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# Factors Influencing Quality of Experience of Commonly Used Mobile Applications

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## ABSTRACT

Increasingly, we use mobile applications and services in our daily life activities, to support our needs for information, communication or leisure. However, user acceptance of a mobile application depends on at least two conditions: the application's perceived experience, and the appropriateness of the application to the user's context and needs. However, we have a weak understanding of a mobile user's quality of experience (QoE) and the factors influencing it. This article presents a 4-week-long 29-Android-phone-user study, where we collected both QoE and the underlying network's quality of service measurements through a combination of user, application, and network data on the user's phones. We aimed to derive and improve the understanding of users' QoE for a set of widely used mobile applications in users' natural environments and different daily contexts. We present data acquired in the study and discuss implications for mobile applications design.

## INTRODUCTION

The growing availability of diverse interactive mobile applications, assisting us in different domains of daily life, makes their perceived quality of experience (QoE) increasingly critical to their acceptance. However, to date, evaluation of QoE has mainly focused on an application's usability [1], which is evaluated in studies conducted for a limited time in controlled laboratory environments, under conditions that do not resemble users' natural daily environments. The results of such evaluations help to discover serious and immediate usability issues, but they are unlikely to help in recovering from issues that are relevant to real-life situations outside the laboratory.

These real-life issues involve, among others, a nondeterministic quality of service (QoS) [4] and, in particular, the performance of the underlying networks' infrastructures supporting the

execution of the mobile application. The QoS is usually provided at the "best effort" level, that is, without any guarantee by a provider on its performance. Yet QoS can be critical to the user's QoE, especially for highly interactive mobile applications, delivery of which depends on frequent data transfers over the underlying infrastructures.

A common practice for QoE provisioning is that mobile application designers use their own judgment and perception of an application's use as a bellwether to gauge an application's perceived experience [1]. This causes users, whose QoE expectations are not satisfied, to give up using the applications or to switch to another provider. It is estimated that more than half of 200 new Apple's iPhone applications available daily, do not achieve a critical mass of user acceptance and are withdrawn from the store's offer within months from the launch.

The challenge for designers and researchers studying new mobile applications is that no robust scientific methods exist for evaluating applications' perceived QoE in the user's natural environments. Rather, there are qualitative methods for usability evaluation in the Human Computer Interaction (HCI) community [1], and there are quantitative methods for the evaluation of the QoS and performance of the underlying network infrastructures in the data networking community [2]. Due to the dichotomy between these approaches, there are no robust methodologies that combine both types of methods. Our approach is to measure QoE and QoS through a combination of methods with a goal of improving our understanding of factors influencing QoE, and enabling us to derive implications for mobile application design and QoE management.

In [11], which was published in the third week of the ongoing user study, the authors presented an overview and then the details of the methodology, followed by a very short presentation of the results for a study in progress. In this article, we shortly present the methodology, and then

expand the analysis and discussion of the study results.

We present related works, methodology, results, and factors influencing users' QoE, and we discuss the role of QoS. We discuss the results, including the implications for application design, and finally, we conclude the work and outline the future work areas.

## RELATED WORK

With respect to mobile user experience, according to Jaroucheh *et al.* [10], while modeling usage of pervasive technology and the resulting user's QoE, one should consider the historical as well as current user context and the flexibility of user behavior depending on this context. Similarly, according to Hassenzahl and Tractinsky [9] user experience is influenced by user's internal state, the characteristics of the designed system, the context within which the interaction occurs, and the meaningfulness of the activity. Korhonen *et al.* [12] surveyed mobile users and concluded that the mobile device, task at hand, and social context are the most influential factors of a user's QoE. Similarly, Park *et al.* [13] indicated usability, usefulness, and affect as the factors, and Shin *et al.* [14] added enjoyment, as well as network access quality to this list. Reichl *et al.* [3] attempt to evaluate QoE in real user environments by capturing user interaction with the mobile phone, as well as the user context using two different cameras mounted on a large woman's hat worn by the user. The approach also includes the acquisition of QoS measures on the mobile phone and relating these to QoE. The authors indicate some design implications for video streaming applications.

The most important difference between the existing studies and ours is the fact that we focus on measuring users' perceived experience in a minimally obtrusive manner on users' (personal) phones, for a set of mobile applications used in their natural daily environments, and we aim to increase the understanding of factors influencing this experience.

## METHODOLOGY

This section presents the design of our methodology, which is detailed further in Wac *et al.* [11].

