# Mobile Cloud Storage: A Contextual Experience

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## ABSTRACT
In an increasingly connected world, users access personal or shared data, stored "in the cloud" (*e.g.*, Dropbox, Skydrive, iCloud) with multiple devices. Despite the popularity of cloud storage services, little work has focused on investigating cloud storage users' Quality of Experience (QoE), in particular on mobile devices. Moreover, it is not clear how users' context might affect QoE. We conducted an online survey with 349 cloud service users to gain insight into their usage and affordances. In a 2-week follow-up study, we monitored mobile cloud service usage on tablets and smartphones, in real-time using a mobile-based Experience Sampling Method (ESM) questionnaire. We collected 156 responses on *in-situ* context of use for Dropbox on mobile devices. We provide insights for future QoE-aware cloud services by highlighting the most important mobile contextual factors (*e.g.,* connectivity, location, social, device), and how they affect users' experiences while using such services on their mobile devices.

### Author Keywords
Context-aware; mobile; Quality of Experience (QoE); cloud storage services.

### ACM Classification Keywords
H.5.m. Information interfaces and presentation (*e.g.,* HCI): Miscellaneous.

### General Terms
Human Factors; Design; Measurement.

## INTRODUCTION
Mobile smart devices such as smartphones and tablets are increasingly intertwined with our lives: Forecasts from 2012 predicted that by 2016, the number of mobile-connected devices will amount up to 10.3 billion [5], while for 2013, expected sales of mobile smart devices were close to 1.2 billion units [9]. These devices offer a vast range of new affordances to users and enable connectivity anywhere, at any time and from any device. However, one unyielding disadvantage of these lightweight, mobile devices is their limited storage capacity, which also limits their possible uses. It is also more common to find services and applications that work across different mobile devices and platforms. As a result, the related user behavior and usage patterns have become more complex and a range of problems has emerged. One recurring challenge is to connect multiple devices that have vastly different characteristics and requirements and how to synchronize the stored data across these devices in an effortless way. With recent improvements on network speed, reliability and increased availability, and based on principles of cloud computing, a growing number of consumer market and business-oriented providers of cloud storage have started to address these and other challenges.

In spite of the controversy surrounding the notion of 'cloud computing' and whether it is really new or just a new wrapping [22], cloud computing is (re-)shaping the Internet and the services it provides [1]. Infrastructure and scalability management are hidden away onto the "cloud." Services such as Amazon's Elastic Compute Cloud, Microsoft's Azure and Google's AppEngine provide "flexible" hardware and storage availability in a cost-effective approach. Currently, Dropbox is one of the most popular cloud computing services, available on desktop and mobile environments [7]. It offers almost unlimited cloud storage on the go, given the availability of Internet connection (except when accessing cached files). Files can be easily accessed and automatically synchronized across a range of devices: laptops, smartphones, and tablets.

However, from a cloud service provider's perspective, it is challenging to gain insight into the users' expectations and experiences, *i.e.*, users' Quality of Experience (QoE). This is crucial to practitioners and service providers to evaluate service performance and to detect and overcome the technical challenges that come along with these applications. Moreover, as personal cloud storage services and applications may be used in different contexts and from diverse other devices, the key influence factors on the QoE need to be investigated and better understood. We find in literature for example, that users' QoE is influenced by waiting times [17] and the availability of services [4] in a desktop environment. However, nearly no previous work has assessed mobile contextual factors influencing users' QoE when using cloud storage services on mobile devices such as smartphones and tablets. In this paper, we therefore


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assess users' Quality of Experience (QoE) when using cloud storage services on mobile devices and how it is affected by the users' context.

## RELATED WORK

### Quality of Experience

Over the last decades, increased attention was given to the world of technology users/society, the actual use and the meaning of technology (*e.g.,* in research, policy and practice). Especially in the context of ICT research and innovation, there has been a growing awareness that users and consumers are demanding, powerful, and self-conscious stakeholders that cannot be simply ignored [15]. In various research fields (*e.g.*, HCI, telecommunications, multimedia and vision research, service management) an effort is being made to measure and understand how users *experience* ICT products, applications and services.

Traditionally, emphasis was put on *technological* excellence and *quality*. Since the 90's however, experiences rendered through the encounters with a product, brand, service or application, have notably been emphasized as a basis for differentiation [19]. The quality of users' experiences have been linked to market success or failure of new and existing products, applications, services [16]. This renewed focus on *experience* is reflected in the literature by relatively young concepts such as User Experience, Quality of Experience and Customer Experience, which stem from distinct disciplines and research traditions, but which nevertheless have some common grounds. We *must* acknowledge that experiences are *subjective*, *individual* and highly *complex* and therefore it is necessary to investigate them from a multi-disciplinary perspective and through involvement of actual users. Other unknown factors may influence users' experiences and should therefore be investigated and better understood.

'Quality of Experience' has its roots in the field of Telecommunications, but over the last decade it has also acquired a more prominent role other fields and disciplines. In 2012, a more holistic and broadly supported perspective on QoE was introduced, defining it in terms of *affective states*, as the: '*degree of delight or annoyance of the user of an application or service. It results from the fulfillment 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*'[3]. In addition, it is argued that a range of factors situated at the human level, system level and context level may have an impact on a user's Quality of Experience[20].

In the domain of communication services, QoE has been shown to be influenced by service, content, network, device, application, and context of use (divided into several dimensions – Where, What, When, Why, Who and How [6]). Whereas much previous work has already focused on factors at the system level (*e.g.,* network-, device-, media- or content-related) and to some extent at the human level, the influence of contextual factors on QoE is still poorly understood and very challenging to investigate. Here, we explicitly focus on the role of contextual factors of and in relation to QoE.

