Computer Science • 17 (3) 2016 http://dx.doi.org/10.7494/csci.2016.17.3.371

Piotr Nawrocki
Adrian Śliwa

QUALITY OF EXPERIENCE IN THE CONTEXT OF MOBILE APPLICATIONS

Abstract *Mobile devices are among the most-popular means of browsing the Internet, sending and receiving e-mail, and sharing content on social networks. People use mobile devices and the applications installed on them in different situations throughout the day. In order to ensure that users are satisfied with a mobile application, its author has to ensure a high Quality of Experience level. The problem of automatic evaluation of the QoE parameter is a very interesting research area. Quality of Experience is a broad issue and requires the analysis of many aspects not only graphical user interfaces but also, inter alia, Quality of Service and user ratings.*

Keywords Quality of Experience (QoE), Quality of Service (QoS), mobile application, mobile device, Android system

Citation Computer Science 17 (3) 2016: 371–385

1. Introduction

Mobile devices are now the most-popular means of browsing the Internet. These devices have mobile operating systems installed on them, thus allowing users to install mobile applications specially developed for these devices. Mobile applications are used for different purposes; e.g., web browsing, sending and receiving e-mail, and sharing content on social networks. These applications are used by a wide range of users whose abilities to use them may differ; therefore, they should be easy and intuitive to use.

The user operates a mobile application primarily through its graphical user interface. Mobile devices have much-smaller screens compared to traditional desktops. Locating graphical interface elements and connections between the individual screens are important parts of mobile application development. Easy access to the main application features is as important as the visual experience of its graphical interface.

A mobile application does not consist solely of a graphical user interface. When analyzing the quality of the experience related to mobile applications, the time needed to present the data is a significant aspect. If the waiting time for data is relatively long, the mobile user will not be satisfied with the mobile application, even if it has an interesting and clear graphical interface. The data required by the mobile application can be obtained primarily from the local database and web services.

The aim of the research presented in this paper is to define Quality of Experience (QoE) for mobile applications.

This paper presents the concept of determining Quality of Experience in the context of mobile applications. The proposed concept takes into account the main factors associated with the operation of mobile applications. In addition to the proposed concept, a system has been developed that allows for the measurement of Quality of Experience parameters. In order to ensure the high quality of the system developed and verify its functionality under real conditions, tests have been executed.

The paper is organized as follows: Section 2 presents related work; Section 3 presents the proposed methods and formulas used to measure the Quality of Experience parameter for mobile applications; and Section 4 presents the tests performed. Finally, the paper is summarized in Section 5.

2. Related work

Quality of Experience is a very important aspect in the context of mobile applications. People are increasingly using mobile devices to browse the Internet; therefore, the amount of research on Quality of Experience in the context of mobile devices continues to grow. Researchers have focused on two aspects of QoE in the context of mobile devices. The first is the theory of QoE measurement, and the second is the software used to calculate the Quality of Experience parameter.

According to [5], QoE is "the overall acceptability of an application or service, as perceived subjectively by the end-user": moreover, "overall acceptability may be influenced by user expectations and context".

The article [8] presents a correlation between Quality of Service (QoS) and Quality of Experience. It discusses the following parameters related to QoS: delay, jitter, loss rate, error rate, bandwidth, and signal-success rate. All of these parameters are used to evaluate Quality of Service. The formula proposed to evaluate Quality of Experience depends only on the QoS measure previously calculated. In the context of determining QoS parameters, an important issue is the fulfillment of a specific SLA (Service Level Agreement) contract [9]. The article presents an example of QoE evaluation using sample network parameters. One of the parts of the presented concept of QoE in the context of mobile applications is the analysis of network performance parameters and extended to user opinions and the manner of use of the mobile application.

Another article [10] presents a method of evaluating the Quality of Experience of mobile applications and services in a Living Lab setting. A Living Lab is a research and development infrastructure where users and authors co-create innovations. It introduces the concept of a mobile agent that is a software tool for QoE measurement. A mobile agent consists of three entities: the QoS-monitoring entity, the Contextual-monitoring entity, and the Experience-monitoring entity. Each entity operates on a mobile device and monitors different aspects of a mobile application.

