On the Fixpoint Problem of QoE-based Charging

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***Abstract*—While with traditional QoS-based charging the pricing structure mainly reflects the delivered QoS in order to regulate the demand, the role of service prices in a Quality of Experience (QoE) context is more complex. Amongst others, the charged price may in addition have a direct impact on the user's quality perception. In this paper, we analyze the structure of the resulting fixpoint problem and discuss the corresponding equilibrium. Based on recent user trials, additional insight into the characteristics of the related feedback loops is provided, before we conclude with outlining some consequences for future QoE-based charging mechanisms.**

Keywords-Communication Ecosystems; Quality of Service; Quality of Experience; Network Economics; Weber-Fechner Law; Cognitive Dissonance

I. Introduction

During its amazing evolution into one of the essential pillars of modern economy and society, telecommunications has been considered first and foremost to be an engineering discipline – and deservedly so. However, with the latest success of Internet and mobile communications and their progressing convergence with traditional fixed-line networking towards unified all IP infrastructures, we have reached a level of maturity where – despite of all the potential for further improvement – most of the fundamental technological problems seem to be basically solved, and where therefore telecommunications is about to become a commodity whose further development will be more and more directed for instance by ecological (green) and user issues, at least during the next couple of years.

In order to account for the resulting strongly interdisciplinary perspective, recently the overarching notion of "Communication Ecosystems" has been introduced to cover the *huge area from technical issues to business models and human behavior* [13]. Historically, the concept of ecosystems is very well established especially in the field of biology where it has been first proposed by Arthur Tansley already in 1935 for describing communities of living organisms together with their physical environment in a holistic manner [30]. Notably, the organisms interact with the environment as well as amongst each other, the latter one often in a hierarchical way, for instance in the form of a food chain (where the main type of interaction between organisms on different hierarchy levels is equivalent to "eating or being eaten"). Typical examples of biological ecosystems include garden ponds, lakes, coral reefs, rainforests, deserts, savannas etc.

In a straightforward analogy, the communication ecosystem may hence be characterized as the community of private and business customers using telecommunication services based on a technological environment (including e.g. networks as well as customer equipment) which interact with each other. Again, we notice clearly hierarchical structures both in terms of technology (as represented e.g. by the layers of the ISO/OSI model) as well as in terms of related value network structures which range from traditional network operators over ISPs (Internet Service Providers) and ASPs (Application Service Providers) up to the so-called OTTs (Over-The-Top providers) like Google, Amazon et al. The corresponding ecosystem thus integrates both the engineering and the user perspective, mediated by micro-economic and game-theoretic models for user and provider cooperation and/or competition.

This paper addresses a typical research issue arising in this interdisciplinary context where technology meets economic and user issues, and deals with the question of how to charge for Quality of Experience (QoE). While previous work (like e.g. described in [20]) has mainly focused on a general analysis of the problem and proposed some potential charging mechanisms, this paper approaches the problem from a more formal point of view and describes it in terms of a fixpoint problem which, in addition to delivered service quality, also takes user context and expectations as well as economic feedback into account.

The remainder of this paper is structured as follows: Section II. discusses briefly the transition from QoS to QoE and reviews some related work. Section III. introduces and analyzes this new type of fixpoint problems which is fundamental for QoE-based charging, while Section IV. presents an overview on user trial results which may serve as initial empirical evidence for further understanding the specific shape of the underlying mappings. The paper closes with some conclusions and an outlook on current and future work.

II. Quality Has Its Price

While the idea of providing Quality of Service (QoS) in communication networks has been around in the research community for more than two decades by now, in practice QoS is still short of being appropriately realized in state of the art network architectures (see for instance the difficult history of the IETF IntServ and DiffServ architecture proposals as well as, more recently, the ailing evolution of 3GPP's and ETSI's IMS initiative). Instead, we currently observe a strong dominance of flat rate tariffs, which may be convenient for the

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customers, but are also known to be far from being economically efficient, as they lead straight into the so-called "tragedy of the commons" [3]; moreover, flat rate prices are severely limiting the possibilities of maintaining or increasing operator revenues, which may limit future investments.

On the other hand, conviction is growing among network operators and ISPs that quality has become and will stay one of the key differentiators on the increasingly competitive telco market. At the same time, it turns out that service quality in this sense needs a much stronger orientation along the user and customer experience than traditional QoS research with its standard focus on improving technical network parameters like bandwidth, packet loss rate, transmission delay and jitter, etc, is offering.

