Resources Variability in m-Health Services: An Adaptive Method for QoS Control

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***Abstract*-The analysis of new e-Health services in mobile environments (m-Health services) where resources are usually limited and network conditions are continuously changing, require a specific technical evaluation in order to guarantee Quality of Service (QoS). This work quantifies QoS levels depending on available resources and proposes a methodology for selecting which simultaneous telemedicine applications fulfill a set of predefined requirements. The results obtained permit to develop adaptive mechanisms and strategies for selecting the best combinations of services and application codecs according to the varying network resources.**

I. INTRODUCTION

Mobile environments are one of the most important technological challenges at the present time and in the following years [1]. In this context, the developments applied to e-Health have been extraordinary and have permitted to extend the quantity and improve the quality of the services offered [2], [3]. Mobile telemedicine constitutes a new area in e-Health (known as m-Health) that tries to take advantage of the most recent advances in mobile networks to use them in sanitary services. The convergence of information and telecommunication infrastructures around telemedicine and teleassistance systems is fostering the development of very diverse, efficient and low cost mobile applications [4]. Emergency telemedicine is a synonym of mobile telemedicine, because the only way to communicate an ambulance with a hospital is through a wireless channel [5], [6].

This paper presents a study of the variability of Quality of Service (QoS) in mobile environments using a patient telemonitoring system for emergency vehicles as testbed. The study is based on the evaluation of system performance from the point of view of the variable assignment of resources to guarantee QoS. The system includes different Types of Service (ToS) that require specific analyses and precise estimations of the QoS level that can be offered.

The medical emergency environment is composed of a mobile Intensive Care Unit (ICU) equipped appropriately that can connect to a hospital network through a Third Generation (3G) Universal Mobile Telecommunications System (UMTS) access [7]. In the hospital, one or several medical specialists take part in a multipoint conference with the personnel of the mobile ICU in a multicollaborative environment, receiving compressed and coded biomedical information about the patient, thus favoring an early diagnosis prior to his reception.

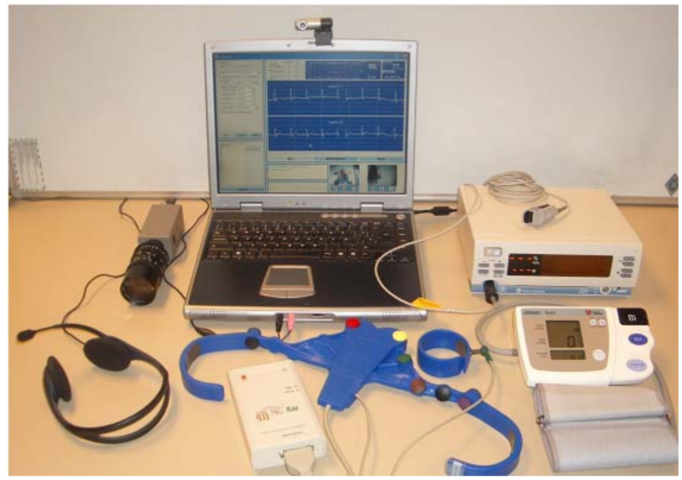

Fig. 1. Telemonitoring application designed for a mobile ICU using an UMTS access, which includes specific real-time transmission modules.

The application designed in the mobile ICU (see Fig.1) includes several modules (videoconference, biomedical signals, high-resolution image, interactive chat and whiteboard, file transfer, web access and voice recognition).

The analysis presented in this article has been carried out by an *ad-hoc* tool [8] that allows integrating the results obtained from experimental measurements (developed at the network laboratory in the University of Zaragoza) and simulated traces (generated with the *Network Simulator* (NS-2) tool and using specific traffic and network models, detailed in [9]).

Section 2 describes the characteristics of the mobile scenario, the use cases and the evaluation parameters. The QoS study as a function of the available resources is detailed in Section 3 for different service combinations: multimedia services, biomedical services and, finally, all the services at the same time. The results obtained and their translations into adaptive QoS decision mechanisms are discussed in Section 4.

II. EVALUATION METHODOLOGY

The m-Health system implemented is based on the communication between a non-medical specialist (situated in a mobile ICU) and the reference hospital in order to strive, with all the available resources, for saving the life of the patient in the way "accident site - hospital", see Fig.2. These scenarios are related to teleemergencies, ambulatory teleurgencies, etc.

