Mapping QoE through QoS in an Approach to DDB Architectures: Research Analysis and Conceptualization

RAMON HUGO DE SOUZA and MÁRIO ANTÔNIO RIBEIRO DANTAS,
Federal University of Santa Catarina

In the context of distributed databases (DDBs), the absence of mathematically well defined equations to evaluate quality of service (QoS), especially with statistical models, seems to have taken database community attention from the possible performance guarantees that could be handled by concepts related to quality of experience (QoE). In this article, we targeted the definition of QoE based on completeness of QoS to deal with decisions concerning with performance correction in a system level. This study also presents a statistical bibliometric analysis before the proposed model. The idea was to show the origin of first studies with correlated focus, which also have initial conceptualizations, and then propose a new model. This model concerns concise QoS definitions, grouped to provide a basis for QoE analysis. Afterward, it is foreseen that a DDB system will be able to autoevaluate and be aware of recovering situations before they happen.

CCS Concepts: • **Information systems → DBMS engine architectures; Parallel and distributed DBMSs**; • **Networks** → *Cloud computing*; • **Computer systems organization** → *Client-server architectures; Grid computing;*

Additional Key Words and Phrases: Big data, cloud services, distributed database architectures, quality of experience, quality of service, user's perspective

ACM Reference Format:
Ramon Hugo de Souza and Mário Antônio Ribeiro Dantas. 2015. Mapping QoE through QoS in an approach to DDB architectures: Research analysis and conceptualization. ACM Comput. Surv. 48, 2, Article 31 (November 2015), 41 pages.
DOI: http://dx.doi.org/10.1145/2828994

1. INTRODUCTION

The absence of quality definitions for distributed databases (DDBs), along with the network-related concepts and their holistic nature, guided this work to start with conceptual definitions from the existing literature to show the importance of defining quality of experience (QoE) in the DDB field. Since this problem still not well grounded in this field, the importance of the problem's characterization seems to be better understood when dealing with the concept of its origins. Showing a better-defined quality of service (QoS) in terms of mean and standard deviation with specific confidence intervals could then be used to give QoE guarantees not only in DDBs but also in network-related systems.

The lack of QoE definition in DDBs seems to come from a gap with its origins from the ordinary QoE holistic interpretation, which is unattractive in system-centric approaches such as DDBs. Within initial exploratory research, an absence of QoS

Authors' addresses: R. H. de Souza and M. A. R. Dantas, Informatics and Statistics Department, Federal University of Santa Catarina; emails: ramonh@inf.ufsc.br, mario.dantas@ufsc.br.

DOI: http://dx.doi.org/10.1145/2828994

definition was found, one lacking precise mathematical or statistical definitions. This fact leads to a scenario in which it is difficult for a system to use evaluations to correct itself from unexpected behavior.

The lack of well-defined QoS guarantees makes it impossible to consider QoE in a system-level approach. Therefore, this absence of a base definition brings a challenge to any system in predicting future behavior and avoiding unexpected situations before they happen. As a result, this research proposes mathematical definitions of QoS to be used with new QoE statistical definitions guarantees in the DDB area.

The proposed definitions are required to deal with an enhanced service evaluation and to be able to provide improved DDB services. Since no reliable and mathematically defined models have yet been suggested, this proposal is an interesting approach that can show improvements related to the utilization of these kinds of definitions for DDBs. Applying QoE evaluations in DDB scenarios offers a mechanism to evaluate and self-correct system performance.

1.1. The Subject Experience

According to Find Your Cloud [2013], the definition of *customer quality of experience* is "the difference between expectations and perceptions for a service" being, in that way, a subjective measure that is not only hard to quantify but also hard to define in terms of parameters, measuring the experience of a customer with a specified service.

That definition could be abstracted in a more mature concept by removing the customer constraint. Since the original quality definitions usually are associated with network-related concepts, the customer, in order to be provided with the services, is usually an Internet user expecting the usual best-effort service delivery.

Even in network-related conceptualization, the idea of satisfying a customer is considered an abstract goal to be achieved. As a system cannot know what the customer wants per se, which could involve abstract psychological issues, dealing with new conceptualizations to be achieved is not a good starting point.

Having pre-established such restrictions, the idea of experience to be evaluated could be encapsulated into the system level. Not only should the system be able to evaluate the level of achievement of the services into an expected quality defined explicitly into a service level agreement (SLA), which is essential for recovering from unexpected states, but it also should be able to evaluate the user's experience on demand and avoid resource overconsumption that may lead to states of unavailability.

And knowing that "QoE is a concept that it is not only limited to the use of a system or service" [Callet et al. 2013], the evaluation can be partially defined as such to provide to a system, or service, the ability to autoevaluate its completeness, as presented on Definition 1.1.

Definition 1.1. The multidimensional concept of QoE can be partially evaluated as QoS completeness, if the QoS is statistically well defined, for system-level purposes.

This is a major issue to establish statistical concepts into the quality to be achieved. When dealing with mean and standard deviation, and especially with the combination of both, a statistical guarantee of an SLA helps to avoid abstract conceptualization that could lead to problems of measuring, thus guaranteeing the services according to an agreement.

The QoE concept, with its origins in network concepts, usually referred to simply as QoE or QX, has its main focus on service experience as a whole. It is usually considered a less conceptual evaluation rather than a sharp *user experience* concept, usually referred to as UX, focused on the software interface, and the *customer experience*, usually referred to as CX, with a focus on support [Find Your Cloud 2014].

A concept that seems to consider abstract evaluations regarding experience is based on intangible measures. A system should be able to evaluate mathematical considerations rather than dealing with psychological abstract considerations. If the analysis is kept into the area of computer science, and therefore into discrete mathematical considerations and concepts, psychological issues should not be considered, and neither are they into the same research area. The goal should be to guarantee an SLA, not happiness.

Technical aspects targeting customer satisfaction and service delivery that relates to QoS parameters seem to be possibly handled, according to Laghari et al. [2011], by a commercial platform. However, there are factors such as "subjective psychological issues and human cognitive aspects that are typically unconsidered and directly determine the QoE" [Laghari et al. 2011]. Such consideration could be avoided with the conceptualization of QoE as a direct map toward QoS definitions into an SLA.

To be measured, the original definitions of QoE seem to require some specific specialized systems that can somehow evaluate these usually unconsidered factors. Such QoE systems, according to Laghari et al. [2011], are systems that try to deal with measurement of the metrics that will directly affect the user's perception as a quality parameter. In short, Laghari et al. [2011] define that QoE provides an evaluation of users' expectations based on how these users feel and perceive a particular service, measuring their satisfaction.

Keeping the focus on DDBs, considerations could be then strictly tied to SLA systems, and the problems concerning unexpected behavior on the user's part should only be a bad SLA choice—a problem that could easily be corrected by acquiring a new SLA.

As defined in the theoretical background explanation of the connection between QoE and QoS concepts, also in Laghari et al. [2011], QoE could be considered as a direct, yet *fuzzy*, map of how the user perceives a service in terms of QoS parameters. It is noteworthy that once QoE parameters are based on human behavior and expectations, it is hard to ensure a certain level of accuracy to this mapping process. This is a problem that disappears when considering systems instead of users.

What this study proposes, in Section 6, is a way to deal with this metrics mapping in a system-level expected behavior, not really considering the user per se but the agreement as defined according to QoS concepts, as presented in our proposal.

Since most studies on QoE and QoS are found in the network research area, this lack of background on databases, and especially on distributed architectures, leads to an open area with lots of interesting topics that still need to be developed to a more mature level. In this study, definitions of QoS metrics for DDBs will be defined in an attempt to try to measure QoE at a system level and then offer guarantees of behavior.

To deal with such concepts, originally coming from the network research area and recently also discussed in a network-centric multimedia approach [Callet et al. 2013; Möller and Raake 2014], it is naturally inferred that delay variation, usually referred to as jitter in the network terminology, in the provided service is a direct influential factor in the QoE level as perceived by the user consuming that service. Thus, the standard deviation is considered as an influential factor when evaluating the user's experience itself, and it is then explicitly defined as part of the SLA parameters for our purposes.

1.2. The Research Analytical Focus

The initial analytical focus of this study is a statistical review of the use of the term *QoE*, especially in publications in the research areas of computer science and engineering, to support the subsequently defined concepts. One of the main goals is to find the behavior of relevant use of the term in the academic field, finding a starting point and normal behavior that indicate the year of the most relevant use of the term in these research areas.

The focus on studies in computer science is self-explanatory, but it has also been found that the term and the concepts are commonly used in publications in engineering research. This is why the focus here is on those two main areas.

After determining the moment when the term started to be used with the expected relevance, this study delves into the subject of QoE in agreement with the DDB architecture area. With these considerations, the volume of data found was restricted, and the analysis of each paper revealed almost no related work. The two main papers found were written by the same authors, with the first showing preliminary results and the second discussing the subject as a problem that still needs to be solved.

In conclusion, these two papers seem to show possible directions that still need to be threshed in a way to accomplish some implementations of QoE systems dealing with decisions in the DDB area.

It is important to note that when considering services in the cloud, especially when considering migration of services to the cloud, QoE is often mentioned as a crucial concept that lacks studies involving the user's point of view [Vandenbroucke et al. 2013]. Moreover, it is mentioned in the exploratory survey of Vandenbroucke et al. [2013] that availability, accessibility, and compatibility are considered to be of crucial importance, as well as the cost-, privacy-, and security-related aspects.

Such concepts seem to be well founded; however, there are no studies exploring the DDB area. The lack of studies seems to leave an open door with no convergence of concepts or implementations yet to be substantiated.

1.3. Organization of the Article

Section 2 begins with a conceptualization and presents the QoS, QoE, and DDB architecture notions, and also introduces the concept of NoSQL, to exemplify the target technologies. This section also presents a brief explanation of how the database community perceives the complexity of DDBs and makes some assumptions about such architectures and QoE.

In Section 3, the study proceeds by defining and explaining the chosen bibliometric methods and the adopted methodological procedures. This section also describes the organization of the scientific databases selected to collect the data for analysis.

Then, according to the defined methodological procedures, the results are presented for statistical analysis in Section 4. In this section, a series of statistical behaviors are analyzed to draw conclusions from the data results toward a guarantee of the relevance of the data.

Section 5 presents details about the two main papers found in the bibliometric research, which seem to indicate related topics on QoE dealing with DDB architectures with QoS concepts that can base the study of QoE applied to DDBs.

Section 6 delves into a new QoE-QoS evaluation method based on the analyzed definitions and presents it with some QoS considerations.

In Section 7, some conclusions are formulated about research paths still to be trodden toward systems that can use these theoretical definitions to ensure corrections on demand without impact on the system performance—actually guaranteeing the system performance as expected.

2. CONCEPTUALIZATION AND BACKGROUND RESEARCH ANALYSIS

Since the analyzed subject is very specific—QoE applied to DDB architectures—and focused on abstract concepts that are not yet well defined in the database context, this study had to first fill a gap in the background conceptualization so as to base the path to be threshed.

The need for a QoS conceptualization urges from the selected approach to a QoE definition in the paper "QoE aware service delivery in distributed environment" [Laghari et al. 2011].

The absence of papers on QoE conceptualization in the DDB architecture area, and the existence of several approaches to the concept itself, reveal the need for a conceptualization and demonstrate the significance of the present approach.

The DDB architecture and NoSQL concepts are presented to contextualize the issue of associating abstract concepts with vague technology definitions.

2.1. Quality of Service

In the technical report *The Relationship between QoS and Business Metrics: Monitoring, Notification, and Optimization* [Wolter and van Moorsel 2001], "the effects of quality of service degradations on the profitability of e-services" are discussed. Our interest rests in the characterization of QoS metrics such as throughput, delay, and availability, but as a mean and standard deviation response times allied with availability guarantees.

Similarly to most publications related to QoS, this one deals with it in its original first conceptualization as network-related metrics. In this technical report, the focus is kept on e-services.

In a more QoE-aware consideration, it is known that with regard to an e-service in a delay parameter consideration, the user usually will not accept more than 8 to 10 seconds when dealing with a website focused on e-commerce [Bhatti et al. 2000; Bouch et al. 2000]. This is even a little worse than a delay variation if the delay is kept under that amount of time.

It is known that delay variation usually makes the user uncomfortable with a service, but a long amount of delay deems the usability of the service unacceptable, especially with with regard to e-commerce.

The impact of QoS effects on businesses dealing with dynamic relationships, presented in Wolter and van Moorsel [2001], is already a weak link to the QoE metrics to be discussed in the following section.

Based on QoS considerations, throughput, delay, and availability are listed as main metrics in Wolter and van Moorsel [2001]. However, in a more rigid definition presented in Shenker et al. [1997], a *guaranteed service* is defined as a service that "provides firm and mathematically provable bounds on end-to-end datagram queueing delays."

In Shenker et al. [1997], guarantees of services, concerning definitions for QoS, are only about delay and bandwidth and do not consider availability, once the definitions used were not about e-commerce applications, as in Wolter and van Moorsel [2001]. In pure network terms, the abstraction of a service in a software-consumed level is not involved in the given guarantees. The definitions in Shenker et al. [1997] are about mechanisms that follow to achieve a guaranteed reservation of resources, with the service specification template described in Shenker and Wroclawski [1997].

The conceptual definition of QoS metrics as metrics with mathematically provable guarantees, as in Shenker et al. [1997], gives a more palpable conceptualization to define these QoS metrics.

Based on such definitions, it is easily perceived that the main QoS concepts are composed of throughput, a concept correlated to bandwidth and bit rate; delay, a well-defined time concept itself; jitter, a delay-related variable that stands for the delay variation in network terms; and availability, which stands for the consideration of fail probability, directly related to packet dropping probability and/or bit error in the network terms' strict considerations.

Besides that, in a more cloud-directed conceptualization from Erl et al. [2013], the key services quality metrics are listed as follows:

—*Availability rate metric*: “Percentage of service uptime; measured as total uptime against total time,” expressed in percentages
—*Outage duration metric*: “Duration of a single outage,” measured by the date and time the outage started and ended, and expressed in hours and minutes
—*Mean-time between failures (MTBF) metric*: “Expected time between consecutive service failures,” measured by normal operational period duration and number of failures, and expressed as the average number of days
—*Reliability rate metric*: “Percentage of successful service outcomes under pre-defined situations,” measured by the total number of successful responses and expressed as percentages
—*Network capacity metric*: “Measurable characteristics of network capacity,” measured by bandwidth and throughput in bits per second, and expressed as the number of megabits per second
—*Storage device capacity metric*: “Measurable characteristics of storage device capacity,” measured and expressed in storage size in gigabytes
—*Server capacity metric*: “Measurable characteristics of server capacity,” measured and expressed as the number of CPUs, CPU frequency in gigahertz, and RAM and storage size in gigabytes
—*Web application capacity metric*: “Measurable characteristics of Web application capacity,” measured and expressed as requests per minute
—*Instance starting time metric*: “Length of time required to initialize a new instance,” measured by the date and time the instance was up and the date and time of the start request, and expressed in minutes
—*Response time metric*: “Time required to perform synchronous operation,” measured by the date and time of response and the total number of requests, expressed as averages in milliseconds
—*Completion time metric*: “Time required to complete an asynchronous task,” measured by the date of request to the date of response and the total number of requests, expressed as averages in seconds
—Storage scalability (horizontal) metric: “Permissible storage device capacity changes in response to increased workloads,” measured and expressed in storage size in gigabytes
—Server scalability (horizontal) metric: “Permissible server capacity changes in response to increased workloads,” measured and expressed as the number of virtual servers in the resource pool
—Server scalability (vertical) metric: “Permissible server capacity fluctuations in response to workload fluctuations,” measured and expressed as the number of CPUs and RAM size in gigabytes
—Mean time to switchover (MTSO) metric: “Time expected to complete a switchover from a service failure to a replicated instance in a different geographic area,” measured by the date and time of failure and the total number of failures, expressed in minutes
—Mean time system recovery (MTSR) metric: “Time expected for a resilient system to perform a complete recovery from a service failure,” measured by the date and time of recovery to the date and time of failure and the total number of failures, and expressed in minutes

The preceding are well-defined quality metrics to provide a guaranteed service with measured metrics—mathematically provable—that firmly provide bounds on end-to-end services as defined in Shenker et al. [1997], and also provide a better-defined model for the QoS approach applied to DDB architectures, even though not all metrics are directly applicable to QoS as necessary in a DDB approach.

