Towards Quality of Experience-aware networks

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***Abstract*—Rapid service creation stemmed from the convergence of fixed line and mobile telephony with the Internet has made user acceptance to be a crucial factor for the success of the telecommunication business. Telecommunications research, therefore, can no longer be considered only from the pure engineering perspective. Within this paper, we present the concept of service quality for future NGN networks called Quality of Experience - QoE, which is different from the well-known notion of QoS (Quality of Service). We demonstrate an example of the user-centric network design called "QoE-aware IMS-based IPTV network". The designed IPTV framework allows flexible user tests of IPTV applications, continuous evaluation of service quality from users' perspective (Quality of Experience - QoE), and dynamic system adaptability according to user satisfaction**

Keywords— QoE, IPTV, IMS

I. QUALITY OF EXPERIENCE IN A NGN NETWORK

Over the last several years, the world of telecommunications has been undergoing a significant paradigm shift from an engineering discipline of architectures and protocols towards a user- and service-oriented business field. The merger of Information, Communication and Entertainment applications has formed "a new I.C.E age". Similarly, the joint business field of Telecommunications, Information Technology, Media and Entertainment has carved "T.I.M.E" industries [18].

In fact, with the rapid expansion of networked applications and services along with their underlay ICT infrastructures in recent years, service quality and user satisfaction are important research interests for researchers and also competitive factors for service providers, especially in the rich content delivery segment. This is especially manifest in the context of the convergence between fixed-line and mobile telephony with the Internet technology.

As an example of a NGN network, recently the IP Multimedia Subsystem (IMS), a 3GPP initiative as a control plane for multimedia services, is a promising candidate for such a convergent Next Generation Network (NGN). IMS provides true convergence of fixed-line telephony, mobile telephony and Internet towards a mobile multimedia platform.

From another T.I.M.E aspect, as an instance for a multimedia system, Internet Protocol Television (IPTV) is one of the most exciting new IP-based services, which started from more than 10 years ago, but majorly boosted from the mass deployment of residential IP broadband and the introduction of Next-Generation Networks (NGN).

Recently, IMS has been proposed to facilitate modern IPTV networks to provide more flexible service deployment and user control, mobility management with fixed-mobile convergence and seamless integration with other service concepts using SIP signaling like VoIP. Work [6] describes the IMS-based IPTV architecture and its service varieties. IPTV has evolved through various architectures and device capabilities, with its standard being harmonized by ITU-T FG-IPTV group since 2006. IPTV technology its own has been advancing to expand its capabilities as well as to its feature sets to raise the service attractiveness to users.

IPTV, as a mixed real-time/on-demand bandwidth-exhaustive application, requires a controllable audio/video quality and smooth user interaction. Therefore it raises an important challenge while running on the best-effort, flexible IP networks. The quality problem is more concerned for IMS-based IPTV due to the re-use of IMS functions together with other services and due to new dimensions like mobility and seamless handover.

The aforementioned convergence alone does not solve the open question for future killer applications. One of the key success discriminators for future communication services is that they have to provide a satisfying and enjoyable quality experience (QoE) for end customers.

Traditionally, the well-established Quality of Service (QoS) metrics and control methods have been thoroughly studied but they only represent the network-centric view and are moving far from being the effective service management components because of the fast-evolving underlying heterogeneous infrastructures while services get converged in the user view (e.g. triple-play, quadruple-play service models…). Nowadays, service quality cannot be taken simply as objective quality parameters of the service. We must also take into consideration every factor that contributes to overall user service perception. The network-centric Quality of Service metrics are not enough to represent the service satisfaction anymore. Consequently, Quality of Experience (QoE) has emerged to be a clear important quality factor, being defined as a user-centric assessment of service expectation and satisfaction and represents the underlying QoS impacts, device capabilities as well as the human perception factors [3][4]. In the quality competition of IP-based service providers, QoE is increasingly critical and tractable to help providers to leverage service quality and user satisfaction while being price-competitive, which is critical in the diversified IP-based service provision competition. Service providers naturally desire to control and ensure a good QoE level while keeping the QoS-related network resources optimized and under control.