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The technical characteristics of communication are related to mobile technologies (UMTS), with a highly variable channel, limited network resources and, probably, with a non-uniform performance. Thus, in order to evaluate the most restrictive situations for the mobile channel in this study, a maximum transmission rate to the hospital (upstream) $r \leq 64$kb/s for every user connection has been considered in the mobile access point. Several ToS are grouped in this user connection, each of them with different Real-Time (RT) features. In order to guarantee QoS, the main parameters have been considered: End-to-End Delay (EED), Packet Loss Rate (PLR), and information quality determined by the main traffic descriptors: Maximum Burst Size (MBS), Burst Tolerance (BT), resolution, etc. The interest of this scenario is analyzing the limitations of available resources, the variability of the mobile environment, and their influence on QoS evolution.

A. Use Cases

Based on the previous technical description of the mobile environment, several evaluation scenarios (Use Cases (UCs) in Fig. 2) are proposed in order to study QoS in the maximum number of relevant situations. The UCs descriptions are:

- **UC1**. One of the most frequent UCs is based on a RT videoconference with a specialist in the hospital to help in the diagnostic process (Media). In this study, it includes audio (Audio) and video (Video) services.
- **UC2**. Other situation of interest is the simultaneousness of a RT videoconference and a biomedical service. In this study three ToS has been considered: Bio, for vital signal RT transmission (ECG, pulse, blood pressure), Img for RT transmission of high resolution images, and EHR for RT transmission of clinical/administrative data and remote access to the Electronic Healthcare Record database.
- **UC3**. It includes the multiple combinations of all ToS.

In every UC, it is interesting to study the QoS evolution depending on available network resources: to evaluate whether channel variability leads to important efficiency changes, whether minimum requirements are modified according to simultaneousness of different ToS combinations, etc. From results and trends obtained with an *ad-hoc* tool [8], the analysis of QoS limits under critical situations with limited resources will permit to propose adaptive decision algorithms.

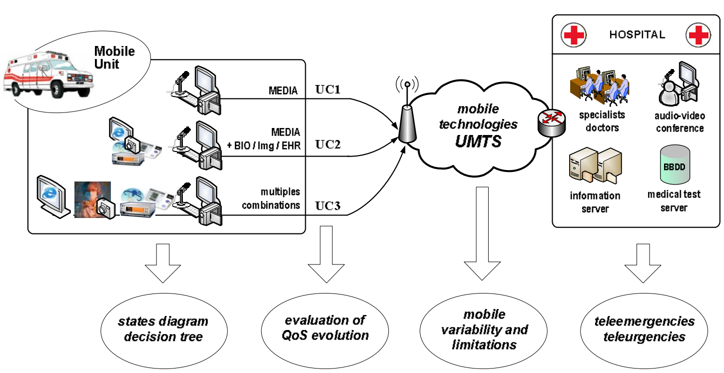

Fig. 2. Evaluation scenario for a m-Health RT service.

B. Service Model

The service model used in this study is based on previous contributions detailed in [9], and it has been designed from the technical results and main traffic descriptors and conclusions over QoS obtained in related works [10]-[18]. All these QoS models include the performance of applications as well as network technologies and, from both points of view, an evaluation scheme for m-Health scenarios is proposed in Fig.3.

The analysis of the QoS levels offered implies to study both points of view. Thus, in this study, a technical evaluation methodology has been developed in two stages:

- **Stage A**. On a laboratory *set-up* including the real applications designed, experimental measurements are taken over the 3G-mobile network (Table I shows codecs used in the present work). Hence, traffic traces obtained characterize the service and model its parameters. These results, together with standard and specific information for e-Health services detailed in the literature [11]-[15], are used as input parameters for simulations of the stage B.
- **Stage B**. From the experimental traces and the traffic and network models, multiple combinations are simulated in order to evaluate the optimum parameters.

Regarding this methodology, specific thresholds of delay (EED_{th}), loss (PLR_{th}) and information quality (QoS_{th}) have been scaled in Table II. These thresholds take into account the standards [11] and specific [16]-[18] requirements for every ToS. For example, for Media services combinations:

- $EED_{th} = \{EED_{th.Audio}, EED_{th.Video}\} = \{150, 250 \text{ (ms)}\}$;
- $PLR_{th} = \{PLR_{th.Audio}, PLR_{th.Video}\} = \{12, 10 \text{ (\%)}\}$; and
- $QoS_{th} = f\,\{[\text{MBS,BT}]_{Audio}, [\text{MBS,BT}]_{Video}\} = \{[7.5,0.2], [19,1.0]\}$.

