Quality of Experience and Human-computer Interaction: A Relation Overview

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***Abstract*—This paper first traces the historic evolution of the Quality of Experience (QoE) concept, and then connects common points between the study of user experience as practiced within Human Computer Interaction (HCI) disciplines and recent efforts to understand how user perception can be incorporated into the definition and management of resources in the area of (ICT). After an analysis of the history of QoE and an examination of its current role in HCI, some research challenges are proposed that open doors to future research projects.**

Keywords-Quality of Experience; Human Computer Interaction; Challenges in mobile environments

I. INTRODUCTION

The telecommunications industry has been a fertile area for applying user-centred solutions [1] as well as a vital part of the economies of all nations, shaping the quality of life of people around the world. It is this area where new research issues are emerging and changing the way that people interact with networks and content. Some of these efforts are oriented to technical developments, while others are focused on non-technical aspects, and it is in this new environment where concepts such as interaction, quality, content, context, and perception become more and more important to the market through operators, content providers, and handset manufacturers for whom the concept of user satisfaction is becoming a new competitive factor. A representative case is Apple; with the creation and consolidation of devices like the iPad and iPhone, this company opened the door to both a new market conception oriented to satisfy user needs through design and detail, and to a greater use of data networks by the same users through increased interest in applications and content. As a consequence of this phenomenon, recent years have witnessed an increase in the network traffic caused by a high demand for content, with users more and more interested in the quality of the content, not only from a network performance perspective, but also in how this content is distributed and consumed, including devices and interfaces. The new paradigmatic eco system (user-interface-network-content) requires novel and disruptive end-to-end considerations, in order to enable and sustain the next generation of services and user experience. In particular, networks are currently agnostic and have no knowledge about the type and characteristics of the specific mobile services they are providing. Further, there is a knowledge separation between service designers/builders, service providers, terminals, Operating Systems and networks. These facts are producing substantial resource optimization deficiencies and discontinuities that affect the user's level of satisfaction. Although Quality of Experience (QoE) has made rapid gains as a new metric influencing the success or failure of new applications and services by involving the user's perception in the evaluation process, most of the methodologies developed to measure it ([2]-[4]) depend largely on the end-to-end Quality of Service (QoS) metrics, which can be categorized as a techno-centric approach.

In response to this, a user-centric point of view is getting more attention as a new and interesting research topic where areas such as human-computer interaction (HCI) have shown interest in developing standardized assessment methodologies, optimization processes and metrics definitions taking into account concepts like User Experience (UX)([5]-[8]). While from a technical approach, user's satisfaction is a result of the adjustment of some network parameters, with a user centric point of view; QoE has a multidimensional character and can be studied from an interdisciplinary perspective [7]. However, this multidimensional character and pluralism of perspectives have naturally contributed to the existence of several definitions and approaches to the same concept. This has not allowed the emergence of a single definition that encompasses within itself the multiplicity of concepts around QoE, as well as the options for standardization in the methods of evaluation, measurement and improvement of the QoE perceived by users. As mentioned by Moor et al. [8] "It is rather uncommon to integrate concepts from other fields less technical than telecommunications in definitions of QoE. A relevant example is the domain of HCI, in which concepts such as UX and "Usability" closely related to QoE are very important." The goal of this paper is to identify coincident points between techno-centric and user-centric approaches, taking into account a review of their respective historical evolution processes that allows one to establish a basis for the development of scheme that allocates resources in a wireless infrastructure based on the evaluated QoE obtained through the implementation of an assessment methodology.

The rest of the paper is organized as follows: In Section II, we present the QoE and the techno-centric approach

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description, In Section III, the concept of QoE is analysed from a user-centric approach remarking the potential contribution of HCI to the QoE evaluation. We conclude the paper in Section V proposing some future challenges in the area and future work.

II. QoE and the Techno-centric Approach

From a technical point of view, different QoE definitions have been proposed ([9] - [11]). A review of some of these definitions allows one to see a gradual evolution since an initial idea of Quality of Service (QoS), with a ”rich tradition in engineering and developing environments” [12] basically oriented to the evaluation and adjustment of some network parameters, to a ’semantic variant’ and user-centric approach denominated QoE, emerging in the late 90’s, where user’s interests and experiences became more important [12].

