What Quality Means for Internet Users: A Guide to Selecting your ISP

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***Abstract*— Traditional QoS related studies handle technical KPI (key performance indicators) which are supposed to measure the quality of telecommunication services. However, while trying to select an ISP, most users are not able to choice the most suitable one for their needs. This papers presents the application of a perceived QoS based model as a tool for helping users in this kind of decisions. Our model represents the impact of each one of the objective performance indicators on the perception of quality for a particular user profile. Once the model is built common users will be able to identify the best combination of performance indicators for their pattern of use of the different Internet services. We have used velocimetro.org, a website that provides measurement services for common users, in order to feed the model with real world values and compare 4 different Spanish ISPs.**

I. Introduction

MOST of the efforts related to "quality" in telecommunication systems have addressed the technical point of view. So, both research community and industry have developed a great variety of architectures, systems and protocols in order to identify, measure and manage a set of well-known parameters (KPI, Key Performance Indicators).

These indicators are supposed to determine the quality in the information transference process. However, they are mainly related to network performance issues, rather than to the actual quality of the service perceived by end users. In fact, in many cases, there is no clear relationship between the objective performance measured with these indicators and the users' satisfaction. Moreover, the impact of the objective performance may vary depending on many factors associated with users' profiles. For example, office users will probably demand some characteristics that most of the common users will not ever know anything about. There are other relevant factors, such as the technical level of the users, their needs or what they use Internet for, that do have an impact on users' satisfaction. So, a simple objective analysis of quality does not appear to be enough.

Furthermore, as Internet access spreads all over the world, end users have at their disposal more and more alternatives to connect to the Internet. In such a market environment, it is difficult for common users to distinguish the best choice for their needs. In many cases indeed, people select their ISP based on variables not associated to performance issues. First, users are greatly influenced by advertising campaigns that offer an amount of bandwidth at a cost. And secondly, users also take into account the reputation of the provider. This issue is discussed in [1] for web services and it can be also applied to Internet access. However, it is clear that the characteristics of the Internet access technologies affect the performance of services [2] and users' satisfaction. For instance, [3] analyzes the effect of delay introduced by access networks into performance of networked games. Besides, not just the internal connectivity of the ISP is significant in users' perceptions, but also the inter-ISP connectivity provided must be considered. For example, in [4] and [5] authors analyze the impact of end-to-end delay into several applications.

Unfortunately, the vast majority of users are not used to handling technical parameters. Therefore, they are not able to assess the quality of their Internet Service Provider with simple technical KPI, such as throughput, delay, losses or jitter. They may probably know that the one with highest throughput and lowest delay, losses and jitter is the best one. However, they will not know which combination may be the most suitable one for their particular needs or the relative importance of each parameter.

On the other hand, if you ask any common Internet user what she demands from her ISP, she will probably give you a lot of answers: "I would like files to be downloaded faster", "I would like games to play smoothly", "I would like on line radios to sound well", etc... So, common users do have an idea of quality and know what they want for their Internet access, but traditional studies do not provide a way to translate these subjective perceptions into objective parameters and vice versa.

In this article we present the application of a general perception based QoS management model in order to carry out this translation and to provide users with a tool to effectively compare their ISP.

The paper is organized as follows: in section 2 we describe the QoS management model and how it addresses both subjective and objective faces of quality in Internet access. In section 3 the Velocimetro.org tool is shown, that provided us with the measurements in order to feed the model. Later, in section 4, we describe the simulation carried out and the main results. Finally, in section 5, we summarize the conclusions derived from the data analyzed and future work.

II. PQoS Management Model

The model we have proposed tries to solve the mismatch between users' satisfaction and traditional objective QoS studies described in the introduction, with the aim to provide a concrete methodology and notation. The basis of the model were presented in [6]. The model has a matrix structure similar to that presented in QFD [7] quality methodology and ITU-T G.1000 recommendation [8], that allows us to

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display the complex relationships between the agents involved in the provision of services and user perceptions for different services.

