mQoL: Experiences of the 'Mobile Communications and Computing for Quality of Life' Living Lab

Katarzyna Wac[1,3], Mattia Gustarini[1], Jerome
Marchanoff[1], Marios Fanourakis[1],
[1] Center for Informatics, ISS, Quality of Life group
GSEM, University of Geneva
Geneva, Switzerland
{forename.name}@unige.ch

Christiana Tsiourti[1], Matteo Ciman[2], Jody
Hausmann[1], Gerardo Pinar[1]
[2] Dep. of Mathematics, [3] Dep. of Computer Science
[2] University of Padua, [3] University of Copenhagen
[2] Padua, Italy, [3] Copenhagen, Denmark
[2] mciman@math.unipd.it, [3] wac@di.ku.dk

Abstract—**Widespread acceptance and use of personalized mobile devices facilitates the provision of the ubiquitous mobile communications and computing applications that enable the human Quality of Life (QoL) improvement. However, there are multiple human factors influencing these applications, stemming from their users' needs, expectations, and ways of maximizing their experience and the impact on their QoL. For a successful adoption of these applications, our mobile technologies lab, *mQoL*, employs an iterative, user-centric, Living Lab approach for the applications' design and evaluation. This paper introduces the concept of mobile technologies for QoL specifically aiming to first understand the individual's QoL from information available in mobile devices, i.e., assess physical, psychological, social or environmental aspects of a daily life of an individual, and, based on this understanding, provide services to improve this individual's QoL. This paper also explains the methodological aspects of our research, including trans-disciplinarity aspects, and delineates the research challenges for a Living Lab approach at large.**

Keywords— Mobile computing; wireless communications; Quality of Service, Quality of Experience, ethics

I. INTRODUCTION

The World Health Organization (WHO) has defined Quality of Life (QoL) as an "individuals' perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns" [1]. The QoL scale, WHOQOL, assesses the individual's QoL across six domains and 24 sub-domains (Figure 1). The domains include physical and psychological health, social relationships and environmental aspects of daily life for an individual. The sub-domains include a variety of subjective and objective aspects being collectively exhaustive and mutually non-exclusive, i.e., there exist overlaps and correlations between these aspects (e.g., influence of environment on a physical health). In fact, the health state of an individual is a pertinent factor across all the QoL domains.

Since the proposal of WHO, there have been many specialized QoL scales developed for the purpose of evaluating a person's QoL. For example, there are scales for a given physical and psychological health condition (e.g., cancer), a given population (e.g., elderly), ethnicity (e.g., a Hispanic) or professional role (e.g., a nurse). There are even separate scales being developed for QoL of animals. In this paper we employ the WHOQOL as the most generic and applicable across health states, populations, ethnicities, professional roles of an individual.

Recently, the smartphone usage became an indispensable skill supporting our needs for information, communication and computing while mobile, i.e., "on the go". There exist many different applications supporting us in these needs, specifically via particular apps, e.g., news, video-chat or gaming. A smartphone becomes our "prosthetic" in our daily life and, as our own research shows, it is at least 50% of the time at our arm's reach [2] and this number is growing. It is inevitable, that a smartphone is becoming a tool enabling us to improve substantially our QoL.

QoL Domain	Facets incorporated within QoL domains
Physical Health	Activities of daily living
	Dependence on medicinal substances and medical aids
	Energy and fatigue
	Mobility
	Pain and discomfort
	Sleep and rest
	Work capacity
Psychological	Bodily image and appearance
	Negative feelings
	Positive feelings
	Self-esteem
	Spirituality/religion/personal beliefs
	Thinking, learning, memory and concentration
Social relationships	Personal relationships
	Social support
	Sexual activity
Environment	Financial resources
	Freedom, physical safety and security
	Health and social care: accessibility and quality
	Home environment
	Opportunities for acquiring new information and skills
	Participation in and opportunities for recreation/leisure act.
	Physical environment (pollution / noise / traffic / climate)
	Transport

Fig. 1. WHO QoL domains and sub-domains [1]

We define the *mobile technologies for QoL* research as a research on fundamental technologies; including methods, models, algorithms and services that enable identification of specific QoL domains and approached and methods leading to the improvements of the individual's QoL for these domains.