One of the first mentions of the QoS concept can be found in [13]. Here, the discussion is focused on describing and determining the relationship between telephone circuit loads and corresponding delays to traffic, and how these delays directly relate to the quality of service. Even though QoS is mentioned, there is no definition of the concept. After three decades, a new mention of the term QoS appears in [14], where the financial influence of the quality of service provided by telephone operators is remarked upon. Even if the work of Pocock also attempts to open the discussion about the importance of the overall quality that user can experience, he just focused the results of the research in the necessary adjustments of the quality transmission. Pocock also tries to show the relation between the user’s appreciation and the speed, availability and reliability of a service, making explicit, for the first time, the relationship between the user’s opinion about a service and the technical factors behind its provision. However, there is no mention of external factors (i.e., economic, social, etc.) that could affect a user’s perception. In the same line of Pocock, different research efforts ([15]-[18]) proposed mechanisms to increase the reliability, and consequently the QoS, through technical modifications in both wired and wireless networks, without mentioning mechanisms for QoS evaluation.

In 1986, Gruber [19] discusses the creation of a QoS framework according to the competitive environment that appeared on the horizon of the telecommunications sector at that time. To Gruber, the possibility of unifying network infrastructures to provide a multiplicity of services required the implementation of monitoring and surveillance systems to manage and automatically control network resources and resulting QoS. While the article sees the prospect of a competition based on the provision of high QoE, neither the assessment methods nor the role that the external factors can play were considered. Only with the research results shown in [20] is presented the option to involve the user directly in the QoS evaluation process. This might be called the first attempt to incorporate subjectivity in the QoS assessment.

With the advent of packet-switching based networks and the opportunities given by this technology to provide multiple services such as telephony and television within the same infrastructure, the QoS concept gained more importance due to the need for emulating the performance of the classic and reliable telephone and television networks using, in the early years, technologies such as the Asynchronous Transfer Mode (ATM). In that sense, one of the first research efforts oriented to work with the concept of QoS focused on broadband networks was developed in the NETMAN Project [21]. According to the Brander et.al, QoS can be expressed as ”the collective effect of service performances, which determine the degree of satisfaction of a user of the service.” Here the term ”satisfaction of a user” appears in the context of this, until now, technical world. As in other cases where the role of the user is considered, until that moment there was no specific methodology to obtain information about user opinion regarding the QoS level of a network. Another important milestone in terms of QoS is expressed in [22]. Authors expressed the importance of a good end-to-end performance within the networks; first considering a clear identification of the QoS parameters to be guaranteed in real-time communications, and at the same time presented a proposal of a performance reference model for real-time packet network analysis and a real-time estimation.

Throughout the 90’s and early twenty-first century, various studies and proposals for the evaluation, improvement and implementation of QoS-based methods were made. The role of the user in the evaluation of QoS was incorporated with the development of assessment schemes such as Mean Opinion Score (MOS), Perceptual Evaluation of Speech Quality (PESQ) and Video Quality Measurement (VQM), which attempted to quantify the subjective opinion of people, giving greater weight to the evaluation from the user. The gradual process of separation between QoS and QoE was revealed in the early twentieth century by authors such as Anna Bouch, Allan Kuchinsky and Nina Bhatti in [23]. According to them, at that moment ”the majority of research on QoS is systems oriented, focusing on traffic analysis, scheduling, and routing. Relatively minor attention has been paid to user-level QoS issues.” With the development of the Internet and the growing usage of applications and different services there is a need for a new approach, where users and their perceptions can get even more involved in the final result of a quality evaluation. Even though this paper is a first approach to establish a mapping between objective and perceived QoS in the context of Internet commerce, and the term QoE is not used, it can be considered as the first attempt to incorporate a new way to evaluate the set of user perceptions regarding new services offered by the Internet. After this article, in [24], the QoE is defined as ”the totality of the Quality of Service mechanisms, provided to ensure smooth transmission of audio and video over IP networks,” which highlights the interest of the telecommunications sector in multimedia content and its effect in a world based on IP networks.

