

Quality of Experience (QoE) Studies: Present State and Future Prospect

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SUMMARY With the spread of the broadband Internet and high-performance devices, various services have become available anytime, anywhere. As a result, attention is focused on the service quality and Quality of Experience (QoE) is emphasized as an evaluation index from the user's viewpoint. Since QoE is a subjective evaluation metric and deeply involved with user perception and expectation, quantitative and comparative research was difficult because the QoE study is still in its infancy. At present, after tremendous devoted efforts have contributed to this research area, a shape of the QoE management architecture has become clear. Moreover, not only for research but also for business, video streaming services are expected as a promising Internet service incorporating QoE. This paper reviews the present state of QoE studies with the above background and describes the future prospect of QoE. Firstly, the historical aspects of QoE is reviewed starting with QoS (Quality of Service). Secondly, a QoE management architecture is proposed in this paper, which consists of QoE measurement, QoE assessment, QoS-QoE mapping, QoE modeling, and QoE adaptation. Thirdly, QoE studies related with video streaming services are introduced, and finally individual QoE and physiology-based QoE measurement methodologies are explained as future prospect in the field of QoE studies.

key words: *QoE, QoS, video streaming, user experience, personalization, physiology*

1. Introduction

Owing to broadband networks and high-performance user devices, Internet services have become rich and diverse including video streaming, virtual reality, and cloud gaming. Because they are “services”, concerns of service providers lie in securing service quality they provide. On the other hand, customers also evaluate a service by its quality. Therefore, tremendous effort has been provided to measure and improve the service quality.

Quality of Experience (QoE) has been attracting attention to study the service quality from the user's point of view for ten years or more. QoE is a subjective metric about the overall service quality reflecting user perception, expectations, and experience for the service [1], [2]. Since QoE deals with the subjective matters, it is difficult to establish a generic theory or model. However, since much effort has been devoted to QoE research so far, a holistic understanding of service quality has progressed and individual research topics have been clarified. In this paper, QoE measurement, QoE assessment, QoS-QoE mapping, QoE modeling, and

QoE adaptation are discussed as the research topics.

QoE is also important in the business domain. Under limited resources, service providers try to deliver appropriate service quality to individual users. When user tolerance for quality impairments is decreasing because of infrastructural limitations, it influences users' choice in adopting one service provider over the other [3]. Therefore, service providers have to focus on QoE to retain customers. The providers monitor the customers' QoE and control the QoE mechanism to prevent the customers from abandoning their service because of QoE deterioration.

Since fifth generation mobile communications (i.e. 5G) has come into practical use and 45% of all networked devices will be mobile-connected by 2023, population of mobile Internet users is expected to increase more. Since the average 5G speed will be 575 Mbits/s, video streaming is becoming one of the most popular services over mobile networks [4]. As a result, according to [5], video streaming will occupy 82% of all consumer Internet traffic by 2022, which was 75% in 2017. Thus, video streaming service, especially in a mobile environment, must be a promising Internet service. Service and network providers have to pay more attention to building services based on QoE. In addition, not just from a business perspective, QoE research for the video streaming service will be conducted actively as one of vibrant study areas. To that end, QoE research field is growing as an interdisciplinary study. Since we have to grasp user's satisfaction, feeling, complaint, and so on, collaboration with other research fields including usability engineering, psychology, and biometrics must be activated more and more [6], [7].

This paper is organized as follows. The historical aspects of QoE are reviewed in Sect. 2. In Sect. 3, QoE research is divided into several individual research topics and respective topics are discussed. Among various Internet services, Sect. 4 overviews QoE research for the video streaming service as a future popular and promising service. After future prospect of QoE study is briefly discussed in Sect. 5, Sect. 6 concludes this paper.

2. Historical Aspects of QoE

Through discussion on the service quality started in the field of telephony at the end of the 20th century, ITU-T (International Telecommunication Union Telecommunication Standardization Sector) defined the terminology “QoS (Quality of Service)” as “Totality of characteristics of a telecommu-

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nications service that bear on its ability to satisfy stated and implied needs of the user of the service” [8]. Although we notice that “the user needs” were already included in the definition, QoS has gradually become the metrics to measure system (especially network) performance. For example, Karim et al. [9] specified bandwidth, transmission, packet loss, and delay as QoS metrics for video quality. As a result, more user-centric concept for the service quality was introduced as “Quality of Experience (QoE)” in ITU-T Recommendation P.10/G.100 Amendment 1 in 2007 [10]. The evolution from QoS is that “Service” has changed to “Experience”. The origin of the term “Experience” is related with “User Experience (UX)”, which is defined in ISO 9241-210:2019 [11], for example, as follows:

user’s perceptions and responses that result from the use and/or anticipated use of a system, product or service.