These key service quality metrics were used as a base to define the quality metrics in the model, as presented in Section 6.

2.2. Quality of Experience

The concept of service quality is well defined in several marketing-related papers [Lewis and Booms 1983; Gronroos 1984; Parasuraman et al. 1985, 1988, 1994] and could be concisely explained as "a result of the comparison that customers make between their expectations about a service and their perception of the way the service has been performed" [Caruana 2002]. That conceptualization holds to the concept used toward QoE, and not QoS, in computer science and probably has its origins in those marketing concepts qualifying the experience of the user about the service.

This link with marketing concepts can be visualized in the definition by ISO 9241-210 [2010], stating that the user's experience is "a person's perceptions and responses that result from the use or anticipated use of a product, system or service."

As stated in the title of a publication by Morris and Turner [2001], "Assessing users' subjective quality of experience with the world wide web: an exploratory examination of temporal changes in technology acceptance," QoE is mostly defined as a subjective metric. The term *users' subjective quality of experience*, as shown in the title, was used in early 2001 publications and became popular in the academic environment, showing the sentiment about this concept's subjectivity. The concept of user acceptance, quoted in Morris and Turner [2001] as a "key [dependent] measure for valuing information technology in it-related research" with a part in the definition of determinants to this kind of technology, has emphasized the importance to define "descriptive information gain and guarantee an improving of utility" for a service. Even though the focus of this study is not the World Wide Web, as in Morris and Turner [2001], the conceptualization of user acceptance as a key dependent measure to value a generic service could also be defined as the heart of the QoE concepts, as will be considered in the present study, where the conceptualization will actually develop to a more generic system acceptance as the research progresses.

In a more computer science approach, the users, in a generic aspect of service consideration, are deemed as the ones wanting something with a special relationship to particular needs that can be somehow provided by a consumed service. The provision of the service implies an interaction between the user and the infrastructure that provides the service. The user expects this relation to be transparent. To reach that, some efforts could be taken, with the usual QoE as a solution to deal with the concepts of service profiles and/or context enablers.

Service profiles [Abramowicz et al. 2006] are a concept that helps to enable a better user experience by preselecting configuration values to a customized service definition. Once the user profile has been selected, the services should be provided according to the definitions of such a profile.

Context enablers [Richter and Bohm 2006] are a solution proposed to automatically retrieve information from the users to decide, when dealing with real-time systems, how to choose the best delivery method that fits the user's needs.

It is interesting to point out that in terms of network concepts, context enablers seem to be a solution that will hopefully ensure a small jitter in the service delivery regardless of how the service will be provided.

A solution toward definitions, either taken on demand or based on preselected profiles, is essential for the application of QoE concepts that somehow need to be mapped for QoS definitions [Laghari et al. 2011].

The most difficult part of QoE definitions is inferring the measure of the service quality compared to the also inferred user experience measure. As mentioned previously, it is very hard to measure the metrics that will directly affect the perception of the user as a quality parameter.

In a paper by Laghari et al. [2012], QoE is considered an abstract concept that, based on user usage data analysis, is used for creating guarantees directly on QoS parameters. In it, *QoE* is defined as "a set of human centric factors which provides quality assessment of services, networks and end-user devices." It also states that '*QoS* is [a] technology centric approach" and "it lacks to satisfy human hedonic and aesthetic requirements."

As defined in Laghari et al. [2011], QoE is a resource that provides assessment of "human expectations, feelings, perceptions, cognition and satisfaction with respect to a particular product, service or application." Moreover, as mentioned in Laghari et al. [2012], to capture QoE, some ways using subjective or objective methods could be considered. These subjective methods rely on feedback about quality from human subjects, and objective methods, as classified in Laghari et al. [2012], are "(i) objective technical factors which infer QoE from available QoS data, and (ii) objective human factors which are related to the human physiological and cognitive system."

In a study by Brooks and Hestnes [2010], the importance of objective and quantitative definitions for QoE is discussed. A conceptualization of QoE with a focus on requirements for its measurement is developed, and it is argued that "QoE measurement should include objective measures of the process and outcomes of usage." It is also pointed out that "subjective measures should be collected as quantitative data rather than qualitative data as is currently common, because quantitative data enables combined analyses of objective and subjective measures for deriving global QoE ratings." These global ratings are considered important matters for the optimization of communicability of the results targeting specific audiences.

Three approaches to "measuring network service quality from a user's perspective" [Brooks and Hestnes 2010] are presented with their advantages and disadvantages in Brooks and Hestnes [2010]. With regard to *testing user-perceived QoS*, the main advantage is the use of a direct measure of the user's behavior, and two critical disadvantages presented as the "end-user focus are entirely in the perceptual domain" [Brooks and Hestnes 2010], and the relation between user behavior and unconscious psychological factors is not visualized in self-reporting of opinion. With regard to *surveying subjective QoE*, a study of user's behavior does not rely on user's opinion, where "QoE is inferred from indirect technical measures" [Brooks and Hestnes 2010] with tests used to identify and later on validate the inferred relationship of the user's behavior with technical parameters. With regard to *modeling media quality*, computational models are said to be objective "because they model measurable technical parameters" [Brooks and Hestnes 2010; ITU-T.P.862 2001] with the advantage of being user centered, and with the disadvantage of speed and economy for dealing with continuous validation against user test data and the limitations of the model validated against user perception of data—the already mentioned relation between user behavior and unconscious psychological factors.

The study by Brooks and Hestnes [2010] also presents objective measures of user performance as accuracy of user task completion; gain or loss to the user; time taken for goal completion; number of user inputs; time between user inputs; number of turns taken to communicate; number of interruptions; number of simultaneous actions; and subjective measures of user performance such as effectiveness, efficiency, satisfaction, enjoyment, social presence, and impression of the communication partner.

All of them are very constructive for QoE definitions in general, but they are still not precise for a DDB approach.

2.3. The Approach to Mapping QoE through QoS

In the literature about quality definitions, especially in network-related literature, some authors make reference to QoE as a direct map of how the user perceives QoS [Laghari et al. 2011]. The main problem when considering a self-evaluating system that could use metrics to recover from an unexpected state, and considering the related work about QoE by several sources [Find Your Cloud 2013, 2014; Laghari et al. 2011, 2012; Vandenbroucke et al. 2013] is that impalpable metrics are not useful.

These related works usually consider QoE as a holistic evaluation, which is of no use for a system. How the user feels means nothing to it. To know if the user is not satisfied does not mean that the system is not working according to an SLA. After all, the only variables that matter, concerning how the user feels, are those about service stability and ones related to the standard deviation.

Because of that, to be able to use the metrics in a self-correcting system, it is first necessary to define these metrics in a nonholistic way. More explicitly, definitions of QoE metrics mapped to palpable QoS metrics are of utmost importance for the chosen approach.

2.4. NoSQL and DDB Architecture Concepts

The emergence of distributed architecture technology was leveraged from the requirement to deal with the integration of large volume of heterogeneous corporate data stored in different spatial locations. It is also the promotion of reusability associated with a possible reduction of maintenance costs, a booster pointing to that technology as an attractive solution to deal with database architectures.

For example, the performance, when considering a system with the premise of much more access to the data than records, could be easily inferred as optimistic in a distributed solution just imagining that the replication would not cause too much load by verifying data records in separate servers, as the considered system deals with massive access and eventual record. In the same way, it is easy to infer that multiple servers could deal with lots of user's access with better performance than just one.

Of course, there are counter examples; however, when considering this kind of solution, the original problem should point to this architecture. Otherwise, this would not be the solution to the proposed problem. This kind of technology focuses on solutions working with hybrid systems that require horizontal distribution, with more servers, and not vertical, with more memory or processing capacity. Being a technology that is easier to scale, it is usually more efficient for reading than writing.

A recurrent consideration to this type of database is the need for a data management system to keep the control and to provide coordinated access to the several interconnected databases. The development of these data management systems is the structural step that resulted in the introduction of this technology as it is known today.

The type of control of the data management system could be generically characterized as *logically centralized* [Smith et al. 1981] or *decentralized* [Heimbigner and McLeod 1985], also called *federated*. That is a determinant of the autonomy's degree, affecting the nature of the coupling between the schema interfaces.

From those two concepts, established in the 1980s, several database models have evolved, each one of them dealing with the limitations of the model in a particular way. The logically centralized ones usually sacrifice the local autonomy, and the federated ones usually retain the local autonomy in a way that it becomes harder to control the global system.

The emergence of more complex models, as knowledge based and nonconventional models, and as object-oriented ones, led to a reconsideration of the perspectives of DDB architectures. With these new concepts introduced into the database's field, it is now manageable to deal with a high-level data modeling strictly connected to software modeling. The clustered architectures, as the environment presented in Papazoglou et al. [1988], combine both logically centralized and federated models. They are a hybrid between these two models with their own unique advantages.

Today, these hybrid database models are in most cases classified as not only SQL (NoSQL) models. The NoSQL concept encompasses database models that do not require SQL for accessing the data, making them nonrelational models.

The NoSQL family model includes a series of submodels[1] as document store, object, key value (cache, store, store eventually consistent and store ordered), wide columnar and column families, data structures, tuple store, graph, multimodel, multidimensional, multivalue, event sourcing, and some specific grid and cloud solutions.

2.4.1. The Complexity of DDB Architectures. To deal with computational complexity, in terms of O, Ω, and Θ, considering DDB architectures, a big effort is required to acquire the functions that correctly describe the complexity of operations.

The variables of interest required to get a more generic function could include the number of processing nodes, number of core in the nodes, how they communicate, protocols used, and probability of fails in terms of storage and memory, among other, much harder to conceive and measure, variables if the focus involves performance.

The complexity could then be measured considering only the number of operations, to avoid hardware-related variables, but the number of replications and how they communicate and guarantee consistency still are very hard to measure in terms of a generic function that describes the complexity of the operations. Even if this could be done, in terms of operations, when done to one specific database, it would still not be a completely valid concept about the behavior of a generic architecture.

Publications about complexity of operations, regarding DDB architectures, generally consider the complexity of the exchange of messages between the replicators and do not delve into real computational complexity per se.

2.4.2. DDB Architectures and Quality of Experience. The given guarantees of QoE could be used to provide assurance for the user's needs and would be provided in terms of resource allocation, priority of execution, or any other definition that guarantees the agreement of the given service.

The usual definitions for service profiles [Abramowicz et al. 2006] and context enablers [Richter and Bohm 2006] could be used to predefine or define on demand, respectively, the needs of the user for the service and then make use of the implementation definitions to provide the service according to these needs.

The lack of studies interconnecting the research areas of DDB architectures and QoE is very concerning, as the topic of QoE seems to have had its maximum research interest in 2012, as shown in Section 4, and the only references to QoE in DDB architectures seem to be implementations of QoS, not yet applied to provide the services for nonexperienced users.

However, the definitions presented in de Carvalho Costa and Furtado [2011], categorizing suboperations in terms of priority, seem to be a first step into the implementation of QoE to DDB architectures.

The statistical results from de Carvalho Costa and Furtado [2013] show a first study about the gain that could be achieved by applying QoE to DDB architectures.

[1]Partially based on NoSQL Databases [2014].

3. BIBLIOMETRIC TECHNIQUES AND METHODOLOGICAL PROCEDURES

To obtain the data about QoE for the present analysis, two databases with scientific recognition and accessibility to researchers where chosen, namely Web of Knowledge [Thomson Reuters 2013] and Scopus [Elsevier B. V. 2013].

The data was obtained from these databases early in 2014, as the articles from this year were not yet indexed at that time.

3.1. Web of Knowledge

The Web of Knowledge database deals with its main collections, called the *Web of Science*, with data from 1945 to the present comprising 65 subject areas; with the *Derwent Innovations Index*, with "value-added patent information from the *Derwent World Patent Index*, as well as patent citation information" [Thomson Reuters 2013] from the *Patents Citation Index*, with data from 1963 to the present; and with *Journal Citation Reports*.

Our research focuses on the subject areas of computer science and engineering, but we also present data obtained when searching over what the engine calls *science technology* and with all subject areas of the database.

3.2. Scopus

The Scopus database deals with its own selection of publications, where the source types are specified as trade publications, journals, conference proceedings, and book series, dealing with 19 subject areas.

Along with the search in this database, we also kept the focus on computer science and engineering. However, besides the data obtained from all of the databases, we present the data from what the tool calls *physical sciences*, which includes "chemical engineering, chemistry, computer science, earth and planetary sciences, energy, engineering, environmental science, materials science, mathematics and physics, astronomy and the multidisciplinary sources" [Elsevier B. V. 2013].

3.3. Techniques and Procedures

After an initial analysis of the crude data results, the study then starts a content analysis of the data with a restriction to the research areas of computer science and engineering, as the volume of data found was very large.

Whenever an accepted statistical behavior was found, the analyzed topic was restricted even more for a better analysis of the data according to their relevance.

Unfortunately, the volume of data associated with the *per-year* discretization was too big, not only in cases where it indicates the initial behavioral traces but also in cases that seem to show the real behavior. And even mirroring the data to the expected future behavior, the Shapiro-Wilk normality test [Shapiro and Wilk 1965], the Jarque-Bera normality test [Jarque and Bera 1980], and the D'Agostino normality test [D'Agostino 1970] seem to get lost, even with the data clearly tending to normal statistical behavior.

Within the final data restrictions, the citation analysis was not essential because the volume of data was very small and directly related, but still was presented in the analysis of publications with the specific topic of interest.

The selected methodological procedures were based on the expectation of a normal statistical behavior, with a clear year indicating the maximum research interest in the subject. The behavior found indicates that the normal already passed its maximum, pointing to a possible lack of interest in this particular subject by the database community, as the results were almost absent up to that date.

4. STATISTICAL RESULTS AND ANALYSIS

This statistical research started with some definitions for the search parameters to restrict the space of search over the two selected databases and then to obtain more relevant data.

With the initial expectation of being able to analyze all of the data over all subject areas on the selected databases, results were initially filtered to avoid several unrelated connotations in research areas that are not of interest in this study. For that reason, the term *QX* was specially excluded to avoid a large amount of unrelated results. The *QoE* term introduced some unrelated results, but not as many as the *QX* term. As it was easier to deal with the unrelated results introduced by the term *QoE*, we decided to keep it on the searches, as some articles used it to specifically quote QoE.

4.1. Web of Knowledge Results

Because of the very useful and easy-to-use engine Web of Knowledge, it was first thought to use it alone to obtain all of the data needed to fulfill the research requirements—the results with this tool seem to be more detailed than those of the second one selected. Unfortunately, some unexpected behavior created a need to deal with more than one engine so as to infer the actual behavior of the relevance of the searched terms.

4.1.1. Analysis of the Results over the Combined Web of Science and Derwent Innovations Index Web of Knowledge Databases. A combination of the two main databases of Web of Knowledge was considered for this search. At the initial moment, they were considered to be checked separately, owning to a possible duplicated number of papers in the results; however, that was corrected by avoiding the use of the term *QX*.

The statistical normal behavior expected was not found here. It seemed to be because of some perturbation between 2009 and 2011, which is why the search dealt with two engines.

