Application-Level QoS Negotiation and Signaling for Advanced Multimedia Services in the IMS

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ABSTRACT

The IP multimedia subsystem (IMS) has been recognized as a reference next-generation network architecture for offering multimedia services over an Internet Protocol (IP)-based infrastructure. One of the key benefits of the IMS is efficient and flexible introduction of new services and access to third-party application providers, thanks to standard interfaces and standardized service capabilities. To support novel media-rich applications across a wide range of user devices and access networks, IMS must support negotiable quality of service (QoS) for IP multimedia sessions. In this article, we describe the application-level QoS signaling as specified by the 3GPP and propose some enhancements based on advanced QoS parameter matching and optimization functionality to be included along the signaling path. We outline various signaling flow scenarios and discuss them in the context of a case study involving an IMS-supported 3D virtual environment, featuring a treasure-hunt-like game.

INTRODUCTION

In the move to an all-IP network architecture, the IP multimedia subsystem (IMS) has been recognized as the key element for providing ubiquitous access to IP multimedia services in a universal mobile telecommunications system (UMTS) and future fixed-mobile converged networks [1]. Initially specified by the Third Generation Partnership Project (3GPP) and now embraced by other standards bodies, including the European Telecommunications Standards Institute (ETSI), IMS has been defined as a multimedia session-control subsystem based on a horizontally-layered architecture and encompassing core network elements for the provision of multimedia services [2]. Although each service comes with a unique set of requirements for network performance, end users expect services to work seamlessly across a wide range of user devices and access networks. As opposed to the currently available best-effort service on the Internet, IMS provides quality of service (QoS) mechanisms aimed at offering users predictable and enhanced service quality.

For the IMS operator, the goal of QoS negotiation is to determine the best service configuration and network resources allocation that would maximize user-perceived service quality. Reaching this goal involves end-to-end (E2E) application-level QoS negotiation and signaling via IMS network entities. The IMS procedures for negotiating multimedia session characteristics are specified by the 3GPP and are based on Internet Engineering Task Force (IETF) Session Initiation Protocol (SIP) [3], Session Description Protocol (SDP) [4], and their extensions as required.

As future IMS services are expected to increasingly include media-rich applications, customized to meet user preferences and capabilities, the networks will face complex and dynamically-changing QoS requirements. Although existing 3GPP specifications describe procedures for QoS negotiation and signaling for multimedia applications — such as audio/video communication and multimedia messaging — the support for more advanced services, involving interactive applications with diverse and interdependent media components, is not addressed specifically and presents an open area for research [5, 6]. Examples of such applications, likely to be offered by third-party application providers and not by the IMS operator, include collaborative virtual environments, smart home applications, networked games, and innovative applications such as interactive story-telling.

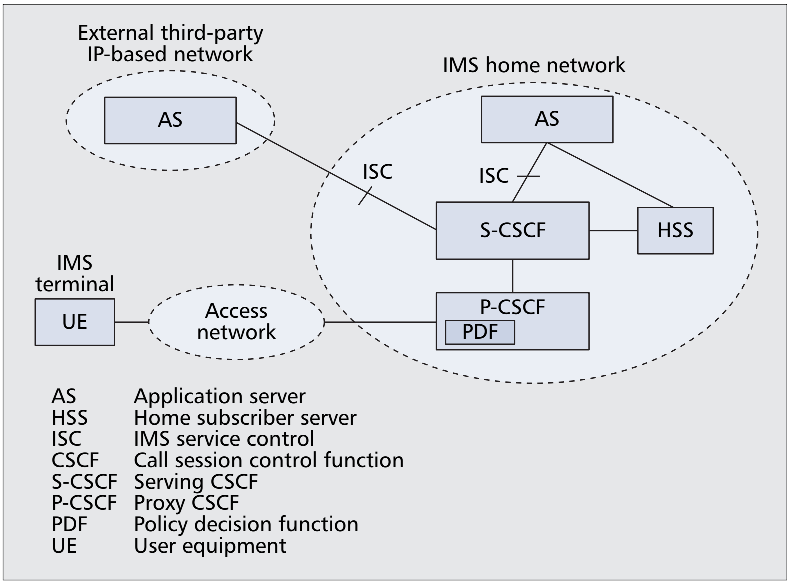
This article deals with application-level QoS negotiation and signaling in the IMS. After presenting the mechanisms currently specified by the 3GPP in the first part of the article, in the second part we discuss the need for more enhanced mechanisms (beyond those currently specified) to meet the demands of future advanced IP multimedia services to be supported by IMS. We also present one possible solution, based on introducing a new SIP application server (AS) within the IMS domain, to provide advanced QoS parameter matching and optimization (QMO) functionality within the QoS negotiation process. In addition to providing better service to users, introducing enhanced QoS support in the network as a generic-reusable service capability would benefit both the IMS operator and third-party service providers. The IMS operator would have additional means to control, differentiate, and appropriately charge the QoS that a particular user receives for a given multimedia session. The service provider would be required to specify a service profile that states service requirements and options, and would further be relieved from implementing complex QoS decision-making functionality for each new service being introduced, hence leading to simplified provisioning and quicker time-to-market for new services requiring such mechanisms. We outline various signaling flow scenarios and discuss them in the context of a case study involving an IMS-supported 3D virtual environment, featuring a treasure-hunt-like game. Assuming that the game is hosted by a third-party AS and that the advanced QoS negotiation is supported by the QMO AS, owned by the IMS operator, we identified events occurring during the gaming session that lead to the need for QoS (re)negotiation and adaptation of QoS parameters. We present and discuss corresponding SIP signaling flows and summarize the advantages of the proposed approach.