In [2], the authors present three important QoE metrics: user-perceived latency, mobile data consumption, and energy consumption. User-perceived latency is defined as the time between the action of the user in the app and the UI response. The article describes QoE Doctor, which is a software tool for analyzing the Quality of Experience of a mobile application. The most important advantage of this solution (unlike in previous work [1]) is the fact that QoE Doctor does not require access to the application source code. It can, therefore, be used to analyze the QoE parameters of popular Android applications such as Facebook and YouTube.

In article [4], the authors present a four-week study, during which they collected data that influences Quality of Experience parameters. The group of people who participated in the study consisted of 29 Android system users. The parameters taken into account during the study included the application user interface, application performance, battery efficiency, user routines, and user lifestyle. The authors also studied the role of QoS and noted the impact of network parameters on the users satisfaction level. The research presented in this paper includes monitoring network parameters, the way users use the mobile application, and integration with application stores in order to automate the collection of user feedback regarding the mobile application.

Interesting techniques to improve Quality of Experience in the context of mobile applications are the Adaptive Web Page layout discussed in [13] as well as the interactive user guides presented in [3].

3. Defining QoE for mobile applications

The following section describes the methods and formulas proposed for measuring the Quality of Experience parameter for mobile applications. To validate the the-

ory proposed, an sample system has been developed and tested in the production environment.

3.1. QoS parameters in the context of mobile applications

In article [7], Quality of Service is presented as a network-related term that specifies the guaranteed level of network performance parameters. In [6], QoS is defined as the "totality of characteristics of a telecommunications service that bear on its ability to satisfy stated and implied needs of the user of the service". The most important parameters to be taken into account when analyzing QoS are delay, jitter, loss rate, error rate, bandwidth, and signal-success rate.

The two types of services most frequently used by mobile applications are web services and a local database. To determine the quality of network services, a mobile application can monitor two connection-performance parameters. First, it can check how much data is received in response from the service and how much time elapses between sending a request and receiving a response. An important issue that should be taken into account in this type of calculation is the presence of delays that occur in the network. The amount of data downloaded is not large in relation to the time that elapses from connecting to the service until receiving a response. In order to calculate the QoS parameter associated with the network service, Formula 1 has been proposed:

$$QoS_{service}(k,t) = a \ * \frac{k}{t} \tag{1}$$

where:

- k – the amount of data in kilobytes;
- t – the time to receive data in seconds;
- a – a factor equal to $1s/kB$.

The second component of the mobile application whose performance can be monitored is the local database. The main purpose of the database is to store the data used by the mobile application locally. In the case of access to the database, the number of records that are received per unit of time can be monitored. To calculate the QoS associated with the database, Formula 2 has been proposed:

$$QoS_{database}(n,t) = b * \frac{n}{t} \tag{2}$$

where:

- n – the number of records returned;
- t – the time to obtain data in seconds;
- b – a factor equal to $10^5 s$.

Factors a and b in Formula 1 and Formula 2, respectively, have been selected so that the values obtained from these formulas are equal to 1 (where the quality of service and, thus, the quality of mobile user experience are optimal). This means a situation where the accessed information is presented to the user within, at most,

0.2 seconds. 0.2 seconds is the maximum time in which the user perceives no significant delay [11]. Based on network conditions and the mobile database, performance parameters a and b were adjusted.

To calculate QoS in the context of mobile applications, Formula 3 has been proposed. This formula averages the values of Formulas 1 and 2. The average result is then normalized to a range between 0 and 100.

$$QoS_{mobile} = \left(1 - \frac{1}{1 + \frac{QoS_{service} + QoS_{database}}{2}}\right) * 100 \tag{3}$$

For Formulas 1 and 2, values equal 1, the mobile application QoS value calculated from Formula 3 is equal to 50, and this is the optimal value (with access to data taking no longer than 0.2 seconds). Subsequently, we use the $1 - 1/(1 + x)$ function, whose values grow from 0 to 1 for positive arguments. An interesting observation is that there is no significant difference in the QoS_{mobile} result irrespective of whether the data is collected in 0.1 seconds or ten times faster, because this does not signify a significant difference for the user. Formula 1 was adjusted so that it mostly reflects the difference between 0.2 seconds and a few seconds.

