A Multi-Dimensional View of QoE: the ARCU Model

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***Abstract*—Understanding and modeling the wide range of influence factors that impact end user Quality of Experience (QoE) and go beyond traditional Quality of Service (QoS) parameters has become an important issue for service and network providers, in particular for new and emerging services. In this paper we present a generic ARCU (Application-Resource-Context-User) Model which categorizes influence factors into four multi-dimensional spaces. The model further maps points from these spaces to a multi-dimensional QoE space, representing both qualitative and quantitative QoE metrics. We discuss examples of applying the ARCU Model in practice, and identify key challenges.**

I. Introduction

Quality of Experience (QoE) has, as of late, become a fashionable research topic. So much so, that a significant portion of work related to *Quality of Service* (QoS) in the literature also carries the "QoE" moniker. QoE, however, is a markedly different concept from that of QoS, and it goes beyond the scope of much of the current QoE literature. For the most part, the current usage of QoE refers to the perceptual quality of multimedia applications. Granted, for multimedia applications, perceptual quality is a very important component of QoE. However, QoE is a multi-dimensional concept, and it is not limited to the technical factors which we can measure, be it at the network level or the application level.

Increasingly, service and network providers are looking to identify and model the complex relationships between factors impacting QoE and the actual QoE as subjectively perceived by end users [1] [2] [3]. In addition to well understood QoS and application-level parameters, additional factors affecting QoE include the usage context and intent of usage of the service [4], service content [5], and the users' cultural, socio-economic and psychological state [6]. These, however, are seldom considered together and in depth in most available QoE literature.

In order to understand QoE for any given service and how to instrumentally estimate it, we need to take into account the different factors that affect QoE for the service in question, and map them to the QoE. There are several difficulties associated with this, namely:

- The list of potential factors that affect QoE is very long, and the most relevant factors need to be identified for each service.
- Some of the factors, in particular those related to the context of usage and the user, are difficult, and in some cases impossible, to measure instrumentally.
- QoE is a multi-dimensional concept, and thus the mapping of the quality affecting factors to the QoE is a rather complex proposition.

In this paper, we propose a novel way to model the quality-affecting factors and their relationship to QoE, for different types of services. The proposed model splits factors into different multi-dimensional spaces, according to their type, and establishes a mapping between those factors and points in an also multi-dimensional QoE space.

The rest of the paper is organized as follows. In Section II we discuss related work on this topic. Section III describes the proposed model in detail. In Section IV we discuss the practical issues associated with applying the proposed model to actual services, and provide examples of how the model can be applied. Finally, we conclude the article and provide future research directions in this domain in Section V.

II. Related Work

While the ITU-T defines QoE as the "overall acceptability of an application or service, as perceived subjectively by the end user" which "may be influenced by user expectations and context" [7], a common definition cited by the research community defines QoE as "the degree of delight of the user of a service, influenced by content, network, device, application, user expectations, and goals, and context of use" [8].

Existing studies have proposed classifications of factors impacting QoE, often termed *QoE influence factors*, for various types of multimedia services [9], [1], [2], [5], [10]. While a factor is a characteristic which influences QoE, it is not a part of the perceived QoE itself. Extensive work on factor classification has been performed by S. Jumisko-Pyykkö [11] in the form of a User-Centered Quality of Experience (UC-QoE) model where characteristics of the user, system/service, and context of use are identified as contributing to different experiential dimensions of QoE.

In addition to understanding what impacts QoE, there is a need to understand and model what constitutes QoE, in terms of different subjective and objective quality metrics that can be identified and perceived by end users [12]. Determining the correlation between influence factors and quality dimensions has proven to be a challenging task.

A large number of studies have modeled the correlation between QoS and QoE [13], [2], [14], [15], [16], however often focusing only on overall user perceived quality (often in terms of a Mean Opinion Score, MOS [17]). Wu et al. [6] have gone on to study the correlation of different dimensions of QoS and QoE, in particular for distributed interactive multimedia environments, identifying the degree to which different QoS factors impact different QoE dimensions.

The notion of considering QoE as a multi-dimensional value has been addressed in a number of approaches. In the context of multimodal human computer interaction, S. Möller et al. [18] relate influence factors and performance metrics with QoE aspects (quality dimensions), including e.g., interaction quality, efficiency, usability, aesthetics, utility, and acceptability. Wälterman et al. [19] study quality dimensions related to speech transmission, and further model integral listening quality in terms of the identified dimensions.