This is also in line with recent developments within the research community which aim at redirecting quality research towards the original meaning of QoS as *collective effect of service performance which determines the degree of satisfaction of a user of the service* [1]. To this end, a few years ago the notion of "Quality of Experience" (QoE) has been coined to explicitly put back the user into the centre of investigation. The most widespread definition of QoE as *overall acceptability of an application or service, as perceived subjectively by the end-user* is due to ITU-T [2] is still subject of current discussions. Amongst others, most recently the following definition proposal has been developed and agreed within the European COST Action IC1003 "QualiNet" [16]: *Quality of Experience (QoE) is the degree of delight or annoyance of the user of an application or service. It results from the fulfillment of his or her expectations with respect to the utility and/or enjoyment of the application or service in the light of the user's personality and current state.*

Within this discussion, we argue that the transition from QoS to QoE is of a far more significant nature than a mere replacement of one buzzword by another one, and should rather be viewed as a quite fundamental paradigm change [27]. Indeed, a comparison of currently discussed QoE models quickly reveals that this new quality notion of course still depends on the QoS delivered by the underlying networks, but in addition takes multiple further aspects into thorough account. K. Kilkki [13] for instance restricts the range of QoS to managing the interactions between applications running in end-user terminals, and refers to QoE as the *human side of the service provision and consumption* which in addition depends on roles like user or customer – hence he proposes a further distinction into Quality of Experience, Quality of User Experience (QUE), Quality of Customer Experience (QCE), and (tentatively) even Quality of Group Members Experience (QGE, see [14]).

In a similar way, the "quality chain" model presented in [21] conceives QoE as a concatenation between network-level QoS which describes quality in the core and access and can be quite dynamic, and Quality of Design (QoD) as a less variable but strongly user-dependent concept which takes mainly the intuitiveness of the interaction with the physical end device and the usability of the respective application and hardware interfaces into account. Note that this approach allows nicely decoupling technological from human-centric impact factors in the resulting QoE metric.

Another comprehensive QoE model has recently been proposed by K. Laghari et al. [15] and is based on distinguishing three main domains organized into two layers together with the interaction between them. In the bottom layer, the "Technological & Business Domain" reflects technological parameters as well as business goals and is paired up with a "Contextual Domain" integrating spatial (physical and virtual) and temporal aspects of the current user condition. Both these domains interact with each other as well as with the top layer "QoE Domain" which includes both subjective and objective QoE metrics, while the way the human entity is concerned again depends on her role as user or customer (in this respect following closely Kilkki's proposal).

The user context plays also a major role in the QoE framework proposed by De Moor et al. [4] and is claimed to provide the link between QoS as an objective quality concept and User Experience (UX) as its subjective counterpart which, for instance, includes user expectations, feelings, thoughts, behavior etc. Note that, later in this paper, we will conceive pricing as one of the pivotal characteristics in this contextual domain, which will turn out to be the key for understanding the difference between charging for QoS and charging for QoE.

In addition to the lack of user orientation, R. Jain [12] points out another reason for the notorious difficulty of introducing QoS-enabled architectures in the current Internet, i.e. the missing integration of economical aspects. He argues that QoS techniques without clear relationship to charging policies have failed in the past throughout; in this sense he follows B. Stiller's remark on the fundamental intimate relationship between the quality of a delivered service and the way customers are charged for it [28]. As a consequence, currently running research projects like, e.g., the EU FP7 IP ETICS (Economics and Technologies for Inter-Carrier Services) [17], increasingly aim at integrating both economical and technical aspects jointly into the development of future architectures for QoS-enabled Internet services.

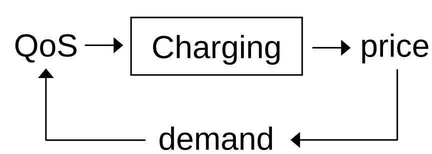

Figure 1. Model 1 (Charging for QoS)

It is out of scope of this paper to review in detail the rich body of related work on Internet charging and pricing schemes for QoS-enabled services, and we refer to overview papers like [29] or [31] instead. It is, however, important to briefly revisit the very basic idea of charging for QoS as sketched in Fig. 1.

According to this simple model, QoS-based charging usually boils down to measuring or estimating one or more QoS parameters as input for a charging mechanism which determines the corresponding price (to be paid by the customer) based on predefined tariff functions. Note that this implies already a feedback cycle (Fig. 1), as the chosen tariff in general regulates the customer demand, which itself may have a direct impact on the network load and thus, assuming finite capacities, on the delivered service quality.

We can easily regard this as a dynamic process where tariffs (and hence prices) are variable and drive the demand towards an equilibrium where the delivered QoS equals the user's willingness to pay for it. For instance with usage-based charging, low prices will cause increasing demand and thus will put pressure on the network, while an optimal tariff is equivalent to a fixpoint (Nash equilibrium) where the price for the delivered quality equals the willingness to pay of the users[1].

Formally speaking, let p indicate the price, d the demand and q the QoS. Then, the model of Fig. 1 is equivalent to the following recursive set of equations:

price function $$p = p(q) \quad (1)$$

demand function $$d = d(p) \quad (2)$$

QoS function $$q = q(d) \quad (3)$$

In other words: the price to be paid is determined as a function of the delivered QoS, the demand depends on the price, and the service quality to be offered is ruled by the size of the demand (which is the case as long as resources are finite or scarce, which is expected to remain true at least for mobile access in the foreseeable future). Moreover, we may assume continuity of these functions as well as that the demand function $d(p)$ and the quality function $q(d)$ are both monotonically decreasing, whereas the price function $p(q)$ is increasing monotonically.

