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Towards Quality of Experience-based reputation models for future web service provisioning

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Abstract This paper concerns the applicability of reputations systems for assessing Quality of Experience (QoE) for web services in the Future Internet. Reputation systems provide mechanisms to manage subjective opinions in societies and yield a general scoring of a particular behavior. Thus, they are likely to become an important ingredient of the Future Internet. Parameters under evaluation by a reputation system may vary greatly and, particularly, may be chosen to assess the users' satisfaction with (composite) web services. Currently, this satisfaction is usually expressed by QoE, which represents subjective users' opinions. The goal of this paper is to present a novel framework of web services where a reputation system is incorporated for tracking and predicting of users' satisfaction. This approach is a beneficial tool which enables providers to facilitate service adaptation according to users' expectations and maintain QoE at a satisfactory level. Presented reputation systems operate in an environment of composite services that integrate client and server-side. This approach is highly suitable for effective QoE differentiating and maximizing user experience for specific customer profiles as even the service and network resources are shared.

Keywords Reputation systems · Quality of Experience (QoE) · Web services · Service composition · Future Internet

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1 Introduction

E-communities are dependent on on-line entertainment, trade and communication which is spread over Internet services. E-commerce sites such as Amazon [1], eBay [7], information and social web portals (Flickr, MySpace, iGoogle, Wikipedia, Facebook) incorporate advanced Web 2.0 mechanisms [33] for customizable content presentation, sharing and delivery. A versatile mechanism for usage of applications and computing resources as a service, called *cloud computing* [2] has moved the margin of the computer user experience from the ordinary simple desktop applications to enriched, any-where and any-time, widely portable web applications.

A significant component of contemporary web services is a mutual user interaction which drives the development of flexible and customizable web applications. To some extent, especially for social web services, a middleware part is operated by a provider, whilst the value-added content is delivered by service users. The Web 2.0 paradigm [33] introduces a certain level of complexity to the service design and imposes new challenges for Application and Internet Service Providers (ASPs and ISPs). They are forced to ensure attributes demanded by the market in terms of (network-centric) *Quality of Service* (QoS), application-specific security as well as ergonomics that fit human needs. These attributes are composed of a mix of objective and subjective metrics of service quality which require appropriate evaluation methods. It has to be realized that the development described above entails an increasingly hazy distinction between service and user, which may lead to the inevitable loss of manageability on the provider's side, resulting in service quality degradation or even failure of users' business. In the growing jungle of self-service, users as consumers of services need to be able to assess whether a particular (web) service matches their needs in an aesthetic, functional, timely and financial manner. *Quality of Experience* (QoE)—is, according to ITU-T Rec. P.10/G.100 Amendment "the overall acceptability of an application or service, as perceived subjectively by the end user"—and this has recently replaced classic QoS parameters (such as loss and delay) when it comes to assess the quality of a service. Thinking of all kinds of potential impact factors such as user expectations, user experience, context of use and technical parameters such as QoS, determining the QoE of a particular service is not necessarily a trivial issue.

A potential approach to the given challenge is the use of *reputation systems* [27, 30, 38]. Apart from the defined service logic and their security assurance, the reputation systems perform a continuous monitoring of user or user agents' activities and stimulate the associated community to behave appropriately. They also support accountability for malicious attitudes, which is often reflected as lowering of service quality. The reputation systems evolved with a mechanism of sharing a *reputation scoring* on a particular entity among all interested users and corresponding service providers [32, 36]. This approach introduces a role of a third trust party who observes and propagates the scoring that stimulates the increase of collaborative attitude across a population. Applying this feature into Future Internet services, we may expect to keep the reputation fairly balanced over the users' and web services' communities.

Reputation scoring usually reflects an aggregated subjective opinion on a party and depends on the user's activity, time scale and service context [30]. These certain key attributes of the service are prepresented by a number of parameters and evaluated by the reputation system. The result of such an analysis forms a reputation-based user experience which is expressed with a set of QoE metrics of the service [10]. The way of building reputation distinguishes between its *subjective* and *objective* nature. For instance, in Mobile Ad Hoc Networks (MANET) [5] a locally created reputation [26, 27] reflects a generalized opinion on the truthfulness of peers in the network, but still remains a subjective measure of the service in a local neighborhood. This is a characteristic property of distributed reputation systems. In contrast, a centralized reputation repository yields *objective scoring* [21], by means of performing a global generalization and assuming that parties of subjective opinions are not related. A diversity of contemporary Web services may impose a need to adapt reputation metrics with use of collaborative filtering in order to get an accurate and context-aware subjective measure, the *subjective reputation* [29]. Collaborative filtering shapes the reputation in order to emphasize and share the characteristic features of subjective metrics and allows the interpretation of a particular reputation to be distinguished, for example *user reputation* and *network reputation*. Operators, for example, might be interested in both subjective and objective network reputation. Subjective reputation reflects the individual customer's view on the quality and value of a service and is strongly related to the risk for churn, i.e., the risk of leaving the operator because of dissatisfaction. However, the operator has to treat the potential risk from single unhappy customers against the overall service quality, which is typically limited by the margin between income and investments. In this context, even the reputation of the (complaining) user might be of interest; a reasonable user's judgment might be weighted higher than that of a well-known grouch.

In the remainder Section 2 presents and illustrates the potential of classification criteria for reputation systems. Section 3 provides an overview of relevant QoE models. Section 4 addresses the use of reputation systems for QoE evaluation, amongst others through a case study. Section 5 concludes the paper and points out directions for future research.

2 Reputation systems classification

In literature one can find a number of proposed reputation systems applied in different protocols and services. This paper presents the analysis of reputation systems in a selective manner and emphasizes a subset of those features which are preferable for applications in distributed and web-oriented environments. The following classification of reputation systems is intended to identify such solutions, which could be further investigated for QoE evaluation in web services. A thorough comparison with notions on reputation applications in many scientific disciplines can be found in [3, 27, 30, 31, 40].