The idea of mapping points in multi-dimensional spaces from one space to another has been used in the past in the context of utility-based multimedia adaptation [20], where points in an adaptation space (representing multimedia adaptation operations) are mapped to resource and utility spaces. Such mappings are also used in the scope of the MPEG-21 digital item adaptation (DIA) [21] standard to be used for making multimedia content adaptation decisions.

III. The ARCU Model

In this section, we build on prior knowledge by proposing a generic QoE model independent of a particular service type. We model QoE influence factors as falling into one of the four following multi-dimensional spaces:

1) *Application space* (A): composed of dimensions representing application/service[1] configuration factors. Examples of such factors include encoding, resolution, sample rate, frame rate, buffer size, SNR, etc. Content type is also a key factor to be considered (e.g., in the case of video, action movie with fast scene changes vs. more static news report).
2) *Resource space* R: composed of dimensions representing the characteristics and performance of the technical system and network resources used to deliver the service. Examples of such factors include network performance in terms of delay, jitter, loss, and throughput. Furthermore, system resources such as server processing capabilities and end user device capabilities (e.g., CPU power, memory, screen resolution, user interface) are included.
3) *Context space* C: composed of dimensions indicating the situation in which a service or application is being used. A wide variety of dimensions may be considered in this category, include ambient conditions (e.g., lighting conditions, noise), user location, time of day, and social context. Furthermore, the task (or purpose) related to using a given application is considered. Dimensions representing economic context may also be considered, such as service costs.
4) *User space* U: composed of dimensions related to the specific user of a given service or application. Example factors include demographic data, user preferences, requirements, expectations, prior knowledge, mood, motivation, specific task/behaviour, etc.

[1]We will use the terms application and service interchangeably throughout the paper, unless otherwise noted.

As compared to previous classifications, we believe that it is beneficial to distinguish between factors related to the actual application and media configuration parameters, from the network/system resources, as these sets of parameters my be considered and varied independently and by different actors.

The proposed model is illustrated in Fig. 1. Dimensions in each of the spaces may correspond to different types of scales, such as e.g., ordinal, interval, and ratio scales. We denote $\mathsf{ARCU} = \mathsf{A} \oplus \mathsf{R} \oplus \mathsf{C} \oplus \mathsf{U}$, and refer to the ARCU space when considering all QoE-affecting factors. Points from the ARCU space are further mapped to points in a *QoE space*. The QoE space is composed of dimensions representing different quantitative and qualitative quality metrics which can be perceived by an end user (e.g., perceptual quality / MOS, ease-of-use, efficiency, comfort, etc.).

A slight conceptual hurdle needs to be dealt with when considering the quality-affecting factors as dimensions in the ARCU space and the A, R, C and U spaces themselves. While conceptually, all the quality affecting factors can be seen as independent of each other, in practice, there often exists a correlation between different subsets of parameters, both within a space (e.g. loss rates and delays in networks tend to be correlated), and across spaces (for example, using a mobile service is an instance in which the context of usage might create bounds for network resources). This would imply that the spaces themselves are not actually spaces, as they don't have orthogonal bases. We model this by introducing a function $\mathcal{V}$ that defines a set of valid regions in the ARCU space by taking into account these correlations, and conforming to reality.

$$\mathcal{V} : \mathsf{ARCU} \to \{1, 0\}$$

$$\mathcal{V}(a, r, c, u) = \begin{cases} 1 \,\text{if}\ (a, r, c, u) \text{ is valid} \\ 0 \,\text{otherwise} \end{cases}$$

for all $\{(a, r, c, u) | (a, r, c, u) \in \mathsf{ARCU}\}$

The *Mapping Function* (MF) can be considered as a function $\mathrm{MF} : \mathsf{ARCU}_{\mathcal{V}} \to \mathsf{QoE}$, where $\mathsf{ARCU}_{\mathcal{V}}$ denotes the valid regions of ARCU under the constraints of $\mathcal{V}$, invoking different QoE assessment methods depending on the type of application. In the case of objective quality assessment, it can feed relevant input parameters to standardized (provided they exist) models to determine values for a given QoE dimension (metric). In the case of subjective assessment, it will correlate input parameters with user specified QoE.

