Qualinet White Paper on Definitions of Quality of Experience

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(*For an explanation of the roles of each group see the preface in Section 0.*)

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0. Preface

(*Authors: Patrick Le Callet, Sebastian Möller, and Andrew Perkis*)

This White Paper is a contribution of the European Network on Quality of Experience in Multimedia Systems and Services, Qualinet (COST Action IC 1003, see www.qualinet.eu), to the scientific discussion about the term "Quality of Experience" (QoE) and its underlying concepts. It resulted from the need to agree on a working definition for this term which facilitates the communication of ideas within a multidisciplinary group, where a joint interest around multimedia communication systems exists, however approached from different perspectives. Thus, the concepts and ideas cited in this paper mainly refer to the Quality of Experience of multimedia communication systems, but may be helpful also for other areas where QoE is an issue.

The Network of Excellence (NoE) Qualinet aims at extending the notion of network-centric Quality of Service (QoS) in multimedia systems, by relying on the concept of Quality of Experience (QoE). The main scientific objective is the development of methodologies for subjective and objective quality metrics taking into account current and new trends in multimedia communication systems as witnessed by the appearance of new types of content and interactions. A substantial scientific impact on fragmented efforts carried out in this field will be achieved by coordinating the research of European experts under the catalytic COST umbrella.

The White Paper has been compiled on the basis of a first open call for ideas which was launched for the February 2012 Qualinet Meeting held in Prague, Czech Republic. The ideas were presented as short statements during that meeting, reflecting the ideas of the persons listed under the headline "Contributors" in the previous section. During the Prague meeting, the ideas have been further discussed and consolidated in the form of a general structure of the present document. An open call for authors was issued at that meeting, to which the persons listed as "Authors" in the previous section have announced their willingness to contribute in the preparation of individual sections. For each section, a coordinating author has been assigned which coordinated the writing of that section, and which is underlined in the author list preceding each section. The individual sections were then integrated and aligned by an editing group (listed as "Editors" in the previous section), and the entire document was iterated with the entire group of authors. Furthermore, the draft text was discussed with the participants of the Dagstuhl Seminar 12181 "Quality of Experience: From User Perception to Instrumental Metrics" which was held in Schloß Dagstuhl, Germany, May 1-4 2012, and a number of changes were proposed, resulting in the present document.

As a result of the writing process and the large number of contributors, authors and editors, the document will not reflect the opinion of each individual person at all points. Still, we hope that it is found to be useful for everybody working in the field of Quality of Experience of multimedia communication systems, and most probably also beyond that field.

1. Introduction

(A*uthors: Fernando Pereira, António Pinheiro, Manuela Pereira, and Patrick Le Callet*)

Since the late 90's, the notion of 'Quality of Experience' (QoE) has gained momentum and followers in different application contexts. For example, in communication, the notion of quality has been largely associated to the so-called 'Quality of Service' (QoS) for many years. The QoE concept has emerged in this field mainly with the basic motivation that QoS is not powerful enough to fully express everything nowadays involved in a communication service.

With time, the QoE phenomenon has not only gained momentum in multimedia services and systems but it also became relevant in other areas ranging from design to human-computer interfaces and aesthetics. This trend is also linked to the explosion of the user experience (UX) field. As *"UX deals with studying, designing and evaluating the experiences that people have through the use of (or encounter with) a system"*[1], some aspects of QoE are certainly related to UX. Nevertheless, QoE is a concept that it is not only limited to the use of a system or service, as it is also related to the content itself.

With the growing level of functional sophistication of services and systems, quality evaluation has become progressively more complex, notably due to the exponentially mounting number of dimensions involved. While some services and systems involve a small number of technologies, functional capabilities, sensory dimensions and consuming paths, other applications are an explosive cocktail of technologies, capabilities, navigation courses and sensations. These growing application scenarios involve a larger user susceptibility, not only to the degree of usability of the overall system but also to the content itself.

Although its relevance has been widening, QoE is still missing a solid, theoretical and practical, framework to strongly affirm itself. While the strength and interest for QoE is well evidenced by the increasing number of dedicated papers, sessions, workshops and standards, it is also clear that those initiatives did not manage to show a coherent and consistent view on the QoE phenomenon. Over time, if not changed, this situation may reduce the relevance and impact of QoE. In fact, while QoE is, at this stage, and for many, a new exciting research field, it is for others simply a buzzword, and still for some others simply a more modern label for the same work they have been doing for decades. This unclear and unstable situation, where the lack of a solid and largely accepted QoE definition is very likely the most evident weakness, justifies increased efforts by all those who believe on the strength and added value of the QoE notion to make this field credible and much more than a fashion.