Assuming that the reputation systems are consistent and applied adequately to the requirements of a service or a protocol, they can have a variety of properties that makes them more or less useful for other services [30, 31], also the web reputation systems that are the subject of this paper. In the particular case of web services one should take into account the specific constraint that the quality of the service can be considered from three points of view. They are: the quality (value) of the website's content, its quality of presentation (represented by, e.g., structure of the page HTML code) and, finally, by the quality of transmission. Therefore, before applying a reputation system, one must investigate and identify the model's assumptions in order to determine subject and scope of the analysis.

A reputation system can be constructed using different mathematical techniques. Enumerating the most popular ones, we have: *probabilistic systems* that describe reputation as a probability of expected reactions of the given party system for a particular request; *fuzzy theories based systems* where reputation is a fuzzy number established on a subjective opinion of customers; and *deterministic systems* where reputation is expressed as an arbitrary number from an assumed range (mainly from the $0, \ldots, 1$ interval). Inside each of the above categories, reputation systems can be classified according to specific mathematical techniques applied for calculating reputation and, especially, consolidating it during a long period and on a basis of data collected from many sources. Concerning global reliability, reputation can be classified as *objective* or *subjective*, with possibly some intermediate states, referred as *hybrid*. We denote the reputation system as objective if the reputation is calculated according to knowledge collected independently of a service's customers or if it is based on information collected from a statistically significant group of users.

The next important property of a reliable reputation system is its *sensibility* in time, that is, how quickly the reputation system reacts to positive or negative changes of the service quality. This is strongly connected with the performance of the system on one hand and its time memory (i.e. memory of reputation history) on the other. This property is especially important when we want to decide how quickly some critical events should affect reputation and when they could lose impact. Such a mechanism, if properly implemented, enables a reputation measure evolution and rehabilitation of parties (service) with low ratings. Finally, one can consider the architecture of reputation systems, which can be *centralized* or *distributed* (decentralized). This property can be understood in two ways. Firstly, we can identify if reputation data is *gathered* and processed in one or in many places. Secondly, a reputation estimate can be *controlled* by one entity, or it can be a result of cooperation of many independent entities.

Analyzing the above properties we can observe that most of them are independent and some of them are even in contradiction. The reputation system constructed for a specific service or protocol must have such properties that are the most appropriate for its functioning and give the most useful information for its managers. Since the purpose of this paper is a construction of the reputation system architecture for supporting QoE in web services, we propose the following, systematic classification.

Reputation systems (RSs) for web services and telecommunication networks can be classified depending on how reputation is assessed, as objective, subjective or hybrid [4]. Subjective reputation systems (SRSs) measures subjective opinions and personal experiences provided by service users. These measures are expressed, e.g., in the form of ratings (or scores). Examples of SRSs are Amazon [1] or eBay [7] auctions. To create reputation measures, objective reputation systems (ORSs) rely on ratings that have been assessed based on objective, well-defined, and repeatable criteria. Reputation scores, provided by users, are created using objective evidence, and the whole community sees them. An example of such an objective reputation system is implemented in Amazon book sales. Hybrid reputation systems (HRSs) combine characteristics of, both, SRSs and ORSs. In most cases these systems rely on ORS but the obtained reputation objective scores are interpreted by means of subjective values and motivations. An example of a hybrid reputations system may be, e.g., the individual rating of books apart from their real (objective) sale history.

The most important criterion of reputation systems classification is a mathematical approach applied to estimation of reputation. The appropriate choice of a mathematical tool is crucial for the effectiveness of reputation systems supporting QoE of web services. Now we will present and discuss examples of the reputation systems classified as probabilistic, fuzzy logic-based and deterministic, to identify their properties which are capable of improving the web services functioning.

2.1 Reputation systems based on the probabilistic approach

For probability theory-based reputation systems, there are two main approaches extensively studied in the literature: *Bayesian Networks-based RS* and *Subjective Logic-based RS*.

Bayesian networks-based RS Bayesian networks in reputation systems enable a theoretical basis for computing reputation scores. Bayesian reputation systems are based on computing reputation scores by the statistical updating of probability density functions (PDF). Two types of Bayesian RS are proposed: a binomial RS [19], which is based on the beta probability distribution, and a multinomial RS [22], which is based on the Dirichlet probability distribution. An updated reputation score is calculated by combining historical reputation data with a new rating.

A serious limitation of binomial reputation systems is that they accept, as inputs, only binary ratings (positive or negative) and cannot reflect graded ratings. Multinomial reputation systems overcome this drawback and can have any number of rating levels that represent graded ratings. For binomial reputation systems, input parameters are provided as scalars. A historical set of data is involved in the form of a *longevity factor.* Positive or negative evidences sum up in calculation of a reputation score. For multinomial reputation systems input parameters are provided as vectors. A historical set of data is also involved in a form of a longevity factor and as accumulated evidence in a given period of time in the calculation of a reputation score.

Bayesian reputation systems collect ratings about users or service providers from members in a community. Then, the ratings are sent to a central location, i.e., a reputation centre, where reputation scores are computed and published. After the ratings about particular users are received, these users' reputation values are changed accordingly. Therefore, such Bayesian reputation systems are objective.

