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Quality-of-Experience (QoE) in Emerging Mobile Social Networks

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SUMMARY Mobile social networks (MSN) provides diverse services to meet the needs of mobile users, i.e., discovering new friends, and sharing their pictures, videos and other information among their common interest friends. On the other hand, Quality-of-Experience (QoE) is a new concept related to but differs from Quality-of-Service (QoS) perception. QoE is a subjective measure of a customer's experiences with a service focuses on the entire service experience, and is a more holistic evaluation. So far, QoS issues have been focused and mainly addressed in the literature of MSNs. To the best of our knowledge, this paper is the first article to address QoE issues in emerging MSNs. In this paper, we first present a comprehensive investigation on recent advances in MSNs as well as QoE issues addressed in various types of applications and networks. From the lessons learned from the literature, then we propose a future research direction of QoE in MSNs.
key words: *mobile social network, quality of experience, survey*

1. Introduction

Mobile social networks (MSN) [1]–[3] have gained tremendous momentum in recent years due to both the wide proliferation of mobile devices such as smart phones and tablets as well as the ubiquitous availability of network services. MSNs allow mobile users to discover new friends, and share their pictures, videos and other information among their common interest friends, which have been witnessed by the super popularity of representative smart phone applications, such as LINE, Twitter, Viber, WeChat, etc.

Quality-of-Experience (QoE) [4] is a new concept related to but differs from Quality-of-Service (QoS) perception. It emerged, combining user perception, experience, and expectations with non-technical and technical parameters such as application- and network-level QoS. In other words, QoE is a subjective measure of a customer's experiences with a service focuses on the entire service experience, and is a more holistic evaluation. For instance, video streaming users may be satisfied with high-quality videos without any delay in home networks while low-quality videos may be acceptable for them when using public WiFi. On the other hand, VoIP users may desire the smooth flow of conversing voices whenever and wherever they are. Since QoE measurements are based on human perception, research issues on QoE are challenging and wide-ranging such as QoE estimation, QoE modeling and control, QoE based system development, QoE management, etc.

QoS issues in MSNs have been widely addressed in the literature [5], however; few research efforts on QoE issues in MSNs have been made so far. To the best of our knowledge, this paper is the first to address QoE issues in emerging MSNs and give a future direction of developing MSNs based on QoE.

The remainder of the paper is organized as follows. First in Sect. 2, we provide a brief overview of MSN and review recent advances in MSNs. Major research issues and network architectures in QoE research domain are presented in Sects. 3 and 4, respectively. Following the comprehensive investigation, we address future research direction of QoE in MSNs in Sect. 5 and conclude the paper in Sect. 6.

2. Mobile Social Networks

The first web-based social networks were created in 2002, followed by lots of social networking service such as Facebook, Twitter, and LinkedIn, emerged from 2003 to 2006. Applications/services in the social networks are diverse such as sharing information, pictures, and videos, finding old and new friends, forming communities, chatting and texting, and distributing ads. With the penetration of smart phones, service providers started to provide the service in mobile networks and the MSNs have emerged. MSN-specific applications were developed such as LINE and Viber which enable mobile users to find friends and exchange messages over IP communications in mobile networks.

Network architectures in MSNs are classified into three categories: centralized, decentralized, and hybrid. The centralized MSN is mostly used where each remote server stores all information of social networking services and provides the services to mobile users through wireless infrastructures deployed in public or private, e.g., cellular networks, WiFi, WLAN, etc. Also, the users communicate with each other, such as text messaging, chatting, and sharing photos and videos, all through the remote server. Thus, they are benefited from high quality services unless any wireless access is available. However, that becomes one of disadvantages as well; the users cannot directly access to one another even though they are physically close each other [1].