Namely, including “Experience” in QoE clearly demonstrates the shift to the user’s perspective. Consequentially, although QoE comes from the telecommunication field and UX comes from Human-Computer Interaction field, both focus on human perception in common.

According to the above consideration, The EU QUALINET community [12] has defined QoE as follows:

A measure of user performance based on both objective and subjective psychological measures of using an ICT service or product. Quality of Experience is the degree of delight or annoyance of the user of an application or service. It results from the fulfilment of his or her expectations with respect to the utility and / or enjoyment of the application or service in the light of the user’s personality and current state.

Additionally, it should be kept in mind that the following description was given under the definition: “In the context of communication services, QoE can be influenced by factors such as service, content, network, device, application, and context of use”.

On the other hand, Study Group 12 of ITU-T discusses the definition of QoE continuously. The initial definition of QoE agreed by ITU-T in 2007 was as follows [10].

The overall acceptability of an application or service, as perceived subjectively by the end-user.

NOTE 1 -

Quality of Experience includes the complete end-to-end system effects (client, terminal, network, services infrastructure, etc.).

NOTE 2 -

Overall acceptability may be influenced by user expectations and context.

Recently, this QoE definition has been replaced as the degree of delight or annoyance of the user of an application or service [13]. It is partially but completely consistent with

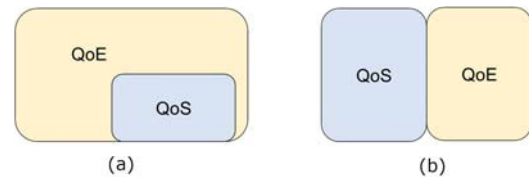


Fig. 1 Relation between QoS and QoE.

the definition of the EU QUALINET community, because the new definition is affected by discussions in QUALINET. The review of the QoE definition has, however, been done constantly in ITU-T, and the above definition is the latest at the time of writing this paper.

Considering these standardization activities, Yang et al. [14] summarized that QoE is a kind of subjective perception generated by users in the interaction process between users and services or applications, or QoE can be considered as the overall recognition degree of the employed services or operations in a certain objective environment. Apparently, the end user is the decision-maker for service quality.

From the above definitions, QoE can be considered as an extension of QoS based on a user’s viewpoint. This concept is depicted as Fig. 1(a); QoE is overall evaluation of a service including QoS elements. On the other hand, QoE is sometimes considered in contrast to QoS. For example, Dong et al. [15] grasped QoE as a new concept related to but differing from QoS perception. This idea corresponds to a concept shown in Fig. 1(b), which has advantages in modeling QoE and QoS. Both of Fig. 1(a) and (b) are correct, and both concepts are used in a mixed way in this paper. This is because a unified definition or scope of QoE is not available through different communities yet; the situation is almost the same one as described in [1].

3. QoE-Related Research Issues

Although a lot of researchers have contributed to QoE-related research, their approaches were different from each other more or less, since their contribution depends on their respective research area such as communication network, media, content, context, and so on [16]–[18]. Moreover, different applications have different QoE requirements (also including different QoS-dependencies). Thus, there are still difficulties to realize and deploy a holistic research basement and common communication services based on QoE.

Nevertheless, through the previous research, the architecture of end-to-end QoE management has been clarified and the architecture can be divided into several research topics. This paper focuses on four research topics: QoE measurement, QoS-QoE mapping, QoE modeling, and QoE adaptation as shown in Fig. 2. QoE measurement, which is called QoE assessment or QoE evaluation in some cases, is the initial method to evaluate QoE assessment. Next, QoS parameters and QoE measurement results are associated by QoS-QoE mapping and QoE models are constructed based on the QoE factors that influence QoE evaluation and the

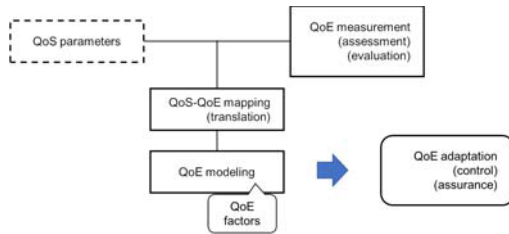


Fig. 2 QoE-related issues.