Following the mapping to a QoE space, we can consider how to then go from a point in a multidimensional space to a measure of integral QoE. The term "integral quality" may be used when the quality due to the totality of quality dimensions (or features) is considered [22]. The overall evaluation of subjective user perceived quality should be based on a weighted, possibly non-linear, combination of quality evaluation metrics (dimensions). If we are using a set of evaluation metrics to evaluate QoE, the issue to determine is how much and in which way each metric contributes to integral QoE.

If we assume that the QoE space is composed of dimensions $q_1, ..., q_n$ with corresponding weight factors assigned as $w_1, ..., w_n$, then we can express $QoE_{Integral}$ as the following

$$QoE_{Integral} = f(w_1 q_1, ..., w_n q_n)$$

Different metrics may be of different relative importance (depending on application purpose / type of application, user task, user preferences, etc.), and hence be assigned different weight factors. For example, an evaluation of the QoE metric "content reliability" is very important for an eHealth application and contributes in large to overall QoE, while evaluation of the same metric contributes to a smaller degree to the overall QoE of a gaming application.

IV. Service Examples

The aim of the proposed model is to provide a systematic and generic view of modeling QoE. A number of challenges need to be addressed related to applying the proposed model in practice, including the following:

- Identification of relevant influence factor dimensions and relevant QoE dimensions for different types of services and applications (e.g., VoIP, streaming multimedia, multi-user networked environments, Web applications, Cloud-based applications, etc.). A challenge related to identifying QoE dimensions will be to cover as many dimensions of user perceived quality as necessary to further enable a reliable estimation of integral QoE.
- Specification of the mapping functions calculating QoE dimensions based on influence factors. In many cases, regression techniques or other machine learning tools such as neural networks (as in [16]) can be used, but the amount of training data required might prove too large for practical application in some instances.
- Specification of integral QoE as a weighted combination of QoE dimensions, taking into account the possibility of different dimensions being represented with different scales. In addition, calculation of integral QoE in the case of a service comprised of multiple modalities, e.g., audio and video (in such cases integral QoE would be considered as a function of the QoE of individual modalities, as studied previously by Prangl et al. [23]).

While more detailed investigation into each of these challenges is out of scope for this paper, we provide an illustrative example set of model dimensions for different service types, as shown in Table IV.

The first example we consider is that of a one-way streaming video service. Relevant dimensions of each of the ARCU sub-spaces are shown in the table. Content type may refer to video sequences differing in Spatial Information and Temporal Information indexes [24]. The characteristics of the device on which the content is displayed are also critical for the user's perception of quality, and are thus also considered. The user's motivation when watching video (e.g. entertainment vs. distance learning) can also play a significant role in how quality is assessed. Example QoE dimensions are listed as being color quality, blurriness, jerkiness, and blockiness. Integral QoE may then be considered as being a function of such dimensions, whose coefficients will be related to the weighted impact of each of the dimensions on integral QoE. For example, a given study may indicate that increased video jerkiness will have a greater impact on integral quality then blockiness.

In the second example, we list input dimensions and QoE dimensions related to a two-way conversational VoIP service. Detailed analysis of factors influencing VoIP quality and the correlation with a set of proposed QoE dimensions can be found in the work done by Wälterman et al. [19], while a mapping of several network- and application-level parameters into conversational quality was done by Couto da Silva et al. in [15]. Wältermann's study shows concrete coefficients (weight factors) assigned to multiple dimensions for narrowband and wideband VoIP, and further used for calculation of integral QoE. For example, of three identified QoE dimensions for narrowband speech transmission, the authors conclude that "discontinuity" is of greatest importance for integral quality, followed by "noisiness" and "coloration".

In the third example, we consider a multiplayer gaming scenario. Application related parameters which are listed are factors specific to networked gaming and / or networked interactive environments. Game mechanics refer to the game design and functional mechanisms. Different levels of cheating protection may be implemented, on one hand securing fair play, while on the other hand in certain case slowing down game play. With regards to system and network resources, input device capabilities play a critical role. Context parameters encompass the situation in which the game is being used. Extensive research on categorizing different user tasks (e.g., trading, peer-to-peer combat, raiding, etc.) in Massively Multiplayer Online Role Playing Games (MMORPGs) and their relationship with network requirements has been reported in [25]. With

