management and release, which are called Call Session Control Functions (CSCF). The CSCF inspects each SIP/SDP message and determines if the signaling should visit one or more application servers en route to its final destination. In this multimodal management environment the MCMS modules comes to enhance the current IMS management capabilities by adding real-time dynamic cross layer adaptation procedures for providing end-to-end perceptual optimization and therefore maximization of the user experience.

The MCMS architecture is based on a central decision module, the Action Engine Module (AEM), responsible for taking optimal adaptation decisions based on the monitoring of network and perceptual statistics, gathered by IMS-based monitoring and adaptation modules. Afterwards, the AEM will process all the selected statistics and define a perceptually optimal cross layer adaptation action.

More specifically, for monitoring purposes the following modules are considered:

- Multimedia Service Monitoring Module (MSMM)

The MSMM performs monitoring of the service session through the P-CSCF and S-CSCF modules of the IMS. This is the only module of the MCMS that is activated when a service is requested; whilst all the rest remain in idle mode until the active adaptation procedure starts. Then, the MSMM, except from simply informing the MCMS for the liability of the service, monitors the QoE and CNR values at the end-user mobile terminal device, while at the service generation site, the content dynamics and the encoding parameters are also monitored through the TAM of the terminal device.

- Transport Network Monitoring Module (TNMM)

The TNMM module is used during the dynamic cross layer adaptation procedure for monitoring network statistics like packet loss, jitter, delay etc. at the DiffServ/MPLS core transport network. Towards this, the appropriate External

Marking Modules (EMM) interface will be developed and integrated at the egress edge router of the core transport network for enabling interaction and communication with the TNMM of the MCMS.

- Access Network Monitoring Module (ANMM)

The ANMM module monitors the UMTS access network statistics, based on the exploitation of historical data, which are updated in near real time by the UMTS performance management system at frequent time periods.

For adaptation purposes, MCMS considers the following modules, through which the optimal adaptation actions for QoE optimization are applied:

- Multimedia Service Adaptation Module (MSAM)

The MSAM performs adaptation actions at the end-user terminal device and at the service generation entity (i.e. the MSRF for IPTV services or the end-user terminal for VoIP applications) relative to the decoding (i.e. buffer scheme) and encoding (bit rate, packetization etc.) parameters, as well as FEC value adaptation towards enhancing the error resilience of the delivered service

- Transport Network Adaptation Module (TNAM)

The TNAM applies the adaptation actions to the DiffServ/MPLS-enabled core transport network through the Internal Marking Module (IMM), which will be developed and integrated at the ingress router of the core network. The IMM receives the adaptation actions from the TNAM and translate them to DiffServ/MPLS compatible commands, which are finally applied by marking appropriately the incoming traffic.

- Access Network Adaptation Module (ANAM)

The ANAM applies the adaptation actions, decided by the AEM of the MCMS, to the UMTS access network through the IMS PDF module. The PDF in turn applies them at the GGSN by performing service bearer classification in order to improve its QoS characteristics and therefore enhance the delivered QoE level.

C. The Specifications of the Proposed MCMS

The MCMS is the central entity of the proposed QoE-aware and user-centric IMS architecture that seamlessly communicates with the already existing IMS modules and interfaces. The MCMS interacts with each element in the service provision chain via real-time monitoring and adaptation/control mechanisms to achieve end-to-end Perceived Quality of Service (QoE) maximization. Thus, MCMS moves away from traditional NQoS-centric adaptation/management scheme and is able to achieve an end-to-end QoE optimisation based on a user/customer-centric approach. This provides an efficient solution/approach for future networked multimedia making it possible to maintain the quality of the media at every step of the media lifecycle from creation to consumption.

There are two functions associated between the MCMS and the TAM of the QoE-enabled user terminals:

- Adaptation function: according to the control command/parameters received from the MCMS, the QoE-enabled user terminal adapts on the fly its VoIP/Videocall codec, encoding bit rate or mode, aiming at end-to-end perceived quality improvement.
- Monitoring function: reporting delivered QoE (e.g. MOS score [3] for voice and video) and relevant terminal parameters (e.g. codec type, bit rate, encoding mode, packetization parameters) to the MCMS module. These parameters are obtained by the TAM interface, which is implemented in the terminal device.