Beside its definition itself, QoE can be seen from other perspectives, notably as the science of QoE or the usage of QoE in an application scenario. Naturally, while some concepts and definitions may have a wide application, their modeling and implementation in different areas may have to differ to consider specific contexts. The science of QoE regards the study of QoE, e.g. what forms QoE, which is intrinsically multidisciplinary and skill demanding, and designing methods for QoE assessment. Moreover, the usage of QoE in an application scenario regards using QoE in designing applications, products, service or producing content, objectively evaluating QoE and also delivering services/content at a certain QoE.

[1] From Roto et al. (2011).

In this context, the main purpose of this white paper is to provide a definition for QoE which should be relevant for the largest possible set of application fields. While multimedia services and systems will be the main focus of this paper, there are general definitions that may be taken from and apply to other areas, and which do not need to be specifically (re)defined for multimedia services. For example, the notions of 'quality' and 'experience' are rather general concepts, and even if they will be defined in this document, this will be made in line with the definitions used in other areas wherever possible as this enriches their overall value. Thus, while the QoE definition and related concepts and definitions may be driven by multimedia services and systems, it is expected that they shall also be applicable beyond.

To have a lasting impact, the proposed QoE definition shall fulfill the following basic requirements:

- being simple and intuitive but also challenging, powerful and complete;
- not confusing the concept with a given model or implementation;
- making clear the relationship and distinction with other related concepts such as QoS.

If needed and useful, the general QoE definition provided may be tuned to specific or relevant applications scenarios, see Section 4.

To reach this purpose, this paper is organized in eight sections. After this first section with the Introduction where the motivation and scope of this paper are presented, Section 2 will provide definitions for the key terms of 'Quality' and 'Experience'. In the sequel, Section 3 will define 'Quality of Experience' while Section 4 will list application areas of Quality of Experience. Next, Sections 5 and 6 will address the factors influencing Quality of Experience and the features of Quality of Experience. Finally, Section 7 will discuss the relation between Quality of Service (QoS) and Quality of Experience (QoE). There will also be a Section 8 with relevant references.

2. Definition of Quality and Definition of Experience

(Authors: Katrien De Moor, Sebastian Egger, Christian Keimel, Sebastian Möller, Jesenka Pibernik, Alexander Raake, Raimund Schatz, and Dominik Strohmeier)

In order to clarify our understanding of the terms 'Quality' and 'Experience' within this paper, we first define the concept of an event as:

Event: An observable occurrence. An event is determined in space (i.e. where it occurs), time (i.e. when it occurs), and character (i.e. what can be observed).

Sensation refers to the responses of sensory receptors and sense organs to environmental stimuli. **Perception**, on the other hand, is a process which involves the recognition and interpretation of stimuli which register our senses.

We then define experience as follows[2]:

Experience: An experience is an individual's stream of perception and interpretation of one or multiple events.

For instance, an experience might result from an encounter of a human being with a system, service or artifact. An experience is not necessarily resulting in a judgment of its quality. In our definition, an experience does not encompass everything a person has undergone in the past, but this is referred to as a human influence factor on QoE, see Section 5.

Quality: Is the outcome of an individual's comparison and judgment process. It includes perception, reflection about the perception, and the description of the outcome. In contrast to definitions which see quality as "qualitas", i.e. a set of inherent characteristics, we consider quality in terms of the evaluated excellence or goodness, of the degree of need fulfillment, and in terms of a "quality event" (see Martens & Martens, 2001, and Jekosch, 2005).

Fundamental for these definitions is the understanding of both terms *quality* and *experience* from an individual's point of view. Thus, in contrast to *performance* they cannot be solely described by only physical properties or the achievement of a certain objective goal (e.g. intelligibility).

For the actual quality formation process (see Figure 1), we distinguish two paths: A perception path and a reference path. The *reference path* reflects the temporal and contextual nature of the quality formation process and also inherits a memory of former experienced qualities, as indicated by the arrow from experienced quality to the reference path. The *quality perception path* takes a physical event, triggered e.g. by a physical signal reaching our sensory organs, as an input. This physical event is processed through low-level perceptual processes into a perceived nature of the signal under the constraints of the reference path. This perceived nature then undergoes a reflection process, directed again by the reference path, which interprets these sensory features by cognitive processing; the concepts can now be described and (potentially) quantified and become perceived quality features.

[2] Both definitions are the result of a discussion process among the authors in which the ideas of Roto et al. (2011) and Jekosch (2005) were initially used as starting point.

Finally, the desired quality features resulting from the reference path and the perceived quality features originating from the quality perception path are then translated into the experienced quality on behalf of the comparison and judgment process. This *experienced quality* is delimited in time, space and character, and thus can be called a quality event. This event happens however inside the human user and relevant information about the event can only be obtained on a descriptive level from the user.