### OVERVIEW

We use mixed methods, incorporating qualitative and quantitative methods in a four-week-long user study:

- Employing continuous, automatic, unobtrusive context data collection on the user's mobile phone through a Context Sensing Software (CSS) application
- Gathering user feedback on the perceived QoE via an Experience Sampling Method (ESM) executed multiple times per day
- A weekly interview with the user along the Day Reconstruction Method (DRM) method

We focus on already implemented and operational interactive mobile applications, which are available and commonly used on a typical smartphone.

## MOBILE USERS AND DATA COLLECTION

**Recruitment: Online Survey** — To recruit the participants, we designed an online survey for mobile users to find out how long they have been using mobile, what phone type they have, through which network provider they are connected, what usual usage pattern for voice and data communication they follow, which applications they use, and the users' experience in general with the current smartphone. Moreover, we got their socio-economic status. The major criteria for the selection of 30 participants were to own an Android smartphone and to use it frequently in various conditions in daily life. Therefore, 30 users were selected randomly from 430 potential candidates.

### Android Sensor Logs: CSS Application

The CSS application unobtrusively collects the information from users' Android phones, regarding cellular network, Bluetooth, WiFi connectivity and its received signal strength indication (RSSI), sent/received data throughput (in kilobytes per second), number of calls and short message service messages (SMSs), acceleration, screen orientation and brightness, running applications, and user location. Most of the data is collected only when the sensor value changes, i.e., the Android operating system (OS) updates the CSS with data. As the QoS indicator, we focus on an interactivity of a mobile application and therefore we measure the median round-trip time (RTT) for an application-level control message (64 bytes), sent every 3 min from the mobile device through the available wireless access network technology to a dedicated server, which is deployed at our university. Simultaneously, server response time (SRT), which is calculated as the time it takes to get an HTTP request-response with updated weather information of the Android smartphone to a dedicated weather application server was also monitored. The CSS sensor logs are immediately written to the phone storage card to minimize the memory allocation on the phone throughout the data collection process, as well as to minimize the risk of data loss. Further details on CSS are provided in [11].

**QoE Ratings and Context Logs: ESM** — We have employed ESM [5] to gather users' QoE ratings. We have implemented this in the form of a short mobile-device-based survey, which is presented to him/her after using an application. Thus, it is aimed to not influence the experience and behavior of a user. Therefore, the survey does not appear after each application usage, but at random times after random application usage, with a maximum of 8–12 surveys per day. The survey poses questions about:

- Rated application QoE (poor [1] to excellent [5] based on the International Telecommunication Union [ITU] Recommendation [6] for mean opinion score [MOS])
- Location (home, office/school, street, other indoor, other outdoor)
- Social context (alone, with a person, with a group)

*The most important difference between the existing studies and ours is that we focus on measuring users' perceived experience in a minimally obtrusive manner on users' phones, for a set of mobile applications used in their natural daily environments, and we aim to increase the understanding of factors influencing this experience.*

*In general, the participants find their QoE acceptable; they have explained that they learned how to maximize their mobile application usage along their routine activities. The participants exhibited knowledge on circumstances that they can expect particular QoE depending on network coverage.*

- Mobility level (sitting, standing, walking, driving, other)

While rating the same application throughout the study or even for a given day, we requested that users do their best to provide independent ratings, while keeping in mind that a rating is a purely subjective QoE, episodic assessment provided on the basis of the given perception of the specific episode of application use. We aimed to capture QoE for a set of widely available mobile applications for entertainment, communication, or information purposes such as Internet-based radio, web browsing, online games, video streaming, email, and news. In total, it takes approximately 5 s for the user to complete each ESM. According to our tests confirmed by the users, neither CSS nor ESM logs negatively influenced the performance of their smartphone.

**Weekly Interview: DRM** — We have followed the DRM method [7] in order to analyze possible relations and causality between QoE ratings, QoS, and user context, and interviewed the users on a weekly basis regarding their usage patterns and experience on the mobile applications along their previous 24 h period. During the interview, users explained their responses from the ESM, and these results were compared to the visualized CSS and ESM data logs from the smartphone. This method has been used for fast identification of any inconsistencies between the collected data by CSS and the DRM. This way we could also identify the factors influencing QoE for this particular user.