3.2. User reviews

User reviews are a subjective parameter in evaluating the quality of the service or application. They indicate the overall satisfaction level among service users.

In order to compare the users ratings between different applications, the *OpinionRate* parameter has been proposed. The average score must be normalized to a range from 0 to 100. To calculate the value of the *OpinionRate* parameter, the average of the ratings derived from a particular application store should be divided by the highest rating possible in that store. Then, the result should be multiplied by 100. In order to calculate the value of the *OpinionRate* parameter, Formula 4 should be used.

$$OpinionRate = \frac{AvgRate}{MaxRate} * 100 \tag{4}$$

where:

- $AvgRate$ – the average rating derived from the official application store;
- $MaxRate$ – the highest rating in the application store.

3.3. Data generated during mobile application usage

The user interacts with a mobile device through the applications graphical user interface. The user can spend variable amounts of time on different screens and switch between them. Usually, the interaction with an application consists of pressing the buttons on the touch screen or using hand gestures.

In order to measure the quality of experience associated with the interaction between users and the graphical interface, the *UserActions* parameter was defined. The default value of this factor is equal to 50, and it should range from 0 to 100.

The value 50 was selected since it is possible to decrease it if some conditions are not met, leave it around 50 if some conditions are met, or increase it to around 100 if all conditions are met. This parameter is calculated in a manner specific to a particular application. The application developer should define the conditions (e.g., the number of clicks of a button or the number of records in a list) whose fulfillment increases the value of the *UserActions* parameter (and the value decreases if these are not fulfilled). Each condition should have a weight (as shown in Formula 5), which is a number ranging from 0 to 50. The sum of all weights should equal 50. The weights are specific to each application and should be defined by the developer. If some functionality is very important, the weight related to this functionality should also be greater than the others; e.g., if the number of records representing a user's friends' game scores is high, the user can compare his or her score with his or her friends, which should be a positive experience. The *UserActions* parameter should be determined individually for each application user. The average score for all users shows the overall quality of experience related to the actions that the users perform in their applications. A high average value suggests that users are able to use the application easily. Conversely, a low average value may point to the fact that certain parts of the application are not very intuitive and require more user involvement. In order to calculate the value of the *UserActions* parameter, Formula 5 has been defined:

$$UserActions = 50 + \sum_{i=1}^{n} w_i \begin{cases} 1, & \text{if condition } i \text{ is fulfilled.} \\ -1, & \text{in the other case.} \end{cases} \tag{5}$$

$$w_i \in (0, 50]$$

$$\sum_{i=1}^{n} w_i = 50$$

- n – the number of conditions defined by the mobile application developer;
- w_i – the weight of condition i.

If a condition is defined as the presence of at least ten rows in the score list, it is met if the score list includes ten or more records. If the score list includes fewer than ten records, the condition weight is multiplied by -1.

3.4. Quality of experience parameter for mobile applications

There are many definitions of the Quality of Experience parameter. The definition included in [5] states that it is the overall acceptability of an application or service as subjectively perceived by the end user. In [12], the relationship between QoS and QoE is described in such a way that the purpose of the network and service is to provide the best user experience, while the high quality of the network connection ensured by QoS is the way to achieve this purpose. Quality of Experience is related to Quality of Service, and this relationship is shown in Figure 1.