First of all, for each service, we must identify those perceptions relevant for gauging the QoS perceived by final users. We use the term Perception to refer to those aspects related to quality of service that have an impact on users' satisfaction when accessing a specific service (i.e., interactivity, file downloading speed, audio or video "quality", reliability,etc...). The perception of quality will be satisfactory or not depending on multiple subjective parameters, such as users' expectations, prior experiences or perceptions. In fact, depending on the type of user considered, we can refer to different perceptions; i.e., the perception of a Web service for a user who wants to accommodate a website on a server is not exactly the same as that of end users who wish to access that information.

On the other hand, in the objective aspect of the model, we have to identify the agents that take part in the service provision and the KPI that allow us to evaluate their performance level.

Finally, we must analyze the relations between a given perception of a service and the functions provided by different agents.

Since both services, perceptions, agents, capabilities and KPI are considered in our abstract model, it provide us with a graphical representation between subjective satisfaction and objective internal parameters from each agent.

The specific formulation behind the model is out of the scope of this document but the general calculus process can be summarized as follows:

1) Analyze different users profiles.
2) Establish the relationships between the simple KPIs and end-to-end objective performance for different services.
3) Establish the relationship between objective performance and a specific perception.

A. *Analyze different users profiles*

In this first stage we must identify different types of users. For each of these types of users we have to calculate:

- The relative importance of each service for this particular type of user.
- The most important perceptions associated with each service and their relative weights.

We use the Analytic Hierarchy Process (AHP) [9], a multi-criteria decision tool in order to identify the most important services and their relative importance.

B. *End-to-end objective performance vs. basic KPIs*

In the second stage, we use Traffic Engineering and simulation tools in order to establish the relationship between each agent's KPIs and end-to-end objective performance. Hence, we can simulate how different contributions of each agent to the service provision do or do not have an impact on final end-to-end objective performance.

C. *Users' perceptions vs. objective performance*

In the third stage, we make use of the results of empirical studies that try to assess the impact of objective performance on users' satisfaction, in order to establish a relationship between end to end objective performance and subjective users' perceptions.

III. The Velocimetro Tool

The Velocimetro.org platform [10] offers a simple and fast way to let users know the performance of their Internet connectivity. Currently, this service allows users to measure the speed and round-trip time (RTT) from their platform to three servers distributed across the Internet. The most relevant characteristic of Velocimetro.org is that user measurements are stored in a repository, which allows us to analyze these results and obtain a series of statistical conclusions from this dataset.

For example, in Fig. 1 we can see the average HTTP throughput throughout 2005 for different ISPs (ADSL 1Mbps access technology).

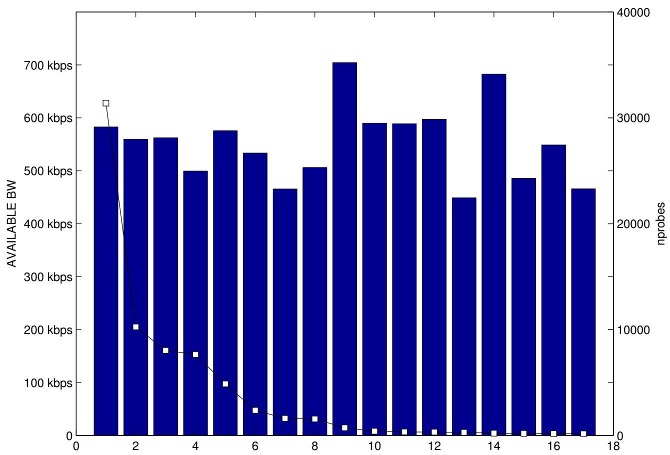

Fig. 1. Different ISPs' average HTTP throughput and ntests

A. *Performance measurements*

The first performance parameter available for end users in Velocimetro.org platform was the measurement of their Internet connection speed. Operational fundamentals of Velocimetro.org are detailed in [11]. Basically, the system maintains a web application based on JavaScript, so that, when users access the webpage, their browser is redirected to each of the dedicated servers to perform a set of data transferences. Since the technology provides the capability of managing time variables in the browser, we can estimate both download and upload speeds with regard to each destination. Velocimetro.org operates since 2002 and is mainly oriented to Spanish users. As a result, we located a server in Espanix (Spanish inter-ISP neutral data interchange point) that allows us to estimate the intra-ISP performance. Besides, we keep two extra destinations in Europe and the USA, intended to provide performance estimations for the external connectivity of the ISP.