The technologies enable to create solutions that improve these domains for a given individual (idiosyncratic approach) or a population (nomothetic approach). Given the research expertise and experience of our lab, for the time being we focus only on technologies enabled by mobile communications and computing, and related fields like context-awareness, ubiquitous and pervasive computing, wireless communications, as well as ethics-driven privacy and security solutions enabling to fulfill the vision for the QoL technologies.

The mobile communications and computing research areas have the following impact on QoL, as we have elaborated in [3]. A mobile service is a data service that is delivered to (or from) a mobile device from (or to) a fixed node, i.e., application server on the Internet (i.e., in 'the cloud'). The service delivery is supported by the deployment of a service infrastructure distributed over mobile and fixed nodes, in turn supported by the underlying heterogeneous network infrastructures including a wireless access network and wired network infrastructures. Wireless access network, e.g., 2.5/3/4G or WiFi enables a user the connectivity to the Internet while 'on the move'. The QoS for a mobile service is defined as "a collective effect of service performances, which determines the (objective) degree of satisfaction of a user" [4] and it embraces the service speed, accuracy, and dependability. The QoE is "the overall acceptability of service, as perceived subjectively (i.e., qualitatively) by the user" [5], yet there is no exact, definite definition of QoE, neither of factors influencing it [6], especially in context of mobile technologies for QoL improvement. For a given interaction of the user with mobile technologies, without the assured QoS, the user's QoE gets influenced negatively, in turn influencing the users' QoL. Therefore, the research on mobile technologies embraces the research on QoS (i.e., objective aspects of these technologies), as well as QoE (i.e., subjective aspects of technologies), and individuals'' QoL. The QoL has a larger scope than QoE/QoS, yet, we live in co-called "experience economy" [7], where providers of applications/services are considered to the level at which they can change the momentary "experience" of the individual.

In this paper we present experiences gained along the research on mobile technologies for QoL improvement and, therefore, we present our infrastructure, methodological approach and collected data summary and research challenges tackled by the mQoL Living Lab. As in our research we aim at understanding QoL from information available in mobile devices, in this paper we also draw some conclusive remarks upon the human factors influencing participants' quality of the collected data.

II. MQOL LIVING LAB INFRASTRUCTURE

A. Motivation & Recruitment of Participants

The mQoL is the 'Mobile Technologies Living Lab' laboratory and its services are deployed along the Geneva area (Switzerland). Geneva has ~200'000 habitants and its region has ~500'000 habitants (for areas of 16 km2 and 300 km2 correspondingly), representing a small-sized, modern, international city. The current quality of life in Geneva is (anonymized, level), as indicated by the recent survey [8]. In our research we go beyond standard QoL surveys and wish to

understand what currently counts for QoL, i.e., at the individual, personal-level, and how it can be assessed from data available on the phone, and, what is more important - what is still missing, especially from the technology perspective. In our research, we do not focus only on Geneva; we collaborate with scientists from other universities, as well as apply our research in collaborative research projects. The full list of the research methods deployed in mQoL and part and current research projects and their scientific outcomes is available from http://www.qol.unige.ch.

It is a goal of the mQoL to involve in its research a representative sample of the mobile users closely collaborating with the mQoL, but not drawn from a convenient sample of students and scientists. For this purpose, in March 2012, based on the internal university budget, 30 new Android OS smartphones were purchased and provided to technologically-savvy adult individuals selected from general public living/working in Geneva area. This became a starting point for the mQoL. As of today the mQoL Living Lab affiliates 54 individuals.

The sole requirement for an individual to be involved in the mQoL was having an Internet enabled SIM card for one of the national operators. An agreement to participate includes a smartphone lending agreement, stating that the smartphone automatically runs the mQoL software (c.f., II.C).

It is important to notice that due to the mQoL gaining some interest by the general public, we have included some Living Lab participants willing to contribute with their own mobile phones. They are driven by the desire to contribute to scientific advancements of the mQoL Living Lab.