Quality of Experience in the context of mobile applications can be defined as the users overall impression when using an application. Many factors affect the value

of the QoE parameter, and this value may vary between different users. In order to determine QoE for mobile applications, Formula 6 has been proposed.

$$QoE_{mobile} = \frac{QoS_{mobile} + OpinionRate + UserActivity}{3} \tag{6}$$

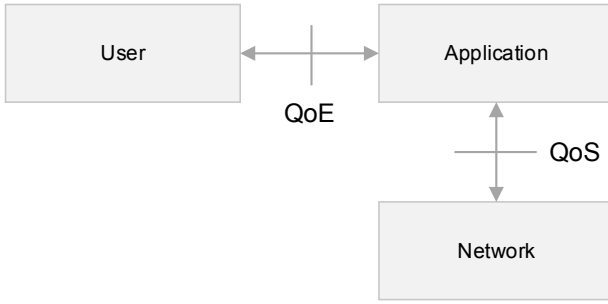

Figure 1. Relationships between QoE, QoS, network, application, and the user.

This formula takes into account the three main factors associated with the use of mobile applications that are presented in this Section:

- QoS_{mobile} – the quality of the services that are used by the mobile application;
- $OpinionRate$ – the average of the application users subjective ratings;
- $UserActivity$ – the value of the actions performed by the user in the mobile application.

Each of the above factors takes values between 0 and 100. This formula contains the arithmetic mean of these three parameters, so each of them carry the same weight when the final Quality of Experience score is calculated. The formula proposed is the arithmetic mean because the author assumes that all parameters are equally important in the context of mobile applications.

4. Tests

In order to test a method for measuring the Quality of Experience parameter for mobile applications, a system that automatically calculates and monitors QoE parameters has been developed. In order to determine the QoE for a mobile application, the system calculates three parameters: Quality of Service, the rating derived from the Google Play Store, and the actions performed by the user in the application. The system collects the data sent from the mobile application. The application in question is a quiz game developed especially for research purposes. The application has been developed for the Android mobile operating system.

4.1. System architecture

The system has been divided into three main components. These components are the mobile library, web application server, and webpage as a graphical user interface. The system architecture proposed in this study is presented in Figure 2.

Figure 2. Tested system architecture.

The most important part of the system developed is the web application server. The server has two interfaces: one for the mobile library and one for the website. The interface for the mobile library includes endpoints designed according to the REST paradigm. The mobile application sends the data generated during its activity via this interface. The server stores this information and then processes it. The second interface is developed for the webpage. This interface has also been designed according to the REST paradigm. The interface provides methods of retrieving the data that is presented to the user of the system.

The purpose of the mobile library is to record the events (e.g., the user pressing a button or moving to the next screen) that occur during the use of the mobile application. These events are stored in the local memory of the mobile device and then sent to the server.

The webpage is responsible for presenting the processed data collected during the activity of the mobile application.

4.2. The test results of calculating the QoE

The purpose of the tests was to verify the results related to the proposed concept of Quality of Experience in the context of mobile applications. After the implementation of the testing platform, the system was deployed, and the mobile application was published in the Google Play Store. The mobile application was advertised via social networks. During a period of 3 months, 63 users played the game, generating the data collected and processed by the platform in the process. The author of the mobile application developed the conditions for the *UserActions* parameter and also took this parameter into account. These conditions were, inter alia, the number of clicks of the refresh button in order to download a new question to be answered and the number of records in the friends' score lists.

During the tests, data from mobile devices was collected. This data allowed QoS parameter values to be graphed versus time. The graph is presented in Figure 3.

The highest QoS parameter value was recorded at the beginning of the tests. The reason for this could be the fact that the application was only used by a single user at that time. When the number of users increased, the value of the QoS parameter

changed from 35 to 47. With a higher number of mobile application users, variability of the QoS parameter decreased. In the final testing phase, the QoS parameter value fluctuated at around 40.

