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A Quality of Experience Hexagram Model for Mobile Network Operators' Multimedia Services and Applications

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Abstract

Superior network Quality of Experience (QoE) is important for Mobile Network Operators (MNO) as it ensures they increase profit margins, attract new customers and differentiate themselves from the competition by providing better quality guarantees. In this paper, we propose a QoE hexagram model that comprises six Key Quality Indicators (KQI). In this model, we introduced an additional KQI, Terminal Quality. Other new metrics like Packet Corruption Rate and Service Access Time were also incorporated. Furthermore, several experiments were conducted by introducing disturbances using the NetEm tool. The QoE value obtained from our model is an indication of the overall acceptability of the applications and services as perceived subjectively by the end users.

Keywords: Acceptability; Mobile Network Operators (MNO); Quality of Experience (QoE); Terminal Quality.

1. Introduction

Traditionally, the approach for measuring the overall performance and user satisfaction of network services in the telecommunications industry is the objective Quality of Service (QoS) parameters gathered from the system. In this regard, the QoS parameters are checked and controlled keeping in mind the end goal to give an acceptable level of service quality. Distinctive QoS parameters like data transmission, packet loss and delay amongst others are basic measurements for deciding the service quality from a specialized perspective.

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Be that as it may, QoS parameters alone do not really mirror the end users' fulfillment and emotions towards a specific network service [1]. Consequently, the estimation of how end users realistically discern networked services is moving from the deficient packet level Quality of Service (QoS) to the end user Quality of Experience (QoE) that incorporates content, the setting or context in which the service is used and their desires. The end user Quality of Experience (QoE) is one of the fundamental issues to be considered during the planning and designing of personalized services in mobile networks, in order to entice and retain more subscribers [2]. According to the International Telecommunications Union–Telecommunication Standardization Sector (ITU-T), QoE is “the overall acceptability of an application or service, as perceived subjectively by the end-user” [3]. This definition has two key points to take note of:

(1) QoE affects the complete end-to-end system (which includes the client, terminal, network and services infrastructure amongst others.)

(2) Overall acceptability may be influenced by user expectations and context.

The European Network on Quality of Experience in Multimedia Systems and Services, otherwise referred to as Qualinet, is a body responsible for multidisciplinary QoE research in Europe. According to the Qualinet white paper, QoE was described as "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" [4]. The perception of QoE is different from one application to another. For example, in a voice conversation scenario, the QoE is positive if there is the quality of the voice transmission is superb and the end user can communicate effortlessly. Similarly, for web surfing, a positive QoE means the end user should be able to download high resolution images, graphics and videos in good time [5]. Multimedia services and applications are a guaranteed money spinner for service providers and mobile network operators, Thus network operators should ensure a rich QoE for subscribers, which will translate to prominent market share and profits. Most Internet Service Providers (ISP’s) and Telecommunications companies (Telco's) have been focusing their attention on the improvement of QoS with the ultimate aim of improving user satisfaction. As a result of saturation in the telecoms and multimedia services industry, it is important that service providers have satisfied customers and are able to maintain and improve their subscriber base. Telcos today must not wait for customers and end-users to complain about the service quality before they react because it is very easy for customers to change network providers when they experience low service quality, due to the ease associated with changing service providers. Thus, it is imperative that service providers are able to continually monitor and improve QoE when necessary [6]. As shown in [7,8] most end users are prepared to pay more money to enjoy a superior quality of experience and they will just as well move to other service providers if their needs are not adequately fulfilled.