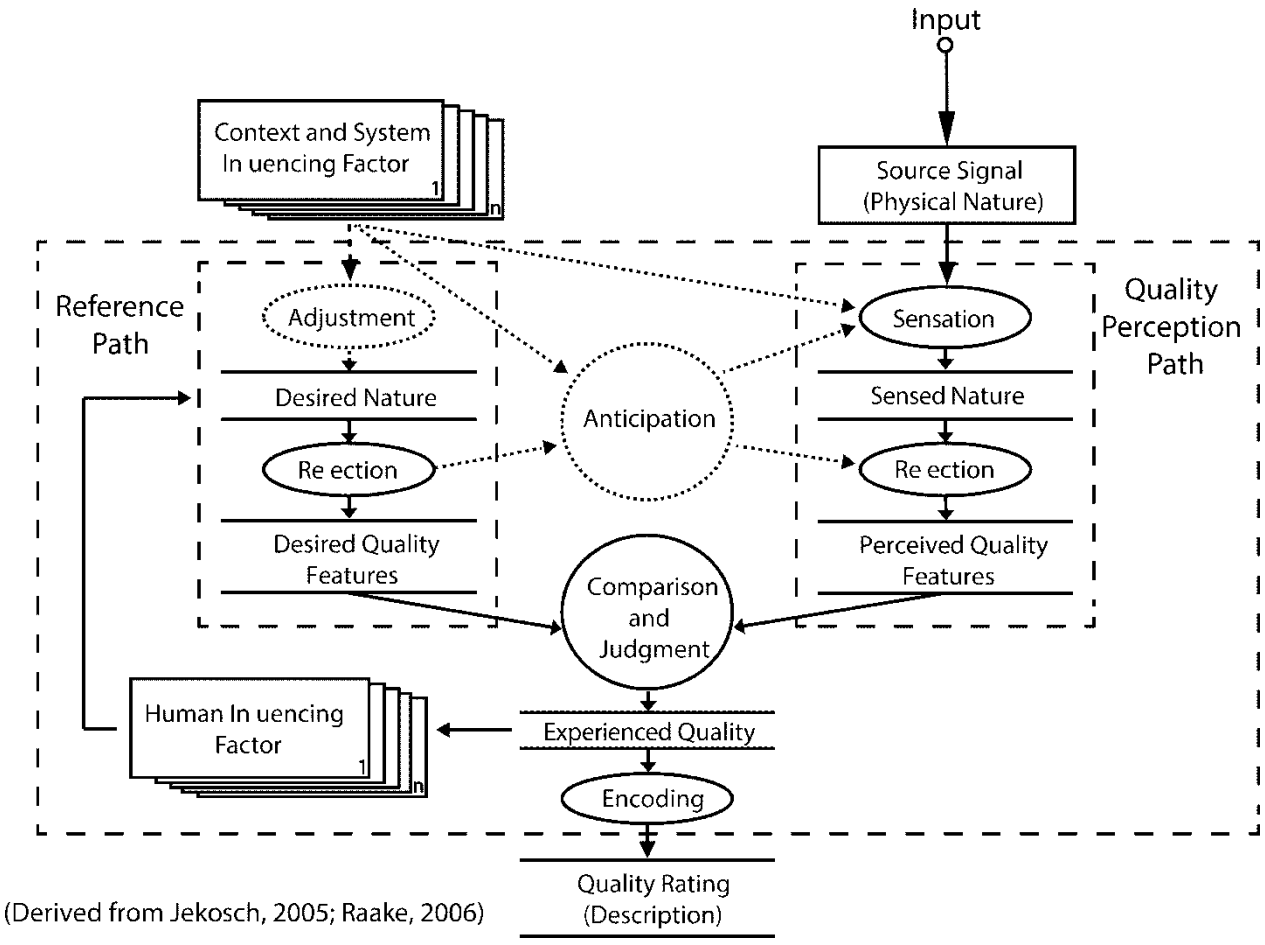

Figure 1 Quality formation process

3. Definition of Quality of Experience

(*Authors: Alexander Raake, Martin Varela, Sebastian Möller, Antonio Pinheiro, Manuela Pereira, Peter Reichl, Peter Schelkens, Ann Dooms, Patrick Le Callet, Andrew Perkis*)

The working definition[3] of Quality of Experience (QoE) is:

Quality of Experience (QoE) is the degree of delight or annoyance of the user of an application or service. It results from the fulfillment 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.

Here, "personality" is used in terms of "…those characteristics of [the] a person that account for consistent patterns of feeling, thinking and behaving" (Pervin and John, 2001) and "current state" in terms of "situational or temporal changes in the feeling, thinking or behavior of a person" (translated from German from Amelang et al., 2006). Note that the current state is both an influencing factor of QoE (see Section 5) and a consequence of the experience. Further, an application is defined as:

Application: "A software and/or hardware that enables usage and interaction by a user for a given purpose. Such purpose may include entertainment or information retrieval, or other."

Moreover, a service is defined as:

Service: "An episode in which an entity takes the responsibility that something desirable happens on the behalf of another entity." (Dagstuhl Seminar 09192, May 2009, cited after Möller, 2010)

In the context of communication services, QoE can be influenced by factors such as service, content, network, device, application, and context of use. For more details see Chapter 5.