#### STUDY PARTICIPANTS AND COLLECTED DATA

The study was conducted for four consecutive weeks in February–March 2011. We have recruited 31 Android users with three types of Android OS phones (Motorola, HTC and Samsung), which are subscribed to four providers (Verizon (23 participants), Sprint (4 participants), T-Mobile (3 participants), and AT&T (1 participant)). Two participants dropped out in the first three days of the study due to battery issues on their older phones (S1, S27). S11 collected only one week of data and then dropped out due to an inconvenience. Participants S2, S8, and S9 experienced data logging outages due to malfunctioning software on their phone or an explicit altering of the logging. Table 1 presents participants (from left): participant ID, gender, profession, phone type, age range, overall MOS as reported in the online survey, overall MOS perception as derived from the study and the percentage of its occurrence within all the collected MOS, number of occurrences of low MOS values: 2 and 1 that are separated by comma, and the total number of MOS ratings collected by the user in the study. None of the participants had accessibility problems related to their phone use and, when asked, none of them admitted that they were adversely affected by the beliefs regarding electromagnetic resonance (EMR) health issues for mobile phone usage. We have collected data logs for 17,699 h in total, which represent 87.8 percent of the hours for the overall study duration of 28 days. On average we have missed 84.9 h (i.e., 12.5 percent) per participant (min. 3 h, max. 378 h).

## RESULTS FOR QoE AND CONTEXT (ESM)

In this section we present results collected for QoE ratings and the user context.

### QoE RATINGS

In total, we collected 7804 QoE ratings from all the participants with an average of 9.29 ratings per day and per participant. The high ratings (4, 5) are much more frequent than low ones (1, 2) as illustrated in Fig. 1. In general, the participants find their QoE acceptable; they have explained that they learned how to maximize their mobile application usage along their routine activities. The participants exhibited knowledge on circumstances that they can expect particular QoE depending on network coverage.

### APPLICATIONS

Amongst the applications, for which we have collected QoE logs, there were standard Android built-in applications, e.g., web or email applications, as well as a variety of specialized ones. After gathering all data from the study, we have identified (from Android Market) the following 13 categories of mobile applications (presented in order of descending frequency of usage):

- Communication: talk, skype, gmail, email, gtalk
- Web: default browser, dolphin
- Social network applications: okcupid, cooliris, foursquare, facebook, twitter, foursquared, tumblr, touiteur
- Productivity tools: astrid, sandbox, calendar, shuffle, callmeter, outofmilk
- Weather apps: weather, weatherservice, weathercachingprovider
- News: espn, sports, news, penguinsmobile, foxnews, penguinsMob, reddit, newsfox, pit-tFight
- Multimedia streaming: listen, youtube, pandora, lastfm
- Games: worldwar, WoW, games, poker, zyn-gawords, words, touchdown
- Lifestyle apps: horoscope, sparkpeople, diet
- Finance: stock
- Shopping: ebay, coupons, starbucks card, craigslist, starbucks
- Travel: navigator, maps locationlistprovider
- Other applications

### CONTEXT

The applications were used mostly at “home,” “office/School,” and “indoor/other,” as depicted in Fig. 2. With respect to the social context, the applications were used on average 80 percent of the time when the user was “alone.” The mobility levels dominant for an application usage were “sitting,” “standing,” and “other,” specified by the user precisely as “bed.” Low QoE ratings occur mostly when a person is at home or school while being alone and sitting.

## FACTORS INFLUENCING QoE

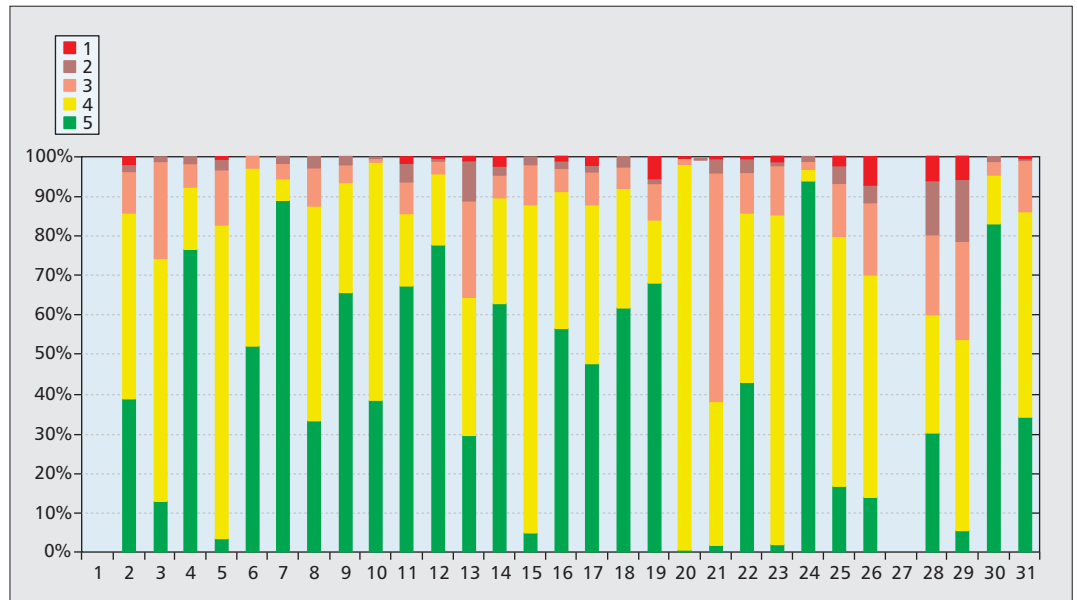
To derive the factors influencing a user’s QoE, a wordcloud was created that visualizes the word frequency in a user’s expressions as a weighted