The article is organized as follows. The multimedia session QoS negotiation in IMS is described first. Next, we discuss the high-level requirements for enhanced QoS negotiation for more advanced multimedia applications and the mechanisms to meet these requirements. Possible enhancements to QoS negotiation in the IMS are presented. Signaling for a case study involving an IMS-supported virtual-environment game is described. We conclude the article with a discussion of the benefits that result from enhancing the IMS service provision with generic QMO functionality and present open issues for future research.

APPLICATION-LEVEL QoS NEGOTIATION IN IMS

The IMS procedures for negotiating multimedia session characteristics between session end points are specified by 3GPP, with basic flow diagrams and session handling described in [2, 7], and extensive descriptions of the contents of signaling flows, based on SIP/SDP in [8]. The procedures include determining the initial media characteristics for a session, modification of an already-established session by adding/removing a media flow, changing media characteristics, and changing bandwidth requirements.

The entities involved in IMS session establishment are shown in the simplified IMS architecture in Fig. 1. The IMS session endpoint may be either an IMS terminal, referred to as user equipment (UE), or an AS, an entity that hosts and executes IMS services. Examples of AS already deployed by IMS operators include push-to-talk over cellular (PoC), presence, messaging, and shared whiteboard AS. As shown in the figure, an AS can be located in the home network, as well as in an external third-party IP-based network.



■ **Figure 1.** *A simplified view of the IMS architecture.*

The general procedure for IMS session establishment begins with a UE obtaining access to IMS through an access network. The next steps involve allocation of a proxy call session control function (P-CSCF) to serve as an outbound/inbound SIP proxy and for SIP application-level registration to the IMS network. The P-CSCF may be located in either the home network, as shown in Fig. 1, or in the visited network. The P-CSCF also interfaces with a policy decision function (PDF) that authorizes the use of bearer and QoS resources for IMS services within the access network. The IMS node responsible for session establishment, modification, and release is the serving-CSCF (S-CSCF) located in the user's home network and acting as a SIP server. All SIP signaling to and from the UE traverses the allocated S-CSCF. The S-CSCF interrogates the home subscriber server (HSS) to access user-profile information, fetch subscription data, and for authentication, authorization, and accounting purposes. Additionally, the S-CSCF plays an important role in service provision by invoking one or more AS(s).

The signaling between IMS entities for the IP multimedia session is shown in Fig. 2. The session end points in this example are UE and AS. (The IMS registration procedure and interaction with the HSS are assumed but not shown.) The session negotiation procedure is based on the SDP offer/answer model [9], which provides a mechanism for entities to use SDP to arrive at a common view of a multimedia session between them (e.g., media components, codecs, IP addresses, and ports that will be used). The model involves one entity offering the other a description of desired session parameters, and the other entity answering with the desired session parameters from its perspective. A number of recent extensions for SIP and SDP — specified within the IETF working groups — SIP,

With the transition to media-rich services, the relationship between the application and the network aspects of communication also becomes more complex. Starting from the basic application-level QoS negotiation procedure, we argue that additional mechanisms are required for media-rich services QoS negotiation.