Based on this notation, the QoS level (α) is defined as a degradation factor of the global quality: from α=10 (optimum quality) to α=0 (no quality). Hence, the available resources factor (β) is defined from a maximum value (100% resources, β = 1, for the maximum transmission rate r = 64kb/s, considered in this study for the mobile channel) to a minimum value (10% resources, $\beta = 0.10 \rightarrow r = 6.4$kb/s). Following the previous example, a service with high quality (α=8) will allow the following thresholds (see Table II):

- EED = 90ms (Audio), and 150ms (Video);
- PLR = 7.2% (Audio), and 6% (Video); and
- QoS = [6, 0.16] (Audio), and [15, 0.8] (Video).

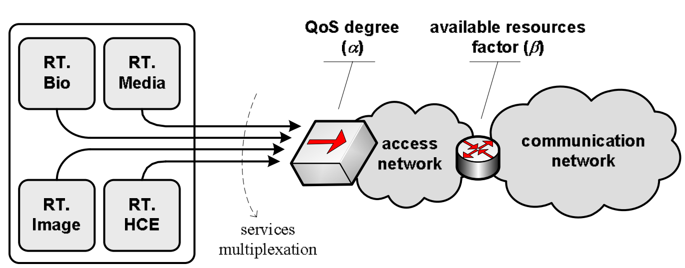

Fig. 3. Traffic sources and network resources associated to the evaluation of m-Health scenarios.

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TABLE I. QOS LEVELS (α) PROPOSED IN THIS STUDY FOR M-HEALTH SERVICES

α		QoS_{th}	EED level	PLR level
10	optimum	=100%	< 10% EED_{th}	< 10% PLR_{th}
9	very high	> 90%	< 20% EED_{th}	< 20% PLR_{th}
8	high	> 80%	< 40% EED_{th}	< 40% PLR_{th}
7	very good	> 70%	< 60% EED_{th}	< 60% PLR_{th}
6	good	> 60%	< 80% EED_{th}	< 80% PLR_{th}
5	suitable	> 50%	= EED_{th}	= PLR_{th}
4	low	> 45%	< 110% EED_{th}	< 110% PLR_{th}
3	quite low	> 40%	< 115% EED_{th}	< 115% PLR_{th}
2	very low	> 35%	< 120% EED_{th}	< 120% PLR_{th}
1	poor	> 30%	< 130% EED_{th}	< 130% PLR_{th}
0	no quality	< 30%	> 130% EED_{th}	> 130% PLR_{th}

TABLE II. MODELS USED IN THIS STUDY FOR EVERY TOS

ToS	*codec*	algorithm	r_d (kb/s)	s_p (bits)
Audio1	G723.1	ACELP	5.3-6.4	184
Audio2	AMRx	AMR	4.7-12.2	95-244
Video1	H.263	5-15-30*fps*	8 - 64	SQCIF 192x144
Video2	H.120	H.32x	50-100	CIF 352x288
Bio	SCP.ECG	constant	5-32-64	250B/channel
	CBR	constant	2-8	32,16,8
EHR	XML	HTTP	24-40	250B-500B
	HTTP	HTTP	6-12-24	20-50-100B
Img	JPEG	24b/*pix*	50 - 200	640 x 480 *pixels*
	BMP/GIF	RLC/LZ	10/40 - 200	640 x 480 *pixels*

r_d = data rate (kb/s), s_p = data packet size (bits)

III. ANALYSIS OF QOS EVOLUTION

A. UC1. QoS in multimedia services

In this subsection, the first situation of interest (UC1) considers the Media services including different combinations of Audio and Video (see Table II). Thus, Fig. 4 shows that the trends obtained with the first Video traffic model (Video1), are much better than those with the second (Video2). With the traffic models related to Audio, the results yield the reverse situation: Audio2 obtains better performance than Audio1. Both situations are reasonable due to the fact that both models selected (Video1 and Audio2) are recommended for mobile technologies. From here, and analyzing all combinations for a suitable quality level ($\alpha > 5$), the QoS conditions are only guaranteed in the following situations: Audio2 + Video1 ($\beta \geq 0.25$), Audio1 + Video1 ($\beta \geq 0.45$), Audio2 + Video2 ($\beta \geq 0.60$), and Audio1 + Video2 ($\beta \geq 0.65$). This means that the combinations including Video2 are only suitable with, at least, 60% of available resources ($\beta \geq 0.60$); meanwhile combinations including Video1 will be allowed in more restrictive situations ($\beta \geq 0.45$). Below this level, the only option recommended is Audio2 + Video1.

