N2Nsoft white paper series

Network planning for Quality of Experience

Quality of Experience on fixed and mobile Internet : not yet carrier-grade!

Quality of experience is increasingly benchmarked and publicized. Good results are generally transformed into advertisements by those best ranked. The first table below shows QoE metrics measured on the six French ADSL access providers networks. Monthly results are published on the web. The second table shows QoE metrics for mobile internet as published every year by the French telecommunication regulation authority (ARCEP). For both fixed and mobile networks, quality is very far from the standard of traditional network technologies i.e. circuit for voice or air broadcast for TV!

ADSL service provider	**TV Mean Opinion Score (MOS)** (1=bad,2=annoying, 3=fair, 4=good, 5=excellent)	**TV av. perturbation** duration during the 8pm news	**VoIP MOS**	**VoIP stability of quality** during a 3 mins. call
A	3.03	76 s	3.66	29.57%
B	2.43	345 s	3.87	85.58%
C	2.74	79 s	3.79	51.70%
D	3.04	35 s	3.77	89.48%
E	2.88	91 s	4.09	100%
F	2.72	78 s	4.12	96%

*Table 1: **Television and Telephony Quality of Experience** provided by the six French ADSL access providers (sources : television: jdnet, Witbe, Benchmarking IPTV Avril 2007, telephony: www.linternaute.com, witbe, Benchmark VoIP de mars 2007). See references for methodology details. (color codes from original report)*

Mobile Internet surfing	**av. success rate**	**provider A**	**provider B**	**provider C**
access to portal	96%	around av.	below av.	better than av.
5 minutes surfing session	84%	much below av.	better than av.	better than av.

*Table 2: **WAP/i-mode surfing Quality of Experience** provided by the 3 French mobile operators (source : ARCEP (French regulatory authority), Oct. 2006, measured in 12 largest cities). (color codes added by N2Nsoft)*

Need for Quality of Experience focus in the network engineering process

Quality of Experience is becoming a key differentiating area for service providers. As people more and more depend on packet data networks for their daily life, having consistently good quality is becoming critical. It becomes a key criterion for access provider selection.

Thus, ***QoE is more than ever a fundamental engineering metrics for network planning and optimization. Unfortunately, QoE is not simple to characterize in the planning process.***

Although QoE metrics are intuitive at the end-user level (e.g. page download time for web surfing, a MOS figure between 1 and 5 for voice or video quality, reaction time for interactive gaming), they are complex to derive from the simple technical figures that traditional planning tools provide. Such tools generally handle average quantifities such as throughput (for most of them), packet loss or delay (for the most sophisticated ones). It is impossible to map them to QoE metrics that are so strongly dependent on the time pattern and the specifics of the application.

- a web page download is a very complex combination of events: establishment of the TCP connection, sending of the "get" request, sending by the server of the page body, then series of "get" requests to download the embedded elements, possibly on one or several parallel TCP connections. The download time depends on many different factors on the end-to-end delivery chain.

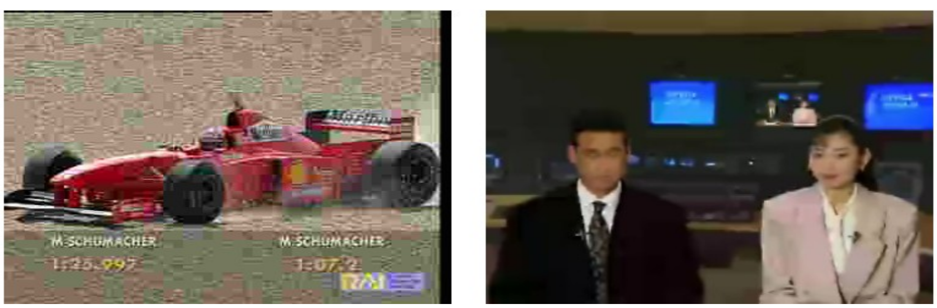


Figure 1: video degradation with blockiness (left) and blurriness (right) (from [5])

- IP television performance depends on which packets are lost. Loosing an I-frame (full picture) strongly degrades quality until the next one, whereas the loss of a B or P-frame (differential information) is less impacting. Also, depending on the player's buffering capacity,delay jitters in the transmission chain may cause image freeze. The overall QoE depends not only on the packet loss or jitter time pattern but also on the content, the encoding and de-jitter buffering strategies.

