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A Survey Study on QoE Perspective of Mobile
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Abstract—Recently the mobile cloud computing (MCC) are
efficiently emerging as an efficient and convenient mobile services for our daily life.
Different from cloud computing, MCC dominant the properties
of mobile devices rather than PC such as mobile network 3G/4G,
limited hardware resources, mobility, etc. Therefore, Quality of
Experience (QoE) on mobile devices plays an important role in
evaluating the quality of mobile service in MCC. In this paper,
we surveyed lots of works on QoE perspective of MCC. The
QoE of end-user affected by network QoS factors (i.e., network
bandwidth and latency) and application QoS factors, which
depend on specific type of MCC services. All of these factors
converged to the responsiveness and content visual quality, which
determined the QoE perceived by end-user. We further presented
the optimization efforts at research literatures to improve the
QoE of MCC. Finally, we proposed couple of promising trends
which have not mentioned before to enhance the QoE. We believe
that the paper is helpful to better understand the impacts of
massive deployment and adoption of MCC services.

I. INTRODUCTION

Evolved from grid computing, cloud computing (CC) has
been widely used to provide infrastructure, platform, and
software as services for users. The features of dynamically
scalable and ubiquitously accessed meet well the trend of
modern business development. With the explosively development
of mobile device, the users of CC have more options to access
to cloud-based service. Thus, mobile cloud computing (MCC)
extends such benefits to mobile device. According to a recent
study [1], cloud adoption continued to rise from 67 percent
last year to 75 percent of those surveyed reporting at 2013.
On another hand, the Juniper Research said [2] the market
for cloud-based mobile Apps will grow 88 percent from 2009
to 2014. To this end, the MCC are increasingly becoming an
effective and convenient environment around our daily life.

Nowadays, MCC provides different categories of mobile
Apps at market. The most common used Apps may belong to
the mobile cloud storage service, such as Dropbox, Amazon
Cloud Drive, Apple iCloud, Yun@Baidu and so on. Audio/Video
streaming service is also widely subscribed by users,
such as YouTube. Cloud computing resource can be utilized
to perform computing intensive tasks of encoding, transcoding,
and transrating to fit for different devices. Cloud interactive
service and mobile gaming service may not be so widespread
as previous services in market. But the market is growing
rapidly and is expected to be next big growth point [3].

Those services also are called rich multimedia services which
include video chat, remote desktop, interactive advertisements,
mobile gaming, augmented reality, and go on. For those
services, the mobile device has inherently disadvantages, i.e.,
the limited resources of computing, memory, network, and
energy. However, by helping of the cloud, those applications
are readily to migrate from conventional PC/Macs to mobile
devices.

As more and more applications migrate to MCC, service
quality will be an important differentiator between each others
[4]. As an important measure of the end-to-end performance
at the services level from the user’s perspective, the Quality
of Experience (QoE) is an important metric for the design
of systems and engineering processes. The QoE may answer
the one of the frequently asked questions, i.e., how good will
the user experience when using the MCC services. So, when
designing a MCC service, QoE is often taken into account.
Inherited from mobile computing, the key problem of QoE
concern of MCC service is caused by wireless communication,
which is characterized by limited and time-varying bandwidth
and large network latency. Another cause may be the type
of services, which may be the one of reasons why mobile
cloud storage service occupied more market than other MCC
services. Compared with other services, mobile cloud storage
service has less hardware and network requirements. Specified
the above cause to user experience, the responsiveness and
content visual quality are the primary feelings that user may
perceived by using MCC services [5].

In this paper, by surveying outstanding works, we describe
the movement of exploring the QoE model of MCC, give
readers state-of-the-art works of this filed. We further present
the optimization efforts at research literatures to improve the
QoE of MCC. Finally, we proposed couple of promising trends
which have not mentioned before to enhance the QoE.
We believe that the paper is helpful to better understand the
impacts of massive deployment and adoption of MCC services.

II. QoE MODEL OF MCC

There are many definitions of MCC [5]–[7]. The main
concept is consistent, which is to move the computing power
and data storage away from mobile devices and into cloud. The
mobile user connects the MCC though 3G or WiFi to fetch
the results of applications that be generated by cloud servers.
In this way, MCC can tremendously broaden the types of application while maintain the mobility of end user. From the comparatively mature services, like mobile cloud storage and Audio/Video streaming, MCC gradually extends services to rich multimedia files, such as remote desktop, mobile gaming. However, the evolution of MCC services is a big challenge. For the storage and A/V streaming services, the target contents may be various kinds of files or different format/definition Video streams which already generated by servers at cloud, just waiting the users to fetch them. But for the evolved services, the target contents are dynamically rendered or generated according to user’s frequent request. Therefore, the QoE of those services are stricter to the wireless communication and cloud computation.