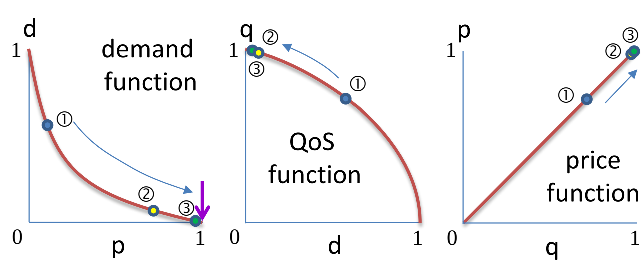

Figure 2. Trivial Stable Fixpoint for Model 1

For the purpose of illustration, suppose that p, d, and q are normalized to the unit interval each, and hence $p(0) = 0$ and $p(1) = 1$, $d(0) = 1$ and $d(1) = 0$, $q(0) = 1$ and $q(1) = 0$. Then, the system of equations (1)–(3) has only two trivial fix points, i.e. $(p^*,d^*,q^*) = (0,1,0)$ and $(1,0,1)$, respectively. Note that $(1,0,1)$ is a stable fix point (i.e. an attractor), whereas $(0,1,0)$ is unstable, see Fig. 2 for a typical example assuming that the "*demand function*" d is a convex function, the "*congestion function*" q representing the dependency of QoS on demand is concave (i.e. the load situation and thus QoS worsens significantly if the demand is approaching the capacity limit), and the "*price function*" p depends linearly on the QoS. Note that in Fig. 2 (as well as later in Fig. 4), the x-axis and y-axis each run from 0 to 1 (i.e. the functions have been scaled to unit intervals), while the first three iterations of the system of equations (1)–(3) are denoted by the numbers ① ② ③. The equilibrium price is marked with an arrow in the graph of the demand function.

Hence, we may conclude that for the rather simple Model 1, there are two potential options: (1) provide the service "for free" (only a fixed fee for access, but without any usage- or quality based tariff component) and on a best-effort base, i.e. without QoS guarantees; (2) as soon as service usage or quality is charged, it should be offered as an (expensive) premium service with top-level QoS. This is of course in most cases not consistent with the interest of the network operator which aims at maximizing its revenue, i.e. $\max d(p)\cdot p$, leading to an interior solution point (i.e. $d(p) \neq 0 \neq p$) for the resulting optimal price and quality.

The interplay between price, demand and QoS is captured in a particularly original way with Odlyzko's Paris Metro Pricing (PMP) scheme [19], where different QoS classes are charged differently (but are not at all different in any other respect rather than the price) and thus attract (or repel) customers based on their willingness to pay until a QoS (in this case: congestion) gap between the different classes is achieved as a direct effect of the gap in prices. For the case of two classes with linear congestion and separable utility functions including a parameter expressing the user-dependent preference for lack of congestion, Gibbens, Mason and Steinberg [9] have nicely demonstrated the resulting Nash equilibrium by introducing the notion of a "marginal user" whose utility from joining one of the classes does not depend on which class she chooses (i.e. is equal for both classes). In fact, due to the direct integration of user preferences, this model of PMP can already be interpreted as a key example of extending purely QoS-based charging as described with the model of Fig. 1 towards schemes that are based on QoE rather than QoS. The remainder of this paper will develop this transition in more detail.

Summarizing, we conclude that QoS-based charging has become a mature research topic within the area of Network Economics. On the other hand, charging for QoE has hardly received a similar attention in the literature so far, despite of the recent strong increase of interest in QoE-related topics. Therefore, in [20] we have provided a rather generic discussion about how to apply fundamental charging principles in a QoE context which has been further extended in [22]. In contrast, the present paper aims at contributing to the formal analysis of QoE-based charging. To this end, the subsequent section will present and discuss an extension of the model depicted in Fig. 1 which explicitly takes a new role of prices in QoE into account.

III. Charging for QoE: Extended Fixpoint Problem and Solution

In the previous section we have already covered the fundamental and inherent relationship between providing service quality and charging for it; for the case of QoS, this has led to a plethora of proposals for related pricing and charging schemes. Considering the transition from QoS to QoE which

[1] Note that, in classic microeconomics, the relationship between price and resulting demand is broadly captured through the concept of "price elasticity" [18], while in our model the impact of the demand level on the quality of the product adds another independent dimension.

puts the concept of service quality into a much broader and interdisciplinary framework, the question arises rather naturally which implications this has in terms of charging for QoE. In the rest of this paper, we will discuss this issue from a formal perspective and survey some current work on individual aspects.

Coming back to the rather simple model depicted in Fig. 1, we can summarize the related charging mechanism as follows: one or more appropriately monitored QoS parameters serve as input to a charging scheme which applies some tariff function in order to determine the price to be paid by the user as output. In this sense, the user pays for delivered QoS.

Transferring this approach to the case of QoE-based charging, it turns out that the situation is much more complicated here, especially because the role of pricing is gaining additional new facets. While we can safely assume that charges are still paid by the user for receiving a certain level of service quality, the level of service quality is now determined from the user perspective rather than on the networking level only. This implies a crucial difference: the charge to be paid appears not only as output of the applied charging mechanism, but at the same time becomes part of the user context, i.e. the Contextual Domain according to [15], if it comes to evaluating the Quality of Experience. In other words: the price to be paid for a certain service quality, or at least the expected price for it, may have a direct influence on the way the user evaluates this service quality. In this sense, it becomes part of the bundle of user expectations towards the delivered service.