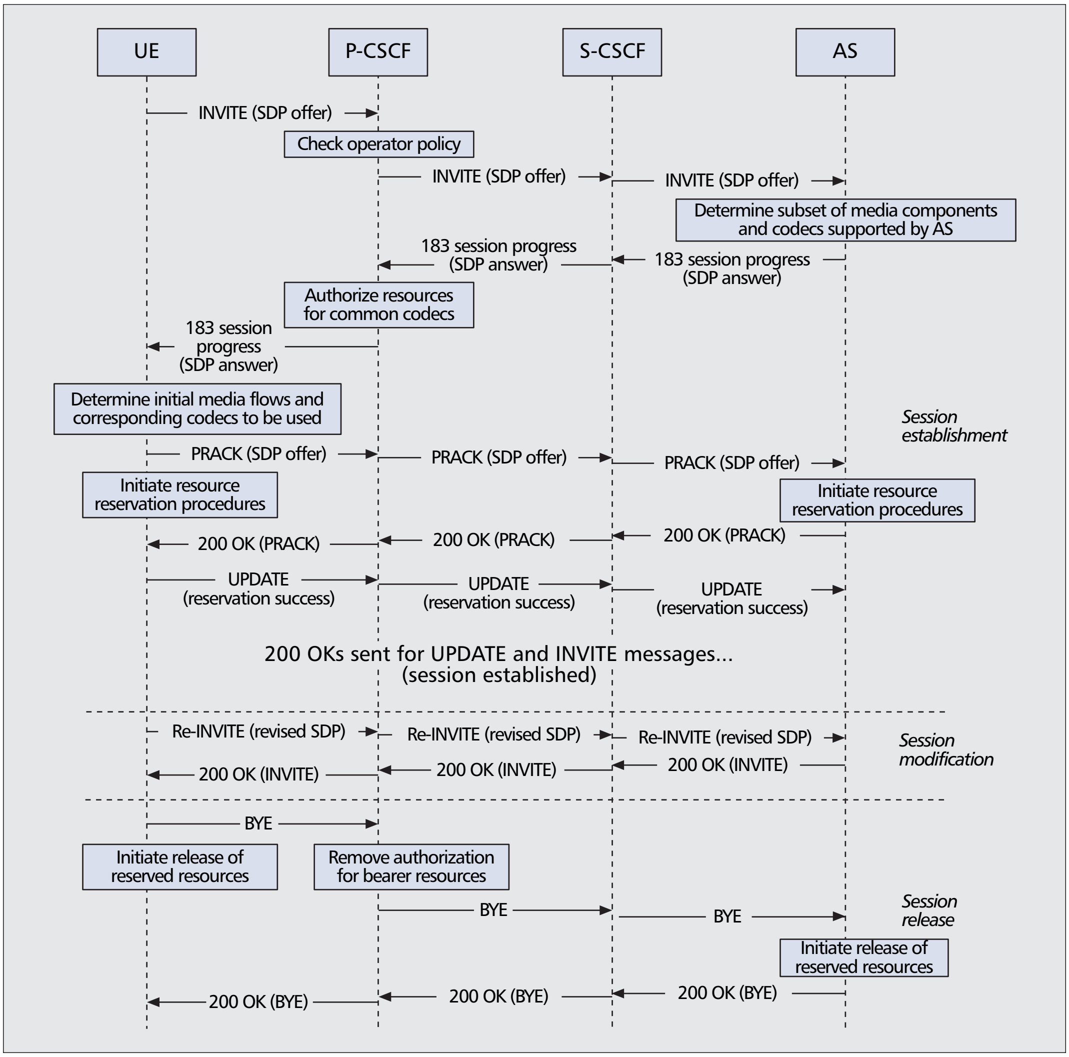


Figure 2. *Signaling for a basic IP multimedia session in IMS.*

SIPPING, and MMUSIC, allow additional ways of specifying user preferences, as well as identifying media components within multimedia sessions.

The client applications are usually designed in such a way as to come with predefined parameters and a simple to use, user-friendly interface for negotiable parameters. Possible parameters to be negotiated include type, quality, and encoding of media, terminal capabilities to be used, and desired QoS per media stream (e.g., guaranteed QoS or best effort). A typical scenario involves a user sending an offer via his UE to an AS (or other UE) indicating support for a number of codecs, the AS (other UE) responding with a subset of supported codecs, P-CSCF entities authorizing resources for common codecs, and the user making a final media and codec selection.

HIGH-LEVEL REQUIREMENTS FOR ENHANCED QoS NEGOTIATION

With the transition to media-rich services, the relationship between the application and the network aspects of communication also becomes more complex [10]. Starting from the basic application-level QoS negotiation procedure described previously, we argue that additional mechanisms (beyond those currently specified) are required for media-rich services QoS negotiation.

The first issue is related to user preferences in terms of multimedia parameters and relative importance of IP multimedia application components. For example, if a user specifies maximum bandwidth availability (constrained by terminal, access network, cost, etc.), then standards do not specify how to optimally distribute bandwidth across different media components comprising the service, with the aim of achieving maximum user perceived quality. A situation that illustrates this case could be a user playing a networked game that consists of the 3D virtual world and optional text and/or audio chat with other players. In this particular game, the timing constraints for displaying and interaction with the virtual world may be the most *relevant*, with audio coming as second, and text chat as third in terms of relevance.

The second issue is related to network constraints. For multimedia applications, there is a need to negotiate and specify the way in which a service will adapt to dynamic changes in the network occurring during the service execution. For example, if the available bandwidth is unexpectedly reduced (e.g., on a wireless link), the decision on how to gracefully degrade the service or which media component to drop if necessary, would probably be user-dependent, as well as application-dependent. However, for the particular user and application, this choice may be pretty straightforward — in our previous example, the desired action may be to drop audio chat or switch to text-based chat instead and try to maintain the maximum achievable frame rate.

The third issue is related to service requirements. For example, the service provider may design the application in several customized versions (similar to Web as high-end and Wireless Application Protocol (WAP) pages as low-end information services). To use the previous example, the networked game may be offered in two versions: a default version with attractive graphics and a low-cost version, which is suitable for users accessing the game server via dialup modem connection. Assuming that during play, the user's prepaid card budget is getting low, he or she may want to switch to a low-cost (lower-quality) version of the game in order to continue playing. This event may be considered a trigger leading to QoS renegotiation and service adaptation. A key matter is relating user/service requirements and transport QoS parameters. Furthermore, service requirements may change dynamically during the course of a service lifetime (e.g., with the addition/removal of media flows), again calling for renegotiation and adaptation mechanisms.

