II INTERNATIONAL CONFERENCE ON COMPUTATIONAL BIOENGINEERING
H. Rodrigues *et al.* (Eds.)
Lisbon, Portugal, September 14-16, 2005

SM3 – QUALITY OF SERVICE (QoS) EVALUATION TOOL FOR TELEMEDICINE-BASED NEW HEALTHCARE SERVICES

I. Martínez* and J. García*

* Instituto de Investigación de Ingeniería en Aragón (I3A)
Universidad de Zaragoza (UZ) – Zaragoza (Spain)
e-mail: imr@unizar.es, jogarmo@unizar.es

Keywords: Measurement, modeling, multimedia, network design, QoS, real-time, store-forward, TCP, technical evaluation, telemedicine, traffic, UDP.

Abstract. *The wide development of multimedia clinical applications and the use of inter and intra-hospital communication networks require a specific analysis to increase healthcare services efficiency. In this paper, we propose a processing toolbox (QoSM3) for technical evaluation of Quality of Service (QoS) traffic requirements in new healthcare services based on telemedicine. This tool consists of the multimedia service definition and the measurement and modelling processes, which permit to analyse QoS requirements and to optimize application design regarding available network resources. The proposed methodology has been tested to evaluate real-time and store-forward medical services.*

1 INTRODUCTION

Telecommunications and advanced information technologies have permitted an important advance in the new telemedicine services in the last years. In order to extract the maximum benefit of these new services, it is essential to define a precise methodology to characterize the Quality of Service (QoS) requirements for the transmitted information and the management of the available network resources [1]. Moreover, to implement a multimedia service it is necessary to carry out a correct evaluation including the efficiency, acceptability and usefulness. And this evaluation is specific according to each particular implementation scenario. Thus, this study has been particularized for the telemedicine-based new healthcare services [2], [3].

Telemedicine services are expected to support multiple and diverse clinical applications over different network topologies. Such heterogeneous environments require that different applications should be provided with different QoS requirements to accommodate their distinct service types [4]. Thus, in order to optimize the QoS in these telemedicine services, it is crucial the study of two aspects [5], [6]: the nature of the transmitted biomedical information, and the behaviour of the communication networks.

The variability of the resources (for example, in mobile infrastructures) and the heterogeneity of the connections (for example, in Internet) require to measure and to model the intercommunication networks [7]-[9].

To establish network models from experimental measures means to inferentially monitor the network, with the purpose to obtain information for the subsequent performance. This telematic discipline is known like network tomography [10]. Thus, when we study the traffic modelling to offer QoS, it is essential to begin from source and network models that compose it to understand traffic dynamics, and to use that knowledge in the subsequent design. Hence, the teletraffic engineer role [11] would be the “feedback” where the measures inform about their behaviour and the QoS criteria define their performance.

An extended criterion consists on to manage and to adapt the information generated by the applications (encoders, transmission rates, compression ratios, etc.) to the available networks resources. Specifically in healthcare environments, it would allow improving the telemedicine service QoS by looking for the optimum values [12]-[13].

In this paper, an automated tool (Service Multimedia Measuring & Modelling, SM3) developed according to a methodology of technical evaluation is proposed. Section 2 describes its main modules and functionalities that determine the service characterization (*QoS Basic*), the application traffic model (*QoS Application*), and the interconnection devices, buffers and links performance evaluation (*QoS network*). Section 3 presents an example of use through the evaluation of a multimedia telemedicine service based on ECG transmissions and medical videoconferencing. Finally, in section 4 the conclusions and further research are presented.

2 MATERIALS AND METHODS

The implementation of a telemedicine-based new healthcare service requires a technical evaluation to study its behaviour under different network conditions. Thus, for measuring the parameters of QoS and modelling the multimedia service, the tool *Service Multimedia Measurement & Modelling* (SM3) has been developed. SM3 includes three main components: multimedia definition (to translate the clinical requirements in telematic parameters), service measurement (to capture not only the experimental traffic -*RealM3*- but also the simulated one -*SimulatedM3*- in homogenous format), and multimedia service modelling.