### QoE & Cloud Computing Services

For end-users, cloud computing promises advantages in terms of services, computation and data access. The migration of services to the cloud is associated with new affordances such as sharing and accessing personal data in a flexible way and from different types of devices, easy collaboration amongst multiple users, and others [11]. However, in order to manage the available resources in an efficient way, while at the same time trying to enable a pleasurable and positive Quality of Experience at the user side, it is necessary to better understand which aspects meet users' expectations, enable delight or lead to frustration (and potentially a decision to stop using a service). Moreover, it should be better understood which contextual factors play an influencing role.

Casas *et al*. [4] argues that due to the explosion of cloud-based services in the mobile domain – characterized by dynamic and volatile network conditions – QoE has become problematic, 'a real bottleneck.' In order to establish QoE within applications, Hoßfeld *et al*. [12] monitored network environment and conditions, terminal capabilities, Service Level Agreements (SLAs) and service and application-specific information. However, QoE is not solely influenced by network, technical and Quality of Service (QoS)-related parameters.

It has been shown that contextual and human factors may also play a major role[20]. For example, in the context of Web QoE, memory effects, *i.e.*, the psychological influence of past experiences, bear a strong influence [11]. Furthermore, a recent study on adoption of cloud services suggests that security and privacy issues impose strong barriers to user adoption [23]. As a result, it is important to look beyond the technical aspects in order to gain a better understanding of the experiences and practices related to the use of personal cloud storage services and applications.

## METHODOLOGY

We attempt to understand better the mobile context in which users' expectations and experiences change, *immediately* after using a cloud storage service (*e.g.*, Dropbox). Our goal is to study the link between QoE and users' mobile context. To accomplish this, we surveyed 349 cloud storage service users on different aspects of QoE (Study 1). In a follow-up 2-week empirical study, we collected 13 users' perceptions on Dropbox mobile phone usage with a mobile Experience Sampling Method (ESM) (Study 2). The ESMs allowed us to collect *in-situ* qualitative and quantitative contextual data, right after the participants used Dropbox. Our work provides evidence of the effects the user's mobile context (*e.g.*, location, network connectivity (speed, signal strength, network type), time of day, social context) has on users' QoE while using Dropbox on their smartphones and tablets.

**Study 1: Mobile cloud storage services survey**

Our goal is to better understand the cloud storage services users, as to gain better insight into the users' expectations when using these services. We developed an online survey based on [2, 16] for the use of personal cloud services, with a total of 26 questions divided into 10 groups:

- ***Cloud services:*** what services and applications are used; how frequent are they used;
- ***Context of use:*** in what locations are clouds services used; how frequent are they used in different locations;
- ***Devices:*** what devices are used to access cloud services; what content is consulted on which devices;
- ***Connection:*** what connection is used to access cloud services; how frequent are the connection types used;
- ***Data:*** what amount (GB) and type of data is stored;
- ***Motivation for usage:*** why are cloud services used; importance of service affordances (sharing, back-up) and QoE influencing factors (availability, privacy, cost, security,…);
- ***Financial:*** does the respondent pay for usage; how much does he pay; willingness to pay for greater storage capacity; maximum fee per month;
- ***Sharing:*** with whom is data shared;
- ***User experience:*** how long does the respondent already use cloud services; perceived benefits and drawbacks of using personal cloud services;
- ***Socio-demographic information:*** gender; year of birth; residence; diploma; occupation;

We promoted the survey using mailing lists, advertising at Facebook and online forums, including dedicated online groups with interest on the field of cloud computing. In total, 349 users of personal cloud services and applications completed the survey (66.2% male; 33.8% female). The mean age of the respondents is 33.63 years (SD=12.32; min=18; max=62).

**Study 2: Dropbox QoE**

In Study 2, our primary goal was to observe the context in which Dropbox mobile application is used, as to understand better users' QoE while using such services in a resource constrained device. More importantly, we wanted to investigate the relationship between context and QoE and how they affect one another, with a real world deployment, *i.e.,* not in a laboratory setting.

We recruited 13 mobile Dropbox users, owning an Android smartphone or tablet (Android 2.3+) as to minimize novelty bias. Additionally, we selected participants whose Dropbox usage varied between several times a day (*i.e.*, frequent user) to 3 or 4 times a week (*i.e.*, occasional user), as to capture diverse cloud service usage (Table 1).

In a 2-week deployment, we used AWARE [8], an open-source Android framework dedicated to infer, log and share mobile context information to acquire data from our participants' phones:

- ***Device***: type (*e.g.*, tablet, phone), hardware specifications (*e.g.*, manufacturer, model) and Android OS version (*e.g.*, 2.3 or higher);
- ***Location***: date, time, and GPS or network triangulation location (as a fallback of a GPS failure);
- ***Network access***: active network connection (*e.g.*, Wi-Fi, network) and network type (*e.g.*, 3G, 2G);
- ***Network traffic***: received and transmitted bytes and packets for active network connection;
- ***Network quality***: signal strength (*i.e.*, RSSI) to connected network point (*e.g.*, Wi-Fi access point, network tower);
- ***Battery life***: battery depletion over time.