The analysis started by getting a definition of an initial year with a relevant conceptual use of the term *quality of experience*. To do so, the searches were chosen to be done over the Web of Knowledge databases with the topic parameter set as (“Quality of Experience” OR QoE) to check for early references to QoE. Then, the topic parameter was set as (“Quality of Experience” OR QoE) AND (Database OR “Distributed Architecture” OR “Big Data”) to check for references to QoE associated with our focus on DDB architectures.

With the results obtained in the first search over Web of Knowledge, refined by the research areas of computer science or engineering, presented in Table I, we found an early reference in 1998 [Mielke et al. 1998]. That was just a coincidence in the use of the term, and a reference in 2001 in an article by Morris and Turner [2001], “Assessing users’ subjective quality of experience with the World Wide Web: An exploratory examination of temporal changes in technology acceptance,” whichhas an already acceptable use of the term for the chosen purposes.

Unfortunately, as can be seen in Figure 1, after 2009, engineering not only passed computer science, but the term *QoE* failed to be as relevant to computer science as it was to other fields—completely the opposite of what was expected—or in some way, Web of Knowledge just neglected the publications in the computer science area from 2009 on.

However, the possibility of shrinking the volume of publications when refining the search into the purposes of the present study is known, as shown in Table II.

As can be seen, Tables I and II have a very similar behavior but, of course, with a much smaller volume of data in Table II. Out of the 28 articles, only 2 articles, both

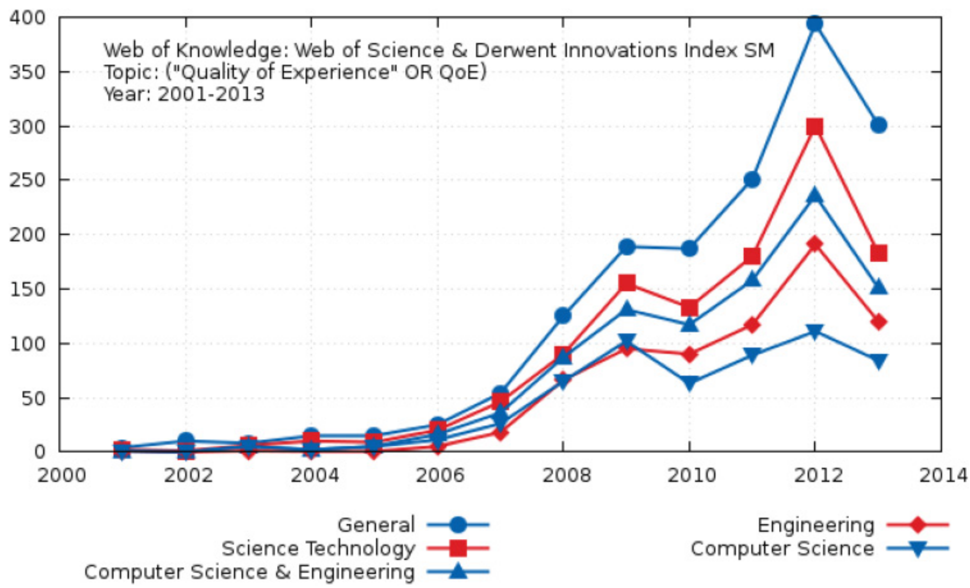


Fig. 1. Histogram of the behavior of Web of Knowledge: Web of Science and Derwent Innovations Index databases search, with the selected topic of (“Quality of Experience” OR QoE) from 2001 to 2013 at http://apps.webofknowledge.com on January 6, 2014.

Table I. Web of Knowledge: Web of Science and Derwent Innovations Index Databases Search

Year	General	Science Technology	Computer Science	Engineering	Computer Science or Engineering
1945–2014	1,619	1,152	567	705	948
2014	2	2	2	0	2
2013	301	183	84	120	151
2012	394	300	111	191	236
2011	251	180	89	117	158
2010	187	133	63	90	117
2009	189	155	102	95	131
2008	125	90	65	66	87
2007	54	46	26	18	36
2006	25	20	11	5	16
2005	15	9	5	0	5
2004	15	10	2	0	2
2003	8	6	5	1	5
2002	10	1	0	0	0
2001	4	2	1	1	1
1999–2000	8	5	0	0	0
1998	5	3	1	1	1
1971–1997	27	7	0	0	0

Note: Selected topic: (“Quality of Experience” OR QoE) at http://apps.webofknowledge.com on January 6, 2014.

Table II. Web of Knowledge: Web of Science and Derwent Innovations Index Databases Search

Year	General	Science Technology	Computer Science	Engineering	Computer Science or Engineering
1945–2014	56	35	16	19	29
2014	0	0	0	0	0
2013	16	10	4	4	6
2012	19	13	6	8	12
2011	7	4	2	3	4
2010	7	5	2	3	4
2009	2	0	0	0	0
2008	4	2	1	1	2
2007	1	1	1	0	1

Note: Selected topic: ("Quality of Experience" OR QoE) AND (Database OR "Distributed Architecture" OR "Big Data") at http://apps.webofknowledge.com on February 12, 2014.

Table III. Relevant Articles Correlating QoE and Distribute Database Architectures found on Web of Knowledge databases on January 6, 2014

Web of Knowledge: Web of Science and Derwent Innovations Index Databases			
Article	Authors	Journal	Year
"Quality of experience in distributed databases"	de Carvalho Costa and Furtado	*Distributed and Parallel Databases*	2011
"Providing quality of experience for users: The next DBMS challenge"	de Carvalho Costa and Furtado	*Computer*	2013

by de Carvalho Costa and Furtado [2011, 2013] in the areas of computer science and engineering were relevant to this study.

These 28 articles, presented later in Table XIII in Appendix A, were about topics mostly related to network and peer to peer (06, 10, 18, 27, and 28), video, VoIP and speech systems (04, 05, 08, 09, 12, 14, 15, 16, 20, 22, 24, 25, and 29), and stereoscopic video and image technologies (03, 07, 11, 19, and 23). The two correlated articles dealing with DDB and QoE concepts, listed in Table III, are detailed in Section 5.

The results underlined later in Table XIII in Appendix A were found on Scopus and Web of Knowledge simultaneously.

4.2. Scopus Database Results

In the same way as was done with the Web of Knowledge database, the parameter 'article title, abstract, and keywords" was set as ("Quality of Experience" OR QoE) to check for early references to QoE. Then the parameter 'article title, abstract, and keywords" was set as ("Quality of Experience" OR QoE) AND (Database OR "Distributed Architecture" OR "Big Data") to check for references to QoE with a focus on DDB architectures.

4.2.1. Analysis of the Results over the Scopus Databases. Results from the Scopus database presented in Table IV, refined by physical sciences, found an early reference in 1987 [Redd et al. 1987], which was just a reference to quasi-one-electron as QoE. Refined by computer science and engineering, found an early reference in 1989 [Hoogeboom 1989] but about development/redevelopment policy for ocean beach areas, and one reference in 1998 [Mielke et al. 1998], which is the same unrelated article found in the Web of Knowledge search. Also references to QoE are found in three articles that were not

Table IV. Scopus Search

Year	General	Physical Sciences	Computer Science	Engineering	Computer Science or Engineering
1960–2014	2,390	2,209	1,794	912	2,177
2014	2	2	1	2	2
2013	440	428	352	173	421
2012	587	571	473	243	566
2011	416	407	351	144	404
2010	332	312	260	108	309
2009	226	222	188	103	220
2008	131	121	89	67	120
2007	77	68	42	32	66
2006	45	39	22	21	38
2005	26	16	8	7	14
2004	15	6	2	5	6
2003	9	3	2	2	3
2002	9	1	0	0	0
2001	10	4	2	1	3
2000	10	3	1	2	3
1999	3	0	0	0	0
1998	9	1	1	1	1
1990–1997	22	3	0	0	0
1989	2	1	0	1	1
1954–1988	19	1	0	0	0

Note: Selected article title, abstract, keywords: ("Quality of Experience" OR QoE) at http://www.scopus.com on January 8, 2014.

related to the subject from 2000: Sato and Verplank [2000], Turner II and Nowell [2000], and Forlizzi and Ford [2000], being that articles about physical QoE in design of embedded technologies' products, virtual environments, and designing for the user experience, with a focus on design, respectively.

In 2001, three references were found: Honda et al. [2001], Morris and Turner [2001], and Wolter and van Moorsel [2001]. The first one is a nonrelated technical paper about a cabin air quality system, the second one is an acceptable reference already found on the Web of Knowledge search, and the third one is the technical report *The Relationship between Quality of Service and Business Metrics: Monitoring, Notification and Optimization*, also with relevant references to QoE.

With the data collected from the two search engines, it could be then concluded that the term QoE began to be used circa 2001 with the expected connotation, as relevant use of the term was found in the two search engines from that year. Even though the term was applied with some connotations unrelated to the subject of interest, in some particular cases the data seem to converge on that initial year.

An important fact is that a statistical normal behavior was found, as expected, with the Scopus engine, as can be seen in Figure 2.

With that engine, not only does computer science have more results than engineering, with the combined two research areas containing almost all papers found, but the volume of response obtained with that engine is larger and very close to the volume up to 2009 in the Web of Knowledge databases. This proves the assertions about a possible neglect in computer science publications in such databases.

Table V shows the results of the search on ("Quality of Experience" OR QoE) AND (Database OR "Distributed Architecture" OR "Big Data"), with 63 papers in the computer science and engineering research areas.

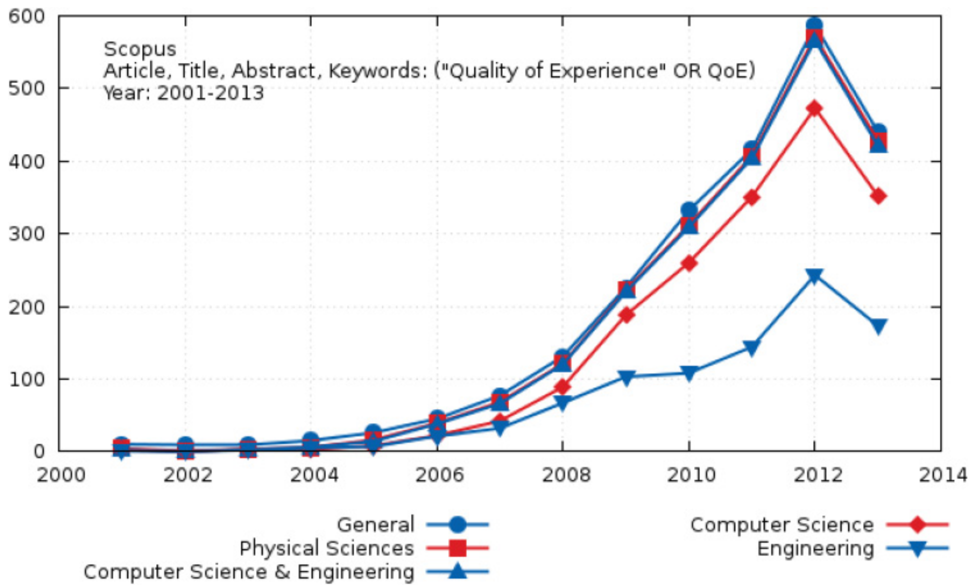


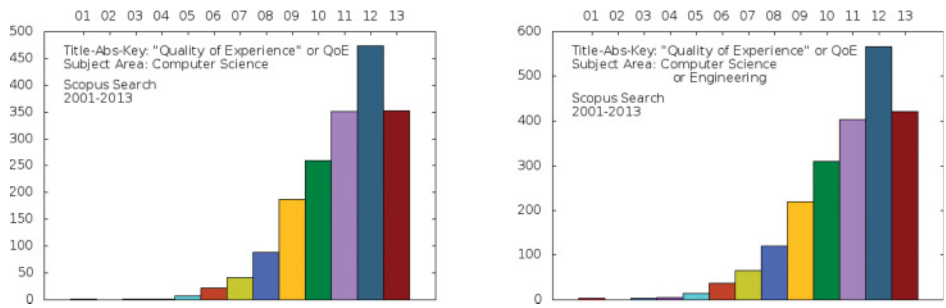
Fig. 2. Histogram of the behavior of the Scopus search. Selected article title, abstract, and keywords: ("Quality of Experience" OR QoE) from 2001 to 2013 at http://apps.webofknowledge.com on January 8, 2014.

Table V. Scopus Search

Year	General	Physical Sciences	Computer Science	Engineering	Computer Science or Engineering
1960–2014	68	64	62	20	64
2014	0	0	0	0	0
2013	23	21	21	8	21
2012	19	19	18	6	19
2011	9	9	9	2	9
2010	9	8	8	2	8
2009	2	2	1	1	2
2008	2	2	2	1	2
2007	2	2	2	0	2
2002–2006	0	0	0	0	0
2001	1	1	1	0	1
1955–2000	0	0	0	0	0
1954	1	0	0	0	0

Note: Selected article title, abstract, and keywords: ("Quality of Experience" OR QoE) AND (Database OR "Distributed Architecture" OR "Big Data") at http://www.scopus.com on February 12, 2014.

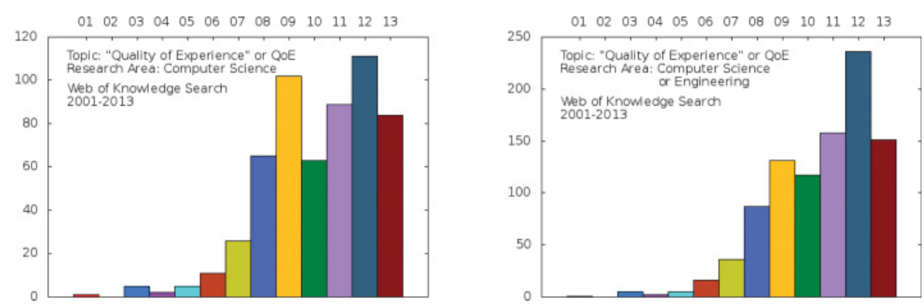
Among these 63 papers, presented later in Table XIV in Appendix A, the first one from 2001 in computer science from Wolter and van Moorsel [2001], as mentioned previously, "deals with the effects of quality of service degradations on the profitability of e-services" but is not focused on DDBs, and the others are mostly related to network and peer to peer (02, 03, 05, 16, 20, 30, 37, 39, 41, 50, 58, and 61), video, VoIP and speech systems (07, 08, 11, 12, 17, 21, 22, 23, 24, 25, 28, 38, 40, 42, 46, 47, 55, 60, and 62), and stereoscopic video and image technologies (01, 06, 14, 18, 19, 27, 35, 43, 51, 52, 53, 54, and 57), and likewise the results obtained from Web of Knowledge. Some of



(a) Scopus well-behaved normal distribution in computer science.

(b) Scopus well-behaved normal distribution in computer science or engineering.

Fig. 3. Results for the topic "Quality of Experience" or QoE from 2001 to 2013 on the Scopus database in the research areas of computer science alone and computer science or engineering on January 8, 2014.



(a) Web of Knowledge not so well behave normal distribution in computer science.

(b) Web of Knowledge not so well behave normal distribution in computer science or engineering.

Fig. 4. Results for the topic "Quality of Experience" or QoE from 2001 to 2013 on the Web of Knowledge database in the research areas of computer science alone and computer science or engineering on January 6, 2014.

the results (04, 29, 33, 34, 48, and 63) are references to proceedings and not to specific articles, so these results were considered errors in the search results.

The relevant papers found, with a focus on DDB, were the same two articles by de Carvalho Costa and Furtado [2011, 2013] mentioned earlier as a result from Web of Science in Table III and detailed in Section 5.

The results underlined later in Table XIV in Appendix A were found on Scopus and Web of Knowledge simultaneously.