Missing in current standards is a technique that covers all identified issues in a comprehensive manner. Mechanisms are required to provide a more advanced decision-making process based on matching restrictive user parameters, service requirements, and network constraints with the goal of achieving maximum user-perceived service quality. To this extent, our contribution is a model for dynamic negotiation and adaptation of QoS [11], which uses generic client and service profiles as a basis. A *client profile* specifies user terminal and access network constraints and application related preferences such as media components. A *service profile* may specify different supported configurations (versions) of the service (e.g., differing in media components, codecs, display size, or processing requirements) to address the issues related to heterogeneity stemming from diverse end-user capabilities and preferences. The service profile also may specify adaptation policy or the actions to take in adapting the service to changing network conditions (e.g., switch from codec C1 to codec C2 when a certain bandwidth threshold is reached). The profiles, together with network constraints, are jointly considered for session QoS (re)negotiation. A detailed explanation of the QoS negotiation process, generic client/service profiles, and matching and optimization algorithms may be found in [11]. Related work on matching and coordinating QoS parameters for multimedia applications can be found in [5], proposing an End-to-End Negotiation Protocol for the active negotiation of *QoS contracts* (service configurations) between users.

PROCEDURE FOR SESSION NEGOTIATION/RENEGOTIATION

The purpose of E2E QoS negotiation is to determine the final service operating point, based on matching the specified user, service, and network parameters. The service operating point refers to the final service configuration to be delivered to the user. We propose the steps involved in a QoS negotiation procedure in Fig. 3. This rather generic procedure is discussed later in terms of possible mapping onto IMS and in the context of a user accessing a service hosted by an AS.

Inputs to the negotiation procedure include client profile, service profile, and network constraints. Upon a user's request for a particular service, the client application sends a service request, accompanied by the client profile. The client profile may be stored locally (in UE), or referenced in an external repository of client profiles (for example, HSS in IMS). A service profile may be retrieved from the AS hosting the service or from an external repository. As shown in Fig. 3, specified parameters serve as input to a matching process (I). The matching process serves to select zero or more *feasible service configurations* as determined by the input parameters. A service configuration is considered feasible when all the following conditions are met:

- The user's terminal capabilities can support the service processing requirements.
- The user's access network can support the minimum requirements for all (required) media objects.
- The user's preferences in terms of acceptable cost, media components, and timing constraints can be met.

The matching process is followed by a negotiation process (II). The offered set of potential session parameters from feasible service configurations is returned to the user. The user may then accept or refuse the (subset of) offered parameters. Then, network entities authorize resources based on the agreed parameters. The authorization includes limits on data rates and traffic classes for uplink/downlink flows and is based on QoS policy and admission control mechanisms in the network.

Based on negotiated and authorized session parameters, feasible service configurations are ordered according to achievable user-perceived quality into a so-called *degradation path*, from the highest to the lowest quality configuration. Establishment of a degradation path is determined by user preferences (e.g., a user considers audio to be more valuable than video). This is used when service degradation or upgrading is necessary. The service profile corresponding to the highest quality feasible configuration is passed to the optimization process (III).

The goal of the optimization process is to calculate the *optimal service operating point* and respective resource allocation across all media flows comprising a multimedia service according to established objective. The optimization objective may be formulated dynamically, for example, based on user preferences indicating that a user wishes to achieve maximum possible service quality, minimum cost while maintaining accept-

Based on negotiated and authorized session parameters, feasible service configurations are ordered according to achievable user-perceived quality into a so called degradation path, from the highest to the lowest quality configuration.

What is important to note is that triggers coming from the application are related to the semantics of the application and can thus be taken into account during the application design. In this way, the application-level adaptation also may be performed to improve the user-perceived quality.

