Impact of Network and Service Paradigm Shift on Evolution of the QoE and QoS Concepts

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***Abstract*—We are witnessing a number of paradigm shifts in many Information and Communication Technology (ICT) areas. 5G, Future Internet and very high resolution digital TV defined a new vision of services with novel approaches to their implementation, deployment and operation based on concepts of Software Defined Network (SDN) and Network Function Virtualization (NFV). Increasing transmission capabilities in both mobile and fixed networks became an enabler for a new generation of multimedia services and applications. Evolution of digital video technology and competition of operator supported services with Over The Top (OTT) applications caused change in understanding of Quality of Service (QoS) and Quality of Experience (QoE) concepts. This paper surveys the change of QoE approaches and interpretation in the context of new services and applications.**

Keywords-QoE; QoS; multimedia services.

I. INTRODUCTION

Delivery of services of appropriate quality has always been one of the key goals of telecom operators and service providers. Evolution of services from fixed network plain voice and data towards rich and complex mobile multimedia and Internet based OTT (Over The Top) applications caused a significant change in quality concepts and approaches to their provision, measurement, monitoring and management.

For a long time, a network centric approach based on the notion of QoS defined by strictly technical parameters associated with data transmission among service access points (ITU-T Rec. X.200) like: transmission delay, jitter, throughput, bit error rate, probability of loss or duplication of data, has dominated. This "engineering" perspective neglected users' point of view. There is of course an intuitive relationship between QoS and quality of service observed by a user. On the one hand, meeting a set of QoS criteria might not guarantee end-user satisfaction. On the other hand, a QoS problem, e.g., higher level of delay or jitter may not affect quality of voice or video to a level that causes users complaints. However, a QoE problem, e.g., macroblocking in a video stream, may be affected by QoS problems like e.g. dropped IP packets leading to continuity count errors. In order to represent also the users' centric perspective, a concept of QoE was introduced. It focuses on the perceptual quality of services from the users' point of view.

According to ITU-T Rec. G.100 [2], QoE is defined as *the overall acceptability of an application or service, as perceived subjectively by the end-user*. An alternative but complementary definition was proposed by the Qualinet "White Paper on Definitions of Quality of Experience" [14]. QoE is defined there as: *the degree of delight or annoyance of the user of an application or service. It results from the fulfilment of his or her expectations with respect to the utility and/or enjoyment of the application or service in the light of the user's personality and current state*.

It is a metric of how well a network satisfies the end-user's requirements and expectations. QoE establishes an aggregated view by covering the complete end-to-end system (client, terminal, network, services infrastructure, etc.) and its effects. QoE is also influenced by user's internal state (e.g., expectations), the characteristics of the designed system (e.g., capabilities) and the context or the environment within which the interaction occurs. In research papers on QoE, many classifications of the QoE Influencing Factors (IF) were proposed. For example, in Qualinet project [14], three categories of QoE influence factors were identified:

1. human (e.g., gender, age, education);
2. system (e.g., bandwidth, security, resolution);
3. context (e.g., location, movements, costs).

Figure 1 summarizes QoE IF considered in twenty selected publications described in [10].

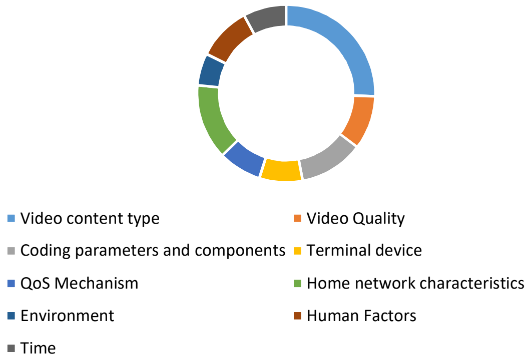

Figure 1. Factors influencing video QoE [10].

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It should be noted that QoE, in contrast to QoS, is subjective in nature and involves context and potentially specific user expectations of “soft” nature, which might not be directly expressed as values of parameters.

In theory, the QoE for a given application is a function of the network QoS parameters, but its discovery might be difficult due to complexity of a service delivery environment. Such perspective makes QoE a challenging issue and calls for individual treatment of each category of service together with its delivery infrastructure. These new areas emerged due to developments in networking: 5G, Future Internet, media: High Definition (HD) voice, Ultra- and Super Ultra HD (UHD/SUHD) video, services and applications: IP TV, VoD, YouTube, Vimeo, Netflix, mobile gaming, and paradigm shift taking advantage of new concepts and approaches such as SDN, NFV, Cloud Computing (CC) and Self Organizing Networks (SON).

The paper discusses the change of QoE approaches and interpretations in context of new services and applications.

II. QOS/QOE IN 4G

The evolution of mobile network architecture from 3G to 4G featured significant change in QoS mechanisms; however, they were still a starting point for mapping to QoE. One of the crucial changes is also common handling of voice and data in an all IP packet network [3].

