TOWARDS A COMPREHENSIVE FRAMEWORK FOR QOE AND USER BEHAVIOR MODELLING

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ABSTRACT

While the modeling of QoE has made significant advances over the last couple of years, currently existing models still lack an integration of user behavior aspects and user context factors along with the consideration of appropriate temporal scales. Therefore, the goal of this paper is to present a comprehensive QoE and user behavior model providing a framework which allows joining a multitude of existing modeling approaches under the perspectives of service provider benefit, user well-being and technical system performance. In addition, we discuss the role of a broad range of corresponding influence factors, with a specific emphasis on user and context issues, and illustrate our proposal through a series of related use cases.

Index Terms— QoE, human factors, network economics, user behavior, user context

1. INTRODUCTION

The paradigm change from the rather network-driven concept of Quality of Service (QoS) towards the user-centric notion of Quality of Experience (QoE), which we have witnessed in the area of communication networks and services over the last couple of years, has amongst others also resulted in significant efforts to develop suitable models for QoE. While initial proposals have typically focused on describing the chain of interfaces [11] or the roles of stakeholders [4], the seminal QualiNet White Paper [1] proposes a model of the QoE formation process, which has been further refined in chapter 2 of [9]. Here, the process of quality perception and experiencing is described in terms of the interaction between sensory, perceptual event formation and anticipation/matching processes, depending on physical signals, contextual information and the user state. Altogether, this serves as a sub-model for the general quality formation process, which includes additional elements like encoding, comparison & judgment, quality awareness, reflection & attribution, and experiencing, as well as corresponding interrelationships. Finally, also a hierarchy of different contexts (interactional, situational, socio-cultural) is specified, which relate to specific stakeholder ecosystems.

While this model is already rather sophisticated, several key issues are still left open, including

a) the introduction of *user behavior* as an output category of its own (along with perceived QoE);
b) a clear distinction between the *dimensions* of system performance, user state and user behavior (from a service provider perspective);
c) the (potentially mutual) *relationships* between QoE perception, user state and user behavior for different types of influence factors.

Therefore, in this paper we present and discuss a significantly amended comprehensive QoE model, which takes these issues into account. To this end, the remainder of the paper is structured as follows: Section 2 introduces the general structure of the model and provides an initial discussion of the three mentioned perspectives as well as the interaction of model components. Based on this, Section 3 focuses on the various influence factors for QoE and user behavior. The model is illustrated through a broad range of relevant use cases in Section 4, before we summarize the results in Section 5 and present an outlook on future work.

2. GENERAL MODEL STRUCTURE

In this section, we present a novel comprehensive joint QoE and User Behavior framework addressing the three different perspectives of QoE (system relevant → "technical"), User State (relevant to user well-being → "eudaimonical") and User Behavior (service provider relevant → "behavioral").

2.1. Framework

The general framework is depicted in Fig. 1. Note that with respect to model hierarchy, we follow a cascaded approach, assuming that system performance / QoE impacts user state which by itself impacts User Behavior (UB).

Therefore, the technical perspective that directly outputs QoE is seen as a kind of nucleus as it exerts direct influence on all other perspectives. It considers mainly technical system factors and seeks to avoid the influence of user related factors, or to control them if avoidance is not possible. For the eudaimonical perspective, which addresses the human well being or quality of experiencing [9], user related factors as well as context factors are considered (note, however, that in this paper we do not deal with the corresponding output dimension in detail and rather focus on the mutual relation between QoE and user behavior models).

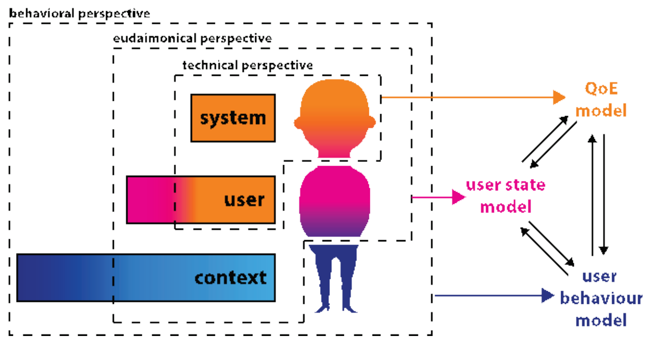

Figure 1: General QoE framework that considers different perspectives (system: technical, user: eudaimonical, service provider: behavioral) on QoE, different outputs (QoE, user state and user behavior) and inter-output relations.