Table 1 An example of MOS scale and corresponding quality.

MOS scale	Quality
5	Excellent
4	Good
3	Fair
2	Poor
1	Bad

above-mentioned results. QoS-QoE mapping is also called QoS-QoE translation. Finally, QoE models are utilized to adapt and guarantee QoE or to control QoS parameters according to the service or system object. This process is called QoE adaptation, control, or assurance. This paper uses the terms of QoE measurement, QoS-QoE mapping, QoE modeling, and QoE adaptation mainly, and each research topic is discussed one by one in the following subsections.

3.1 QoE Measurement

Returning to the latest QoE definition of ITU-T, it is the degree of delight or annoyance of service for the user [13]. Accordingly, the best way to know the user's satisfaction degree is to inquire it of the user.

There are generally two main QoE measurement methodologies: subjective and objective approaches [2], [3], [19], [20]. The most common subjective approach is the Mean Opinion Score (MOS), which is defined by ITU-T [21]. As a typical subjective QoE measurement, a group of users experience a provided service, evaluate it, and rate the service on a MOS scale. Common guidelines for conducting subjective measurement are issued by ITU-R (International Telecommunication Union Radiocommunication Sector) [22]. An example of the MOS scale is provided in Table 1.

One of the drawbacks of the subjective approach is that it is costly and time consuming to gather a number of users. Moreover, the subjective tests should be experimented in a controlled laboratory environment.

Zhu et al. [3] pointed out two inconveniences for lab-based experiments in addition to costly and time-consuming points. One is that the demography of the users is often not representative of the general population, and the other is that the laboratory environment often fails to simulate the real-life environment. Subsequently, they suggested Internet-based subjective experiments which utilize Web sites, social media, and/or crowdsourcing platforms [23]. Niida et

al. [24] developed Web-based mobile services and studied the end user perception of the waiting time for Web access. They conducted Internet-based field experiments to collect MOS as a metric of subjective quality of user satisfaction.

On the other hand, Seshadrinathan et al. [25] recruited 38 subjects to assess video quality by the difference mean opinion scores (DMOS). Then they used the subjective DMOS results to evaluate several objective video quality assessment algorithms using Peak Signal-to-Noise Ratio (PSNR) and so on. PSNR is used to detect video signal distortions pixel by pixel. Also, some service quality estimation from several network parameters is another example and it is related with QoS-QoE mapping in Sect. 3.2.

Another QoS measurement related with the objective approach was presented by Yamazaki et al. [26]. Since subjects usually evaluate service quality at a stationary time during or after experiments, it is normally difficult to evaluate time-varying video quality. Yamazaki et al. developed a tool to record the subjective video quality evaluation continuously during video playing. Simultaneously, the user's objective quality evaluation was recorded by physiological measures. In their experiments, Skin Conductance Activity (SCA) was measured as the objective quality evaluation. The value of SCA changes depending on skin sweating and is suitable to measure the degree of psychological stress. They recorded QoE and SCA data for video streaming services simultaneously. The video streaming was deteriorated by abrupt playback pause. After the measured QoE and SCA signal data are analyzed by the two-way analysis of variance, it has been clarified that they are correlated and differentiated by the video category and the playback pause period.

Through exhaustive survey of QoE research, it is found that QoE assessment is used with exactly the same meaning as QoE measurement. For example, Huang and Ishibashi [27] and Hofffeld et al. [28] used QoE assessment instead of QoE measurement. Barman and Martini [29] referred QoE assessment as the process of measuring or estimating the QoE and described that the main objective of QoE assessment is the design of a system which can identify the various factors and their influence on the end user QoE. In this way, one idea is that the role of QoE assessment should be judgement for the user QoE, whereas QoE measurement is just to collect QoE data from the users.

3.2 QoS-QoE Mapping

Based on the concept shown in Fig. 1(b), it is assumed that user QoE can be separated from the QoS parameters that demonstrate system performance. The QoS parameter examples are packet loss rates and delays in the network layer and frame rates and resolutions in the application layer. The QoS-QoE mapping means relationship between the QoS parameters and QoE evaluation. The QoS-QoE mapping is sometimes called the QoS-QoE translation. Hofffeld et al. called their method as QoS-to-MOS mapping because they used MOS rating as QoE evaluation [30]. Although the

QoS-QoE mapping can be bi-directional in principle, it is often used to provide QoE evaluation from available QoS parameters.