In the same line of thought, Heddaya [25] presents the Internet and its penetration level as the key factors to evolve from the old conception of QoS to a new concept, where there is a clearer need to separate the internal aspects of the network, beyond the control of the user, from the perceptible results delivered to the user by the network and its content. However, there is no mention of the effect of interfaces and

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presentation formats on the user's perception. In 2003, different researchers, such as Siller and Woods [26], proposed frameworks to evaluate QoE using QoS metrics, network feedback and user requirements. At the same time, Siller and Wood proposed a definition for QoE where the effect of the application/interface layer over the user's perception is remarked: "QoE is the user's perceived experience of what is being presented by the Application Layer, where the application layer acts as a user interface front-end that presents the overall result of the individual Quality of Services." In fact, this article states that QoS required and perceived by the user can be specified as a single parameter: low, fair, good and excellent, while, by contrast, the user requirements can also be specified by several parameters such as resolution, height, width, colour, etc., directly linked to the application layer and the QoE evaluation. With this new idea in the air, different researchers have tried to establish mechanisms to deepen the understanding and evaluation of user's perception [27], [28]. Some others have attempted to adjust technical parameters, related to QoS, considering the results generated by assessment tests [29]. The impact of the QoE over wireless infrastructures has been evaluated ([29]-[31]) while other researchers have talked about the growing commercial and economic importance of QoE applied in the distribution of different types of content.

As a result of the different research efforts focused on QoE, ITU decided, in 2007, to incorporate within the recommendation P.10/G.100 [9] a standard definition for QoE "The overall acceptability of an application or service, as perceived subjectively by the end-user." In the same recommendation, ITU considers that the overall acceptability may be influenced by user expectations and context, and includes complete end-to-end system effects (client, terminal, network, services infrastructure, etc.). On the other hand, when ITU defines QoS in the recommendation E.800 [10] as the "Totality of characteristics of a telecommunications service that bear on its ability to satisfy stated and implied needs of the user of the service," claims that QoE measures the effect that a service or application has in the user, considering the external factors, as well. In contrast, QoS, with its point of view focused on the network performance is seen as one of the factors, together with the Grade of Service (GoS), the environmental aspects, the user profile and the Quality of Resilience (QoR), which affects the user's perception assessed in terms of QoE (Figure 1). Based on this separation, current research looks for the development of a well-defined methodology that allows establishing a clearer measurement of the user's perception in order to incorporate these results into the technical adjustments related to the network performance, to achieve the desired level of user's satisfaction based on the type of infrastructure and the applications running over it.

Nevertheless, and as mentioned by Moor et al. [7] Thakolsri et al. [4] and by Stankiewicz et al. [12], "literature on QoE and its related concepts (such as Quality of Service, User Experience), is rather fragmented. As a result, it is still largely unknown which factors affect the mobile QoE and how users' subjective experiences of such applications and services could be adequately identified and optimized."

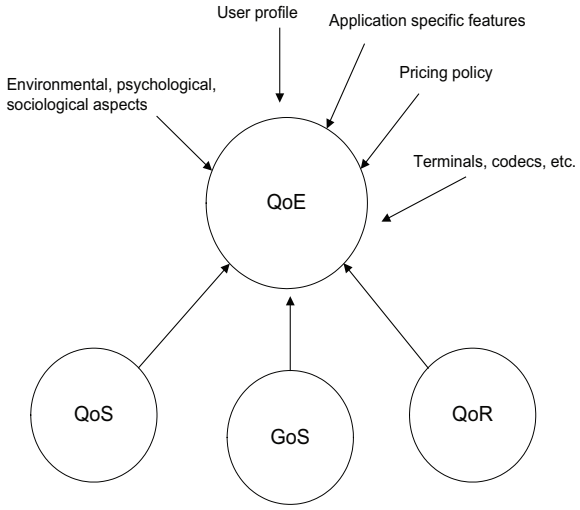

Figure 1. Elements influencing QoE [11]

III. QOE AND THE USER-CENTRIC APPROACH

An attempt to trace out the historical evolution of HCI and its relation with the concept of QoE might start by mentioning the research done by Card, Moran and Newell's, who in the book "The Psychology of Human-Computer Interaction"(PHCI) [32] proposed an empirically based cognitive theory of a skilled HCI and applied it to the specific problem of text editing. They discussed the processes involved, the techniques to use and the methods to follow when human factors research is performed. Finally, the Goals, Operators, Methods, and Selection rules model (GOMS) is proposed, while exploring ways in which this proposal can be extended and used to predict performance in other task-related areas. In [33], Newel and Card extended the vision proposed in [32], restating the importance of the psychological science in the design and development of interfaces, but remarking, as well, the need to provide engineering tools for this science in order to make less marginal its influence in the HCI area. While it is claimed that there is a chance to incorporate user's perception into the daily work of HCI, the need for the development of mental and cognition models that help to adjust the interfaces design is also shown. As a pioneering work on cognitive engineering models, Newel and Card's arguments were not without critics. Some authors, such as Newell et al. [34] and Carroll et al. [35], remarked on the gaps in the understanding of the whole process of interacting with computers. Even if the utility of the GOMS model in both initial design, evaluation and training is recognized, the lack of a deeper description of the user's context and its effect on the implementation of the model in a real design scenario was pointed out as its main weakness [36]. Another point of discussion was the hard science interpretation of the PHCI framework. To Caroll and Campbell, rather than reducing