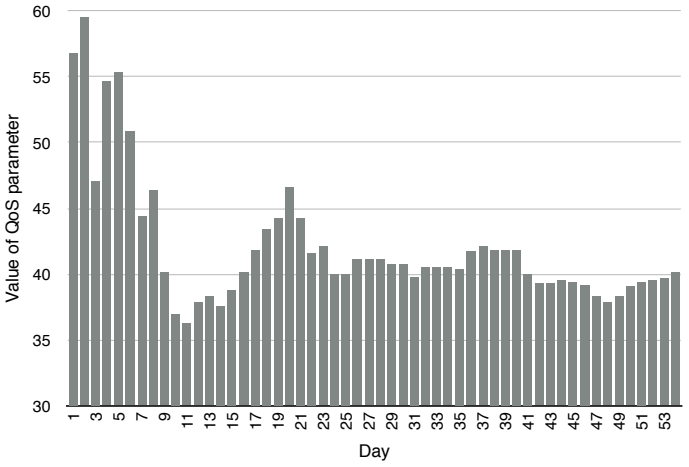

Figure 3. Graph of QoS parameter values versus time.

During the tests, the *OpinionRate* parameter took only three values. These values are derived from the Google Play Store, in which the application developed was available for downloading. Only 4 out of the 63 people who took part in system tests rated the QuizProject application in the Google Play Store. The application received two 5-star, one 4-star, and one 1-star ratings. At the beginning, the application received two 5-star ratings; therefore, the value of the *OpinionRate* parameter was equal to 100. Subsequently, the application received a 1-star rating, and the *OpinionRate* parameter dropped to 73. The last rating obtained was 4 stars, which resulted in a final value of the *OpinionRate* parameter of 75. The number of ratings received by the mobile application compared to the number of application users suggests that only a small percentage of users are willing to rate applications. The graph of *OpinionRate* parameter values versus time is presented in Figure 4.

Like in the chart of QoS parameter values, the maximum value of the *UserActions* parameter was reached at the beginning of the tests. Again, this is due to the fact that this value was obtained when a single person was using the application. As the number of application users increased, values of the *UserActions* parameter stabilized. Most of the time, the value of the *UserActions* parameter was slightly above 50. The graph of changes in the value of the *UserActions* parameter over time is presented in Figure 5.

Values of the QoS, *OpinionRate*, and *UserActions* parameters affect the Quality of Experience parameter. The trends visible in the QoE values chart (Figure 6) are similar to those in the QoS (Figure 3) and *UserActions* (Figure 5) charts. The highest

QoE parameter value was recorded at the beginning of the system tests. The maximum value of the QoE parameter was equal to 70.86. At the time when the number of application users was 11, the QoE parameter value was 60.33. When the number of application users increased, changes in the QoE parameter became smaller. When the number of users registered in the database was 53, the value of the QoE parameter was equal to 55.7. Several days after the tests had started, values of the QoE parameter stabilized at slightly above 55.

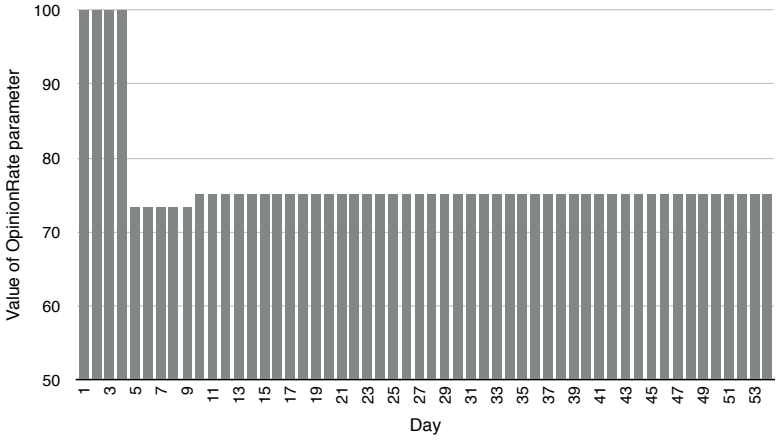

Figure 4. Graph of *OpinionRate* parameter values versus time.