Subjective logic-based RS Subjective logic [18] is a part of probabilistic logic, which includes in its calculations uncertainty, belief and disbelief. Inputs and outputs in the Subjective Logic approach are considered as subjective opinions on states in a state space. Such a method can be used to formulate a reputation system, see, e.g., [20]. Authors assume that the opinion (a kind of reputation metric) ω_x^A has the following form:

- $\omega_x^A = (b, d, u, a)$, for the binomial distribution, which expresses party A's belief in the truth of the statement x. The scalars b, d and u represent belief, disbelief and uncertainty, where $b, d, u \in [0, 1]$ and $b + d + u = 1$. The parameter a is the base rate used to express the expectation of an opinion in a linear form, $E(\omega_x^A) = b + au$;
- $\omega_x^A = (\mathbf{b}, u, \mathbf{a})$, for the multinomial distribution, which expresses the relying user's A's belief over state space X and coordinates of the vectors $\mathbf{a}$ and $\mathbf{b}$, and the constant u belong to the interval [0, 1]. The vector $\mathbf{b}$ represents belief masses for the states from X, the scalar u represents an uncertainty mass $|\mathbf{b}| + u = 1$ and the vector $\mathbf{a}$ represents base rates over X, where $\mathbf{a}$ is used to express the expected value of the state x in a linear form, $E(x) = \mathbf{b}(x) + \mathbf{a}(x)u$.

If reputation values are expressed as subjective opinions, then each transitive reputation path can be computed with a *discounting* operator. Moreover, paths can be combined by means of a cumulative or an averaging *fusion* operator. These operators form a part of Subjective Logic. Reputation systems based on Subjective Logic are used to derive local and subjective reputation scores, so they are applicable mainly to distributed systems.

Bayesian reputation systems are compatible with reputation systems based on Subjective Logic. The combination of these two mathematical approaches provides a powerful basis for assessing quality of on-line services, in particular, web services. A reputation system using these two approaches was proposed in [23]. The solution proposed and created a flexible tool that allowed creating reputation scores that consist of both subjective and of objective ratings. Such a reputation system could be a good support for modeling QoE for a web service in frames of the probabilistic approach presented above.

2.2 Reputation systems based on fuzzy logic

Fuzzy logic is an attempt of rigorous mathematical approach in situations where a model should reflect individuals' opinions, but one cannot collect sufficiently large statistical data (experience) to apply a probability theory-based approach. Such cases are typical when we try to classify rare events and therefore fuzzy methods found their place in reputation models. Here we present several fuzzy logic based methods of calculation of reputation and identify their properties useful for the web services case. All of them use fuzzy measures to express trust and reputation. They differ in how individual trust of one entity to another is expressed, what kinds of reputation are considered, and how individual and social reputations are aggregated to obtain effective reputation for application in a decision-making system.

A good example of a fuzzy logic-based reputation system is presented in Sabater and Sierra [40] where three kinds of reputation are considered: individual, social, and ontological. In their model, individual reputation takes two values, -1 and 1, and is based on an individual's decision. Social reputation is what an individual inherits from a group it belongs to, while ontological reputation is a consolidated value of individual and social reputation. Moreover, a calculated reputation value has a property which decreases in time. The authors in [3] proposed a system where a party can play several roles, each in a certain proportion. The global reputation value of the party is a weighted aggregation of the reputations in each of the roles (quantified according to defined measures). In [37] a site assigns the party one of three linguistic trust levels $(-1, 0, 1)$ after each interaction and cumulates the experience of contacts. When the number of contacts is sufficiently big, the reputation is calculated according to the user's (site's) own experience. Otherwise, the site uses reputation of the party obtained from other sites. Song et al. [43] defined a system where a site's reputation is formed based on party's own aggregated experience (using four factors: prior success rate, cumulative site utilization, job slowdown ratio, and job turnaround time) and the site self-defence capability (taking into account four security factors). Apart from calculating reputation, some models also propose mechanisms of cheating detection (see, e.g., [42]) that help in reducing false decision-making.

2.3 Reputation systems based on deterministic approach

One may find a set of reputation systems that incorporate a deterministic approach to realize a mathematical evaluation engine of reputation systems. These groups of systems are usually optimized for real applications and take an opportunity of heuristic reputation modelling. For example, Google's PageRank [34] scores a web page according to how many other pages are linked with the scored one. For such a hyperlinked network of pages, reputation of a referring site has an influence on scoring of pages that are referred to. This system has a centralized nature—in order to avoid illegal positioning, additional mechanisms are utilized, for instance domain name costs or frequency of updates of a page. An approach similar to PageRank may be found in Liu et al. [27], where a reputation system is proposed for MANETs. Scoring is built according to nodes' own experience and shared reputation of members of their close neighbourhood.

Liu's model assumes that management of subjective opinions is realized in a decentralized environment. The system has an ability to reflect a history of collected opinions and evolve with changing dynamics. An input parameter vector is composed of a weighted list of attributes, which are shaped respecting the importance of evaluated features. Opinions are mostly connected on the basis to trust to network nodes, but they may be extended to parameters reflected in QoE metrics. A proposed extension of Liu's proposal may be found in [5, 9] where a reputation system was applied for an anonymous communication and the real-time communication system SecMon. These extensions point out that Liu's reputation system performance and sensibility stay in close relation with the amount of input data. This means that reputation provides less reliable output results especially in initial phases of building reputation or in a period of limited activity. To cope with this drawback outlined in [5, 6], a *virtual time quantum* was proposed in order to keep the reputation evolution on a sustainable level. Liu's reputation system has a native ability of scoring QoE-related metrics and reflecting a context dimension of application. It makes the reputation system a suitable and interesting candidate for reputation building in web services.

A short review of reputation systems presented above shows that the known systems provide a number of possibilities to take into account different properties of reputation that could be expected in our QoE reputation system for web services. However, there is no single reputation system which could satisfy all designed requirements. Further in this paper we make an attempt to specify a sketch of properties the effective reputation system for QoE should satisfy.

