# QoE and *-awareness in the Future Internet

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**Abstract**
Future Internet will have to cope with yet unknown terminals and services (even users), in a number and heterogeneity never seen before. So, flexibility or adaptability will be considered as one of the most important design principles. This flexibility will demand different kinds of *awareness* both in the ends and in every node in the service supplying chain, while targeting users' satisfaction as the final goal of any management process. Although virtualization and "everything is a service" approaches seem to be promising foundations to guarantee this flexibility, Future Internet will be built upon real world mobile wireless network technologies, so that cross-layers issues and quality constraints will persist. Quality of Experience (QoE) could play a significant role there, since it could provide an unified metric, isolating users from low level details or complex NQoS definitions. We will also show an example of how user-aware network tuning mechanisms are able to provide similar users' QoE with lower resources consumption and therefore propose that QoE and *-awareness were considered in the Future Internet design from the very beginning.

**Keywords.** QoE, NQoS, awareness, network intelligence

## Introduction

During the past years researchers have shifted the focus on the deployment and growth of the Internet, from an initial technology-driven approach to a user needs-driven one. This user-centered approach has resulted in several proposals aimed at bringing *awareness* to the network beyond the bit-pipe service-neutral network paradigm.

This *awareness* reflected the need for future networks **capable of coping not only with technological challenges related to performance, but also with users' preferences, location or context**. These networks will be built upon different access technologies and would deal both with network performance issues, service-specific constraints and even characteristics of the content (such as its type of content, codec, or the dynamics of the information represented).

These multiple needs lead to different research topics that have been widely studied in latest years:

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- QoS-aware networks (including *-constrained routing protocols, traffic differentiation and TE schemes, QoS brokers...)
- Ambient networks
- Location based services (including multihoming aspects, location based CDNs...)
- Self -managed, -learning, -organizing networks, technologies, radio interfaces...
- Content-aware networks
- Network-aware content and services

Most of the management schemes proposed in these different user-centered research areas usually share a common target: all management activities are devoted to guaranteeing *quality*. Since these proposals usually focus on a single technology, managed performance issues (i.e. Key Performance Indicators -KPIs-) are technology dependent. However, at the end, actual user satisfaction or *Quality of Experience (QoE)* will depend on several factor related not only to these “simple" network performance issues but also to more complex non-technical ones, such as content characteristics, users expectations and their particular context. Future networks should consider user satisfaction as the final end and, therefore, should be able to handle every single parameter in all aforementioned domains (content, network performance, services, users preferences...) that has an impact on this satisfaction.

On the other hand, quite surprisingly, network infrastructure seems to be no longer a constraint for e2e services. In fact, its structure, including network nodes and links, has already begun to dissolve into the “*everything is a service*" paradigm by means of **virtualization**. These virtualization proposals somehow admit the **incapability of a single protocol suite or network architecture to cope with the great variety of different services and users requirements**. So, instead of trying to provide a good solution for all, virtualization aims at providing “users” with the means for building the network that best fulfills their particular requirements.

Nevertheless, although virtualization seems to be a promising foundation for future networks, at the end there will be a real (certainly mobile and wireless) transmission technology behind all virtual networks. Then, even with virtualized links and network nodes, cross-layer issues will appear and demand richer and more accurate definitions of network behavior, far beyond traditional simple NQoS parameters (i.e. capacity, delay, jitter, losses), and more closely related to specific aspects of the services to be deployed (see [1] and [2] for examples of other type of definitions).

Future Internet will have to handle all these new service requirements, so that flexibility or adaptability should be considered as the first design principle. This flexibility will demand **different kinds of *awareness* both in the ends of the communication and in every node in the service supplying chain with users’ QoE as the final objective**.