For the context factors, two different types have to be distinguished: context type I factors do mainly influence the perceptual process in QoE, whereas context type II factors do mainly affect user behavior, which is the main output the service provider is interested in. As far as the output dimensions are concerned, note that we distinguish between *direct output* (QoE, user behavior) and *compound output* (user behavior as a consequence of QoE, and vice versa).

Factor	Examples	QoE	UB	UB → QoE	QoE → UB
System	*bitrate*	☒			
	noise	☒			☒
	...				
User	*mood*	☒	☒		
	goal/task	☒	☒		
	...				
Type 1 Context	*physical*	☒			☒
	price	☒	☒		
Type 1 Context / Type 2 Context	*social environment*		☒	☒	
Type 2 Context	*privacy*		☒		
	...				

Figure 2: Influence factors vs output dimensions (direct vs compound)

As an example, consider "noise" and "social environment" as two specific influence factors. According to Fig. 2, noise is classified as a system factor, which directly impacts perceived QoE (as significant noise reduces the MOS value), and may at the same time result in users abandoning the service (due to bad QoE). On the other hand, the social environment is a context factor belonging to both spheres of user's well-being (type 1 context) and user behavior (type 2 context); as such it directly impacts user behavior (e.g. due to peer pressure) and at the same time shapes user expectations and thus indirectly influences also perceived QoE.

2.2. QoE Model - System Perspective

QoE is strongly impacted by the underlying technology, such as terminals, hosts, networks, links, etc. For instance, slow terminals challenge the user's wellbeing (frustration) and may even impact user behavior (e.g. causing user churn). In the corresponding QoE models, the impact of underlying technology (i.e. network and media-related factors) is typically captured by Quality of Service (QoS) parameters on network and application level (such as packet loss or video buffer state). Typically, content- and device-oriented impact factors parameterize such QoE models; for instance, different codecs yield different reductions in QoE when facing similar loss rates [7].

Providers and operators typically have system-wide monitoring views on such QoS parameters, while they hardly can assess QoE on a general basis, and instead try to extrapolate QoE from application- and network-level QoS measurements. This perspective drives the formulation of QoE models, which depend on QoS, in order to bridge the most business-relevant, actionable parameters between the stakeholders. In this sense, QoE enables a broader, more holistic understanding of the factors that influence the performance of systems and, thus, complements traditional, technology-centric concepts such as QoS. Therefore, generic relationships between QoS and QoE are of key importance.

2.3. User State Model – End User Perspective

The user state is considered as a model of all specific user-related factors, which potentially might carry an influence on QoE or on User Behavior (UB). QoE might be influenced by the characteristics of the perception processes (e.g. auditory or visual impairments) inherent to the user, or by references which have been formed inside the user through prior experiences with the service at hand, or with other services (e.g. a user which is used to a specific type of sound or to a particular video resolution through long-term usage). User Behavior might be influenced through the perception and judgment process, but there are a number of other (e.g. demographic, experience-related) factors which might affect User Behavior and thus service usage directly. Such factors may relate e.g. to the usability of the service (users who are not experienced with the set-up of the service), or to other service-related factors such as security and privacy (users who have particular privacy concerns with certain services and thus refrain from using them).

From a modeling perspective, a user state model has two purposes: First, it can produce user state factors as output variables; for example, we could imagine a model which predicts the user's affective state on the basis of previous experiences – this is what we call "eudaimonical" model. Second, the user state factors can themselves be input to a User Behavior model; for example, the mentioned emotional state can trigger specific user behavior, such as terminating a service episode early or quitting the service provider entirely. If both directions are joined, then the user state model can serve as an intermediate, latent set of state variables of a comprehensive QoE and User Behavior model.