We have also recently added a new functionality intended to estimate the RTT users experience from their platforms to measurement servers. The test operation remains similar to the speed test, taking the measurements at application level. In this case, we need to emulate as accurate as possible the "network ping" without requiring end users to install extra software in their platforms. Basically, the operation is as follows: the browser requests already cached objects to force HTTP NotModified messages from the server and we take the total time between the request and the response.

B. Results storage

For each performance test made in Velocimetro.org, we save in our database different parameters such as mean, maximum and minimum values. Moreover, we also store other several data, such as the particular ISP of the user, type and maximum speed of Internet access technology, date and time slot and post code. During last years we have gathered a great amount of sample values that allow us to carry out statistical analysis that show the evolution of Internet access in Spain. Registered users can access comparative reports in order to contrast the performance they are experiencing with results from other users that belongs to the same or other ISPs, which can operate in the same or other regions. We also provide periodical publicly available reports that show the performance experienced by Velocimetro.org users, including regional maps for different ISPs - Internet access technologies. This can be useful for ISPs, which can easily estimate the actual speed their customers are obtaining.

C. Discussion about measurement methodology

The measuring methodology adopted for Velocimetro.org is based on "code instrumentation". This methodology bases its operation on adding extra code to the service (e.g., to web pages) in order to establish performance measurements. As a result, service performance measurements can be made with no need of additional specific software in client-side. In our case, since we instrument our specific test web pages instead of common web pages, we consider this methodology as "active probing through code instrumentation". The main reason for adopting this methodology is that users are usually reluctant to install extra software in their equipments in order to accomplish this kind of performance measurements. Years of experience offering the service demonstrate the acceptability of this measurement methodology among common end users. As a result, we keep a fully-distributed measurement platform with a huge number of measurement points (Velocimetro.org users' platforms) difficult to achieve with other kind of methodologies. However, the main drawback associated to this measurement methodology is that we can not assure that obtained values are one-hundred percent reliable. Measurements are made by using end users' web browser, so we must take into account that the status of user platform may be affect the measurement. Nevertheless, for statistical processing with such a high number of samples we can assume the existence of these "outliers".

The service stores all resulting data from the tests to perform further filtering and analysis that led to the publication of periodical reports in our site. From ISPs' point of view, this is a very useful tool to estimate the actual speed their customers are obtaining.

IV. Simulation and analysis of the results

A. Application of the model

We have applied the different stages described in section 2 in order to build up a complete model of users satisfaction toward their ISPs.

We have identified three major user profiles as our target audience: Office users, SOHO users and Home users.

After that, we have evaluated the importance of different traditional internet services (FTP, WWW, e-mail, VoIP, VoD, Games and Customer Support Service). First, we have applied the AHP method to this services list for each user profile. Then, we have normalized the AHP coefficients for most important services only, so that, for those with a relative importance below a certain level $(0, 1)$ we have considered no valuable impact on user satisfaction for these services. At a latter stage, we have repeated the process in order to find out the most important perceptions for each user profile and their relative weights. In Table I we can see the result of this process for office, SOHO and home users.

User type	WWW	E-MAIL	VoIP	Games	Customer Support
Office	0,3054	0	0,4093	0	0,2852
SOHO	0,3043	0,2163	0	0	0,4795
Home	0,3969	0	0	0,2306	0,3724

TABLE I

AHP RESULTS FOR DIFFERENT SERVICES AND USER PROFILES

In the second stage, related to linking simple KPI to end-to-end objective performance, we have used real end-to-end measurements, by feeding our model with data collected with the Velocimetro.org tool. For the VoIP and online games services, the end-to-end objective performance has been directly calculated from end-to-end delay (and losses).

Finally, in the third stage, we have collected most commonly accepted subjective empirical studies in order to model the relationships between subjective and objective facets of the model.