Customer-oriented QoE planning is not about average values

End-users are not just sensitive to average values of Quality of Experience metrics. They are often more sensitive to predictability (i.e. fluctuations). Furthermore, people or organisations are looking for guaranteed services, possibly SLA's. Thus, metrics such as the 95-percentile value (95% of the downloads times are less than this value) are much better adapted. To include them in the planning process, we need the full QoE distribution, not only average metrics. Traditional circuit-based voice networks are engineered such that 99% of the calls can go through. There is no reason why IP networks should not be engineered with 99 percentile metrics.

Packet data networks exhibit chaotic traffic behavior. Simple average models can't describe it

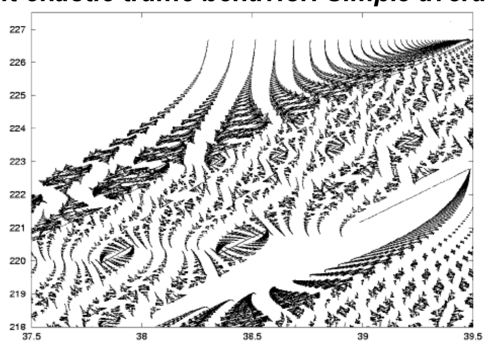


Figure 2: interaction of TCP flows

Traffic fluctuations on transmission links or at the input of equipment buffers induce heavy-tailed behaviors that have a strong effect on dimensioning requirements for packet data networks. TCP, which carries most of the Internet traffic, is a decentralized reactive protocol. Traffic dynamics are strongly affected by its behavior. A number of studies have demonstrated the fractal behavior of aggregate TCP traffic, both on real networks and theoretically from mathematical analysis (see e.g. [6] and the enclosed figure that shows how several flows sharing a bottleneck interact; it plots the throughputs of a flow class versus those of another class). Traditional dimensioning tools don't account for the actual packet traffic dynamics.

QoE-based network planning requires the simulation of the full packet dynamics

To account for the packet dynamics that have such a strong impact on network behavior and end-user Quality of Experience, a fast, efficient and accurate simulation tool is required. It should overcome the limitations of traditional discrete-event simulators that don't scale : they cannot simulate large traffic on large networks.

Limitations of traditional network simulation and benefits of NetScale

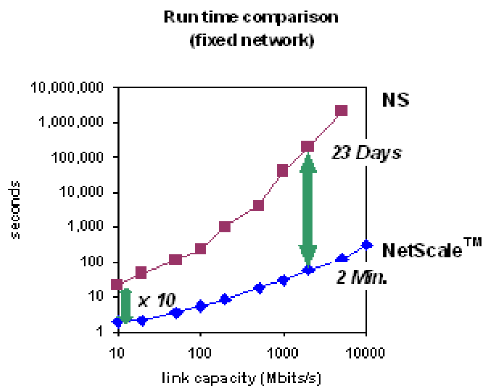


Figure 3: NetScale's simulation time and memory requirements grow linearly with traffic whereas they grow exponentially with traditional discrete events techniques.

Traditional discrete event simulation techniques track each and every packet as it goes through protocol layers and equipments. They are very accurate but suffer from a dramatic weakness: they can't scale. They can simulate an application from end-to-end, but they won't simulate the thousands or millions of simultaneous users on the network. Traditional planning technologies overcome this limitation by neglecting key networking features, such as TCP, or reverting to analytical models with further simplifications, such as neglecting equipment buffers, or - more common - applying back-of-the-envelope algebra simply requiring that the network handles the sum of data bytes demanded by the customers. Network engineering and the quality of the offered service to the end customers are not really in control. Dimensioning errors by a factor of two or more can easily be made. The business is at risk of lacking reliable engineering foundations.