2.4. User Behavior Model – Service Provider Perspective

An important application of QoE analysis is to predict the behavior of users of commercial services, as service providers try to maximize their revenue while minimizing costs. There are different approaches to pursue this goal. Service providers can develop new services, allocate network resources between different services, or change prices and pricing models; all of these require understanding about the User Behavior.

It is of particular importance to know how a given action influences the attractiveness and usage of a service. This analysis can be divided into three parts: the willingness to pay for a service package, the willingness to be charged a usage-based tariff (if time or volume based pricing is applied), and the willingness to use the service in a regular manner. All of these depend essentially on the *benefits* provided by the service, which may additionally depend on many other aspects, including the context and other activities of the user. The services, applications and their user interfaces shall be designed in a way that produces high value or benefit and satisfaction in those situations in which the service or application is typically used.

Moreover, we may distinguish between *satisfaction* which is rooted essentially in a comparison between expected and realized experiences (typically measured on the MOS scale), *value* which is measured on a continuous, wide-ranging scale (e.g., $/h or €/min), and *importance* (services can be most of the time of low importance, such as TV, or of great importance, such as voice calls used to convey some critical information). Finally, the service provider needs proper understanding about the potential *usage* of the service when certain quality and price requirements are met.

Based on the corresponding context information, the overall process of modeling QoE and User Behavior works as follows: Observed context factors (e.g., location, time) and historical behavioral data are used to estimate contextual parameters, which, together with user and system factors (including price) are used to estimate QoE and user behavior. The main parameters to describe QoE are satisfaction with the service compared to expectation measured, and the benefit obtained both during the event (e.g., pleasure or flow experience) and as a result of finalizing an action. The main aspect of User Behavior is the expected usage of the given service and application. Note that, of course, both QoE and User Behavior will influence the decision to buy new products and services.

3. INFLUENCE FACTORS

While the general framework depicted in Fig. 1 already describes model outputs for each perspective, we will now address input aspects for each of the three models.

3.1. System Factors

Any communication system generally comprises of a chain of components (e.g. sender, network elements, receiver) that connect the service or content provider with the user. All these elements can influence the technical QoS (and thus QoE) on different layers, predominantly in terms of network- and application-level QoS. The latter can be related to the traditional Internet Hourglass Model, with Quality of Delivery (QoD) and Presentation (QoP) as application-level parameters in-between network-level QoS and QoE [7].

The technical influence factors are abstracted on the system level, and cover influences of the transmission network(s), the devices with their user interfaces (e.g. screens), but also of the implementation of the application itself (e.g. video buffering strategies). As an example, for web browsing, technical influence factors are: network delivery bandwidth, page load time, browser type, etc. This also includes aspects on the content level e.g. for video delivery the video codec, format, or resolution. Other content related factors like video (consumption) duration may belong to context factors, cf. Section 3.3.

Different classification schemes of system factors have been proposed which reflect different perspectives and approaches. From a media-driven perspective, Reiter et al. in [9] consider four different classes of system factors, i.e. content-, media-, network-, and device-related factors. In contrast, the ARCU model [14] specifies system factors to fall into Application (A) or Resource (R) space, besides Context (C) and User (U) space. Finally, from a networking perspective, [2] distinguishes between provisioning- and delivery-related factors, which have been shown to have distinctly different kinds of impact on QoE: provisioning-related factors (e.g. video resolution) drive QoE in the positive direction, while delivery-related factors are typically related to disturbances (e.g. data loss) and thus have a negative impact on QoE. Amongst all influence factors, system influence factors are the least complicated ones to instrumentalize. Therefore, a broad range of QoE prediction models utilizes mainly these factors as input aspects.