In most papers that we reviewed here [3], [5], [8]-[12], the method of Mean Opinion Store (MOS) is adopted to assess the subjective quality of experience of MCC services, which is defined in ITU-T Recommendation P.800 [13]. In the recommendation, subjects are instructed to rate their perceived quality of the services at experiments, according to the following opinion scales: 5(excellent), 4(good), 3(fair), 2(poor), 1(bad). Then, an arithmetic mean of the collected scores is used as the value of QoE. The benefits of such an approach rely on the participation of real end-users and on the full control of the experiment process, providing such tangible and solid results.

The following subsections will discuss the QoE of different MCC services in detail.

A. Mobile Cloud Service of Storage and A/V streaming

Casas, et al [8], [12] made an exploratory work on QoE of this field. At [8], a complete study of the QoE of cloud storage service is conducted, in which the author characterized the service as Cloud Storage and File Synchronization (CSFS). 52 CSFS users are recruited to participate in a controlled subjective lab tests. The tests are performed on a CSFS Dropbox-like application named The Box, which is C# multi-threading application, in terms of different network bandwidth and RTT. In the experiments, participants assessed their overall experience of the service (MOS) and service acceptability, which stating whether they would continue using the application under the corresponding conditions or not, by using CSFS applications in different scenarios, e.g., file storage (from device to cloud server), multi-device file sync (from device A, to cloud server, to device B), and file sharing (from cloud server to device). All the tests are performed for a different number of uploaded/downloaded files: batches of 5,10 and 20 files, in which the size of each file is 500 KB in order to limit the duration of each tested condition. The methodology behind the test is depicted in figure 1. The upper part illustrated that the QoE is a multidisciplinary concept. Besides the technical characteristics of the application, the user personality and expectations, device usability and usage context are also the determiners. This philosophy is realized by analyzing and correlating the three layers depicted in figure 1. The results of the subjective tests at table 1 showed the high correlation between network bandwidth and QoE of end users in cloud storage services.

The similar study was conducted for mobile cloud A/V streaming service [12], using YouTube as concrete case. However, instead of lab experiments, which may miss out some QoE influence factors such as usage context, content preferences, device usability, the authors made a field trial experiments to get more reliable results in terms of end-user experiences. During 31 days, 33 recruited participants watched the YouTube video clips through the 3G HSPA network, using 3.5G modems. In streaming service, video bit-rate, page-load time and video stallings are preferable in application layer of figure 1, to the response time and sync time in storage service. From the experiments result, a DBW of about 768 kbps was sufficient to reach a 90% share of positive acceptance ratings with good QoE (MOS ≥ 4), in which the videos being watched had 670 kbps average video bit-rate (VBR). Therefore, the QoE of YouTube is highly sensitive to throughput bottlenecks. If the VBR is higher than a DBW, then the chance of having video stallings and a corresponding bad QoE is higher. A stalling event corresponds to the interruption of the video playback due to the depletion of the playback buffer at the user’s terminal. Further, the author define the ratio \( \beta = \frac{VBR}{DBW} \) as a video quality indicator. If \( \beta > 1 \), the proportion of videos receiving bad MOS rating (i.e., MOS < 3) is always higher than 84%, whereas videos with very good MOS ratings (i.e., MOS ≥ 4) have \( \beta < 1 \). The authors concluded the YouTube study with the figure 2,
pointing out that only one single stalling event has already an important impact on YouTube QoE, reducing the MOS from good to fair.

B. Interactive Mobile Cloud Service

From network bandwidth sensitive MCC services, we are moving our survey to the network latency sensitive services. At work [9], Casas, et al conducted a subjective lab experiment, tried to find the relationship between network performance (i.e., network delay and bandwidth) and QoE in remote display service. The study was performed on a dedicated remote virtual desktop based on Citrix technology. Participants were instructed to evaluate four different desktop tasks which were text typing, screen scrolling, drag & drop, and menu browsing. The results showed that all the tasks’ QoE degraded below to fair quality (i.e., MOS < 3) when the network RTT greater than 350 ms. But in the case of typing, acceptance rate is above 60% even for very poor network conditions (i.e., RTT = 500 ms), which once again evidenced the strong existing correlation between QoE and the corresponding application and task.

The problem of how to use mathematical function to model the correlation between network QoS parameters and QoE was studied in [5] from a different perspective. The authors have identified various objective and subjective factors affecting the cloud mobile gaming user experience (MGUE), as shown in figure 3. However it was hard to integrate all the objective factors as the model inputs. Thus only five parameters were chosen by analysis the impact on QoE: Game genre played, VConfig used, source video PSNR, network packet loss (Ploss), and gaming response time (RT). By using MOS method, the proposed game QoE model was

$$GMOS = f(Game, VConfig, RT, PSNR, PLoss)$$ (1)

where the explanation of each parameter could be found at figure 3.

