QoS Evaluation Methodology for Multimedia Telemedicine Services

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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 methodology for technical evaluation of Quality of Service (QoS) traffic requirements in new healthcare services based on telemedicine. It includes the service description, considering both application requirements and network topologies, and the service evaluation, implemented by an automated tool. 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 a real-time medical service.

keywords

Methodology, multimedia, network design, QoS, services, technical evaluation, telemedicine.

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1 INTRODUCTION

Telecommunications and advanced information technologies have increasingly been used for clinical activities and research to improve health care delivery. These technologies have undergone many investigations to evaluate their effectiveness, efficiency, and feasibility[1, 2, 3]. The technical evaluation firstly requires a measurement methodology [4, 5] in order to analyse application and network requirements and consequently to optimize the service design and modelling according to available resources.

Service design is considered by diverse authors as definitive for the correct implementation, performance and maintenance. This design process follows a logical order: first, to determine the available resources in the network, then to analyse the type, volume and Quality of Service (QoS) requirements of the information to be transferred, and finally to tune the applications that the network is going to support. Service modelling is at the heart of any performance evaluation in a telecommunications network [6].

Telemedicine services are usually based on multimedia technologies and they 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 [7]. An accurate estimation of network performance is critical for the success of these multimedia services [5, 8].

The Internet Engineering Task Force (IETF) is currently studying models and architectures for supporting differentiated services, in order to better evaluate multimedia streams QoS requirements [2, 3, 9]. An extended idea consists on trying to adapt the applications to the network characteristics [10, 11] by handling a variety of quality measures, such as packet dropping rate, delay, *jitter*, bandwidth and variable source rate availability [12, 13, 14]. This permits to improve the quality of e-health communications over best-effort networks [15, 16].

In this paper, a methodology for technical evaluation of QoS traffic requirements in new healthcare services is proposed. Section 2 defines the test methodology that includes service description and evaluation based on a measurement and modelling tool. This tool aims at optimization of telemedicine applications design. Thus, an overview of a telemedicine service based on different clinical routines and communication technologies is given in section 3. Section 4 defines the complete process of multimedia definition, measurement and modelling. Results obtained from a representative example of telemedicine services, performing on different network environments, are discussed in section 5.

2 METHODOLOGY

A telemedicine service is usually based on the use of an application over a communications network. The service implementation can be optimized from different perspectives: by adjusting the application end-to-end design and by improving the network edge/backbone characteristics. In order to easy both tasks, a technical evaluation methodology is proposed, which includes the description and the evaluation of the service. The general methodology consists of the following steps (see Fig. 1):

1. **Service Description.** It implies the selection of:
   - Application requirements regarding medical activities needed in the service (signals transmission, multimedia communications, etc.).
   - Network scenarios for inter/intra-hospital connections, corresponding to Wide/Local Area Network (WAN/LAN) environments, respectively.
2. **Service Evaluation.** It consists of three modules:

A. *Multimedia Service Definition Module.* It translates the healthcare service description into an initial telematics definition in order to test different design possibilities. This translation can be based on theoretical studies or on the implementation of a real environment. Both perspectives consider three principal analysis points:

- Application End-to-End. It permits to select suitable traffic flow parameters: encoder types, compression methods, etc.
- Network Edge/Backbone. It permits to select suitable access characteristics (fixed or mobile, available resources, etc) and to select suitable technologies for the inter-networking link (priorities allocation, resources reservation, etc).

B. *Measurement Module.* Starting from the previous module output (theoretical studies, real environments configurations, etc.), this module produces data traces which correspond to different connections and scenarios. The implementation of this measurement module is performed through two complementary settings:

- Experimental. It captures and filters time packets through a real implemented scenario to experimentally characterize each intermediate analysis point of the service.
- Simulation. It captures and filters time events through the simulated scenario to obtain multiple results under varying conditions.

C. *Modelling Module.* The results obtained from experimental and simulated measures are compared and evaluated after a telematics processing. It consists on the calculation of key traffic parameters to study QoS, to improve devices and network functionalities, by adjusting iteratively the initial telematics definition.

Using this general methodology, we have measured experimentally a real application through a real network scenario. The captures produce an initial model which is used to see how the service performs. Subsequently, the obtained model is simulated under varying conditions to propose service improvements. This progressive adjustment allows optimizing the telemedicine service design according to changing resources and heterogeneous networks.