2. Review of Related Works

In this section, a review of existing QoE models was carried out [9] defined a QoE model considering both quantifiable and non quantifiable parameters in quality assessments. The motivation behind their model was to have the capacity to plan quantifiable measurements for quality assessments by estimating how the end user perceives the service on offer. In [10], the authors introduced a QoE-based administration structure for the development of QoE models for various sorts of mixed media contents conveyed onto end user devices. The proposed structure depended on statistical techniques which relates QoS metrics specifically with assessments of perceived quality, and distinguished the level of impact of each QoS parameters on the user observation. By utilizing this data, the limits at which the user feels the service quality was unsuitable was characterized. Notwithstanding, the authors just considered how to expand end-user quality and they didn't think about the effect of the network or how to advance the utilization of network and system resources. The authors in [11] proposed a scheme to obtain end users' observations when utilizing system applications. The One Click structure included two stages. The primary stage included setting up experiments to gather feedback from the users, and the second examined the gathered crude data to decide how the users perceive the service under various system settings. The end users were requested to click a particular button at whatever point they felt disappointed with the quality of the application being used In [12], the authors proposed a pentagram model for estimating QoE. The model comprised five elements: "integrality, retainability, availability, usability, and instantaneousness" and these elements were used to measure the QoE. Tests carried out demonstrated that this model performed better as far as quality estimation was concerned when compared to traditional techniques. The main drawback with this model was that the model was evaluated for only QoE for VOIP services. Also, the overall QoE can be improved with the use of richer QoE metrics. An exhaustive model was proposed in [13] that incorporated both innovation contextual and business viewpoints. The proposed structure comprised four clearly defined segments: use process, end-user, ICT product and setting which were examined in greater detail from the user and technical viewpoints, providing relevant data on how they can be estimated. A comprehensive QoE model was proposed by the authors in [14] by trying to add up different aspects of the communication ecosystem together to achieve total QoE. The authors proposed an expanded variant of previous models by incorporating the innovation, business, setting, and human spaces. In addition, they characterized new attributes in each domain and presented the QoE categorization. In [15], the authors created a QoE framework that made use of a quantitative connection amongst QoS and QoE, with the goal that data and information can be gathered for mobility end users' encounters, examined, and after that the estimation of the contributing QoS factors for related QoE parameters can likewise be ascertained. In their research, the authors proposed a general QoE framework for network mobility and this was made up of two key interrelated areas: A QoE part and a QoS part. The authors in [16] developed a QoE management framework that was dependent upon end user feedback. In addition, they put forward an algorithm to ascertain why there are quality drops. The framework consisted of five different steps: "Service classification, main quality parameters extraction, feedback collection, QoE analysis and performance upgrade" and dissatisfied users were identified using a Simple Fault Reporting (SFR) scheme. A QoE estimation framework, called Web_QoE was created and implemented by [17] to obtain users' perceptions. A test database was created in the laboratory, and the sample database was trained using a machine learning algorithm. Thereafter, a QoE model was developed to evaluate the end-user QoE fulfillment. In [18], the authors opined that the concept of QoE to a very large extent is rarely considered by network providers during the network design phase. They tend to retrofit QoE into existing systems. As a result of this, the authors provided insights on the integration of QoE in mobile networks and then proposed a method for provisioning and managing QoE from end-to-end. They also investigated the viability, and key challenges for realization of end-to-end QoE were identified and discussed. In [19], the authors briefly described the main QoE frameworks.

In their research, they used exploratory qualitative techniques involving focus group discussions/ interview to carry out the experiment. The data obtained was recorded, analyzed and discussed. A novel model that is suitable for managing QoE of Web Services was proposed by [20]. This model was developed by iterating certain QoE activities: QoE modeling, (which was achieved by integrating the Key Performance Indicators and Key Quality Indicators) QoE monitoring, measurements, forecast, and optimisation. In [21], the authors carried out a survey of recently proposed QoE frameworks based on certain defined features such as data analysis, and parameters for data collection and monitoring. A comparative analysis of existing QoE frameworks were reviewed in terms of some predefined qualities and characteristics. It was observed that most of the frameworks reviewed did not support both subjective and objective QoE assessment and policy change on degradation of users' QoE. The authors in [22] focused on a Software Defined Network (SDN)-based framework QoE management. In their research work, the authors analyzed the framework and its three layers and thereafter, they connected the component parts of the framework to develop a SDN-based system, by utilizing the Opendaylight platform and Mininet emulator. From the reviewed literature, it was observed that most researchers focused on implementing QoE models that could evaluate the QoE for one particular service only (e.g. Voice over IP or Video on Demand only). The models developed lack widespread applicability in other services. In this research work, a QoE hexagram model was developed that would evaluate the QoE for multiple services.