Unfortunately, most research in the field of networked services so far has primarily focused on these technical QoS aspects of quality, thus lacking sufficient evidence regarding the user's actual quality perception.

In this article, we will describe our work of designing a QoE-aware IMS-based IPTV network as well as demonstrate some results as an example of a QoE-aware system. Our aim is to explore the potential links between IMS-based IPTV user experience and the networked service delivery, and to pave the way for service providers to ensure the competitive quality and identify related service optimization approaches.

As a matter of fact, QoE for multimedia services including IPTV has already been studied in ITU-T (SG12) to seek the requirements and analysis methods. Research on QoE has contributed from foundation ideas to measurement techniques, from qualitative design concepts to quantitative models to identify QoE properties and their links to lower layers, especially to the network-level QoS as seen from [3] to [15]. However, to the best of our knowledge, study of QoE/QoS correlation in different network/service contexts can be only seen in papers [5][12]. Both works in [5][12] tried to establish a generic function of the QoS/QoE correlation for the video streaming service and made some case studies. But they lack of validating the proposed functions in many other contexts, for example, IMS-based IPTV network context.

The remaining of the paper is structured as follows. The next section explains the general QoE-aware IMS-based IPTV architecture. In section III, we describe more in detailed how QoE functionalities are built up in the network prototype and some significant results. The final section is for the conclusion and possible future extension of this topic.

II. FRAMEWORK FOR QOE-BASED SERVICE PROVISIONING

A. Service Architecture

IMS-based IPTV is the next generation IPTV architecture that makes use of the advanced NGN functionalities to provide novel, interactive and blending IPTV services. It can also facilitate QoS guarantee based on the existing IMS service control capabilities.

Fig. 1 shows a high-level functional IPTV network architecture being supported by an IMS infrastructure. The model provides multimedia services to the end user by means of the SIP Application Server (SAS). The SAS implements the service logics which users interact and request the movies and/or other online contents in the personalized and intelligent ways. Important logics have been implemented for the special features like enhanced electronic program guide (eEPG), interactive (parental) authorization, blending sessions, etc. SAS interacts with the IPTV Terminal Functionality (IUF) that handles the display and interactivity functions for viewers.

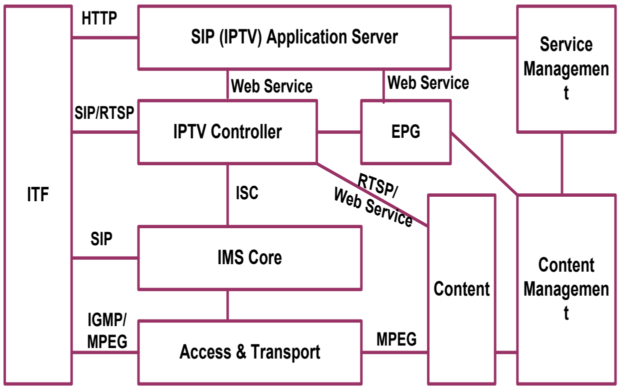

Fig. 1. IMS-based IPTV architecture

The IUF also performs functions such as content encoding/decoding and buffering for both unicast and multicast streams. The system is divided into a number of logically separated parts, namely, the home domain, the core network, the access/transportation network, and the service/content domain and service management.