[**Fig. 1 about here**]

3 SERVICE DESCRIPTION

A healthcare service based on telemedicine includes clinical characteristics and technological requirements which need to be defined in order to improve the new healthcare models. Thus, we establish two analyses:

A. Application Requirements. The application of telematics technologies to the healthcare environment is associated to multimedia communications. Some representative kinds of medical activities may include (see Fig. 2):

- *Off-line* applications: administrative files and Electronic Patient Report (EPR) transfer (from medical data exchange between centres or speciality sections), clinical routine consults during accesses to databases, queries to medical report warehouse, etc.

- *On-line* applications: multimedia connections including audio and video exchange, biomedical signals and vital parameters (such as electrocardiogram (ECG) signal, blood pressure, oxygen saturation, etc.) transmission, etc.

B. Network Scenarios. The inter/intra hospital communications design is based on the hierarchical health system structure. Studies of WAN environments correspond to network technologies, devices, topologies and, in summary, desirable resources to guarantee communications among geographically dispersed centres. LAN definition corresponds to intra-connection among hospital equipments, signal acquisition devices, databases, etc. Some representative scenarios are shown in Fig. 2, including fixed and mobile accesses.

[**Fig. 2 about here**]

4 SERVICE EVALUATION

The implementation of a new healthcare service based on telemedicine requires a technical evaluation to study its implementation under different network conditions. An automated process to measure QoS parameters and to model the multimedia service has been developed for this purpose. This tool, Multimedia Service Measurement and Modelling (*Service M3*), is divided into three modules:

A. Multimedia Service Definition Module. This module translates clinical requirements into telematics parameters which can be measurable and valuable. The software implementation of this module is shown in Fig. 3(a) and Fig. 3(b) (upper and lower area, respectively). This process implies two initial definitions:

A1. Application End-to-End. It has been derived from two perspectives:

- Theoretical studies, from the analysis of telemedicine application characteristics (data traces) and from previous work [17, 18, 19]. Thus, several traffic models have been analysed (the agents and parameters considered are summarized in Table 1):
  - Real Time (RT) service for*non-elastic* applications (*on-line* transmissions that are "no waiting data arrival" later than a threshold time), based on a multimedia connection model. It is generally defined over User Datagram Protocol (UDP), for non-flow-control transmission, to provide with a connection characterised by low delay and small nonzero loss ratio.
  - Non Real Time (NRT) service for *elastic* applications (generally, *off-line* transmissions), based on an ASAP (as-soon-as-possible) model. It is generally defined over Transmission Control Protocol (TCP), for non-loss mode transmission, to provide with a connection characterised by dedicated bandwidth.
- Real traffic models derived from real application designs, including hospital videoconference, biomedical signals and clinical data transfer, database accesses, etc.

In both cases, the traffic model is further used to be sent to the real network devices and to train the simulated scenarios.

A2. Network Edge/Backbone. It has been derived from two perspectives:

- Theoretical studies, based on previous works [17, 18, 19] in order to define restrictive conditions and study traffic *bottlenecks*. The studies include queue size design, scheduling algorithms (based on priority allocation methods), flow control methods, delay thresholds, loss probability models, etc. The main network parameters considered are summarized in Table 1.
- Real network equipment, including interconnection devices (hubs, switches, routers) and WAN links based on Frame Relay (FR), Asymmetric Digital Subscriber Line (ADSL) and Universal Mobile Telephone Service (UMTS) technologies.

[Table. 1 about here]

B. Measurement Module. This module captures real and simulated traffic flow in a valuable format for the Modelling Module. It integrates two application tools:

B1. Experimental. This application (*Real M3 Tool*) implements the remote process of real traffic measurement (based on *shell* codes, C processing codes and *tcpdump* [20] software running with *libcap* packet capture library, which uses Berkeley Packet Filter (BPF) system to capture frames of traffic from both network ends). Each different test is defined by using a configuration input file, containing IP addresses and ports for the traffic generator and the receiver of each connection, and the measure machine. Since input traffic can be provided from a real application or from a trace generator model, this input file also includes the parameters of the related generated traffic. A screen capture of this application is shown in Fig. 3(a) that includes:

- Packet Capturing. Once the network scenario is defined and implemented, the measurement process is launched, following the RFC-2330 [21] of IP Performance Metric (IPPM) and using *tcpdump* software. The application traffic is captured by means of the temporal stamp (*timestamp*) that *libcap* applies to each packet, following ASAP assignation from the *kernel*. Traffic capture can be done in a machine which has two network interfaces or in two different machines (using Network Time Protocol (NTP) [22] commands to synchronize each process). As result, two event output files (in sending and receiving ends) are created.
- Packet Filtering. Using the output files generated in the previous step, packet filtering is applied considering IP directions, ports, traffic types, etc. As a result of the filtering process, each pair of files is analysed to obtain information referring to captured packets: packet identifier, sending time, reception time, packet size, delay, etc. These data are stored in a results file in a suitable format.