Since GMOS was determined by 5 factors and its function could be a complex, the author attempt to further apply the ITU-T E-model [14] to the GMOS, which could be

$$GMOS = 1 + 0.035R + 7 \times 10^{-6}R(R - 60)(100 - R)$$ (2)

where $R = 100 - Ic(Game, VConfig) - Ic(Game, RT) - Ic(Game, PSNR) - Ic(Game, PLoss)$. Then subjective quality assessment experiments were conduct to identify the effect of each factors, in which the parameters were determined using linear regression. At last, the MOS model was applied to measure the MGUE in real wireless mobile networks. In outdoor locations, the gaming video was streaming at 600kbps bit rate. But the game only can provide the minimum acceptable MGUE (MOS > 3) at most times. In indoor and in mobility conditions, the MGUE even worse. The GMOS scores varied between 1 and 3.

Though the model is derived from mobile cloud gaming service, it also be appropriate for the mobile cloud remote display service since they have similar concepts in MCC.

III. OPTIMIZATION EFFORTS ON QOE OF MCC

The above works show that how crucially the network parameters (i.e., bandwidth and delay) affected the QoE of end user. It’s worth noting that with the advancement of 4G/5G wireless networks, some of these challenges may be partially alleviated. The improvement of access technology and mobile core network turns to the networking guys. However, what can we do now to optimize the QoE of MCC from application layer perspective? By using the philosophy behind the figure 1, we can undertake from the following aspects:

1) Decrease Bit-rate of Streaming and Reduce Round-Trip Response Time: Data-rate and bandwidth is always a pair of metrics. Nowadays, the bandwidth of wireless network may be insufficient for some MCC services. The development of 4G network is being carried out. From another perspective, decreasing bit-rate of streaming also can rise the QoE. In YouTube, videos are compressed into different bit-rate. The user can choose the optimal one based on the current network condition. In remote display service, Song, et al [15] proposed hybrid remote display protocol, in which high motion area were compressed by M-JPEG encoder. Their work not only decrease the bit-rate of streaming, but also reduce the compress time by using GPU to do a part of a compress task. In MCC scenario, the round-trip response time is not only includes network delay. The operations both in server and client can
bring in latency to response time by depicted at figure 3. The work [16] investigate the rendering process of mobile game, four parameters are identified to have impacts on video content complexity, which greatly affects the video bit rate, frame generation time: Realistic Effect, Texture Detail (down-sample rate), View Distance, and Environment Detail. The first optimization solution is to remove unimportant objects in the game video to reduce game video content complexity and server load. Another solution is to construct an adaptation level matrix and its corresponding cost matrix. Given current network and cloud server condition, a level selection algorithm can be used to adapt the game video rendering setting to maximize the QoE. For example, if the network RTT is detected as greater than a threshold, the algorithm will adjust the rendering setting $S$ from $S(H, 0, 0, Y)$ to $S(M, 2, 300, N)$.

2) Adaptive Level Selection Algorithm: Compared with wired network, the wireless channel is more fluctuating. Adaptive level selection algorithm often adopted in MCC services. The second solution of [16] is a good instance, and in [17], a set of application layer optimization techniques (including a downlink rate-selection algorithm, an uplink delay optimization technique, and a client playout delay adaptation algorithm) is designed to ensure acceptable gaming response time and video quality.

3) Classify the Type of Applications: In interactive mobile cloud service, the type of applications running inside affects the QoE a lot since those applications have different network traffic characteristics. The work [11] showed that statistical classification techniques were effective in detecting on-the-fly the application that ran inside the thin-client protocols, by passively observing IP-level features of packets of the thin client connection, such as packet size and rate.

IV. CONCLUSION WITH RESEARCH TRENDS

In this paper, we surveyed lots of works on QoE perspective of MCC. The QoE of end-user affected by network QoS factors (i.e., network bandwidth and latency) and application QoS factors, which depend on specific type of MCC services. All of these factors converged to the responsiveness and content visual quality, which determined the QoE perceived by end-user. Decrease bit-rate of streaming and reduce round-trip response time are the directly optimization methods. However, since the fluctuating of wireless network, adaptive level selection algorithm is also widely adopted to achieve the comparable maximum QoE.

There are still many topic that haven’t mentioned before, which may guide future researches.

- Busy server with multiple clients accessing: How to distribute the tasks from perspective of user’s QoE.
- Integrated with the MCC scenario, how to further reduce the RTT response time. E.g., making a intermediate agency at wireless bone network to buffer contents
- Energy issues: Exploring the correlation between energy and QoE

QoE of MCC is a not a separate issue. Rather than being independent, the factors of QoE are intertwined and even conflict with each other. Integration of optimization of single factor and optimal tradeoff among several factors is the principle of future QoE study of MCC.

ACKNOWLEDGMENT

This research was supported by the MSIP (Ministry of Science, ICT&Future Planning), Korea, under the ITRC (Information Technology Research Center) support program (NIPA-2013-H0301-13-4006) supervised by the NIPA (National IT Industry Promotion Agency). Professor Eai Nam Huh is corresponding author.

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