The MCMS waits in an idle mode which changes to active as soon as the TAM triggers an Alarm event to the MSMM. A two alarm method is chosen for more flexibility in experimenting and minimizing the amount of data exchanged. The alarms considered are two: Warning Alarm and Red Alarm.

- **Warning alarm**

It is triggered through the TAM interface of the terminal when the PQoS degradation is below the first defined threshold with longer duration than a specified time. This prevents false alarm activations.

The alarm captured by the MSMM is delivered to the AEM, which in turn starts the monitoring stage, interrogating those monitoring modules whose QoS statistics are useful for selecting the adaptations if a red alarm is triggered. These modules are selected by an expert system depending on the rules used and the alarm data provided [4]. A possible example of a warning alarm reception is shown in Figure 3.

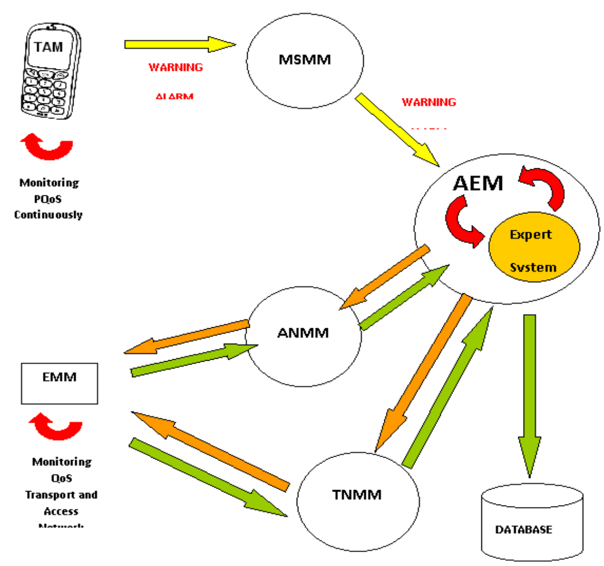

Figure 3. Example Reception Warning Alarm

In the case of Figure 3, the TAM is collecting continuously QoS session statistics in the terminal if the Perceived QoS (PQoS) or QoE is below the first defined perceptual threshold for enough time. The TAM sends a warning alarm to the MSMM which forwards it to the AEM. The AEM asks the Expert System for orders. The Expert System suggests asking the ANMM and the TNMM for monitoring data. Then the ANMM and the TNMM ask their respective EMM for monitoring data and forward it to the AEM which stores that monitoring data into the database.

In Figure 3, the yellow arrows symbolize the warning alarms sent by the TAM, while the orange arrows symbolize the monitoring data requests and the green arrows symbolize the monitoring data returned.

- **Red alarm**

It is triggered through the TAM interface of the terminal when the PQoS or QoE level at the user terminal decreases enough and gradually reaches the second defined perceptual threshold. Once the red alarm reaches the AEM, the previous stored data and the alarm data is evaluated by the Expert System and some adaptations are selected in order to improve the deteriorated Perceived QoS. An example of red alarm reception is shown in Figure 4.

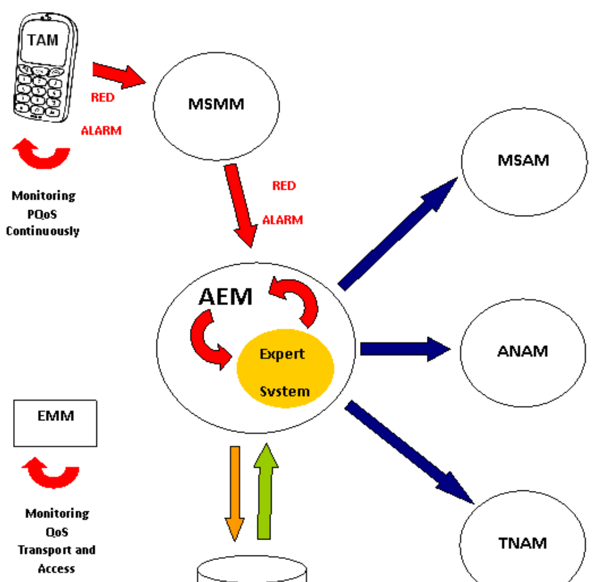

Figure 4. Example Reception Red Alarm

In the case of Figure 4, the TAM is collecting continuously QoS session statistics in the terminal if the PQoS is below the second defined threshold for enough time. The TAM sends a red alarm to the MSMM which forwards it to the AEM. The AEM asks the Expert System for orders. The Expert System suggests asking the database for the stored monitoring data. When the AEM gets the stored monitoring data it asks the Expert System for orders. Then the Expert System suggests ordering adaptations to the respective adaptation modules, ANAM, TNAM and/or MSAM.