| | | | | | | | MOS | | |
|---|---|---|---|---|---|---|---|---|---|
| Participant | Gender | Age | Occupation | Device | Brand | Model | ESM | Debriefing | # ratings |
| PP1 | M | 20 | Student | S | Sony | LT22i | 4.33 | 4 | 3 |
| PP2 | M | 27 | Student | S | HTC | Desire X | 4.00 | 4 | 3 |
| PP3 | M | 26 | Translator | S | Samsung | GT-I9300 | 3.62 | 4 | 8 |
| PP4 | M | 23 | Student | T | Samsung | GT-P7500 | 3.30 | 4 | 20 |
| PP5 | F | 26 | Student | T | Asus | Prime TF201 | 3.30 | 5 | 10 |
| PP6 | F | 26 | Officer Shipping | S | Samsung | GT-I9300 | 2.89 | 3 | 29 |
| PP7 | F | 23 | Student | T | Samsung | GT-P5110 | 3.86 | 4 | 7 |
| PP8 | M | 29 | Banker | S | HTC | One X | 3.75 | 4 | 12 |
| PP9 | M | 24 | Developer | T | Samsung | GT-P7320 | 4.12 | 4 | 41 |
| PP10 | F | 24 | Student | S | Sony | LT22i | 4.00 | 4 | 1 |
| PP11 | M | 26 | Developer | T | Samsung | GT-P7510 | 5.00 | 5 | 3 |
| PP12 | M | 33 | Consultant | S | Sony Ericsson | LT18i | 4.07 | 4 | 15 |
| PP13 | M | 28 | Student | T | Samsung | GT-P3110 | 3.50 | 4 | 4 |
| M - Male, F - Female, S - Smartphone, T - Tablet | | | | | | | Mean=3.68 SD=1.11 | Mean=4.08 SD=0.49 | N=156 |

**Table 1. Participants' QoE ratings, socio-demographics and device related information.**

In addition to the metrics collected via AWARE, we added the functionality to collect traces on the Dropbox app, such as date, time and amount of time spent using the application. To capture QoE-relevant usage information *in-situ* and independently of the current user's context and to avoid missing data (*e.g.*, daily diaries [14]), we used the Experience Sampling Method (ESM). ESM is a "*research procedure for studying what people do, feel, and think during their everyday lives. It consists of asking individuals to provide systematic self-reports at non-deterministic occasions during the waking hours of their lives*" [10]. Our software (CloudUX) triggered a short on-device step-by-step questionnaire when Dropbox is closed (Figure 1).

This data was collected after the user finished using Dropbox and while responding to this questionnaire, as to not affect routinely device and application usage. We could not determine specific implementation problems within Dropbox. Instead, we asked the participants to report if they had encountered any problems retrospectively to the current session.

- ***Dropbox session expectation*** [16]: the users' rating of their user experience with Dropbox (*e.g.*, -2 much worse; -1 worse; 0 as expected; +1 better; +2 much better);
- ***Purpose of Use***: why is the user using Dropbox? (*e.g.*, uploading, viewing, sharing file, other);
- ***Location context***: where the user is at the moment (*e.g.*, at home, at work/school, indoors, outdoors, on the way somewhere);
- ***Mobility context***: sitting/lying down, standing, walking, in vehicle, other;

- ***Social context***: how many people were around the user, in different scales (*e.g.*, 0, 1-2, 3-4, 5-6, 6+);
- ***Social disturbance***: if social presence disturbed the application use;
- ***Troubleshooting***: if the user encountered problems while using Dropbox;
- ***QoE metrics*** [3]: delight, frustration, surprise, annoyance metric (*e.g.*, not at all, slightly, moderately, fairly, extremely);
- ***Mean Opinion Score (MOS)*** [13]: the users' rating of the Dropbox experience (*e.g.*, between 5 stars (*i.e.*, excellent) and 1 star (*i.e.*, bad).

We collected 156 fully answered (64.5% of a total of 242) ESMs. To complement the ESMs, and as a final step of our study, we collected qualitative feedback from our participants to better understand their opinions of the contextual factors of Dropbox's QoE.

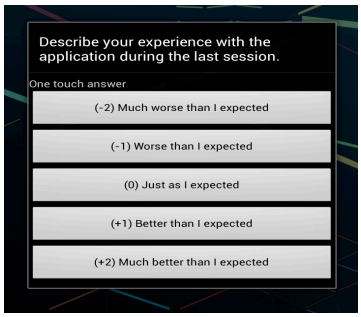


**Figure 1. Example of one QoE question.**

## RESULTS FROM STUDY 1

### Service Affordances & Mode of Access

A total of 72% of the respondents have been using personal cloud services for longer than one year, where 56.4% use cloud storage daily, several times in a day. Dropbox (86.5%) and Google Services (*e.g.*, Gmail, Picasa) (55.3%) are used the most, followed by Google Drive (43.6%), Microsoft Hotmail (35.8%), iCloud (29.2%) and Microsoft Skydrive (24.9%).

The most prevalent content stored were text files (95%) (*e.g.,* PDF files, Word documents, spreadsheets,…), followed by pictures (74%), e-mail (50%), calendar (46%) and contacts (42%). 94% of respondents use several portable computer for accessing their personal cloud applications (*e.g.*, smartphone (72%), desktop computer (66%) and tablet (46%)).

This is not surprising since, according to our respondents, the most important affordance of cloud computing applications is their *transversal availability*, *i.e.*, they enable that data and media can be accessed from different devices at any time, with sharing of and backup of data being also considered important affordances (Figure 2).

In contrast, 16% of respondents indicated that they did not share data with others. A total of 50.6% of the respondents uses cloud services at home and 44.2% at school/work on a daily basis, several times a day. While nomadic, *i.e.*, going from one place to another (*e.g.*, in a car, bus, train), only 11.8% of our respondents used cloud services.

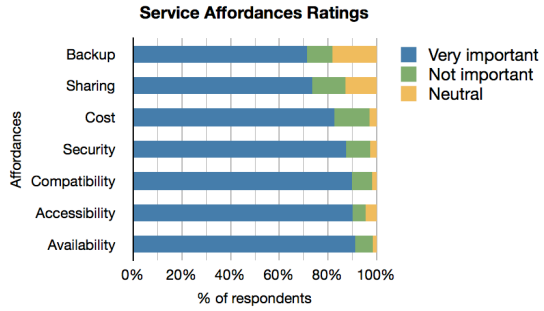


**Figure 2. User ratings per service affordances and factors influencing users' QoE**

Based on a subjective rating on usage of different access networks, we notice that access to cloud computing services is the lowest when connected to a mobile network (Figure 3).