B2. Simulation. This application (*Simulated M3 Tool*) controls the execution of Network Simulator (NS) for the simulation measurement process [23, 24]. Each different simulation test is automated by using a configuration input file (that contains suitable values for the agents and links properties, obtained from real captures or theoretical studies) and a configurable network setting (that generates the complete environment under simulation). A screen capture of this tool is shown in Fig. 3(b). The simulated measurement process is similar to the real process and includes the following steps:

- Event Capturing. NS execution is launched and event *timestamps* are written in an event output file.
- Event Filtering. By selecting the flow identifiers, traffic types, sending and receiving nodes, etc., the packet information generated in those nodes is obtained. These results are presented in the same format as in the real process.

C. Modelling Module. This module generates a complete traffic and network model after processing the results files by means of a *toolbox* of QoS analysis techniques, as it is shown in Fig. 3(c). Some of these analysis functions are: intermediate times estimation (propagation, transmission, queuing, switching, access, etc.), calculation of traffic rates and flows (*PDR, SDR, MBS, BT*, etc.) and measuring of QoS network parameters (*BW, aBW, PLR, PTD, PDV*, etc.). Moreover, this module permits the representation of graphics and statistics. Thus, interpretation and comparative of these results (of different tests on the same scenario and of the same test on different scenarios) allow characterising the service behaviour.

[Fig. 3(a) about here]

[Fig. 3(b) about here]

[Fig. 3(c) about here]

5 EXAMPLE OF SERVICE EVALUATION

The proposed methodology was used to evaluate a real time medical service. The principal aim of this test was to analyse the requirements of an ECG *on-line* transmission sharing available network resources with a variable number of simultaneous multimedia connections (medical videoconference, EPR transfer, etc.). Thus, the applied methodology consisted on the following steps:

- **Service Description.** A multimedia based service that integrates *on-line* applications (multiple videoconferences and ECG signal real-time transmission) with *off-line* applications (clinical consults and EPR transfers) was designed [25]. Experimentally, it was installed (see Fig. 6) over two remote computers performing as two ends (hospital and health centre, respectively) of the WAN connection link. Moreover, the service model was simulated in order to compare results of the proposed methodology.

[Fig. 6 about here]

- **Service Evaluation.**

  A. Multimedia Definition. The application model includes RT agents for *on-line* models (considering the ECG, audio and video encoders shown in Table 2) and NRT agents for *off-line* models (performing as "noise traffic" to congest the link). The network edge model, based on Switched Ethernet, corresponds to the LAN intra-hospital access. The network backbone model, based on FR technologies, corresponds to the WAN connections among sanitary centres.

[Table. 2 about here]

  B. Measurement.

  B1. Experimental. Through the defined network scenario, the traffic flow under study (*ECG-traffic*) was aggregated with audio/video transmissions and EPR transfers. Multiple combinations were captured and analysed depending on the available BW variation (regarding to the QoS thresholds shown in Table 2). Fig. 4 illustrates SDR evolution for each traffic flow. It shows that flows are much more uniform for audio and ECG applications than for video (due to the high variability in the image capture process). Anyway, experimental mean values (indicated in upper legend) are very close to theoretical rates shown in Table 2 (in fact, deviation is due to captures include low level protocol overhead).

  B2. Simulation. From experimental results, the main parameters in the SDR variation (s_i and Δt_i) were adjusted. Thus, multiple simulations were launched regarding to available bandwidth (aBW). The variation ranges of simulation parameters are summarised in Table 3. Most significant result (using $s_i > 512 bytes$ and $\Delta t_i = 90ms$) shows that $aBW = 128Kbps$ is necessary to guarantee QoS for $PTD < 115ms$ (see Fig. 5).

[Fig. 4 about here]

[Table. 3 about here]

[Fig. 5 about here]

  C. Modelling. In summary, the *ECG-traffic* flow can be modelled by means of a $SDR = f(s_i, \Delta t_i)$. These parameters are related with ECG compression ratios (s_i) and with encoder on-line transmission rates (Δt_i). Thus, the proposed methodology allows adjusting dynamically the service behaviour regarding to aBW and QoS thresholds, and therefore optimizing the service performance.