S	Gender	Profession	Phone type	Age	QoE–survey	QoE–study	MOS = 2,1	Total no. of ratings
2	M	Customer service	Samsung Captivate	18–24	5	4 (47%)	4, 4	218
3	M	Owner, moving company	Motorola Droid	25–35	2	4 (61%)	3, 0	181
4	M	Driver	MyTouch 4G	25–35	4	5 (77%)	4, 0	233
5	F	Research assistant	HTC Incredible	18–24	5	4 (79%)	5, 2	227
6	F	Admin. higher education	G2	25–35	4	5 (52%)	1, 0	323
7	F	ICT consultant	Motorola Droid X	25–35	5	5 (89%)	5, 1	390
8	M	Web developer	Motorola Droid	25–35	5	4 (54%)	4, 0	143
9	F	Medical admin. asst.	Motorola Droid	25–35	5	5 (66%)	4, 0	197
10	F	Nanny	HTC Incredible	25–35	5	4 (60%)	4, 0	543
11	F	Unemployed	Sam. Vib. Galaxy–S	25–35	5	5 (68%)	3, 1	62
12	M	Unemployed	HTV Evo (WiMAX)	36–45	4	5 (78%)	3, 6	620
13	M	Univ. program mgmt.	Motorola Droid	25–35	5	4 (35%)	25, 3	254
14	M	Contractor	Motorola Droid X	25–35	4	5 (63%)	8, 9	369
15	M	Accounts coordinator	Motorola Droid	25–35	4	4 (84%)	4, 1	196
16	F	Operations analyst	Motorola Droid X	25–35	5	5 (57%)	7, 4	327
17	M	System analyst	Motorola Droid	36–45	5	5 (48%)	4, 5	240
18	M	ICT consultant	HTC Evo (WiMAX)	25–35	4	5 (62%)	5, 0	209
19	M	Teacher	Motorola Droid	25–35	4	5 (68%)	4, 18	317
20	F	Administrative assistant	HTC Evo (WiMAX)	25–35	4	4 (97%)	1, 1	296
21	M	University student	Motorola Droid	25–35	4	3 (57%)	7, 1	195
22	M	Grant administrator	HTC Incredible	25–35	5	5 (43%)	10, 1	276
23	M	Graduate student	Motorola Droid 2	25–35	2	4 (83%)	1, 2	137
24	M	Systems analyst	HTC Evo (WiMAX)	25–35	4	5 (94%)	2, 0	198
25	F	University student	Motorola Droid 2	18–24	5	4 (63%)	16, 10	386
26	M	Senior admin. asst.	Motorola Droid	25–35	5	4 (55%)	11, 20	253
28	M	Graduate student	Motorola Droid X	25–35	5	5 (30%)	34, 15	251
29	M	Paramedic	Motorola Droid	36–45	4	4 (48%)	33, 12	213
30	F	Housewife	Motorola Droid X	36–45	5	5 (83%)	3, 1	341
31	M	Registered nurse	Samsung Captivate	25–35	5	4 (52%)	1,1	209

**Table 1.** Participants: demographics and QoE ratings (S1, S27 dropped out).



Application interface and interaction was mentioned very often; users did not like the position and location of the keys on the smartphone screen, they had difficulty with resizing, web-page scrolling, they did not agree with built-in dictionary items, and they complained about inefficient manual input.