This last component -*QoSM3*- receives as input a trace file, obtained from the previous measurements or simulations, and it generates a complete model of the traffic and the network. It includes a tool that allows representing graphs and statistics in a portable format in order to facilitate the evaluation. Thus, the interpretation and comparison of results (not only between different tests over the same scenario, but also the same test in different environments) permits to characterize the service behaviour and to evaluate the complete system.

The global evaluation process is based on a trace file from a laboratory setting or a simulation scenario. The theoretical method includes several default parameters: number of links (L), propagation distance (D_{prop}), bit time (d_{bit}), etc. Using these parameters and the input traffic traces, a data structure is generated with four main parameters (defined for each connection (c), measured in each link (l) and identified for each packet (i) as $x^l_{c.i}$): *timestamp* ($t^l_{c.i}$), inter-packet time ($\Delta t^l_{c.i}$), OFF-time ($d_{off\text{-}i}$) and packet size ($s_{c.i}$). From these four basic parameters all the traffic indicators are estimated and calculated. The complete time-scheme, with sending (snd) and receiving (rcv) ends, is shown in Fig.1.

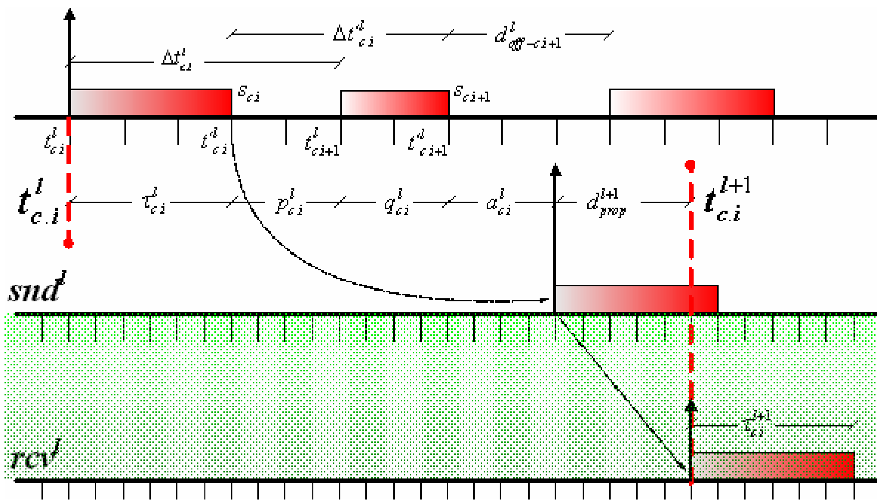


Fig.1. Evaluation time-scheme.

QoSM3 is composed by multiple utilities, divided in three modules (see Fig.2):

A. QoSM3 Basic. This module implements a previous basic analysis, which describes elemental characteristics of the related service. It includes the calculation of Sustained and Peak Data Rate (SDR and PDR) in (1) for a selected k samples interval, and the latency and significant delays estimation (see Fig. 1): transmission ($\tau^{l}_{c.i}$), processing ($p^{l}_{c.i}$), queue ($q^{l}_{c.i}$), medium access ($a^{l}_{c.i}$), propagation (d^{l}_{prop}) delays, etc.

$$PDR_i = \frac{s_i}{\Delta t_i} \rightarrow SDR_i^n = \frac{\sum_n s_i^n}{t_{i+n} - t_i} \quad (1)$$

B. QoSM3 Application. This module implements analysis and probabilistic adjust methods in order to model the observed traffic behaviour [14]. It estimates the Maximum Burst Size (MBS) in (2) and the Burst Tolerance (BT) in (3). Moreover, it validates statistically the alone and/or whole traffic to characterize the behaviour of the isolated and/or multiplexed sources. This process consists of two stages:

- First order statistics [15], by means of calculating statistical values like media μ and variance σ^2, histograms *h(i)* in (4), Probability Density Function (PDF) in (5), Cumulative Distribution Function (CDF) in (6), etc.
- Superior order statistics [16], by means of the analysis of the captured samples temporal dependence like autocorrelation in (7) or subexponenciality degree in (8).

$$PDR_i = \frac{s_i}{\Delta t_i} \rightarrow SDR_i^n = \frac{\sum_n s_i^n}{t_{i+n} - t_i} \quad (1)$$

$$MBS = \left\lfloor 1 + \frac{BT}{T_s - T} \right\rfloor \quad with \quad \begin{array}{l} \overline{PDR} = 1/T \\ \overline{SCR} = 1/T_s \end{array} \quad (2)$$

$$BT = (MBS - 1) \cdot \left(\tfrac{1}{SDR} - \tfrac{1}{PDR} \right) \quad (3)$$

$$h(i) = \sum_{n=1}^{N} I_{[r_{i-1}, r_i)}\left(\Delta t_{i[n]}\right) \quad with \quad i = 1, \ldots, L_h \quad and \quad I_{[r_{i-1}, r_i)}\left(\Delta t_{i[n]}\right) = \begin{cases} 1 & if \quad r_{i-1} \leq \Delta t_{i[n]} < r_i \\ 0 & other\ cases \end{cases} \quad (4)$$

$$\text{PDF} \quad \hat{f}_{\Delta t}(\Delta t) = \sum_{i=1}^{L_h} I_{[r_{i-1}, r_i)}(\Delta t_i) \cdot \frac{h(i)}{N \cdot (r_i - r_{i-1})} \quad (5)$$

$$\text{CDF} \quad \hat{F}_{\Delta t}(\Delta t) = \begin{cases} \sum_{i=1}^{L_h} I_{[r_{i-1}, r_i)}(\Delta t_i) \cdot \left(\frac{\sum_{j=1}^{i} h(j)}{N} \right) & si \quad \Delta t_i < máx\left(\Delta t_i[n]\right) \\ 1 & si \quad \Delta t_i < máx\left(\Delta t_i[n]\right) \end{cases} \quad (6)$$

$$\hat{R}_{\Delta t}(k) = \frac{1}{\sigma^2_{\Delta t}(N - k)} \sum_{i=1}^{N-K} (\Delta t_i - \mu)(\Delta t_{i+k} - \mu) \quad (7)$$

$$\text{Hill estimator} \quad \hat{\alpha}(k) \propto \left[\frac{1}{k} \sum_{i=1}^{k-1} \text{Log}\left(\frac{\Delta T_{[N-i]}}{\Delta T_{[N-k]}} \right) \right]^{-1} \quad (8)$$