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everything to a ”monolithic view of conflict between hard computer science and soft psychology” [34], an interdisciplinary field of HCI was taking form. According to their point of view, only a joint effort between science and psychology would allow the development of research areas like artificial intelligence and rapid prototyping. One of the proposed areas of cooperation was the design of interfaces, where psychologists would play an effective role addressing the questions that designers need answered, and contributing to the analysis involved in the design process of new products, but without touching the level of numerical quantification proposed by Card et.al. Meanwhile, in [37], the importance of the a deeper comprehension of the user's understanding process based on the application of cognitive theories was remarked by Booth, with the consideration of making this new framework more accessible to designers. At this moment, while a continuous analysis of the role of HCI and the future of this area is under discussion, the potential effect of some elements of this area of study in infrastructure issues, or content management is not considered or studied.

Despite the discussed weaknesses, over the years different studies ([38]-[48]) have developed and extended the use of GOMS as a cost-effective way of evaluating designs without the participation of end users in human-computer interaction fields. On the other hand, this evolution led to the gradual consolidation of the soft science perspective in the PHCI, as mentioned by Holleis et al. [49], where most of the papers published in the HCI area from 1990s became more oriented to show case study, field experiment or field study than research work based on lab experiments. Within this new panorama, the input of Norman and Card work is reflected in the development of different cognitive modelling approaches and the consolidation of a multidisciplinary HCI, but without the idea of building a monolithic science with the integration of PHCI within an engineering conception. So far, only the importance of cognitive processes in the growth of HCI has been treated. From here, some similarities between the evolution of the QoE techno-centric approach and the process described above can be identified. However, the lack of multidisciplinary work enhancing the development of more complete models to link user experience and resource allocation is still evident. Up to now, most of the communication network deployments have been done taking into account economic, technical and ecological considerations with the user's satisfaction regarding content provided through these infrastructures will be reached only by having better technology and higher bandwidth. Before this fact, HCI and the research about user's comprehension might become a new tool to develop infrastructures providing, in a smart and efficient way, content and information to a user fulfilling expected levels of quality.

In tune with the evolution of the soft science concept, the gradual consolidation of a user-centric approach has allowed the growth of new and complimentary areas within HCI such as Experience Design (XD) and User Experience (UX), which can be considered in the future as providers of judgement elements to clarify the QoE concept in the techno-centric approach. In recent years, users have had more chances to choose among multiple options with different levels of design, complexity and innovation. This has empowered users, who have become more demanding and critical, and the HCI field has not been immune to this phenomenon. According to Stankiewicz et al. [12], during the '70-'80s, people involved in HCI was focused on understanding the way that people thought and processed information in order to increase the efficiency and provide more functionality in their solutions. However, at this moment, the users' expectations and experiences were not considered. Some efforts to involve people in the development and design of HCI solutions were done from the late 80's and early 90's with the origin of participatory design and contextual design [12]. But since the late 90's, with the wider presence of computers and technology, more importance is given to evaluate how this success of technology adoption and diffusion is explained. There were efforts to incorporate aspects such as beauty, enjoyment, or fun, into HCI in general and usability engineering specifically ([50][51]). These approaches have three aspects in common: ”a focus on the subjective side of usability, namely user perceptions and experiences; on the positive sides of using products (instead of simply avoiding usability problems), and on human needs as a whole [52]”. At the same time, there was an identical shift from a more R&D-driven 'push'-oriented mentality towards a more (marketing-driven) 'pull'-oriented stance in which the user became the starting point of the technology development [12]. User is now the king, and this consumer-oriented mentality as is defined by Edwards [7], is orienting the efforts to measure the user experience and reflect it in the provision of high quality. Under these conditions, the experience of a user regarding a device, product or interface gains more importance, despite the differences expressed by UX and XD experts. In words of Marc Hassenzahl [53], UX is focused on usage and only rooted in action, while XD is a way to create experiences considering with more interest the history behind what the user experience. In certain way, UX has seen focused on how a person feels about using a system, considering the external things that can affect this experience (i.e., brand, cost of the system, image, ease of use, etc) [54], but with the introduction of usability in the design process. Most of the efforts in the area seems oriented to the design of ways to interact with computers, but with a failure to understand how information is communicated to a person and how they interact with and interpret that information to accomplish their goal [55].