4.3. Statistical Analysis of Research Interest

Initially, by analyzing the Web of Knowledge database, it was noticed that the subject seems to have a peak of interest in 2009 and later again in 2012, as mentioned previously. However, when analyzing the Scopus database, a well-behaved normal distribution was noticed with a peak in 2012, as shown in Figure 3(a) in the research area of computer science and in Figure 3(b) when considering the combined research areas of computer science or engineering.

When considering the research areas of computer science and engineering together, there also seems to be a peak of interest in 2012 on the Web of Knowledge database, as shown in Figure 4(b).

However, the data obtained seem to lead to a more complex aspect to be considered. The behavior of the databases seems to differ after 2009. Before that, the number of results seemed to be in an acceptable consistency, not only in behavior but also in terms of magnitude.

Looking at it more carefully, it is possible to figure out that even before 2009, the Web of Knowledge database dealt with fewer data than the Scopus database. However, it seems that especially after 2009, the Web of Knowledge sources did not grow as the Scopus ones, and that is why this effect is perceived, as if Web of Knowledge had neglected the computer science sources in which this study was precisely interested.

It could then be assumed that the peak of use of the term on the searches was in 2012, with an expected statistical normal behavior.

Additionally, even with the peak of interest already being achieved, the existing studies of QoE, or even QoS in a way that can be better applied to QoE considerations, to DDBs are almost absent.

That absence of studies about a service consideration to be evaluated, in service provider models such as DDBs, seems to be a lack that needs to be filled with the already provided concepts in the literature.

5. BIBLIOMETRIC DETAILS

This bibliometric review focuses on combined topics of DDB architectures and QoE rather than considering them separately.

Even though the concepts in both topics are very interesting, the results found in separate searches are associated with some research fields that are not of interest for the present study.

5.1. Quality of Experience in DDBs

The 2011 publication *Quality of Experience in Distributed Databases* [de Carvalho Costa and Furtado 2011] claims to be a first introduction to the use of QoE in DDBs. It is a proposal to improve the level of QoE that could presumably be provided by DDB systems, with the main focus on mechanisms that could increase user satisfaction in the question of accessing these DDB systems.

It is worth considering the point that this study deals with the assumption that "in traditional database systems, users cannot specify execution-related constraints," concluding that "the database system cannot evaluate if user expectations are satisfied and neither the system can take corrective actions when necessary" [de Carvalho Costa and Furtado 2011]. It is a valid point, but with the assumption that the user needs to have a strictly specific knowledge of database operation to deal with execution-related constraints. It would make more sense, in an abstract way, to develop systems with that layer as follows instead of expecting users to deal with it.

That is exactly what de Carvalho Costa and Furtado [2011] claim: a "QoE-oriented distributed database system," grouping QoS definitions that allow the use of QoE and not a QoE solution per se. This is a first introduction of these concepts applied to DDB systems and a first opening that allows QoS definitions to be used for the development of QoE systems in a way that when these concepts are applied to DDB systems, theoretical models of QoE systems can then be applied to databases.

In the presented QoE-DDB model, "each user's command is translated into tasks that are executed by data services called *community modules*, and local data services negotiate service level objectives (SLOs) for each task, improving the system dependability" [de Carvalho Costa and Furtado 2011]. They also present "QoE-oriented scheduling and dynamic data placement strategies" [de Carvalho Costa and Furtado 2011].

They propose seven types of data access requirements (DARs), which are "expressed in terms of query execution constraints" [de Carvalho Costa and Furtado 2011], with the following definitions:

—*Data availability requirement*: Indicates periods when certain data must be available
—*Data freshness requirement*: Indicates how updated a certain data replica should be to be used to answer a query
—*Execution deadline requirement*: Specifies the interval on which a command execution should be finished
—*Disconnected execution mode requirement*: Indicates that the command should be executed even though the user is disconnected from the system
—*Execution priority requirement*: Specifies the execution priority of the command
—*Execution start time requirement*: Specifies a date/time on which a command execution may start
—*Execution finish time requirement*: Specifies a date/time on which a command execution should already be finished

Then they infer the absence of capability of the "traditional performance metrics, as response time and throughput, in order to measure the QoE level that the system provides" [de Carvalho Costa and Furtado 2011] to introduce a unique set of key performance indicators (KPIs). These KPIs are supposed to be able to measure the "system's capacity to achieve users' expectations" [de Carvalho Costa and Furtado 2011].

According to de Carvalho and Furtado [2011], the proposed KPIs are:

—*Acceptance rate*: Provides a measure of the number of commands with DARs that the system agreed to execute (and satisfies corresponding DARs)
—*Commitment maintenance rate*: Measures the systems capacity to satisfy the DARs that it agreed to satisfy
—*Success rate*: Provides a measure of the amount of commands with DARs that the system executes while satisfying specified DARs
—*QoE level*: Provides a measure of the level of QoE that the system is providing for users

Subsequently, as mentioned earlier, de Carvalho Costa and Furtado [2011] present "QoE-oriented scheduling and dynamic data placement strategies." It seems to be a reliable model that deals with a very specific set of selected performance indicators to measure the QoE level provided for the system.

De Carvalho Costa and Furtado [2011] also present experimental results in some scenarios to highlight the importance of the following:

—Evaluating DARs before executing users' queries
—Informing users about the possibility (or not) of satisfying specified DARs
—Not spending computing power executing commands whose DARs cannot be achieved
—Using DARs to improve user satisfaction

5.2. Providing QoE for Users: The Next DBMS Challenge

The paper "Providing quality of experience for users: The next DBMS challenge" [de Carvalho Costa and Furtado 2013] considers the need of "QoE oriented mechanisms, not currently available in traditional database management systems," in a way that it could somehow allow the consideration of user-specified requirements by a system that could, based on that, adjust its operations considering these user expectations.

The paper makes a comparison of data management strategies, reinforcing earlier results and showing the gain that could be achieved by applying QoE-DDB strategies.

6. A THEORETICAL MAP MODEL OF QoE THROUGH QoS

The theoretical map model of QoE through QoS presented here, as considered to be applicable to DDBs, reaches from the definitions of Brooks and Hestnes [2010], where they state that objective and quantitative definitions of QoE parameters are a crucial step. And then trying to avoid the network-related concept considerations of a user's hedonic and aesthetic requirements [Laghari et al. 2012], since in DDBs the SLAs seem tied to a more complex layer than the usual best effort network point of view, a hybrid QoE-QoS with confidence interval considerations is presented, even knowing that it is not a completely QoE covering model. Since QoE is a multidimensional user-centric concept, it is hard for a system to give exact guarantees of this kind.

DDBs can be usually seen as a service provider architecture, and thus it is easier to define the exact values to be provided. Additionally, considering that the services are usually hired with specific definitions, that model is not as abstract as a model of an unknown user consuming a generic Internet service. Shenker et al. [1997] state that QoS metrics should be mathematically provable guarantees, and allying that concept with the theoretical background explanation of the connection between QoE and QoS concepts in ur Rehman Laghari et al. [2011], we focused on having mathematical guarantees of mean and standard deviation to try to achieve the expected QoE, even knowing that this is an oversimplification.

The two previously introduced studies [de Carvalho Costa and Furtado 2011, 2013] show practical results of applying QoS metrics—at this point, the so-called QoE seems to be strictly connected with metrics for evaluating the agreed level of QoS—for DDBs and methods associated with parameters to evaluate such metrics, not actually mapping parameters strictly connected to the user's satisfaction, as the QoE conceptualization defined in ur Rehman Laghari et al. [2011]. Those two papers evaluate the expected QoS measures according to an SLA and are not strong definitions; instead, they are guidelines for a QoE-aware system. The QoE level seems to actually be the level of completeness of the expected QoS defined by an SLA—a new concept, the completeness of QoS that could lead to a parameterized conceptualization of QoE.

To clarify the punctuations about SLAs, not mentioned in the cited works, in a QoS usual view of a system, the user cannot specify how the behavior is supposed to be, as the expected behavior is tied to the defined QoS agreement. In the view of de Carvalho Costa and Furtado [2011, 2013], it is assumed that the user can specify how things are expected to be, what actually is only acceptable in a view of a controlled QoS layer. What can be considered in the present study, after these two analysis, is that the definitions are supposed to be used by a layer that can evaluate the expected behavior, not the user per se. This is the origin of the SLA reference consideration.

To define a QoE-QoS model, a main step is to define, in a concise way, the QoE parameters to be measured in the DDB approach. Even though one paper [Brooks and Hestnes 2010] states that the objective and quantitative definitions of QoE parameters are a crucial step, it does not present any specific model with QoE parameters, and this allowed the conclusion that the QoE-level parameters are strictly tied to QoS definitions agreed, with very specific guarantees, on every specific service. To define QoE, in terms of QoS mapping, it is crucial to define the QoS parameters. In a comparison with the concepts in chapter 2 of Erl et al. [2013], de Carvalho Costa and Furtado [2011] present the DARs requirement definitions as follows:

—*Data availability*: Could be measured with the Erl et al. [2013] availability rate metric
—*Data freshness*: A requirement to execute a task that does not seem to be directly mapped to the metrics presented by Erl et al. [2013], not a part of reliability rate metric, as a new concept to be considered by this study definitions
—*Execution start/finish time and deadline*: Encompasses almost all of the Erl et al. [2013] metrics, as an instance starting time metric that considers the time to initiate an instance, the response time metric if it is a synchronous operation, or the

completion time metric if it is an asynchronous task; the MTSO metric as a fail probability recovery time variable when switching from a flawed service to a replicated instance; the MTSR metric considering the probability of a service recovery from complete failure; the mean time between failures metric to consider several possible fails in case of a long task; the outage duration metric as a probability metric associated with the all replications fault; the network capacity metric to know if the operation is achievable considering the network characteristics; the server capacity metric to know if the servers providing the service can achieve the task in the deadline; when considering storage services, the storage device capacity metric associated with the storage scalability horizontal metric; and considering variable workloads, the server scalability horizontal and vertical metrics
—*Disconnected execution mode*: An option usually associated with long time tasks that are not directly associated with time necessities, as a guarantee consideration
—*Execution priority*: A regular QoS definition of priority that, in this case of DAR subtasks, could be an automatic definition associated with specific predefined groups of DARs

The preceding information about the so-called QoE level, classifying as the expected QoS is achieved, and the level of that achievement, is not the expected definition of QoE based on Laghari et al. [2011], but it could be considered as such for simplification matters. Additionally, the fuzzy definitions of QoS should not be that fuzzy, as shown in the comparison of de Carvalho Costa and Furtado [2011] with the work of Erl et al. [2013], as they consider that exact metrics for QoS are a crucial step for QoE definitions.

According to three papers [Erl et al. 2013; de Carvalho Costa and Furtado 2011, 2013] about distributed networks in clouds and management and evaluation of QoS in DDBs, it was observed that resources and quality (R&Q) capacity (with execution, storage, networking, and workloads constraints) and reliability/availability/serviceability (RAS[2]) capacity S^2 (with RAS or maintainability constraints, including the fault tolerance constraints) could be defined as two main families of QoS guarantees when dealing with cloud services, and potentially with DDBs, as shown in Tables VI and VII.

These metrics are almost all based on the ones proposed in Erl et al. [2013], except for the reliability capacity's freshness rate metric, which is based on DDB needs, as exposed in de Carvalho Costa and Furtado [2011], which its grounded in Wei et al. [2004], and the storage capacity's storage replication metric, which is an explicit default definition for cloud-based databases.

The extra guarantees, as well as the disconnected execution and execution priority, presented in de Carvalho Costa and Furtado [2011] are considered inherent to the process of QoS guaranteeing and for that reason are not presented as directly measurable metrics.

Now with the QoS parameters well defined, and with measurable metrics specified, the definition of QoE parameters can be delineated and mapped to the referred QoS metrics.

The QoE metrics identification based on users' expectations, according to Soldani et al. [2006], could be grouped generically "under two main categories: *reliability* and *quality*." This may *initially* seem an oversimplification, where reliability is better replaced by the definition of RAS, which is a more comprehensive concept, and quality seems strictly directed to the considerations for the cellular systems of Soldani et al. [2006] and is better replaced by the definition of R&Q.

[2]RAS: A term originally used by IBM to describe the robustness of their mainframe computers [Siewiorek and Swarz 1998].

Table VI. QoS Guarantee Type: R&Q Capacity

Type of Capacity	Applicable Metric
Execution	Server capacity metric → CPU: number → CPU frequency: GHz → RAM size: GB → Storage size: GB → Replication: number of replicas Instance mean starting time metric → Time up–time requested: average in minutes Instance standard deviation starting time metric → Standard deviation of (time up–time requested) Response mean time metric (synchronous operation) → Mean time of response: average in milliseconds Response standard deviation time metric (synchronous operation) → Standard deviation time of response: average in milliseconds Completion mean time metric (asynchronous task) → Mean time of response: average in seconds Completion standard deviation time metric (asynchronous task) → Standard deviation time of response: average in milliseconds
Storage	Storage device capacity metric → Storage device capacity: GB Storage horizontal scalability metric → Permissible storage changes to increased workloads: GB Storage replication metric → Number of replicas: minimum number guaranteed
Networking capacity	Network capacity metric → Bandwidth, throughput: MB/s → Delay, jitter: milliseconds Application capacity metric → Application capacity: requests/minute
Workloads capacity	Server horizontal scalability metric → Permissible changes to increased workloads: number of virtual servers in resource pool Server vertical scalability metric → Permissible capacity fluctuations to workloads: fluctuation number of CPUs and RAM size in GB

In another approach, Gong et al. [2009] present a very consistent model for measuring QoE called the *pentagram model*, which is composed of these KPIs: integrality, retainability, availability, usability, and instantaneousness. Gong et al. [2009], just as Soldani et al. [2006], certainly deal with network-related technologies not directly applicable to the DDB paradigm. However, Gong et al. [2009], interestingly deal with an exact formula for evaluation, and their work seems to be a good orientation to the model as it should be defined.

The "factors that influence QoE and its most important measures" [Gong et al. 2009], are presented in a more generalized model in Table VIII.

Table VII. QoS Guarantee's Type: RAS Capacity

Type of Capacity	Applicable Metric
Reliability	Success rate metric → Successful service outcomes: number of successful responses in percentage Freshness rate metric → Access update ratio (AUR): $\frac{AccessFrequency}{UpdateFrequency}$
Availability	Uptime rate metric → Percentage of service uptime: $\frac{TotalUptime}{TotalTime}$
Serviceability	Outage duration metric → Duration of a single outage: outage end time–outage begin time Mean-time between failures metric → Time between consecutive service failures: $\frac{NormalOperationalPeriodDuration}{NumberOfFailures}$ Mean-time to switchover metric → Time to switchover from a failure: minutes Mean-time system recovery metric → Time to a complete recovery from a service fail: minutes

Table VIII. Factors That Influence QoE and the Most Important Measures [Gong et al. 2009]

QoE KPI	Most Important Measures	Symbol
Integrality	Delay, jitter, and loss ratio	a
Retainability	Interruption ratio	b
Availability	Success ratio of access	c
Usability	Usability	d
Instantaneousness	Response time of establish and access	e

Based on the KPIs presented in Table VIII, Gong et al. [2009] consider the QoE evaluation formula, with the a, b, c, d, and e values between 0 and 1, with an area of a pentagon varying from 0 to ∼2.37775, considering $sin(72^o) \cong 0.9511$, as shown in Equation (1).

$$\begin{aligned} QoE = &\ \tfrac{1}{2} \times sin72^o \times (ab + bc + cd + de + ea) \\ \cong &\ \tfrac{1}{2} \times 0.9511 \times (ab + bc + cd + de + ea) \\ \cong &\ 0.48 \times (ab + bc + cd + de + ea) \end{aligned} \quad (1)$$

However, a problem easily noticed in that model is when, supposedly, "a" and "c" are zero, the value of "b" has no influence on the result. And, of course, the evaluation considering the same weight for different parameters may not be the best option either.