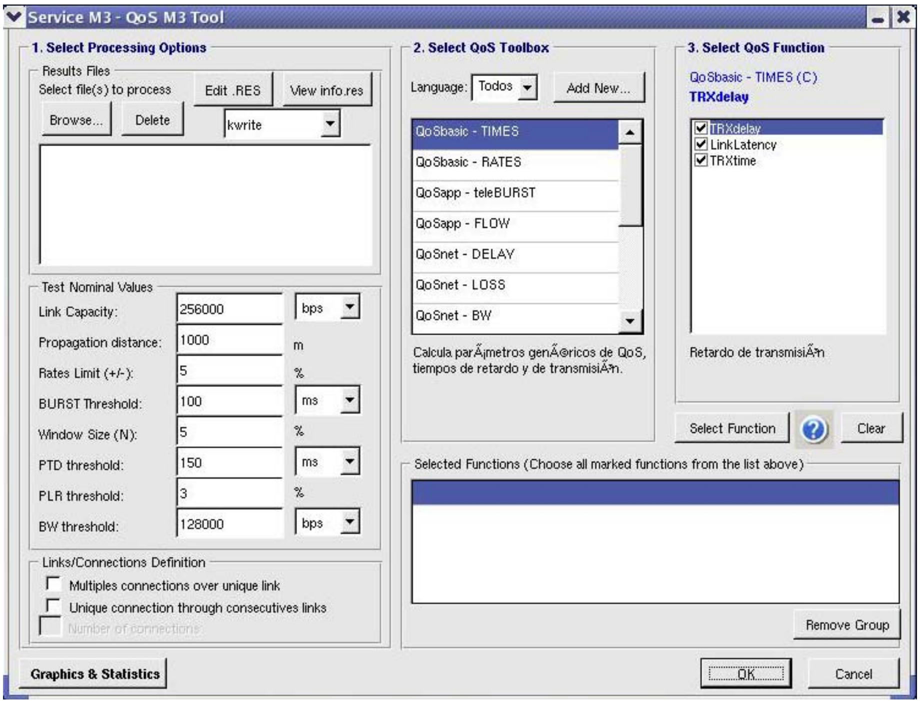


Fig.2. Screen capture of *QoSM3* implemented tool.

C. QoSM3 Network. This module calculates network parameters referred to required QoS thresholds regarding International Union Telecommunications (ITU) [17]:

- End-to-End Delay (EED) is the delay that each data packet suffers along the entire intercommunication path.
- Packet Loss Rate (PLR) shows its temporal evolution and it is associated to each transmitted packet. Moreover, the PLR/EED ratio allows evaluating the global service.
- BandWidth (BW) is referred to the useful capacity resources in a determined instant. It is included the normalized utilization factor ρ^* in (9), which measures the ratio between real data caudal and offered network mean load. It also implements calculations of the instantaneous, cumulative and median bandwidth, and an adaptative Bandwidth Estimation algorithm, BE in (10), weighting the measuring delay (τ_e) according to a suitable temporal window (Δt_k).

$$\rho^* = \frac{\rho}{\rho_{máx}} = \frac{C_e/C}{C_{e_{máx}}/C} = \frac{C_e}{C_{e_{máx}}} \tag{9}$$

$$\begin{aligned} BE_i &= \alpha_k \cdot BE_{i-1} + \\ &+ \tfrac{1}{2}(1-\alpha_k)(BW_i + BW_{i-1}) \end{aligned} \quad \left(with \ \ \alpha_k = \frac{2\tau - \Delta t_k}{2\tau + \Delta t_k} \right) \tag{10}$$

3 RESULTS AND DISCUSSION

The proposed QoS analysis follows a technical evaluation methodology over a network topology, as it is shown in Fig. 3. In this work, the study has been particularized for the telemedicine-based new healthcare services. Thus, the selected characteristics for this scenario have been:

- **Application Model.** It is based in Real Time (RT) applications, including Adaptive MultiRate (AMR) encoder for audio-12.2Kbits/s, H.263 encoder for video-16Kbits/s, and Standard Communications Protocol (SCP) over Real Time Protocol (RTP) for electrocardiography (ECG) signal 5Kbits/s-transmissions.
- **Edge Network Model.** It is based on intra-networking technologies corresponding to a Local Area Network (LAN). This access multiplexes several RT connections, concentrated in a *Fast Ethernet switch* that provides multiple 2Mbps links towards the external *front-end* (*edge router*).
- **Backbone Network Model:** It is based on inter-networking technologies corresponding to a Wide Area Network (WAN). It has been considered a variable Committed Information Rate (CIR) of n·64Kbits/s.