3. Proposed Hexagram Model

The proposed QoE hexagram model is an enhancement of the pentagram model proposed by [12]. The hexagram model consists of certain Key Quality Indicators (KQI) and Key Performance Indicators (KPI). KPIs are "a set of quantifiable measures that are defined according to the key performance objectives" [23]. The Key Quality Indicators (KQI) values are obtained by evaluating the KPI's of a particular area of a service and are directly used to evaluate the QoE. As a rule of thumb, various KPI's have been defined by different standards' bodies. In this hexagram model, a new Key Quality Indicator (KQI), Terminal Quality was introduced with the associated Key Performance Indicators (KPI)- Terminal CPU Performance and Memory Consumption. This addition is important because irrespective of the values obtained for all the other mentioned KQI's, if the terminal quality is poor, it ultimately affects the overall QoE. Furthermore, a new KPI for usability, which takes care of the environment in context was introduced. In addition, two new KPIs, Packet corruption ratio and service access time were introduced for the Integrality and Retainability KQIs respectively. Table 1 shows the Quality of Experience Key Quality Indicators (KQI) and their associated measures.

Table 1: Quality of Experience KQI's and their associated measures. (Adapted from [12])

QoE Key Quality Indicators (KQI)	Key Performance Indicators (KPI) (Important Measures)	Symbol
Service Integrality	Packet Corruption, Delay, Jitter & Packet Loss Ratio	a
Service Retainability	Service Access Time, Service Interruption Ratio	b
Service Availability	The success ratio of user access service	c
Service Usability	Service Usability, Satisfaction, Environment	d
Service Instantaneousness	The response time(s) of established and access service	e
Terminal Quality	Terminal CPU Performance, Memory Consumption	f

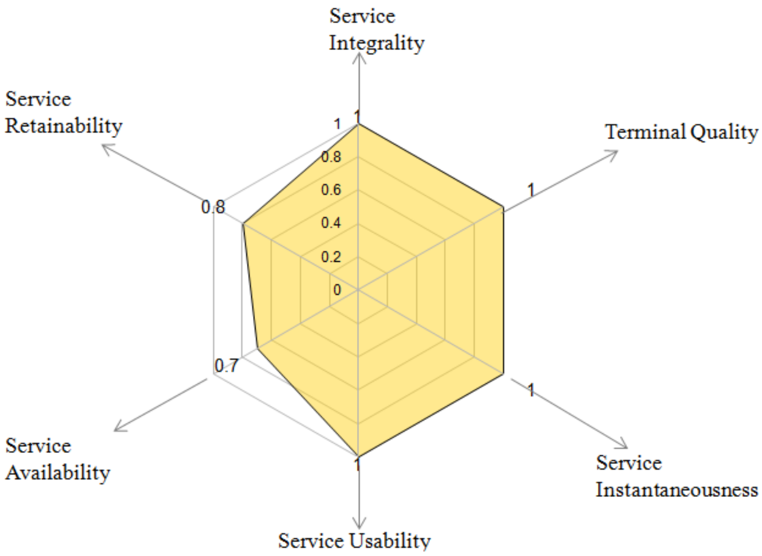

Figure 1: QoE Hexagram

In the QoE Hexagram model as illustrated in the hexagram in Figure 1, the QoE will be defined based on the evaluation and measurement of six QoE Key Quality Indicators (KQI) presented in Table 1. The value of the individual KQI's is obtained from the results of the KPI's established. We assume that the maximum and minimum values for each factor is 1 and 0 respectively. The area of the hexagram represents the QoE. The minimum QoE value is 0 and the maximum QoE value is approximately 2.58.

The hexagram comprises six triangles and the area of each triangle is computed as:

0.5 * L1 * L2 * Sin ϴ, where L1, L2 represents the sides of the triangles and ϴ represents the 60^0 angle between the two sides. The letters' a, b, c, d, e and f represent the six QoE Key Quality Indicators KQI's. The QoE is computed as:

$$QoE = \frac{1}{2} \text{Sin } 60^0 [ab + bc + cd + de + ef + fa]$$

$$QoE = \frac{1}{2} * 0.8660 * [ab + bc + cd + de + ef + fa]$$

$$QoE = 0.43 * [ab + bc + cd + de + ef + fa]$$

3.1 Definition of Key Quality Indicators (KQI) and Their Associated Measures

In this section, we define the Key Quality Indicators (KQI) and the associated quality metrics that are used in the QoE Hexagram model.

3.1.1 Service Integrality

Service Integrality defines the state of completeness of the service. In our model, we associate the following key

QoE metrics with service integrality: Packet Corruption, Delay, Jitter and Packet Loss Ratio.

Packet loss can be defined as the failure of IP packets travelling across a network to reach their destination. This could be as a result of transmission issues, congestion or limited memory. Packet Loss Ratio is defined as PLR = (No of Packets Lost / No of Packets Sent).