3.2. User Factors

There are several ways to classify user influence factors. In [9], Reiter et al. adopt the concept of a human (not necessarily user-related) influence factor as "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". The authors classify these factors on two layers: On the early sensory (low-level) layer physical, emotional and mental constitution of the user may play a major role. These factors include dispositional, mostly static factors such as the user's visual and auditory acuity, age, gender, etc., as well as dynamic factors such as emotions, mood, motivation, and attention. On the top-down (high-level) layer, knowledge-based influence factors are considered, such as the user's socio-cultural and educational background, values, needs, goals, motivations, preferences and sentiments, attitudes and personality traits [9].

We consider all these factors relevant for QoE, and most of them also relevant for affecting user behavior, either directly or through their QoE impact. However, we think that there are additional factors, which affect mostly user behavior, and not so much QoE. As an example of such a factor, we briefly discuss the user's security and/or privacy concerns. For instance, users may refrain from using a service because of concerns about potential threats in using the service, such as security concerns with an online banking service, or privacy concerns with a social network service. In such a case, user influence factors like the user's knowledge about security mechanisms or her risk aversion may play a major role – factors which are not considered relevant in the area of purely perception-oriented QoE research. Another example is that of factors which are known to affect the usability of services, such as the user's affinity towards technology, or the user's knowledge of processes which are necessary for installing and adapting a particular service. As in most QoE research it is assumed that the services under consideration are readily installed and running, such factors have to be added when user behavior is to be analyzed or modeled.

3.3. Context Factors

Context refers to anything that can be used to specify or clarify the meaning of an event. In research settings, context is typically used to illustrate something that complicates a seemingly neutral situation, such as a research laboratory with as few disturbing effects as possible. However, a laboratory is just a very specific context that affects the behavior of all actors. There is no context-free situation. Still, we may state that a model based on a study in a controlled environment forms a kind of common reference case, and the effect of a context factor may then be defined as the change compared to the laboratory reference.

With respect to communication networks and services, context often refers to the physical environment in which services and devices are used. A typical categorization is home, office, commuting, and other places, or indoors vs outdoors. Another important aspect is social environment, e.g. alone, with an important person, with a group of friends, or in a public place. Both the physical and social environment may affect the behavioral patterns in a predictable way, and thus might be used to adjust services and applications, even if this kind of information is very specific and difficult to incorporate in a general framework.

Here we aim at creating a set of general-purpose contextual parameters that describe the context in a succinct way that enables the development of generic behavioral models without knowing what exact context information is available and how that information should be interpreted. The resulting intermediate layer between context information and user behavior models may include the following parameters: (1) *opportunity cost* or the value of the best alternative activity; (2) *interruption cost* or the cost of interrupting the current activity even for a very short period of time; (3) *social attention* or how much other people are paying attention to you and what are their expectations; (4) *time pressure* or how much time there is available for an action; (5) *disruptions and distractions* or the probability and seriousness of disruptions during the action; (6) *pressure to be satisfied or dissatisfied*, i.e. how physical and social environment affects the experienced and expressed satisfaction.

The first two parameters are mainly related to User Behavior (type 2 context), for instance, whether or not to answer to a phone call; the other four parameters affect mainly the experience during an action (type 1 context). In terms of instrumentalization, these parameters are usually very hard to measure directly; and even if something is measurable, like background noise, the measurement covers only part of the phenomenon. Often, the only feasible way is to make reasonable inferences based on available concrete data (e.g., time, location, speed, current or recent use of applications etc.). In addition, there can be information about the social situation (e.g., based on the location of other people), or about the physical state of the user (e.g., heart rate, or in the future even illness etc.).

4. USE CASES

In this section, we will illustrate and validate our model using a set of examples and demonstrating how they fit into the general framework described in the previous sections.