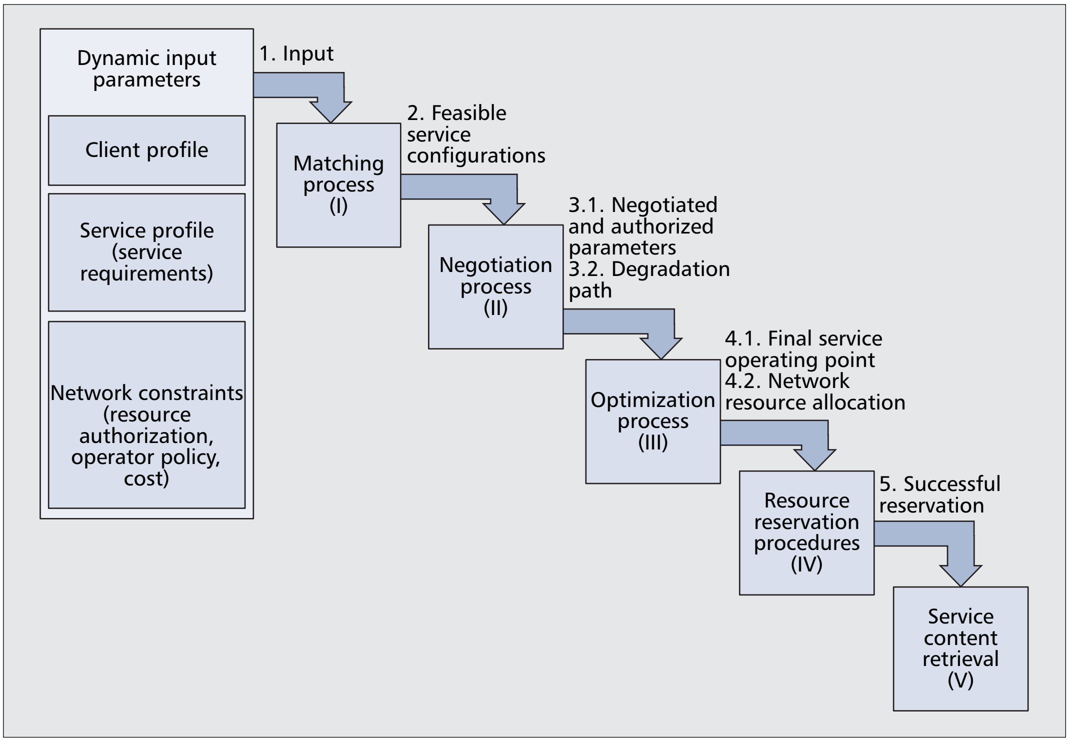


Figure 3. *Generic QoS negotiation procedure.*

able service quality, or the best value for money service. This article does not aim to further specify the actual optimization problem formulation and algorithm(s) to be used, as this decision may be left to the operator. A possible solution was presented in our previous work [12], where the objective of maximizing service quality is formulated as a linear combination of media flow utility functions (relating user perceived service value and allocated network resources per flow) multiplied by weight factors (indicating relative media flow importance based on user preferences).

After the calculation is completed, the network resource reservation procedures (IV) are invoked. If successful, customized multimedia content is retrieved from the AS and delivered to the user (V).

The previously described cycle may be repeated at any time during service execution, in response to a significant change in relevant factor(s) that affect service feasibility. For scalability and performance reasons, it is clearly not realistic, nor desired, to assume re-calculation of the optimal operating point at every change. Instead, thresholds may be established indicating events that trigger modifications considered *significant enough* for re-calculation and subsequently leading to QoS renegotiation. Such triggers may come both from the network (e.g., degraded wireless link), or from the multimedia application (e.g., a user's action within the networked game). What is important to note is that triggers coming from the application are related to the *semantics* of the application and can thus be taken into account during the application design. In this way, the application-level adaptation (e.g., multimedia stream buffering) also may be performed to improve the user-perceived quality.

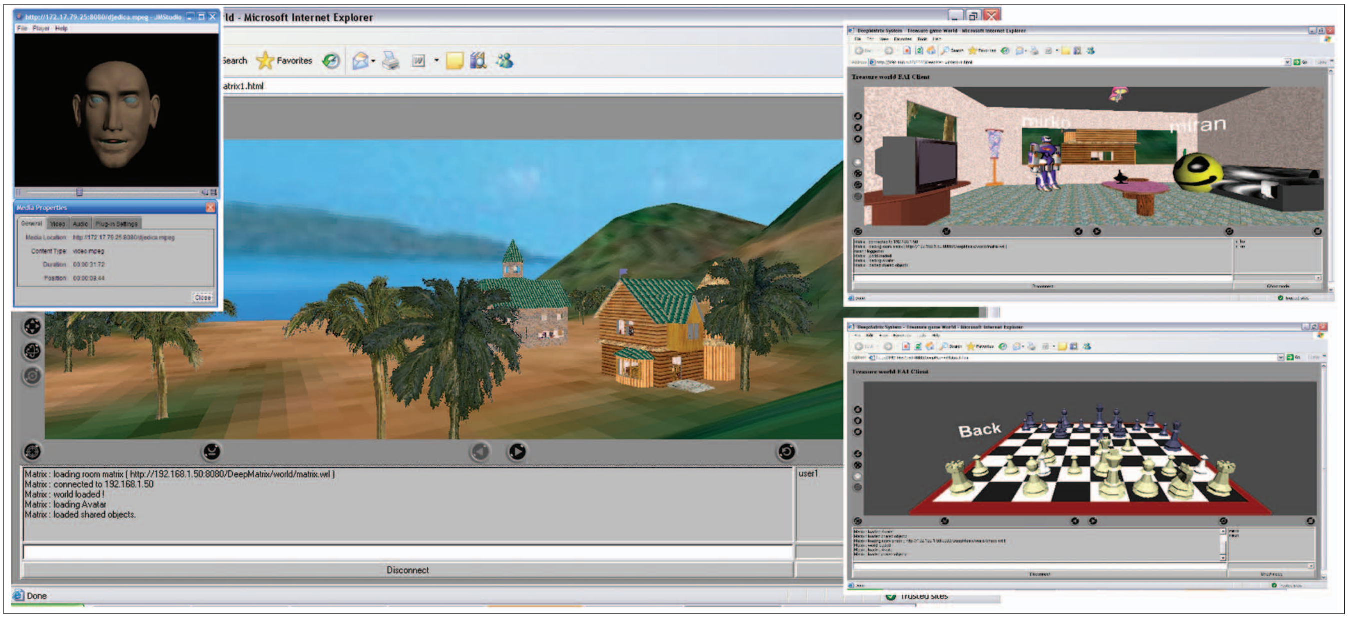
POSSIBLE ENHANCEMENTS TO IP MULTIMEDIA SUBSYSTEM

Considering the QoS negotiation requirements of advanced multimedia services described in the previous section, we now focus on issues related to meeting such requirements in the IMS. Rather than standardizing IMS services, 3GPP specifies an architecture enabling services to use standardized service building blocks, offered as common IMS functions and service enablers. The leading industry forum providing specifications for market-driven service enablers (presence, group list management, location, etc.) is the Open Mobile Alliance (OMA).