NetScale™ addresses the need for fast, accurate and scalable network simulation

To address QoE-based network engineering, NetScale™ proposes very fast, large scale network simulations with extensive packet generation details, through the end-to-end network, including the relevant network protocol layers and equipment features. Network can be planned, capacity growth scenario can be tested as well as new configurations, technologies or features. New service launch strategies can be assessed. Sensitivity studies can be performed. Furthermore, the actual traffic profile as observed on the real network can be reproduced in the simulator. In other words, ***the network can be planned and optimized, service launch strategy can be defined with full command on the end-user Quality of Experience.*** To do so, NetScale leverages patented mathematical techniques that have strong similarities to finite elements simulation techniques used to design planes or cars, except that it is time not space that is discretized. NetScale has been successfully used on large-scale realistic gigabit networks (with hundreds of thousands of nodes) running about 1000 times faster than traditional simulation tools.

Simulation of applications and QoE assessment with NetScale™

NetScale simulates the full data plane: the end-user behavior that describes how users download content and read them, the application, the session and transport protocols, MAC and RLC layers. In the next section, we provide some details on how web or wap surfing (http protocol), VoIP and video-streaming are simulated. Having such accurate simulations with all packets generated, one can have (or create) all the relevant QoE metrics for QoE-based network engineering!

Web surfing simulation by NetScale™

A web (or WAP or i-mode™) session is described as a suite of page downloads separated by reading times (see e.g. [1]). Each page is described as a main body and a series of embedded elements (style sheet, images,..). They are downloaded according to the HTTP 1.0 or HTTP 1.1 protocol with their main features : using one or several TCP connections that can be open in parallel and kept permanent, with possibility to pipeline the requests. NetScale's user can select among a list of predefined statistical laws to draw the parameters that describe the session (reading time, page size, number of elements, etc..) or create its own distribution that will be included in the simulator. Such distribution can reproduce the actually observed traffic.

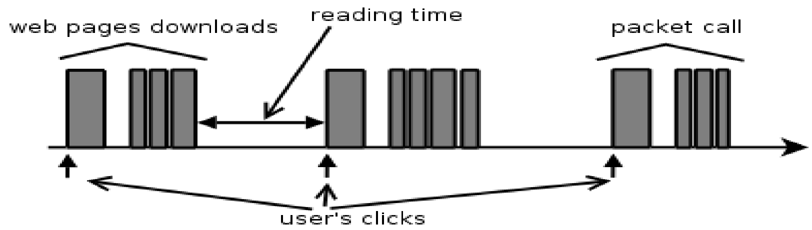


Figure 4: web page session model from [1]

As an example, the main end-user metrics for QoE evaluation can be considered to be the web page download time. For instance, knowing that a download time threshold of 5s has often been measured (after this duration, users start giving up the web navigation), the network can be planned with the objective that 95% of the downloads are done within less than 5s.

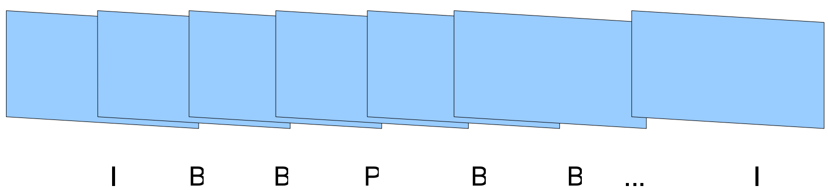
VoIP simulation by NetScale™

The perceived quality of a telephone call largely depends on two factors: distortion, the difference between the received signal and the original one, and mouth-to-ear delay from speaker to listener. Distortion can stem from the use of a low-bit-rate codec or the loss of voice packets. Losses can occur in the network, because of congestions or erroneous transmissions in unreliable links, or in the dejittering buffer: packets received in the dejittering buffer after their play-out time are immediately dropped. Mouth-to-ear delay includes, besides the propagation and switching delays encountered in a PSTN, delays from coding, packetization, queueing, and dejittering.