As a first conclusion, these results permit to establish decision algorithms in order to be able to select every transmission codec according to the required QoS degree.

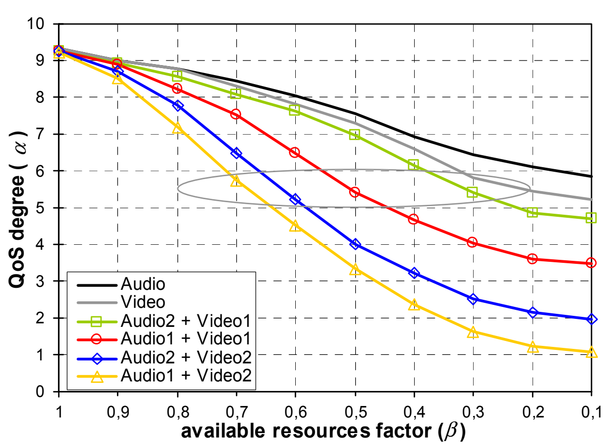

Fig.4 QoS evolution for multimedia services.

B. UC2. QoS in biomedical services

The second situation of interest (UC2) corresponds, from the mobile ICU towards the hospital, to the simultaneousness of various services among the following ToS (in a continuous way and real-time): transmission of patient vital signs and biomedical signals (Bio), remote access for EHR update and management (EHR), transference of high resolution images (Img), telephonic conversation to detail the emergency level (Audio), and video transmission to know each specific situation that occurs inside the ambulance (Video).

Fig. 5 shows the evolution of the QoS degree for each combination proposed. In order to establish quantitative levels, with a suitable quality ($\alpha > 5$), all the proposed combinations fulfill this threshold with 55% of available resources (β=0.55). When the resources decrease, several combinations do not guarantee QoS: Video + Img (β<0.55), Video + Bio (β< 0.50), Video + EHR (β< 0.45), Audio + Img (β < 0.35), Audio + Bio (β< 0.30), and Audio + EHR (β< 0.25).

These results, with the sequence previously obtained, contribute to design adaptive mechanisms of QoS control by means of the optimal selection among the different ToS. Thus, a scheme of the decision method between the proposed models that offer the best performance according to the decrease of the factor of available resources (β), selecting a suitable QoS threshold ($\alpha > 5$), is shown in Fig.6.

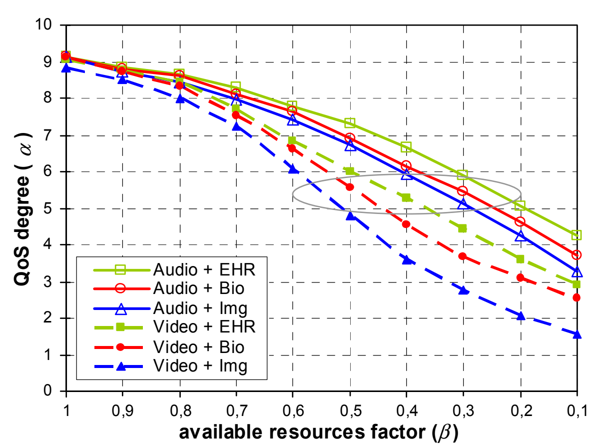

Fig.5 QoS evolution for biomedical services.