**Figure 1.** QoE ratings distribution for mobile users. Participants S1 and S27 dropped out early in the study and therefore were not included in the analysis.

list. Font sizes are set in relation to the frequency of the corresponding word as illustrated in Fig. 3. We have used all 376 expressions from our 29 user's weekly DRM interviews, as well as data from an online survey with 430 entries. The most frequently mentioned key words are applications, mobility, Internet, battery, performance (e.g., "slow," "freeze"), as well as features such as Global Positioning System (GPS), camera, and flash player. Many of these are difficult to evaluate automatically. We have grouped these words into clusters by using the affinity clustering method, which we then have labeled along the identified factor. The coding and grouping of words into clusters were done by two independent people, and their measure of agreement was 90 percent. Most disagreements were related to the interface and application performance clusters, especially for cases where the participants were not clear on pinpointing the main issue. Finally, we have distinguished the following factors influencing the user's QoE.

#### AN APPLICATION INTERFACE'S DESIGN

Application interface and interaction were mentioned very often; users did not like the position and location of the keys on the smartphone screen, they had difficulty with resizing or web-page scrolling, they did not agree with built-in dictionary items, and they complained about inefficient manual input (e.g., the "fat finger" problem). Some users preferred interacting with a web-based interface of particular applications (e.g., Facebook) than with its widget.

#### APPLICATION PERFORMANCE

"Freeze," "sloppy," "sluggish," "speed," "performance," "usage of memory," and "sdcard" were the expressions used when referring to low application performance. Especially for mobile applications users previously experienced on a fixed PC, the expectations for performance were high, which resulted in low QoE.

For those users who had a PC as an alternative device (e.g., to receive/send emails), their rated QoEs were limited to reception of emails on the smartphone since they used the PC for sending emails. The reason for this is that typing on a real keyboard of a PC provides a better experience, especially for long messages. On the other hand, some users preferred a smartphone to run most of the applications. For those users, mobile applications achieved enough usability to enable them not to use a larger and potentially more comfortable PC. In the future, we wish to understand the characteristics of these users and the applications they use on a mobile and a PC better.

Two particular participants were adaptive, at the same time complaining about the applications, but they had to use them anyway: S4 complained about the "stupid" autocorrect function of messaging, and S16 had to use a specific virtual private network (VPN) application with low usability to access corporate email.

Some mobile users expressed their tolerance for worse application performance when they use it "on the move." In parallel, users regularly mixed network performance with application performance metrics; for example, while saying "Skyping service is incredibly spotty," the concern is actually the underlying network connectivity of Skype service, not the application itself.

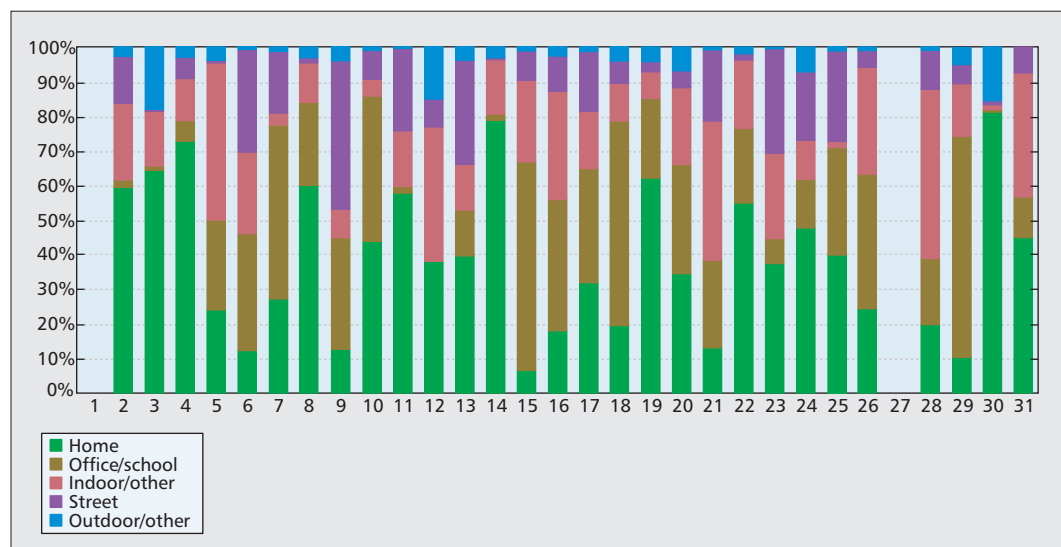
#### BATTERY

Battery efficiency consistently influenced the experience of the mobile users, as it limited their phone usage, especially at the end of the day, when the phone was completely discharged. S12 resolved that issue by carrying an additional battery.