The UMTS 3G [12] defines four QoS classes differing by traffic delay sensitivity: *Conversational*, *Streaming*, *Interactive* and *Background*. Conversational and Streaming classes were dedicated for real-time services like voice and video streaming, while the other two Interactive and Background were appropriate for best-effort services with less stringent delay requirements (e.g. web browsing and progressive download of video content). The UMTS High Speed Downlink Packet Access (HSDPA) standard [20] introduced an additional QoS control means - a Scheduling Priority Indicator (SPI), a number from the 0-15 range, which could be used by each nodeB for scheduling. Due to their local character, SPIs priorities had limited applicability from the core network perspective.

Development of 4G Long Term Evolution (LTE) standard [21] assumed delivery of real-time, multimedia services with support for appropriate levels of QoE [4]. It introduced a QoS-aware mechanism for end-to-end service delivery based on Evolved Packet System (EPS) bearers and Quality of Service Class Identifiers (QCIs). The end-to-end QoS is established from User Equipment (UE) to the Packet Data Network Gateway (PDN-GW) in a core network using bearer service which provides the QoS level of granularity for different service flows. EPS bearer QoS profiles include following parameters: QCI, Allocation and Retention Priority (ARP), Guaranteed Bit Rate (GBR), and Maximum Bit Rate (MBR). The QCI is a number from the 1-8 range used to control bearer level packet handling in scheduling and admission control. Two categories of QCIs are defined:

- Guaranteed Bit Rate (GBR) for applications such as conversational voice, video streaming, buffered streaming and real time gaming, with QoS constraints to be observed;
- Non-Guaranteed Bit Rate (Non-GBR) for applications such as voice, video, TCP based applications and IP Multimedia Subsystem (IMS) signaling, with no QoS constraints.

The 4G LTE bearer centric QoS architecture has a constraint. It is not able to differentiate traffic flows that are served by the same EPS bearer unless dedicated EPS bearers are used for different traffic flows. It means that different traffic flows of the same service which needs better level of QoE/QoS may not differ in 5-tuple (source IP address, destination IP address, source port, destination port, protocol), identifying packets associated with a related unidirectional flow [12]. As a consequence, though there is rich support for QoS LTE there still a need for extra resources to deliver an intended QoE for real-time applications. In case of video services using GBR or QoS to give priority for forwarding of video related packets will improve QoE but at the same time will deteriorate quality of best effort data traffic. Moreover, diverse user devices with different screen sizes and resolutions, i.e., tablets and smartphones, but in the same radio conditions, should be treated individually.

III. QOS/QOE IN 5G

Forthcoming 5G network makes a great step forward in comparison to 4G, in terms of speed (1-10 Gbps), extremely low latency (1 ms round trip time), base station capacity, longer battery life, availability (99.999%) and perceived quality of service (QoS). All these features will also contribute to improvement of QoE. Dominating role of multimedia traffic with growing share of HD and UHD video [1] will broaden a list of factors to be considered in the context of QoE. This in turn will make QoS to QoE mapping even more complex. There is also another dimension of complexity for QoS and QoE. Implementation of 5G networks will be based on the concepts of SDN and NFV and will employ cloud computing technology.

In 5G, services may use different allocation of network functions in Radio Access Network (RAN) and Core Network (CN) both for user (u-) and control (c-) plane according to required QoS/QoE needs. This capability and decoupling of control and data plane in SDN provides flexibility alleviating improvement of QoE [15][16].

In 5G NORMA project [19], SDN technology is used to implement a prototype of virtualized QoS/QoE mapping functions using open interfaces and flexible selection of functional blocks to integrate specific requirements for each user. Such solution will provide network programmability capabilities allowing third parties, e.g., virtual operators to set-up their specific QoS/QoE control strategies. It will enable support of fully dynamic, context aware QoE/QoS management capable to dynamically set QoS/QoE target based on detected application flows of the end users and adapt the end-to-end resource allocation and the data plane functions accordingly.

CC technology used for 5G architecture will also enable applying of Mobile Edge Computing (MEC) concept to implement QoE by making caching/replacement decisions based on both content context (e.g., segment popularity) and network context (e.g., RAN downlink throughput).

IV. RELATIONSHIP BETWEEN QOS AND QOE

A generic relationship between QoS and QoE defines three zones (Figure 2) and is described by (1). For QoS disturbance from Zone 1, QoE has a high value, representing the fact that user's appreciation is not affected. When the QoS deteriorates and disturbance reaches Zone 2 the QoE decreases. Finally, when the QoS disturbance grows and reaches Zone 3, the QoE may cause user abandons a service because of its unsatisfactory quality. Generally, when the QoS disturbance parameter increases, the QoE metric and user's perception of quality decrease [6]. Getting insight into the nature of the relationship between QoS and QoE, and understanding it to a level enabling control over QoE is still a research topic.