B. mQoL Living Lab Infrastructure Components

The mQoL infrastructure provides a complete end-to-end platform for automatic, unobtrusive data collection from mobile users (via mQoL software) and for providing them specific feedback, and it is deployed over the wireless networks available for the individual anywhere-anytime (i.e., WiFi, 4G).
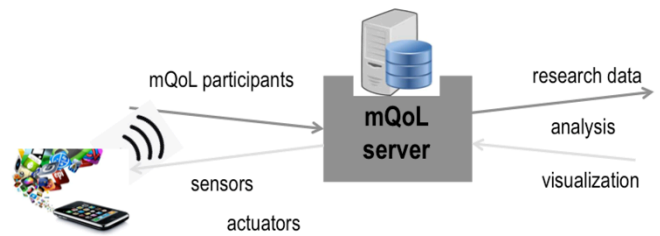

Fig. 2.   mQoL Infrastructure Components

In theory, the mQoL participant has a set of mobile sensors, actuators, data communication, storage and processing facilities interconnected to provide some specific mobile services to this participant. In practice, currently any mQoL participant is equipped with a smartphone with deployed mQoL software on it. Depending on the study in which the participant is enrolled, additional applications may be deployed remotely on his smartphone (given his consent) for example to

gather the user's input via survey or sample additional sensors not included in the current deployment of mQoL software.

The mQoL component at the smartphone aggregates the sensor measurements and any data required for the study, the participant is in, and transmits them in a secure manner via a long-range wireless network (e.g., 3/4G, WiFi) to the secure mQoL-server, i.e., dedicated back-end system at the premises of the University of Geneva (Switzerland). The mQoL participants' data is accessed at the mQoL-server by the authorized researchers for visualization or a direct download in the preferred file form (e.g., csv, json).

Figure 2 provides the mQoL infrastructure overview, emphasizing the main sensor-data stream from the mQoL participants and the main research data stream for the researchers participating in the mQoL Living Lab.

Automated feedback provided to the participants via different smartphone modalities (auditory, kinesthetic, visual including images or text) is equally supported by the mQoL infrastructure although so far not much exploited yet beyond the specific studies. In other words, we do not yet provide any automated feedback to the user specifically aimed at improving his/her QoL; we are still researching this aspect.

C. mQoL Software: mQoL-Log

mQoL-log is a measurements-based tool which unobtrusively and efficiently collects from a users' mobile device the data and context factors potentially contributing to the researched phenomena, i.e., Quality of Life. The log data includes the minute-based user's geographical location, network connectivity details, phone/SMS usage patterns, running and currently used applications and user touches of the screen (touch strength). To be energy-efficient, the data is collected every minute or only when the sensor value changes, i.e., the OS updates the mQoL-log with data. The service logs are immediately written to the phone memory in a compressed/encrypted manner to minimize the risk of data loss and they are synchronized occasionally in a secure manner with our dedicated mQoL-server. If the service was not able to synchronize automatically the data collected, and the server have not seen the device "online" for the last 72 hours, the server send to the user an automatic email asking to synchronize manually the logs (i.e., via rebooting the phone and connecting to WiFi network for 30 minutes).

The mQoL-log is collecting data in an encrypted manner, i.e., it is not possible for a user to tamper and change the data logs being collected. Additionally, our server only accepts mQoL-log data from the authenticated and authorized devices.

With respect to the research on the user's perception of QoL, the mQoL-log data enables to collect the user's context and phone usage data and utility potentially influencing the QoL. Different aspects of the individual's QoL – relating to physical, intellectual, emotional health, social interactions and environmental aspects of the individual's context are researched along different projects as explained at http://www.qol.unige.ch. Given the amount of data collected over the last 3 years, at this moment we research a QoL characterization for each individual participating in the mQoL Living Lab. Towards this end, we leverage solely data collected on the phone, and aiming to bring new insights to the research community.

D. Current Status

We have followed an iterative design method to build an operational version of the optimal mQoL infrastructure. Since March 2012 we are iteratively improving the mQoL smartphone component and the server component for its speed, accuracy, dependability, computational complexity, communications overhead, battery efficiency, monetary cost and the smartphone component 'mobility' across different daily life contexts of its user.

As of June 2015, 54 participants (18-57 years old, majority males, diverse occupations, average participation of 350 ± 79 days, and $10 \pm 6h$ being captured in average per day) collect data in mQoL. The participants are equally distributed across the Swiss network providers. Selected and/or volunteering Living Lab participants have been also involved in evaluation activities for the ongoing research projects.

On average a participant visits a University lab and meets with the researchers twice a year to undergo surveys or interviews related to specific aspects of the research project at hand. Participation in the mQoL is anonymous from the perspective of the participants, who do not know each other.