3 QoE model classification

Quality of Experience combines user perception, experience and expectations with non-technical and technical parameters such as application- and network-level QoS. There is, however, still a lack of quantitative descriptions or exact definitions of QoE. One particular difficulty consists in matching subjective quality perception to objective, measurable QoS parameters for various applications. Reputation may be an appropriate means to overcome this and to obtain a QoE value without explicitly knowing a direct relationship between QoE and QoS parameters. Indeed, the reputation provided by a user implicitly covers QoS parameters as well, and by changing the latter in a controlled way, relationships between QoS and QoE can be derived [41]. In this section, we introduce a classification of existing QoE metrics and how to measure them. There exist two basic measurement options, which are *subjective testing* and *objective testing*. Usually, subjective quality tests form the basis for perceptual objective test methods. The subjective tests are carried out by test panels of (real) users. While many (possibly even diverging) views on the quality of the outcome can be taken into account leading to accurate results as well as a good understanding of the QoE and its sensitivity, this type of test can be both time-consuming and costly, since the tests have to be conducted by a large number of users under well-defined conditions for statistically relevant results. Objective tests are carried out by an algorithm on behalf of a real user, trying to imitate (or predict) user perception based on key properties of the reference and/or the product. Objective tests can follow psychophysical approaches and engineering approaches, a detailed description of which is found in [10]. For instance, for VoIP—which is easy to test real-time service—the PESQ (Perceptual Evaluation of Speech Quality) standard [17] objectively evaluates and quantifies voice quality of voice-band 300–3400 Hz speech codecs. It uses a psycho-acoustic and cognitive model to analyze and compare the reference and the outcome. PESQ allows for repeatable and automated measurement processes, which is necessary for obtaining statistical significant results.

Depending on the available information for subjective or objective tests, quality metrics can be classified according to the following three categories, cf. amongst others [10, 25, 35]:

– *Full Reference (FR) metrics*: Both outcome and reference are available and allow for detailed subjective and objective comparisons of voice, images, videos, download times on an application level, as well as packet traces on network level, etc. Concretely, this means extraction, evaluation and comparison of QoE- and QoS-related parameters on any level in an off-line manner, which is most interesting for deriving QoE to QoS relationships. FR metrics deliver the highest accuracy, but require high computational effort. Typically, FR metrics are applied in a test environment.

- *No Reference (NR) metrics*: Quality information has to be extracted from the outcome, as no reference is available. This is a typical on-line situation with sole focus on the resulting quality as perceived by the end user, e.g. evaluated through questions or observations, or the user's representative, e.g. an algorithm. Obviously, user ratings and recommendations of services and content typically apply the NR approach. Due to judging the outcome "as is" in a subject- and context-dependent way, NR metrics might have a large variance. In a networking context, NR metrics are usually lacking the possibility of discerning between quality problems stemming from the reference, e.g. quality degradations due to encoding, and additional disturbances by the network. Thus, NR metrics are not applicable for deriving QoE to QoS relationships aiming at capturing the impact of the network.
- *Reduced Reference (RR) metrics*: Instead of comparing directly the reference with the outcome, parameters on an application and/or network level are extracted at the sending and receiving side, which help in predicting the QoE. As an example, on an application level the RR Hybrid Image Quality Metric (HIQM) [25] computes various criterions of the reference image and sends them to the receiver. The extracted parameters are taken into account for estimating the quality of the received image without needing the reference image at the receiver. As a further example, on network level throughput variations and losses may be derived and compared to estimate the quality on receiver side as done in [12] and [11]. Such parameters often have their roots in FR research as a means of summarizing and interpreting the outcomes. However, as they represent key QoE and QoS parameters in a very condensed manner, they can be applied in an on-line in-service scenario by transmitting them between source and sink, and subsequently comparing them in order to find out about quality problems. Because of their background, they represent promising candidates to build QoE to QoS relationships upon [11–14, 41]. Users, however, are generally not confronted with reduced references.

QoE metrics exist mainly for speech as well as video transmissions. The Mean Opinion Score (MOS) enables a subjective assessment of experienced speech quality, which is based on the subjective placement of voice samples by test persons on a scale from 1 (bad) to 5 (excellent) as defined in ITU-T P.800. In contrast, objective scoring mechanisms try to determine the experienced quality of speech based upon measurable values. One of these, the E-model (ITU-T G.107), maps the influence of different factors impeding the transmission of voice data onto the so-called R-factor, which is a measure of voice quality. Another, the PESQ value [17],

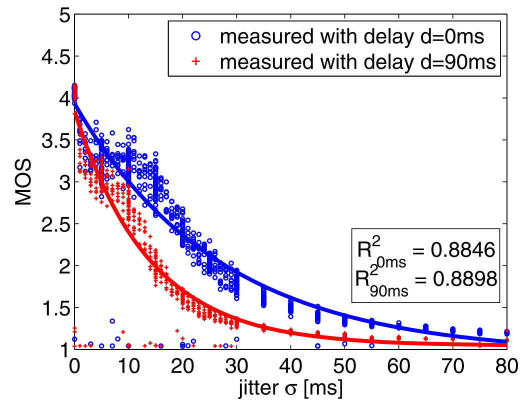

Fig. 1 Measurement results and obtained mapping functions between network jitter and MOS for a VoIP service using the iLBC codec as investigated in [16]

results from a comparison of two voice samples. It is typically used to evaluate transmission quality in a network using test samples.

Prior work on the topic of QoE, cf. [15] and [16], showed that VoIP is heavily impacted by network parameters such as jitter, packet delay and loss, whereas mainly effective throughput is determining the experienced quality for data services [24]. Here, an exponential interdependency between QoE and the according QoS parameter (e.g., packet loss) was found in the examined scenarios. This implicates that QoE is very sensitive to QoS disturbances in case the experienced service quality is high. Under negative conditions, i.e., a low QoE, further disturbances have a smaller effect. The reputation system has to take this varying sensitivity, as e.g. indicated (3), into account. Fine-grained QoS measurements are needed to correctly assess the impact on QoE when the latter is high. For QoE below the acceptance level, the exact level of QoS is not that critical any more.