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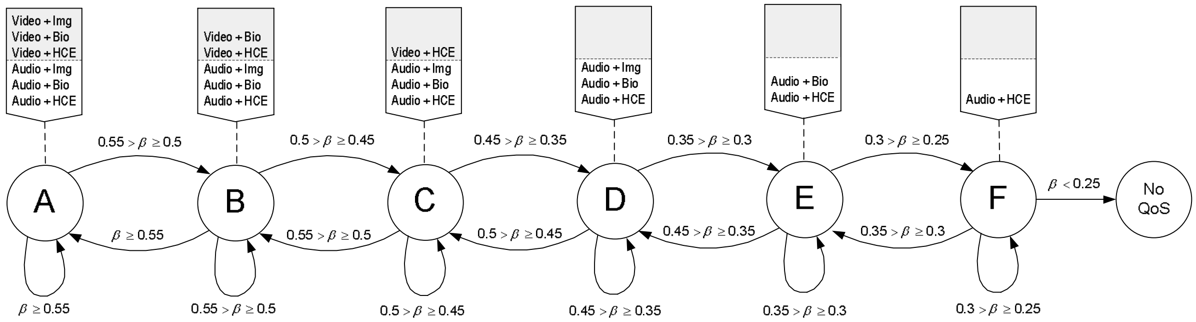


Fig.6 QoS decision method applied to combinations of two simultaneous EHR, Bio or Img services.

The possibility of a telephonic conversation (Audio) is guaranteed in all cases, but video transmission for watching the inside of the ambulance (Video) is only allowed if $\beta \geq 0.45$. Moreover, it permits to sort each ToS: for the situations with the lowest resources ($\beta \geq 0.25$) it would only be possible the combination with remote accesses (EHR), but an increase of resources would permit to add the RT transmission of biomedical signals (Bio, with $\beta \geq 0.30$) and high resolution images (Img, with $\beta \geq 0.35$). In a similar way as in the previous subsection, a real implementation will imply to monitor the value of β continuously and select the best state (with its corresponding services and combination of codecs), according to the monitored value.

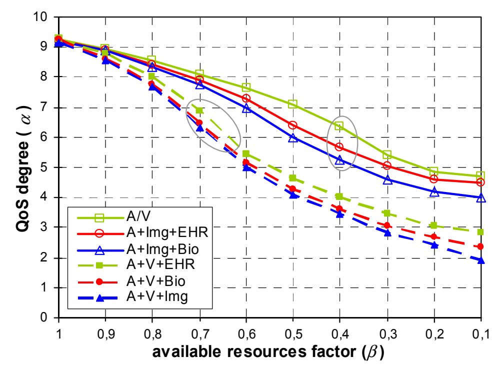
C. *UC3. QoS in multiple combinations of ToS*

The last situation proposed (UC3) analyzes the most critical combinations that include the largest number of simultaneous ToS. The results obtained have been classified into two groups as a function of the performance criteria in a teleemergencies system. The first group, see Fig. 7(a), includes the combinations of Audio+Img or Audio+Video services with the rest of ToS, in order to evaluate the situations where the telephonic communication between the ambulance and the hospital (Audio) is a priority. The second group includes the combinations of Bio+EHR with the rest of ToS, in order to evaluate the situations where the most important criterion is the transmission of patient vital signals (Bio), with the possibility of a remote EHR query (EHR). These cases, as it is shown in Fig. 7(b), imply adding more ToS because it can be necessary to include the transmission of clinical images (Img), the telephonic conversation with the hospital (Audio), the transmission of video from inside the mobile ICU (Video), or even the combination of all these ToS.

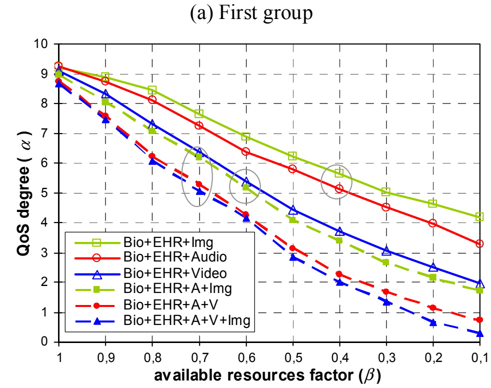
For the first group, see Fig. 7(a), similar trends are shown when Audio+Img is multiplexed with Bio or with EHR, and in both cases the QoS levels obtained are acceptable ($\alpha > 5$ with $\beta > 0.40$). These combinations of three simultaneous services produce a performance similar to the best combination of Audio+Video. Moreover, the performance of the last curves (Audio+Video with EHR, Bio and Img) can be grouped into a QoS range of 1 point, and 1.5 points below the previous trends: for $\beta > 0.70$, $\alpha \in (6, 7)$; versus $\alpha \in (7.5, 8.5)$ for $\beta > 0.80$.