6 CONCLUSIONS

A methodology for technical evaluation of QoS traffic requirements in telemedicine services has been proposed. It includes the healthcare service description, considering both application and network requirements, and the healthcare service evaluation implemented by an automated tool, *Service M3*. This tool includes the initial multimedia service definition (from real data flows or theoretical data traces over real devices or simulated equipment conditions) and the measurement and modelling processes that allow parameter analysis, trends interpretation, model validation and real and simulated behaviour comparison.

A representative telemedicine service, based on an ECG *on-line* transmission, has been discussed on an integrated scenario with multiple multimedia applications (medical videoconference, clinical consults, EPR transfer, etc.) that share available network resources.

Thus, the proposed work constitutes an automated and versatile methodology for technical evaluation that allows measuring QoS requirements of multimedia services (in particular, telemedicine-based healthcare services) and optimizing application design (e.g. by adjusting *encoders* types, compression ratios, number of simultaneous connections, suitable packet sizes or bit rates) according to the network resources.

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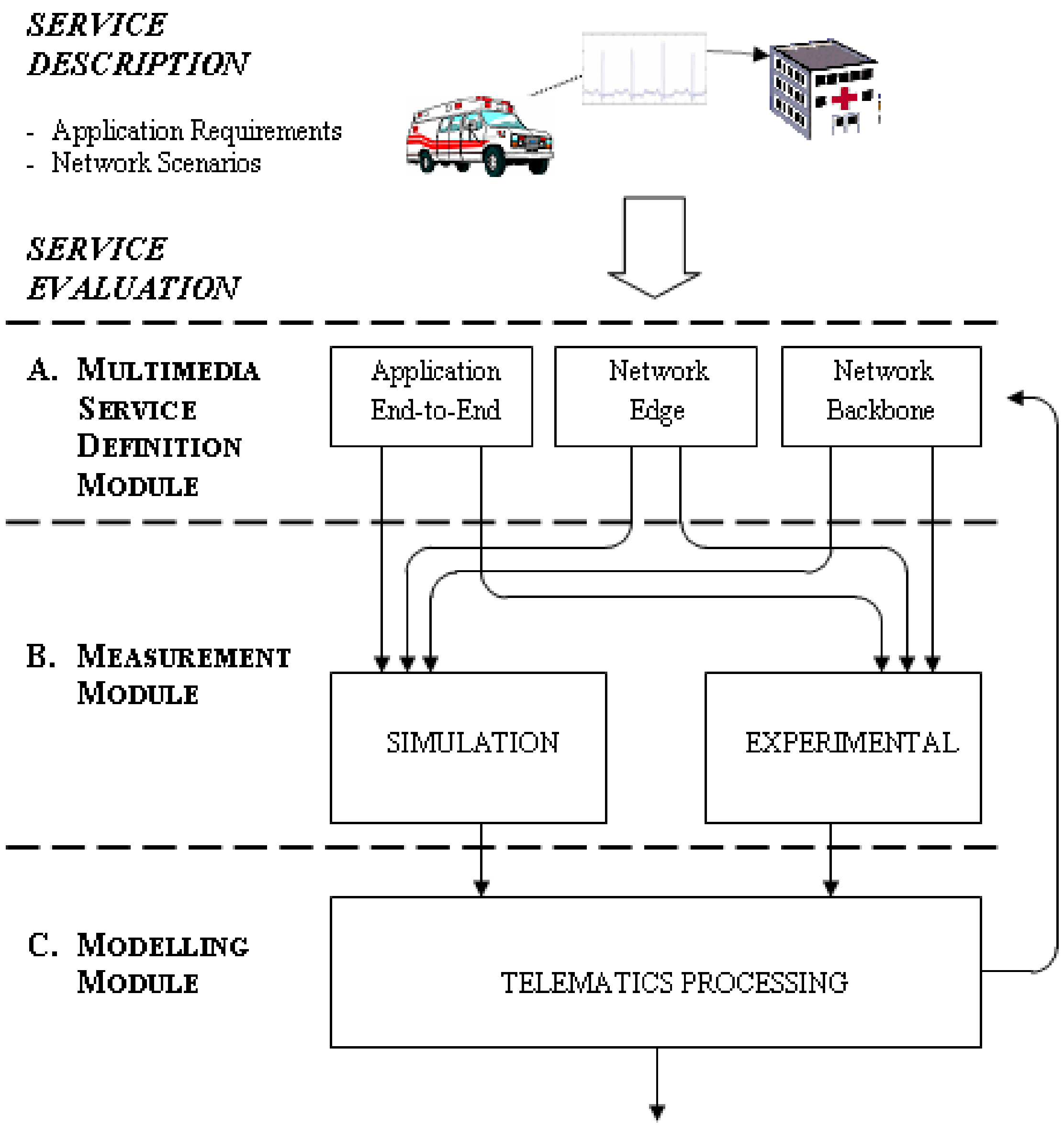