The rest of the document is organized as follows: In Section 1, today’s initiatives around including *awareness* in networking technologies will be analysed. In Section 2, we will examine two important drawbacks of current proposals aimed at developing more intelligent networks, namely technology dependence and cross layer issues. Then, the role of Quality of Experience (QoE) management will be described. The case study of VoIP over $\geq 3G$ accesses will therefore show in Section 3 the importance of handling QoE. This analysis will motivate the conclusions in Section 4, that will state the need for considering content and service characteristics, together with user preferences in the design and operation of the core of a QoE-aware Future Internet.

## 1. *Awareness* in Today's Internet

Following the maxim "those who cannot remember the past are condemned to repeat it" we have analysed prior research proposals while trying to draw a coherent picture of network related roadmaps and different visions of *awareness* in Today's Internet.

We have carried out an intensive survey of EC funded research projects in Europe over the past 10 years. This roadmap should not be seen as a proposal toward non-disruptive design principles for the Future Internet (vs. the clean-slate approach that is gathering momentum among the research community). Instead, we just have tried to identify unsolved research hot topics that have been faced with nowadays technologies but that will still determine the design of the Future Internet. Neither it was an exhaustive statistical exercise, but an attempt to figure out the big numbers behind *awareness*.

In the introduction of this document we identified 6 different areas of the so called *awareness*. Based on these 6 different research areas we have selected and classified 66 research projects that covered one or more of these areas, within successive Framework Programs (from FP4 to FP7, in IST/ICT areas). The basic information of these projects is publicly available using the search tools in the EC CORDIS website [3].

The first result of our analysis was that funding associated directly to some kind of awareness-related topic has been increased dramatically over the past years (see Figure 1), showing the growing interest on research areas related to bringing awareness to the network. Besides, in our survey we have only considered those projects that explicitly addressed these topics in their summarized description (and/or keywords). So, there would be many other networking projects that, although focused on different research topics, considered also awareness as a secondary target within Integrated Projects or Networks of Excellence. We should also notice here that statistics for year 2008 and later show a decrease because they do not take into account future Calls and proposals currently under evaluation.

The growth is not equal in all the research areas (see Figure 2), since some of them have appeared recently and some others have been surrounded by *buzzwords* that have changed over the years (while the main concept has remained more or less the same). In fact, since these 6 different research areas are inter-related, the overall contribution in Figure 1 provides a clearer view of time evolution of *awareness* in Today's Internet.

An inspection of the results and proposals within analysed projects lead to some well know issues:

- **QoS-aware proposals** quite often use some kind of QoS brokering systems on top of traditional network management protocols and resource managers (see for example [4] for DAIDALOS QoS architecture). Most of these initiatives claim that complex QoS request mechanisms are usually not standardised. As a result, nowadays there seems to be no working global scale NQoS management framework. We could point out different reasons to explain this lack of success, such as the traditional scalability issues of QoS management systems or that different connectivity providers take part along the service provision path (so, administrative or business model issues rather than technical ones). The need for per flow marking and scheduling lead also to well-known performance problems while, at the end, handled NQoS parameters do not ensure that final QoE will satisfy users' needs. So, the *quality* of the content delivered to users due to network transmission effects would be still an open issue.