#### PHONE FEATURES

Mobile users noted missing features of the phone, which then hindered their experience; for example, lack of a flash player, lack of a person-

*Routine of the user implied that different sets of applications were used in the morning, in the evening before going to sleep, in the car, and outside the office. The user rating is influenced by the user's environment and the importance of the mobile application to the task at hand.*



**Figure 2.** Mobile users' locations distribution. Participants S1 and S27 dropped out early in the study and therefore were not included in the analysis.

alized alarm clock, lack of special settings for vibrate-only mode, lack of or a faulty GPS, and lack of features for privacy settings.

#### APPS AND DATA CONNECTIVITY COST

In the online survey, many of the mobile users indicated that the cost of applications and data usage prohibits them from experiencing these applications.

#### USER ROUTINE

The routines of the users implied that different sets of applications were used in the morning, in the evening before going to sleep, in the car, and outside the office. The user rating is influenced by the user's environment and the importance of the mobile application to the task at hand.

#### USER LIFESTYLE

There were highly ranked applications that support a user's lifestyle choices (e.g., sports, fashion, nutrition, and leisure). They are used on a smartphone due to their convenience of usage (e.g., in the gym for logging of burnt calories), in the cafeteria (for logging caloric intake), or on the street while trying to find a fancy restaurant.

### THE ROLE OF QoS

Along the data analysis, we realized that we do not have much evidence of the influence of QoS on the user's QoE. There are low QoE ratings in our data, but there is no strong evidence for a low QoS. One of the reasons for that can be, as indicated in the previous section, the fact that factors influencing a user's low QoE are different than QoS. Another reason for that can be insufficient granularity of our QoS measurements with limited permissions (i.e., non-rooted phones) to access network level metrics on user phones.

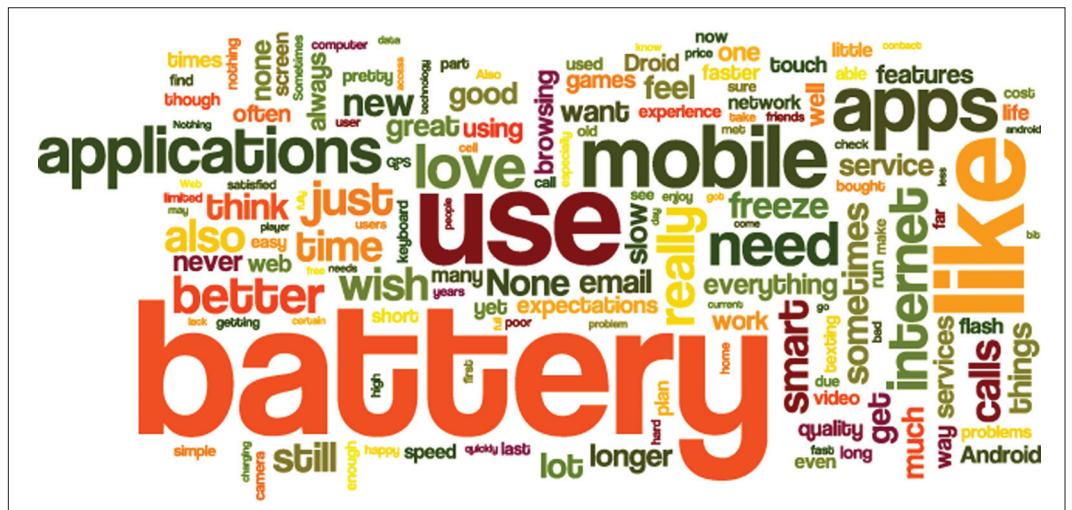
With respect to the QoS, it is influenced by the choice of wireless access technology, that is, wireless LAN (WLAN), 2.5 generation (2.5G), third or fourth generation (3G or 4G), thus

influencing QoE. In our study we observe, however, that the performance of the access network is not an issue, as users are well-connected and have a choice of networks (as ordered by an increasing nominal capacity), GPRS, 1xRTT, CDMA, EDGE, UMTS,  $EVDO_0$ ,  $EVDO_A$ , and HSPA. WiMAX was available for selected users in selected urban locations: S12, S18, S29, and S24. Some number of users were connected over WiFi at home and office, in order to ensure better QoS. We observed diversity in the connectivity through WiFi interfaces among the users, ranging from 0 to 398.5 h. In total, nine participants never used WiFi during the study, while six participants never turned the interface OFF that allows the smartphone to connect to any available WLAN access point when detected. We have attempted to investigate the influence of the WiFi signal strength on MOS; however, no clear trends were observed.