In Figure 4, the red arrows symbolize the red alarms sent by TAM, while the orange arrow symbolizes the monitoring data requests, the green arrow symbolizes the monitoring data returned from database and the blue arrows symbolize the adaptation requests.

Once the MCMS has been switched to active mode because of a warning alarm or red alarm, the current QoS relative statistics across the network delivery chain (i.e. from the core and access network) are reported to the AEM via the ANMM and the TNMM modules. Also, reports from the encoder about the coding parameters, the content dynamics of the multimedia service, the current FEC scheme (if applied) and the decoding parameters at the terminal (i.e. buffer scheme) are reported to the AEM via the MSMM. If a VoIP session is considered, then the session monitoring takes place at both end-user terminals that participate in the session, where the voice is encoded and decoded at the sender and receiver terminal respectively. All the collected statistics are further exploited by the MCMS, through a sophisticated processing procedure and a decision algorithm.

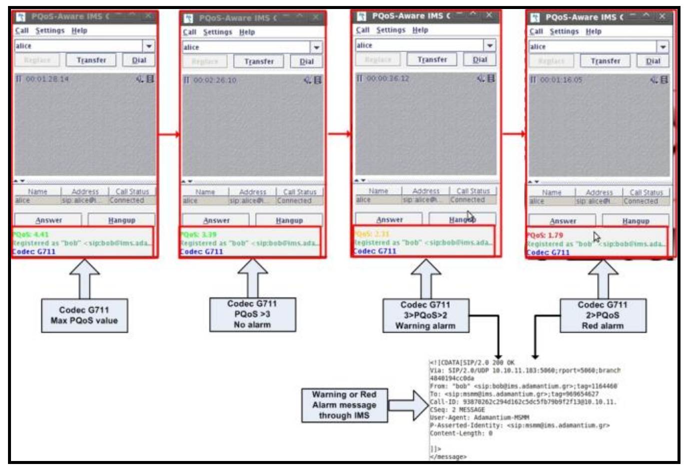

Figure 5. Warning or Red alarm steps on VoIP Service

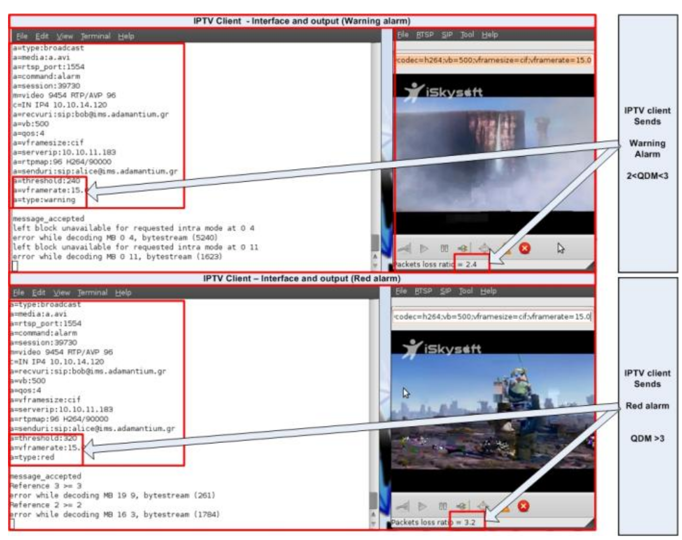

Figure 6. Warning or Red Alarm steps on IPTV Service

After the monitoring phase of the network statistics across the delivery chain has been completed, the adaptation phase is following. This is performed through the adaptation action modules of the MCMS (i.e. MSAM, TNAM and ANAM). Towards this, the AEM processes all the received statistics from the ANMM, the TNMM and the MSMM in order to define the adaptation actions across the network delivery chain, aiming at the optimization of the NQoS, which leads to maximization of the user satisfaction and the delivered PQoS level, without altering the total service traffic of the bearer.