A solution to that approach could be to consider a five-dimension line, with the values of a, b, c, d, and e defining the other end of a line that starts on the origin (0, 0, 0, 0, 0).

Besides this quantification definition, Kim et al. [2008] present a model of QoE-QoS correlation for QoE evaluation based on QoS parameters, but the QoE subjective metrics of *opinion* seem not feasible for the approach as desired in this study. Additionally, the QoS parameters used, as in most of the studies on this topic, are the simple network-related triad: delay, delay variation, and information loss.

Table IX. Insertion Service QoS Guarantees

Guarantee	Type of Capacity	Metric
R&Q	Execution capacity	Instance mean starting time Instance standard deviation starting time Response mean time Response standard deviation time
RAS	Reliability capacity	Success rate
	Availability capacity	Uptime rate

However, Kim et al. [2008] also point out that for each service, "the QoS level which is required in order to satisfy the QoE class is different." And considering that the aim of the present study is to find definitions for DDBs, we can define the services as insertion, update, deletion, and selection.

At this point, with the QoS metrics well defined and the services to be evaluated specified, the conclusion step is to define the QoE metrics associated with each service mapped in terms of QoS metrics.

It is noteworthy that measuring QoS completeness in the QoE-level evaluation, considering a well-defined QoS agreement, is not a direct measure per se, but it is crucial to the evaluation when considering avoidance of the usual inquiry about how the user feels about the experience of the consumed service, which is a factor of direct influence on the way the user feels about that experience.

6.1. Insertion Service, QoS Guarantees, and QoE Measurement

Considering the insertion service, to be evaluated with the QoS metrics presented on Table IX, the main concern is easily inferred as the availability capacity when considering the QoS guarantees to be evaluated in a preventive way. As for a capacity that directly influences the reliability capacity, the main concern is the QoE evaluation in the user's point of view. The freshness rate metric is actually not influential in the insertion service guarantees.

The availability capacity is directly connected with the serviceability capacity, and once measured, serviceability is already considered in the service provider guarantees, but it should also be verified for corrections of unexpected behavior and QoS recovering.

It is important to note that directly or indirectly measuring the serviceability capacity is not a way of measuring the serviceability guarantees, but is one to correct the behavior of the system to achieve the QoS level as agreed. Guaranteeing a maximum time between failures and measuring the mean time between failures are not the same thing. However, considering the fact that this study deals with QoE-level measurement, the QoS definitions could be *relaxed* when not affecting the QoE metrics.

With respect to the R&Q guarantees effect over the RAS ones, they are mostly secondary guarantees to them, which simplifies the needed considerations for the RAS evaluation formulas.

Taking reliability capacity as the capacity that has more influence on the user's RAS experience, it would be called the *QoE* of the user. But as this study is also calculating the QoS completeness, as system QoE, the availability capacity is also a main factor. It is noteworthy that these metrics are not only inferring the user's QoE but also about guarantees of QoE at the system level, as the availability capacity is considered together with the reliability capacity.

Equation (2) shows the QoS *RAS* evaluation at the system level for the insertion service according to the rate agreed in the SLA.

$$QoE_{RAS}^{system}(ins) = UptimeRate / SLA(InsertionRASGuarantee) \quad [0;1] \tag{2}$$

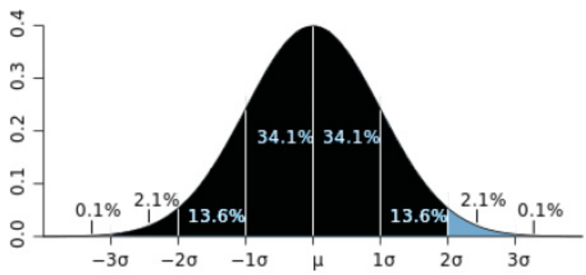


Fig. 5. Accumulated standard deviation for 2σ.

The value is considered as 1 when the uptime rate of the service is bigger than the guarantee given by the SLA.

Additionally, as discussed previously, when evaluating the level of QoE as seen by the user, the focus of the RAS evaluation goes to the success rate as shown in Equation (3).

$$QoE^{user}_{RAS}(ins) = SuccessRate\,/\,SLA(InsertionRASGuarantee) \quad [0;1] \tag{3}$$

The value of $QoE^{user}_{RAS}(ins)$ is also considered as 1 when the success rate of the service is bigger than the guarantee given by the SLA.

The R&Q guarantees are mostly time references, checking if the time to start an instance plus the time to execute it is in compliance with the expected $SLA(InsertionR\&QGuarantee)$. This gives a worst-case scenario with a guarantee of approximately 97.7%, considering a normal behavior with $\mu + 2\sigma$, with two standard deviations in both instance starting time and response time when considering the system-level evaluation in Equation (4), as the normal distribution shown in Figure 5.

$$\begin{aligned} QoE^{system}_{R\&Q}(ins) = {} & SLA(InsertionR\&QGuarantee)/((InstanceMeanStartTime \quad [0;1] \\ & + 2 * InstanceStdDevStartingTime) + (ResponseMeanTime \\ & + 2 * ResponseStdDevTime)) \end{aligned} \tag{4}$$

And then, based on the system QOE-level evaluation, the system could perform tasks to recover when not corresponding to the agreed level of QoE.

In the user's point of view, the time to start the service plus the time of response should correspond to the time guarantees of R&Q given by the SLA, as shown in Equation (5).

$$\begin{aligned} QoE^{user}_{R\&Q}(ins) = {} & SLA(InsertionR\&QGuarantee)/(InstanceStartingTime \quad [0;1] \\ & + ResponseTime) \end{aligned} \tag{5}$$

It is a more punctual evaluation, transaction by transaction.

Thus, to compute these two types of QoE qualification as one, they could be simply multiplied, as shown in Equations (6) and (7).

$$QoE^{system}_{total}(ins) = QoE^{system}_{RAS}(ins) * QoE^{system}_{R\&Q}(ins) \quad [0;1] \tag{6}$$

$$QoE^{user}_{total}(ins) = QoE^{user}_{RAS}(ins) * QoE^{user}_{R\&Q}(ins) \quad [0;1] \tag{7}$$

It is interesting to note that the QoE formulation will be almost the same in all operations considered, but the factors that affect response time and success rate will not be the same.

Table X. Update Service QoS Guarantees

Guarantee	Type of Capacity	Metric
R&Q	Execution capacity	Instance mean starting time Instance standard deviation starting time Response mean time Response standard deviation time
RAS	Reliability capacity	Success rate
	Availability capacity	Uptime rate

What led to the same original problem of dealing with abstract considerations, after measuring the mean time and considering the standard deviation, was not a guarantee at all; the measures were actually tools for the QoS guarantees to deal with recovery when dealing with unexpected behavior. Therefore, at this point, the mean time and the standard deviation needed to be considered as system guarantees to be compared to the SLA, while also considering that the system can somehow try to fix the unexpected rate error. Since this study deals with evaluation, the focus will not divert to this specific recovery direction.

6.2. Update Service, QoS Guarantees, and QoE Measurement

The update service, to be evaluated with the QoS metrics presented on Table X, is mostly like a partial selection with an insertion operation, and for that definition it will work mostly as the insertion with a little more delay in time response.

The equations and QoS considerations are analogous to the ones given in the insertion service definitions, as shown in Equations (8) through (13).

$$QoE^{system}_{RAS}(upd) = UptimeRate / SLA(UpdateRASGuarantee) \quad [0;1] \tag{8}$$

$$QoE^{user}_{RAS}(upd) = SuccessRate / SLA(UpdateRASGuarantee) \quad [0;1] \tag{9}$$

$$\begin{aligned} QoE^{system}_{R\&Q}(upd) = \; & SLA(UpdateR\&QGuarantee)/((InstanceMeanStartingTime \quad [0;1] \\ & + 2 * InstanceStdDevStartingTime) + (ResponseMeanTime \\ & + 2 * ResponseStdDevTime)) \end{aligned} \tag{10}$$

$$\begin{aligned} QoE^{user}_{R\&Q}(upd) = \; & SLA(UpdateR\&QGuarantee)/(InstanceStartingTime \quad [0;1] \\ & + ResponseTime) \end{aligned} \tag{11}$$

$$QoE^{system}_{total}(upd) = QoE^{system}_{RAS}(upd) * QoE^{system}_{R\&Q}(upd) \quad [0;1] \tag{12}$$

$$QoE^{user}_{total}(upd) = QoE^{user}_{RAS}(upd) * QoE^{user}_{R\&Q}(upd) \quad [0;1] \tag{13}$$

6.3. Deletion Service, QoS Guarantees, and QoE Measurement

The deletion service guarantees, to be evaluated with the QoS metrics presented on Table XI, are also analogous to the insertion and update considerations, except on the QoS level, since the storage capacity is not relevant.

Equations (14) through (19) show the evaluations as considered.

$$QoE^{system}_{RAS}(del) = UptimeRate / SLA(DeletionRASGuarantee) \quad [0;1] \tag{14}$$

$$QoE^{user}_{RAS}(del) = SuccessRate / SLA(DeletionRASGuarantee) \quad [0;1] \tag{15}$$

Table XI. Deletion Service QoS Guarantees

Guarantee	Type of Capacity	Metric
R&Q	Execution	Instance mean starting time Instance standard deviation starting time Response mean time Response standard deviation time
RAS	Reliability	Success rate
	Availability	Uptime rate

Table XII. Selection Service QoS Guarantees

Guarantee	Type of Capacity	Metric
R&Q	Execution	Instance mean starting time Instance standard deviation starting time Response mean time Response standard deviation time
RAS	Reliability	Success rate Freshness rate
	Availability	Uptime rate

$$QoE^{system}_{R\&Q}(del) = SLA(DeletionR\&QGuarantee)/((InstanceMeanStartingTime + 2 * InstanceStdDevStartingTime) + (ResponseMeanTime + 2 * ResponseStdDevTime)) \quad [0;1] \tag{16}$$

$$QoE^{user}_{R\&Q}(del) = SLA(DeletionR\&QGuarantee)/(InstanceStartingTime + ResponseTime) \quad [0;1] \tag{17}$$

$$QoE^{system}_{total}(del) = QoE^{system}_{RAS}(del) * QoE^{system}_{R\&Q}(del) \quad [0;1] \tag{18}$$

$$QoE^{user}_{total}(del) = QoE^{user}_{RAS}(del) * QoE^{user}_{R\&Q}(del) \quad [0;1] \tag{19}$$

6.4. Selection Service, QoS Guarantees, and QoE Measurement

In selection service guarantees, to be evaluated with the QoS metrics presented on Table XII, as in deletion guarantees, the storage capacity is not relevant. Here, the influential difference appears in the fact that the freshness rate should be considered as well.

Then, the uptime rate is on the system level, and the success rate is on the user level, which are multiplied by the freshness rate in Equations (20) and (21) to adequate the behavior to the operations evaluation.

$$QoE^{system}_{RAS}(sel) = UptimeRate * FreshnessRate / SLA(SelectionRASGuarantee) \quad [0;1] \tag{20}$$

$$QoE^{user}_{RAS}(sel) = SuccessRate * FreshnessRate / SLA(SelectionRASGuarantee) \quad [0;1] \tag{21}$$

Equations (22) through (25) are kept in the same format as the equations presented previously.

$$QoE_{R\&Q}^{system}(sel) = SLA(SelectionR\&QGuarantee)/((InstanceMeanStartingTime + 2 * InstanceStdDevStartingTime) + (ResponseMeanTime + 2 * ResponseStdDevTime)) \quad [0;1] \tag{22}$$

$$QoE_{R\&Q}^{user}(sel) = SLA(SelectionR\&QGuarantee)/(InstanceStartingTime + ResponseTime) \quad [0;1] \tag{23}$$

$$QoE_{total}^{system}(sel) = QoE_{RAS}^{system}(sel) * QoE_{R\&Q}^{system}(sel) \quad [0;1] \tag{24}$$

$$QoE_{total}^{user}(sel) = QoE_{RAS}^{user}(sel) * QoE_{R\&Q}^{user}(sel) \quad [0;1] \tag{25}$$

6.5. Equations' Effects over the System and User QoE

In Equations (2), (8), (14), and (20), the $QoE_{RAS}^{system}(ins/upd/del/sel)$ is defined as completeness of the uptime rate agreed, with the factor of freshness in the special case of selection. The uptime rate is defined as the percentage of the service uptime, and the freshness is defined as the access update ratio (see Table VII).

Disregarding the cases of mean outside the confidence interval, when the system verifies that the mean is getting higher than expected, or the standard deviation is outside of the given guarantees, the system should start a system recovery performance tuning procedure in a way to avoid unexpected behavior before it occurs. The effect could be the system launching, or switching to, a service mirror instantly from a pool.

In Equations (3), (9), (15), and (21), the $QoE_{RAS}^{user}(ins/upd/del/sel)$ is defined as completeness of the success rate agreed, also with the factor of freshness in the special case of selection. The success rate is defined as the successful service outcomes (see Table VII).

This is a consideration that usually will deal with an active pool of backup service providers that will automatically switch from one provider to another transparently to the user consuming the service. If the guarantees seem to be out of the expected mean or with a higher standard deviation, more services could be instantly started in the pool of service providers.

The uptime and the success rate seem good parameters to evaluate the system and the user's experience, respectively, under the RAS point of view. On the other end, in the resource and quality point of view, the response time, dealing with the confidence interval, seems to be the better approach to follow.

In Equations (4), (10), (16), and (22), the $QoE_{R\&Q}^{system}(ins/upd/del/sel)$ is defined as completeness of the time expected for the service to start and respond, with the considerations about the standard deviation already in the evaluation. In cases of a mean outside the expected, or higher standard deviations, the system could perform a priority tuning, serving more hardware resources to the services in the pool, to achieve the expected times.

In Equations (5), (11), (17), and (23), the $QoE_{R\&Q}^{user}(ins/upd/del/sel)$ is defined as the real time of response against the expected time, a case when more hardware resources could be reserved instantly while trying to correct the $QoE_{R\&Q}^{system}(ins/upd/del/sel)$ as a whole.

The combination equations, namely Equations (6), (12), (18), and (24), defining $QoE^{system}_{total}(ins/upd/del/sel)$, and Equations (7), (13), (19), and (25), defining $QoE^{user}_{total}(ins/upd/del/sel)$, are equations crossing the expected times with the uptime and success rate in a way to simply evaluate global ratings.

The final effects of the application of these equations are to give the providing system ways to evaluate future behavior and correct it before it happens. The correction of these unexpected behaviors are not covered in the model, as it is just an evaluation model.

Since the QoE conceptualization is holistic and user centric, the completeness is obviously not clearly subject to review. But the model proposes to try, based on QoS definitions, to achieve a better QoE level dealing with confidence intervals as specified.

The feasibility of the considerations, and the effectiveness, are evaluations more applicable to specific implementations of this generic model. For instance, it could be demonstrated that is not effective to trigger a procedure of energy saving when the mean is just a little bit smaller than the expected and with the same standard deviation, as the energy to change the behavior will not actually avoid energy consumption. Or, in extreme error cases, it may not be feasible to recover in a determined amount of time, because the existing recovery definitions do not cover the expected value, or the system will just crash.

Finally, the usefulness of the model is clear—since the QoS service is a hired specific service, the model may propose an ambience that could deal with means and standard deviations to guarantee user expectancy into a specific confidence interval that provides the expected level of QoE. Of course, that the view of QoE as a completeness of a more elaborated QoS is not the usual QoE definition, it suffices to this purpose.