Delay, also referred to as latency, is the time involved in sending a packet from host to destination or vice versa.

Jitter can be defined as variation in delay and it usually caused by network congestion. If packets take the same time to move from one point to another in a network, there is no jitter.

"**Packet corruption** occurs when the receiver cannot correctly decode transmitted bits. Such decoding errors cause the cyclic redundancy check in the Ethernet frame to fail and force the receiver to drop the packet." [24]

The sum of the QoE of the Service Integrality is given by

$a = \beta 1 \text{ X Delay} + \beta 2 \text{ X Jitter} + \beta 3 \text{ X Packet Loss Ratio (PLR)} + \beta 4 \text{ X Packet Corruption}$

Where β1, β2, β3 and β4 represent the weighting of Delay, Jitter, Packet Loss Ratio and Packet Corruption respectively.

3.1.2 Service Retainability

Service retainability defines the continuity of service connection under given times for a given duration. This is defined by the service interruption ratio and the service access time, and is given as b = ά1 X Service Access Time + ά 2 X Service Interruption Ratio.

Where ά1 and ά2 represent the weighting of Service Access Time and Service Interruption Ratio respectively.

3.1.3 Service Availability

This defines success ratio of user access service. Service availability is given as

c = (Uptime) / (Uptime + Downtime)

3.1.4 Service Usability

This is "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use." [25]. In this model, Quality of usability is defined as

d =ΎΥ1 X Efficiency+ ΎΥ2 X Service Completion + ΎΥ3 X Satisfaction + ΎΥ4 X Environment

Where ϒ 1, ϒ 2, ϒ 3 and ϒ 4 represent the weighting of Efficiency, Service Completion, Satisfaction and Environment respectively.

3.1.5 Service Instantaneousness

This defines the time it took to establish and access a particular service without perceptible delay. Instantaneousness, e, is defined as a subjective weighted metric based on the end user feedback.

$e = f$ (response time)

3.1.6 Terminal Quality

This defines the quality of the end user device used in accessing the service. In this model, the performance of the central processing unit (CPU) of the device and the memory consumption of the device are used to establish the quality of the terminal.

$f = \lambda 1$ X CPU Performance + $\lambda 2$ X Memory Consumption

Where $\lambda 1$ and $\lambda 2$ represent the weighting of CPU performance and Memory Consumption respectively.

4. QoE Experiment and Analysis

The QoE of multimedia services and applications was evaluated using the proposed model. Experiments were performed on both web and video services and users were asked to rate the quality of their experiences. In this experiment, Packet Loss Ratio (PLR), packet corruption and jitter were kept constant while delay was introduced and varied in ascending order of magnitude from 100ms to 1000ms with intervals of 100ms. This was achieved using the NetEm tool, which is a WAN emulator / traffic shaper was used to emulate different QoS scenarios. NetEm is a Linux traffic control functionality which can be utilized in emulating packet loss, delay, packet reordering, jitter amongst others [26]. We conducted the user experiments with 36 subjects. The mean age of the subjects was 30 and the gender distribution had 22 males and 14 females representing 61% males and 39% females respectively. 50% of the subjects were students while and the other 50% were working class. There was a pre-experiment briefing of 10 minutes at the start of each experiment for each cohort and a 10 minute break between experiments. Each experiment lasted for 20 minutes duration. For the web browsing sessions/experiments, the webpage classes used were news pages, photo albums, geo location maps and online shopping sites. For the video streaming sessions, popular video streaming services like Netflix, YouTube and Footytube were used. At the end of each experiment, subjects were provided with questionnaires for feedback about the acceptability of the services under investigation. Applying the QoE hexagram model, the following results were obtained. Table 2 shows a summary of the results obtained from the experiment and Figure 2 shows the graph of overall QoE plotted against delay.