Content influences QoE in different ways: 1) It has certain signal-properties that may be affected by processing such as capture, delivery or presentation; 2) it is related with "meaning". Artists or content producers create experiences, and may try to deliberately achieve pre-determined user experiences[4]. Then, at the one end, "meaning" is related with the creator's intentions ("sender"), and at the "receiving" end, "meaning" results from experiencing and interpreting the content. In both cases, it reflects the subjective viewpoint of the sender, or receiver, respectively.[5] The "sender" assigns a certain form to the content, which in semiotic terms is often referred to as the sign carrier. It is related with

[3] The current definition is considered to be a "working definition", owing to the fact that it may further evolve and be refined with the advances in QoE-research.

[4] "Content creators" in this context include directors, cinematographers, photographs, composers, painters, web-designers etc., further persons involved in subsequent production steps such as cutting or postproduction, mixing, but also the conversation partner(s) in a phone call.

[5] It is related with semantics, pragmatics, utility and/or emotions, or enjoyment in the light of intentions and expectations. It can be assumed that one cannot create a piece of art or message that is experienced alike by everyone, as not all recipients have the same background etc.

signal properties, but also symbolic properties.[6] The receiver (user, conversation partner etc., possibly identical with the sender), on the other hand, processes the carrier, eventually resulting in "meaning", now from the perspective of the receiver. Due to her/his different perspective, the meaning assigned by the recipient will likely differ from the one intended by the creator (see e.g. Jekosch 2005).[7]

It must be noted, that it is still under QoE research, how content and QoE are interrelated. As defined here, QoE does not explicitly address the degree of success achieved by an artist or creator to convey the intended message, but rather how a technical system or technical processing may have positively or negatively affected the success of conveying an artistic or of another (e.g. speech) message.

According to ITU-T Rec. P.10 (Amendment 2, 2008), QoE is defined as:

QoE: "The overall acceptability of an application or service, as perceived subjectively by the end user." (ITU-T)

Note 1: Includes the complete end-to-end system effects

Note 2: May be influenced by user expectations and context

In contrast to this definition, in this white paper QoE is explicitly differentiated from Acceptability, in terms of the "characteristic of a service describing how readily a person will use the service":

Acceptability: "Acceptability is the outcome of a decision which is partially based on the Quality of Experience." (Dagstuhl Seminar 09192, May 2009, cited after Möller, 2010)

Based on similar reflections, during discussions at the Dagstuhl Seminar 09192 "From Quality of Service to Quality of Experience" (May 2009), the following definition of QoE was developed to mitigate some of the problems related with the ITU-T definition:

QoE: "Degree of delight of the user of a service. In the context of communication services, it is influenced by content, network, device, application, user expectations and goals, and context of use." (cited after Möller, 2010)

Further, QoE must be differentiated from Performance, which can be defined as:

Performance: "The ability of a unit to provide the function it has been designed for." (Möller, 2005)

[6] For speech e.g. the acoustic signal, at higher level the chosen words, syntax, intonation etc.; for a painting, e.g. the chosen colors, size of the canvas, type of paint/brush etc.

[7] The ability of a human being to decode the meaning of a message or an artwork is 1) learned during his/her socialization process, and 2) is based on knowledge about the context of where, how and possibly by whom the artwork or, more generally, message has been created and/or presented.
Note that complex compounds such as an artwork, a speech message or a movie typically are composed of a multitude of parts or sub-signs, analyzed during the dynamic process of "semiosis" (cf. e.g. Nöth, 2000; Jekosch 2005).

4. Application Areas of Quality of Experience

(*Authors: Manuela Pereira, Antonio Pinheiro, Bob Lawlor, Chaker Larabi, Martin Varela, Tobias Hoßfeld, and Christian Timmerer, Andrew Perkis, Sergio Beker*)

Quality of Experience is part of the complete eco system for the media industry at large. This eco system forms the natural basis for a media value chain which is built around 4 major roles; Creative (Content), technology (Deliver and Interaction), market/finance (Business models) and user (Usage). The eco system provides the interdependencies between these roles and identifies the interfaces where quality plays a major role. Some of the interfaces are identified in the eco system from a media delivery perspective as shown in Figure 1, and other eco system descriptions have been described e.g. by Leghari et al. (2012) and Kilkki (2012).