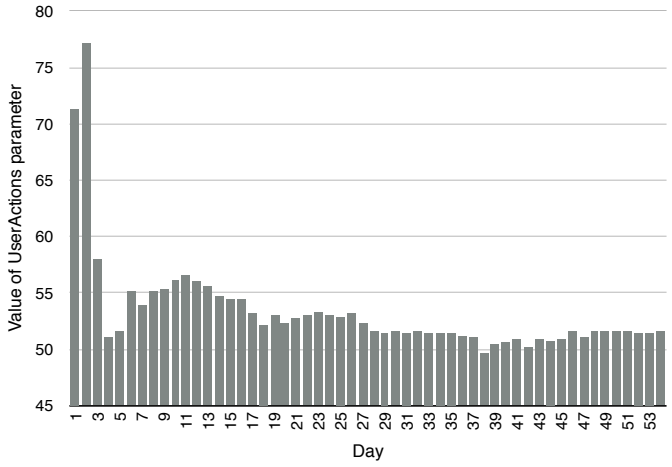

Figure 5. Graph of *UserActions* parameter values versus time.

The chart in Figure 7 shows that the highest value of the QoE parameter was recorded when the QoS parameter was also the highest. In most cases, higher values

of the QoS parameter were correlated with higher values of the QoE parameter. For QoS parameter values close to 40, changes in the value of the QoE parameter were minor, and the other parameters tested (*OpinionRate* and *UserActions*) had a greater impact on the QoE parameter.

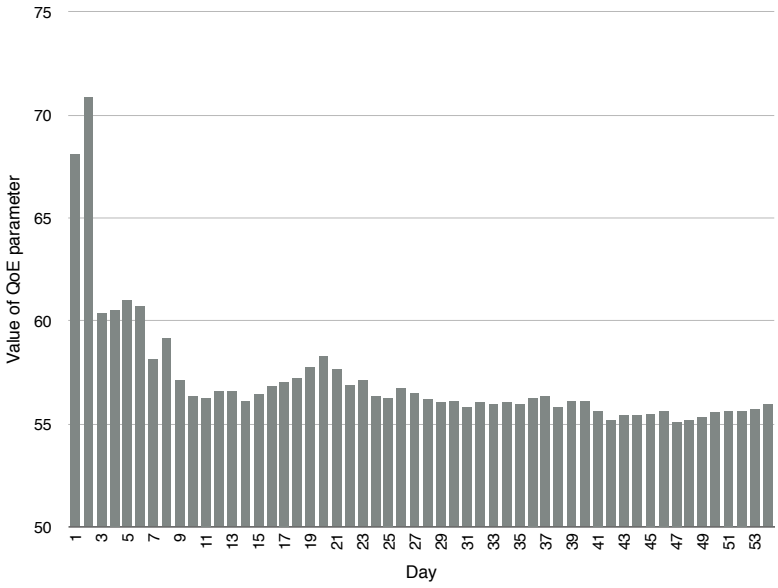

Figure 6. Graph of QoE parameter values versus time.

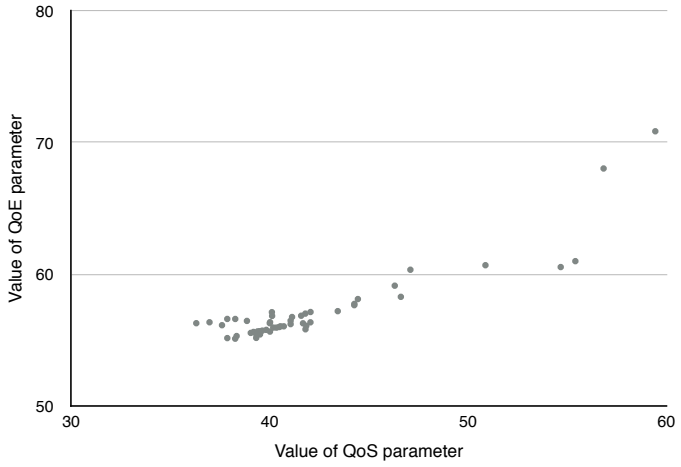

Figure 7. Graph of Quality of Experience parameter values versus Quality of Service parameter values.