B. Testbed Infrastructure

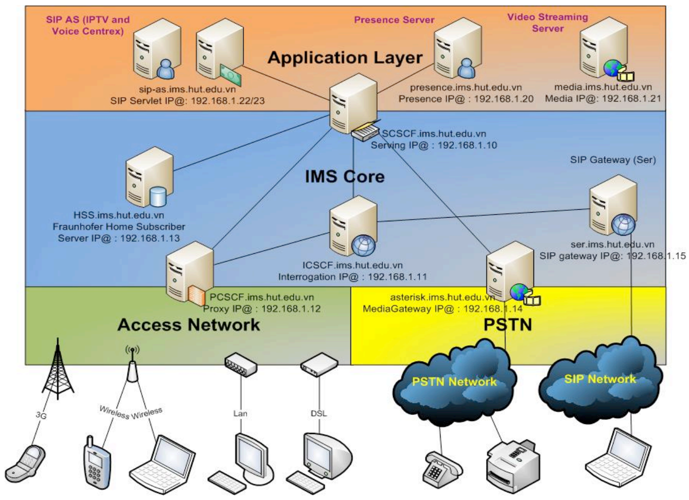

Fig. 2. The HUST IMS Testbed

A next generation network testbed has been set up in our lab for the purpose of prototyping new multimedia and rich-feature communication services using IMS framework. The testbed consists of all three layers: the media layer for transportation of media traffic in unicast, multicast and broadcast. The core layer for signaling and session/service control makes use of the FOKUS open source IMS Core [11,12,13] that delivers CSCF servers and a light user profile database (HSS). Our main focus is on the application layer in which we specified and developed prototypes for IP telephony and IPTV value added services based on Sailfin platform. A Media Server was also developed Darwin Streaming Server. Besides that we have developed a comprehensive framework and prototype of IMS IPTV Client that is based on the open source IMS Communicator. Finally, several IMS interfaces, namely, Sh, Mw etc. are implemented. Figure 2 depicts high-level view of our testbed setup.

C. Architectural Design Concept of QoE-aware IMS-based IPTV Client

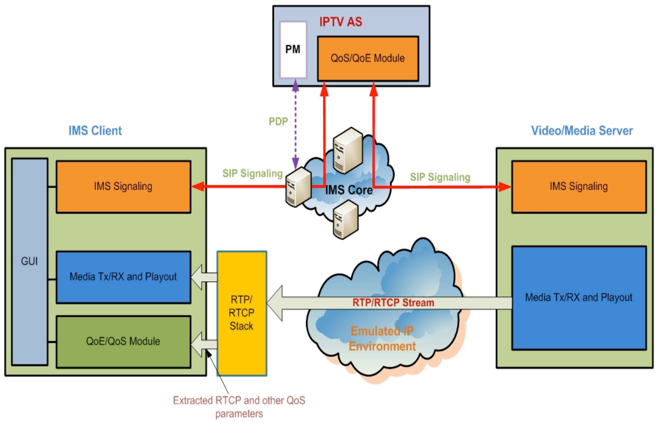

Fig. 3. QoE-enabled IMS-based IPTV Archiecture

The goal of our framework design is to smartly enable network dynamic adaptability according to user's satisfaction of the on-going media session. The goal is challenging especially for the context of mobile client where the mobile transportation environment condition could be changed frequently that impacts the session quality. In order to react timely to the session quality fluctuation, service providers should receive the user's feedback periodically during the course of an IPTV session as a criterion to change the network provisioning policy.

As depicted in Fig. 3, our architectural design for this QoE-enabled IMS IPTV follows the standards. Furthermore, some entities in the architecture are modified to support QoE for video services. Several important modifications are QoE and QoS processing modules embedded on both the IMS Clients and the IPTV Application Server. The QoE engine at a client either allows its viewer to score his satisfaction (by the Mean-Opinion-Score, or MOS) of the video quality or predicts the viewer's MOS automatically. Whilst the QoE/QoS module at the AS is in charge of translating that MOS to different class of QoS profile. With this QoS profile, the IMS Client then interacts with AS to optimize the video stream from Video Server as well as with P-CSCF to allocate enough resources for better (video quality).

Section **Error! Reference source not found.** will give the detailed explanation of the functionalities of these QoE/QoS module**.**

III. PROTOTYPE IMPLEMENTATION

To enable better service provisioning and resource optimization practice (bandwidth allocation, bit rate adaptation, delay/jitter reduction etc.) to have better ranked video quality from users' point of view, the IPTV AS must comprehend its users by modeling a QoE-QoS relation for each user.

Rich multimedia content, IPTV as a great example, brings more complexity to the QoE-QoS relationship, and the importance to transparently control the end-user quality of experience, instead of managing via the diverse lower-layer QoS parameters.