Our proposed enhancement relates to scenarios in which an advanced IP multimedia service is hosted by an external AS, and is thus not subject to standardization as such, but which makes use of common IMS enablers. This approach is similar to Parlay/OSA principles for making common network capabilities available via standardized interfaces. We propose to integrate described QMO functionality and add it in the form of a *QMO AS*, along the IMS service-control (ISC) interface within the IMS domain. As such, the QMO AS would be considered a reusable service building block offered by the IMS network, relieving third-party service providers of implementing complex QMO procedures.

With the specification of generic client and service profiles, the implementation of QMO functions is independent of the actual service content. As with every other AS, the decision whether or not to involve the QMO AS for a particular service would be made by the S-CSCF.

With respect to the currently standardized



Media Location: http://172.17.79.25:8080/djedica.mpeg
Content Type: video.mpeg
Duration: 00:00:31.72
Position: 00:00:08.44

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Matrix : loading room matrix ( http://192.168.1.50:8080/DeepMatrix/world/matrix.wrl )
Matrix : connected to 192.168.1.50
Matrix : world loaded !
Matrix : loading Avatar
Matrix : loaded shared objects.
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Figure 4. *Snapshots of the* Inheritance Chase *game.*

application-level signaling for QoS negotiation in the IMS, the approach presented in this work offers the following benefits:

- The service delivered to the end user is customized to optimally meet user terminal/network capabilities, media preferences, and budget constraints.
- Various dynamic QoS parameter adaptation scenarios are supported based on triggers received by the QMO AS from session end points and the underlying network.
- With the specification of standard client and service profiles and the introduction of a generic QMO function, new services deployed within the IMS can inherit this functionality and include advanced QoS negotiation and optimization support.
- Having additional knowledge about IP multimedia application components offers another mechanism for routing application requests and selecting between multiple AS.

CASE STUDY: QOS SIGNALING FOR A VIRTUAL ENVIRONMENT

A case study is presented to illustrate the inclusion of a QMO AS along the signaling path. The case study uses a Web-based multimedia application hosted by a third-party end-point AS. The prototype application, called *Inheritance Chase*, is a multi-user 3D virtual environment featuring an interactive adventure game in which users are given a series of clues to direct them to a hidden last will left by a deceased relative that is the key to the relative's treasure. The clues are to be found in the form of streamed audio and video clips (using the Java Media Framework API), activated by the user's actions or in some cases by proximity to objects. The world is divided into two 3D scenes, implemented in virtual reality modeling language (VRML): an island world and a large chessboard related to one of the clues (Fig. 4). All players are represented with human-like 3D virtual characters.

Implementation of the end-point AS that hosts this service includes SIP-signaling functionality for session control and multimedia content-handling functionality. Both were developed for the purpose of this application that runs on a common service platform (Web server). The game has three service versions that differ in multimedia components and quality thereof, as follows:

- Version 1: textured 3D graphics objects with high quality audio-and-video streaming
- Version 2: textured 3D graphics objects with low quality audio-and-video streaming
- Version 3: textured 3D graphics objects with low quality audio-only streaming

The particular service version to be delivered to a user is determined by the QoS negotiation process.

QOS NEGOTIATION AND ADAPTATION SCENARIOS

Various events, or triggers, dynamically occurring during the game can lead to the invocation of QoS (re)negotiation and adaptation procedures. We identified five such events to illustrate the procedures and to analyze corresponding IMS signaling flows.

- Event 1: Session establishment is invoked by an end user. This involves UE registration to the IMS network, negotiation of initial service parameters, and service retrieval (3D scene download). Network resources are authorized and reserved.
- Event 2: Scene download is completed and an indication is sent to the network to free the resources reserved for download.
- Event 3: A change in service requirements is caused by the user initiating an audio and/or a video stream. Stream parameters are negotiated and corresponding network resources are authorized and reserved.
- Event 4: A change in the client profile is caused by a change in user preferences (e.g., the user has chosen to switch to a low