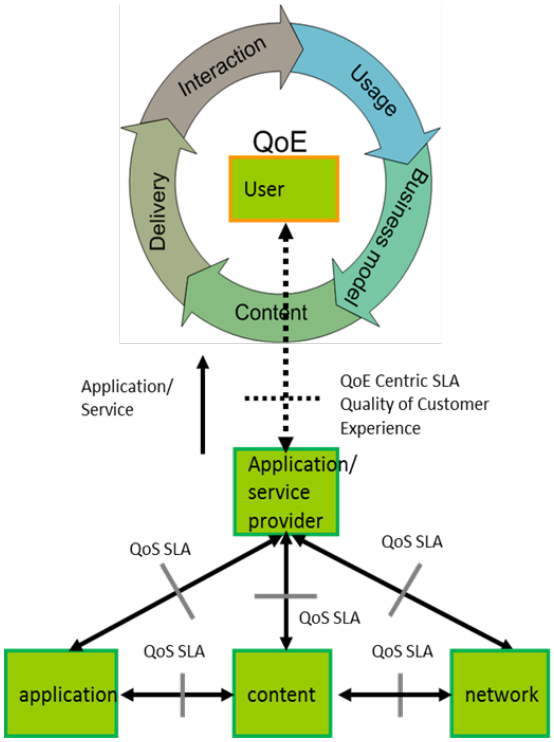

Figure 1 QoE in the ecos system for a application/service provider

It is well understood that the Quality of Experience (QoE) depends on the context of use, which is, to a certain extent, determined by the application domain. Hence, it is recommended to take into consideration the targeted application domain when defining the QoE. Application domains are typically multifaceted ranging from unidirectional to bi-/multi-directional services adopting different content modalities such as

- delivery (streaming, broadcast, file, etc.) of different sorts of content (audio, video, etc.);
- conversational, collaborative applications including social and arts aspects;
- educational and medical applications; etc.

each of them with a different set of requirements concerning on-/offline consumption, real-time behavior including buffer constraints, and interactivity.

Based on the application's context it shall be possible to use real-time estimation of QoE in order to make informed decisions on how to best exploit (infrastructure and media) resources (Varela et al., 2011). Having models for QoE simplifies the application's planning process by modeling the performance in terms of the user experience rather than just using low-level performance metrics (e.g., delay, loss rates, battery, CPU, and memory usage). This is made explicit in the ecosystem through the different interfaces accepting Service Level Agreement (SLA) definitions. SLAs shall be defined in terms of QoE whenever the provider faces the user and in terms of service component performance whenever the provider faces the component providers. Today, SLAs are commonly defined in terms of QoS. Considerations on the relationship between QoS and QoE are given in Section 7. User-centric service modeling provides the translation between both domains.

In the following some example application areas are described with respect to QoE:

Web and Cloud (Hoßfeld et al., 2012): The shift of computation and data into the cloud has become a key trend in the Internet-based applications. Current approaches for managing quality, however, are mainly implemented within the domain of a single stakeholder. Their effectiveness suffers from an inherent lack of information exchange between the involved constituents, including service infrastructure, network providers, and end-users. To remedy this problem, *flexible cooperation* between the involved entities, ultimately enabling every user (1) to access the offered cloud service in any contexts and (2) to share content, interact, collaborate, etc. with other users in a dynamic, seamless, and transparent way while maximizing QoE at the same time.

Multimedia Learning (Mayer, 2009): Multimedia learning is the building of a mental representation from learning material presented in different media such as pictures or text. The science of multimedia learning relies on experimental comparisons to measure the level of achievement of the transfer learning outcomes. The term 'transfer learning' refers to the ability of the learner to apply what they have learned to solve a new (albeit related) problem.

Meaningful learning requires deep mental processing of the learning material; however, the human processing capacity is limited. Presenting learning material in different media is assumed to support deep-level understanding, as different media refer to different cognitive resources: while pictures relate to the visual-spatial processing modality, text is associated with the verbal-auditory one. Cognitive overload can, therefore, be prevented by distributing the mental workload across the respective cognitive resources. Consequently, multimedia learning is more beneficial than learning with material that is only coded verbally (Mayer 1997), and this has been included into the twelve principles of multimedia learning (Mayer 2009).

Furthermore, it is known that learning success is heavily determined by the learner's motivation, especially his/her intrinsic motivation to learn. Intrinsic motivation is driven by the inherent reward of the activity that is the satisfaction and joy experienced while undertaking it (Ryan & Deci, 2000).

The Quality of Experience of Multimedia Learning could correspondingly be defined as the extent to which the learner's primary needs in using the multimedia learning system or service are satisfied. In order to properly assess the Quality of Experience of Multimedia Learning, both cognitive factors (such as perceived learning success), and affective factors, (like engagement in the learning process or experienced joy), ought to be fully considered. In addition to Quality of Experience metrics, the actual success of the transfer learning should be measured, e.g. by using best practice assessment methodology associated with the targeted learning outcomes.

Sensory Experience (Timmerer et al., 2012): The consumption of multimedia assets may stimulate also other senses such as olfaction or mechanoreception. Therefore, multimedia assets are annotated with sensory effects (e.g., ambient lighting effects, wind, vibration, scent) which are synchronized with the actual multimedia assets and rendered on appropriate devices (e.g., ambient lights, fans, motion chairs, scent vaporizer). The user will perceive these additional sensory effects giving her/him the sensation of being part of the particular multimedia asset. Hence, the *QoE needs go beyond audio-visual* taking into account all – human – senses as well as the emotions and feelings of the user. That is, QoE is *multi-dimensional* and *multi-sensorial*.