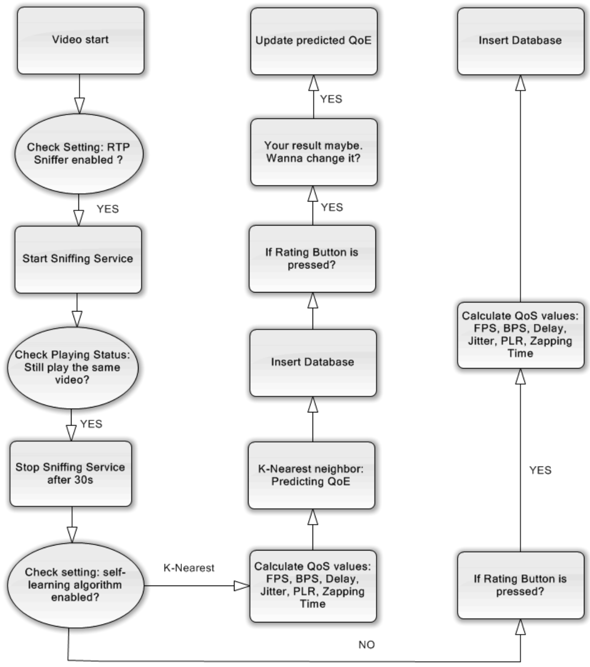

Fig. 4. Flow diagram of the QoE Engine

For the dynamic adaptability of the IPTV network in favor of user's satisfaction, the network should get perception feedback from QoE-aware-enabled IPTV clients. Our design prototype is built on a smartphone running Android platform, and is equipped with functions to run IMS-based IPTV video-on-demand. As shown in our framework proposed in Section C, the QoE engine embedded at user terminals enables the QoE-aware service provisioning. It gives a portal for users to rate the video-audio quality, feeding back their service satisfaction to service providers. But manually rating one or more times during the course of an ongoing session is inconvinient for viewers. The QoE engine, therefore, is designed to be in charge of estimating automatically QoE scores periodically on behalf of the human user and feeding back those user's perception to service providers. That is, it allows the QoS-QoE module at the IPTV AS to periodically collect user's perception of an ongoing session in a timely manner; and using QoE to guide QoS provisioning in the IMS core. The flow diagram of the QoE engine is illustrated in Fig. 4 where the k-Nearest

Neighbors algorithm was deployed as the QoE estimation algorithm.

A. *On-session database collection*

As seen in Fig. 5, before the QoE estimation algorithm can be activated, the embedded QoE engine shall collect enough data points of on-session-measured QoS parameters at the Andoird IMS Client.

_id	frame_rate	bit_rate	delay	jitter	plr	q_mos
31	30	697880	205	198	236	2
33	30	411452	121	119	144	2
34	30	726179	3	2	0	5
35	24	502392	258	204	584	1
37	24	554736	110	51	448	1
38	30	611711	106	54	340	2
39	15	62436	107	53	375	1
40	24	514464	325	271	10	2
41	30	714122	432	376	23	2
42	60	449524	244	180	411	2
43	15	63514	113	107	0	4
44	30	75544	0	0	537	1
45	30	719596	72	68	364	2

Fig. 5. Training database displayed at the IMS Client

The monitored QoS values and QoE value rated by users are then formed into a so-called training database as illustrated in Fig. 5, where the column attributes (e.g. delay, jitter…) are inserted from on-session QoS measurements; and the last column shows Mean Opinion Score values. The online QoS monitoring process is carried periodically (every 30 seconds in our experiement) during an ongoing IPTV session that keeps the training database updated continuously. Once the training table has enough data collection (Rating of MOS from 1 o 5 exist), the estimation algorithm is activated to predict a QoE value (shown in the last column of the table) for each new set of QoS parameters that are filled in the continuing row of the table. Outcome of the QoS parameters monitoring is demonstrated in Fig. 6.

Fig. 6. QoS parameters monitoring at Android client

B. *QoE Estimation Algorithms.*

The algorithm is applied over the time, which helps to gradually understand QoE variation on QoS values and "learn" to predict new QoE (MOS) from measured QoS values. This method can be more easily to embed in the user devices, and can be combined mapping function at AS to form a smart QoE control and resource optimization for the multimedia service system.