The decentralized MSN can overcome this disadvantage. Without any central server, mobile users communicate with each other in an ad-hoc manner using WiFi or Blue-

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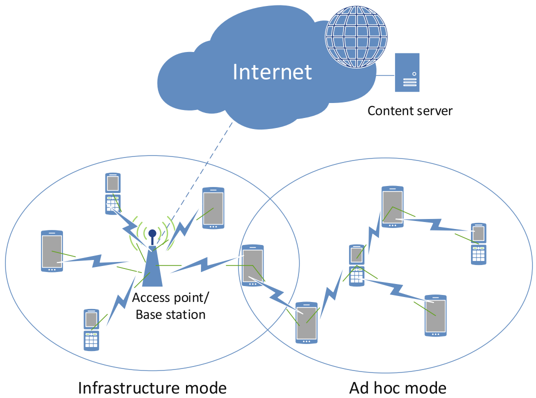

Fig. 1 Typical architecture of hybrid MSNs.

tooth, or with the help of any wireless infrastructure as a relay node. For instance, MobiClique [6] was developed to form ad hoc social networks which enable users to disseminate content using a store-carry-forward technique. Gupta et al. [7] presented MobiSoC which is a middleware providing a common platform for capturing, managing, and sharing a social state of physical communities. However, it brings new challenges including how to minimize the end-to-end delay [8], how to achieve high delivery rate [9], how to securely communicate among the mobile users [10], etc.

The hybrid MSN is composed by both the centralized and the decentralized MSNs as shown in Fig. 1. The mobile users selectively/automatically join the either networks to share information and to find friends/communities. Recent work [11] focused on MSNs for mobile data offloading and reduced the amount of mobile data traffic by exploiting opportunistic communications to facilitate information dissemination in MSNs. While the hybrid model still has the same problems with the decentralized one such as delay and privacy issues, it will also require a new design for seamless transit from the infrastructure mode to the ad hoc mode and vice versa, that may include a cross-layer approach to improve the performance of protocols across different layers.

3. QoE Research Issues

In this section, we review research on QoE in the literature and present major research issues. Since QoE is promising to be applied for several kinds of systems, network architecture, and applications, diverse research efforts have been made to solve challenging issues, which can be broadly classified into three main categories: QoE assessment, QoE clarification, and QoE assurance. The first two categories, QoE assessment and clarification, introduce research on how to quantify QoE by QoS-based approaches and experiment-driven approaches, respectively. On the other hand, the third category of QoE assurance introduces research on how to provide better service/applications to end-users by using QoE.

3.1 QoE Assessment

QoS is measured by network-centric parameters such as response time, packet loss, jitter, throughput according to system requirements. On the other hand, QoE is defined as "overall acceptability of an application or service, as perceived subjectively by the end-user" by the International Telecommunication Union (ITU). QoE measurements are influenced by user-centric parameters: emotions (how does the end-user feel?), objective (what does the end-user want?), incentive (why does the end-use do?), and so forth. Since QoE is not as straightforward as QoS, it is one of challenging issues to properly assess QoE measurements for various types of service/applications. Service providers are usually supposed to design QoS parameters according to desired QoE. For example, VoIP users desire the smooth flow of conversing voices and QoS parameters are considered as packet loss and jitter rate.

Because of strong correlation between QoS and QoE, some research focus on how to translate from QoS parameters into QoE and vice versa [4], [12], [13]. Fiedler et al. [4] proposed a generic formula in which QoS and QoE parameters have an exponential relationship. The feasibility of the proposed formula is evaluated through case studies addressing different QoE parameters such as a relationship between cancellation rates of web browsing users (QoE) and corresponding delivery bandwidth (QoS). In a paper [13], a QoS/QoE correlation model was developed to evaluate IPTV subscriber's QoE using QoS parameters measured in the network layer. However, authors in [12] argued that those offline methods are insufficient for perfect mapping between QoS and QoE due to changeable QoE according to time and circumstances around the end-user. To solve the problem, a framework for extending QoS to QoE in wireless networks was proposed [12]. It allows users to dynamically express the satisfaction with respect to the instantaneous experience of service quality at the overall network QoS-aware resource allocation process. The proposed framework was applied to a CDMA cellular network supporting multimedia services for performance evaluation.