4.1. Modelling QoE

QoE models are in wide use for speech, video streaming and videotelephony services, during all phases of service planning, set-up and operation, and usually comprise a subset of the framework factors and components described earlier. As an example, speech communication services are planned based on the E-model developed by ETSI, see ITU-T Rec. G.107. The E-model links system factors (see section 3.1) such as loudness ratings, delay times, packet loss rates and type of speech codec, are used for an estimation of QoE, in terms of a transmission rating which is defined on a so-called "perceptual scale", on which different types of perceptual impairments are expected to be additive (for the perceptual space covered by this scale cf. [16]). This output is considered as an estimation of QoE, and may be directly translated to MOS scale via a monotonous relationship defined in ITU-T Rec. G.107. Context factors (see section 3.3) are considered at two points of the model: The model defines the impact of pure delay according to an assumed conversational situation (e.g. highly-interactive business call vs. standard private call), and it provides a tradeoff bias for the transmission rating scale for services which offer an "advantage of access" in specific situations, such as mobile telephony or calls to hard-to-reach areas via a satellite.

4.2. Modelling User Behavior

While the output of the E-model is defined on the "perceptual" transmission rating scale, it would be interesting for a service provider to estimate how a specific transmission rating translates into a proportion of user that are inclined to terminate a call early (%TME). Functions relating transmission ratings to %TME were discussed in ETSI ETR 250 when the E-model was developed, but have not been retained in the actual ITU-T standard, probably because their derivation originates from the Bellcore model defined in the 1970es, and thus the estimations might no longer reflect today's service subscribers' behavior.

A second example of a model predicting user behavior, as discussed in section 2.4, has been proposed by Kort [7] to predict whether a user is likely to abandon telephone service usage before the dial tone, when dialing (depending on the number of digits to be dialed), and before network response. Note that this model is based on other service factors than the ones used by the E-model, and it also differs from the previously mentioned model as it does not explicitly try to model UB on the basis of QoE, but in a more direct way.

4.3. Modelling Price Impact on QoE

In [12], a fixed-point model for the reflexive relationship between QoE and service pricing is proposed which again fits nicely into our broad framework. In a nutshell, the paper starts from the observation that the price to be charged for a certain service is not only a consequence of the service quality provided (QoE based on QoS, cf. section 2.2), but at the same time has itself a certain impact on quality perception, and thus serves also as a (type 1) context factor (see section 3.3) influencing the user state based on his or her willingness-to-pay (cf. sections 2.3 and 2.4). Assuming limited resources for the underlying network, the authors then contrast a simple demand-based QoS feedback model (demand impacts QoS impacts price impacts demand etc.) with an extended model taking the additional feedback cycle between QoE and price (QoE impacts price impacts QoE etc.) into account. It is demonstrated that both cases result in fixed-point models of different complexity which, however, both are convergent due to the structure of the involved mappings. Thus, altogether, the model presented in [12] fits nicely into the general framework proposed in this paper.

4.4. Modelling Price Impact on Acceptance and Churn

The cost of winning a new customer is typically much larger than the cost of retaining an existing one. Thus service providers want to avoid churn even when the total number of customers is increasing. Churn is studied extensively in many business sectors, typically by regression analysis, neural network or decision trees [4]. The problem often is the limited information about the customers and their service experiences. For instance in [13], the most important variable that affected churn was Customer Service Calls. That is a plausible result, but does not give much information about the root cause of dissatisfaction and churn. In fact, there is hardly any study assessing the effect of QoE on churn; we may, however, assume that the effect of QoE on churn is mediated by overall satisfaction with the service, or in practice, by deep dissatisfaction, as discussed in section 3.3.

Price may have two-fold effects: high price may directly improve experience or it may create high expectations that then decrease satisfaction when the expectations are not fulfilled. Following our framework, dissatisfaction then is transformed to churn or to lower readiness to buy similar products from the same provider. Here, our framework allows dividing the long chain of analysis to several phases and then use general knowledge on each phase. Different variables including price influence QoE which in turn affect user satisfaction. The measured or estimated satisfaction can then be used for general churn models.