The overall mean of RTT values collected in the study is 231 ms with a standard deviation of 73 ms. However, it differs per MOS level (Fig. 4 presents the mean of SRT and RTT). From the figure, we observe that higher values of SRT and RTT correspond to lower MOS. For both measures, the confidence intervals gets narrower as the MOS increases. The fluctuation in these measures observed for low ratings, especially for MOS values 1 and 2, may be related to the influence of these measures on the application performance. From Fig. 4, we conclude that the recommended server response time for a mobile application assuring the MOS level of 3 is 950 ms, the response time of 850 ms corresponds to the MOS level of 5 and high user experience.

Turning to throughput (i.e., bytes received per second by the smartphone), in Fig. 5 we observe the relation between its average value and the MOS levels; the mean throughput increases with the increase in MOS values, and the confidence interval increases as well. This means that there are many different throughput ranges resulting in the same MOS level.

The applications, for which there were many



low QoE ratings, were streaming multimedia applications like *Listen*, *YouTube* and *Pandora* — audio feeds application, video streaming and real-time radio streaming accordingly. Any participant in our study was using one of these applications in average 1.67 h per day, which involved 50 MB of download traffic and 1.7MB of uplink traffic per day. A total of 1.38 Gbyte for downlink and 0.5 Gbyte for uplink traffic is observed in 28 days. A participant was running listen application in average for 0.8 h, YouTube for 0.34 h, Pandora for 0.5 h/day, although most of the usage was observed within a fixed group of 10 participants with a varying distribution of

population. The applications Listen, YouTube, and Pandora involved around 32.7 Mbytes, 8.15 Mbytes, and 8.36 Mbytes of downlink traffic per day, and 1.03 Mbyte, 0.3 Mbyte, and 0.36 Mbyte of uplink traffic, correspondingly. Some of the mobile users using these applications rated ‘1’ for MOS, being critical of its performance, but some other users were tolerant, knowing that they gain possibility of accessing these applications while being mobile, and paying a performance ‘price’ for that. Low ratings can be related to the fact, that these applications require high network capacity or, as we learned from participants, some application widgets were buggy and influenced the application performance. Additionally, some participants were launching pre-loaded MPEG-2 Audio Layer III (MP3)s when driving, in the bus, or walking outside.

The 4G (WiMAX) service was rarely used because of its unavailability, as S18 claimed: *“Unfortunately, I don’t get 4G in (A). And when I’m in (B), the 4G connection keeps switching on and off, and the notifications are just annoying. So I keep 4G switched off.”* Another (S20) said: *“My phone can operate on a 4G network, but I usually keep it set to 3G because in my experience, the 4G is not considerably faster and just eats up my battery... Generally I keep 4G turned off unless I am doing something network intensive and I know it is available.”* We were surprised to hear that, because according to the results of performance measurements we conducted for the 3G and 4G networks, use of the 4G network results in better QoS parameters than 3G. We presume that the applications used by this particular user worked sufficiently well on 3G. It seems to contradict our initial hypothesis that a mobile user always wishes to have the best possible and fastest service. Our future work includes analysis of the data to support or refute this hypothesis.

Additionally, using our DRM, we discovered clusters of users for which network selection and the resulting QoS depended directly on their phone charging behaviors. Users who were able and willing to charge their phones often preferred the access technologies in the order WiFi-4G-3G, while this changes to 3G-WiFi-4G for



the ones who charged their phones less often. A common feeling among our users was that 4G was as good as WLAN but drained too much battery. In addition, 4G coverage is a problem, so users who are subscribed to providers with 4G support are not necessarily always within the 4G coverage, which leads to connectivity oscillations between 3G and 4G, resulting in draining extra battery and putting users at risk of instant disconnections.