Figure 1: *Technical evaluation methodology.*

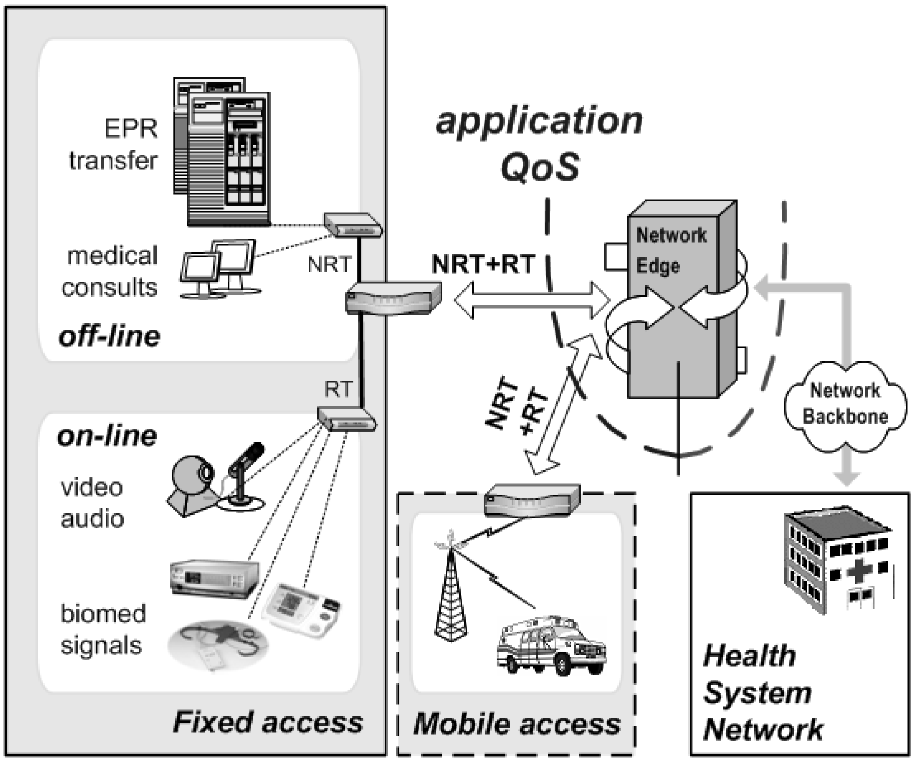


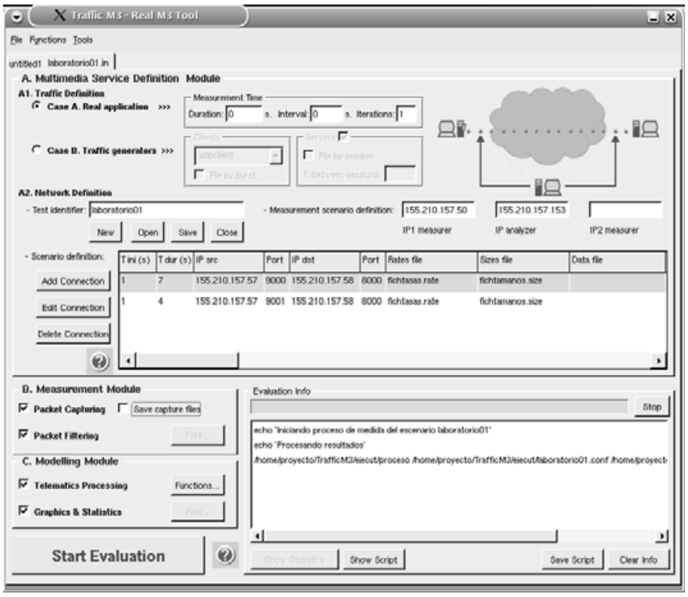
Figure 2: *Telemedicine service model.*

agents	**applications**	**models**	**(1)**	**(2)**	**(3)**	**parameters**
	Medical test	CBR	X	V	X	packet size (s_i)
NRT	transfer	FTP	X	V	X	interpacket time (Δt_i)
off-line	Clinical consults	Exponential	X	V	V	idle/busy times (d_{off}/d_{on})
	(web connections)	Pareto	X	V	V	Peak/Sustained Data Rate (*PDR/SDR)*
		Weibull	X	V	V	Burst Tolerance/Shaping (*BT/BS)*
	Biomedical signal	CBR	V	X	X	Maximum Burst Size (*MBS)*
RT	transmission	ON/OFF	V	X	X	Maximum Transfer Unit (*MTU)*
on-line	audio/video	CBR	V	X	X	Occupation factor (ρ)
	transmission	VBR-rt	V	X	X	Activity factor (n_c)

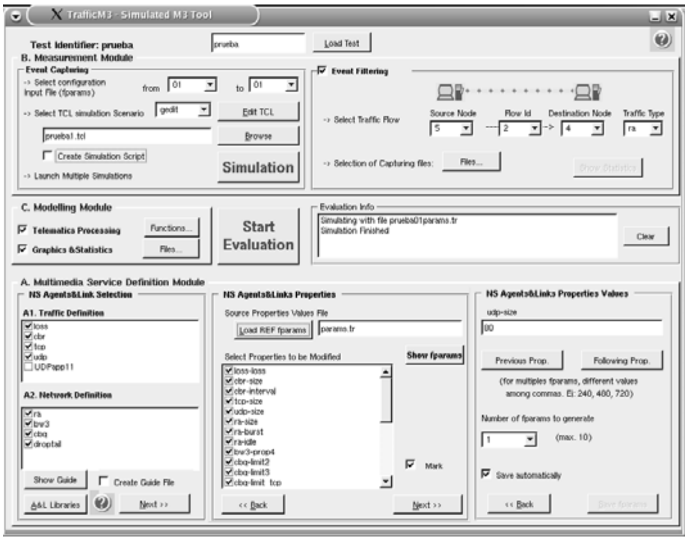