IV. CHALLENGES AND FUTURE WORK

An attempt to trace out the historical evolution of HCI and its relation with the concept of QoE might start by mentioning the research done by Card, Moran and Newell's, who, in the book “The Psychology of Human-Computer Interaction” (PHCI) [32], proposed an empirically based cognitive theory of a skilled HCI and applied it to the specific problem of text editing. They discussed the processes involved, the techniques to use and the methods to follow when human factors research is performed. Finally, the Goals, Operators, Methods, and Selection rules model

(GOMS) is proposed, while exploring ways in which this proposal can be extended and used to predict performance in other task-related areas. Technology-centric interpretations of QoE go hand-in-hand with the assumption that by optimizing the QoS, the end user's QoE will also increase. However, this is not always the case: Even with excellent QoS, QoE can be really poor [8]. These gaps are usually caused by a lack of insight in the totality of dimensions of a customer's experience, and here is where HCI can offer the tools to complete the development of a structured QoE system of assessment and implementation where users are really involved. Some authors, like Stankiewicz et al. [12], claim that it is necessary to involve users in certain stages of the development process of a new technology or application, but there is no complete clarity about issues like the right stage of the process to involve their opinions, and the type of users that should be involved, etc. [12]. Another fact to mention is pointed out by Stankiewicz et al. [12], when they say that QoE "is usually measured in terms of technical metrics (QoS), ignoring the fact that the ultimate goal should not be to deliver applications with the most advanced features, but to deliver products that will ensure a good Quality of Experience." On the other hand, a challenge for HCI is to understand how layers of underlying technological infrastructure that may not be designed with the full range of human-centred concerns in mind work, and, based on this knowledge, adjust to these constraints to maintain the user experience at the highest level. Being UX subjective, the user is the centre of the whole system, and his/her opinions and concepts will determine the adjustment of technical features inside the network. However, there is also a need for an understanding of those external factors that can influence the final perception and experience of the user. Here, is where the QoE concept becomes "the picture to measure the perceived connection quality in the current context" [54]. Considering the multiple aspects that affect the overall experience, evaluators need to understand the whole picture and identify the reasons behind each good or bad experience. About this last point, and how Edwards [7] expresses "experience has a multi-dimensional character, where some authors highlight the importance of emotions, expectations, and the relationship to other people and the context of use, while others remarks the importance of the broader context." The challenge with respect to the QoE area is to look for the way to combine both points of view (technical and user-centric) so that, when seeking the satisfaction of a user with a specific content or application, we have a broad understanding of how complex human beings are. As mentioned by Kellerer et al. [5] "we need to develop practices that allow infrastructure and interaction features to be co-designed." But, a challenge for the HCI community is to create communication bridges with other disciplines to become real a scenario where, effectively, the use of technical resources and user satisfaction work hand-in-hand.

Regarding deployment of mobile networks, recent introduction of new generation of wireless infrastructures is being accompanied by an increase in both the number of users and their interest in multimedia content. This growth has been driven in the last decade by the popularity of multimedia content (e.g., video-sharing websites, social networks, video on demand sites, mobile IPTV, etc.), that according to the tendency will generate much of the mobile traffic growth through 2016, showing, at the same time, the highest growth rate of any mobile application. From this point of view, mobile operators have to tackle increasing operational costs given by energy consumption due to the traffic growth. From the users perspective, it represents the need for the development of mechanisms to extend mobile terminals life to enjoy during more time multimedia content with higher quality level. In that sense, classical approaches like deploying additional infrastructure are not likely to be economically viable for this challenge. On the other side, severe resource limitations in mobile networks can lead to dramatic levels of delays and interruptions, which can significantly affect user perceived experience (QoE). In this scenario, the need for obtaining improvements in terms of the quality perceived by users is more and more important in the networks evolution scenario. An alternative way to improve the QoE is having networks capable of identifying users expectations and using this information to dynamically allocate resources adjusted to a semantic model of the mobile service requirements while the content is being processed in the user terminal. An it is here where a better understanding of user's perceptions might contribute to the creation of network infrastructures with better performance based on the evaluation of predefined QoE model.

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