III. MQoL LIVING LAB: LESSONS LEARNED

Reflecting systematically on our research activities conducted since 2010, we have identified the following key insights and lessons learned.

A. Transdisciplinary User-Centric Design & Mixed-Methods Approach

The user acceptance factors for the researched and developed basic and applied research solutions have the most importance for the years to come in such an important, interesting and challenging domain, as mobile technologies. We must stay open for the users' inputs and feedback and shape our solutions accordingly in an interactive design process – until the users needs and expectations are satisfied and acceptance is assured (at least to a large extend). Following the above line of reasoning, we accept the fact that the research on user acceptance factors for mobile technologies for QoL improvements is trans-disciplinary, i.e., there is no one discipline or method, which would ensure the users' acceptance.

We employ a mixed method-approach, i.e., incorporating qualitative and quantitative methods in the mQoL Living Lab. It enables to grasp the factors influencing the individual's QoL, 'in the wild' - in the real users environment with little or no control over the users actions. The methodology employed consists of four methods (3 qualitative and 1 quantitative), which triangulate the data collected [9] with respect to the mobile interactions and QoL aspects of interest. The methods are qualitative and quantitative. The qualitative methods include: (1) a survey/interview, to gather the cumulative users' opinion via open-ended interviews and surveys; (2) a Day Reconstruction Method (DRM) gathering the episodic users' opinion upon some specific aspects along semi-structured interviews based on the diary for the last 24 hours [10]; (3)

Experience Sampling Method (ESM) gathering the momentary users' opinion/impressions [11] upon some specific aspects like health behaviors, moods, feelings, social interactions, or environmental and contextual conditions. The quantitative method embraces the mQoL-log software (c.f., Section II.C).

To fully ensure the user acceptance in any mQoL project, we iteratively and collaboratively identify, via a trans-disciplinary effort, other user acceptance factors. So far from our projects we learned that these factors encompass the technological (e.g., mobile computing and communications, back-end servers), organizational (i.e., if the system/services are deployed in company workflow), economic (i.e., if the system monetary cost is significant and must be reimbursed), legal (i.e., if the system must hold liability), and social (i.e., what are the security, privacy and ethics solutions for the service) factors.

The key insight is that along the mQoL studies we need to research and design with users and for users (involving them via a variety of research methods) and other stakeholders, to assure the depth of the research and acceptance of its outcome.

B. Ethics, Study Participants' Privacy and Security Aspects

The topic of life quality for an individual is a very private, intimate topic and must be treated with a highest respect. Many variables and correlations are still unknown and a researcher investigating it, driven by their own curiosity may be perceived as intrusive and unethical by the participants. We therefore deploy multiple levels of ethical assurance for the research conducted in the mQoL Living Lab, as follows.

Due to the private nature of the collected data, we follow the EU regulations and the University of Geneva laws. We involve only mentally healthy adult volunteers, from outside of the university, and with different levels of literacy in technology. All participants are always informed about the goal of the studies, the procedure, the data being collected, stored and processed for the purpose of research, the risks and benefits of participation, and that they can withdraw from the studies and request their data deletion at any point in time, without any negative consequences. Each participant signs two copies of the consent form providing the above information in detail and exchange one copy with the principal investigator (PI), signing it as well.

At the recruitment, all participants are assigned a random ID number, which is then used throughout the study to anonymize the collected data. The original file matching the participant ID with personal data are stored in paper form in a locker owned by the PI. Only the authorized researchers: PI as other PIs involved in the specific project, have an access to the anonymized collected data. When involving personal opinion via an interview or survey, we follow the regular protocols from HCI domain, assuring the privacy and security of the answers given and noted in a paper or electronic form. The participants can always contact the PI over post, email or phone; they are in control of their own data. The data is not shared with external to the project researchers, other than in a cumulative form – when presented in a scientific paper or a talk.

For the purpose of its diverse collaborative research projects, the mQoL lab has several distinct ethical protocols approved by Institutional Research Board (IRB) for ethics.

C. Real-World Deployments "in the wild"

We have learned along our research and development that it is important to understand the standardization and interoperability issues for any infrastructure. For example, the mQoL, as well as any real life deployment for any QoL project, must embrace diversity of mobile phones and their OS API nuances, which may result in different form, granularity and accuracy of data collected from the user's mobile devices.