Haptic Communication (Steinbach et al., 2012): The relatively young field of research on haptic communications aims to expand traditional audio-visual communication towards presence in remote environments, physical interaction, and manipulation thereof to enable true immersion. The QoE for haptic communication is still in its infancy but it is well understood that the QoE for the visual and hearing feedback needs to be combined with the haptic feedback into a joint *multi-dimensional* and *multi-sensorial* QoE metric.

In conclusion, different application domains may have different requirements in terms of QoE. Thus, there is a need to provide specializations of a generally agreed definition of QoE (cf. Sections 2 and 3) pertaining to the respective application domain taking into account its requirements formulated by means of influence factors (cf. Section 5) and features (cf. Section 6) of QoE. Consequently, an application-specific QoE definition is provided by selecting the influence factors and features of QoE reflecting the requirements of the application domain and incorporating them into the generally agreed definition of QoE.

5. Factors influencing Quality of Experience

(Authors: Ulrich Reiter, Kjell Brunnström, Marie-Neige Garcia, Satu Jumisko-Pyykkö, Chaker Larabi, Katrien de Moor, Manuela Pereira, Antonio Pinheiro, Lea Skorin-Kapov, Dominik Strohmeier, Christian Timmerer, Junyong You, and Andrej Zgank)

In this section we focus on the factors influencing Quality of Experience, which we define as follows:

Influence Factor: Any characteristic of a user, system, service, application, or context whose actual state or setting may have influence on the Quality of Experience for the user.

Influence Factors must not be regarded as isolated as they may interrelate. A certain set of Influence Factors may be described by users in terms of QoE features. Influence Factors may be grouped in three categories, namely Human IF, System IF, and Context IF.

A **Human IF** is *any variant or invariant property or characteristic of a human user. The characteristic can describe the demographic and socio-economic background, the physical and mental constitution, or the user's emotional state*. Human IFs are complex and strongly interrelated. They may influence the perceptual process at two important levels (Jumisko-Pyykkö et al., 2007). At the level of early sensory or so-called low-level processing, properties related to the physical, emotional and mental constitution of the user may play a major role. These characteristics can be dispositional[8] as well as variant and more dynamic[9]. At the level of higher-level cognitive processing, interpretation and judgment, other human influencing factors are important. Again, these properties can have an invariant or relatively stable character[10] as well as a variant and more acute character[11] (Geerts et al., 2010; Wechsung et al., 2011).

System IFs refer to *properties and characteristics that determine the technically produced quality of an application or service (*Jumisko-Pyykkö, 2011*). They are related to media capture, coding, transmission, storage, rendering, and reproduction/display, as well as to the communication of information itself from content production to user*. The System IFs may be divided into four sub-categories: (1) *Content-related System IF*s referring to the content type[12] and content reliability, (2) *Media-related System IFs* referring to media configuration factors[13], (3) *Network-related System IFs* referring to data transmission over a network[14] and finally (4) *Device-related System IFs.* The latter refer to the end systems or devices involved along the end-to-end communication path, including system specifications[15], equipment specifications[16], device capabilities[17] and provider specification and capabilities[18].

[8] E.g., the user's visual and auditory acuity, gender, age (Strohmeier et al., 2010).
[9] E.g., lower-order emotions, user's mood, personality traits, motivation, attention level. (Reiter et al., 2012)
[10] E.g., socio-economic situation, education background, attitudes and values, personality traits.
[11] E.g., expectations, needs, knowledge, previous experiences, emotions.
[12] E.g., specific temporal or spatial requirements, color depth, texture, 2D/3D. (Korhonen et al., 2011)
[13] E.g., encoding, resolution, sampling rate, frame rate, media synchronization (Zinner et al., 2010).
[14] E.g., bandwidth, delay, jitter, loss, error rate, throughput (Nahrstedt et al., 1995; Fiedler et al. 2010).
[15] E.g., interoperability (Vetro et al., 2005), personalization, security, privacy.
[16] E.g., type/complexity/usability, ergonomic aspects, mobility.
[17] E.g., display size, screen resolution, color depth, user interface capabilities, loudspeakers, headphones, luminance, audio loudness, computational power, memory, battery life-time.

Finally, **Context IFs** *are factors that embrace any situational property to describe the user's environment in terms of physical, temporal, social, economic, task, and technical characteristics* (Jumisko-Pyykkö et al., 2010; Jumisko-Pyykkö, 2011). These factors can occur on different levels of magnitude[19], dynamism[20], and patterns of occurrence[21], either separately or as *typical combinations* of all three levels. The *physical context* describes the characteristics of location and space, including movements within and transitions between locations. Temporal aspects of the experience, e.g. time of day, duration, and frequency of use (of the service/system), are covered by the *temporal context*. Costs, subscription type, or brand of the service/system are part of the *economic context*. The experience can be perceived focused or in a multitasking situation (i.e., *task context*), alone or with other people present or even involved in the experience (i.e., *social context*). Finally, the *technical and information context* describes the relationship between the system of interest and other relevant systems and services including devices[22], applications[23], networks[24], or additional informational artifacts[25].