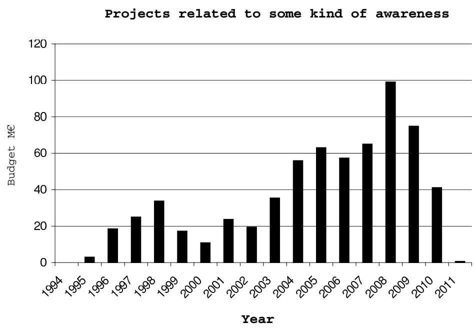


**Figure 1.** Total budget of *awareness* related projects

- Regarding **Ambient Networks**, associated projects introduce research challenges regarding intelligent handover between very different access technologies based in different criteria (such as signal strength, coverage, terminal type, user preferences,... -see for instance [5]-) while providing seamless connectivity. Once more, the actual situation is that there has been no standardized global scale deployment of such kind of solutions and that, most of them, are deeply technology dependent (i.e. handover between all possible combination of different radio access technologies).
- **Location based services** are generally focused on two different planes: on one hand, location awareness as an input for the logic behind end-to-end services (such as the service that suggest you the best restaurant closest to your location). On the other, as a support tool for some routing/handover decision mechanism (i.e. as in location based mobility management -i.e. see [6] for WINNER IST project results-). However most protocols' inner structure does not provide fields or mechanisms to include any location information yet.
- **Self managed/organized systems** address a large variety of different research fields, from MANETs to sensors networks or cognitive radios. The use of different kind of algorithm, such as simulated annealing, genetic algorithms, bayesian reasoning or neural networks, in this type of proposals aims at optimizing general network performance parameters in an automated way (see [7]). Self-managed systems are a rather new and promising research field that, although still not too mature, will definitively play a significant role in the design of the Future Internet.
- **Content-aware networks** try to behave according to the specific content delivered (including the content itself, used codec, packetization scheme, transport protocol, etc...). In order to do so, some kind of source coding (or intelligent edge marking) is needed in order to allow an efficient handling of multimedia flows throughout the different networks nodes. So, some common frameworks to define content characteristics have been defined (i.e. MPEG7, MPEG21 Digital Item Adaptation, or specific ones such as those in [8,9]). However the specific treatment applied to each flow is usually based on particular effects of each technology into end to end transmission (i.e. interaction between VoIP calls and low level UMTS RLC procedures to be seen in Section 3).

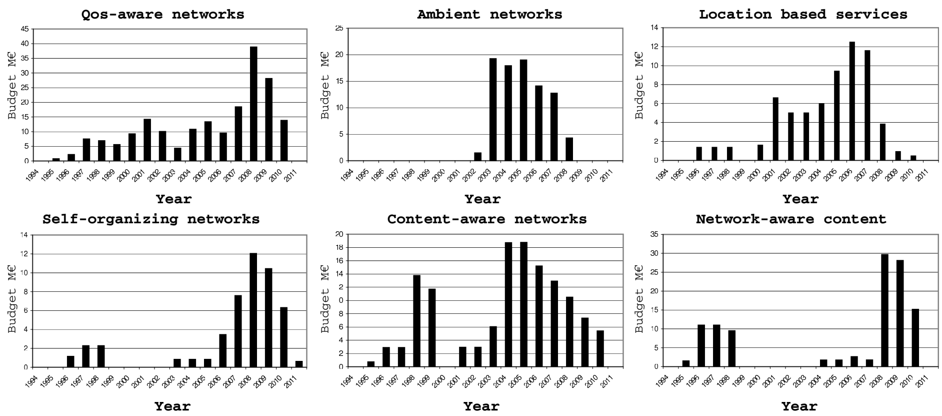


**Figure 2.** Budget evolution of *awareness* related projects

- Finally the term **Network-aware content** is used with those multimedia services (or more precisely codecs) that adapt their behavior according to particular network conditions. A higher content quality increases the QoE under perfect network conditions, but requires more QoS resources. Thus, upon network impairments, a lower target content quality may result on better service experience. This concept is currently being introduced into multimedia services. The Adaptive Multi-Rate (AMR) codec, standardized by the 3GPP in 1998, implemented eight codec modes at different data rates and, consequently, different initial listening quality. Under network degradations, VoIP services are able to decrease the target bitrate in real-time to cope with the new QoS constraints and enhance usersŠ experience. A similar approach is being adopted by the joint Video Team (JVT) for networked video services. The Scalable Video Coding (SVC) extension endows the H.264/MPEG-4 AVC video compression standard with the capability to divide a video flow in a set of substreams, each of them providing different estimated QoE levels, and with the particular property that the reception of different substreams may contribute to the content quality additively (see for example [10], that shows results from DANAE IST project).

## 2. Technology dependence, cross layer issues and the role of QoE

In previous Section we have reviewed the outputs of several R&D projects and identified troubles to be still faced. As an overall conclusion, current “independent layers"-based structure of Internet protocols and their technological-only approach make it difficult to provide users with the different service characteristics they demand. So there are several common aspects related to technology dependence and cross-layer issues that will have to be considered in the design of the Future Internet.