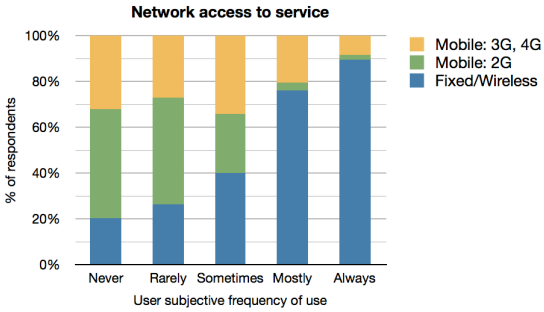


**Figure 3. User ratings per network access.**

### Cloud User Profiles

Using K-Means Cluster Analysis (KMCA) on the respondents' use frequency (on a monthly basis: not at all (1) to several times per day (7)) in different contexts (home, school/work and mobile), we found 3 cloud user profiles: *low*-cloud, *medium*-cloud and *high*-cloud users (Table 2). KMCA is used to cluster respondents into internally homogeneous and externally heterogeneous groups. We found significant differences between the clusters on socio-demographic variables:

- ***Low*-cloud**: a younger population, with balanced gender distribution. The majority are students or employees using 2 devices to connect between 1-3 personal cloud services. With the lowest amount of data stored in their personal clouds, the majority is not paying and have the lowest market potential, *i.e.*, only 10.7% of them are willing to pay for any larger storage capacity. They also use cloud storage the least (75.3% uses cloud services less than weekly). The majority is novice (a user for less than a year) and rarely resorts to a mobile network to access their data. Only 33% of these respondents use cloud storage for professional reasons.
- ***Medium*-cloud**: predominantly a male population (71.6% male), with a higher counts of employees, independent and managerial professionals. The majority uses 3

devices to access their personal cloud data, amongst 4 or more different cloud service providers and are experienced users accessing the services several times in a day. These users are more inclined to pay for the extra storage space and use it for professional purposes.

- ***High*-cloud**: the most mature and predominantly male cluster (83.1% male). Not surprising, this cluster contains the lowest amount of students, with higher number of independent and managerial professionals. These experienced users have 4 or more devices that connect to several cloud storage providers (4 or more), storing the largest amount of data "in the cloud" using any available network anytime and anywhere. Almost half of these users are willing to pay for such services (47.2%), where 73.9% of the users use cloud storage for professional purposes.

| | | Low | Medium | High |
|---|---|---|---|---|
| Respondents | | 118 | 139 | 92 |
| Mean age (years) | | 29,8 | 32,9 | 36,3 |
| SD age | | 11,4 | 12,2 | 12,4 |
| | | Percentage of respondents | | |
| Gender | Male | 46,4 | 71,6 | 83,1 |
| | Female | 53,6 | 28,4 | 16,9 |
| Occupation | Student | 48,2 | 42,2 | 24,7 |
| | Employee | 19,6 | 22,4 | 21,3 |
| | Independent | 10,7 | 17,2 | 23,6 |
| | Management | 8,1 | 13,8 | 19,1 |
| | Other | 13,4 | 4,4 | 11,3 |
| Devices | One | 20,6 | 9,5 | 2,2 |
| | Two | 46,4 | 31,0 | 20,2 |
| | Three | 21,4 | 41,4 | 31,5 |
| | Four or more | 11,6 | 18,1 | 46,1 |
| Cloud Services | One | 11,6 | 11,2 | 2,2 |
| | Two | 22,3 | 13,8 | 11,2 |
| | Three | 27,8 | 23,3 | 13,5 |
| | Four or more | 38,3 | 51,7 | 73,1 |
| Data stored | < 10 GB | 63,6 | 64,5 | 45,6 |
| | 10-20 GB | 7,6 | 11,6 | 17,4 |
| | > 20 GB | 6,8 | 15,2 | 28,3 |
| | Unknown | 22,0 | 8,7 | 8,7 |
| Never use mobile data plan | | 65,9 | 42,9 | 20,7 |
| Longer than 1 year (%) | | 51,4 | 83,6 | 82,0 |
| Several times a day (%) | | 16,2 | 76,7 | 87,5 |
| Paying | | 3,9 | 16,1 | 25,9 |
| Willing to pay more | | 10,7 | 25,9 | 47,2 |
| Professional cloud user | | 33,0 | 73,0 | 73,9 |

**Table 2. Respondents' demographics and clustered profiles.**

In summary, a key affordance of personal cloud applications is *availability* and the possibility to *share* and *backup* data at a *minimal cost*. Other important affordances are *compatibility*, *privacy* and *security*. The use of personal cloud services seems to be constrained by *contextual* factors, such as network availability, device performance (CPU, operating system), location, all of which influence the *availability* and the users' QoE while using cloud storage services on their mobile devices.

## RESULTS FROM STUDY 2

We conducted Study 2 to obtain a better understanding of the roles of these contextual factors have in users' QoE and cloud storage services.

### Effect of location and mobility context

On average and across all our participants, Dropbox is used the most frequently at home (49.4%), followed by school/work (21.8%), other indoor (12.8%) and outdoor locations (1.3%). However, Dropbox is reported to perform better at School/Work (96.6% sessions without problems) and at home (89.7%), and was less reliably in other indoor (60% sessions without problems) and outdoor locations (43.5%)(Figure 4 - left). There is a significant effect between the location and users' mobility state (*e.g.*, sitting/lying, standing, nomadic) in regard to MOS: users rated Dropbox poorly in outdoor locations and when nomadic ($p<0.01$, Fisher's exact tests) (Figure 4 - right).