- For the *web service*, several studies have evaluated the impact on users' satisfaction of non-funcional subjective aspects [12], [13] such as accessibility, ease of use, security, etc. Since all of these aspects depend on the contents of the page but not on the transference process, we have focused our analysis on the perception related to "interactivity or browsing speed" which is closely related to network issues. Thus, we have used the results in [14] and [15], where the authors provided a logarithmic formula for modeling this dependence (see eq. 1).

$$MOS = 6 - log_2(T_{down}) | 1 \leq MOS \leq 5 \quad (1)$$

- For *VoIP service* the most commonly used relationship between satisfaction and end-to-end objective performance is related to "speech quality" and can be derived from the e-model [16] as seen in eq. 2.

$$MOS = \begin{array}{l} 1 for R \leq 0 \\ 1 + 0.035 \cdot R + R \cdot (R - 60) \cdot (100 - R) \cdot 7.10^{-} \\ 4.5 for R \geq 100 \end{array} \quad (2)$$

where R depends on the codecs used and the network performance following the expression in eq. 3.

$$R = R_o - I_s - I_d + A \quad (3)$$

We consider S/N at 0 dBr point as $R_o = 93.2$. Impairments simultaneous to voice signal I_s, impairments delayed after voice signal I_d and the advantage factor A are calculated as in [16] and [17].
- For the *online games service* [18]–[21] several authors have analyzed the impact of the delay on the players' satisfaction. Most of them simply establish a maximum tolerable delay threshold that users can stand. In order to provide a detailed relationship we have used the minimum and maximum delay thresholds as parameters to build up a family of utility functions as in [22] with the expressions in eq. 4 and 5.

$$s(x) = 5 - 4 \cdot a \cdot \ln(b \cdot x + c) \quad (4)$$

where

$$\begin{array}{l} a = \frac{1}{p-10} \\ b = \frac{(\exp(1/a)-1)}{(S_{max}-S_{min})} \\ c = \frac{(S_{max}-S_{min} \cdot \exp(1/a)}{(S_{max}-S_{min})} \end{array} \quad (5)$$

With a minimum noticeable delay of 20 ms. and maximum tolerable delay threshold of 150 ms. we have obtained the family of utility functions in Fig. 2. Depending on the value of the p parameter we can choose between more or less "tolerant" users. In our simulations we have used $p = 11$ for "half tolerant" players.
- For the *customer support service*, we have once again applied AHP methodology to identify the most important perceptions: "response time", "accuracy of response", "staff knowledge" and "staff courtesy". We have calculated the overall satisfaction for this service for each ISP and user profile considered.

B. Simulation

We have coded the model derived from the application of our perception QoS based model to the problem of choosing the best ISP. Once the simulation tool was developed, we wanted to use it to compare real ISPs, in order to get useful data about actual users' satisfaction. Therefore, we have considered the four "most popular" (with the highest number of tests) Spanish ISPs from the Velocimetro.org database (see Fig. 1).

Then, we have used bandwidth and delay data collected from real users throughout 2005 in order to feed our simulation model.

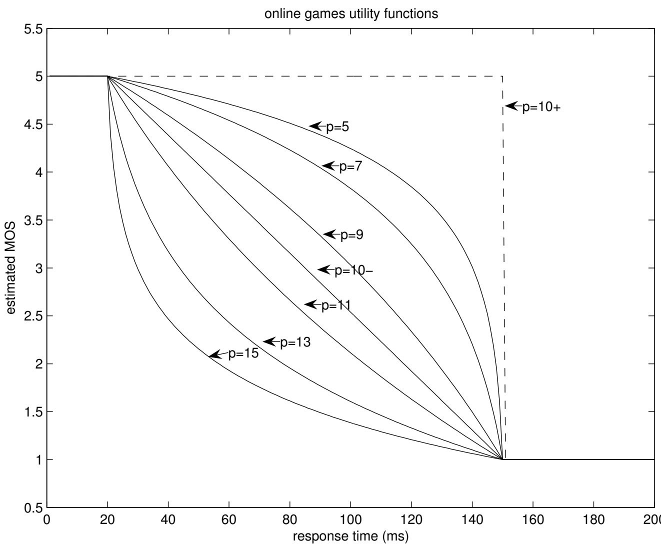

Fig. 2. Family of utility functions for online games service

With these data we have run different simulations of the PQoS model in order to calculate estimated satisfaction for three different users profiles considered (office, SOHO and home users).

Each one of the profiles has been considered in 4 different points of the simulation model.