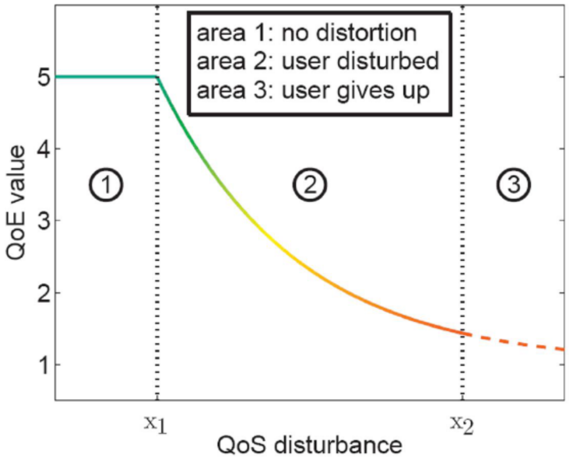

Figure 2. Generic mapping curve between QoS and QoE [6].

$$QoE = \alpha \exp(\beta - QoS) + \gamma \quad (1)$$

where α, β, γ, x1 and x2 are configurable positive value parameters. Usually QoS is calculated by taking into consideration four generic criteria: availability, reliability, delay and capacity. These four criteria are independent of context and in practice are represented by parameters relevant and specific for a case (e.g. round trip delay, jitter, packet loss rate, bit error rate, throughput, bandwidth, etc.). The above formula represents an objective approach to QoE known as "IQX hypothesis" which is typically used to estimate the QoE for VoIP services and web browsing [6]. It expresses QoE as an exponential function of the QoS degradation. Its weaknesses are:

- Doubts concerning values of parameters which might be relevant only for specific use cases;
- Neglecting the actual end users' opinions.

Their perspective is taken into consideration by subjective metrics of QoE, which are based on psychoacoustic/visual experiments with human users. Historically, the most important and the oldest metric for assessment of perceived service quality or human perception is the Mean Opinion Score (MOS) with a five quality levels (from 5=excellent to 1=bad) Absolute Category Rating (ACR) defined by ITU-T Rec. P.800. Despite criticism for being too simplistic, it is still very popular not only for voice but also for multimedia services (e.g., UHD TV) [5]. The drawbacks of MOS method are complexity and costs.

Evolution of video quality assessment methods and issues of QoS/QoE mapping are discussed in detail in [4][8]. Table I presents video QoE standards developed by ITU-T and Video Quality Experts Group (VQEG) [22].

TABLE I. VIDEO QOE STANDARDS [22][8]

Image res..	*Subjective estimation*	*Full reference*	*Non Reference*		*Reduced Reference*
SDTV HDTV	ITU-R: BT.500 ITU-T: J.140, J.245	ITU-T: J.144 J.341	ITU-T: P.1201, P.1202, G.1071	VQEG: RRNR-TV, HDTV	ITU-T: J.147, J.249 J.342
VGA CIF QCIF	ITU-T: P.910, P.911	ITU-T: J.247		VQEG: MM Project	ITU-T: J.246

Subjective methods have been studied for many years and have enabled researchers and operators to get better understanding of the subjective aspects of QoE. Typically, the results of subjective experiment are quality ratings obtained from users during use of the service (in-service) or after service use (out-of-service), which are then averaged into MOSs and extended to other ITU standard-based subjective assessment procedures classified by type of application and media (Table I).

Several models were proposed for QoS/QoE mapping [7]-[11]. A comprehensive discussion can be found in [13] and [18].

V. CONCLUSIONS

The relationship between QoS and QoE is a challenging task and a moving target due to: evolution of services towards collaborative multimedia, migration of mobile network architecture to a new 5G networking paradigm based on virtualization, and extension of the list of QoE influencing factors. Managing and controlling QoE is still a research topic.

CC technology applied in 5G architecture enables usage of Mobile Edge Computing (MEC) concept to implement QoE by making caching/replacement decisions based on both content context (e.g., segment popularity) and network context (e.g., RAN downlink throughput). For this case, mobility can be used as context information for future location and anticipated trajectory enabling pre-caching of content-based on user location.

Ubiquity of smartphones and tablets together with increasing performance of networks open an opportunity for substantial reduction of costs of conducting MOS tests by using crowdsourcing for subjective assessments of QoE of multimedia services and applications.

Possibly new performance metrics are needed for more appropriate evaluation of QoE/QoS of mobile web services. Diversity of terminals that differ with resolution of screens and other features like power consumption or supported data rates requires separate treatment in terms of QoE. Common performance parameters like speed in bits per second should be replaced by screen per second in order to express webpage delivery and display. Tests conducted by operators revealed that there is a gap between measured QoS indicators and user perceived experience. Large difference in network performance might result in thin margins of users' experience as a result of complex relationship between QoS and QoE influencing factors.

For video, a natural challenge will be providing satisfactory QoE for UHD TV content up scaled from UHD and HD formats.

Changing communication landscape calls also for redefinition of traditional Service Level Agreements (SLAs) which are closely related to both QoS and QoE. Today, QoE models could be used as guides for setting and negotiating proper SLAs. By analogy to the mapping between QoS and QoE, it is worthwhile to consider an idea of Experience Level Agreement (ELA) as a special type of SLA which establishes a common understanding of the quality levels that the customer will experience through the use of the service [17].

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