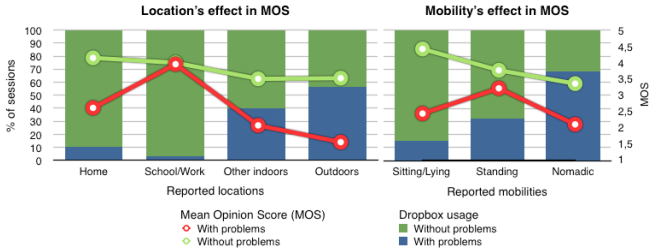


**Figure 4. MOS (Mean Opinion Score) per location and mobility states and reported problems.**

### Effect of network context

Our participants predominantly used Wi-Fi (56.4%), otherwise, they preferably used high-speed mobile network access (HSPA+, HSPA – including HSDPA)(32.4%) or a slower network (EDGE)(8%). In seldom occasions, users had no network connection (3.2%). On average, participants rated using Dropbox on high-speed mobile network higher than when using Wi-Fi ($p<0.01$, Fisher's exact test) (Figure 5). We found no significant effect of network signal strength and QoE, however we know this to not be true [18], surely a consequence of our limited samples of signal strength while on a mobile network (N=49).

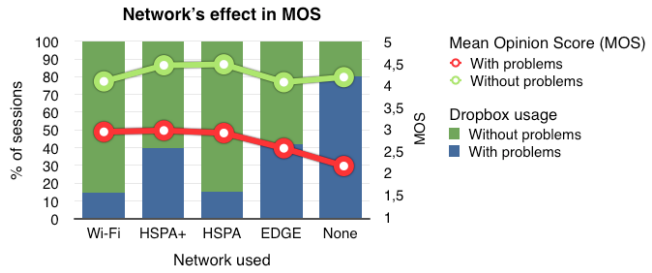


**Figure 5. MOS (Mean Opinion Score) per network access.**

### Effect of device context and affordances

We sampled data from 6 tablet and 7 smartphone users (Table 2). Our participants used Dropbox mostly to visualize images (38.5%), read (24.4%) or access other miscellaneous files (8.3%). On occasion, participants uploaded files (9.6%) or shared data with others (2.6%). Our participants also reported doing "other" things (10.9%), such as sharing files between personal devices and replicating files. Surprisingly, on average our

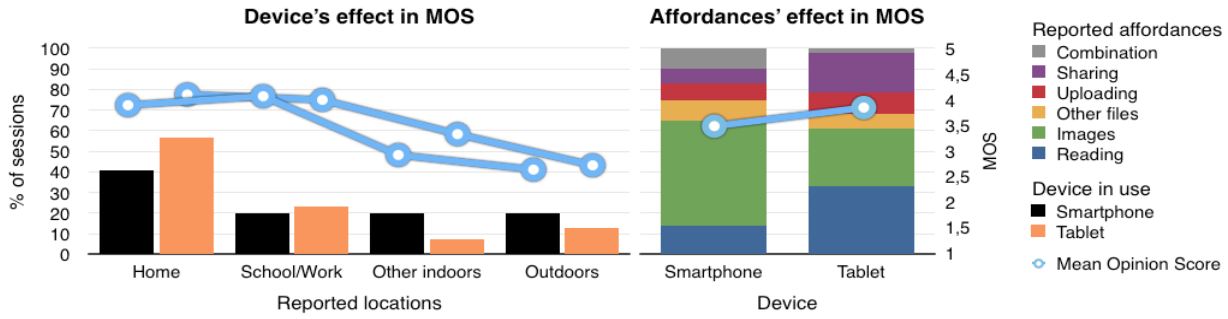


**Figure 6. MOS (Mean Opinion Score) per location, and device affordances (*e.g.*, smartphone, tablet).**

participants rated their experience uploading files (M=4.47, SD=0.64) higher than when visualizing them (M=3.33, SD=1.17)(Figure 6). The use of Dropbox in different contexts differs significantly between smartphones and tablets ($\chi^2(1, N=156)=8.116$, $p=0.04$). We found that Dropbox usage on tablets (M=3.85, SD=1.09) provided a better QoE than on smartphones (M=3.49, SD=1.10); $t(154)=-2.011$, $p=0.046$, especially when the user is at home (M(tablet, home)=4.10, SD=1.08) or at school/work (M(tablet,school/work)=4.00, SD=0.79).

When outdoors and in other indoor locations, the preferred device is the smartphone (62.2% of instances). Also, we notice that the affordances of Dropbox differ significantly between smartphones and tablets ($\chi^2(1, N=154)=19.040$, $p<0.01$): smartphones are mostly used for viewing images (50.7%), while tablets are mostly used for reading documents (32.9%). We found no correlation between the device used and the occurrence of problems.

### Effect of social context

Most of the time, participants used Dropbox alone (35.9%) or within a small group (1-2 people)(36.5%). A Spearman correlation analysis between MOS and amount of people around the user while using Dropbox shows a significant indirect social effect ($r(154) = -.389$, $p < 0.01$). In other words, participants rated higher their MOS when alone (M=4.07, SD=0.98), lower when with someone (M=3.80, SD=0.87) or others (M=2.57, SD=1.39). Five out of the 13 participants considered the presence of others "annoying" (12.2%)(M=2.35, SD=0.99).

### Effect of time context

On average, a Dropbox session lasted 44.8 seconds (SD=55). The elevated standard deviation is due to the ESM mechanism: the questionnaire would only be shown to the users when idle (*i.e.*, not interacting with Dropbox), as to not interrupt them. Consequently, a Dropbox session was inadvertently prolonged. However, it did not affect *detecting* the mobile context.