The Human IF factors relate to the user/human role in Figure 2; the System IF relate more to the creative and technology role in Figure 2, and the Context IF relate to the business models/market component (here: economic context) in Figure 2.

[18] E.g., server performance and availability.
[19] I.e., micro vs. macro.
[20] I.e., static vs. dynamic.
[21] I.e., rhythmic vs. random.
[22] E.g., existing interconnectivity of devices over Bluetooth or NFC.
[23] E.g., availability of an app instead of the currently used browser-based solution of a service.
[24] E.g. availability of other networks than the one currently used.
[25] E.g., additional use of pen and paper for better information assimilation from the service used.

6. Features of Quality of Experience

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Apart from the factors of the service, user and context-of-use which influence QoE, QoE itself can also be decomposed into perceptual features. Following Jekosch (2005), we define:

QoE feature: A perceivable, recognized and namable characteristic of the individual's experience of a service which contributes to its quality.

QoE features can be represented in a multidimensional perceptual space (Wältermann, 2012; Raake, 2006; Möller, 2010) and are not necessarily independent of each other. With respect to their contribution to the experience of quality, there are two types of features: Vector-model features for which their contribution to quality is monotonic ("the-more-the-better" or "the-more-the-worse")[26], and ideal-point features[27] for which an ideal point, i.e. the reference, can be represented as a point in the multidimensional space (Carroll, 1972); quality can then be determined as a distance to this reference which is formed under the constraint of the QoE Influence Factors.

QoE features can be identified on a perceptual level and can be analyzed using multidimensional analysis[28]. Additional qualitative evaluation approaches allow creating more general sets of QoE features also on an interpretational level[29]. The relevance of QoE features for quality preferences can finally be determined by regression techniques[30]. Once being identified, the features can also be scaled directly in a psychophysical experiment, see e.g. Voiers (1977), Quackenbush et al. (1988) or Wältermann et al. (2012). A relationship between perceptual features and objective, instrumentally-measurable metrics is in practice often desirable, but not a necessary prerequisite.

Given their importance for QoE evaluation, a categorization of QoE features becomes crucial. They can be classified on four levels:

- **Level of direct perception**. In this category all QoE features related to the perceptual information created immediately and spontaneously during the media consumption can be included. They are based on sensory information that plays the main role in any QoE evaluation process. In case of video, examples include atmosphere[31] and involvement[32], space[33] and motion[34], action[35] and color

[26] E.g. the noisiness of an audio signal: The more noisy the worse.
[27] E.g. the loudness of an audio signal: A too loud or too soft signal will be perceived as degraded, whereas there is an optimum loudness between these.
[28] E.g., similarity or distance scaling and subsequent Multidimensional Scaling (Borg & Groenen, 2005), Semantic Differential Scaling (Osgood et al., 1957) and subsequent Principal Component Analysis, or of sensory evaluation (Bech et al., 1996; Lorho, 2010; Strohmeier, 2011) and subsequent Multiple Factor Analysis or Generalized Procrustes Analysis.
[29] E.g., interview-based techniques (Jumisko-Pyykkö, 2011) or Extended-Open Profiling of Quality, Extended-OPQ (Strohmeier, 2011) and subsequent hypothesis-free qualitative data analysis.
[30] E.g., External Preference Mapping (Mattila, 2001) or Partial Least Square Regression (Strohmeier, 2011; Abdi, 2010).
[31] I.e., the articulation and density of the atmosphere.
[32] I.e., the relation of the individual with the atmosphere.
[33] I.e., the illusion of being in a projected space.
[34] I.e., the illusion of physical flow, including the three dimensional space, in case of 3D video.

features[36]. Additional examples are sharpness, darkness, brightness, contrast, flicker, distortion. Example features for services with audio are localization[37], timbre[38], whereas for services with speech examples include listening quality features[39], talking-quality features[40], and conversational quality features[41] (Möller et al., 2011). For services that include multiple modalities simultaneously such as audiovisual and/or sensory effects (Timmerer et al., 2012), relevant features are balance[42] and synchronism.

- **Level of interaction**, i.e. the level that includes human-to-human and human-to-machine interaction. Features include responsiveness, naturalness of interaction, communication efficiency, and conversation effectiveness.
- **Level of the usage situation** of the service, i.e. the physical and social situation. Examples of such features are the accessibility and the stability during a usage instance and can be categorized at the situational level.
- **Level of service**, which is related to the usage of the service beyond a particular instance. Aesthetic feeling, usability, usefulness, joy and ease of use, long-term stability are examples of features included in this category.