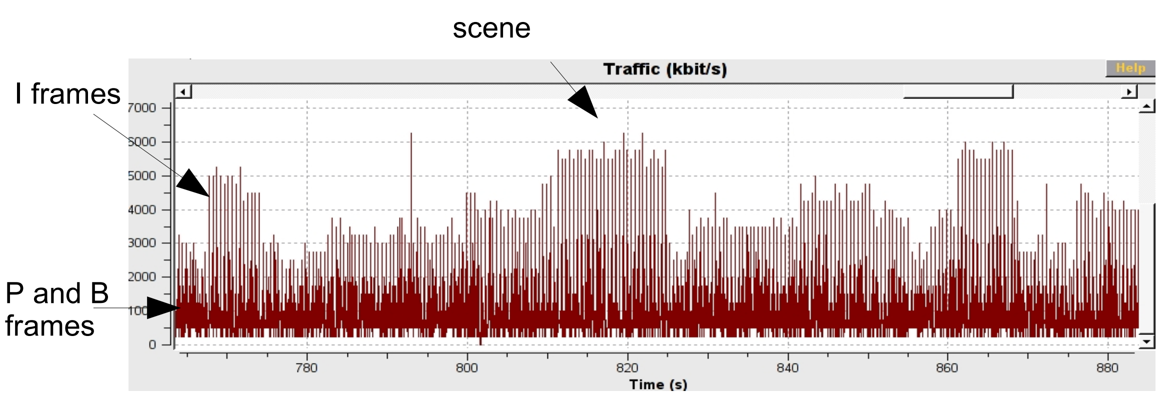
NetScale's estimation model of the Mean Opinion Score (MOS) is driven from [2]. It is based on the ITU-T e-model ([3]) and predicts the subjective effect of combinations of impairments, as a function of delay, echo, codec type, and packet loss. The MOS is estimated on each call by analyzing the received stream and applying the MOS model.

Video streaming simulation by NetScale™

Standard MPEG encoders generate three types of compressed frames: I, P and B. While I frames are intracoded, the generation of P and B frames involves, in addition to intra-coding, the use of motion prediction and interpolation techniques. As a result, I frames have, in average, the largest size, followed by P frames, and finally B frames. An important feature of common MPEG encoders (both harware and software) is the manner in which frame types are generated. Athough not required by the standards, typical encoders use a fixed Group-of-Pictures pattern when compressing a video sequence (the GOP pattern specifies the number and temporal order of P and B frames between two successive I frames).



A traffic model driven from [4] is used to generate each frame. In particular, a notion of scene is introduced: a scene is defined in the visual sense as a portion of the movie without sudden changes in view, but with some panning and zooming. At the beginning of each scene, a mean scene activity is drawn; during the scene, I frame sizes fluctuate around this value. Currently NetScale reproduces the traffic characteristics of selected movies such as "Silence of the Lambs", "Star Wars" or "Goldfinger"!



The perceived quality of the video is characterized by the following two main metrics:

- probability of rebuffering: end-to-end delay and frame size fluctuations may empty the player's buffer. It generates an image freeze and user waiting time until rebuffering.
- corrupted/lost frames: the video quality degradation depends on which frame is affected by a lost packet. The MPEG features that characterize the frame type are taken into account by NetScale to accurately assess the impact of packet loss on Quality of Experience.