Dropbox is more frequently used on the weekdays (85%), mostly throughout the afternoon (31.8%) and evening (40.3%). We did not find any significant effect of hour of day, weekday or weekend on MOS (Figure 7).

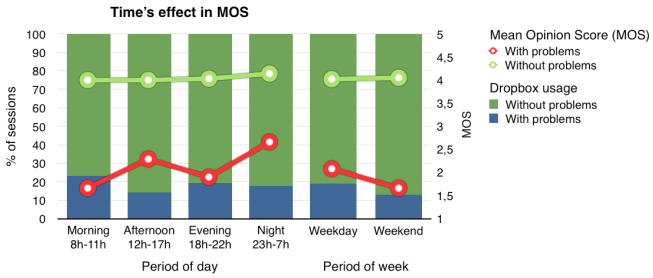


**Figure 7. MOS (Mean Opinion Score) per period of day/week.**

### Effect of emotional context

Our participants rated (*e.g.*, 1 is "Not at all", 5 is "Extremely") 4 emotional states that drive QoE [3]: delight; frustration; annoyance; and surprise. We assessed the effect of these emotions in the users' QoE (Figure 8). We found a strong negative correlation between MOS and frustration (Pearson $r(154)=-0.72$, $p<0.01$) and annoyance (Pearson $r(154)=-0.71$, $p<0.01$). In other words, users rated poorly Dropbox whether they felt frustrated or annoyed. On the other hand, we found a direct correlation between MOS and users' delight (Pearson $r(154)=0.40$, $p=0.01$), but no significant correlation to users' surprise. The emotional states' rating, except for surprise, differs significantly from the scores given when there were no problems (t-test for Equality of Means: $p=0.001$).

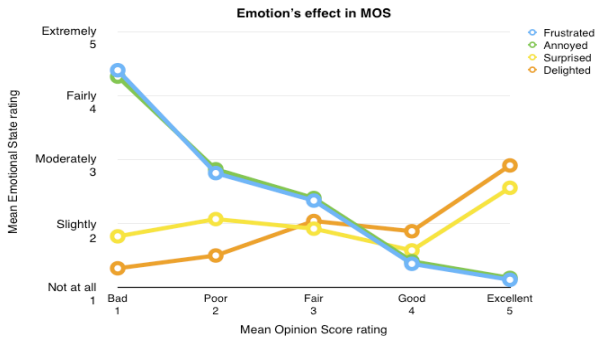


**Figure 8. Users' emotions vs MOS (Mean Opinion Score)**

### Qualitative QoE

At the end of Study 2, we retrieved all participants' data and invited them to fill out an online debriefing survey. We asked 19 questions, 10 of them open-ended. We aimed to

investigate further the users' experiences and context by focusing on positive and negative aspects of Dropbox and any perceived external factors influencing users' QoE. We describe the different aspects explored in the debriefing survey in the following paragraphs.

*Device satisfaction*

On user's satisfaction towards the mobile device itself, 10 participants indicated that were very satisfied, while 3 had concerns. Surprisingly, good software and hardware, proper function, constant Internet access and apps crashing were *rarely* mentioned as positive aspects. On the other hand, participants with a smartphone frequently indicated the insufficient phone memory, limited text editing possibilities and battery discharging too fast as disadvantages of their device.

*Mobile Dropbox application*

We also inquired participants about the mobile Dropbox application usage and other aspects perceived as positive or negative. Reported positive aspects of Dropbox were: usability (ease of use); easy to upload; download and share data; automatic synchronization; the ability to not only view files but also to (jointly) modify them; stable application (*i.e.,* rare crashes); easy folder navigation and the fact that there is only one non-conflicting application between different machines or users (*i.e.,* platform compatibility). Similarly reported as positive is the ability to secure their files with a pin code, so nobody else has access to them (privacy and security). Accessibility was also mentioned, *i.e.*, the ability to access their data on different (mobile) devices.

Cached files or favorite files can be accessed even when there is no Internet access. However, this can easily be a nuisance of Dropbox: when files are not available and there is a poor Internet connection – or none at all – users are unable to open them, thus frustration arises. Also problematic is the inability to upload a complete folder, Dropbox not supporting all file formats and often slow synchronization between fixed and mobile devices.

Besides the mobile Dropbox application itself, we also found other aspects of mobile devices that affect Dropbox's QoE: a good Internet connection, a device that functions well and short waiting times are good QoE factors. On the other hand, having a device with limited memory, slow, too small screen (smartphone), poor battery life, delays and a poor Internet connection are negative QoE factors.

*Social surroundings*

We asked our participants if the presence of others in the immediate surroundings possibly influenced the user experience. As PP9 points out: *"I only use Dropbox when I'm alone or when I want to show something to a colleague at work. It's really an advantage that I can show files to others with my tablet and that I don't have to open my laptop to show it. When people in my immediate surroundings are disturbing, I probably won't use Dropbox or any other app until its calm."* In another instance, PP6 used Dropbox in a train with free Wi-Fi during rush hour and there were many other people in the train using this Internet access, causing longer waiting times resulting in lower QoE. Nonetheless, most participants mentioned that other people had no influence because the use of a mobile device is mainly personal and mostly there is no interaction with the immediate surroundings while using Dropbox.

*Real-world deployment*

We also asked if participants had encountered any problems with Dropbox during Study 2. Several participants mentioned that they could not always open their files due to unreliable mobile Internet connection, someone sending an unrecognizable file or simply having low battery level at the time.

Lastly, the participants were asked to rate their overall experience with Dropbox during the past two weeks based on the Mean Opinion Score. Dropbox was rated as Good by almost all of the respondents *retrospectively* (M=4.08, SD=0.49)(see Table 2 and Figure 5).