CBR: Constant Bit Rate   FTP: File Transfer Protocol   VBR-rt: Variable Bit Rate-real time

network	**requirements**	**parameters**
(1)	Capacity guarantee	bandwidth(BW), available BW (aBW), capacity effective (C_e), queue size (Q_i)
(2)	Reliability guarantee	Packet Loss Rate (PLR), Mean Time To Repair ($MTTR$), Mean Time Between Failures ($MTBF$)
(3)	Delay guarantee	Packet Transfer Delay (PTD), PTD variation (PDV), queuing (q^i), switch/processing (p^i), service/access (d^i)

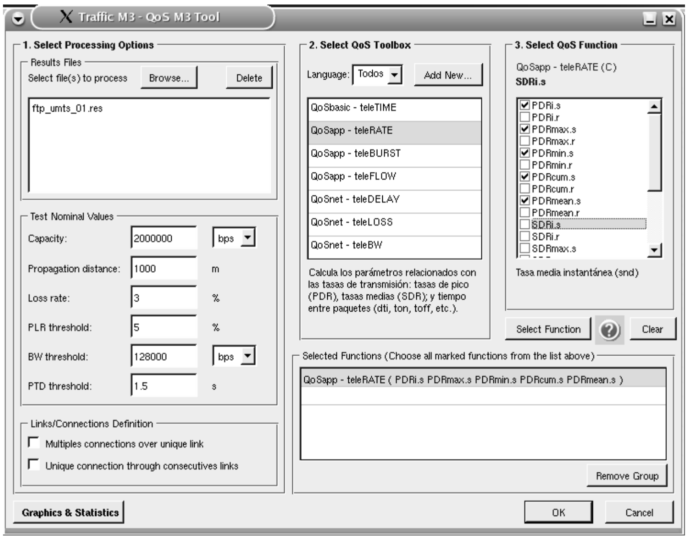
Table 1: *Application and network parameters included in the Multimedia Service Definition Module. Columns (1), (2) and (3) show if the minimum network requirements regarding capacity, reliability and delay, respectively, are necessary (V) or not (X) to guarantee QoS.*