To demonstrate the sensitivity of the QoE, Fig. 1 shows the impact of network jitter on user perceived quality. In this measurement study [16], a VoIP service which uses the iLBC voice codec is tested in a laboratory environment within an Ethernet local area network. In the experiments, the network conditions were emulated. In particular, two different delay values, $d = 0$ ms which means no additional delay and a delay of $d = 90$ ms in addition to the propagation delay in the LAN, have been investigated. For both values of additional delay d, the jitter was varied from 0 ms to 80 ms. To obtain the QoE, the FR metric PESQ has been used which compares the original audio signal with the received audio signal. The objective PESQ value can then be mapped onto a MOS corresponding to an average user's subjective rating. Each dot in Fig. 1 represents a single experiment with a jitter value preset in the experiment. While the additional delay of $d = 90$ ms leads to a worse QoE than the same jitter without additional delay $d = 0$ ms, the shape of the two fitting curves remains the same. In both cases, an exponential relationship can be observed. The coefficient of determination R^2 shows that an exponential shape fits quite well the measurements. However, the variations of the MOS for small jitter values, which yield high MOS scores, highlights the sensitivity of the QoE from a different viewpoint. Users perceive quality in a more complex way depending not only on the technical environment described by measurable, technical parameters, but also on psychological aspects like expectations, emotions, etc. As a result, a large set of (measurable and non-measurable) parameters influences the QoE, resulting in a multidimensional mapping function. Reputation systems may overcome this difficulty when taking into account the QoE sensitivity as outlined before.

Apart from these, numerous ways to assess the objective and subjective quality of video exist, such as the ITU-T J.144 standard for cable TV evaluation. Other mechanisms to judge video quality, multimedia content and IPTV are developed by the ITU study group 12 and especially the Video Quality Experts Group (VQEG). There exists also a large number of publications on this topic, with selected examples being [39] or [45].

However, for other Internet services and applications like web service there are only a few studies available, which directly focus on the quantification of QoE. Relationships between QoE and QoS parameters have been presented in ITU-T G.1030, expressing user ratings of response times; in [24], expressing cancellations rates as a function of perceived throughput; in [41], systematically investigating the consequences of loss on QoE and session volumes; and [13], revisiting and refining the approximations given in ITU-T G.1030 and [18]. Even though reference [13] points out a potential generic exponential relationship between QoE and QoS, the majority of services and circumstances still needs to be investigated quantitatively. Thus, the collection of reputation values is a viable complement, in particular when the conditions on network level can be changed in a controlled way [13, 15, 16, 41].

4 Applications of reputation systems for QoE evaluation

The complexity of contemporary web services makes the quantitative evaluation of QoE a multidimensional challenge. One may identify these dimensions as several user- and service-oriented items, which contribute to QoE metrics. Such metrics are linked with web services and a mix of multimedia content (audio, video, metadata), varying context (social web portals, news, science, advertisement, entertainment, e-commerce) and meaning (usefulness, importance) for the end user. In addition, the service logic and its design add a substantial input to the service ergonomics, which determines how efficient and convenient web surfing is. Also, the user's expectations and his cognition on the web service depend on the individual's profile (age, hobbies, attitude, etc.). Finally, as the previous section presented, the links between network measures (such as QoS parameters) and QoE for web services are not necessarily explicit. For this complex picture of QoE metric a reputation system is a viable solution to be applied for QoE assessment. Aiming for an accurate evaluation of QoE, it is important to enable a monitoring and evaluation of QoE on a short-time basis which assure an appropriate resolution of data quality. Some proposals for handling the real-time event by dedicated reputation systems can be found in [5, 6]. Without loss of generality, we may assume that contemporary web services, for which the QoE evaluation is foreseen as an important feature, may be composed of a real-time (RT) and non real-time applications (n-RT). Amongst social networking services the next really important observation is that the services follow a multi-user and multi-service interaction trend that seems to be leading in the Future Internet societies (Web 3.0 paradigm [8], e.g. multiplayer games with on-line chat, VoIP communication or videoconferencing with desktop sharing tools for collaborative office works).

The reputation system capabilities are aligned and particularly inherent to be applicable within a web service-oriented world. Many proposals, available in the literature [31], utilize reputation to assess and stimulate the most preferable behavior of user's agents which increase significantly a recognition of the user's trust in a population. Some approaches [1, 7] indirectly consider a reputation system as a motivator for improving perceived QoE, some go further and directly address QoE delivery as a web service middleware [28]. None of the known solutions incorporates the reputation measure for direct QoE evaluation, where the reputation system equally interacts with users, providers and composite web services. The key item characterizing such an approach is the break-down of the well known reputation peering model of users' agents into service and user sites, which are connected by multi-user sessions and multi-service context.

The motivation for our work comes from the most realistic observation of web-oriented trends for the ubiquitous computing environments which is aligned with Web 2.0 [33] and the Future Internet [8]. Thus, Fig. 2 illustrates a novel proposal of service delivery with a distributed reputation system, that plays a role of a complementary value added web service. Only key modules of the service delivery chain were presented virtualizing the complexity of network architecture. The Reputation Management System (RMS) is split into two domains of service execution: on the client-side as an easily manageable, lightweight monitoring module (e.g. web widget) running on a user terminal simultaneously to the title web services and the second one implemented at the