The points in the graph in Figure 8 are arranged along three straight lines, because the *OpinionRate* parameter took only three different values during the tests. The graph demonstrates that, for the highest possible value of the *OpinionRate* parameter (100), the QoE parameter was also the highest. In the graph in Figure 8, it can also be seen that, for the lowest value of the *OpinionRate* parameter (73), the value of the QoE parameter was higher than for the *OpinionRate* parameter equal to 75. This resulted from the fact that the values of the other parameters tested (QoS and *UserActions*) were higher at the time.

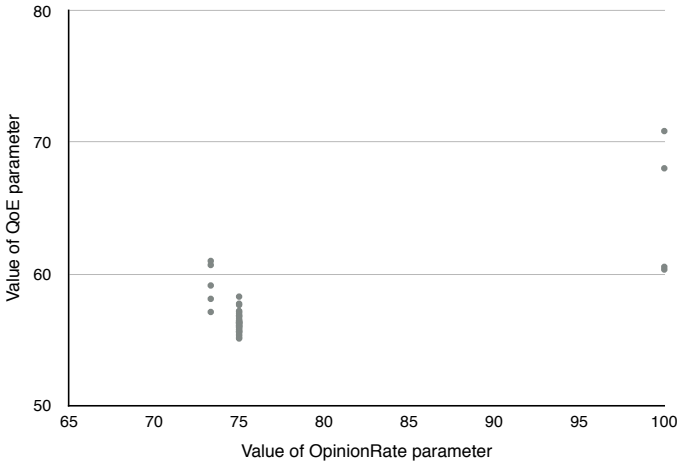

Figure 8. Graph of Quality of Experience parameter values versus *OpinionRate* parameter values.

The graph in Figure 9 demonstrates that, for the two highest values of the *UserActions* parameter, the QoE parameter was also the highest. For other values of the *UserActions* parameter (which ranged from 49 to 58), values of the QoE parameter ranged from 55 to 61.

Tests have demonstrated that the values of QoE parameters calculated by the system remain stable during long periods of mobile application and system operation. All of the parameters tested (QoS, *OpinionRate*, User Actions, and the resulting QoE parameter) were the highest on the second day of testing. The purpose of the tests was to verify whether the formulas proposed are correct and do not generate results that would be overly low or high and whether individual parameters change after long periods of time. The tests demonstrated that the results are meaningful and the theory proposed could be developed in the future (and also verified using different types of applications).

The platform developed can be used by any other Android application. The only requirement is to add a prepared library to the application project and – instead of

using standard views like buttons and edit fields – replace them with their overridden implementations supplied with the library.

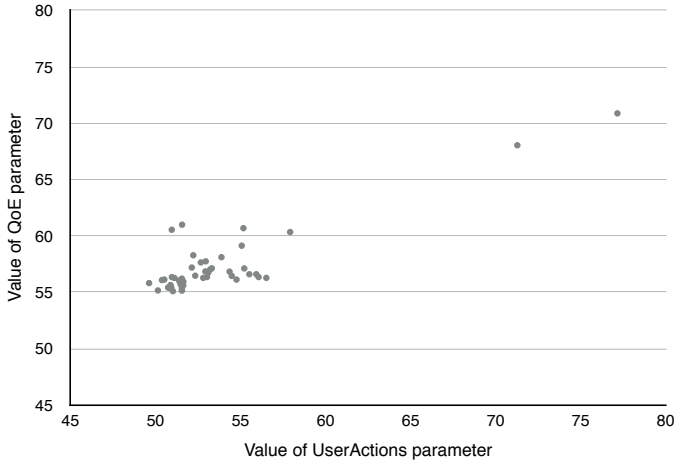

Figure 9. Graph of Quality of Experience parameter values versus *UserActions* parameter values.

5. Conclusions

The Quality of Experience parameter in the context of mobile applications has been defined as a metric dependent on the following parameters: Quality of Service related to network and database performance, ratings derived from official application stores (e.g., Google Play, App Store), and actions performed by application users. At the same time, a formula was proposed to calculate QoE parameters.