Table 2: Delay Comparison

S/N	Delay Value (Ms)	Number Satisfied With Service (%)	Number Willing To Reuse Service (%)	Average Mean Opinion Score (MOS)	Overall QoE
1	100	100	100	4.86	2.30
2	200	100	100	4.83	2.27
3	300	100	100	4.69	2.15
4	400	100	100	3.81	1.86
5	500	100	100	3.00	1.38
6	600	83	100	2.81	1.29
7	700	77	100	2.81	1.17
8	800	66	88	2.81	1.17
9	900	61	72	2.47	1.09
10	1000	0	0	1.66	0.74

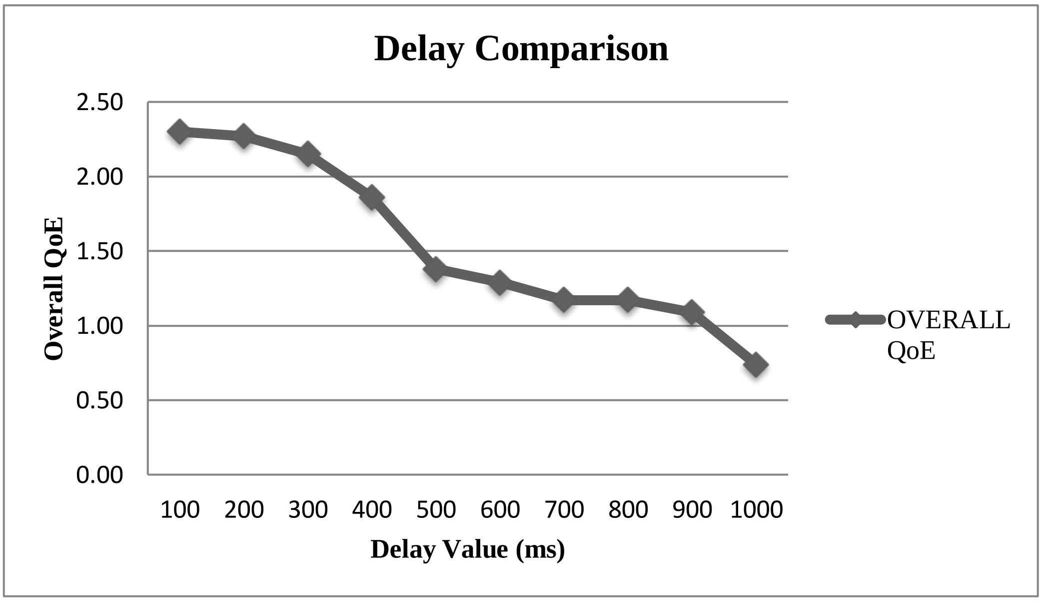

Figure 2: Overall QoE vs. Delay

5. Discussion

This study investigated the effect of delay on the overall QoE using the proposed model. The delay value was specified in milliseconds and it caused netem to delay all packets by this amount of time. The overall QoE of all subjects in the study for each delay level was averaged and the results obtained as shown in Table 2. This study revealed that users began to feel dissatisfied with the service when delay values rose to 600ms. The threshold for acceptability of the service was found to be 900ms as users were not willing to reuse the service at delay values exceeding 900ms. The QoE at this point was 1.09. It was observed that a negative correlation existed between the delay value and the overall QoE.

6. Recommendations

The benefits of superior network QoE in present and future multimedia communications cannot be over-emphasized. In this study, a model which directly reflects the end user's perspective of the overall end-to-end performance of the network services was developed. Mobile network operators can use the obtained results to develop and create user focused strategies and implement network services that will ensure end user acceptance and satisfaction. In addition, researchers in the network performance and quality of experience domain and professionals in the telecommunications industry can also leverage on the findings of this study. Furthermore, it is recommended that QoE should be incorporated in network design and not retrofitted.

7. Conclusion

Today's market for mobile network operators and service providers is unpredictable, fast-paced and very competitive. End users now have more options when choosing service providers, so the challenge now for service providers is to keep users happy and prevent churn. In this paper, we developed a QoE model for Mobile Network Operators Applications and Services and we also conducted several experiments on web and video content to obtain the QoE and acceptable threshold for users using the developed model. To calculate the QoE value, according to our model, the values for the KPIs are computed along with their associated weights and the total sum is the QoE. With our QoE model, MNO's can ensure superior network QoE for end users, attract new customers and reduce churn rate. MNO's can also increase profit margins by charging more for better quality. The study was limited to evaluating the QoE using the KPIs earlier discussed. In future, we plan to examine the effect of other metrics on the QoE as the more the metrics involved, the higher the accuracy of the QoE value. In addition, the subject diversity was limited as the experiments were conducted in a laboratory setting and most of the test subjects were members of the academia. In future, field trials could be carried out or crowdsourcing approaches employed.

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