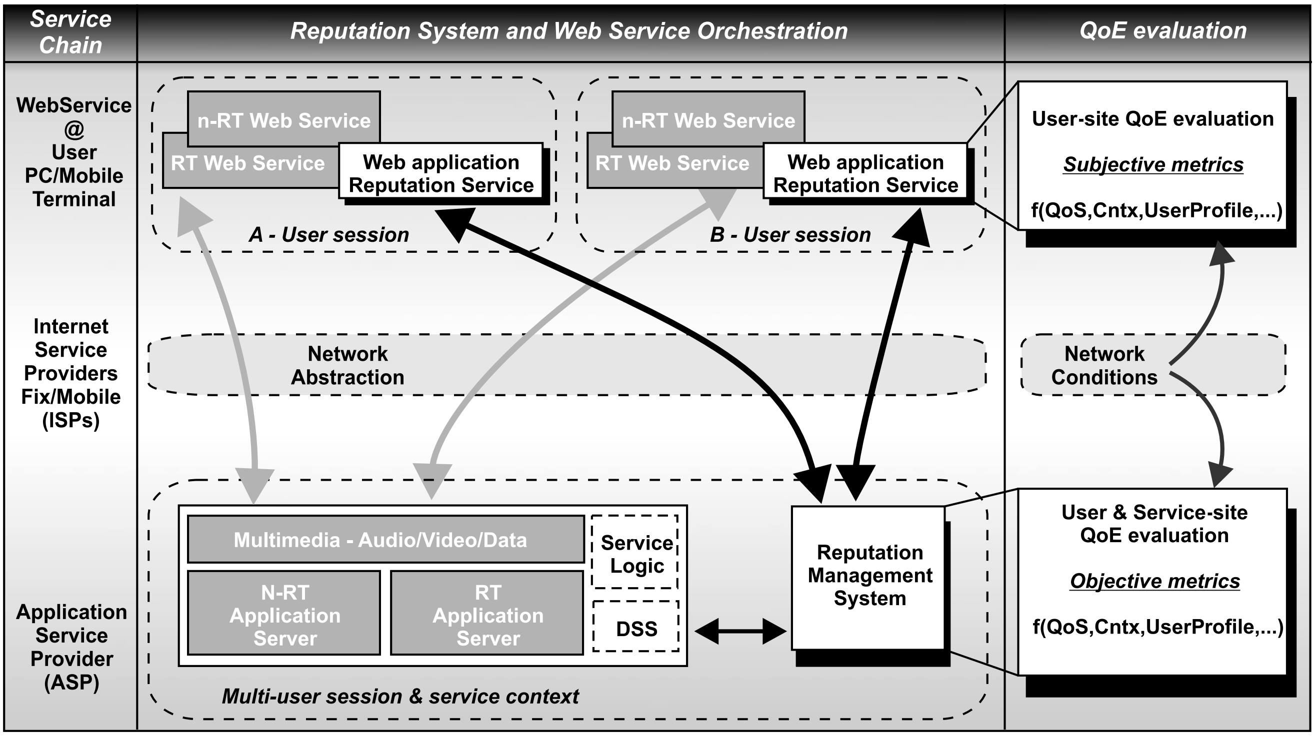

Fig. 2 Reputation System framework for QoE evaluation within web service environment

Application Service Provider's (ASP) premises. This second item is responsible for collecting application and server side measurements for QoE evaluation purposes. For an ordinary web service we allow for the interaction of several users with different terminal capabilities (PC desktop, PDA) that may have access to the complex services with non-real-time and time-sensitive data exchange. In this case the users, at least a couple, are interconnected with a web Application Server (AS). This AS enables those parties to collaborate and serves the multimedia content (audio, video, data) to every user according to the Service Logic (SL). Such an activity is organized in separated *user sessions* with a *service context*. The web client of the reputation system is aware of every particular user session and, together with a preconfigured method of evaluation, collects QoE subjective data, which it finally shares with the centralized RMS. At the same time the RMS collects QoE data for the same user session but at the level of ASP on entry points to the Internet Service Provider's network. Such an approach allows for detection of any network disturbances that may appear in the Network Abstraction (NA) layer. The client-server QoE data comparison may allow for constituting a reference method of subjective QoE evaluation as it was presented in Section 3. An aggregation of QoE metrics from different users' sessions at the level of ASP leads the reputation construction to the objective (network) QoE. As the user-oriented and network-oriented QoE data changes in time the RMS performs on-line QoE follow-up and is eligible to trigger remedy actions when QoE evaluation falls below an acceptable level. The consolidated and QoE-dependent triggers are sent to the Decision Support System (DSS) according to the web service polices. The DDS is implemented in the body of the SL in the Application Server (AS) and influences web service behavior for a particular user session (e.g. media transcoding, media renegotiations, data bitrate changes, synchronization of RT and n-RT data streams).

The major advantage of our proposal is a usage of the value added Web-based application which orchestrates with the reputation and QoE evaluation process in an automated manner without any detailed knowledge about specific service and network topology, introducing service virtualization.

It is important to distinguish the conversational data related to the composite web-services from measurements collected and analyzed by the reputation system engine, which is hosted at premises of the ASP (not necessarily owned by service provider). Referring to Fig. 2, communication along the supply chain between web service providers (at ASP) and end-users is enabled by virtualized networks of Internet Service Providers (ISPs). The communication model follows an approach of client-server (user-service), between which a number of communication paths are set up, namely: conversational (signaling, media, metadata) and reputation. Reputation data is measured at the user's site by a light-weight web monitor and exchanged with other users via a server-site reputation service, which collects, monitors and evaluates QoE for the composite services. Reputation data could be securely exchanged with limited resources occupation via covert channels [6]. In this framework the Network Abstraction makes that ISPs are not directly involved in the service supply chain and SLA are controlled only for the web-service level. However though, the proposed reputation models derive from distributed environments and could be easily extended to allow ISPs to intermediate along the reputation path and to improve the accuracy of QoE evaluation with respect to the impact of ISPs' networks.