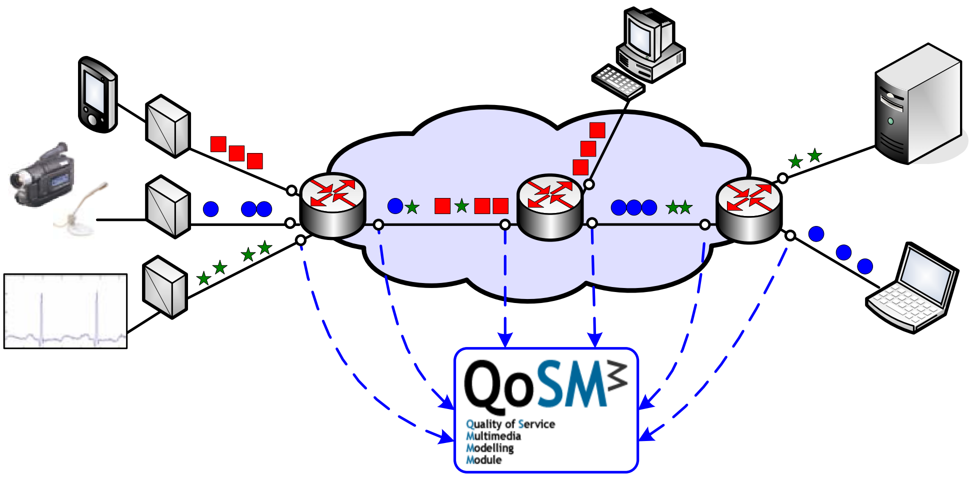


Fig.3. Evaluation scenario of QoS multimedia.

3.1 *QoSM3 Basic* Evaluation.

From this scenario, the first step was to characterize each Type of Service (ToS).

For RT-audio, the evaluation showed a low variability in the evolution of PDR with a mean value of SDR = 12.4Kbits/s, as it is shown in Fig.4(a). Moreover, Fig.4(b) shows only two significant occurrences for the inter-packet time (Δt_i).Thus, these results could be associated to Constant Bit Rate (CBR) traffic following an ON-OFF model.

For RT-video, Fig. 5(a) shows that its behaviour follows a non-uniform distribution regarding the H.263 encoder. The statistical tendency could be approximate to a Rayleigh, log-normal or exponential distribution, as it is shown in Fig. 5(a). To clarify these tendencies, *QoSM3* includes the Kolmogorov-Smirnov (K-S) test [18]. This K-S test obtains the distance between distributions, which permits to quantify the measurements associated to the tendency under study. In Fig. 5(b) the exponential distribution is justified from the numeric values using only significant samples of the related traffic. Thus, these results could be associated to Variable Bit Rate (VBR) traffic following an exponential model.

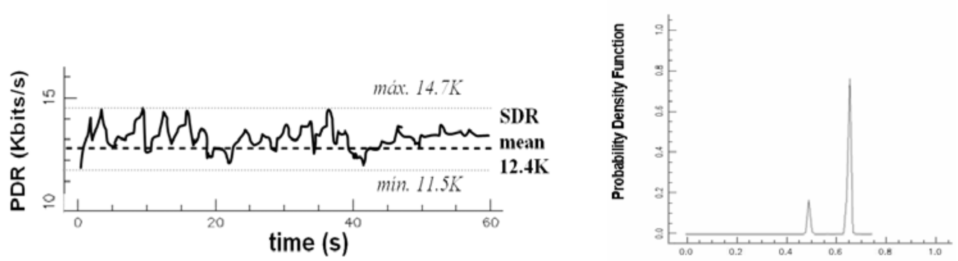
For RT-ECG transmissions, the evaluation shows in Fig. 6(a) a packet size (s_i) practically constant with MBS=1, which justifies its CBR behaviour. Further, this CBR characteristic also is showed in Fig. 6(b) where the (normalized) utilization factor is approximately $\rho^* \approx 1$. Thus, these results could be conclude in a CBR traffic following an uniform model.

3.2 *QoSM3 Application* Evaluation.