First, there’s no doubt that seamless mobile connectivity will be built upon several different access technologies. With Today’s technology, even with full IP access networks, some patches must be used in order to solve handovers between each pair of technologies, both from the mobile terminal's and internetworking technologies' point of view (regardless many efforts of IETF, 3GPP, ITU or UMA standardization initiatives). Most of needs for *awareness* related to handovers are the result of a tight coupling between content delivery capabilities and network constraints.

Similarly, different other alternatives try to adapt content to actual network capabilities by recoding and/or protocol adaptation. In any of these cases researchers have to deal with a lot of low level interactions between different layers, which result on poor e2e performance even when typical averaged NQoS parameters in each layer are apparently above acceptable thresholds.

Therefore, Future Internet will have to provide mechanisms to ensure that required complex *quality* demands are satisfied. This complexity is usually specified now by different metrics, associated with the low level parameters in the underlying technology. Since the objective of any network is providing users with multimedia content with enough quality for them to be satisfied, QoE could be used as a final single metric associated to the specific service and technology independent. For example, most users have already identified some multimedia formats as "enough quality". Except from advanced users, few of them bother about MP3 codec rate or DIVX/mpeg4 encoding scheme, framerate of number of processing steps (if you can burn it into a CD it is "good"). So, they have assimilated that nearly any MP3 or divx film fulfills their requirements. At the same time, clock speed has suddenly disappeared from microprocessors names and advertisements, replaced by other performance benchmarks. **Future Internet should be able to provide this kind of confidence to users. They should be provided with multimedia contents with the QoS required for them to be fully satisfied**, regardless all the low level technical details that the network intelligence will have to deal with.

In order to do so, a lot of research has been focused on proposing cross-layer adaptation techniques for the latest audio and video encoding standards. The overall aim of all the cross-layer adaptation concept is to provide QoS continuity across different layers of the delivery chair. More specifically, the research interest has been focused on the impact of each layer involved in the provision process (i.e. Service, Application and Network Layer) on the perceptual quality level of the finally delivered service by defining and correlating the various *quality*-related metrics of each layer. Regarding the mapping between the various discrete *quality* layer (i.e. QoE/ApQoE/NQoS), Table 1 provides an example of the representative metrics of each level, which will be used in the mapping process, for Video delivery systems:

At the **Service layer** the critical metric is the user satisfaction. The QoE evaluation will give service providers and network operators the capability to minimize storage and network resources by allocating only those resources needed to preserve a specific level of user satisfaction. At the **Application layer**, given that during the encoding/compression process of the initial content the quality is degraded by the appearance of specific artifacts, the values of the Application QoE (ApQoE) parameters (i.e. bit rate, resolution) determine the finally achieved QoE. Thus, the various encoding parameters must be considered as significant metrics of the application layer, since they have a straightforward impact on the deduced QoE level. If additional transmission problems are considered due to limited available bandwidth, network congestion etc... they will be also should be also considered as metrics at the ApQoE layer. At the **Network layer** NQoS related metrics (i.e. Packet Loss Ratio, Packet Loss scheme and Packetization scheme) are used in an objective aspect, trying to determinate the impact of all low level interactions into final e2e NQoS achieved.

| **Service QoS Level** | **Application QoS Level** | **Network QoS Level** |
|---|---|---|
| User Satisfaction | Decodable Frame Rate | Packet Loss Ratio |
| QoE level | Decoding Threshold | Packet Loss Scheme |
| Terminal Specifications | Encoding Parameters | Packet Size |

Table 1.: Example of metrics at different layers for video

Similarly, in VoIP communications, the QoE is mainly determined by the following characteristics:

- **Session establishment delay**. In mobile data networks, the most relevant delays to be taken into account are the radio bearer set-up time and the performance of the session signalling protocol.
- **Interactivity**. The feeling of interactivity in conversational services is determined by the round-trip delay at user level. If this time increases over a threshold, both users could not coordinate when to speak or to remain listening.
- **Listening quality**. The primary factor determining the listening quality level is the fact that words are understandable. Otherwise, the purpose of the communication would not be fulfilled. The quality of received voice is mainly determined by the digitalization and codification processes, and the possible loss of voice frames in the transmission.