6.6. Implications of the Study's Results

As mentioned in the previous section, the standard deviation used as a complement of the mean to evaluate the services is a key parameter with notable trustworthiness to achieve an acceptable level of QoE. Even the QoE being a set of holistic parameters with the goal of trying to satisfy human hedonic and aesthetic requirements [Laghari et al. 2012], in a system-centric approach focused on a QoS-based evaluation, the user's comfortability level could be encapsulated into the confidence interval definition.

In a straightforward exemplification, if a QoS definition guarantees that a user's data insertion on a specific data format, say one that is social network related, will occur with a mean of n seconds, when adding the guarantee of n seconds with standard deviation of d, what is equivalent to $= n \pm 2 * d$ in 95.4% of the cases or $\leq n + 2 * d$ in 97.7% of the cases, the QoS guarantee could now be understood as more of a QoE-QoS guarantee.

It would now be possible to consider self-tuning QoE-QoS systems, where the corrections could be then applied on demand to standard deviations until they fit the user's needs.

The standard deviation considerations also present the possibility for a system to try to recover from an unexpected behavior slowly, without the need to force the system to achieve a regular mean too fast. This way, the system is not forced to extremes, and the user has a sensation of nonabrupt service stabilization.

The main point is therefore about system recovery. The small, or at least controlled, standard deviation is essential for a system to recover correctly. It is not about good recovery, or recovery of mean quality, but about recovery itself. Uncontrolled standard deviation could lead to replication of the state that caused the initial fault, leading to instability in a switch between high resource consumption and crash. To recover too fast to an expected mean could mean not to recover at all.

When considering values outside the confidence interval, the system is expected to take measures instantly,because something is clearly wrong. This could be a behavior already expected with any kind of service provider. However, when dealing with the interval of response inside the confidence interval, with this model the system could now predict and correct future behavior before it happens.

A high standard deviation could indicate that the system needs a performance improvement, as a small mean with a small standard deviation can indicate a scenario liable of energy saving.

As this is a generic map model, without a specific system's behavioral analysis, and since the only other QoE-QoS to DDB model found in the literature [de Carvalho Costa and Furtado 2011] does not give specific equations and is also only applied to a specific database model, the comparison of the models was not possible considering that the presented model is a first quantitative model for QoE evaluation based on QoS parameters mathematically well defined to DDBs.

The behavioral analysis for a better QoE application still needs to be addressed—after all, the generic model does not give the triggers for performance tuning or even energy-saving scenarios. And since the values presented as $2*\sigma$ could be extrapolated to any $n * \sigma$, the model claimed is generic enough to open discussion over the parameters, methods of recovering, and energy saving, as are the triggers to these methods.

The application of this model will surelyoffer a better level of user acceptance for services, but it also will require a complex system behavioral evaluation on the service provider side.

6.7. Limitations of the Proposed Model and Possible Implementation Issues

Although the proposed model could be very interesting in several cases, it has some limitations due to the complexity of DDB environments. One example that could illustrate this argument is the complexity of the supposed QoE-aware recovering systems for database configurations.

Being a model of a partial QoE evaluation based on QoS completeness, it is limited by the SLA definitions and by the QoS adequacy to it. The multidimensional concept of QoE is larger than the limited conceptualization that was applied in this research, with the focus kept on system-level evaluation and not on the user, as it is considered when dealing with the ordinary QoE holistic definition.

QoS evaluations presented in this research work, to the best of our knowledge based on the bibliometric review, represent a first model to provide a QoE system-centric evaluation for DDBs. These definitions are standard deviation based and are made in such way that the known values to tune in a system are not predefined. Those values are kept generic enough to cover many possibilities and are a generalization approach adopted for the mathematical definitions. Thus, systems will be able to correct themselves.

As an example of an implementation issue, it is possible to foresee the system requirement to acquire information before self-tuning begins. However, since the tuning definitions are well defined, the challenge will not be related to the evaluation itself but instead will be about how to recover to the expected behavior. This aspect will be addressed in future work.

7. CONCLUSIONS AND FUTURE WORK

The initial scientific bibliometric review provided a systemic view about the topic of QoE in a generic consideration and showed a lack of academic research on QoE focused on DDB architectures through statistical indicators. Although the subject of QoE seemed to be on the rise since 2001, it still does not seem to have repercussion in the DDB research area.

Even so, the topic has several interesting definitions in addition to a lot of publications with already well defined QoS concepts in the network research area besides fuzzy QoE definitions. However, concerning the definitions of QoE-QoS models, palpable models were not presented, even in publications that mentioned the importance of explicit mapping.

It was shown that the subject of QoE reached its peak of research interest in 2012, and it is still a subject of ongoing research. It is expected that based on the correlated works of de Carvalho Costa and Furtado [2011, 2012], as well as on the conceptualization presented here, new research applying QoE to DDB architectures may be carried out.

Theoretical definitions of a QoE-DDB model based DARs to define SLOs were briefly presented, in addition to a way to measure QoS with key performance indicators (KPIs) found in de Carvalho Costa and Furtado [2011], and quoted comparisons in some scenarios presented in de Carvalho Costa and Furtado [2011, 2013], supporting not only the presented model but also the idea of reaching a better level of QoE on DDBs.

The model that these authors have defined still seems to be, besides the one presented in this study, the only proposed model in the literature on DDB architectures that reaches for QoE systems implementation, at least up to 2013, as showed in the bibliometric's statistical results. Even though there were tests showing that DARs defining SLOs measured by KPIs seemed to have good results in the cited works, the results are hard to reproduce by the lack of mathematical explicit definitions.

Although that problem of reproducibility is valid, this model has opened new ways of considering QoE evaluation. And even considering that the user can explicitly define the expected behavior—a point that is disregarded in the two works mentioned earlier—the authors in question showed a way to start services evaluation over DDBs.

A conclusion that could be drawn is that a first base for QoS on DDB systems could be defined indeed, but the existence of QoE-QoS auto-recovering systems is still a gap to be filled, as a base for them has just been defined.

Additionally, as an evident implication of this first mathematically well defined model, the path to these QoE-QoS autorecovering systems could be now covered. They have a possible interesting future impact over the users and DDBs service consumers, as well as also over the service providers and general database industry.

The analyzed QoS parameters to conclude a QoE evaluation were presented in the previous section, aiming to show a measurable way to correlate QoE and QoS dealing with DDBs.

In future work, an implementation of the QoE evaluation, as presented here, should be used with a system for QoS compensation recovery to help guarantee QoS as defined in an SLA, with its QoE confidence intervals.

APPENDIX

A. DATABASE SEARCH RESULTS

Table XIII. Web of Knowledge: Web of Science and Derwent Innovations Index Databases Search

Number	Article	Cited By (#)
01	"Paired comparison-based subjective quality assessment of stereoscopic images" [Lee et al. 2013]	4
02	"Subjective evaluation of stereoscopic image quality" [Moorthy et al. 2013]	2
03	"Providing quality of experience for users: The next DBMS challenge" [de Carvalho Costa and Furtado 2013]	0
04	"On quality of experience of scalable video adaptation" [Li et al. 2013]	1
05	"Spatiotemporal no-reference video quality assessment model on distortions based on encoding" [Zerman et al. 2013a]	0
06	"Approach for service search and peer selection in P2P service overlays" [Fiorese et al. 2013]	0

(Continued)

Table XIII. Continued

Number	Article	Cited By (#)
07	"Rendering 3-D high dynamic range images: Subjective evaluation of tone-mapping methods and preferred 3-D image attributes" [Mai et al. 2012]	0
08	"Guidelines for an improved quality of experience in 3-D TV and 3-D mobile displays" [Xu et al. 2012]	1
09	"QoE prediction model and its application in video quality adaptation over UMTS networks" [Khan et al. 2012]	9
10	"QON: Quality of experience (QoE) framework for network services" [Laghari et al. 2012]	0
11	"A reputation based vertical handover decision making framework (R-VHDF)" [Loukil et al. 2012]	0
12	"QoE assessment of multimedia video consumption on tablet devices" [Floris et al. 2012]	0
13	"Quality of experience assessment for stereoscopic images" [Qi et al. 2012]	0
14	"PNN-based QoE measuring model for video applications over LTE system" [He et al. 2012]	0
15	"QoE analysis for scalable video adaptation" [Li et al. 2012a]	0
16	"QoE-aware resource allocation for scalable video transmission over multiuser MIMO-OFDM systems" [Li et al. 2012b]	0
17	"Comparison of stereoscopic technologies in various configurations" [Fliegel et al. 2012]	0
18	"Peer selection in P2P service overlays using geographical location criteria" [Fiorese et al. 2012]	0
19	"Quality of experience in distributed databases" [de Carvalho Costa and Furtado 2011]	1
20	"A flexible QoE framework for video streaming services" [Alvarez et al. 2011]	0
21	"Objective metrics for quality of experience in stereoscopic images" [Xing et al. 2011]	0
22	"A study of artificial speech quality assessors of VoIP calls subject to limited bursty packet losses" [Jelassi and Rubino 2011b]	0
23	"Proposed framework for evaluating quality of experience in a mobile, testbed-oriented living lab setting" [Moor et al. 2010]	6
24	"New single-ended objective measure for non-intrusive speech quality evaluation" [Mahdi and Picovici 2010]	2
25	"Comparison of approaches for instrumentally predicting the quality of text-to-speech systems" [Möller et al. 2010]	1
26	"Temporal synchronization in stereoscopic video: Influence on quality of experience and automatic asynchrony detection" [Goldmann et al. 2010a]	1
27	"Optimizing user QoE through overlay routing, bandwidth management and dynamic transcoding" [Wijnants et al. 2008]	0
28	"Dynamic QoS provisioning for Ethernet-based networks" [Angelopoulos et al. 2008]	0
29	"QoE monitoring platform for video delivery networks" [Vera et al. 2007]	1

Note: Selected topic: ("Quality of Experience" OR QoE) AND (Database OR "Distributed Architecture" OR "Big Data") 2001–2013 results in computer science or engineering at http://apps.webofknowledge.com on February 10, 2014.

Table XIV. Scopus Search

Number	Article	Cited By (#)
01	"DCT-based objective quality assessment metric of 2D/3D image" [Liu et al. 2013]	0
02	"SmartenIT cloud traffic management approach and architectural considerations" [Papafili et al. 2013]	0
03	"Logging real packet reception patterns for end-to-end quality of experience assessment in wireless multimedia transmission" [Sladojevic et al. 2013]	0
04	"*Proceedings of the 10th International Joint Conference on ICETE 2013*; *Proceedings of the 4th International Conference on DCNET* 2013; *Proceedings of the 10th International Conference on ICE-B 2013 and OPTICS 2013; and Proceedings of the 4th International Conference on Optical Communication Systems*" *[ICETE 2013]*	0
05	"A feasible solution to provide cloud computing over optical networks" [Taheri and Ansari 2013]	0
06	"Paired comparison-based subjective quality assessment of stereoscopic images" [Lee et al. 2013]	2
07	"A dynamic system model of time-varying subjective quality of video streams over HTTP" [Chen et al. 2013]	0
08	"Robustness of speech quality metrics to background noise and network degradations: Comparing ViSQOL, PESQ and POLQA" [Hines et al. 2013]	0
09	"Use- and QoE-related aspects of personal cloud applications: An exploratory survey" [Vandenbroucke et al. 2013]	0
10	"How much longer to go? The influence of waiting time and progress indicators on quality of experience for mobile visual search applied to print media" [Cao et al. 2013]	0
11	"High definition H.264/AVC subjective video database for evaluating the influence of slice losses on quality perception" [Staelens et al. 2013]	0
12	"Perceptual experience of time-varying video quality" [Rehman and Wang 2013]	0
13	"Providing quality of experience for users: The next DBMS challenge" [de Carvalho Costa and Furtado 2013]	0
14	"Subjective evaluation of stereoscopic image quality" [Moorthy et al. 2013]	3
15	"A network-aware virtual machine placement algorithm in mobile cloud computing environment" [Chang et al. 2013]	0
16	"Optimal design of virtual networks for resilient cloud services" [Barla et al. 2013]	0
17	"Spatiotemporal no-reference video quality assessment model on distortions based on encoding" [Zerman et al. 2013b]	0
18	"Towards standardized 3DTV QoE assessment: Cross-lab study on display technology and viewing environment parameters" [Barkowsky et al. 2013]	0
19	"A survey on 3D quality of experience and 3D quality assessment" [Moorthy and Bovik 2013]	0
20	"Approach for service search and peer selection in P2P service overlays" [Fiorese et al. 2013]	0
21	"On quality of experience of scalable video adaptation" [Li et al. 2013]	1
22	"QoE analysis for scalable video adaptation" [Li et al. 2012a]	0
23	"QoE-aware resource allocation for scalable video transmission over multiuser MIMO-OFDM systems" [Li et al. 2012b]	0

(Continued)

Table XIV. Continued

Number	Article	Cited By (#)
24	"PNN-based QoE measuring model for video applications over LTE system" [He et al. 2012]	0
25	"QoE assessment of multimedia video consumption on tablet devices" [Floris et al. 2012]	0
26	"A reputation based vertical handover decision making framework (R-VHDF)" [Loukil et al. 2012]	0
27	"Comparison of stereoscopic technologies in various configurations" [Fliegel et al. 2012]	0
28	"Comparison of objective quality metrics on the scalable extension of H.264/AVC" [Lee 2012]	0
29	"*Proceedings of the 2012 3rd IEEE International Conference on Network Infrastructure and Digital Content (IC-NIDC'12) Infrastructure and Digital Content*" [IC-NIDC 2012]	0
30	"PP2db: A privacy-preserving, P2P-based scalable storage system for mobile networks" [Crotti et al. 2011]	0
31	"Empirical study based on machine learning approach to assess the QoS/QoE correlation" [Mushtaq et al. 2012]	0
32	"Supporting wireless access markets with a user-centric QoE-based geo-database" [Fortetsanakis et al. 2012]	0
33	"*Proceedings of the 7th ACM Workshop on Mobility in the Evolving Internet Architecture" (MobiArch'12)* [MobiArch 2012]	0
34	"*Proceedings of the 2012 4th International Workshop on Quality of Multimedia Experience" (QoMEX'12)* [QoMEX 2012]	0
35	"Quality of experience assessment for stereoscopic images" [Qi et al. 2012]	1
36	"Rendering 3-D high dynamic range images: Subjective evaluation of tone-mapping methods and preferred 3-D image attributes" [Mai et al. 2012]	0
37	"Peer selection in P2P service overlays using geographical location criteria" [Fiorese et al. 2012]	0
38	"Guidelines for an improved quality of experience in 3-D TV and 3-D mobile displays" [Xu et al. 2012]	0 0
39	"Resilient virtual network design for end-to-end cloud services" [Barla et al. 2012]	0
40	"QoE prediction model and its application in video quality adaptation over UMTS networks" [Khan et al. 2012]	15
41	"QoE content distribution network for cloud architecture" [Tran et al. 2011]	0
42	"A flexible QoE framework for video streaming services" [Alvarez et al. 2011]	1
43	"Objective metrics for quality of experience in stereoscopic images" [Xing et al. 2011]	1
44	"An approach to peer selection in service overlays" [Fiorese et al. 2011]	0
45	"Quality of experience in distributed databases" [de Carvalho Costa and Furtado 2011]	1
46	"Evaluation of video quality metrics on transmission distortions in H.264 coded video" [Sedano et al. 2011]	0
47	"A comparison study of automatic speech quality assessors sensitive to packet loss burstiness" [Jelassi and Rubino 2011a]	3

(Continued)

Table XIV. Continued

Number	Article	Cited By (#)
48	"Proceedings of SPIE-IS and T electronic imaging—multimedia on mobile devices 2011, and multimedia content access—algorithms and systems V" [SPIE-IS 2011]	0
49	"Visual quality assessment algorithms: What does the future hold?" [Moorthy and Bovik 2011]	19
50	"Analysis of overlay topology of peer-to-peer applications" [Yu et al. 2010]	1
51	"Estimating quality of experience on stereoscopic images" [Xing et al. 2010a]	0
52	"Temporal synchronization in stereoscopic video: Influence on quality of experience and automatic asynchrony detection" [Goldmann et al. 2010a]	3
53	"An objective metric for assessing quality of experience on stereoscopic images" [Xing et al. 2010b]	1
54	"Guidelines for capturing high quality stereoscopic content based on a systematic subjective evaluation" [Xu et al. 2010]	0
55	"A user-perceived video quality assessment metric using inter-frame redundancy" [Shi et al. 2010]	6
56	"Proposed framework for evaluating quality of experience in a mobile, testbed-oriented living lab setting" [Moor et al. 2010]	23
57	"A comprehensive database and subjective evaluation methodology for quality of experience in stereoscopic video" [Goldmann et al. 2010b]	17
58	"Foreword-cognitive radio: From equipment to networks" [Moy et al. 2009]	0
59	"Qualia: The geometry of integrated information" [Balduzzi and Tononi 2009]	33
60	"New single-ended objective measure for non-intrusive speech quality evaluation" [Mahdi and Picovici 2010]	0
61	"Optimizing user QoE through overlay routing, bandwidth management and dynamic transcoding" [Wijnants et al. 2008]	0
62	"QoE monitoring platform for video delivery networks" [Vera et al. 2007]	1
63	"*Proceedings of the 7th Nordic Signal Processing Symposium*" [NORSIG 2006]	0
64	"The relationship between quality of service and business metrics: Monitoring, notification and optimization" [Wolter and van Moorsel 2001]	0

Note: Selected article title, abstract, and keywords: ("Quality of Experience" OR QoE) AND (Database OR "Distributed Architecture" OR "Big Data") 2001–2013 results in computer science and engineering at http://www.scopus.com on February 12, 2014.