From the previous characterization, this application evaluation allows studying the evolution of the service performance in different configurations of encoders characteristics: source rate, compression ratio, etc. Fig. 7(a) shows the evolution of packet size for three transmission rates: Maximum (M), minimum (m) y average (a). It underlines the CBR behaviour for RT-audio and RT-ECG and it shows the variable bit rate associated to RT-video. Moreover, the SDR in every situation is presented in Fig. 7(b) (with Fig. 7(a) in background grey), which shows how the joint traffic is practically constant in all the cases, although RT-video high variability may lead to congestion situations. Thus, they should be evaluated in the next module.

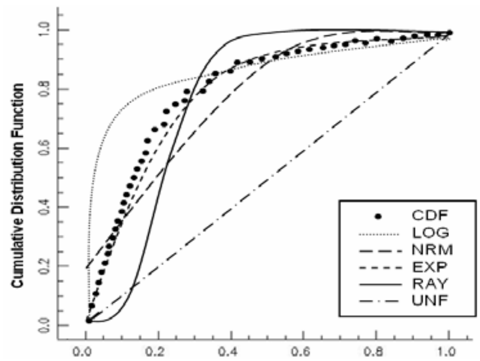
3.3 *QoSM3 Network* Evaluation.

Finally, this module evaluates the service performance regarding nerwork resources. It includes the relation between losses and delay, PLR/EED. This ratio allows evaluating whether the studied service fulfills the QoS requirements. In Fig. 8(a), this ratio indicates that RT-ECG service is always valid, the RT-audio service only could be useful with CIR>128Kbits/s, and that the RT-video requirements are the most restrictive of three services (CIR>192Kbits/s). Anyway, real measurements showed that CIR=128Kbits/s could be enough with high compression ratios. Thus, Fig. 8(b) shows the BW evolution through four consecutive communication links. Since full capacity is shared with other traffic sources, SM3 indicates when the service does not fit to the required thresholds (third and fourth links).



(a) (b)

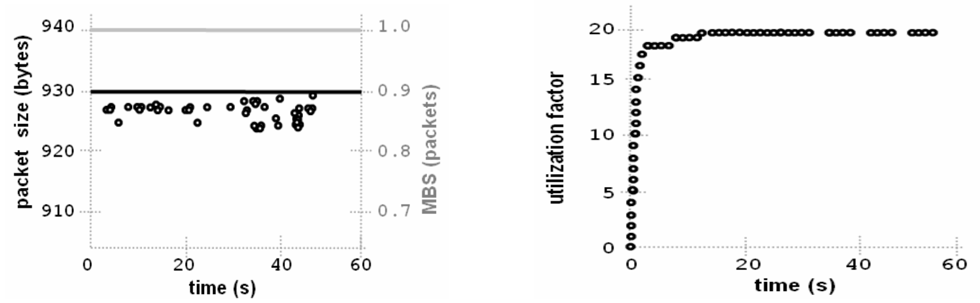
Fig. 4. RT.audio service characterization. (a) Peak Data Rate (PDR). (b) Inter-packet time (Δti).




```
Res-FRcaseI-RTvideo.log
K-S Test (972 packets)
-----------------------------------------------------
LOG Ave Error = 0.1747     Var Error = 0.0140
LOG Max Error = 0.3455          in X = 0.0750
-----------------------------------------------------
NRM Ave Error = 0.2868     Var Error = 0.0327
NRM Max Error = 0.5322          in X = 0.3170
-----------------------------------------------------
EXP Ave Error = 0.1331     Var Error = 0.0024
EXP Max Error = 0.1878          in X = 0.0010
-----------------------------------------------------
RAY Ave Error = 0.1768     Var Error = 0.0092
RAY Max Error = 0.2957          in X = 0.0640
-----------------------------------------------------
UNF Ave Error = 0.1853     Var Error = 0.0475
UNF Max Error = 0.4697          in X = 0.4520
```

