Quality of Experience (QoE) Measurement and its Challenges in Mobile Networks for Multimedia

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Abstract— **In the recent past, technological innovations have enabled a constant spread of novel immersive and interactive services that pose ever-increasing demands to the available communication networks and add to their load. Instances include: social TV, immersive environments, mobile gaming, HDTV over mobile, 3D virtual world, book/newspaper consumption, social networking, and IPTV applications, just to mention a few. Transitioning from Quality of Service to Quality of Experience and the measurement of Quality of Experience (QoE), especially in mobile networks, is the challenge which needs to be addressed since the relation between the perception of quality and quantifying Experience has to bring together the principle elements of the User, Technology and Business.**

Keywords- Quality of Service (QoS), Quality of Experience (QoE), Mean Opinion Score (MOS)

I. INTRODUCTION

There are several performance parameters that affect the quality of content provided including Delay, Jitter and Bandwidth. These form the Quality of Service (QoS), which is mostly assessed from the service provider's end. On the users' end factors which affect performance quality include low bit rate of video, variable network delay, and low resources of user device. These form the Quality of Experience (QoE). The current trend is that there is dynamic media processing and consumption which requires constant attention so that there is a balanced QoS/ QoE relation. In this dynamically evolving context, network operators and service providers are struggling to keep their increasingly sophisticated customers happy while remaining profitable at the same time. Consequently, optimization and management of QoE has become a crucial concept in the deployment of successful services and products. However, even if the concept itself seems straightforward to understand, it is complex to be efficiently implemented in real end-to-end systems/networks. The complexity of QoE is mainly due to the difficulties in its modelling, measurement, and translation to Quality of Service (QoS), which is multi-disciplinary due to the different kinds of feedback flows like acceptance, usage, cost and quality covering a wide range of networks, applications, systems, devices, contexts and expertise.

According to Qualinet (2012), QoE forms a part of the complete ecosystem of the media industry whereby the value chain for the media comes to play. Therefore, the quality of the media being delivered to the user has more value hence the way the content is created, the technology used to deliver the content and interact with the user (network and device), the cost (market and finance) and the user matter a lot in establishing measurement for Quality of experience. The ecosystem connects these four aspects, showing how they depend on each other as shown in the diagram below.

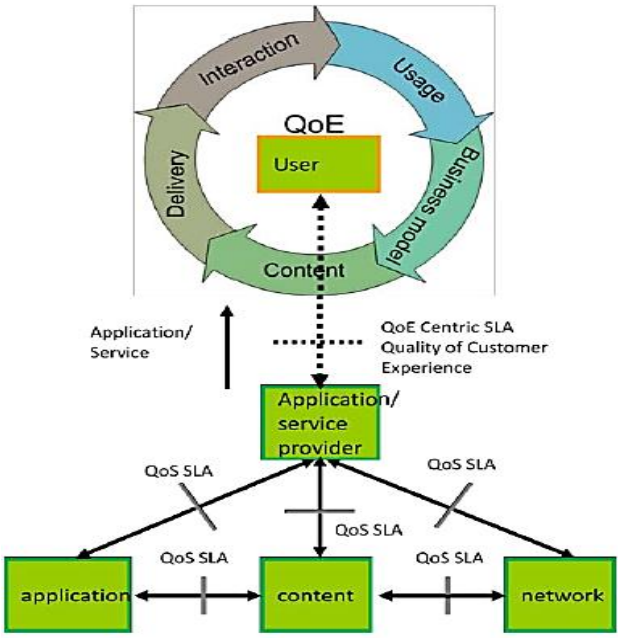

Figure 1: QoE in the ecosystem for application/service provider (Khalil, 2011)

II. BACKGROUND AND RELATED WORK

As multimedia services are being deployed, user Quality of Experience is the determining factor for these deployments (Pedro de la Cruz Ramos et al, 2012). Different kinds of uses, like video streaming on the mobile terminals is very popular whereby people stream a video on the internet to get information or to just have fun (Yipeng Zhou, 2012) while travelling or just somewhere in the wild (Petteri Repo et al 2004). In these kinds of situations the important concern which is raised is whether the quality of the video has satisfied the user and the perceived quality of the video the user is streaming. This brings the Quality of Experience into perspective. Quality of Experience (QoE) can be defined as "the degree of delight or annoyance of the user of an application or service which results from his/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"(Qualinet, 2012). The service provider has the objective of giving quality of service to all users, those who use different devices like computers, IPAD, smart phones or simple mobiles phones. The problem is that a user does not get a satisfactory experience because of various reasons such as low bit rate of video, variable network delay, low resources of user device (Asif Ali et al, 2012). Another major factor for the service provider to understand about the end user's reaction and satisfaction is that it is related to a particular product such as a smartphone, service reception or a particular application. For ensuring quality of service (QoS) guarantees, conventionally, technical parameters are changed time by time by network administrators but despite that user satisfaction remains a big issue for service providers because it is hard to capture user needs and requirements during service usage.