There is also an increasing interest in how to properly assess QoE from a "subjective factor" [14]–[16]. Two main factors, *objective* and *subjective*, are used to measure QoE [16]. The objective factor indicates parameters which can be measured by physical devices such as body sensors to obtain heart rate and blood pressure. QoS is also included in this factor. The subjective factor indicates other parameters which cannot be measured by such devices. Commonly, survey and user studies are conducted to quantify the subjective factor and results are translated into numerical values. For instance, mean opinion score (MOS) [17] is a typical method to quantify the subjective factor where users evaluate service/application based on absolute category rating (ARC) and a final result is calculated as average from all the users' rating scores. Although the final result comes from the average, it may be evaluated by "unbiased users" and is not applicable for other users. In a paper [15], an approach to QoE modeling and control was presented. It aimed at more clearly defining parameters and mappings for QoE estimation always achieved equally for all end-users and services. Meanwhile, [14] focused on design of QoE assessment methodology to improve a traditional method where human observers evaluate the audiovisual quality of IPTV in controlled environments. The proposed approach enabled the QoE assessment in end-users' natural daily environments. Some researches effort have been done on the assessment on the QoE in tearms of audio quality [25]. The authors show that Skype' audio is not consisitent and the FEC mechanism is required.

3.2 QoE Clarification

So far, most of the research have proposed approach/methods based on any hypothesis and validated their feasibility/efficacy by experiments. For example, research introduced in Sect. 3.1 [4], [12], [13] has proposed QoS-QoE translation methods based on an assumption that there exists strong correlations between QoS and QoE. However, that assumption may not always correct because QoE is basically evaluated by humans and personal interests and preferences among humans vary a great deal. How and what QoE is exactly affected are still undiscovered and thus, some efforts on experiment-driven research have been made to understand effects of current technologies on QoE and clarify factors influencing QoE [18], [19].

Mehmood et al. [18] contributed a cross-layer QoS and QoE analysis of web video streaming in Next Generation Mobile Networks (NGMN) by implementing a prototype NGMN testbed with WiFi and 3G networks. The authors focused on the objective factor and PSNR (Peak Signal to Noise Ratio) was used as a QoE metric. Experimental results showed that better video QoE can be achieved in WiFi even with high packet loss while the QoE in 3G is more sensitive to packet loss due to high variations in network QoS (throughput and delay). Also, the authors found that the congestion control of TCP greatly impacts on QoE and handover from WiFi to 3G leads to QoE degradation.

Ickin et al. [19] presented several lessons learned from conducting a 4-week-long 29-Android-phone-user study where both QoE and QoS measurements were collected through a combination of users, applications, and network data on the phones. Based on an analysis of the collected data, the authors highlighted factors that impact the user's QoE: application interface design, application performance, battery efficiency, phone features, application and connectivity cost, user routines, and user lifestyle. With respect to QoS, the authors recommended a server response time for a mobile application to ensure an MOS level of 3 (rating 3 out of 5) is 950 ms. However, no strong evidence of the influence of QoS on QoE was shown in the paper. The experimental results demonstrated that the choice of wireless access technology (e.g., WLAN, WiMAX, LTE) influenced QoE. However, it was not because of the performance of access networks since users had a choice of the networks and could connect to one of them if desired.

3.3 QoE Assurance

As already mentioned in this paper, an ultimate goal of QoE research is to provide better service/applications to end-users while assuring optimal QoE. Many interesting projects were presented to deal with this issue [20]–[22].

To solve a problem on multicast transmission in WLAN where a transmission rate is changed with a static-threshold based on QoS measurements, a dynamic rate adaptation mechanism using QoE was proposed [20]. Multicast communication is essential in real-time multimedia applications in order to reduce growing bandwidth consumption. The paper argued that most existing schemes used Signal to Noise Ratio (SNR) as QoS metric for changing the rate which was not always fit for QoE. In the paper, a real-time QoE assessment tool named Pseudo Subjective Quality Assessment was used to evaluate QoE instead of MOS evaluation.

Khan et al. [21] aimed at optimum video streaming suitable for a network and content type with a requested quality of video as well as maximization of existing network infrastructures by providing service differentiation. To this end, a QoE adaptation scheme was proposed for video applications over wireless/mobile networks. The proposed scheme achieved ideal content quality by adapting a video sender bit-rate (SBR) according to users' QoE requirement. The authors studied the impact of the QoS parameters on end-to-end perceptual video quality and found the optimum trade-off between SBR and frame rate.

Sterle et al. [22] presented an application-based approach to in-service QoE control in Next Generation Networks (NGN) where various access, transport, control and services solutions are merged into a single multimedia-rich service provisioning environment. NGN is a promising service-oriented approach and provides transport-independent service by dynamically exploiting various transport technologies. Because of its heterogeneous and dynamic nature, NGN requires new mechanisms for consistent service provisioning and end-to-end QoE assurance. Proposed QoE control is accomplished through context-based QoE modeling that provides a detailed description of circumstances under which a communication is established and by which an end-user's QoE is affected. Testbed implementation results demonstrated that the proposal is efficiently designed in the direction of full standards compliance, favorable signaling overhead efficiency, and objective application-based QoE control principles.