NetScale™ application example: Comprehensive end-to-end simulation of an HSDPA network over Paris

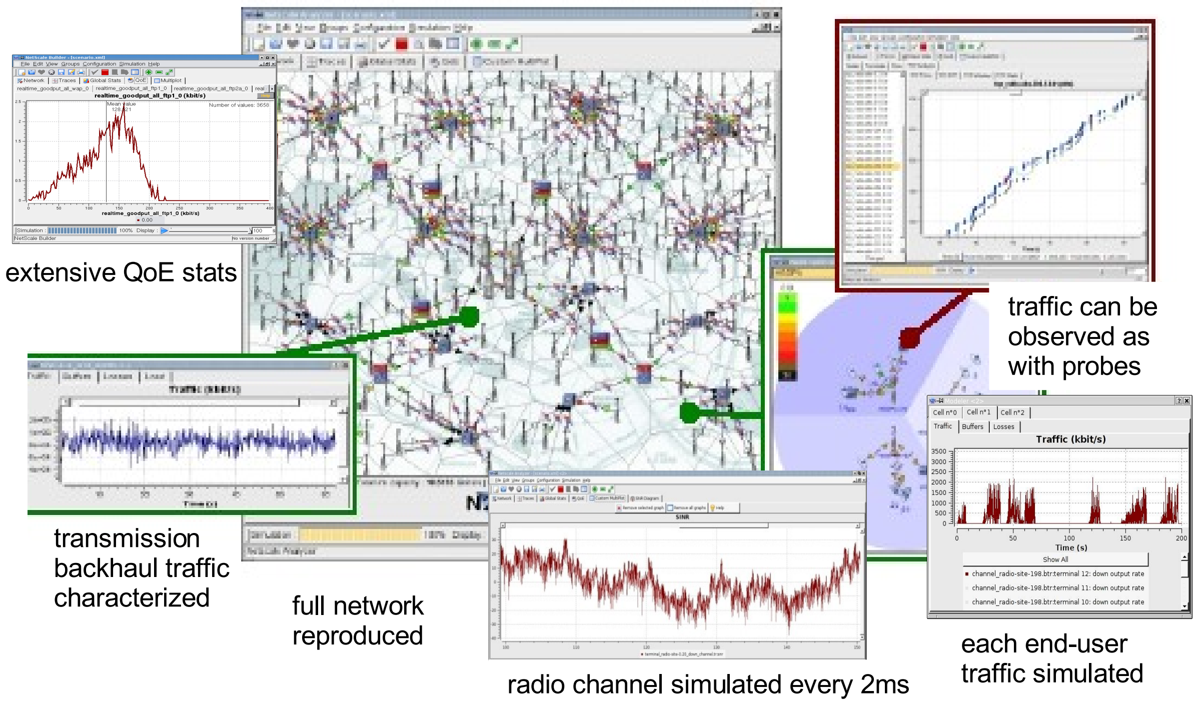


Figure 6: Excerpts from NetScale's user interface highlighting comprehensive simulation details. Simulating such a large scale wireless network is impossible with traditional simulation tools. Yet it is a critical asset to the engineering team in charge of delivering QoE with optimized Capex/Opex.

Abbreviations

MOS: Mean Opinion Score

QoE: Quality of Experience

SLA: Service Level Agreement

HSDPA: High Speed Downlink Packet Access (evolution of the 3G UMTS mobile system)

MPEG: Motion Picture Expert Group (standard for video encoding)

VoIP: Voice over IP

References

[1] 3GPP TR 25.892 V6.0 (2004) (section A.3.4.1)

[2]Jan Janssen, Danny De Vleeschauwer, Maarten Büchli, and Guido H.Petit (2002) Assessing Voice Quality in Packet- Based Telephony, IEEE Internet Computing, May-June 2002

[3] e-model: http://portal.etsi.org/stq/presentations/emodel.pdf

[4] M. Krunz, S.K. Tripathi, On the Characterization of VBR MPEG Streams, Sigmetrics, May 1997

[5] Color Image Quality on the Internet, Susstrunk S., Winkler S., (2004)

[6] Baccelli,F. Hong, D. (2003) Interaction of TCP flows as billiards. Proc. of INFOCOM, San Francisco.