At each of these four levels, service-specific and more fine-grained subcategories can be identified (see e.g., Jumisko-Pyykkö, Strohmeier et al. (2010) for mobile 3D Video).

Certain QoE features have a recognizable and namable temporal dimension or only become namable under temporal considerations. Therefore, the temporal dimension is currently considered as a perceptual feature, too. Especially waiting times may be perceived before service consumption (initial delays) or during service consumption (interruptions) which are differently perceived by users (Hoßfeld et al., 2012). In applications like web browsing or HTTP-based media streaming, the perception of waiting times before streaming or web page loadings is an important feature to measure and monitor QoE of such systems (Egger et al., 2012).

At more interactional and situational levels, examples for temporal QoE features are perceived responsiveness or perceived duration of a pause during conversation or stalling events (Hoßfeld et al., 2011), which are often connected to additional visual QoE features like throbbers. Finally, at the service level, both micro-temporal and macro-temporal features can be identified (Karapanos et al., 2010). Examples of micro-temporal features are perceived availability or perceived service set-up time (Möller et al., 2011a). On the other hand, temporal QoE features can also have a longer-term character, such as perceived service QoE development over time or perceived service reliability over time (Möller et al., 2011b).

[35] I.e., the sensation of dynamic intensity and power.
[36] E.g., color naturalness.
[37] I.e., sensation of distance and direction.
[38] E.g., separability, tone color, richness, distortion, disruption, clarity and balance of the sound (Lorho, 2005).
[39] E.g., coloration, noisiness, discontinuity, loudness.
[40] E.g., echo, reduced double-talk, non-optimum sidetone.
[41] E.g., impacted flow of the conversation.
[42] I.e., harmony between stronger sound and stronger picture, or audiovisual content and sensory effects.

7. Relation between Quality of Service (QoS) and Quality of Experience (QoE)

(Authors: Marie-Neige García, Tobias Hoßfeld, Chaker Larabi, Fernando Pereira, Peter Reichl, Lea Skorin-Kapov, and Martín Varela)

Quality of Service has been defined[43] by the ITU (ITU-T Rec. E.800, 2008) as:

Quality of Service: "[The] Totality of characteristics of a telecommunications service that bear on its ability to satisfy stated and implied needs of the user of the service."

In this definition, we find several clear differences with the concept of Quality of Experience put forward in Section 3, and its defining characteristics, as discussed in Section 6. In particular, we note that while the QoS is focused on telecommunications services, QoE has a wider scope. We also note that factors that are important for QoE, such as the context of usage and the user characteristics, as well as the multi-dimensional nature of QoE are not comprehensibly addressed by QoS as defined by the ITU.

A more important distinction, however, is given by the fact that the vast majority of QoS research, which has a long tradition spanning over 20 years, does neither really conform to this definition of QoS, nor to its previous incarnation (ITU-T Rec. E.800, 1994)[44]. Instead, the issues of interest are usually centered around notions of network performance, and in some cases other systems-level performance parameters. Thus, Quality of Service considers quality only in terms of "qualitas", i.e. in terms of inherent characteristics in terms of performance.

We have, then, besides the "official" definition of QoS, a *de-facto* definition, which diverges even more from what QoE is, dealing mostly with physical, measurable performance factors of networks and delivery platforms in general. Sometimes, also application-level factors, such as encodings, and their effect on the underlying network's performance are addressed (e.g. by taking more of the available bandwidth).

Thus, the difference between QoS and QoE boils down to several factors, including:

- **Scope**: QoS typically focuses on telecommunications services, whereas QoE covers a much broader domain, which sometimes does not even involve telecommunications, e.g. HD video played in a home theater.
- **Focus**: QoS deals with performance aspects of physical systems. QoE deals with the users' assessment of system performance, as colored by context, culture, the users' expectations with respect to the system or service and their fulfillment, socio-economic issues, and psychological profiles, among other factors.

[43] Note that this is not the only possible definition of QoS, but is very often cited. Moreover, the term "QoS" sometimes is applied to technologies and architectures for improving network performance, such as DiffServ, which is out of scope for this paper.

[44] In ITU-T Rec. E.800 (1994), Quality of Service is defined as follows: "The collective effect of service performance which determine the degree of satisfaction of a user of the service."

- **Methods**: QoS has a very technology-oriented approach, and it relies on analytic approaches and empirical or simulative measurements. QoE, on the other hand, requires a multi-disciplinary and multi-methodological approach for its understanding.

Having stated these differences between QoS and QoE, it is also important to remember that QoE is, in a large part of instances, highly dependent on QoS. The technical aspects of a system's performance (and particularly so in the case of multimedia systems) can have a significant (and sometimes defining) impact on some dimensions of QoE (Fiedler et al., 2010; Couto da Silva et al., 2008). This is most notably the case when thinking about perceptual quality dimensions, for example, but also applies to other QoE dimensions.

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