REFERENCES

NORSIG. 2006. *Proceedings of the 7th Nordic Signal Processing Symposium (NORSIG'06)*.

SPIE-IS. 2011. Proceedings of SPIE-IS and T electronic imaging—multimedia on mobile devices 2011, and multimedia content access—algorithms and systems V. In *Proceedings of SPIE: The International Society for Optical Engineering*, Vol. 7881.

IC-NIDC. 2012. *Proceedings of the 2012 3rd IEEE International Conference on Network Infrastructure and Digital Content (IC-NIDC'12)*.

QoMEX. 2012. *Proceedings of the 4th International Workshop on Quality of Multimedia Experience (QoMEX'12)*.

ICETE. 2013. *Proceedings of the 10th International Joint Conference on ICETE 2013*; *Proceedings of the 4th International Conference on DCNET 2013*; *Proceedings of the 10th International Conference on ICE-B 2013 and OPTICS 2013*; and *Proceedings of the 4th International Conference on Optical Communication Systems*.

W. Abramowicz, M. Kaczmarek, M. Kowalkiewicz, and D. Zyskowski. 2006. Architecture for service profiling. In *Proceedings of Services Computing Workshops*.

A. Alvarez, S. Cabrero, X. G. Paneda, R. Garcia, D. Melendi, and R. Orea. 2011. A flexible QoE framework for video streaming services. In *Proceedings of the IEEE GLOBECOM Workshops (GC Wkshps'11)*. IEEE, Los Alamitos, CA, 1226–1230.

J. Angelopoulos, K. Kanonakis, H. C. Leligou, T. Orfanoudakis, and M. Katsigiannis. 2008. Dynamic QoS provisioning for Ethernet-based networks. In *Proceedings of the International Electronic Conference on Computer Science (AIP Conference Proceedings)*, Vol. 1060. 151–154.

D. Balduzzi and G. Tononi. 2009. Qualia: The geometry of integrated information. In *PLoS Computational Biology*, Vol. 5. DOI:http://dx.doi.org/10.1371/journal.pcbi.1000462

M. Barkowsky, J. Li, T. Han, S. Youn, J. Ok, C. Lee, C. Hedberg, I. V. Ananth, K. Wang, K. Brunnstrm, and P. Le Callet. 2013. Towards standardized 3DTV QoE assessment: Cross-lab study on display technology and viewing environment parameters. In *Proceedings of SPIE: The International Society for Optical Engineering*, Vol. 8648. DOI:http://dx.doi.org/10.1117/12.2004050

I. B. Barla, D. A. Schupke, and G. Carle. 2012. Resilient virtual network design for end-to-end cloud services. In *NETWORKING 2012*. Lecture Notes in Computer Science, Vol. 7289. Springer, 161–174. DOI:http://dx.doi.org/10.1007/978-3-642-30045-5_13

I. B. Barla, D. A. Schupke, M. Hoffmann, and G. Carle. 2013. Optimal design of virtual networks for resilient cloud services. In *Proceedings of the 2013 9th International Conference on the Design of Reliable Communication Networks, (DRCN'13)*. 218–225.

N. Bhatti, A. Bouch, and A. Kuchinsky. 2000. *Integrating User-Perceived Quality into Web Server Design*. Technical Report HPL-2000-3. Hewlett-Packard Labs.

A. Bouch, N. Bhatti, and A. Kuchinsky. 2000. *Quality Is the Eye of the Beholder: Meeting User's Requirements for Internet Quality of Service*. Technical Report HPL-2000-4. Hewlett-Packard Labs.

P. Brooks and B. Hestnes. 2010. User measures of quality of experience: Why being objective and quantitative is important. In *IEEE Network*, Vol. 24. IEEE, Los Alamitos, CA, 8–13. DOI:http://dx.doi.org/10.1109/MNET.2010.5430138

P. Le Callet, S. Möller, and A. Perkis. 2013. QualiNet white paper on definitions of quality of experience. In *European Network on Quality of Experience in Multimedia Systems and Services (COST Action IC 1003)*, Lausanne (Ed.). Switzerland. Version 1.2.

Y. Cao, C. Ritz, and R. Raad. 2013. How much longer to go? The influence of waiting time and progress indicators on quality of experience for mobile visual search applied to print media. In *Proceedings of the 2013 5th International Workshop on Quality of Multimedia Experience (QoMEX'13)*. 112–117. DOI:http://dx.doi.org/10.1109/QoMEX.2013.6603220

A. Caruana. 2002. Service loyalty: The effects of service quality and the mediating role of customer satisfaction. *European Journal of Marketing* 36, 7–8, 811–828. DOI:http://dx.doi.org/10.1108/03090560210430818

D. Chang, G. Xu, L. Hu, and K. Yang. 2013. A network-aware virtual machine placement algorithm in mobile cloud computing environment. In *Proceedings of the 2013 IEEE Wireless Communications and Networking Conference Workshops (WCNCW'13)*. 117–121. DOI:http://dx.doi.org/10.1109/WCNCW.2013.6533325

C. Chen, L. K. Choi, G. De Veciana, C. Caramanis, R. W. Heath Jr., and A. C. Bovik. 2013. A dynamic system model of time-varying subjective quality of video streams over HTTP. In *Proceedings of the IEEE International Conference on Acoustics, Speech, and Signal Processing*. 3602–3606. DOI:http://dx.doi.org/10.1109/ICASSP.2013.6638329

Find Your Cloud. 2013. The Definition of Customer Quality of Experience. Retrieved September 29, 2015, from https://www.findyourcloud.com/Articles/Quality-of-Experience/The-Definition-of-Customer-Quality-of-Experience/ .

Find Your Cloud. 2014. Quality of Experience Articles. Retrieved September 29, 2015, from https://www.findyourcloud.com/Articles/Quality-of-Experience/.

M. Crotti, D. Ferri, F. Gringoli, M. Peli, and L. Salgarelli. 2011. PP2db: A privacy-preserving, P2P-based scalable storage system for mobile networks. In *Security and Privacy in Communication Networks*. Lecture Notes of the Institute for Computer Sciences, Social Informatics, and Telecommunications Engineering. Springer, 533–542. DOI:http://dx.doi.org/10.1007/978-3-642-31909-9_34

NoSQL Databases. 2014. NoSQL Home Page. Retrieved September 29, 2015, from http://nosql-database.org/.

R. L. de Carvalho Costa and P. Furtado. 2011. Quality of experience in distributed databases. *Distributed and Parallel Databases* 29, 5–6, 361–396. DOI:http://dx.doi.org/10.1007/s10619-011-7083-x

R. L. de Carvalho Costa and P. Furtado. 2013. Providing quality of experience for users: The next DBMS challenge. *Computer* 46, 9, 86–93.

R. B. D' Agostino. 1970. Transformation to normality of the null distribution of g1. *Biometrika* 57, 679–681.

T. Erl, R. Puttini, and Z. Mahmood. 2013. *Cloud Computing: Concepts, Technology & Architecture.* Prentice Hall.

A. Fiorese, P. Simoes, and F. Boavida. 2011. An approach to peer selection in service overlays. In *Proceedings of the 7th International Conference on Network and Service Management (CNSM'11)*.

A. Fiorese, P. Simoes, and F. Boavida. 2012. Peer selection in P2P service overlays using geographical location criteria. In *Computational Science and Its Applications—ICCSA 2012*. Lecture Notes in Computer Science, Vol. 7334. Springer, 234–248.

A. Fiorese, P. Simoes, and F. Boavida. 2013. Approach for service search and peer selection in P2P service overlays. In *Proceedings of the 27th International Conference on Information Networking (ICOIN'13)*. IEEE, Los Alamitos, CA.

K. Fliegel, S. Vitek, T. Jindra, P. Pata, and M. Klima. 2012. Comparison of stereoscopic technologies in various configurations. In *Proceedings of the Conference on Applications of Digital Images Processing XXXV (Proceedings of SPIE)*, Vol. 8499. DOI:http://dx.doi.org/10.1117/12.929237

A. Floris, L. Atzori, G. Ginesu, and D. D. Giusto. 2012. QoE assessment of multimedia video consumption on tablet devices. In *Proceedings of the IEEE Globecom Workshops (GC Wkshps'12).* IEEE, Los Alamitos, CA.

J. Forlizzi and S. Ford. 2000. Building blocks of experience: An early framework for interaction designers. In *Proceedings of the Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques (DIS'00)*. ACM, New York, NY, 419–423.

G. Fortetsanakis, M. Katsarakis, M. Plakia, N. Syntychakis, and M. Papadopouli. 2012. Supporting wireless access markets with a user-centric QoE-based geo-database. In *Proceedings of the 7th ACM International Workshop on Mobility in the Evolving Internet Architecture (MobiArch'12)*. 29–36. DOI:http://dx.doi.org/10.1145/2348676.2348685

L. Goldmann, J.-S. Lee, and T. Ebrahimi. 2010a. Temporal synchronization in stereoscopic video: Influence on quality of experience and automatic asynchrony detection. In *Proceedings of the IEEE International Conference on Image Processing*. IEEE, Los Alamitos, CA, 3241–3244. DOI:http://dx.doi.org/10.1109/ICIP.2010.5651142

L. Goldmann, F. De Simone, and T. Ebrahimi. 2010b. A comprehensive database and subjective evaluation methodology for quality of experience in stereoscopic video. In *Proceedings of SPIE: The International Society for Optical Engineering*, Vol. 7526. DOI:http://dx.doi.org/10.1117/12.839438

Y. Gong, F. Yang, L. Huang, and S. Su. 2009. Model-based approach to measuring quality of experience. In *Proceedings of the 1st International Conference on Emerging Network Intelligence*. IEEE, Los Alamitos, CA, 29–32. DOI:http://dx.doi.org/10.1109/EMERGING.2009.17

C. Gronroos. 1984. A service quality model and its market implications. *European Journal of Marketing* 18, 4, 36–44.

Y. He, C. Wang, H. Long, and K. Zheng. 2012. PNN-based QoE measuring model for video applications over LTE system. In *Proceedings of the 7th International ICST Conference on Communications and Networking in China (CHINACOM'12)*. IEEE, Los Alamitos, CA.

D. Heimbigner and D. McLeod. 1985. A federated architecture for information management. *ACM Transactions on Information Systems* 3, 3, 253–278.

A. Hines, J. Skoglund, A. Kokaram, and N. Harte. 2013. Robustness of speech quality metrics to background noise and network degradations: Comparing ViSQOL, PESQ and POLQA. In *Proceedings of the IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP'13)*. 3697–3701. DOI:http://dx.doi.org/10.1109/ICASSP.2013.6638348

Y. Honda, H. Ninomiya, and Y. Sassa. 2001. Development of cabin air quality system. In *Proceedings of the SAE 2001 World Congress*. DOI:http://dx.doi.org/10.4271/2001-01-0292

K. R. Hoogeboom. 1989. Restoration and development guidelines for ocean beach recreation areas. In *Proceedings of the 6th Symposium on Coastal and Ocean Management (Coastal Zone'89)*, Vol. 4. 3120–3134.

A. Turner II and L. T. Nowell. 2000. Beyond the desktop: Diversity and artistry. In *Proceedings of the Conference on Human Factors in Computing Systems (CHI EA'00)*. 35–36. DOI:http://dx.doi.org/10.1145/633292.633317

ISO 9241-210. 2010. ISO 9241-210:2010-Human-Centred Design Processes for Interactive Systems. Retrieved September 29, 2015, from http://www.iso.org/iso/catalogue_detail.htm?csnumber=21197

ITU-T.P.862. 2001. *Perceptual Evaluation of Speech Quality (PESQ): An Objective Method for End-to-End Speech Quality Assessment of Narrow-Band Telephone Networks and Speech Codecs*. Technical Report. Telecommunication Standardization Sector of ITU, Geneva, Switzerland.

C. M. Jarque and A. K. Bera. 1980. Efficient tests for normality, homoscedasticity and serial independence of regression residuals. *Economic Letters* 6, 3, 255–259. DOI:http://dx.doi.org/10.1016/0165-1765(80)90024-5

S. Jelassi and G. Rubino. 2011a. A comparison study of automatic speech quality assessors sensitive to packet loss burstiness. In *Proceedings of the IEEE Consumer Communications and Networking Conference (CCNC'11)*. 415–420. DOI:http://dx.doi.org/10.1109/CCNC.2011.5766503

S. Jelassi and G. Rubino. 2011b. A study of artificial speech quality assessors of VoIP calls subject to limited bursty packet losses. *Eurasip Journal on Image and Video Processing* 2011, 9. DOI:http://dx.doi.org/10.1186/1687-5281-2011-9

A. Khan, L. Sun, and E. Ifeachor. 2012. QoE prediction model and its application in video quality adaptation over UMTS networks. *IEEE Transactions on Multimedia* 14, 431–442. DOI:http://dx.doi.org/10.1109/TMM.2011.2176324

H.-J. Kim, D.-H. Lee, J.-M. Lee, K.-H. Lee, W. Lyu, and S.-G. Choi. 2008. The QoE evaluation method through the QoS-QoE correlation model. In *Proceedings of the 4th International Conference on Networked Computing and Advanced Information Management (NCM'08)*, Vol. 2. IEEE, Los Alamitos, CA, 719–725. DOI:http://dx.doi.org/10.1109/NCM.2008.202

A. A. Laghari, K. U. R. Laghari, M. Ibrahim, and T. H. Falk. 2012. QON: Quality of experience (QoE) framework for network services. In *Proceedings of the 4th International Conference on Software Technology and Engineering (ICSTE'12)*.

J.-S. Lee. 2012. Comparison of objective quality metrics on the scalable extension of H.264/AVC. In *Proceedings of the International Conference on Image Processing (ICIP'12)*. 693–696. DOI:http://dx.doi.org/10.1109/ICIP.2012.6466954

J.-S. Lee, L. Goldmann, and T. Ebrahimi. 2013. Paired comparison-based subjective quality assessment of stereoscopic images. In *Multimedia Tools and Applications*, Vol. 67. Springer, 31–48. DOI:http://dx.doi.org/10.1007/s11042-012-1011-6

R. C. Lewis and B. H. Booms. 1983. The marketing aspects of service quality. In *Emerging Perspectives in Service Marketing*, L. L. Berry, G. Shostack, and G. Upah (Eds.). American Marketing Association, Chicago, IL, 99–107.