A straightforward example for this janiform role of pricing is provided by well-known VoIP services like Skype which operate for free. In terms of user experience, the fact that people know that they do not have to pay anything for using Skype naturally influences their judging on the delivered service quality and increases their tolerance with respect to noise, delay or session cancellation effects. On the other hand, for premium communication services we may suspect an opposite behavior: the more the customer is expecting to pay, the higher his expectations concerning service quality will be. Later in this paper, this will be supported by experimental evidence.

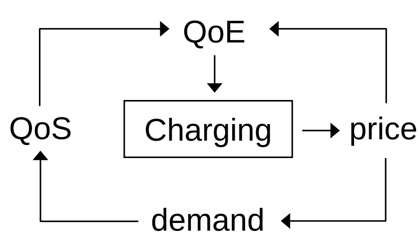

Figure 3. Model 2 (Charging for QoE)

In order to capture this role change, Fig. 3 provides an extended feedback model of charging for QoE. Observe that in line with the QoE models mentioned in Section II., QoS parameters continue to play an important role, but do no longer serve as direct input to the charging scheme. Instead, together with pricing (and several other factors depending, e.g., on the used application, which are not explicitly mentioned in the diagram, see for instance [26]) it serves as determinant for the QoE evaluation, and it is the joint result of the latter which now provides the essential input for the charging mechanism.

The formal description of this second model is more complex than it was the case with Model 1. Let again d indicate the demand, q the QoS, p the price as well as x the Quality of Experience. Then we have the following set of recursive equations:

price function $$p = p(q) \tag{4}$$

demand function $$d = d(p) \tag{5}$$

QoS function $$q = q(d) \tag{6}$$

QoE function $$x = x(q, p) \tag{7}$$

where equation (7) reflects the multidimensional nature of QoE. To simplify the situation, assume x to be separable, i.e.

$$x(q, p) = x_1(q) \cdot x_2(p) \tag{8}$$

which can be interpreted as follows: the QoE depends first of all on the underlying network QoS (*quality function* x_1), which is then weighted according to the user expectations due to the price to be paid (*expectation function* x_2).

Fig. 4 sketches a typical example for the second model, depicting the first five iterations (① ② ③ ④ ⑤) and indicating their convergence to the equilibrium state indicated by the arrow in the first graph. Again, all functions have been scaled to the unit interval [0,1], while the axes are left blank in order to enhance readability. Compared to Fig. 2, demand and QoS functions have been left unchanged. At the bottom of the figure, the functions x_1 and x_2 as introduced in equation (8) are depicted, where x_1 is assumed to be concave (we will justify this later), and x_2 is assumed to be linear with $x_2(1) = 0.5$, i.e. for a given QoS, a high price may reduce the QoE by 50%. In fact, linearity at this place does not provide more than a very rough approximation (we will discuss this difficulty in detail in Section IV.C), and the particular form chosen for equation (7) is also due to enhancing the resulting illustration of convergence, as scaling x_2 to the unit interval (as we have done with the other functions) would just further speed up the convergence without changing the basic qualitative behavior.

It is straightforward to derive that similar to Model 1, Model 2 has again an unstable trivial fixpoint for the chosen scenario at $(p^*,d^*,q^*,x^*) = (0,1,0,0)$; moreover, from Fig. 4 we learn that the additional feedback loop between price and QoE leads to the establishment of a second non-trivial (and stable) fixpoint. As mentioned, again the equilibrium price is marked with an arrow.

Indeed, this indicates a significant difference between both models. In order to justify the underlying assumptions, in the following section we will discuss in more detail the mappings and functional relationships, and present some results and empirical evidence from recent and currently running user studies.

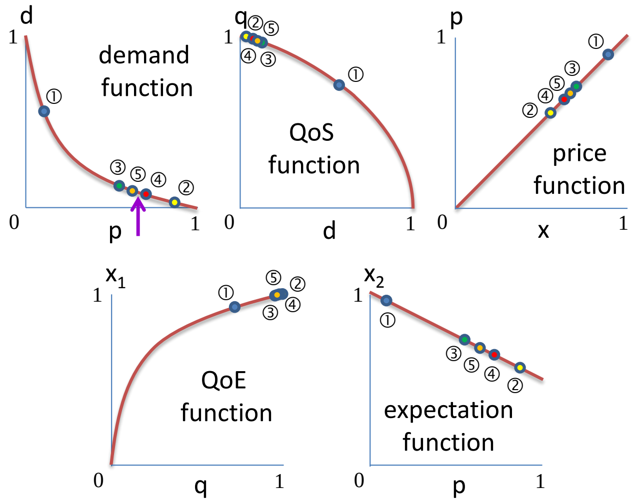

Figure 4. Non-trivial Stable Fixpoint for Model 2 (First Five Iterations)

IV. CHARACTERISTIC PROPERTIES OF UNDERLYING FUNCTIONS

In this section, we will have a closer look to the individual functions making up the system of equations (4)–(8), and further discuss their specific shapes.