4. Network Architecture Targeted in QoE Research Domain

In this section, we categorize QoE research from the viewpoint of network architectures for understanding a relationship between the architecture and QoE research issues. We here divide into three categories: wired networks, wireless networks, and next generation networks.

4.1 Wired Networks

QoE has a long history of been the hot research topic. In this sub-section, we first revisit historical problems and solutions done with the wired networks field to help the understanding. In the wired networks, all terminals are physically connected and thus network connections are relatively stable. QoS mainly depends on network capabilities and underlying hardware/software technologies. Since QoS correlates with QoE, QoE can be improved with QoS by enhancing the network capabilities. It implies that users will be satisfied with better QoE as long as service providers always maintain the highest QoS. This is an ideal way, however; it is unpractical because this may result in wasting network resources. For instance, users may not feel anything although web pages are delivered in a shorter time than before delivery delay is improved. Another reason is that QoS is provided based on network access fee paid by each user in reality. It is common that the users are benefited from higher QoS if they pay more. However, cost performance is subjectively evaluated by the users. Thus, QoE does not always increase proportionally to QoS.

The service providers have to more carefully observe users' perception and tune QoS parameters according to the observation. To deal with this issue, accurate assessment of QoE has been studied in early projects in wired networks [13], [14], [23], [24]. Specially, Chen et al. [23], [24] proposed a framework to capture users' perception when they are actually using network applications. The proposed framework only requires a subject user to click a dedicated key whenever he/she is dissatisfied with the quality of the application in use, which makes the user's feedback more efficient and accurate than a traditional way (e.g., MOS).

4.2 Wireless Networks

In the wireless networks, mobile terminals (e.g., smart phones, tablet, laptop) are connected via wireless infrastructures deployed at a public area, home, and office. Comparing to the wired networks, connections in the wireless networks are unstable because of mobility of the terminals. QoS greatly relies on environments surrounding users such as interference and fading because of obstacles and a long distance from a wireless base station. The users' environments dynamically change from time to time especially in outdoor locations. Due to changeable QoS parameters, QoE research in the wireless networks have more focused on understanding a relationship between QoS and QoE [12], [26]–[28]. Agboma et al. [26] studied QoE models for different types of multimedia contents delivered onto mobile terminals and found QoS and QoE correlations that were dependent on terminals and multimedia content types. To understand QoE assessment for mobile broadband scenarios, Reichl et al. [27] found basic relationships between QoS and QoE which can be described by the Weber-Fechner law used in psychophysics.

4.3 Next Generation Networks

The next generation network (NGN) is defined by ITU such as "a packet-based network able to provide services including Telecommunication Services and able to make use of multiple broadband, QoS-enabled transport technologies and in which service-related functions are independent from underlying transport-related technologies." In other words, a single network platform will deliver voice, data, and multimedia services under heterogeneous networking systems. It is very challenging to ensure user satisfaction in such complicated systems [31], [32]. Zhang et al. [31] discussed challenges on optimizing end-to-end QoE which depends on the effects of whole systems including networks, terminals, and users. The authors presented a possible solution to assure end-to-end QoE such that QoE/QoS performance reporting components are installed at the terminal-side while QoE management is installed at the network-side. Meanwhile, Amram et al. [32] designed a dynamic transport architecture adapted to video service requirements in NGNs.

Table 1 summarizes QoE research with reference numbers according to the categories of research issues and network architectures, respectively.

5. Future Directions: QoE in Mobile Social Networks

We have comprehensively investigated QoE research in previous sections and most of the research proposed approaches dedicated to specific applications, network models, and service scenarios. Since the future MSNs are created on the hybrid networks/NGNs, those approaches should be merged properly and effectively in order to meet each user's requirements on QoE under different circumstances. Therefore, it is necessary to develop a QoE management and control framework for a variety of service provisioning in different network architectures as shown in Fig. 2. To this end, we present the following three design goals for the framework: *energy-aware and user-friendly QoE assessment, dynamic and flexible QoE control, and efficient and secure QoE management*.