III. QUALITY OF EXPERIENCE (QOE)

Quality of Experience (QoE) is an emerging area of research which provides an "assessment of human expectations, feelings, perceptions, cognition and satisfaction with respect to a particular product, service or application" (Khalil U. R., 2011). This definition has been named the Mean Opinion Score (MOS) (ITU – T, 1996).

The International Telecommunication Union ITU-T (2007) defines QoE as "The overall acceptability of an application or service, as perceived subjectively by the end-use". This definition has further been extended by introducing objective QoE concept "QoE is a blueprint of all human subjective and objective quality needs and experiences arising from the interaction of a person with technology and with business entities in a particular context." (Khalil U. R., 2012). QoE is captured using two main methods one is Objective and other is subjective (Asif A. L. (2012), Khalil U. R., (2011) & Khalil U. R. (2012)). Subjective methods rely on human participants to provide useful and reliable QoE feedback about a particular multimedia service. Subjective testing, however, is expensive and time-consuming. Objective is subdivided into two parts one is estimating user satisfaction from collected network and application layer QoS data and other is collecting human physiological data (Khalil U. R. 2012).

From a business perspective QoE is very important as low QoE may drive users away from a particular service provider and shift to a "better" one (Canberk Temiz, 2014). According to Laghari et al (2012), "Today, humans are quality meters, therefore it is crucial to consider their needs, perceptions, and expectations with respect to a particular product, service or application. Because human pleasure carries a great value."

According to Vasillios A. S. et al (2014) QoE is dependent on both human and technical factors which include aspects such as VoIP (Voice over Internet), video streaming, VoD (Video on Demand) – encompassing video pauses (stalls), transaction delays, encoding changes and transport characteristics such as UDP, HTTP/TCP; Video conferencing, end system (interface, screen resolution, battery, power consumption), and Network level QoS such as bit rate, packet loss, delay and jitter. Service characteristics considered in the mobile context of multimedia usage include reliability, coverage, availability, cost, etc. These show that the QoS which the service provider promises in the SLA (Service Level Agreement) are very important in determining the user factors such as expectations, perceptions, demographics and requirements.

The estimation for QoE can be achieved using subjective and objective means. Subjective QoE assessment involves user participation and quantifies the QoE in terms of a Mean Opinion Score (MOS), "where the quality is assessed using a 5-point scale score: 5-Excellent, 4-Good, 3-Fair, 2-Poor, 1-Bad" (Vasillios A. S. et al, 2014). On the other hand, objective QoE evaluation estimates the QoE using a parametric model, without requiring the involvement of users. The parametric model can depend on the application, context, etc, and is a function of the network-level QoS which is typically estimated from measurements.

In a mobile network QoE framework would include a model which defines how QoE is quantified along with which factors influence the QoE and how, QoE measurement for measuring and predicting QoE and QoE – aware management and control (Qualinet, 2013). According to Vasillios A. S. et al (2014), the increasing reliance on mobile networks and mobile data services have given QoE more importance because use of these mobile gadgets and more involvement of users becomes a prime concern for the service providers. Also the process of assessing QoE in the mobile networks gives more challenge in the view of resource constrains in the devices and infrastructure, high

levels of dynamism and user characteristics as well as their contexts.

In the fixed/ wired networks QoE is easy to quantify by the use of the MOS value as well as mapping QoS to QoE (S. S. Krishnan and R. K. Sitaraman, 2012). The metrics used here include observing user's behavior and reactions depending on their experiences when using multimedia systems (R. K. Mok et al, 2011). According to A. Balachandran et al (2013), the metrics that are used include the percentage of a video that is viewed, number of videos viewed, number of visits, video pausing, etc; what is termed as user engagement by J. Shaikh et al (2010).

According to P. Reichl et al (2010), the above relations can be mapped to each other to show how QoS connects with QoE in a wired network using indicators like;

- Linear: Whereby additive changes to QoS influence QoE
- Logarithmic: Dependence of the kind whereby a multiplicative change of the QoS has a linear influence on the QoE.
- Exponential: dependence of the kind whereby an additive change of the QoS has a multiplicative influence on the QoE.
- Power: dependence of the kind that a multiplicative change of the QoS has an exponential influence on the QoE.