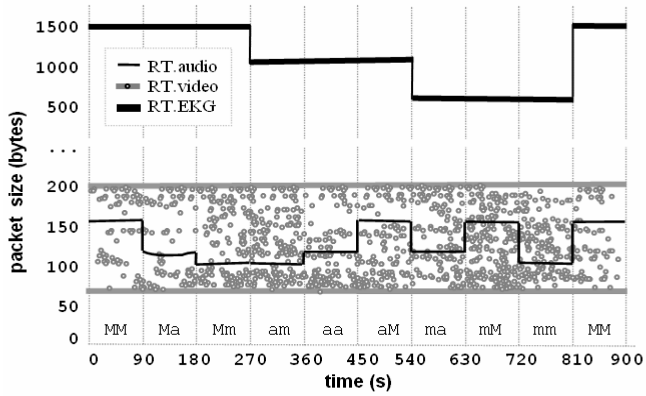
(a) (b)

Fig. 5. RT.video service characterization. (a) Obtained CDF vs classic distributions: log-normal, normal, exponential, Rayleigh, and uniform. (b) Kolmogorov-Smirnov test applied to the CDF,

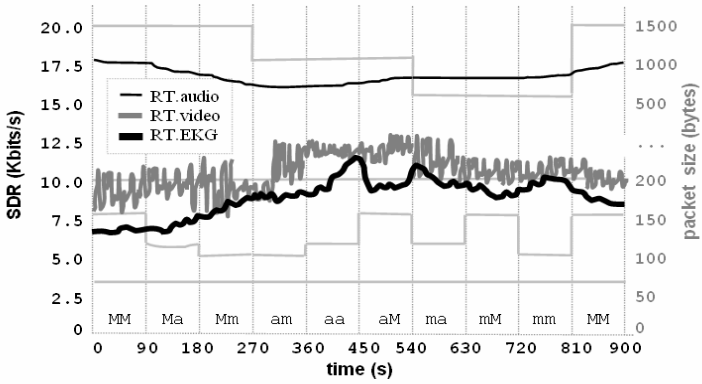


(a) (b)

Fig. 6. RT.bio service characterization. (a) Packet size evolution, with its associated MBS. (b) Utilization factor, for a intermediate *buffer* with queue size Q=20.



(a)

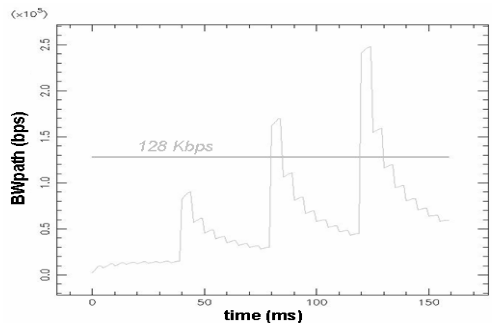


(b)

Fig. 7. Evaluation of the service performance. (a) Packet size evolution for different transmission rates: M=Maximum, a=average, m=minimum. (b) SDR evolution.

```
Res-FRcaseI-RTvideo.log
Ratio EED(s)/PLR(%)
----------------------------------
CIR=64K   Audio    0.203/10.25
          Video    0.297/12.73
          ECG      0.073/02.10
CIR=128K  Audio    0.147/03.87
          Video    0.286/11.27
          ECG      0.069/01.98
CIR=192K  Audio    0.098/02.70
          Video    0.164/07.48
          ECG      0.068/01.87
CIR=256K  Audio    0.090/01.23
          Video    0.137/04.81
          ECG      0.049/00.60
```

(a)



(b)

Fig. 8. Evaluation of the service performance regarding network resources (a) PLR/EED ratio. (b) BW evolution through consecutive communications links to evaluate congestion situations.

4 CONCLUSIONS

This work has presented a tool (*Service Multimedia Measuring & Modelling*, SM3) developed according to a methodology of technical evaluation. SM3 provides a quantitative and qualitative analysis of each part of the measured scenario. It includes three modules that determine the service characterization (*QoS basic*), the application traffic model (*QoS application*), and the interconnection devices, buffers and links behaviour evaluation (*QoS network*). It permits to study the QoS associated to the multimedia services and to model their network tomography and related applications traffic. Moreover, it would permit to avoid adaptatively the congestion situations in advance varying the traffic source parameters (rates, encoders, compression ratios, etc.)