In order to apply the concept put forward, a system for calculating Quality of Experience parameters for mobile applications was developed. The most important elements of this system are a mobile library that is attached to the mobile application and monitors its activity, and an application server that is responsible for storing and processing the data received from mobile devices.

System tests lasted for three months. During this time, the system collected 80,000 events generated as a result of the operation of mobile applications. Those events were generated by 63 mobile application users.

An interesting observation made during the tests concerns the ratio of the number of ratings for the mobile application in the Google Play Store compared to the number of its users. The QuizProject application[1] received ratings from just 4 out of 63 users, which means that just a little over 6 percent of users were willing to rate it. Opinions

[1]QuizProject application – `https://play.google.com/store/apps/details?id=com.quizproject.app`.

rated by only a few users were enough to calculate the *OpinionRate* parameter. If the application was more popular and had more active users, these users would rate the application more often.

Acknowledgements

The research presented in this paper was partially supported by the Polish Ministry of Science and Higher Education under AGH University of Science and Technology Grant 11.11.230.124 (statutory project).

References

[1] Aggarwal V., Halepovic E., Pang J., Venkataraman S., Yan H.: Toward Quality-of-Experience Estimation for Mobile Apps from Passive Network Measurements. *HotMobile*, 2014.

[2] Chen Q.A., Luo H., Rosen S., Mao Z.M., Iyer K., Hui J., Sontineni K., Lau K.: QoE Doctor: Diagnosing Mobile App QoE with Automated UI Control and Cross-layer Analysis. *Proceedings of the 2014 Conference on Internet Measurement Conference*, 2014.

[3] Chua W.Y., Wan M.P.H., Chang K., Wu Y.: Improving Mobile Applications Usage Experience of Novice Users through User – Acclimatized Interaction: A Case Study. *Americas Conference on Information Systems*, 2014.

[4] Ickin S., Wac K., Fiedler M., Janowski L., Hong J.H., Dey A.K.: Factors influencing quality of experience of commonly used mobile applications. *Communications Magazine*, 2012.

[5] ITU-T: *Definition of Quality of Experience (QoE).* International Telecommunication Union, 2007.

[6] ITU-T: *Definitions of terms related to quality of service.* International Telecommunication Union, 2008.

[7] Kelly E.B.: Quality of Service In Internet Protocol (IP) Networks. *Infocomm*, 2002.

[8] Kim H.J., Lee D.H., Lee J.M., Lee K.H.: The QoE Evaluation Method through the QoS-QoE Correlation Model. *Networked Computing and Advanced Information Management*, vol. 2, 2008.

[9] Kosinski J., Nawrocki P., Radziszowski D., Zielinski K., Zielinski S., Przybylski G., Wnek P.: SLA Monitoring and Management Framework for Telecommunication Services. J. Bi, K. Chin, C. Dini, L. Lehmann, D.C. Pheanis, eds., *Networking and Services, 2008. ICNS 2008. Fourth International Conference on*, pp. 170–175, IEEE Computer Society, 2008.

[10] Moor K.D., Ketyko I., Joseph W., Juan-Verdejo A., Pessemier T.D., Marez L.D.: Evaluating Quality of Experience of mobile applications and services in a Living Lab setting. *Mobile Networks and Applications*, vol. 15, 2010.

[11] Nielsen J.: *Usability Engineering*. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA, 1993.

[12] Noman Muhammad Davide Chiavelli D.S., Li M.: *QoS and QoE Management in UMTS Cellular Systems*. John Wiley and Sons, 2006.

[13] Vu Q.D., Vu D.V., Nguyen H.T., Bui P.D.: Adaptive Web page layout for mobile devices. *Computing, Management and Telecommunications (ComManTel), 2014 International Conference*, 2014.

Affiliations

Piotr Nawrocki
AGH University of Science and Technology, Krakow, Poland, piotr.nawrocki@agh.edu.pl

Adrian Śliwa
AGH University of Science and Technology, Krakow, Poland, adrianmsliwa@gmail.com

Received: 29.10.2015
Revised: 3.03.2016
Accepted: 13.04.2016