A. *Demand and QoS Functions*

Describing demand curves subject to price setting has been widely discussed in the classical microeconomic literature. Amongst others, Friedman has extensively captured these relationships in [8], and typically recommends proposing non-linear curves for this interdependency. Following this rich body of literature, in our above analysis we have used a convex demand function (see Fig. 2 and Fig. 4 top). Note that we may safely date back the discovery of general relationships to economic research almost a century ago (see for instance the discussion of price elasticity of demand in A. Marshall's ground-breaking work [18], published in the first edition already in 1890), while particular demand curves still must be regarded as one of the most important business secrets of companies even today.

The QoS function is basically determined by the relationship between supply (capacity) and demand, as increasing network load in the case of finite capacities sooner or later leads to congestion and results in decreasing QoS. It is however difficult to agree on a standard model for such a function, as the impact of high load in a communication network significantly depends on congestion control and/or avoidance mechanisms in place. In any case, QoS metrics like packet loss rate (PLR) may not linearly be linked to demand [32]; instead it is typical that low and medium congestion level can easily be compensated by the network, leaving the PLR close to zero, whereas high levels of congestion may cause abrupt increases and/or a steep slope of the PLR curve. Therefore, we propose to use concave and monotonically decreasing QoS functions in our models, while, as already mentioned, the detailed characteristics of such a curve are subject to the chosen protocols and scheduling discipline.

B. *QoE Function: The Weber-Fechner Law*

Determining a functional relationship between network QoS and user-perceived QoE is one of the core topics of interest in current QoE research, with results depending heavily on the QoS parameter considered. Especially for the case of bandwidth, a series of recent studies has established a logarithmic dependency for a couple of interesting scenarios including VoIP and mobile broadband [26]. As discussed extensively in [23], a similar logarithmic dependency, known as Weber-Fechner Law, is considered to be characteristic for a wide range of the human sensory system (hearing, viewing, smelling), and as such has become fundamental to the entire research field of psychophysics. In a subsequent step, the above mentioned results also provide empirical evidence for the new established "WQL hypothesis" claiming that the relationship between **W**aiting time t and its **Q**oE evaluation on a linear ACR scale is **L**ogarithmic [5], which immediately bridges the gap towards psychological research on the perception of time.

For all these scenarios, we may consider bandwidth as a kind of stimulus which triggers certain QoE judgements on the side of the user – the larger the bandwidth, the higher the QoE. In our analysis, we follow this approach and propose concave functions like the logarithm as "QoE function" during the analysis of the fixpoint structure of Model 2 (see Fig. 4 bottom left). Note, however, that this is not the only fundamental law between QoS and QoE. For instance, if we consider QoS change in terms of an impairment rather than a stimulus (for instance due to an increasing packet loss rate), Fiedler et al. postulate an exponential dependency. This so-called "IQX hypothesis" [7] is highly interesting as well, its validity has already been verified for specific VoIP codecs (like iLBC) using PESQ.

C. *Expectation Function: M3I User Study*

The expectation function x_2 is probably the least explored one in our model. For the particular scenario of video quality, D. Hands [10] reports on an experiment performed within the EU project M3I in 2001 where user expectations with respect to pricing have been controlled by the simple step of assigning each user arbitrarily to one of three classes (gold, silver, bronze) and convincing her that gold class members are charged higher than silver class members etc. The participants have then been presented identical video material where quality differentiation has been realized via a variable frame rate (between 1 and 25 frames per second). For each video, QoE parameters like acceptability, MOS (Mean Opinion Score) evaluation and willingness to pay have been collected.

As an interesting result of this user trial, it turns out that users who have been classified as gold customers evaluate for instance the acceptability of an offered service quality significantly lower than silver and bronze users. Also with respect to willingness to pay, clear differences between the three classes have been observed, see [22] for a more detailed discussion. Thus, we may conclude that there is evidence for an influence on expected charges on the QoE evaluation results, however there is a clear need for further research before we are in a position to propose to determine reliably the shape of a suitable expectation function. For the time being, we have therefore included a linear function (see Fig. 4 bottom right) assuming that high tariffs may reduce the QoE value by 50%.

D. Price Function

As far as the mapping from service quality to the price actually charged is concerned (Fig. 2 righthand side and Fig. 4. top row righthand side), there is a variety of options depending on the specific scenarios (for instance applications producing elastic traffic like file download or email vs. applications with non-elastic traffic characteristic like voice over IP or video on demand), see [20] for further details. For reasons of simplicity, for both our models we have chosen the identity function, i.e. the user is charged in proportion to the delivered quality.

E. ETICS User Trials

Partially inspired by the M3I experiments described above [10], a larger-scale user trial has recently been conducted within the ETICS project [17], in order to address the notoriously difficult task of approximating the users' willingness to pay for enhanced network quality from classical QoE curves and thus to enhance our understanding of the key forces behind the interweaved quality-price relationship leading to purchases [24]. The goal of this user trial was to empirically investigate the users' willingness to pay for improved network video quality by adapting network parameters in direct relation to purchasing decisions. While in principle every QoS metric could serve as a suitable starting point, for our experiments we have chosen the packet loss rate (PLR) for reasons of technical feasibility, intuitiveness and comparability to related QoE results available from literature.