For instance according to Vasillios A. S. et al (2014), in the area of VoIP and Video conferencing, there is a logarithmic dependence on the bitrate as well as a logarithmic dependence of QoE for video streaming and the initial delay for the video to start. According to M. Fiedler et al (2010) there exists an exponential dependence of the QoE for VoIP. This means that these indicators can be used to translate user experience to QoS, which is beneficial to the business of the service provider. According to Leghari et al (2012), "today, humans are quality meters, therefore it is crucial to consider their needs, perceptions, and expectations with respect to a particular product, service or application. Because human pleasure carries a great value". This shows how important Quality of Experience is and why finding the best measurement for it.

When it comes to mobile networks, things are completely different. The evolution of mobile phones to smartphones and the increase in mobile data traffic nowadays is making this problem more complex. It is also crucial to understand that the QoE on, for instance, smartphone real time video environments, the interface is very key since it is the layer that the user sees the video from and perceives the video quality. That is why in the mobile networks environments the device features matter a lot.

Current mobile networks offer their users the opportunity to stream multimedia, use social networks, shop online, etc. Furthermore, with the ongoing rollout of 4G LTE networks in many countries, it is estimated that there will be a 13-fold increase of global mobile data traffic during the five-year period of 2012-2017, according to CISCO (2014), making QoE measurement and QoE driven adaptation even more crucial.

IV. MEASURING QUALITY OF EXPERIENCE

Some of the factors that influence Quality of Experience for the user include user characteristics, system in use, service, application and the context in which the multimedia application is in use (Qualinet, 2012). The user experience has also been enhanced by the fact that multimedia content has increasingly moved to being delivered through HTTP (Hypertext Transfer Protocol). Compared to RTSP (Real Time Streaming Protocol) which is a UDP based streaming. TCP based streaming which is in HTTP guarantees packet delivery hence video quality is not reduced out of packet loss or reordering. But at the same time network congestion can easily lead to delay of data delivery in time for the system to use which leads to frame stalls (frame pause or re – buffering). The solution used here is to buffer some video before it begins to play. Among these issues above, that is, initial buffering delay, duration of stall events and the frequency of stall events; are the key factors that are used to measure the Quality of Experience (QoE) (R. K. Mok et al, 2011).

For instance, according to T. Hossfeld et al (2012), the initial buffering delay for YouTube video streaming lasts up to 16 seconds so has no or very small impact on the Quality of Experience. The challenge with this finding is that the results we gotten from a specific context and environment and may not necessarily apply on another, since we have established that the Quality of Experience (QoE) is also dependent on the device capabilities, the network coverage and congestion in the network. This issue brings in the factors of network Quality of Service (QoS) or Application Quality of Service (QoS) metrics which are used also to determine Quality of Experience (QoE). Network QoS are measured at the Network provider's side while application QoS are measured at the application level hence at the user's side.

According to Vasillios A. S. et al (2014), mobile network operators typically use theoretical models and in-field measurements during network planning activities to optimize network coverage and performance. However, due to the intrinsic nature of mobile networks, which is dominated by the air interface, their performance is location and time dependent. As a result, there may exist non-trivial deviations between "expected" and user-perceived performance. Traditionally, the provided performance of mobile services is expressed using QoS-related metrics such as throughput, latency and jitter. However, the application-

oriented use of mobile networks necessitates a more user-centric assessment of service delivery. For instance, it is challenging to assess the quality of video content delivery through usual QoS measurements, as it would also depend on other factors such as video frame rate and codec, QoE bridges that gap.

V. BENEFITS OF QUALITY OF EXPERIENCE MEASUREMENT

Vasillios A. S. et al (2014), outlines the benefits of QoE measurement in mobile networks as follows;

- It captures mobile experience as perceived by the users. Real user experience in mobile networks can be largely different than the "expected" performance and the performance indicated by network-level QoS metrics.
- It provides insight on the factors that influence customer satisfaction. Such factors (e.g., application interface, device features, etc.) do not necessarily depend on the underlying network.
- It takes into account the broad range of network usage profiles. For some users making and receiving voice calls is the most influential factor, while for others data services are equally or more important.

This is good especially for business since when users give their reactions to the experience they have on the service, it actually becomes very easy to establish the Quality of Service on the part of the service providers.