Before the term “QoE” arises, several layered QoS models were proposed to separate the user side from the system side and an interface between both sides was defined [31]–[33]. The function of the interface connecting the user and system sides was called QoS mapping.

As the conventional QoS mapping methods were categorized into two classes [34]: a table-based mapping (e.g., [35]) and a function-based mapping (e.g., [36]), the QoS-QoE mapping also have these two categories. The table-based mapping makes use of QoS mapping tables of sample data which are prepared in advance. On the other hand, the function-based mapping uses mathematical functions for mapping that derive an appropriate output for an input; none the less, the challenge is how to determine the type or the dimension of the function. In effect, the function-based mapping is major in these days.

The function-based QoS-QoE mapping method normally derives a mapping function with QoE as an output objective variable and the QoS parameters as input explanatory variables. Concrete QoS-QoE mapping instances are presented in the below.

Benmir et al. [37] selected packet loss rate, jitter, and delay as the explanatory variables and computed QoE evaluation from these explanatory variables. The formula of computation originated from [38]. Then the computed QoE was converted to MOS.

Georgopoulos et al. [39] studied video quality in a video streaming service. They selected resolution and bit rate (kbps) in a log scale as explanatory variables. As a corresponding objective variable, they selected the Structural Similarity (SSIM) index that is a functional model of the human visual system. They specified the function type and computed its coefficients by matching sample data with the function type.

Egger et al. [40] derived a slightly different mapping function from the above two cases. They studied psychological perspective on the waiting timing and brought over the Weber-Fechner law. The Weber-Fechner law is a psychological stating that the perceived intensity of a sensation is proportional to the logarithm of the stimulus. In their research, the waiting timing corresponds to the stimulus and the perceived intensity corresponds to QoE. They dealt with simple waiting tasks such as file downloads, where the waiting time was considered as an explanatory variable and the user’s perception is considered as an objective variable.

Finally, a more recent approach using Machine Learning (ML), that is an ML-based mapping, is introduced. Menkovski et al. [41] constructed QoE prediction models that determine the user thresholds of acceptability for the QoS parameters. The QoS parameters were time (s), video bit rate (kbit/s), audio bit rate (kbit/s), and frame rate (frames/s). Using the datasets, QoE prediction models were constructed by two ML methods: the Decision Tree (DT) and the Support Vector Machine (SVM). For their case, the

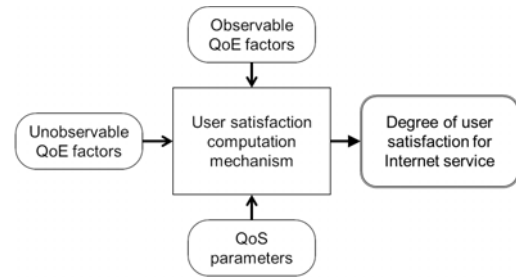


Fig. 3 A QoE model - a service quality coordination model.

DT outperformed the SVM. Alreshoodi and Woods also cited the previous studies of QoE prediction models using several ML methods including the DT and the SVM [2].

3.3 QoE Modeling

In this paper, QoE modeling is defined as specifying the elements that influence QoE evaluation and clarifying their mutual relationship. The influential elements for QoE evaluation are called the QoE factors. Although the QoE factors depend on the issues dealt with and there are a great variety of QoE factors, some classification of the QoE factors has been proposed.

Figure 3 presents a QoE model introduced in [42]; In the original literature, it was called a service quality coordination model. It is a relatively simple and abstract model, so that it is adaptable for any service situation. The user satisfaction computation mechanism is located in the center of the QoE model with the QoS parameters and the QoE factors as its inputs. After the computation, a degree of user satisfaction for the telecommunication service is provided as the output. The QoS-QoE mapping function is one of the essential realization of the model.

In Fig. 3, the QoE factors are divided into two types: observable and unobservable. The observable QoE factors are defined as the QoE factors that can be observed and parameterized directly. On the other hand, the unobservable QoE factors are defined as the one that cannot be parameterized easily. For example, the type of content such as video or audio and the media-related parameters (e.g., frame rates and resolution) can be specified as the observable QoE factors. Meanwhile, relationship and synchronization among different media are difficult to be parameterized automatically. Here, synchronization means temporal relationships between different kinds of media presented to a user. When the presentation timings are identified, these media are considered to be synchronized. Without time stamps, it is normally difficult to be parameterized. In many cases, the QoE factors are considered as unobservable.