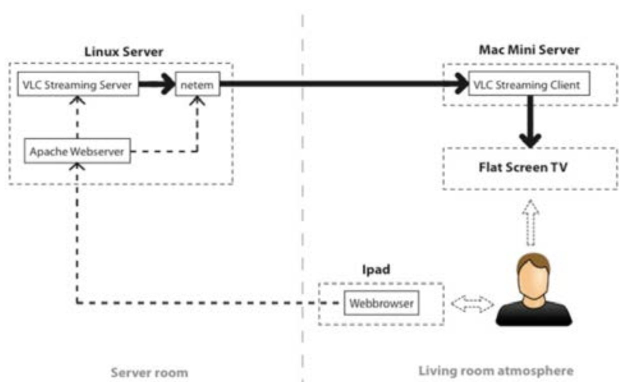

Figure 5. Technical Setup of the ETICS Study (cf [24])

The technical setup of the ETICS study is sketched in Fig. 5. A large collection of video stream stored on a Linux server allows test participants to choose suitable content which is matching their interest. The video transmission quality is impaired in real-time through a netem[2] command which allows to set random packet loss rates in an arbitrary way. The videos are streamed via a Mac Mini server to a directly connected flat screen TV.

All in all, more than 40 users have participated in this test which has been conducted in FTW's i:lab facilities[3] in the fall of 2011, see [24] for demographic details. In order to be as close to reality as possible, we have followed the approach of [10] and have provided test participants with real money (10 Euro in total), leaving it entirely to their decision whether to spend this money during the trial for enhancing the network transmission quality (and hence the perceived video quality) or to save it for later individual spending.

Note that this experimental setting for video on demand (VoD) service quality covers a significant portion of Model 2, starting from varying QoS conditions which lead to differentiated quality perception; at the same time, we are probing explicitly the users' willingness to pay for the resulting video QoE. However, the additional feedback cycle from price to QoE which is characteristic for Model 2 has not been addressed in this experiment.

Fig. 6 depicts the overall average spending behavior for each of the 44 test participants. Note that the maximum amount which could be spent for one video has been set to € 1.50 in accordance with current tariff structures in the VoD business. As an important result, we observe a broad willingness to purchase network quality upgrades; in fact, around 20% of the participants decided to spend always the maximum price and thus went for optimal QoE throughout, whereas roughly 10% of the participants were behaving extremely reluctant and did not spend anything for quality upgrades. The remaining 70% of the test population have used the offer to adapt their quality experience with rather fine granularity to their actual interests and needs. Thus, the trial has also revealed a set of interesting differences in terms of the user's strategic behavior which are further discussed in [24].

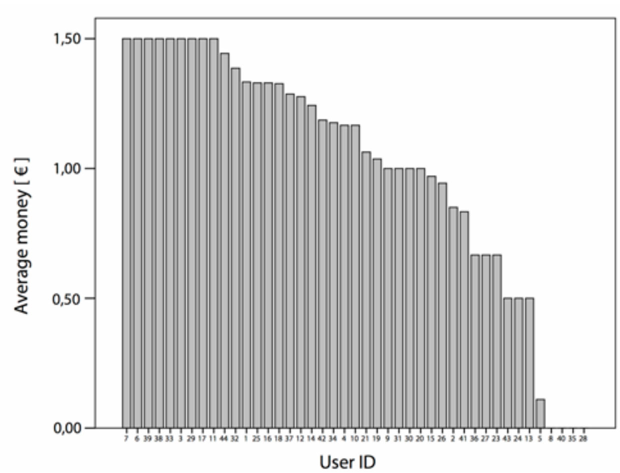

Figure 6. Average Actual Spending for QoE (per movie per user)

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[2] see http://www.linuxfoundation.org/collaborate/workgroups/networking/netem; last access 20-07-2012.

[3] see http://www.ftw.at/portfolio/i-lab?set_language=en; last access 20-07-2012

F. *Cognitive Dissonance Phenomena*

Building upon the ETICS trials described in the previous section, we will now discuss an interesting discrepancy between user satisfaction and their quality estimation inferred from the trial results. Questioning the participants about their quality acceptance ("Would you consume this video in the presented quality at home?"), the study of [24] has revealed surprisingly positive results, even for low quality levels. Also the subjective video quality assessments were unexpectedly positive and uncritical. Therefore, in [25] we propose following the socio-psychological theory of cognitive dissonance [6] for a proper explanation of these inconsistencies based on human irrationality. Facing a set of contradictory cognitions, e.g., low price and low quality, the decision-making process related to purchasing requires the individual to find an internal equilibrium, i.e., a decision how contradictory cognitions are personally handled. In our case, this means that, while poor video qualities may be rated equivalently by individuals in pure quality ratings via Mean Opinion Score (MOS), an active purchasing decision (probably at low price) positively biases the acceptance rating of customers, i.e., even poor video qualities would tend to receive high acceptance rates.