Measurement frameworks for Quality of Experience

There are very many methodologies of collecting values for measuring Quality of experience. Most of them are subjective (ie MOS) in controlled environments and these face the challenge that they are neither adequate since each user has their own experience nor efficient since the Quality of Experience in Mobile environments is dependent on both time and context.

According to S. Ickin et al (2012), I. Ketyko (2010) and K. De Moor et al (2010), QoE any measurement framework for Mobile Networks in the delivery of Multimedia content should have both qualitative and quantitative metrics in order to give a comprehensive and correct result. It should have QoS metrics which would be checking the network performance (ie bitrate and latency), User behavior information which would be showing the different users in the network and how they use their devices (it is important to note that here users could be either experts in device usage or simply novice users, and the devices could be basic connectivity devices/ phones without many features or sophisticated smartphones/ tablets with large screen interface, high resolution and so on), context information showing where the user is located, whether he/she is indoors or outdoors, which connectivity device the user is connected to i.e. access point or base station and so on, subjective experience information which entails the kind of reaction the user would have when or after using the service, like, how many times of replays, the entire duration of using the service, would the user come back to use the service and so on.

Another factor that influences QoE in Mobile Networks is web response time (M. Fiedler et al, 2011). This is the time it takes to download a web page and it can be determined using throughput and mapping the throughput to MOS values using logarithmic relationship. But these user – reported MOS values are always from different contexts which is a challenge. Also, the users have different devices which have different application interfaces, smartphone batteries, features and data connectivity costs. So all these factors have to be considered and clustered together.

One of the metrics used to measure QoE in mobile networks is Network side passive monitoring which is used to monitor network traffic by the service providers. A lot of information is collected in real time like congestion, availability and bitrates. This is more to the service provider than it should be to the user. According to M. Fiedler et al (2012), this provider side challenge can be resolved by implementing a more user – centric approach whereby the service provider can consider the number of times a user aborts a service due to long response times and web delays.

Like it has been shown earlier that user context is crucial when measuring QoE, Network side passive monitoring faces the challenge of getting the user's context and especially in areas where there is no network coverage, it becomes extremely impossible to collect data at all. Another challenge is that this metric measures user experience from the provider's perspective so it would be very difficult to really know the exact user experience for sure.

Another metric used is drive testing whereby the service provider goes to the field in an effort to measure user experience. This method gives a solution to the challenge of the user not giving experience responses more directly since its metrics are more user – centered. The challenge with this metric is that it is not cost effective and the user context is not fully captured because it would be outdoors yet, users could also be indoors and their exact location is not known.

Crowd sourcing is another metric that is used to measure QoE whereby user participation is key. According to OpenSignal (2013), in this approach the service provider runs distributed agents on the end user device and is able to perform both real – time active and passive measurements. The OpenSignal research shows that this metric is cost – effective, scalable and it captures the real user experience. According to OpenSignal, the present day smartphones are equipped with applications that can collect a "wide range of on-device data, like network data (e.g., received signal strength, network type, throughput, etc.) and user/context data (e.g., location, time of measurement, etc.)"; and hence

easy to monitor user behavior. The data are aggregated and shared publicly in the form of coverage maps which aim to increase consumer awareness. Although there is not a direct mapping to QoE-related metrics (e.g., MOS values), systems like OpenSignal measure the provided service as the users experience it.

The challenge with this metric is that the agents are restricted to specific Operating systems running on the smartphones like android and IOS as well as application interfaces. Also the number of users who participate in such measurement studies is also limited due to enthusiasm and level of understanding (Canberk T., 2012).

VI. CHALLENGES

The process of measuring QoE depends heavily on the metric used. The outlined metrics, especially crowdsourcing passive network monitoring have their own challenges but if their positive aspects were combined, they would provide an excellent solution.

Another challenge which comes into play when measuring QoE using the application agent is the "digital divide" among users in terms of their characteristics and knowledge in using smartphones and utilizing the services. How they know how to operate the devices is also a challenge.

The devices also form a challenge in terms of their designs, chip capabilities, operating systems, battery life of the device, and bandwidth caps, since these factors have an impact on the QoE.

VII. CONCLUSION

Since mobile phone usage is increasing and there is a major shift of computation and data into the cloud, Quality of Experience becomes more crucial and an interesting area of research. Current methods of measuring QoE are not completely efficient because there isn't a framework that is giving complete and accurate information to the network service providers as well as end users in terms of quality experienced that is cost effective and knowledgeable, especially to end-users. To get a remedy there needs to be a metric that gives cooperation between the involved entities, that is the provider and the user.

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