Although there is no unified and decisive classification of the QoE factors, a few studies indicate the classification of QoE factors. Barman and Martini [29] cited the QoE factors as “any characteristic of a user, system, service, application, or context whose actual state or setting may have an influence on the Quality of Experience for the user” [12],

and categorized them into four categories of Influence Factors (IFs):

1. System IFs which mostly consist of the technical aspects of quality, for example, the ones which can be measured using QoS based measurement approaches.
2. Human or User IFs which include aspects referring to the information about the end user and related aspects.
3. Context IFs which deal with factors such as location, end user environment, time of the day, type of usage, time of service consumption.
4. Content IFs which address the characteristics of the content.

Skorin-Kapov and Varela [43] built a generic QoE model called the ARCU (Application-Resource-Context-User) Model independent of a particular service type. In this model, they defined four multi-dimensional spaces including the QoE influence factors.

1. Application space A: it is composed of dimensions representing application/service configuration factors.
2. Resource space R: it is composed of dimensions representing the characteristics and performance of the technical system and network resources used to deliver the service.
3. Context space C: it is composed of dimensions indicating the situation in which a service or application is being used.
4. User space U: it is composed of dimensions related to the specific user of a given service.

These four spaces can correspond to the four IFs one by one in [29].

Zhu et al. [3] also extracted the system factors and the context factors as the QoE factors as follows:

System factors

These determine service quality from the system aspect. For example, visible artifacts such as blockiness, blur, and ringing are the factors in the application level. The network QoS parameters such as buffer ratio, buffering duration, and average bit rate belong to them.

Context factors

These are the factors that influence user situation. They entail characteristics of the physical environment, the presence (in situ or remote) of other users experiencing the same media, or economic conditions regulating for the service fruition.

In addition, user factors were also introduced in [3], which are shortly introduced in Sect. 5.

Focusing on video streaming and with reference to [12], [14], Benmir et al. [44] grouped the QoE factors in three categories: human, system, and context influence factors (IFs).

1. Human IFs are any property or characteristic of a human. They could be divided into two subgroups. The

first is the low-level IFs such as age, gender, personality and mood. The second is the high-level IFs such as socio-economic conditions, educational background, needs, previous experience and life stage. Examples of Human IFs are gender, age, and educational background.

2. System IFs refer to properties and characteristics that determine the technically produced service quality. They could be classified into content-related, media-related, network-related, and device-related factors. Examples of System IFs are delay, loss, and resolution.
3. Context IFs consider the environmental factors associated with the user. Their classification includes six subgroups: physical factors, time factors, social factors, economic factors, factors associated with task assignments, and technical factors. Examples of Context IFs are location, cost, and frequency of use.

3.4 QoE Adaptation

After measuring, assessing, and modeling QoE for an Internet service, the final purpose is to provide optimal QoE for the end users. As seen in the QoS-QoE mapping, QoE tightly correlates with QoS parameters that control system performance. More concretely the network and application parameters should be adjusted to maximize the end user QoE within the constraints of available resources, since the goals of network management are efficient resource allocation typically [45]. Thus, system resource management based on QoE is called QoE adaptation, QoE control, or QoE assurance.

Dai [1] advocated QoE-based QoS engineering, where the service quality was expected to be improved by network resource optimization. Its target was to maximize the user experience while reducing network costs concurrently. Although a top-down approach for QoE-based QoS engineering was proposed as an algorithm, there was no substantive instance.

Georgopoulos et al. [39] introduced an OpenFlow-assisted QoE Fairness Framework (QFF). The object of QFF was to optimize the QoE for all video streaming users, i.e. to fairly maximize users' QoE. OpenFlow allows vendor-agnostic functionality to be implemented for network management and active resource allocation. They constructed a home network environment testbed, where an OpenFlow switch connected several PCs that imitated user devices in the home network environment. The home network was connected to an HTTP Web server via Internet. The experimental results demonstrated that QFF provided network stability and optimized video streaming QoE across three heterogeneous user devices in the home network environment.

Kwon et al. [46] proposed an adaptive mobile VoIP (mVoIP) service architecture based on network QoS and mVoIP QoE data in SDN (Software Defined Network) networks to improve mVoIP QoS. They presented two key ap-

proaches: flow path optimization for mVoIP traffic using the SDN controller and the adaptive codec selection method. However, only an algorithm was offered to realize the proposed architecture.

