Adaptive Control based on Quality of Experience for Multimedia Communications

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1. The notion of Quality of Experience (QoE)

Nowadays, network providers pay an increasing attention to multimedia communication whereby the available server capacity and network bandwidth become overloaded by the evolution of high quality multimedia services (e.g. IPTV, online gaming, social networking, etc.). What is missing is a user-centered approach that is represented by the notion of Quality of Experience (QoE) [1]. This subjective measure relates to how end-users perceive the quality of a network service and includes the complete end-to-end system effects. It is expressed by human feelings like "excellent", "good", "bad", etc. Designing a network system based on QoE is today not only a solution to improve network quality but also the trend for competition between network providers. As a combination of user perception, experience, satisfaction and expectations, QoE is an important metric for the design of systems and engineering processes that can only be measured dynamically at the end of any transmission activity. QoE management takes into account the needs and the desires of the end-users when using network services, while the traditional concept of Quality of Service (QoS) [2] only attempts technical measurements of the delivered service.

Regarding the QoS/QoE relationship, QoE covers the QoS concept, whereas there is a common belief that QoE is a part of QoS. Fig. 1 illustrates this theoretical point. The quality of a network service including core network and access network is determined by *QoS Access* and *QoS Backbone*. The quality perceived by end-users when using end-devices is called

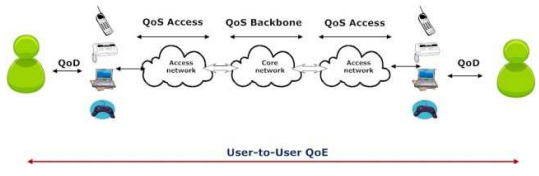

Figure 5: Quality chain of an e2e service.

QoD (Quality of Design). Therefore, QoE is satisfied only if both QoD and QoS are satisfied. So we can see that the end-to-end QoE is a conjunction of QoD and QoS.

2. Classification of QoE methods

There are today various methods for QoE assessment. We propose to classify QoE methods in three different approaches [18]: *usability metric*, *hedonistic concept* and *buzzword extension*. These three approaches can cover the whole QoE notion. Indeed, what makes us interested in considering the user perception concept are the three following issues:

- **Usability metric -** *The ease of use and learnability of a service*: This approach includes measuring and comparing usability metrics. Such metrics is of vital importance for user satisfaction. In fact, it is of decisive importance that users actually are satisfied with the network service or they will simply quit this service. Such metrics are useful for assessing long-term progress on a system. Usability metric is all about how easy a network service is to use. The purpose of usability is to set the design direction of a network system. For this approach, Soldani et al. propose a QoE management method in [3].

- **Buzzword extension -** *An extension of the known QoS concept* [5]: From a historical point of view, the QoS metric came first to designate a set of techniques to ensure the routing of network traffic such as voice or sensitive multimedia applications. Since then, QoS highlights the performance improvement of network systems. QoE appeared much more recently and directly affects end-users. As a comprehensive approach to quality (measured end-to-end), the QoE is considered as an extension of QoS. For this approach, S.Winkler et al. propose a subjective testbed for evaluating video quality of streaming applications [4].

- **Hedonistic concept -** *The pleasure and satisfaction of end-users when using a service*: QoE represents the overall level of end-user satisfaction with a service and expresses user satisfaction both objectively and subjectively. While not always numerically quantifiable, QoE is

the most important single factor to assess the user experience. In other words, QoE is considered as a hedonistic concept. Some methods for this approach are described in [6, 7].

3. QoE in a Cloud CDN environment

Cloud Service [8] has become today a key IT technology. It allows us to access data, programs and other multimedia services from a Web browser via the Internet hosted by network service providers. This technology allows end-users to use applications without installation and access their personal files at any computer with internet access. However, the requirement of high bandwidth connection is an issue in Cloud Service deployment. Recently, we proposed an approach to integrate cloud services into a QoE-based Content Distribution Network.

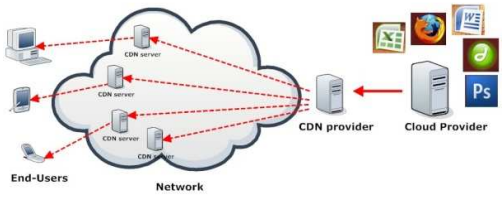

Figure 6: Cloud Content Distribution Network

Content Distribution Network (CDN) [9] are deployed to improve network quality and to optimize resource utilization. The main idea of CDN operation is to move the content from the origin server to servers that are close to end-users, namely *replica servers*. In our model (Fig. 2), the Cloud provider gives the cloud data and services to a CDN provider. The latter serves end-users using distributed replica servers in the edge network.

We focus on two layers of our CDN model: a *routing layer* and a *meta-routing layer*. In the routing layer, we propose a routing protocol, named QQAR [10] (QoE Q-Learning-based Adaptive Routing protocol), which is based on a Q-learning algorithm [11]. In the meta-routing layer, we propose a server selection method that we formalize as a Multi-armed bandit problem [12]. Both of our approaches are based on QoE-feedbacks from end-users.

4. Knowledge dissemination for QoE

In order to make appropriate decisions, the network needs to integrate the QoE parameter on each node. QoE is one of the components of the knowledge plane. This plane is responsible for knowledge management and the strategies selection. It must be created autonomously, continuously and dynamically. However, the knowledge dissemination in the network remains an open problem [13]. While a greedy approach suggests distributing knowledge over all network elements, this idea is impractical in reality.

An improvement of this assumption is using a diffusion region model [13]. This kind of diffusion model solves the overhead problem but knowledge is still partial in some cases. Thus, in [14] we propose a new knowledge dissemination mechanism based on selection of some nodes called “master nodes” in charge of knowledge management. This problem is a multi-constraint optimization problem. Looking for a solution to this problem, we use the concept of Pareto dominance by performing a comparison between different possible solutions with multiple criteria. Moreover, our proposition uses dedicated overlay networks, which consist of dividing the knowledge plane into many sub-planes, each of them representing a view of the knowledge plane corresponding to a given service (or application). Finally, we support the idea of a backbone implementing intelligent agents over routers, such as programmable overlay routers [16].

5. Current development for QoE Testbeds

While a plethora of tools have been proposed for automated quality assessment of video and audio, there is a lack of public datasets to evaluate and validate them on a common ground. In our research, we propose two complementary approaches to build reliable QoE assessment datasets. The first approach is a testbed, developed in the framework of European Celtic IPNQSIS Project [17], in which each parameter affecting QoE (at the network level, but also at the video and user levels) can be precisely tweaked. The platform consists of a video server whose flows are disturbed by a customizable network emulator. Users are asked to rate a series of short videos on various devices (laptop, smartphone, TV, etc).

The second approach is a crowd-sourced experiment enabling the collection of realistic QoE data at a large-scale. It consists in a plugin for the Firefox Web browser that detects the presence of a video in a page, and automatically inserts a sober user interface enabling the user to rate the video. At the same time, network-level metrics are recorded, as well as other useful information on the device and user. These datasets will help us in devising an accurate and generic model for automated correlation of QoS and QoE.

6. Conclusion

The future Internet will be user-centric and a ferocious competition between providers will be based on Quality of Experience. Consequently, any new architecture and protocol must take into consideration the QoE of clients.

In this paper, we defined the concept of Quality of Experience, which quantifies the satisfaction of end-users. We then highlighted the main differences with QoS and proposed a classification of QoE methods. Afterward, we presented our user-centric research works that aims at optimizing end-user QoE by tackling the problems of routing, meta-routing and knowledge dissemination.

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