- *Usage temporal pattern*. We had to consider the temporal usage pattern of each user throughout a typical day. Hence, for Office users we have assumed typical 9to5 "weekdays" jobs, discarding ISP behavior out of these periods. For SOHO users the period was set from 9 AM to 7 PM (weekdays). Finally, for Home users we have considered more extensive use from 6 PM to 12 PM (weekdays) and from 10 AM to 12 PM in the weekends, to emphasize the behavior of users who have "semi-flat ADSL access" contract (no additional fare in those periods).
- *Service usage pattern*. The Velocimetro.org tool consists of three servers located in Spain, US and Europe. Each one of the user profiles shows different browsing, VoIP-calling and gaming traffic use pattern. We have taken into account these different behaviors by weighting the relative importance of each server for each user type.
- *Services weights*. We have used the AHP coefficients shown in Table I.
- *Perceptions weights*. For Web, VoIP and online games services there was a single perception ("browsing speed", "speech quality" and "interactivity or playing smoothness" respectively). For the customer support service we have carried out the AHP method in order to calculate relative importance of each perception for different user profiles.

C. Results

The results for each user profile are shown in Fig. 3, 4 and 5. We have plotted "average", "maximum" and "minimum" MOS for each ISP and user profile throughout a whole weekday, in 15 minutes intervals. The terms average, maximum and minimum refer to three particular situations:

- Average situation: Average throughput, delay and losses.
- Best possible situation: Maximum throughput, minimum delay and losses.
- Worst possible situation: Minimum throughput, maximum delay and losses.

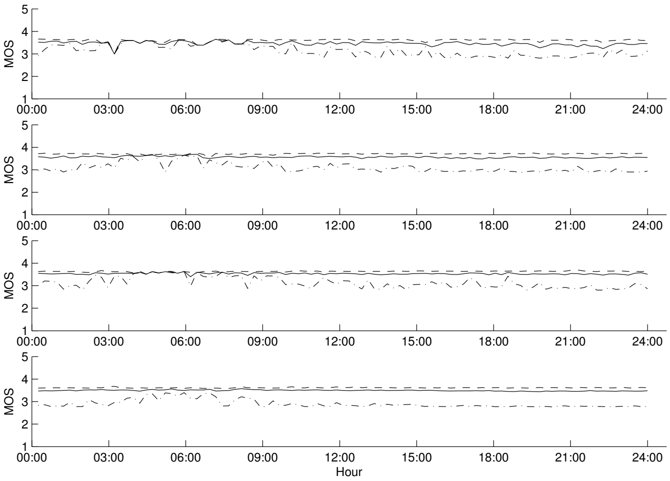

Fig. 3. MOS variation for 4 ISPs considered. Office Users.

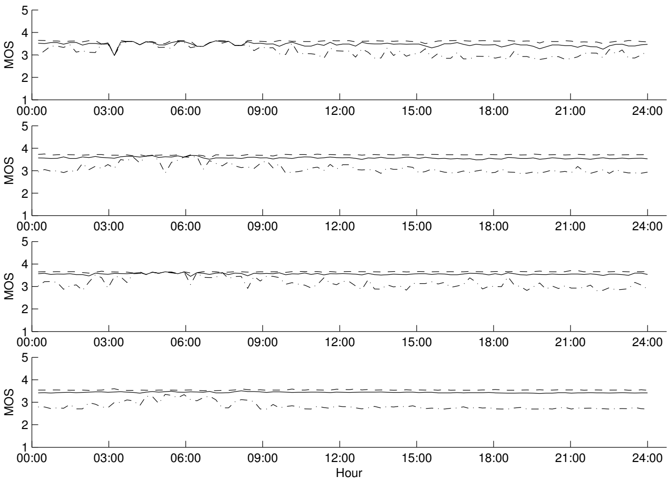

Fig. 4. MOS variation for 4 ISPs considered. SOHO Users.

As we can notice from the figures, the average MOS line does not match with the traditional "average" meaning due to our particular definition. In fact, these three definitions try to point out the fact than, in some cases, using only the average values of technical parameters can hide certain degradation situations.