(a) *Real M3 Tool.*



(b) *Simulated M3 Tool.*



(c) *QoS M3 Tool.*

Figure 3: *Service M3.*

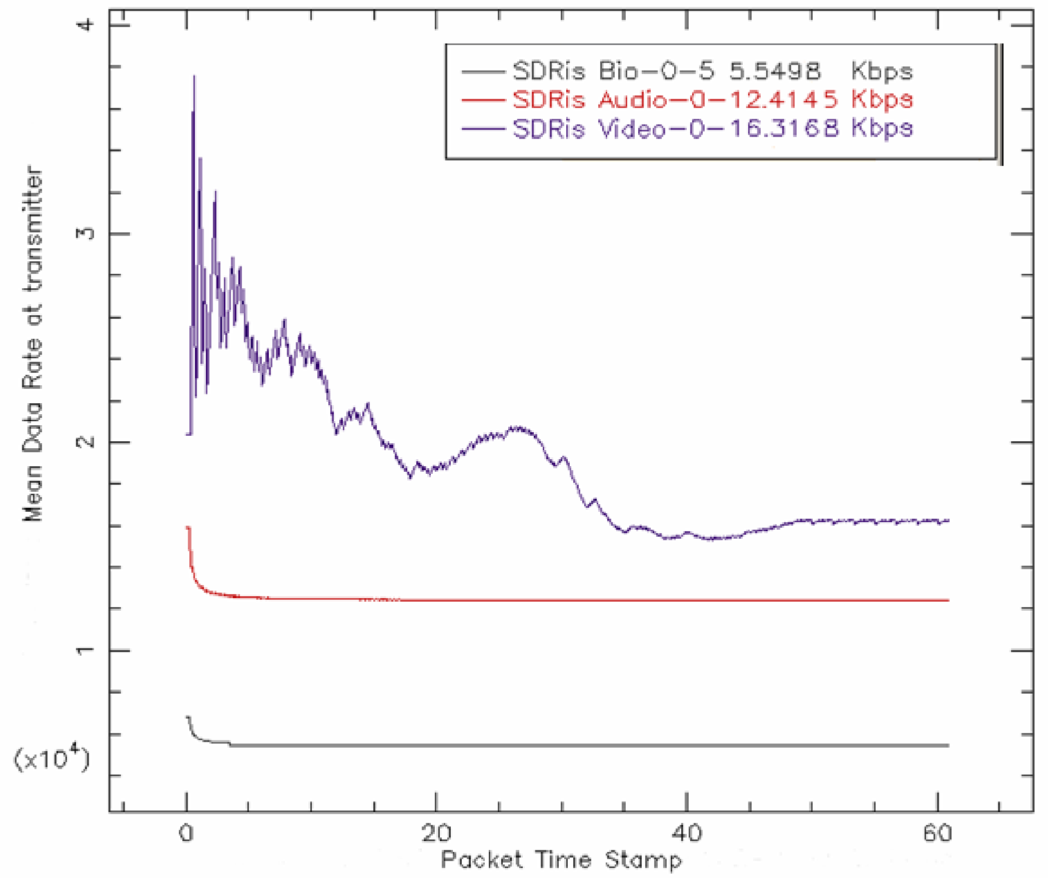


Figure 4: *SDR evolution in experimental tests.*

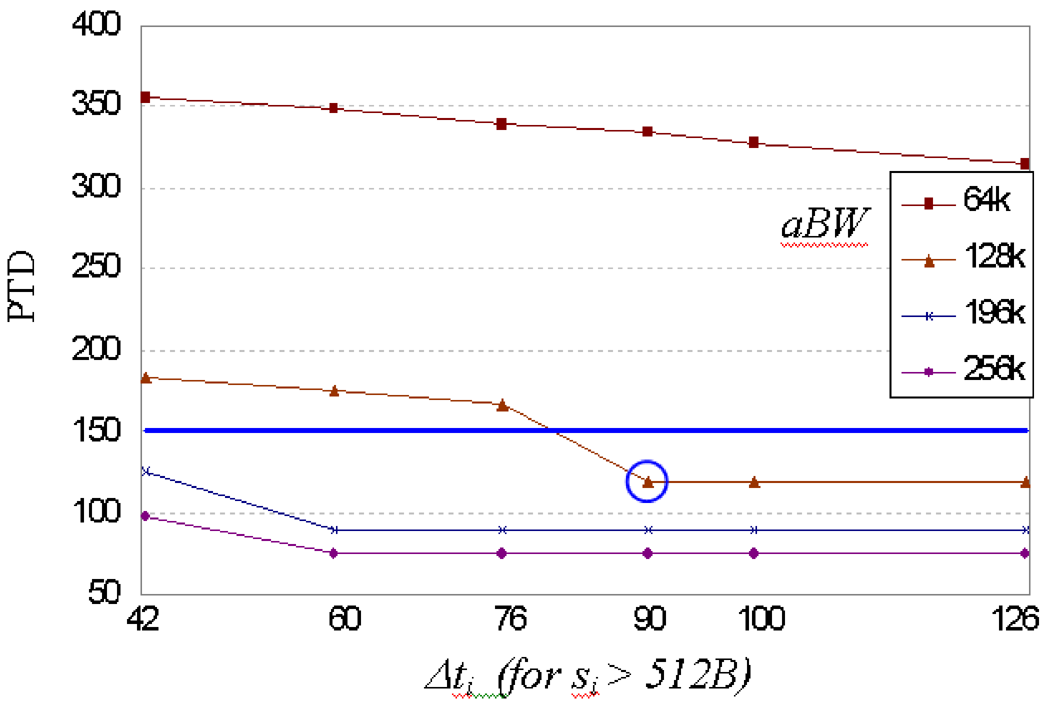


Figure 5: *PTD statistics in simulation tests.*

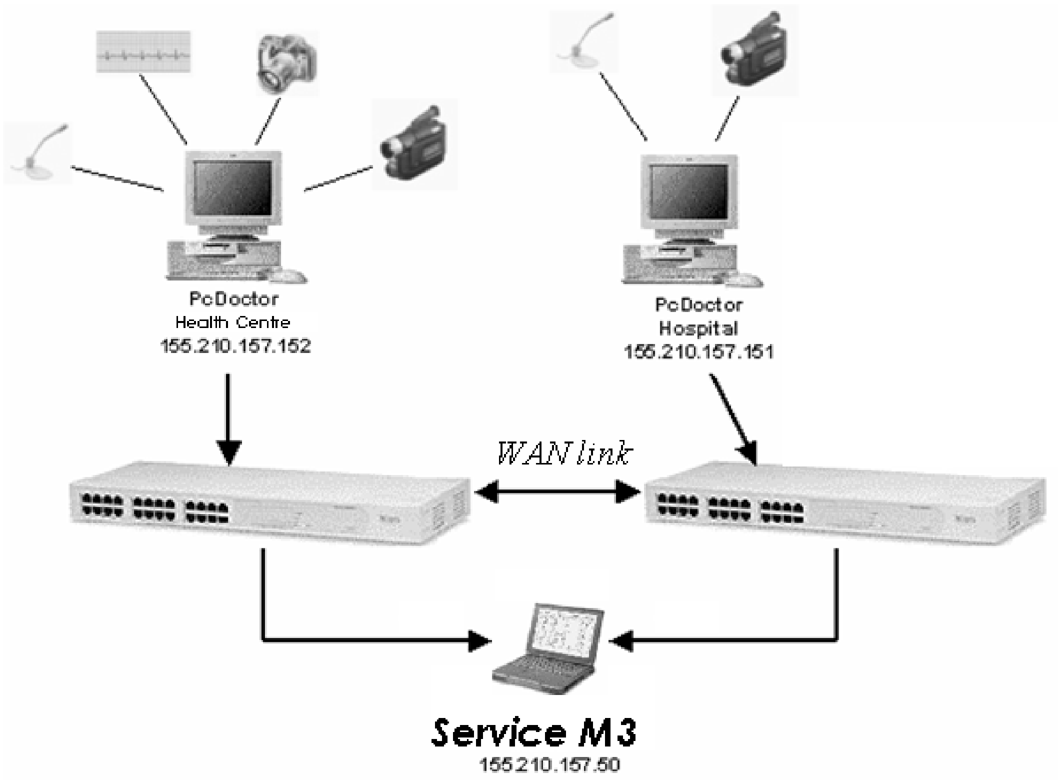


Figure 6: *Designed scenario for experimental evaluation.*

encoder	rates	QoS thresholds
ECG RTP	5 Kbps	PTD < 150ms
audio AMR	12.2 Kbps	PLR < 0.10
video H.263	16 Kbps	BW < 2Mbps

Table 2: *Multimedia encoders and QoS thresholds.*

parameter	variation range	
s_i	40-80-240-480-**512**-1024-1500	*(bytes)*
Δt_i	30-42-60-76-**90**-100-126	*(ms)*
aBW	32-64-**128**-192-256-384-512	*(Kbps)*

Table 3: *Variation ranges for telemedicine services.*