The AEM, which has been implemented via Expert Systems, executes a sophisticated processing procedure and a decision algorithm, and it decides the appropriate actions and adaptations across the network delivery chain, in order to optimize the delivered PQoS. The AEM needs to have some intelligence to process the information coming from the different Monitoring Modules, and make decisions about the best way to improve the PQoS, sending instructions to the Adaptation Modules. As described above, input data is collected from the different monitoring modules, and it is used by the AEM to make some decisions to be sent as adaptation commands to the adaptations modules. In the following sections the input data coming from the different monitoring modules are listed. All the MCMS modules communicate with the AEM using a communication library which implements a tail of POSIX messages. This tail is created and destroyed by the MSMM and the rest of modules only use it.

D. *Definition of the RED alarm perceptual threshold*

The pre-defined perceptual threshold (RED ALARM) corresponds to the lowest acceptable perceived quality level and is dependent on the application/service type and has been also defined subjectively as follows:

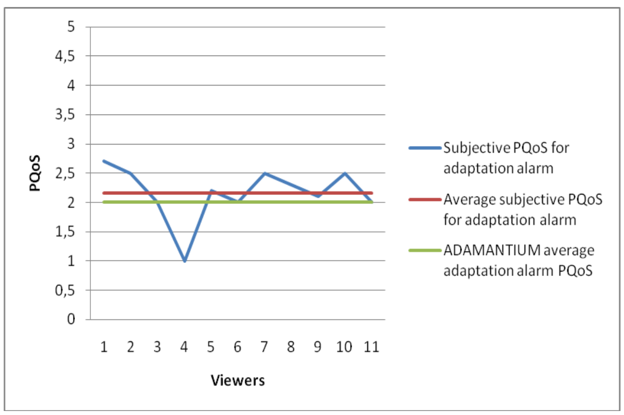

Figure 7. VoIP Perceptual Threshold subjective test results

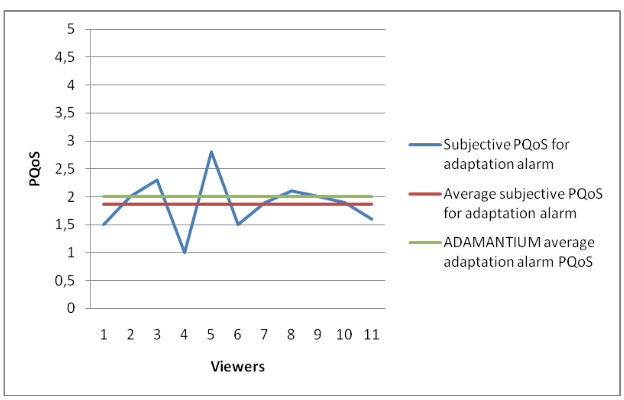

Figure 8. IPTV Perceptual Threshold subjective test results

Following the results of subjective tests (the framework of the subjective tests is provided in Section III), Figure 7 and Figure 8 presents the measurements per participant (i.e. blue line) and the respective average value (i.e. in red line) in comparison with the system Perceived QoS threshold (in green line) for VoIP and IPTV respectively. The viewers were asked to evaluate the level, below which quality of the service is unacceptable and the service should be immediately upgraded (adapted). As it can be observed, for both VoIP and IPTV, the perceptual threshold estimated at the value 2 in the MOS scale.

III. Small Scale Prototype Evaluation

This section summarizes the subjective evaluation actions that performed in order to evaluate the efficiency of the proposed MCMS fully functional small-scale prototype both on IPTV and VoIP services [3]. Each participant in the test was explained about the procedures, the testing scenarios that will be followed and the verbal marking that he/she should provide orally during the test. The scenarios under test were practically two: i) the VoIP service subjective test and ii) the IPTV service subjective test with MCMS system enabled and disabled respectively.