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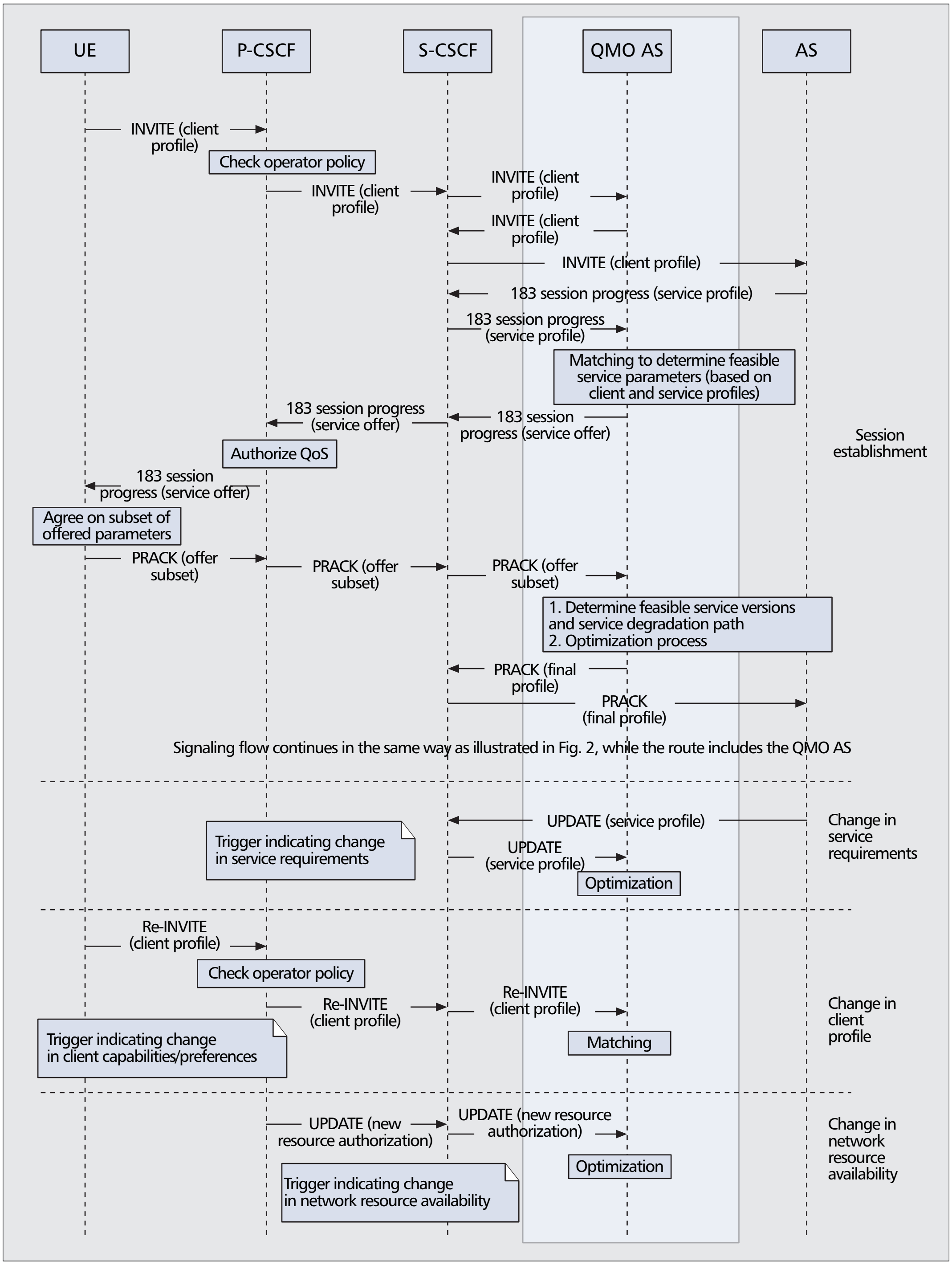

Figure 5. *SIP signaling in the case study.*

cost session). This leads to the renegotiation and adaptation of service parameters and reserved network resources.

- Event 5: A change in network resource availability is detected by the network, leading to renegotiation and adaptation procedures.

END-TO-END SESSION SIGNALING FLOWS IN THE IMS

The diagram in Fig. 5 shows the SIP signaling in the case study; however, signaling related to network resource authorization and reservation is omitted for simplification purposes. SIP messages specify session parameters and client/service profiles by using the XML-based SDP-next-generation (SDPng).

Initial session establishment signaling (Event 1) includes negotiation of session parameters that will/may be active throughout the session. Consequently, at initiation, a user can agree to certain parameters that may not be active at the start of the session, but may be relevant later (e.g., a user joins a gaming session that later will involve audio/video streaming). The benefit is that renegotiation time and signaling traffic are reduced (when dynamic changes occur during