While such a sugarcoating does not only give strong support for the existence of a price loopback on quality perceptions and service satisfaction, this also renders opportunities for intentional economic utilizations. Although the customer segment of discount offers (low cost and low quality) has not attracted sufficient interest in networking recently, it may serve as an interesting use case supporting the transition to quality differentiated services. Enforcing an active decision on a low price and low quality offer (due to subjectively less attractive other offers) may still educe acceptable customer satisfaction on average. Hence, the introduction of higher QoS offers may intentionally be linked to the proposition of low quality offers.

Economically, the understanding of cognitive dissonance may also be used to influence purchasing decision through advertisements or branding effects in general. While a product may be too expensive to be rationally purchased, the advertisement gives rise to the positive product aspects appealing to the positive cognitions. In turn, a user may selectively a priori or a posteriori collect or even distribute such information in order to justify and blandish an expensive and hence irrational purchase: Why should we accent the price of our new luxury car, when we can boast about its performance? Similar principles may be transferred to networking, where users need to be given arguments blandishing negative aspects of upgrading decisions. Hence, advertisement may be used for internationally modifying the discrepancy between pure quality ratings and the users' willingness to pay for this quality.

G. *Discussion*

In Section IV., we have surveyed related work as well as recent empirical evidence in order to better understand the shapes of the individual functions which make up the feedback cycles of Model 1 and Model 2. Whereas demand and price functions have already been treated in the standard economical literature to a far more than sufficient extent, the mapping of demand (traffic) to QoS is heavily depending on congestion control algorithms and protocols employed in the network. Determining the shape of the QoE function which represents the relation between user-perceived quality and network QoS is subject of intensive current research activities, which have led to first results like the Weber-Fechner Law and the IQX hypothesis. Moreover, the topic of quantifying the impact of price expectations onto QoE evaluation is still in its infancy – we have presented some indicative evidence, but there is a clear need for much more research into this direction. Hence, altogether the individual interrelationships integrated into Model 2 are far from being equally mature; nevertheless we argue that the functions we have chosen to analyze the fixpoint problem in Section III. can be considered as representative for a broad set of interesting and relevant scenarios.

V. CONCLUSIONS

This paper has been devoted to investigating a simple model for the interplay between network QoS, user perceived QoE, the prices to be charged for providing quality, the traffic (demand) generated due to the tariff schemes employed, and back to implications for network QoS due to resulting congestion in the network. It turns out that all these dependencies need individual treatment using an interdisciplinary approach joining economical, psychological and technological methodologies, and thus represents a highly interesting example for a research topic in the area of communication ecosystems. Analyzing the resulting feedback cycle reveals that QoS-based charging leads either to provisioning best effort services for low fees which do not depend on the offered quality (i.e. basically flat rates), or highly expensive top-level quality. However, we have seen that none of these solutions is of interest to the network operators which first of all aim at maximizing their revenue. But as soon as we consider QoE as a fundamental quality concept to be charged for, the situation changes and a stable, non-trivial fixpoint appears which balances the tradeoff between user expectations, offered QoS and price.

Of course, the fact that today flat rate schemes can safely be considered to be the dominating way to charge for communication traffic and services has to be ascribed to a plethora of reasons, including the customer interest in simple, transparent and reliable tariffs which do not deliver major surprises at the end of the month. Nevertheless, we believe that our analysis provides at least some indication that a stronger focus on user perceived quality might also change the perspective on future charging mechanisms and contribute to re-establishing a way of tariffing which avoids the notorious "tragedy of the commons" mentioned in the beginning and aims at achieving economic efficiency instead.

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REFERENCES

[1] ITU-T Rec. E.800: Definitions of terms related to quality of service. International Telecommunications Union, Geneva, August 1994.

[2] ITU-T Rec. P.10: Vocabulary for performance and quality of service, Amendment 2: New definitions for inclusion in Recommendation ITU-T P.10/G.100. International Telecommunications Union, Geneva, 2008.

[3] C. Courcoubetis, R. Weber: Pricing Communication Networks. Wiley, 2003.

[4] K. De Moor, I. Ketyko, J. Wout, et al.: “Proposed Framework for Evaluating Quality of Experience in a Mobile, Testbed-oriented Living Lab Setting”. Mobile Networks and Applications, vol. 15 no. 3, pp. 378–391, Jan 2010.

[5] S. Egger, P. Reichl, T. Hossfeld, R. Schatz: “"Time is Bandwidth"? Narrowing the Gap between Subjective Time Perception and Quality of Experience”. Proc. IEEE ICC’ 2012, Ottawa, Canada, June 2012.

[6] L. Festinger: A theory of cognitive dissonance. Stanford University Press, 1957.

[7] M. Fiedler, T. Hossfeld, P. Tran-Gia: “A generic quantitative relationship between quality of experience and quality of service”. IEEE Network, vol. 24 issue 2, pp. 36-41, March/April 2010.

[8] M. Friedman: Price theory. Transactions Publishers, New Brunswick, NJ, USA, 2007.

[9] R. Gibbens, R. Mason, R. Steinberg: “Internet Service Classes under Competition”. IEEE Journal of Selected Areas in Communications, vol. 18 no. 12, pp. 2490-2498, Dec 2000.