Huong Pham-Thi et al. [47] also proposed a bandwidth allocation method considering user characteristics. In this research, they classified users into different groups based on their characteristics such as relaxed or busy. Then different utility functions, that is QoS-QoE mapping functions, are assigned for each user group differently. Under the resource limitation, the bandwidth of the sharing network was properly assigned for the user groups respectively.

4. QoE-Based Video Streaming

As described in Sect. 1, video streaming traffic, particularly in mobile, is growing in volume. Continuously, video streaming is expected to expand on the business side. Therefore, video streaming services have been the focus of attention as the service to introduce the QoE adaptation.

Before the popularity of video streaming increased, standardization activities progressed for objective quality assessment of audio and visual media, IPTV services [48]. The media-layer models in the standardization activities are just briefly referred to in this paper. There are three objective video quality assessment methods: full-reference (FR), reduced-reference (RR), no-reference (NR). FR methods extract the quality difference by comparing the source reference video signal and its processed counterpart, assuming that the undistorted reference signal is fully available. RR methods extract some features of the source reference and its counterpart videos and compare them to offer a quality rating. NR methods assess the quality of a processed or distorted video without any reference signal. Due to the absence of a reference signal, video quality assessment must be more difficult than FR or RR.

Considerable and rapid progress for QoE-based video streaming services is also observed in the area of research and development.

Zhu et al. [3] were motivated to devise accurate tools to measure the extent to which the user deems the multimedia experience to be of a high quality, because resource scarcity makes flawless delivery more challenging. Consequently, they developed a Facebook application YouQ, for the collection of individual video QoE data. These are multiple advantages of YouQ.

- It can reach users with diverse demographics in real-life viewing environments.
- It can collect user information automatically from Facebook.
- It allows checking for user reliability at every stage of the experiment.
- It is open-sourced for research. Researchers are free to edit the set of stimuli and questionnaires based as need be.

Zhu et al. have more interests for “individual QoE” that is

discussed in Sect. 5.

Recently, HTTP adaptive streaming (HAS) has gained much attention [29]. HAS is currently used by the major video streaming services such as Netflix and YouTube. Therefore, many research works have focused on developing QoE models targeting HAS-based applications. Also, The ITU-T Recommendation series P.1203, known as P.NATS, describes a parametric bitstream-based model for the quality of progressive download and adaptive streaming based applications over a reliable transport protocol such as TCP [49]. In this context, Yamagishi and Hayashi [50] presented a quality model which was submitted as part of the competition for the ITU-T Recommendation series 1203.

Video streaming services are discussed as a mobile environmental service. Benmir et al. [37], [44] discussed on video streaming services over Vehicular Ad-hoc Networks (VANETs). VANETs are a class of Mobile Ad-hoc Networks (MANETs) [51] and are designed for communication between vehicles (V2V) or between vehicles and road infrastructure (V2I) [52]. One of the promising services implementing on VANETs is video streaming services for traffic safety or entertainment.

Firstly, Benmir et al. [44] surveyed a large number of previous works and concluded that the previously proposed models had many limits and drawbacks. For example, few proposed models were dealing with QoE over VANETs, the relationship between QoE and its influencing factors was complex and nonlinear, and only a limited number of influencing parameters were considered in the previous models.

Then, Benmir et al. [37] proposed a QoE-aware geographic protocol for video streaming over VANETs. In the proposed protocol, the selection process of the next relay vehicle was based on a correlated formula of QoE and QoS factors to enhance the users’ QoE. They evaluated the proposal by computer simulation. The simulation results showed that the proposed protocol outperformed two existing protocols in providing the best user QoE of video streaming service.

5. Future Prospect

As future prospect, two research topics in QoE measurement are considered. One is individual QoE, or personalize QoE, and the other is physiology-based QoE measurement.

MOS is one of the popular schemes to obtain subjective QoE evaluation and has been used as one of the standardized methods in subjective experiments so far. Zhu et al. [53], however, pointed out QoE measured through MOS is perceived by an “average user”. Individual preferences have mostly been neglected, due to the inherent difficulty in dealing with quantifying and measuring individual characteristics. Accordingly, they conducted experiments to mimic users’ viewing experience in real life and reflecting users’ natural behavior by using a Facebook application YouQ described in Sect. 4. They performed the YouQ experiments in two different sessions. With 136 subjects in the online environment and 20 subjects in the laboratory environment, they

concluded that individual QoE evaluations collected through YouQ were consistent with those reported in the previous literatures [53], [54].