## STUDY LIMITATIONS

We recognize study limitations influencing the generalization of results. Firstly, the study has been conducted on self-selective group of mobile users, with self-selective set of applications. We have analyzed the QoE ratings of participants in our study and we have identified some participants who use many applications in a short time. The maximum number of applications that were used within the last 3 min of the given QoE rating were 19. We observed that the applications are rated with high MOS values, 4 and 5, as more applications are used within the 3 min time period. We hypothesize that either such a user is more advanced and uses many mobile applications, with which he/she is satisfied, or by using so many applications in a short time, this user has no time to pay attention to details of his/her low experience, just grasping the essence of, say, information provided by the application for the given situation at hand. It would also be more contributive if it were possible to clearly pinpoint the type of access network technologies (e.g., 3G, 4G) in relation to the MOS values. In addition, we were not able to capture extreme conditions (i.e., extremely high RTT or SRT values) due to lack of granularity of the selected samples for the study. Capturing worst conditions in real-life scenarios is challenging and nontrivial, so a longer time of study could be suggested in order to capture all scenarios a user can experience. Moreover, there would have been a wider variety of measurable QoS network metrics (e.g., delay jitter and packet loss) if the smartphones were rooted and privacy concerns were not important.

## CONCLUSIONS AND FUTURE WORK

In this article, we have presented our research toward understanding a mobile user's QoE in his/her natural daily environments. Our approach is a blend of both quantitative and qualitative procedures, where the user becomes an active participant in the research. First, it requires gathering in situ spontaneous information about the user's mobile experience for a set of widely used mobile applications, employing the Experience Sampling Method (ESM) for interaction with the user directly after each mobile application usage. Second, it requires a retrospective analysis of the user's experience and the state of factors influencing it, employing the Day Reconstruction Method (DRM) to assist with the recollection of the past 24 hours. DRM was supportive in validating the collected data through the CSS application. In this article, we have presented an analysis of the collected data by highlighting some factors that impact the user's QoE.

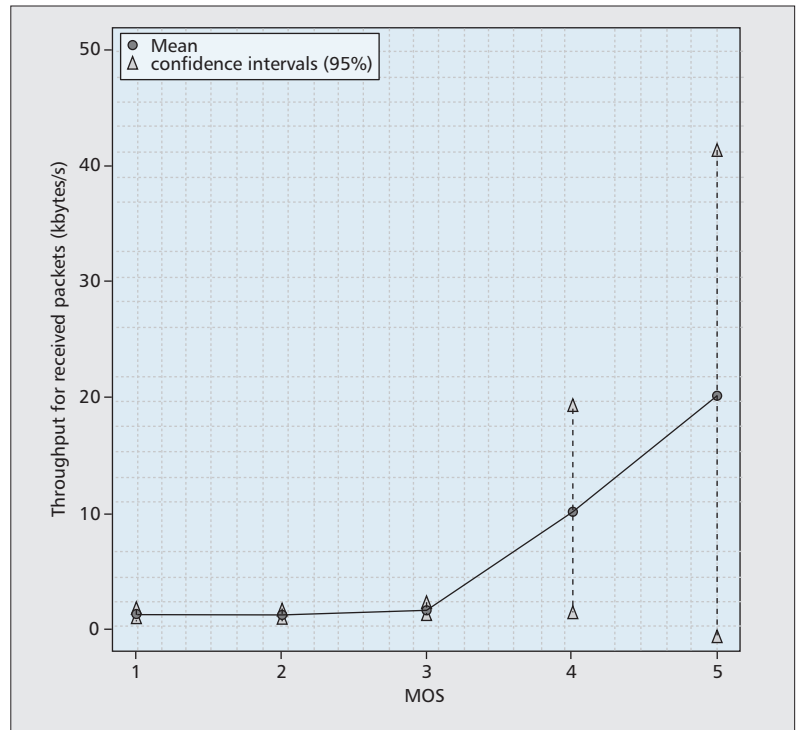


Figure 5. Mean received throughput (95 percent CI) vs. MOS.

The novelty relates to the factors that influence QoE, including application interface design, application performance, battery efficiency, phone features, application and connectivity cost, user routines, and user lifestyle. These factors go beyond the usual usability, usefulness, and user value factors, as already indicated in the literature. The role of QoS was also studied, and it was indicated that increased SRT and RTT values and decreased received throughput reduces the MOS values; however, in general, we observed that the users are well connected, and use their applications mainly while in fixed indoor position and being alone. The recommended SRT for a mobile application to ensure an MOS level of 3 is 950 ms.

Our future work includes analysis of other factors and user context influencing this experience, and grounding them [8] via additional user studies. The implications for design-based factors are numerous; the QoE management for mobile applications and services must be multifaceted, and cannot only focus on maximizing the QoS of the underlying network infrastructures but also on the application's interface design, application performance, and mobile device performance factors, given the user's expectations and tasks at hand. In addition, machine learning techniques can be applied to the user data with carefully chosen attributes and appropriate algorithms toward accurate prediction of user QoE in different contexts.

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