M. Li, Z. Chen, and Y.-P. Tan. 2012a. QoE analysis for scalable video adaptation. In *Proceedings of IEEE Visual Communications and Image Processing (VCIP'12)*. IEEE, Los Alamitos, CA, 1–6.

M. Li, Z. Chen, and Y.-P. Tan. 2012b. QoE-aware resource allocation for scalable video transmission over multiuser MIMO-OFDM systems. In *Proceedings of IEEE Visual Communications and Image Processing (VCIP'12)*. IEEE, Los Alamitos, CA.

M. Li, Z. Chen, and Y.-P. Tan. 2013. *On Quality of Experience of Scalable Video Adaptation*, Vol. 24. Academic Press, 509–521. DOI:http://dx.doi.org/10.1016/j.jvcir.2013.03.006

X. Liu, C. Sun, and L. T. Yang. 2013. DCT-based objective quality assessment metric of 2D/3D image. In *Multimedia Tools and Applications*, 1–18. DOI:http://dx.doi.org/10.1007/s11042-013-1698-z

M. Loukil, M. Zekri, T. Ghariani, and B. Jouaber. 2012. A reputation based vertical handover decision making framework (R-VHDF). In *Proceedings of the IEEE Globecom Workshops (GC Wkshps'12)*. IEEE, Los Alamitos, CA.

A. E. Mahdi and D. Picovici. 2010. New single-ended objective measure for non-intrusive speech quality evaluation. In *Signal Image and Video Processing*, Vol. 4. Springer, London, 23–38.

Z. Mai, C. Doutre, P. Nasiopoulos, and R. K. Ward. 2012. Rendering 3-D high dynamic range images: Subjective evaluation of tone-mapping methods and preferred 3-D image attributes. *IEEE Journal of Selected Topics in Signal Processing*, 6, 597–610. DOI:http://dx.doi.org/10.1109/JSTSP.2012.2193555

R. Mielke, A. Zahralddin, D. Padam, and T. Mastaglio. 1998. Simulation applied to theme park management. In *Proceedings of the 1998 Winter Simulation Conference (WSC'98), Part 1, Vol. 2.* IEEE, Los Alamitos, CA, 1199–1203.

MobiArch. 2012. *Proceedings of the 7th ACM International Workshop on Mobility in the Evolving Internet Architecture (MobiArch'12)*.

S. Möller, F. Hinterleitner, T. H. Falk, and T. Polzehl. 2010. Comparison of approaches for instrumentally predicting the quality of text-to-speech systems. In *Proceedings of the 11th Annual Conference of the International Speech-Communication Association*, Vol. 1–2. 1325–1328.

S. Möller and A. Raake (Eds.). 2014. *Quality of Experience: Advanced Concepts, Applications, and Methods.* Springer. DOI:http://dx.doi.org/10.1007/978-3-319-02681-7

K. De Moor, I. Ketyko, W. Joseph, T. Deryckere, L. De Marez, L. Martens, and G. Verleye. 2010. Proposed framework for evaluating quality of experience in a mobile, testbed-oriented living lab setting. In *Mobile Networks & Applications*, Vol. 15. Springer, 378–391. DOI:http://dx.doi.org/10.1007/s11036-010-0223-0

A. K. Moorthy and A. C. Bovik. 2011. Visual quality assessment algorithms: What does the future hold? In *Multimedia Tools and Applications*, Vol. 51. 675–696. DOI:http://dx.doi.org/10.1007/s11042-010-0640-x

A. K. Moorthy and A. C. Bovik. 2013. A survey on 3D quality of experience and 3D quality assessment. In *Proceedings of SPIE: The International Society for Optical Engineering*, Vol. 8651. Burlingame, CA. DOI:http://dx.doi.org/10.1117/12.2008355

A. K. Moorthy, C.-C. Su, A. Mittal, and A. Conrad Bovik. 2013. Subjective evaluation of stereoscopic image quality. In *Signal Processing Image Communication*, Vol. 28. Elsevier Science BV, 870–883. DOI:http://dx.doi.org/10.1016/j.image.2012.08.004

M. G. Morris and J. M. Turner. 2001. Assessing users' subjective quality of experience with the World Wide Web: An exploratory examination of temporal changes in technology acceptance. *International Journal of Human-Computer Studies* 54, 6, 877–901. DOI:http://dx.doi.org/10.1006/ijhc.2001.0460

C. Moy, L. Doyle, and Y. Sanada. 2009. Foreword-cognitive radio: From equipment to networks. In *Annales des Telecommunications/Annals of Telecommunications*, Vol. 64. 415–417. DOI:http://dx.doi.org/10.1007/s12243-009-0125-y

M. S. Mushtaq, B. Augustin, and A. Mellouk. 2012. Empirical study based on machine learning approach to assess the QoS/QoE correlation. In *Proceedings of the 17th European Conference on Network and Optical Communications (NOC'12), and the 7th Conference on Optical Cabling and Infrastructure (OC and I'12)*. DOI:http://dx.doi.org/10.1109/NOC.2012.6249939

I. Papafili, J. Rückert, P. Poullie, S. Soursos, T. Bocek, K. Wajda, D. Hausheer, G. D. Stamoulis, and B. Stiller. 2013. SmartenIT cloud traffic management approach and architectural considerations. In *Proceedings of the Future Network and Mobile Summit (FutureNetworkSummit'13)*.

M. P. Papazoglou, J. Bubenko, and M. Norrie. 1988. INTENT: An integrated environment for distributed heterogeneous databases. In *Proceedings of the 1988 ACM SIGPLAN Workshop on Object-Based Concurrent Programming (OOPSLA/ECOOP'88)*. ACM, New York, NY, 126–128. DOI:http://dx.doi.org/10.1145/67386.67421

A. Parasuraman, V. A. Zeithaml, and L. L. Bery. 1985. A conceptual model of service quality and its implication for future research. *Journal of Marketing* 49, 41–50.

A. Parasuraman, V. A. Zeithaml, and L. L. Bery. 1988. SERVQUAL: A multiple-item scale for measuring consumer perceptions of service quality. *Journal of Retailing* 64, 1, 12–40.

A. Parasuraman, V. A. Zeithaml, and L. L. Bery. 1994. Alternative scales for measuring service quality: A comparative assessment based on psychometric and diagnostic criteria. *Journal of Retailing* 70, 3, 201–30.

F. Qi, T. Jiang, S. Ma, and D. Zhao. 2012. Quality of experience assessment for stereoscopic images. In *Proceedings of the IEEE International Symposium on Circuits and Systems*. IEEE, Los Alamitos, CA, 1712–1715.

E. Redd, T. J. Gay, D. M. Blankenship, J. T. Park, J. L. Peacher, and D. G. Seely. 1987. Measurements of helium excitation in Be+-He and Mg+-He collisions. *Nuclear Inst ruments and Methods in Physics Research B*, 24–25. 305–308.

A. Rehman and Z. Wang. 2013. Perceptual experience of time-varying video quality. In *Proceedings of the 2013 5th International Workshop on Quality of Multimedia Experience (QoMEX'13)*. 218–223. DOI:http://dx.doi.org/10.1109/QoMEX.2013.6603240

Thomson Reuters. 2013. Web of Knowledge at Web of Science v.5.1.3.1. Retrieved September 29, 2015, from http://apps.webofknowledge.com.

S. Richter and A. Bohm. 2006. A location and privacy service enabler for context-aware and location-based services in NGN. In *Proceedings of the Telecommunications Network Strategy and Planning Symposium*.

K. Sato and W. Verplank. 2000. Panel: Teaching tangible interaction design. In *Proceedings of the Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques (DIS'00)*. ACM, New York, NY, 444–445.

I. Sedano, M. Kihl, K. Brunnstrom, and A. Aurelius. 2011. Evaluation of video quality metrics on transmission distortions in H.264 coded video. In *Proceedings of the IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB'11)*. DOI:http://dx.doi.org/10.1109/BMSB.2011.5954960

S. S. Shapiro and M. B. Wilk. 1965. An analysis of variance test for normality (complete samples). *Biometrika* 52, 34, 591–611. DOI:http://dx.doi.org/10.1093/biomet/52.3-4.591

S. Shenker, C. Partridge, and R. Guerin. 1997. *RFC 2212: Specification of Guaranteed Quality of Service*. Technical Report. Internet Engineering Task Force (IETF). http://tools.ietf.org/html/rfc2212.

S. Shenker and J. Wroclawski. 1997. *RFC 2216: Network Element Service Specification Template*. Technical Report. Internet Engineering Task Force (IETF). http://tools.ietf.org/html/rfc2216.

Y. Shi, Y. Ding, and J. Li. 2010. A user-perceived video quality assessment metric using inter-frame redundancy. *International Journal of Digital Content Technology and Its Applications* 4, 151–160. DOI:http://dx.doi.org/10.4156/jdcta.vol4.issue4.15

D. P. Siewiorek and R. S. Swarz. 1998. *Reliable Computer Systems: Design and Evaluation* (3rd ed.). Natick, MA: A. K. Peters. https://archive.org/details/reliablecomputer00siew.

S. Sladojevic, D. Culibrk, M. Mirkovic, D. Ruiz Coll, and G. R. Borba. 2013. Logging real packet reception patterns for end-to-end quality of experience assessment in wireless multimedia transmission. In *Proceedings of the 2013 IEEE International Conference on Multimedia and Expo Workshops (ICMEW'13)*. DOI:http://dx.doi.org/10.1109/ICMEW.2013.6618453

J. M. Smith, P. A. Bernstein, U. Dayal, N. Goodman, T. Landers, K. W. T. Lin, and E. Wong. 1981. Multibase: Integrating heterogeneous distributed database systems. In *Proceedings of the AFIPS National Computer Conference*. ACM, New York, NY. DOI:http://dx.doi.org/10.1145/1500412.1500483

D. Soldani, M. Li, and R. Cuny. 2006. *QoS and QoE Management in UMTS Cellular Systems*. Wiley.

N. Staelens, G. Van Wallendael, R. Van De Walle, F. De Turck, and P. Demeester. 2013. High definition H.264/AVC subjective video database for evaluating the influence of slice losses on quality perception. In *Proceedings of the 2013 5th International Workshop on Quality of Multimedia Experience (QoMEX'13)*. 130–135. DOI:http://dx.doi.org/10.1109/QoMEX.2013.6603225

M. Taheri and N. Ansari. 2013. A feasible solution to provide cloud computing over optical networks. *IEEE Network*, 27, 31–35. DOI:http://dx.doi.org/10.1109/MNET.2013.6678924

H. A. Tran, A. Mellouk, and S. Hoceini. 2011. QoE content distribution network for cloud architecture. In *Proceedings of the 2011 1st International Symposium on Network Cloud Computing and Applications (NCCA'11)*. 14–19. DOI:http://dx.doi.org/10.1109/NCCA.2011.10

K. U. R. Laghari, N. Crespi, and K. Connelly. 2012. Towards total quality of experience: A QoE for multimedia services in communication ecosystem. *IEEE Communications Magazine* 50, 4, 58–65.

K. U. R. Laghari, N. Crespi, B. Molina, and C. E. Palau. 2011. QoE aware service delivery in distributed environment. In *Proceedings of the 2011 International Conference on Advanced Information Networking and Applications (WAINA'11)*. 837–842. DOI:http://dx.doi.org/10.1109/WAINA.2011.58

B. V. Elsevier. 2013. Scopus Home Page. Retrieved September 29, 2015, from http://www.scopus.com.

K. Vandenbroucke, K. De Moor, and L. De Marez. 2013. Use- and QoE-related aspects of personal cloud applications: An exploratory survey. In *Proceedings of the 2013 5th International Workshop on Quality of Multimedia Experience (QoMEX'13)*. 36–37. DOI:http://dx.doi.org/10.1109/QoMEX.2013.6603202

D. De Vera, P. Rodriguez-Bocca, and G. Rubino. 2007. QoE monitoring platform for video delivery networks. In *IP Operations and Management*. Lecture Notes in Computer Science, Vol. 4786. Springer, 131–142.

Y. Wei, S. H. Son, and J. A. Stankovic. 2004. Maintaining data freshness in distributed real-time databases. In *Proceedings of the 16th Euromicro Conference on Real-Time Systems (ECRTS'04).* IEEE, Los Alamitos, CA, 251–260. DOI:http://dx.doi.org/10.1109/EMRTS.2004.1311028

M. Wijnants, W. Lamotte, B. De Vleeschauwer, F. De Turck, B. Dhoedt, P. Demeester, P. Lambert, D. Van de Walle, J. De Cock, S. Notebaert, and R. Van de Walle. 2008. Optimizing user QoE through overlay routing, bandwidth management and dynamic transcoding. In *Proceedings of the IEEE International Symposium on a World of Wireless, Mobile, and Multimedia Networks*, Vols. 1–2. IEEE, Los Alamitos, CA, 557–563.

K. Wolter and A. van Moorsel. 2001. *The Relationship between Quality of Service and Business Metrics: Monitoring, Notification, and Optimization*. Technical Report 96. HP Laboratories.

L. Xing, J. You, T. Ebrahimi, and A. Perkis. 2010a. Estimating quality of experience on stereoscopic images. In *Proceedings of the 2010 International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS'10)*. DOI:http://dx.doi.org/10.1109/ISPACS.2010.5704599

L. Xing, J. You, T. Ebrahimi, and A. Perkis. 2010b. An objective metric for assessing quality of experience on stereoscopic images. In *Proceedings of the IEEE International Workshop on Multimedia Signal Processing (MMSP'10)*. 373–378. DOI:http://dx.doi.org/10.1109/MMSP.2010.5662049

L. Xing, J. You, T. Ebrahimi, and A. Perkis. 2011. Objective metrics for quality of experience in stereoscopic images. In *Proceeding of the 18th IEEE International Conference on Image Processing (ICIP'11)*. IEEE, Los Alamitos, CA.

D. Xu, L. Coria, and P. Nasiopoulos. 2010. Guidelines for capturing high quality stereoscopic content based on a systematic subjective evaluation. In *Proceedings of the IEEE International Conference on Electronics, Circuits, and Systems (ICECS'10).* 162–165. DOI:http://dx.doi.org/10.1109/ICECS.2010.5724479

D. Xu, L. E. Coria, and P. Nasiopoulos. 2012. Guidelines for an improved quality of experience in 3-D TV and 3-D mobile displays. *Journal of the Society for Information Display* 20, 397–407. DOI:http://dx.doi.org/10.1889/JSID20.7.397

K. Yu, Y. Cao, X. H. Huang, and X. F. Wu. 2010. Analysis of overlay topology of peer-to-peer applications. *Journal of China Universities of Posts and Telecommunications*, 17, 60–66. DOI:http://dx.doi.org/10.1016/S1005-8885(09)60581-1

E. Zerman, G. B. Akar, B. Konuk, and G. Nur. 2013a. Spatiotemporal no-reference video quality assessment model on distortions based on encoding. In *Proceedings of the 21st Signal Processing and Communications Applications Conference (SIU'13)*. IEEE, Los Alamitos, CA.

E. Zerman, G. B. Akar, B. Konuk, and G. Nur. 2013b. Spatiotemporal no-reference video quality assessment model on distortions based on encoding. In *Proceedings of the 21st Signal Processing and Communications Applications Conference (SIU'13)*. DOI:http://dx.doi.org/10.1109/SIU.2013.6531235

Received November 2014; revised June 2015; accepted September 2015