This rating is slightly, but not significantly, higher than the MOS on the ESM questionnaires (M=3.68, SD=1.11). Since the ESM mechanism prompted the users for their opinion immediately after using the application, we suspect that any *momentary* frustration could have affected their scores negatively. In other words, the participants' post-usage QoE is better because these problems do not occur often enough and participants continue to use Dropbox regardless.

## DISCUSSION

### Cloud users' profiles

We found 3 kinds of cloud users from our Study 1 results. The *low*-cloud profile fits the younger population; in our sample they were mostly students. These are novice users to cloud services and only a small percent (10.7%) of them are willing to pay to use cloud services, as they often do not need hefty amounts of cloud space.

In the interest of cloud service providers, the associated *financial cost* (or absence) of the cloud services is affected in two scenarios: first, there are costs of mobile internet usage, not always appreciated by their users especially with high data roaming costs to use cloud storage while travelling; secondly, is their cost for personal cloud services. Only 15.2% of respondents currently pay for cloud computing services and the non-paying users are admittedly satisfied with the offered storage capacity (between 5 to 20 GB, depending on the provider), and only 1:3 respondents indicated that they would actually be willing to pay in exchange for more storage capacity. Most of cloud services providers offer a free plan for 'standard' users. We anticipated a *medium*-cloud user to be a better (*i.e.*, as in paying) customer (25.9% says they would pay if needed). However, we found that these users often juggle

between different free cloud services to store their data, thus avoiding further expenses. Their expense is however, on service access. Many of our respondents use mobile data plan interchangeably with Wi-Fi for storage access. On the other hand, *high*-cloud users are often paying customers, as 47.2% are willing to pay. They host large amount of data on the "cloud" (28.3% have more than 20GB) by any means possible (*i.e.,* any network available) and for professional purposes (73.9%). From a market perspective, future research could focus on adoption potential, market potential and domestication of cloud applications, *i.e.*, the shift from usage in a professional context to usage in a domestic context.

**Users' expectation versus users' experience**

An optimal QoE is a direct match between the *pre-usage* expectations and the actual *post-usage* experience [16]. In our ESMs, we first asked the participants to describe their Dropbox session expectation (*e.g.*, "Much worse than I expected" or "Much better than I expected") and lastly to rate their Dropbox experience using MOS (*e.g.*, 1 is "Poor", 5 is "Excellent"). Within the same context, we investigated the relationship between pre-usage expectations and post-usage experience and found a direct correlation (Pearson $r=0.60$, $N=156$, $p<0.01$) between both measures. In other words, Dropbox QoE is indeed *lower* when the users' experience *does not meet* the users' *expectations*.

**Contextual Factors of QoE**

Users' QoE is a highly subjective and complex measure[21]. We found evidence that it is partly influenced by the users' mobile context. Taking into account these different contexts can help provide a better understanding when assessing users' QoE. We know that the different contexts are no secluded but interdependent factors effecting each other and users' QoE. However, to provide better understanding, we will discuss the contextual dimensions separately. For each specific context, we discuss how we could meet the users' expectations.

*Device context and affordances*

***Obs. 1: Users demand connectivity from any device***

Migration to the cloud is associated with new affordances such as sharing and accessing personal data in a flexible way and from different types of (mobile) devices. However, challenges rise in terms of connecting and synchronizing data between these resources constrained devices. 94% of Study 1 respondents indicated that they use several devices to connect to the cloud, thus, transversal availability is of major importance.

Study 1 shows that prevalent data stored in the cloud are text files (including e-mail) and pictures, whereas Study 2 shows that Dropbox was used most of all for visualizing images or reading text files. Also, smartphones are mostly used for viewing images and tablets for reading documents. Study 2 also showed that uploading data is better experienced than visualizing data. The reason for this is the fact that uploading data is often a background process, not burdening the user unless it actually fails. On the other hand, visualizing data can be influenced by device performance and waiting times. One option for cloud service providers to overcome low QoE when visualizing data is to utilize compressed and memory-efficient file formats (*e.g.,* generate a .pdf automatically from a .doc for mobile consultation; re-encode multimedia files to lower bitrates).

*Time Context*

***Obs. 2: Users demand access to their cloud services at any time.***

Our survey shows that 56.4% of respondents use cloud storage daily (one or several times per day). When cloud services are not available, lower QoE are reported. Study 2 shows that 85% of Dropbox sessions took place on weekdays and 72,1% of them occurred during the afternoon and evening (between 12h and 22h). Surprisingly, participants were more tolerant when problems were encountered at night than in the morning (Figure 6). Hence, we recommend service providers to optimize their services during the first half of the day, as to improve QoE during these sessions (*e.g.*, dynamically add redundancy servers to satisfy burst of requests for data).

*Location context*

***Obs. 3: Users demand cloud connectivity anywhere***

A core requirement is *mobility*: we need to be able to access data and media at any place. While cloud usage is reported mostly at Home or at School/Work, we found a low percentage of Study 1 and Study 2 participants using cloud services when being outside or nomadic. Associated to this, Dropbox seems to perform better at Home and at School/Work (fewer problems) and poor ratings are given when the user is nomadic and/or in outdoor locations. A recommendation to overcome this low QoE in outdoor locations can be to rescale images to lower quality, download text files page per page (so the document can download while the user is already reading), warn the users when waiting times longer than 5 seconds can occur or display a download progress bar as to inform the users of the waiting times.

*Network context*

***Obs. 4: Users demand high-speed (mobile) networks***

Previous research has shown that QoE in mobile services is influenced by network conditions, but due to the explosion of cloud services in the mobile domain, QoE has become problematic [4]. Besides signal strength [17] and availability of services [4], waiting times (*i.e.*, user perceived delays) have a high impact on QoE [16].