Table 1 Comparison of QoE research.

Research Issue / Archtecture	QoE Assessment	QoE Clarification	QoE Assurance
Wired Network	[13], [14], [23], [24]	[25]	[21]
Wireless Network	[12], [26], [27], [28]	[18], [19]	[20], [29], [30]
Next Generation Network	[15]	[22]	[31], [32]

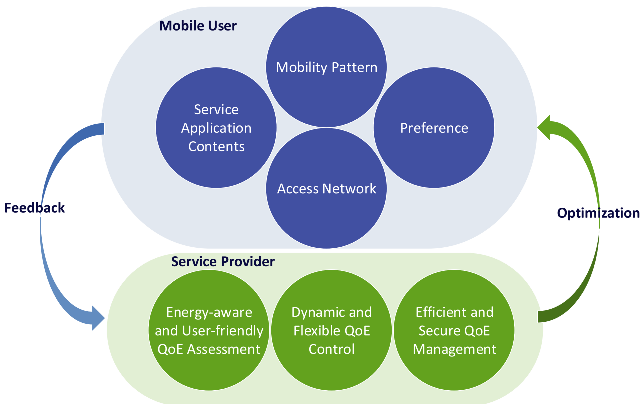

Fig. 2 QoE management and control framework for MSNs.

5.1 Energy-Aware and User-Friendly QoE Assessment

QoE assessment is important in the future MSNs where a mobile user has many opportunities to change the time and place to enjoy various services. QoE in the MSNs is expected to dynamically change according to both conditions of a network accessed by the user and the user's perception of the services. Thus, it is necessary to make QoE assessment not only offline (e.g., QoE estimated from QoS parameters), but also online (e.g., QoE measurements based on the user's feedback, MOS evaluation) to properly measure the user's perception. The online QoE assessment is on a real-time basis, however; that may consume much energy on mobile devices while most of them are energy-limited. Meanwhile, an application interface is better to be simplified for the mobile devices so that the mobile users are not annoyed by QoE assessment procedures. Also, the interface should be attractive for the users to have more incentives to join the QoE assessments. In summary, energy-awareness, lightweight, user-friendliness, and attractiveness is key factors to design QoE assessment in the future MSNs.

5.2 Dynamic and Flexible QoE Control

Based on the real-time QoE assessment, it is expected to dynamically optimize the service quality to provide better service to the mobile users. In other words, QoS parameters (e.g., throughput, delay, jitter, packet loss) are adjusted according to QoE requirements. However, the mobile users in MSNs are supposed to reside in different networks (e.g., WiFi, cellular networks, mobile ad hoc networks). Thus, although the same QoE is observed all in the different networks, QoS parameters are tuned independently with respect to each network condition. Moreover, QoS parameters should be selectively adjusted in consideration of service contents. Therefore, it is essential to design QoE control to achieve dynamic and flexible mapping from QoE measurements to QoS parameters to be adjusted according to types of networks and applications provided in the future MSNs.

5.3 Efficient and Secure QoE Management

More frequently collecting users' feedback leads to better QoE control because the users' preference will be reflected to the service quality in the right place and at the right time. However at the same time, service providers are supposed to manage a huge amount of data including real-time users' feedback and network parameters in addition to service contents. Unless carefully designed, QoE management can occur any service delivery delay and finally results in degrading QoE. Also, such users' feedback may include personal information such as a current location, mobility patterns, download/upload history, and application preference. That information should be confidentially transferred from an end-user to the management system. A key challenge is to achieve secure communication among mobile users when they connect in an ad hoc mode. Therefore, efficient and secure QoE management is crucial for MSNs to manage a huge amount of data including mobile users' confidential information.

6. Conclusions

This paper comprehensively surveys recent advances in MSNs and QoE issues addressed in various types of applications and networks. From the lessons learned from the literature, we have found that most of the research proposals are dedicated to specific applications, network models, and service scenarios. For the future MSNs, it is necessary to develop a new framework to match the expectation that each user is always satisfied with QoE under different circumstances. To this end, we present three design goals to realize the framework: energy-aware and user-friendly QoE assessment, dynamic and flexible QoE control, and efficient and secure QoE management. This will give service providers and researchers a fresh insight into the future MSNs as well as an initial clue to develop a QoE control and management framework in the MSNs.

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