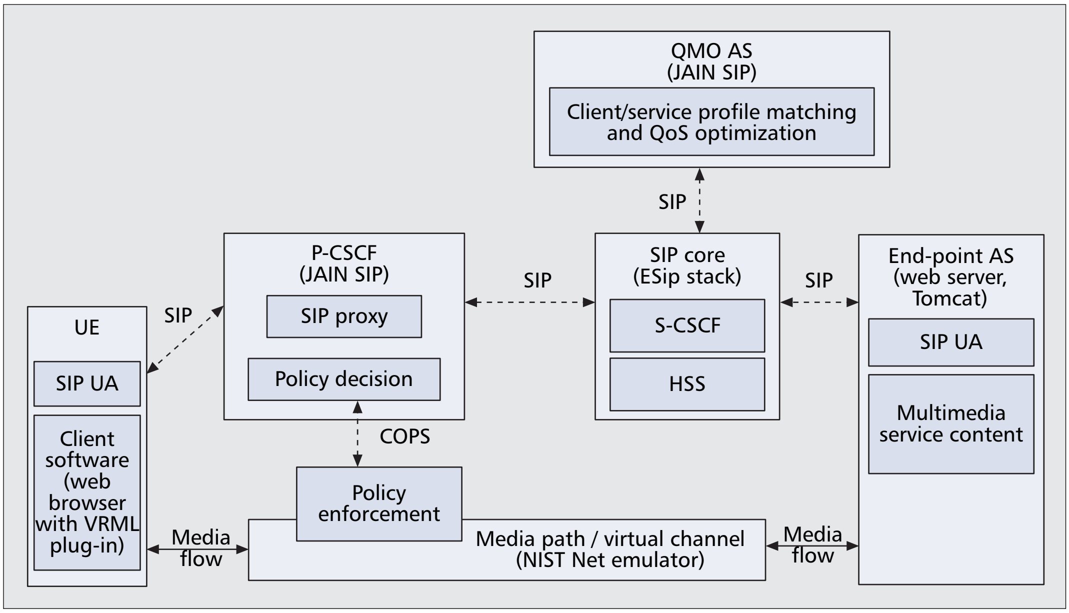

Figure 6. *A logical view of the testbed.*

Emulated P-CSCF and both AS are implemented as SIP servers and proxies using the NIST-SIP package, a certified JAIN SIP implementation. The SIP core is implemented in C++ and uses the ESip stack Version 1.0.6 developed by Ericsson AB. Network parameters are emulated by using NIST Net.

the session, the user is simply updated). In addition, the user is less likely to experience session failure later, because those service configurations that are not and will not be supported by the user are discarded early in the process.

In addition to session establishment signaling, the diagram in Fig. 5 shows signaling messages triggered by Events 3, 4, and 5. Signaling for *Change in service requirements*, initiated by the end-point AS, depicts the scenario in which a user, while playing the game, activates a streaming audio/video clue. The *Change in network resources* scenario depicts signaling being triggered by an increase or a decrease in available/authorized resources detected by the network. This results in the calculation of a new service configuration and resource allocation. A change occurring in the client profile may result in the user sending a SIP re-INVITE message, with the remainder of the call flow being essentially equivalent to initial session establishment.

In comparison, the standard 3GPP session-control procedures in IMS specify matching functionality performed by session end points (UE and AS hosting the game), but optimization functionality is not specified.

TESTBED AND MEASUREMENTS

For the purposes of experimentation, and as a basis for future study, we created a laboratory testbed (Fig. 6). All software runs on standard personal computers (PC) in a 100 Mb/s LAN. Emulated P-CSCF and both AS are implemented as SIP servers and proxies using the National Institute of Standards and Technology (NIST)-SIP package, a certified Java APIs for integrated networks (JAIN) SIP implementation. The SIP core is implemented in C++ and uses the ESip stack Version 1.0.6 developed by Ericsson AB. Network parameters are emulated by using NIST Net.

We captured and analyzed the SIP-signaling traffic in different game scenarios, caused by the events listed in the previous section. We repeated the run five times and calculated the average values. The results obtained are summarized here for illustration purposes, without an attempt to set numerical objectives for the values measured.

- The average time required for the *Session establishment* scenario, including the time for the user to accept the offered parameters, was 7.83 s.
- After the session establishment and the initial 3D world download, the resources reserved for this purpose are released. The average time interval for the related signaling to be completed was 0.19 s.
- In the *Change in service requirements* scenario, audio/video streaming was added while using the low quality service profile. The average time interval for the related signaling was 2.23 s.
- In the *Change in client profile* scenario, the user requests the service to switch from a low-quality to a high-quality service profile. Including the time for the user interaction to accept the offered parameters, the average time to complete the related signaling procedure was 3.78 s.
- In the *Change in resource availability* scenario, the indication of decrease in available bandwidth caused the change to a lower-quality audio codec. The average time to complete the related signaling was 1.40 s.

Although the previous results can not be generalized, because they are specific to the testbed and the prototype application, they do provide an idea of what to expect in a real environment. For example, they show that renegotiation times are significantly smaller than times for initial session establishment. This adheres to the logical assumption that a user is more tolerant about initial delays than about disruptions occurring in an ongoing session. Regarding the acceptable response time for the adaptation to take place, the authors in [5] address the active negotia-

Further research is needed to conduct measurements in both a laboratory testbed and a real network scenario deploying the IMS to provide insight into the amount of signaling traffic and the effects of the time required for session establishment/renegotiation on user-perceived service quality.

tion/renegotiation of QoS for multimedia and conduct measurements to determine session establishment/management times in various emulated networks. They propose an evaluation criterion that session establishment should not last longer than 2–5 s, and adaptation during a session should not last longer than 1 s to meet a user's expectations for almost immediate reaction.

CONCLUSIONS AND FUTURE WORK

Today's Internet model is based on a user-centric view of the network, with intelligence being pushed to the communication end points and the network being used as a pipeline. The IMS model uses a more operator-centric approach with operators providing call/session control functions and offering service-enabling capabilities in the IMS applications domain. To this extent, our approach aims to further enhance the IMS objectives of providing users with customized and enhanced service quality. Our QMO functionality resides on an IMS (SIP) AS and offers generic capabilities that can be shared across different applications and used to enhance service offerings.

Further research is needed to conduct measurements in both a laboratory testbed and a real network scenario deploying the IMS to provide insight into the amount of signaling traffic and the effects of the time required for session establishment/renegotiation on user-perceived service quality. With regard to scalability, it is clear that for a large number of users, running the QMO procedure separately for each session is definitely time-consuming and costly. In addition to the establishment of recalculation thresholds, a solution could be to offer a set of service configurations calculated in advance for particular combinations of constraints.

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