There have been several studies about this practice as in [1,2,3,4] in which [1,4] presented the Decision Tree approach. However, the Decision Tree model needs a very accurate training data points otherwise the prediction could come out awkward. In this paper, we proposed to use *k-Nearest Neighbouring* algorithm (kNN) [5] since kNN can predict QoE rating in any case in trade off of larger database. Also, it has simpler implementation. kNN algorithm needs only few parameters to tune (distance metric and the k value) while Decision Tree algorithm requires a large input training table with as many attributes as possible to get a precise decision. kNN in turn results in running faster than Decision tree algorithm.

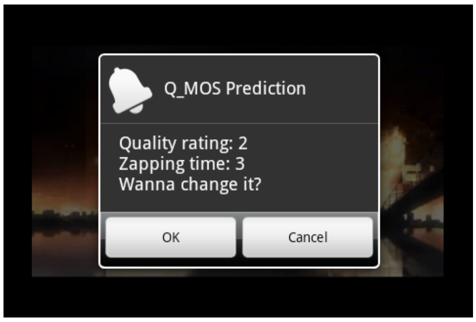

Fig. 7. MOS value prediction outcome by kNN algorithm

Every 10 seconds, the kNN-predicting QoE engine performs QoE prediction. A demonstration of the prediction outcome is presented in Figure 9 in which the MOS value for audio-video quality was given 3, and MOS for zapping time was given 2 in the MOS ranking system (1 ÷ 5).

C. *Service and Resource Provisioning based on QoE Requirements*

For a rich multimedia audio/video service like IPTV, there are a number of content-specific parameters like audio/video bitrates, jerkiness, delay, zapping time, blurring, and glitches directly influencing the user perception. One important factor we need to consider is that the level of perception, or satisfaction, also depends on the content types: the experience of a high motion–sensitive video such as sports, action movies are more prone to bad packet loss rate than a low motion-sensitive ones like talk show, news broadcast. So the same sets of network-layered QoS parameters may still bring different satisfaction because of content type related effects. An IPTV efficient system, as we believe therefore, needs to understand and form QoE-QoS relations in several different profiles for each single user.

QoE-aware service provisioning has already been suggested in previous works by other authors. For instance, in paper [8] proposed several approaches by performing QoE-perceptual-statistics-based adaption actions based on the feedback from QoE-enable user terminals such as 3G mobile phone, SIP voice/video phone. A terminal sends its evaluated Mean Opinion Score (MOS), a popular QoE metric, and other terminal parameters (e.g. codec type, bit rate, encoding mode, etc.) to an enhanced IMS component to provision the service with adaptation either at the end-user device or at the service generation entity such as: codec/bitrate/encoding mode adaptation, buffer scheme, packetization, etc. However, *it was not specified yet how to periodically translate the MOS into the to-be-adjusted network parameters to adapt the real measured QoE to user's QoE requirements for an ongoing session.*

In our work, we look into the influences of network-layer QoS parameters onto the user-perception QoE and the possible mathematical relationship between them. A clear form or a clear method of translating QoS to QoE or vice versa will help to build suitable policies to bring the quality control more closely and adaptively to service user's desire of an ongoing session, while draw out better points to optimize resources for single- and multi-user scenarios.

D. QoS-QoE correlation studies

There are some related studies in this matter. Paper [9] presented some correlations between QoS parameters and MOS values for audio/data. Where in [10], the authors believed that relationship between QoE to each QoS parameter (Packet Loss Rate - PLR) for VoIP and Web browsing could be derived, by means of non-linear regression model, in the exponential and lograrithmic form.

Our previous work [7] also studied the issue by analyzing, from multiple-user statistics, the varied values of each selected single QoS parameter against the resulting QoE scores (MOS) of video-audio quality in polynomial forms. Simple regression with one variable helped to model the data sets into closed-form (in polynomial) equations of QoS vs. each QoS metric with good accuracy over a large data set.

In this case study, PLR was always kept 0% (no loss). We did 5 experiments with 5 different delay values (50ms, 100ms, 150ms, 200ms, 300ms). In each experiment, jitter is increased up to the point where users were no longer able to accept the video-audio quality.