Figure 9. In-LAB testbed basic entities

Figure 10 describes the network topology of the small-scale prototype. The testbed (figure 9) consists of a Core (Transport) Network, the Access Networks, on which the Terminals are connected, the IMS network and the IMS Gateway, which offers communication among all the above mentioned networks and finally the MCMS entity.

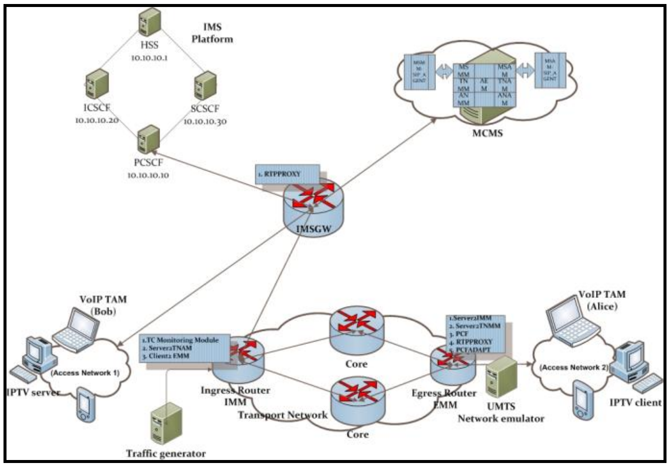

Figure 10. The small scale prototype topology

The subjective scale that was used for the benchmarking procedure is a modified version of the five values of the MOS scale, ranging from 1 to 5 according to Table 1, where in the verbal description of each MOS value, the term ‘annoying’ has been replaced with ‘unsatisfied’ in order to denote the efficiency of the MCMS system by the end-user side.

TABLE I. SUBJECTIVE SCALE

Scale Value	Verbal Description
1	Very Unsatisfied
2	Unsatisfied
3	Medium Satisfied
4	Satisfied
5	Very Satisfied

In this section we present the evaluation actions of the project that have been based on subjective procedures in order to demonstrate the efficiency of the proposed MCMS. During the subjective test, 11 users have been selected as a representative sample, whose each one’s expertise and relevance to the project area is different (marking from 1 to 5). The users were selected in order their average level of expertise to be around 2.5 in the fifth scale in order to receive a balanced result. More specifically, the average level of expertise for the participants has been calculated to be 2.64.

The above users were invited via email and each one of them, accompanied by a technician, entered the room of the prototype platform and seated in front of a terminal device. Then the participant was explained about the procedures of the subjective test, the testing scenarios that will be followed and the verbal marking that he/she should provide orally during the test. The scenarios under test were practically two: i) the VoIP service subjective test and ii) the IPTV service subjective test. The scope of both the tests is to benchmark how the proposed system enhances the delivered QoE level of the requested media service, when packet losses or network congestion occur.

A. VoIP service subjective tests

This subsection summarizes the subjective tests that performed for the VoIP service [6]. The test is performed in two phases:

- With MCMS disabled, where the user is asked to state when he/she feels that the QoE alarm should be initiated and
- With MCMS enabled, where the user is again asked to evaluate his/her satisfaction by the requested service under various network congestion conditions

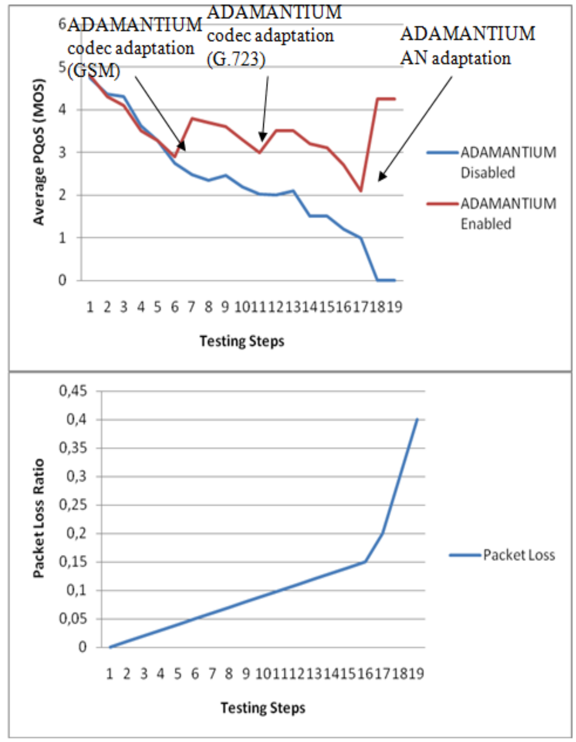

Figure 11. Subjective benchmarking for VoIP service

Both scenarios are performed while at the Access Network, specific packet loss ratio is introduced. The results of this subjective evaluation and benchmarking of MCMS system are graphically presented on Figure 11 in relation with the packet loss steps under which the experiment was performed. From the specific figure, the following outcomes are derived:

- MCMS system maintain the perceptual level of the VoIP service at significantly higher levels even under severe network conditions
- The average perceptual added-value that the use of MCMS system introduces is >1 unit (of the MOS scale) for packet loss values up to 15%
- For severe network congestions (i.e. >20% packet loss rate), MCMS system reassures the viability of the service session, while without MCMS the service will have been interrupted (this denotes the zero MOS value in the experiment).

- For severe network congestions (i.e. >20% packet loss rate), MCMS system manages to maintain the perceptual quality level of the active service session at very high MOS level (i.e. >4).
- MCMS system managed to maintain the perceptual quality level during all the duration of the session above 2 in the MOS scale.

B. *IPTV service subjective tests*

This subsection summarizes the subjective tests that performed for the IPTV service [6]. The test is performed in two phases:

- With MCMS disabled, where the user is asked to state when he/she feels that the QoE alarm should be initiated and
- With MCMS enabled, where the user is asked to evaluate its satisfaction by the requested service under various network congestion conditions

Both scenarios are performed while at the Access Network specific packet loss ratio is introduced.

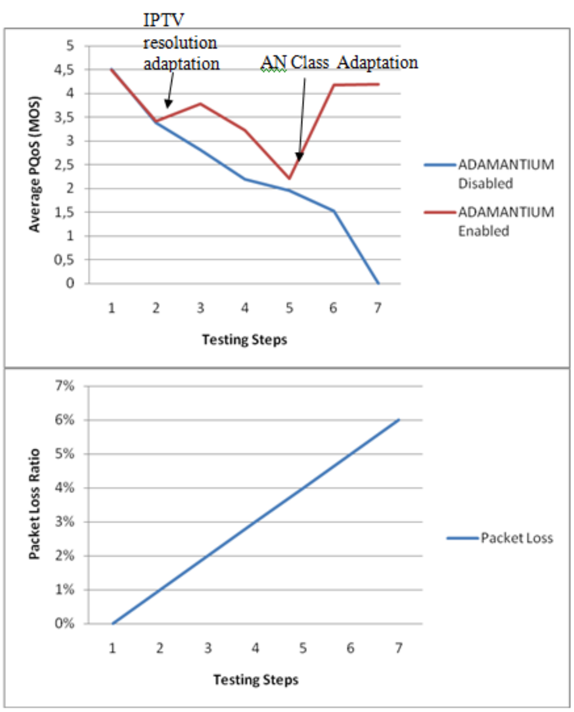

Figure 12. Subjective benchmarking for IPTV service

The results of this subjective evaluation and benchmarking of MCMS system are graphically presented on Figure 12 in relation with the packet loss steps under which the experiment was performed. From the specific figure, the following outcomes are derived:

- MCMS system maintains the perceptual level of the IPTV service at significantly higher levels even under severe network conditions
- The average perceptual added-value that the use of MCMS system introduces is approximately 1 unit (of the MOS scale) for packet loss values up to 5%
- For severe network congestions (i.e. >5% packet loss rate), MCMS system reassures the viability of the service session, while without MCMS the service will have been interrupted (this denotes the zero MOS value in the experiment).
- For severe network congestions (i.e. >6% packet loss rate), MCMS system manages to maintain the perceptual quality level of the active service session at very high MOS level (i.e. >4).
- MCMS system managed to maintain the perceptual quality level during all the duration of the session above 2 in the MOS scale.

IV. CONCLUSIONS

This paper has presented the trial and evaluation process of the proposed IMS architecture. More specifically, subjective benchmarking actions have been performed for VoIP and IPTV services, showing the efficiency of the proposed MCMS system.

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