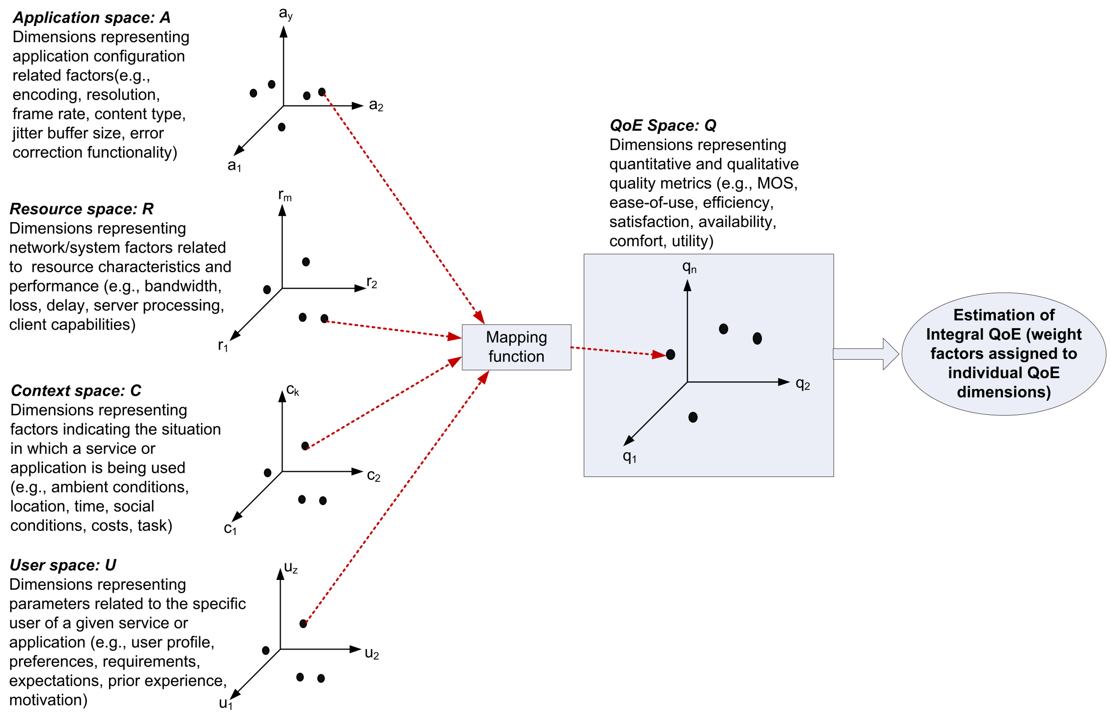

Fig. 1. The ARCU Model

regards to end user parameters, game experience and player motivation are key QoE influence factors. The QoE dimensions listed are in part taken from a categorization of user perceived quality metrics related to networked virtual reality services in general [26] (interactivity, immersion, and plausibility - user acceptance of events as reasonable and valid). A weighting of the individual dimensions would in large part depend on the gaming scenario, for example with user perceived quality of highly interactive combat games relying most heavily on perception of real-time interactivity, whereas a strategy game may rely more on plausibility or immersion.

V. Conclusions and Future Work

The proposed model is intended to provide a basis for the systematic identification of QoE influence factors and understanding of their relationship with different dimensions constituting parts of the overall QoE. Ongoing work is targeted at studying identification and specification of QoE dimensions and integral QoE functions for different types of services, additionally taking into account the temporal nature of QoE. We are further looking to address the issue of modeling QoE in the case of multimedia services composed of multiple media components.

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Service example	Input Dimensions				QoE dimensions
	A	R	C	U	
Streaming video	codec frame rate resolution playout buffer size content type spatial information index	throughput delay jitter loss rate loss burstiness device CPU device resolution device memory display brightness display color depth	user mobility location lighting conditions service cost	age motivation gender	color quality blurriness jerkiness blockiness
VoIP	codec bit rate FEC echo cancellation loss concealment	throughput delay jitter loss rate loss burstiness audio rendering (headset / handsfree)	ambient noise user mobility service cost language	age motivation gender hearing level	intelligibility clipping talking quality conversational quality listening quality coloration noisiness
Multiplayer gaming	game genre scene update rate dead reckoning algorithms game mechanics cheating protection	throughput delay loss rate device CPU display resolution GPU power device memory	number of players player environment playing task	age gender skill player class motivation	interactivity immersion enjoyment plausibility

TABLE I
Example set of model dimensions for different services

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