ACKNOWLEDGES

This work was supported by projects from Comisión Interministerial de Ciencia y Tecnología (CICYT) and Fondos Europeos de Desarrollo Regional (FEDER) TSI2004-04940-C02-01, and Fondos de Investigación Sanitaria (FIS) FISG03/117.

REFERENCES

[1] G. Fortino and L. Nigro, "A methodology centered on modularization of QoS constraints for the development and performance evaluation of multimedia systems", *Proc. 33rd Annual Simulation Symposium SS'00*, pp. 177-184, 2000.

[2] R. Holle and G. Zahlmann, "Evaluation of telemedical services", *IEEE Trans Inf Technol Biomed*, 3(2):84-91, 1999.

[3] S. de Lusignan, S. Wells, P. Johnson, K. Meredith, E. Leatham "Compliance and effectiveness of 1 year's home telemonitoring. The report of a pilot study of patients with chronic heart failure". *Eur J Heart Fail*, 3(6):723-30, 2001.

[4] T. Yamazaki and J. Matsuda, "Adaptive QoS management for multimedia applications in heterogeneous environments: A case study with video QoS mediation", *IEICE Trans. Commun*, vol. E82-B, no. 11, pp. 1801–07, 1999.

[5] M. Maheu, P. Whitten, A. Allen, "E-health, telehealth and telemedicine: guide to start-up &success", *Jossey-Bass*, 2001.

[6] W.C. Hardey, "QoS Measurement and Evaluation of Telecommunications Quality of Service", *Eds. John Wiley*, Handcover, 230 pages. [Book Review – R. Chodoreck, *IEEE Communications Magazine*, 40(2):30-32, 2002].

[7] K. Zielinsky, "Krakow Centre of Telemedicine – Developing the Platform for Regional Telemedical Networks", *Proc. Conference 'E-health in Common Europe'*, 2003.

[8] D. Caramella and S. Giordano "An advanced IP based telemedicine trial supporting QoS for multimedia teleconsulting", *International Conference EuroPACS*, 2000.

[9] W.R. McDermott et al., "Optimization of Wide-Area ATM and Local-Area Ethernet/FDDI Network configurations for high-speed telemedicine communications employing NASA's ACTS", *IEEE Network*, 13(4):30-38, 1999.

[10] M. Li and R. Sampigethaya. "Network Tomography", *STAT 593E*, 2003.

[11] P.E. Wirth, “The role of teletraffic modeling in the new communications paradigms,” *IEEE Communications Magazine*, vol. 35, pp. 86-92, 1997.

[12] J.F. Huard, I. Inoue, A. A. Lazar and H. Yamanaka, "Meeting QoS guarantees by end-to-end QoS monitoring and adaptation", *V IEEE International Symposium on High Performance Distributed Computing*, pp. 348-355, 1996.

[13] I. Martínez, J. Salvador, J. Fernández, J. García, "Traffic requirements evaluation for a Telemedicine network", *International Congress on Computational Bioengineering ICCB'03*, pp. 389-394, 2003.

[14] E. Casilari. "Caracterización y modelado de tráfico de vídeo VBR", *Tesis Doctoral*, Universidad de Málaga, 1998.

[15] A. Coppola, "Practical Statistical Tools for Reliability Engineers", *DoD Reliability Analysis Center*, 1999.

[16] M. Taqqu, "Theory and Applications of Long-Range Dependence", *Birkhäuser*, Boston, 2003.

[17] D. Wright, "Informe UIT sobre telemedicina en los países en desarrollo", *Journal of Telemedicine and Telecare,* 4(1), 1998 [Versión española en *International Telemedicine*,7-8, 1998].

[18] J.L. Romeu, "K-S: A goodness of fit test for small samples", *START Reliability Analysis Center*, vol. 10, number 6, 2003.