Regardless the type of service considered, in order to deploy QoE-driven network performance management systems we will have to evaluate the relationships between technical and user perceptions dimensions, which are greatly affected by the service conditions. For example, the content codification method has a great impact on quality perception results, since different codecs show different resiliency to frame losses. Additionally, the user device type and configuration is also to be considered. The same network performance values could result on different QoE levels depending e.g. on the device buffering capacity, the screen resolution or the processing capacity. However, **QoE related considerations have been mostly incorporated into QoS management systems as upper thresholds for every individual performance metric** leading to an over-provisioning of resources for some users and under-provisioning for others.

In addition to a better resource planning, the user- and QoE-awareness is a critical factor in the Future Internet for overcoming possible network degradation states. The reaction to network degradations performed by the current QoS management model is based on the set of pre-established actions for the affected class of service regardless special characteristics of each flow. Yet, a QoE-driven QoS management mechanism would try to maximize the general QoE level by taking into consideration specific content characteristics, such as the specific codec and FEC characteristics or loss patterns, in a specialized way.

As a result, the Future Internet will not only benefit of a QoE-driven management in terms of a higher capacity, but will be able to mitigate the effects of network impairments in a more optimal way.

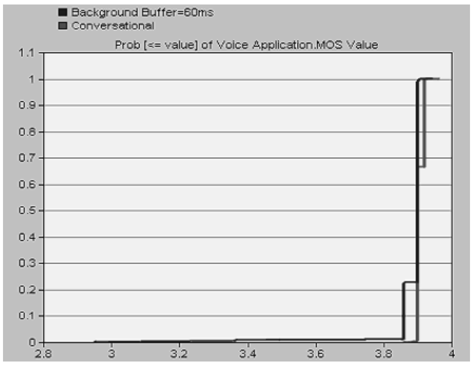


**Figure 3.** VoIP MOS CDF for Conversational and Background UMTS QoS classes

## 3. Case Study: VoIP and $\geq 3G$ data access

The evolution of radio access technologies makes us think on a Future Internet with plenty of itinerant users launching resource-greedy multimedia-enabled services. Thus, besides the performance variability inherent to the radio transmission technologies, one of the hot topics is how currently proposed access and backhaul networks will cope with the resulting volume of variable data rates.

**The expected evolution of users and services in the Future Internet requires a more specialized and personalized QoS management, based on keeping the accurate QoE levels**. On one hand, the perceptual schemes of mobile users are not the same to the traditional fixed-access case, resulting on different tolerance thresholds. On the other, Internet access through radio technologies is becoming more and more usual even for non-mobile users. Thus, **the user-awareness can not be performed just based on the connectivity, but also the location and other contextual factors have to be considered.**

As cited previously, the current resource management model based on aggregating traffic flows of similar QoS requirements into classes of services involves several deficiencies. For example, the QoS model proposed by the 3GPP recommends that VoIP services should be treated as Conversational class, associated to a set of maximum values for different network metrics.

Then, the transmission delay for the UMTS Bearer Service of a Conversational class is recommended to be kept below 100ms. Following the E-model [11], up to 100ms of one-way delay can be considered negligible for the conversation quality, while an increase from 100ms to 200ms corresponds to a perceptual degradation of 0.1 in the MOS scale. Therefore, it shall be individually considered if the increase in resource consumption is in correspondence to users' service experience.