Necessity of the individual QoE, it is underpinned by the strong assertion “There is no such thing as an “average” user” by Zhu et al. [3]. Although it has not progressed to individual adaptation of each person, Huong Pham-Thi et al. [47] classified users into several groups with different personalities. Consequently, resource allocation by the user groups with different utility functions outperformed homogeneous user setting, that is a group of average users. Personalization of service must become the next research target in QoE studies, and individual QoE must be one of the key points to realize personalized services.

Zhu et al. [53] also identified user factors on QoE: psychological, socio-cultural, demographic, and physiological factors.

1. Physiological Factors are related with the human sensory system. Models of visual perception and attention have been incorporated in objective video quality assessment metrics.
2. Socio-Cultural Factors are related with the educational and the socio-cultural background of the user. For example, cultural background has been shown to influence visual perception and attention between Westerners and Asians [55].
3. Demographic Factors (e.g., age, biological sex, or nationality) may influence QoE. For example, the fact that elderly people are found to be more critical than younger users suggests that elderly people usually have higher requirements for QoE [56].
4. Psychological Factors are the affective state or the user’s mood, for instance. Möller and Raake found that the user’s mood has been shown to influence quality preferences, and multimedia experiences have been shown to influence mood in turn [57].

As the physiological factors are firstly listed in the above, recently, instead of MOS, an advanced approach using physiological measures is being watched with intense interest to evaluate the video streaming services [58]. Particularly, electroencephalogram (EEG) is often used to evaluate multimedia quality [58], [59]. Yamazaki [60] also analyzed the relationship between the quality of the communication service and the biometric signal in a mobile role-playing game situation. Subjective QoE assessment data and EEG data during game operation were collected and the relationship between QoE and EEG has been verified by analysis of correlation between the QoE evaluation and the EEG data of gaming. Thus, physiological assessment such as EEG or SCA is starting to attract attention, because it can evaluate the relationship between physical stimuli and conscious perceptions quantitatively [61]. Since the physiological methodologies measure implicitly the users’ evaluation for services, they might be able to compensate explicit measurement methodologies such as MOS.

6. Conclusion

This paper described the present state and future prospect of QoE studies. Since the end user ultimately decides the service quality, subjective quality evaluation of the user cannot be avoided. Accordingly, collaborative researches on psychology, physiology, intension and feeling of the human beings, etc. must be necessary. Once QoE evaluation is determined and obtained for the Internet service providers or the network operators, they would control service, application, or network parameters, so that the optimal QoE will be offered to the end users. Therefore, technologies of the multimedia codecs and / or network engineering should also collaborate with QoE studies. Consequently, QoE studies must be truly interdisciplinary.

On the other hand, different users, different services, and different applications hold different QoE requirements. As a result, it seems to be difficult to have any common research platform or basement for QoE studies. Nevertheless, since several subclasses of QoE studies have been clarified through the previous devoted works, one QoE management architecture was proposed in this paper. The architecture consists of QoE measurement, QoE assessment, QoS-QoE mapping, QoE modeling, and QoE adaptation. The categorization of QoE subproblems presented in this paper may be controversial. Actually, it is true that QoE measurement and QoE assessment are equated in many studies. Standardization of the types and concepts of QoE factors as well as comparison of different QoE models are open issues for further study.

Next, development and deployment of video streaming services based on QoE were surveyed and discussed, because video traffic occupies the network bandwidth mostly and many users enjoy watching videos anytime and anywhere. It is important for the service providers not to lose the customers by providing appropriate service quality according to the customers’ QoE evaluation. Although many researchers and developers in the world focus on this study, there remain several open challenges and issues such as QoE modeling, QoE measurement, privacy issues, stakeholder, and QoE-based management [29].

Finally, novel challenges for QoE studies were introduced as future prospect: one was individual QoE, and the other was physiology-based QoE measurement. Relating with measurement and collection of individual QoE, physiology-based QoE measurement might play an important role. As examples of EEG and SCA were introduced, perceptual changes associated with video quality degradation could be detected by the physiological assessment. Development of the wearable devices with physiological sensing may bring new evolution to QoE studies.

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