When connected to a mobile network, cloud access is lowest (Figure 2), confirmed by Study 2's data, where 56.4% Wi-Fi, 32.4% high-speed mobile network, 8% slow network and 3.2% no network usage was reported. However, Dropbox is rated higher on high-speed mobile networks than on Wi-Fi, even though more problems were

reported on mobile network than on Wi-Fi (Figure 5). According to our analysis and survey, this is because the user has *lower expectations towards the network capabilities when connected to a mobile network*. Thus, when files can be accessed flawlessly, good QoE comes as a great outcome. When connected to Wi-Fi, we found the users to be more demanding and less tolerant when problems are encountered. Obviously, when there is no network connection available and if the users want to see a non-cached file, a low QoE is reported.

Although, steps have been taken to improve users' QoE in terms of network connectivity and QoS measures, we suggest future QoE-aware cloud computing applications to transfer changes (synchronize data) when a better signal/network access is available, to warn the user if a network is not good enough as to better meet the user's expectations and take accountability from the user and place it on the current context influencing factors we have less control over.

*Social context*

***Obs. 5: Users demand collaboration amongst multiple users but not directly***

One of the key features of cloud computing applications is that they enable to share and (jointly) edit files via the cloud. Only 16% of the survey respondents say they do not share data with others. When looking at social environment, Study 2 showed that Dropbox is mostly used alone (35.9%) or with 1 or 2 people (36.5%). Strikingly, when the user is alone, higher QoE is reported than when with others. Also, a reasonable part of participants considered the presence of others "annoying."

However, in the debriefing survey following Study 2, those same participants said that the presence of others mostly has no influence on their overall experience and that jointly modifying files is considered to be a positive QoE factor. Our study shows that sharing data via the cloud is key, but direct interpersonal contact during the use of Dropbox affects QoE, although users do not realize this *a posteriori*.

*Emotional context*

***Obs. 6: users demand security and privacy in cloud computing***

In contrast to QoS as an objective measure, QoE is a highly subjective measure influenced by the user's emotions [20]. In the Qualinet white paper, QoE has been defined in terms of affective states [3]. In Study 2, 8 out of the 13 participants reported experiencing problems while using Dropbox. Our analysis (see Figure 8) confirms that QoE is indeed lower when users are frustrated or annoyed and higher when delighted. Similar to [16], this is a result statistically different from when there were no problems at all. Experiencing the occurrence of problems, that also has a major impact on QoE [20], is also highly subjective to the users' emotions. 80.3% of our Study 1 respondents indicate that it is frustrating when they are not able to access personal cloud applications due to slow mobile Internet access or facing technical problems (*i.e.,* service availability). However, problems are not always related to service availability, but can also be caused by the user's expectations and preferences, emotional state and memory effects [22]. A suggestion to overcome low QoE caused by user-related problems is using persuasive messages (*e.g.*, marketing an application update with: "We are really better now", as to convince users of the improved application).

Other factors that are perceived subjectively are privacy and security [22]. With Study 1 respondents initially indicating that they were not concerned about privacy infringement or to lose the data stored in their personal cloud, they later indicated to not be eager to store files that might contain confidential or private personal information in the cloud. In an open question on the disadvantages of personal cloud services, a third of the respondents mentioned possible violation of privacy and security issues, such as dependency of the provider (*i.e.,* not fully controlling the data); the location of the servers; and who else might have access. The ability to secure files with a pin code is therefore considered as a positive QoE factor. From a cloud provider's point-of-view, it is important to make its users aware of the precautions that have been taken towards file securing, data ownership and privacy protection.

**Limitations**

We acknowledge the limited sample of Study 2 (N=13). We consciously decided not to recruit many participants because of the possibility of privacy issues, especially since we were tracking their mobile (cloud) application usage. Furthermore, since each participants had to answer an ESM questionnaire *every time* they used Dropbox, we decided to limit the study to 2 weeks, as to not overburden our participants and to not bias our data collection.

Also, we acknowledge that not all *possible* contextual dimensions were taken into account in this study. To provide a broader, more holistic vision on context and subsequently users' QoE, we could for example, have mapped meteorological (weather, temperature, humidity), organizational, psychological and cultural context.

Other contextual factors that we initially wanted to measure but were unable to during Study 2, was battery life and network traffic. We could have assessed cloud-storage efficiency in terms of mobile battery and network traffic (stored versus transferred). This can be used to make a contribution to cloud-storage as a means to overcome mobile devices' storage limitations and possibly highlight quality assurances for a better cloud-service for mobile devices.

However, collecting network traffic data is battery intensive, as we need to constantly request this data from Android OS (*i.e.*, no event is shared regarding network traffic) so we decided against it. Lastly, a hiatus in Study 2 is that we only logged signal strength in a mobile context

and not in a fixed (Wi-Fi) environment. Therefore, we were not able to link QoE to Wi-Fi signal strength, although we assume this to be related [18]. This might provide a better understanding of fluctuations in QoE ratings in a Wi-Fi context. Another aspect of Dropbox that was not highlighted in this study is evaluating QoE when sharing data (*i.e.,* How does the user know that his/her shared data on Dropbox is perceived by the other end without problems?) This should be studied on both ends to conclude the QoE evaluation.

## CONCLUSION

The purpose of this paper is to gain insights in the use- and QoE-related aspects of cloud storage services and how users' context might affect QoE. Firstly, an online survey with 349 users of cloud computing services was conducted. In an exploratory follow-up study, the use of Dropbox on mobile devices was monitored in real-time using a mobile-based Experience Sampling Method (ESM) questionnaire. In total, we collected 156 responses on *in-situ* context of use for Dropbox on smartphones and tablets. Future QoE-aware cloud services should take into account a number of observations to meet users' expectations: users demand connectivity from any device, at any time and from any place. Also, users expect high-speed (mobile) networks, collaboration amongst multiple users and lastly, they demand security and privacy in their cloud computing services.


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