The general trend is to consider that currently deployed UMTS networks, mainly based on the Background class, are not sufficient for an accurate provisioning of conversational services, due to the variable delays. However, suitable service and device configuration can do the best out of this type of networks, allowing users to reach similar QoE levels to the QoS-enabled solution based on live network measurements. Even more, under certain conditions, it could be preferable to provide a mobile VoIP service based on Background class. Not only the economical perspective shall be considered, that will

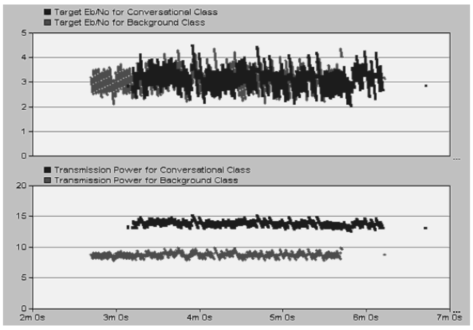


**Figure 4.** $E_b/N_o$ for both simulations

lead to a user-awareness, but also the power consumption is to be taken into account, introducing the device-awareness.

In order to evaluate how low level QoS affect end users QoE we have carried out several simulations with 2 scenarios. The first one uses Background UMTS QoS class that should lead to poorer QoE in comparison to the second one that uses Conversational UMTS QoS class (and therefore, with guaranteed bitrate and BLER targets). In our Background class scenario, we have tried to achieve the best QoE possible by tuning VoIP service parameters (such as AMR codec type, packetization scheme and dejittering buffer size and mechanisms) according to UMTS low level parameters (i.e. ARQ schemes in AM RLC mode, length of TTI) and delays and losses in different parts along the service provision path (including delays due to dejittering buffer and error recoveries in AM mode).

Figure 3 shows the estimated Mean Opinion Score (MOS) according to the e-model in two simulations considered. With our accurate combined network and service configuration, the experienced quality levels are found similar (since the Cumulative Density Function shows similar probabilities of high MOS values -around 3.5 out of 5-) . However, as seen in Figure 4 the same target Eb/No ratio is resulting on a greater transmission power on the mobile handset for the Conversational class, which could be worse for the general QoE perception (since battery will run out sooner) and result in worse cell efficiency for the network operator.

As a result, we can see how **an efficient management of low level network parameters focused on enhancing QoE can result in more efficient network operation and management**. So, user would get **“better" services with equivalent (or even lower) network resources consumption** with this kind of **QoE-aware management mechanism that take into account both technology, service and users constraints**.

## 4. Conclusions

In this work we have analysed the role of QoE-targeted *awareness* in the design of the Future Internet.

By carrying out an intensive analysis of R&D projects during the last 10 years in Europe we have identified 6 different research areas around *awareness* with open issues in Today’s Internet. In order to face associated challenges most of the proposals have aimed at bringing some kind of *awareness* to the network. However, since associated intelligence has not been incorporated in the design of Today's Internet from the beginning, proposed "patches" generally lack of global scale adoption.

Furthermore, even when virtualization seems to be a promising approach in order to define a flexible Future Internet, cross-layer and technology dependence problems still arise since, after all, future networks will be built upon real mobile wireless access networks. Far beyond typical technical only NQoS demands, users' satisfaction should be addressed as the final target for any network management mechanism. In order to do so, Quality of Experience (QoE) could be used as the final metric in order to guide the design process of Future Internet while isolating users from all low level details and complex NQoS metrics.

We have shown the relevance of our QoE approach by analysing the results of a comparison between VoIP services over different UMTS accesses and how carefully selected low level parameters could lead to equivalent users' QoE with lower resources consumption. So, in both simulated cases users' will not notice any difference and network will cope with its responsibility of providing users with highest *quality*.

Finally, Future Internet should be designed by incorporating mechanisms to provide service-, user-, content-, terminal- and network- aware capabilities targeted at guaranteeing users' QoE in a flexible and service-dependent way, beyond the bit pipe approach. This will demand not only more intelligence in network nodes but also content and user preferences describing languages and world scale NQoS management schemes (including QoE-aware, service dependent and cross-layer request mechanisms and evolutioned inter-provider SLAs).

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