[10] D. Hands (ed.): M3I user experiment results. Deliverable 15/2, EU FP5 Project M3I (IST 1999-11429), 2002.

[11] T. Hayashi, A. Takahashi: “QoE Assessment Method for Video Quality and Pricing in IPTV Services”. ETSI Workshop on Effects of Transmission Performance on Multimedia QoS, Prague, Czech Republic, June 2008".

[12] R. Jain: “Internet 3.0: Ten problems with current internet architecture and solutions for the next generation”. Proc. IEEE/AFCEA Military Communications Conference 2006 (MILCOM’06), pp. 1-9, Washington, USA, Oct. 2006.

[13] K. Kilkki: “Quality of Experience in Communication Ecosystems”. Journal of Universal Computer Science, vol. 14 no. 5, 615-624, 2008.

[14] K. Kilkki: “Next Generation Internet and Quality of Experience”. Workshop on Socio-Economic Issues of NGI, Santander, Spain, June 2007.

[15] K. Laghari, N. Crespi, K. Conelly: “Towards Total Quality of Experience: A QoE Model in Communication Ecosystem”. IEEE Communications Magazine, vol. 50 no. 4, pp. 58-65, April 2012.

[16] P. Le Callet, S. Möller, A. Perkis et al.: Qualinet White Paper on Definitions of Quality of Experience. Output version of the Dagstuhl Seminar 12181, Dagstuhl, June 2012.

[17] N. Le Sauze, A. Chiosi, R. Douville et al.: “ETICS: QoS-enabled Interconnection for Future Internet Services”. Proc. Future Network & Mobile Summit 2010, Florence, Italy, June 2010.

[18] A. Marshall: Principles of Economics (revised edition). London, Macmillan, 1920.

[19] A. Odlyzko: “Paris Metro Pricing for the Internet”. Proc. ACM Conference on Electronic Commerce (EC'99), pp. 140-147, 1999.

[20] P. Reichl: From Charging for Quality-of-Service to Charging for Quality-of-Experience. Annals of Telecommunications, vol. 65, no. 3, pp. 189–199, Springer, 2010.

[21] P. Reichl: “From ‘Quality-of-Service’ and ‘Quality-of-Design’ to ‘Quality-of-Experience’: A Holistic View on Future Interactive Telecommunication Services”. Invited Paper, SoftCOM’07, Split, Croatia, September 2007.

[22] P. Reichl, B. Tuffin, P. Maillé: “Economics of Quality of Experience”. In: A. M. Hadjiantonis, B. Stiller (eds.): Telecommunication Economics. Springer LNCS 7216, pp. 158-166, 2012.

[23] P. Reichl, B. Tuffin, R. Schatz: “Logarithmic Laws in Service Quality Perception: Where Microeconomics Meets Psychophysics and Quality of Experience”. Telecommunication Systems Journal (Springer), vol. 55 no. 1, January 2014.

[24] A. Sackl, P. Zwickl, S. Egger, P. Reichl: “The QoE Alchemy: Turning Quality into Money. Experiences with a Refined Methodology for the Evaluation of Willingness-to-Pay for Service Quality”. 4th International Workshop on Quality of Multimedia Experience (QoMEX’12), Yarra Valley, Australia, July 2012.

[25] A. Sackl, P. Zwickl, S. Egger, P. Reichl: “The Role of Cognitive Dissonance for QoE Evaluation of Multimedia Services”. Proc. Quality of Experience for Multimedia Communications Workshop (QoEMC), IEEE Globecom 2012, Anaheim, CA, Dec. 2012.

[26] R. Schatz, S. Egger: “Vienna Surfing - Assessing Mobile Broadband Quality in the Field”. Proc. ACM SIGCOMM Workshop on Measurements Up the Stack (W-MUST), Toronto, Canada, August 2011.

[27] R. Schatz, P. Reichl: “Quality of Experience - More Than Just Another Buzzword?” 11th ITG-EuronNF Würzburg Workshop on IP, Würzburg, Germany, August 2011.

[28] B. Stiller: “Quality-of-service issues in networking environments”. Technical Report TR-380, Computer Laboratory, University of Cambridge, UK, 1995.

[29] B. Stiller, P. Reichl, S. Leinen: “Pricing and Cost Recovery for Internet Services: Practical Review, Classification and Application of Relevant Models”. NETNOMICS - Economic Research and Electronic Networking, vol. 3 no. 1, March 2001.

[30] A. G. Tansley: “The Use and Abuse of Vegetational Concepts and Terms”. Ecology, vol. 16, no. 3, pp. 284-307, July 1935.

[31] B. Tuffin: “Charging the Internet without bandwidth reservation: an overview and bibliography of mathematical approaches”. Journal of Information Science and Engineering, vol. 19, pages 7-5-786, 2003.

[32] S. Wahlmüller, P. Zwickl, P. Reichl: “Pricing and Regulating Quality of Experience”. Proc. 8th Euro-NF Conference on Next Generation Internet (NGI 2012), Karlskrona, Sweden, June 2012.