4.5. Modelling User Characteristic Impact on QoE

Defining the parameters of the Deterministic QoE Model (DQX) [15] has revealed the demand of modeling UB impact on QoE, such as user goal and/or tasks, as our above framework suggests. During MOS collection experiments, the collected MOS values concerning latency in a VoIP scenario seemed rather high. Three different conversational tasks that are proposed by ITU-T P.805 were tested: (a) a travel office role-play, (b) a random number verification task, and (c) a contacts exchange task. The results of these experiments were unexpected: For instance, the majority of the participants rated scenarios with 1500ms latency with a relatively high MOS value. It is assumed that this is due to certain cultural phenomena. As stated in ITU-T P.805, MOS can vary due to cultural differences. In this case, most experiment participants spoke Swiss German which is a rather "slow" language, therefore latency probably disturbs less. This hypothesis is supported by additional VoIP test calls between non Swiss German speaking participants (held in English). Here, conversations seem to be faster and more interactive, hence high latency apparently tends to disturb the experiment participants. DQX is aligned with the comprehensive framework for QoE and UB modeling presented here, since the reference value for each parameter can be specified as a parameter in DQX. E.g., maximum latency a specific end-user can tolerate at a given VoIP scenario.

4.6. Modelling Energy Consumption Impact on QoE

For mobile users, running out of battery is one of the worst experiences [4]. Thus, energy consumption is one of the most prominent (type 1) influence factors on QoE in the mobile context (cf. sections 2.1 and 3.3), potentially disturbing the user's well-being to a significant degree. In essence, it has been shown that it is important to deliver content with as little latency-related disturbance as possible in order to minimize the overall energy consumption; thus, optimized delivery (see section 3.1) goes along with both optimized QoE and energy consumption [4].

Mobile application design has shown to be a key parameter for energy consumption. Many mobile applications keep exchanging status messages even when running in the background, and thus, they keep the power-intensive radio communication parts up-and-running. By reducing the update frequency, savings can be obtained [2][4]; however, at the risk of a negative type 1 influence on QoE, as the user may have to wait for the updates.

With the aid of QoE studies and models, optimal saving strategies can be developed, with potential savings in the order of 20% [2][4]. In particular, [4] proposes switching off the radio part for data traffic while the user is inactive, and a fast wake-up when the user turns back its attention to the device. Comprehensive QoE models should address both (potentially negative) type 1 influences by the energy saving mechanisms as well as (potentially positive) compound influences due to the increased battery time.

4.7. Modelling Goal Impact on QoE

As a last example in the series of use cases, which illustrate our general framework, the authors in [10] have proposed an extension to the well-known E-Model (ITU-T G.107) for speech quality. The proposed extension incorporates the influence of the conversational context on the overall QoE (= speech quality in the context of ITU-T G.107, which translates to a QoE model output in our general framework, see section 2.1) of a considered call through a delay sensitivity parameter. This parameter is set according to the call purpose and the associated sensitivity to transmission delay, and hence constitutes a user factor (cf. section 2.3). Furthermore, the model allows estimating a delay sensitivity parameter passively from the interlocutors' conversational behavior (e.g. corrected speaker alternation rate or unintended interruption rate).

5. CONCLUSIONS AND OUTLOOK

In this paper, we have presented a novel framework for jointly modeling QoE and user behavior, where user behavior is treated as one of the framework dimensions along with system performance and user state. Our proposal allows to clearly separate the technical perspective of the system from the eudaimonical perspective of the user and the context-related behavioral perspective relevant for the service provider. At the same time, output factors can be easily structured with three different models (for QoE, user state and user behavior, resp.), whose mutual interrelations allow for a differentiated view on the interplay between the three key framework dimensions. This framework serves as a comprehensive umbrella for a plethora of related work, as is demonstrated by briefly discussing a set of seven use cases, which range from traditional QoE, user behavior, charging and pricing models over churn issues and the impact of user characteristics and goals up to problems related to energy consumption. As these examples represent only a small number of potential use cases to be covered by our framework, in our future work we will extend this analysis and additionally focus on capturing the mapping between influence factors and output dimensions in more detail.

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