These results indicate, for example, that the transmission of clinical data or video is allowed with 60% resources, but with $\beta < 0.60$, it will be better to avoid the video transmission in order to guarantee QoS for the audio-conference or the high resolution images (always that it was medically recommended).

For the second group, see Fig. 7(b), in generic terms it is noticeable that the QoS degree decreases notably when the network resources do, because of the larger number of simultaneous ToS. The combination of three services (Bio+EHR with Img, Audio or Video) produces good performance ($\alpha > 5$ for $\beta > 0.60$), and the trends obtained with Video and Audio+Img are similar (also between Audio+Video and Audio+Video+Img). All these situations evaluated remark the necessity of designing new mechanisms of QoS control that permit to select the best ToS combinations depending on the proposed factors α and β.



(a) First group



(b) Second group

Fig.7 QoS degree (α) evolution according to available resources factor (β) for critical combinations of multiple simultaneous RT services.

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D. *QoS global evaluation*

In order to complete these results of the evaluation methodology, we have compared them with experimental measurements studied in previous works [7]. For audio, the experimental tests showed that the transmission codecs with a larger number of packets (related to Audio2) imply a reduction of the BW used more than the rest of cases (related to Audio1). This trend was also shown in the previous subsections where the best performance was related to Audio2. For video, the experimental tests showed that, in average, it was the service that required the highest resources (remarked in this subsection); moreover, there was a high variability of resources depending on the movement degree related to the particular sequence of the transmitted video scene. Finally, the experimental tests showed that the transmission of high resolution images and biomedical signals, using codecs with the lowest transmission rates, do not imply critical situations of QoS degradation. When the bandwidth (BW) occupation was monitored: for each isolated service, BW<6kb/s (<10% of capacity), and for both simultaneous services, BW<10kb/s. This concludes that the simultaneousness of these two services is reliable in a teleemergencies service from a mobile unit.

In summary, following the criteria of the results obtained previously, a third state diagram is shown in Fig. 8. It represents the evolution of the most critical situations and permits to select the ToS combinations according to the available resources (for $\alpha > 5$, related to previous examples). The design of this type of state diagrams is automatic from the evaluation methodology developed, and it can be extensible to other simultaneity situations among interactive services.

The state diagrams proposed are obtained by fixing a determined QoS level (design conditions) and identifying the ToS combinations that fulfill it (system states) according to the factor of available resources (state transitions). This method, considering the monitored value of β as basis, will permit to be implemented in a ToS dynamic selector (depending on the required α thresholds). In parallel, there is another static model: establishing as premises the available resources degree (design conditions), permits to determine the best values for each ToS (system states) that not only guarantee a minimum QoS threshold but also offer the best performance according to the α factor required (state transitions).

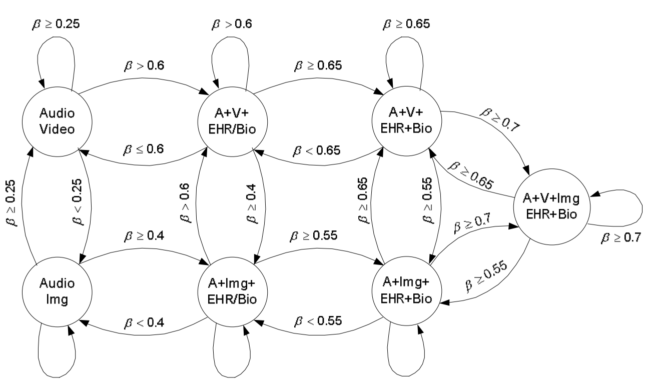

Fig.8 QoS decision method for combinations of multiple simultaneous ToS.

IV. Discussion and Conclusions

This paper presents a complete study of the QoS evolution regarding available resources in mobile scenarios with high variability and limited capacity for RT services. Results obtained from the monitoring of mobile channel conditions permit to optimize the design of the service by implementing an adaptive algorithm for QoS control which allows selecting the most appropriate codecs (e.g., for audio or video) and other application parameters (e.g., image resolution).

Moreover several state transition diagrams, which permit to select the most suitable combination of simultaneous services to accomplish the QoS requirements depending on the network resources, have been presented. The future lines of this work are focused on the implementation of a decision algorithm for selecting the services with require guaranteeing QoS (e.g., audio and medical images vs. video), and new proposals in the design of the QoS control methods.

Acknowledgment

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