In [9], an approach of evaluating the impact of network-induced problems on QoE and thus on performance of reputation was provided. This approach used the concept of *utility functions* to reflect disturbances U_i on network level onto user perception [14]. In particular, the utility in the disturbed case, the outcome U_{out}, is calculated from the utility in the undisturbed case U_{in} as

$$U_{\mathrm{out}} = \left(\prod_i U_i\right) \cdot U_{\mathrm{in}}. \tag{1}$$

The product of utility functions is used to capture the impact of different parameters on the perceived quality. For instance, the impact of loss is seen from a deviation of the amount of sent traffic as compared to the amount of received traffic, both of which can be expressed by their averages m_{sent} and m_{rcvd}. The m-utility function expresses that impact as $U_m(m_{\mathrm{sent}}, m_{\mathrm{rcvd}})$. In its simplest shape [14], it weighs the loss by a constant parameter k_m, i.e.

$$U_m = \max\left\{1 - k_m\left(1 - \frac{m_{\mathrm{rcvd}}}{m_{\mathrm{sent}}}\right), 0\right\}. \tag{2}$$

An exponential shape as basis for U_m is seen from the example presented in Fig. 1. The linear shape (2) can actually be seen as a first-order approximation of

$$U_m = \exp\left(-k_m\left(1 - \frac{m_{\mathrm{rcvd}}}{m_{\mathrm{sent}}}\right)\right). \tag{3}$$

Similarly, the coefficient of variation of throughput values measured during small time intervals reflects the impact of jitter; the corresponding c-utility function is given by $U_c(c_{V\mathrm{sent}}, c_{V\mathrm{rcvd}})$ and exemplified as

$$U_c = \max\{1 - k_c(c_{V\mathrm{rcvd}} - c_{V\mathrm{sent}}), 0\}. \tag{4}$$

Further details can be found in [9].

The usage of reputation may be profitable for service providers in terms of SLA fulfillment or retaining QoE at a satisfactory level for users, who share the same network or service resources. Figure 2 illustrates that QoE is expressed via a function of QoS, a service context, a user's profile and terminal capabilities that may define SLA contract parameters between the service provider and its consumer. QoE-aware reputation systems, by their design, are able to monitor such a SLA contract and to react in run-time with the Decision Support System (DDS). The DDS enforces SLA polices by applying predefined remedy actions, e.g., changes of multimedia stream parameters. This leads to the automated SLA fulfillment and gives the answer whether specific sanctions should be undertaken or not, financial ones inclusive. Moreover, the SLA contract is a bilateral agreement with clarification on commitments of both parties: a service user and a service provider. The proposed framework respects such a requirement and introduces dedicated mechanisms on the client and the server sides which facilitate SLA tracking and policy execution. This major advantage assures that SLA fulfillment limits falls of the perceived service quality (QoE) and disables end-users for service abuses.

In order to perform QoE assessment according to the proposed architecture (Fig. 2), we introduce the Reputation Management System depicted in Fig. 3. A Data Collection layer is responsible for feeding a Reputation Evaluation Engine with measurements obtained from a subjective scoring of context aware web transactions between web parties as well as objective metrics related to network aggregated QoE and QoS parameters. The reputation evaluation engine *adopts* and *normalizes* input data in order to extract and emphasize the characteristic features of the opinions, which are under evaluation by the reputation system. The Reputation Vector is an internal metric, which reflects the history and context of the scoring. It is stored in an Evidence Repository.

In the proposed RMS model we envisage a use of reputation metrics shared between users' web clients in order to recommend the preferred service parameters that should be applied within a multiparty service session. This approach is intended for QoE management and balancing the web service load. The last common item is a Decision Support System Interface, which plays an important role in producing the output related to the reputation metrics and the service context for the given timeframe.

Within the three classes of reputation systems presented in Section 2, everyone has capabilities which are suitable for QoE evaluation. They can handle the multidimensional QoE nature in a distributed web service environment.

Probabilistic methods possess an innate mechanism for calculation of statistical correlations between data and metrics of QoE parameters. This feature is useful when certain web portal delivers several web services with a significantly different context. The statistical processing of interactions and collected data may result in a precise reputation generalization, but on the other hand limits input data sensibility in time.

Fuzzy-based reputation systems are effective in an evaluation of scoring for social services considering time frames of interactions. One of the drawbacks of this solution might

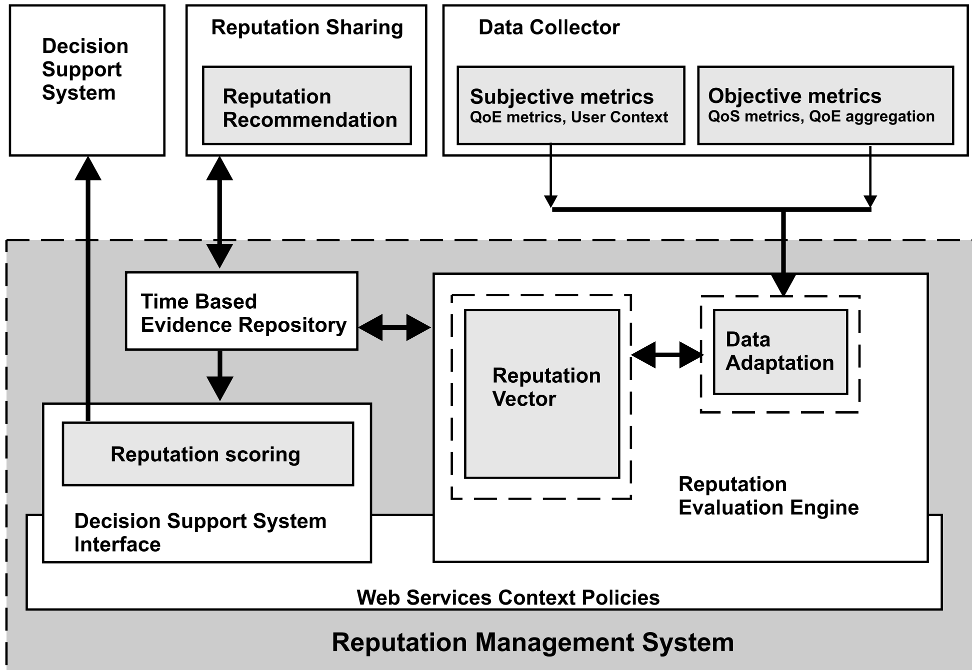

Fig. 3 Reputation Management System with QoE and DSS interrogation interfaces

be a limited granularity of input parameters. The advantage of this system is its ability to perform an accurate ranking, even if tampering and attacks on the system are possible. Moreover, the fuzzy systems, due to mechanisms of aggregation, allows to consider several different properties or roles of a party being evaluated. Such systems could be useful in advanced models of reputation for web services where the three aspects of quality mentioned in above would be taken into account: contents, presentation and transmission quality.