To address these issues, we have inspected the OS API for given phones and adapted our methods (especially the mQoL-log) to accommodate the API nuances and normalize the data collection process cross the participants. Additionally, some of these differences resulted in different battery efficiency for different phones. This led to some diminished user experience especially for users who expected that their phone would at least support them throughout the full day (from early morning to late evening). In such case we have adapted the API calls further – to get a quality data at the minimal "battery expense" for the user.

The key insight is that the context of the real world deployment may be the major factor influencing the quality of the collected data and thus the success of the research and development of the mQoL projects.

D. Incentives for Participation

Participants in the QoL studies are often provided with remuneration for their efforts and data provided – either explicitly by means of, e.g., cash coupons or implicitly by means of a recognition and research results. Our key learning was that in cases, where the study timeline was limited (e.g., some hours, or at most a day) and the study task was structured with a clear end, the participants were happy to participate without being remunerated. The longer the time of participation and the more complex the task, the incentives played a larger role.

The most interesting learning was with respect to participants who had received (i.e., had been lent) the free phones. As we have explained, the phones used in the data collection and the participants did not need to do anything at the early stages of the mQoL, besides using the phone as their own.

Because of the high cost of the phone they had received, we have anticipated that the participants will be happily contributing to the new studies. However, it occurred that not all of them find the participation in the additional studies as enjoyable and some of them did not even responded to personal emails inviting them to our offices. In this case we have introduced an incentive system consisting of points. Participants have a limited number of points, which they can loose, if they do not follow the studies. Once a participant looses all the points, he may be dismissed from the participation in the mQoL. Given these rules, we have much better collaboration with the participants and much higher response rate for the studies. However, we are aware of the fact of the potential influence of this new incentive system on the

outcomes of research, where participants may provide us low quality feedback just to keep their participation (i.e., number of points) in tact.

The key insight is to design for Living Lab participants a smart, an adaptive incentive system, which does not negatively influence the quality of the data collected along the mQoL studies.

E. Continuity of Research Across Variable Funding

The research projects conducted in the mQoL are supported by the European Commission grants in the frame of the Ambient Assisted Living project, the Swiss State Secretariat for Education, Research and Innovation, the Swiss National Science Foundation, Google Research and University of Geneva internal grants. Each of the projects has a limited budget, scope, timeline and number of participants who can be involved in the research. What is important for the lab management is to keep the vision along the way, despite the intermittent shortages of the budget or administrative difficulties.

Given the complexity of the topic tackled in the research, each project is treated as a piece of "puzzle" bringing its results to the bigger picture of mobile technologies for QoL improvements. In this spirit, it is a common practice that research results from one project are reused (to the extend to which is possible) in other projects. This way, the results of a basic research underlying a given research project (i.e., model, algorithm or method) are disseminated to other projects, as the applicability of these results its evaluated in other contexts.

The key insight is that the financial constraints of the projects might have influenced the research and development activities of the mQoL Living Lab negatively, however, it is not the case given that the lab management follows the vision of the lab and leverages the finances to follow this vision, rather than allowing the financial situation to rule the quality of the mQoL Living Lab outcomes.

IV. CONCLUSIVE REMARKS

This paper presents the mQoL Living Lab approach focusing on mobile technologies for QoL improvements research area and conducted for last three years by our research laboratory across different research projects. Based on our research experience and outcomes, we provide key lessons learned for the successful deployment of the Living Lab approach.

Overall, we can conclude so far that a considerable fundamental research is still needed in the individual QoL domains (physical, psychological, social, environmental) to first accurately assess the individual's QoL only from data available on the mobile phone, and then, based on these, propose reliable and user-acceptable solutions, contributing to the individual's QoL. Additionally, along the applied research,

trans-disciplinary, iterative, user-centered design approach is required towards satisfying the needs, requirements and, what may occur to be most important, implicit expectations of all the stakeholders involved.

An aim of the mQoL Living Lab is to build and maintain a community of mobile users who use the developed QoL services and applications and are motivated to contribute with their feedback and collect reliable data "in the wild", which could be then used to provide quality services and data, improving their QoL and the QoL of other individuals in the future. The mQoL mobile members will collectively empower each other to make better daily life choices improving the overall community's QoL.

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