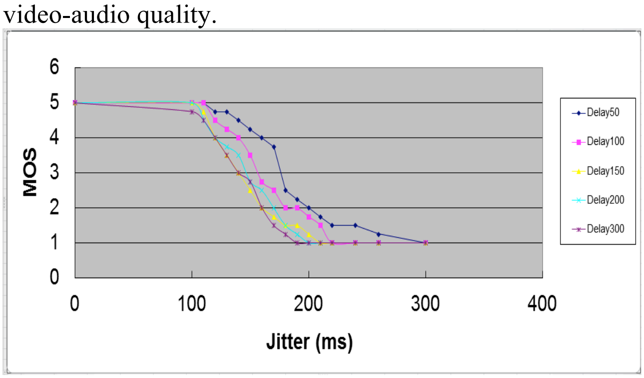

Fig. 8. – MOS-based QoE estimation as a function of jitter

Based on the result of the 5 experiments, the approximate correlation function of QoE and QoS can be depicted as follows:

$$y = \begin{cases} 5 & 0 \le x \le 110 \\ -0.0361x + 0.8468 & 110 < x \le 220 \\ 2 & x > 220 \end{cases}$$

Where: y: MOS; x : Jitter(ms)

We then extended the work to a QoE dependency on a set of multiple major QoS parameters observed with one content type. We selected three main QoS parameters greatly impacting an IPTV video service quality that are bitrates, jitter and PLR. A closed-form mathematical QoE-QoS representation, using linear regression from a large set of pre-collected data points is built for each single user for each of their service profiles. These 3 QoS metrics can be considered as independent variables thanks to the known service provider's abilities to control them. Furthermore, to simplify our human perception, the effect of each of those QoS metrics can be "summed" together. For example, a low jitter level will bring the smoothness to video progression, and that happy experience will add up to the user's good feeling from clear and sharp video picture thanks to low PLR and suitable video bitrates. Mathematically saying, we can sum the "quantified" QoS effects from each of those QoS variables. With those implications for a good approximation, we use linear regression method on 3 independent variables to derive the needed closed-form equation and its coefficients. An example of QoE-QoS translation is studied as in Fig. 9 below:

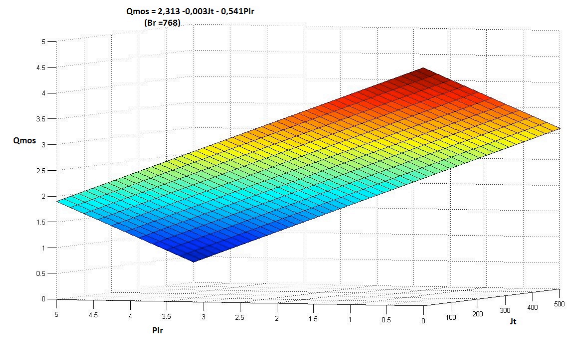

Fig. 9. Example of QoE as the function of PLR and Jitter in case Bit rate = 768 kbps

While QoE expression as a function of 3 QoS parameters can be presented as the follows:

$$\begin{cases} MOS=3.063 + 0.002\,Bitrate - 0.003\,Jitter - 0.541\,PLR & \text{If MOS > 1} \\ MOS=1 & \text{If MOS < 1} \end{cases}$$

Where:

Bitrate: [Kbps]; *Jitter*: [ms] ; *PLR*: [%]

The mapping function is established from 1000 tests. Having similar statistical results from different users, the mapping function can be approximately generalized in the form:

$$MOS = 3 + \alpha\, Bitrate - \beta\, Jitter - \gamma\, PLR \qquad (1)$$

where α, β, γ are adjustable coefficients, varying with some small error range for each user case around the above specific values.

IV. Conclusions and Future Work

In the paper, we described an extension to the existing architecture of the IMS-based IPTV systems enabling the resource provisioning and the IPTV session adaptation based on QoE feedback from users. The extended architecture and its components are deployed in real testbed, which could be used in the near future to investigate and develop QoE model for other multimedia and value-added services, such as voice, online-gaming etc.

Moreover, we are interested in expoloring the QoE issue in various Telco networks. Another open research issue we are researching: QoE for services in the cloud within datacenter systems.

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