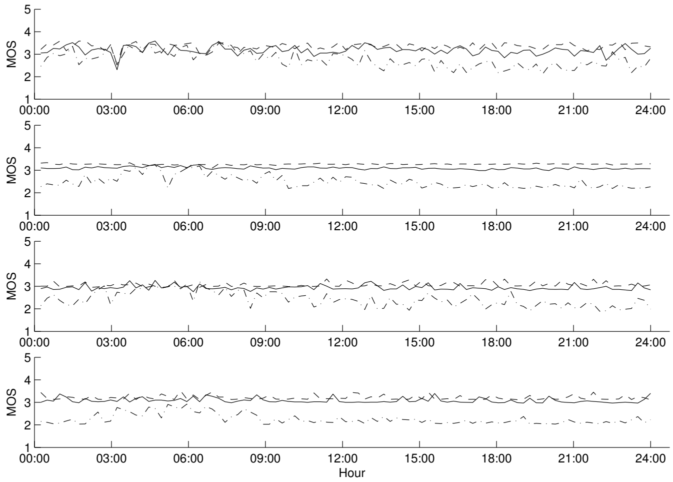

Fig. 5. MOS variation for 4 ISPs considered. Home Users.

After that, we have applied the temporal usage pattern for every user profile in order to weight the simulated MOS throughout a day and calculate a single average, maximum and minimum score for the simulated MOS (for every ISP-user profile). The results are shown in Tables II, III and IV.

ISP	Average MOS	Max MOS	Min MOS
ISP 1	3,44	3,59	3,14
ISP 2	**3,56**	3,71	3,10
ISP 3	3,53	3,63	3,13
ISP 4	3,49	3,61	2,90

TABLE II
AVERAGE, MAX. AND MIN. MOS FOR OFFICE USERS

ISP	Average MOS	Max MOS	Min MOS
ISP 1	3,46	3,59	3,15
ISP 2	**3,57**	3,70	3,10
ISP 3	3,56	3,65	3,16
ISP 4	3,44	3,55	2,83

TABLE III
AVERAGE, MAX. AND MIN. MOS FOR SOHO USERS

ISP	Average MOS	Max MOS	Min MOS
ISP 1	**3,17**	3,34	2,76
ISP 2	3,09	3,26	2,49
ISP 3	2,93	3,06	2,42
ISP 4	3,07	3,21	2,26

TABLE IV
AVERAGE, MAX. AND MIN. MOS FOR HOME USERS

After analyzing these tables we can conclude:

- There is no "best-for-all" ISP. For Office and SOHO users the winner (in average) would be ISP number 2, while it would be the ISP number 1 for home users.
- There is no single classification, because there are several objective and subjective aspects (temporal and spatial

service usage pattern, relative importance of the services and perceptions, non-technical issues...) that do have an impact on overall users' satisfaction.

- There appears different levels of uncertainty in the MOS estimated for each ISP (due to the gaps between maximum, minimum and average MOS). This uncertainty could affect the election of some users, since some of them would prefer less but more stable ISP, rather than a ISP with higher average quality but with periods of high degradation.
- There is not a single technical parameter in order to measure the quality end users will finally achieve. In fact, although it was the ISP number 1 the one with higher throughput levels (see Fig. 1), it has not been the winner in the two first "categories". Since throughput would be one of the most significant criteria for most users to make their choice we can see that our model can provide them with a more suitable decision tool.

V. Conclusions and future work

We have presented the application of a general PQoS based model in order to provide users with a tool to effectively compare different ISPs. The model takes into account the relative importance of the services for each kind of users, as well as their service usage pattern.

We have chosen three different user profiles (Office, SOHO and home users) in order to simulate their satisfaction towards four different Spanish real ISPs.

Once we have applied our perceived QoS base model to this particular situation, we have fed the model with data collected with the Velocimetro.org tool throughout 2005 for these 4 different ISPs and 1Mbps access technology (currently, one of the most widespread access technology in Spain).

After analyzing the results of our simulations we can conclude that there is no single technical parameter suitable for evaluating the final "quality". We believe that this kind of analysis allows users to obtain a better picture of the real service they would get for their money.

Finally, as future work, we are currently involved in the development of a newer version of the Velocimetro.org. This version, now in alfa stage, will include additional tools in order to provide users with more extensive measuring capabilities. It will also incorpore automatic subjective survey procedures, in order to get real feedback about our users' satisfaction and tune our model.

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