In the deterministic approach, the sensibility and time resolution may be adapted and parameterized for particular features of input data. This makes the reputation systems of this group a good candidate for QoE assessment of web services. However, the heuristic reputation modeling within these methods may lead to biased results and long-term outcomes could be misleading in reasoning. A possible overcome to this issue is a hybrid approach, where probabilistic and deterministic systems are combined allowing for self cross-checking the reputation evaluation. How to design the hybrid reputation system applicable for QoE could be a subject for further research.

In the following case study we describe a realistic case of on-line gaming as a good illustration of a composite web service interaction with an on-line QoE evaluation where an integrated and distributed reputation system triggers actions.

4.1 Case study: on-line gaming with real-time inter-player communication

Consider a composite web application that is an interactive on-line game of a fast paced type, e.g. a FPS (First Person Shooter) game, which also allows players to communicate in real-time. The application permits players to form teams and compete with each other. To be able to exchange information within the team, e.g. to plan strategies to defeat opponents or to warn allies, users can communicate, which due to the dynamics of the situation has to happen in real-time via chat or IP telephony.

Both application components *on-line game* and *inter-player communication facility* during the game have an impact on the users perceived QoE. The overall quality of experience QoEO in such a case depends on two elements—the qualities of experiences of on-line game (QoEG) and inter-player communication (QoEC), yielding

$$QoEO = f(QoEG, QoEC). \tag{5}$$

These QoE values may be loosely related to each other and may be treated separately. For example, if the game quality is poor due to bad network conditions, users experience delays or visual losses. Thus their perceived quality suffers while they still are able to communicate. On the other hand, if real-time communications is disturbed while game quality is preserved, users overall QoE is also influenced because real-time cooperation is affected. From the network perspective these two application components have different QoS requirements, they may be implemented by two different distributed network services and hosted on different servers in different locations. The network conditions and network resources may be correlated with QoEG and QoEC. This correlation heavily depends on where the network problems are located. If the link towards the end user is affected, both communication and gaming experience might be affected. When the gaming server is overloaded, communication might not suffer and vice versa.

In this example, when network disturbances happen the QoE analysis which are performed by the RMS may result in producing consolidated and time-related QoE measures. If they are shared with all players, the DSS may trigger QoE recovery actions. It should be noted, however, that for each of the application components, there is a different adaptation dynamic and sensitivity of QoE parameters. Thus, they can be treated rather independently from each other. Thus, the outcome of reputation system operations are mapped into service classes, which the DSS (see Fig. 3) may consider during prioritization of traffic streams generated by applications components. E.g., game traffic may gain high priority while VoIP communicator (e.g. chat) low priority. Possible DSS reactions based on estimation of the user's QoEO value are as follows:

– For on-line gaming: modification of screen resolution, color depth, changing frame per second rate, enabling/disabling music and sounds features and/or encryption etc.
– For real-time communication: increasing/decreasing compression, modification of routing in P2P network, switching VoIP into chat, etc.

5 Conclusions

This paper concerns the applicability of reputations systems for assessing QoE for web services in the Future Internet. The presented framework is a generic architecture proposal for reputation systems, which provide mechanisms to manage subjective opinions in a web society and yields general scoring of particular users' behavior as well as service and network reliability. QoE parameters express the level of satisfaction of the users, which may vary greatly in time and depend on a service context or its type. This multidimensional nature of QoE metrics can be handled by reputation systems, which produces time and context related scoring on the users, service and network operator.

The application of the reputation systems for QoE assessment faces the challenges of adapting QoE metric features into the data collection module with a need to define how the input measurements are correlated with user behavior and service context. This part is not clearly covered in literature and drives new research areas related to the QoE and user behavior modeling.

The usage of reputation may be profitable for service providers in terms of SLAs fulfillment or retaining QoE on the satisfaction level for users, who share the same network or service resources. In the paper, we are proposing a framework architecture of QoE evaluation in a distributed web environment of composite services. Without loss of generality, it is illustrated that QoE is expressed via a function of QoS, a service context, a user profile and terminal capabilities that may define SLA contract parameters between the service provider and its consumer. QoE-aware reputation systems, by their design, are able to monitor such a SLA contract and to react in run-time with the Decision Support System (DDS). DDS enforces SLA polices by applying predefined remedy actions, e.g., changes of multimedia stream parameters. This leads to the automated SLA fulfillment and gives the answer whether specific sanctions should be undertaken or not, financial ones inclusive. Moreover, the SLA contract is a bilateral agreement with clarification on commitments of both parties: a service user and a service provider. The proposed framework respects such a requirement and introduces dedicated mechanisms on the client and the server sides, which facilitate SLA tracking and policy executing. This major advantage assures that SLA fulfillment limits decreases of the perceived service quality (QoE) and disables end-users for service abuses.

In the scope of application advantages, the reputation systems for QoE evaluations are able to support automated decision makers and adapt web services or networks for keeping QoE at a satisfactory level. The benefits of such adoption are as follows: It is aligned with business objectives [44]; the reputation system may deliver input for Decision Support Systems (business intelligence systems); and the outcome of the reputation analysis may be used to trigger remedy actions for retaining QoE at satisfactory level. Such remedy actions include load balancing of network traffic driven by reputation; limiting the number of concurrent web sessions for a user when QoE degradation is detected; and influence the content adaptation mechanisms for real-time sessions (such as dynamic audio or video codecs changes) [39].

Building upon the ground laid in this work, QoE-related reputation will need to be addressed in experiments involving real users. The Euro-NF Specific Joint Research Project "QoEWeb", in whose scope this work was carried out, treated this challenge in its testbed and targeted quantitative results for reputation reflecting QoE shortcomings due to underlying QoS problems.

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