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Performance Evaluation of Rural e-Health Scenarios: Users and QoS Management

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Abstract—**The development of e-Health services in rural environments, where broadband accesses are usually not available, requires a specific analysis of available resources to improve the management of Quality of Service (QoS). This work studies the sharing of resources among several users and the system efficiency in rural areas, guaranteeing QoS. The results obtained show that, with the premises considered in this study, a rural centre can establish a maximum number of simultaneous real-time services with the hospital, which varies between 2 and 3 for each 64kb/s of available link capacity.**

I. Introduction

NEW telemedicine services are usually based on multimedia technologies, taking advantage of the possibilities they offer to support multiple users and very diverse clinical applications over different network topologies. Such heterogeneous environments require applications to be provided with different analysis in order to accommodate their distinct Types of Services (ToS) [1].

The different characteristics of each application/network technology lead to very diverse Quality of Service (QoS) levels, which can have a great impact on application performance, particularly on multimedia real-time ones. Therefore, an accurate estimation of network performance is critical for the success of any multimedia service [2], [3]. This fact is even more important due to the scarce network resources available in rural areas. Primary Health-care (PH) centres in rural environments are usually located in geographically disperse areas, and mainly use network communications based on the old Public Switched Telephone System Network (PSTN) or, at the most, on Asymmetric Digital Subscriber Line (ADSL) technologies.

An extended idea in the literature consists of trying to estimate network performance, and then adapting application data to fit it [4], [5]. The most relevant parameters that influence QoS, such as Packet Loss Rate (PLR), End-to-End Delay (EED) and link capacity (C) can be used for this purpose [3]. This idea has been widely developed in multimedia scenarios over best-effort networks like Internet, but a specific analysis over rural telemedicine environments, such as the study presented in this paper, would permit to improve the quality of e-Health communications in rural areas [6], [7].

In this paper, a performance evaluation of an e-Health service in a rural area with varying load conditions and simultaneous user connections is proposed. The main characteristics and use cases for the scenario under study are given in Section II. The results obtained under different network conditions are analyzed in Section III in order to characterize, model and optimize the e-Health service.

II. Materials and Methods

The analysis presented in this paper has been possible thanks to an automated tool [8] that allows to translate clinical requirements into multimedia parameters, to measure the service (capturing not only the experimental traffic, but also the simulated one), and to characterize, optimize and model its behaviour.

This work evaluates the QoS in rural environments associated with the remote communications among physicians that belong to a PH centre, and the specialists in the reference hospital to send patient medical tests, to share interactive applications (e.g. for tele-assistance), etc. These PH centres usually use PTSN or ADSL network technologies. In the user's access point, considering rural environments without broadband access, the maximum upstream transmission rate to the hospital is usually 64kb/s, depending on the available network resources. Each user connection is multiplexed in the hospital server that provides a higher capacity $C=k\cdot 64$kb/s ($k>1$). Moreover, each user connection may include several multimedia applications, associated with different ToS and specific QoS requirements. These ToS are usually grouped into two main categories: Store-and-Forward (SF) for applications that do not require Real-Time (RT) work (such as transferring clinical test files), and RT for services with critical requirements of PLR and EED.

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Therefore, an evaluation of the maximum number of user access connections becomes necessary in order to manage service efficiency under the most critical conditions of the rural environment. This evaluation scheme (Fig. 1) is completed with the specific RT and SF parameters (Table I) to define the complete scenario under study, which distinguishes four main use cases (UCs):

- **UC1**. The physician sends biomedical tests such as ecography (ECO) or electrocardiogram (ECG) from the PH centre to the hospital in SF mode (SF.Test).
- **UC2**. Including UC1, the physician also queries the hospital database to manage the Electronic Patient Report (EPR) through a RT web link (RT.EPR).
- **UC3**. Including UC2, the physician establishes a RT multimedia conference with the hospital specialist to support in the diagnosis (RT.Media). It includes audio (RT.Audio) and video (RT.Video) services.
- **UC4**. In addition to the UC1, the physician from PH centre may need to send in real-time a specific signal to complete the patient diagnosis (RT.Bio). This includes biomedical tests and patient's vital signs.

UC1 requires the study of the valid range of the number of users (N), depending on C and on the recommended EED and PLR levels, which guarantee the best service performance. In UC2, UC3 and UC4, more critical than UC1, it is necessary to obtain a new range for N and study the combination of RT parameter values that fulfill QoS thresholds and provide the best efficiency areas.

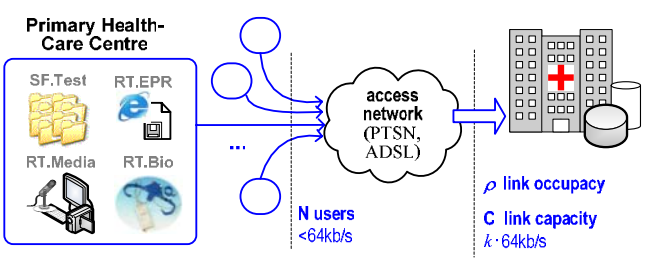


Fig. 1. Generic scenario to evaluate a rural e-Health service based on tele-diagnosis between a Primary Health-care centre and a hospital, including medical tests and patient-related information transfers, EPR updating, audio and video conference, and transmission of biomedical signals.

TABLE I. PARAMETERS UNDER STUDY AND TOS MODELS

Use Case	e-Health service	ToS	parameters
UC1	biomedical test SF transmission	SF. Test	application packet size (s), burst size (MBS), transmission rate($1/\Delta t$) network user number (N) link capacity (C) capacity factor (k) occupancy factor (ρ)
UC2	EPR management database query	RT.EPR	
UC3	audioconference videoconference	RT.Media	
UC4	biomedical signals *on-line* transmission	RT.Bio	

III. RESULTS AND DISCUSSION

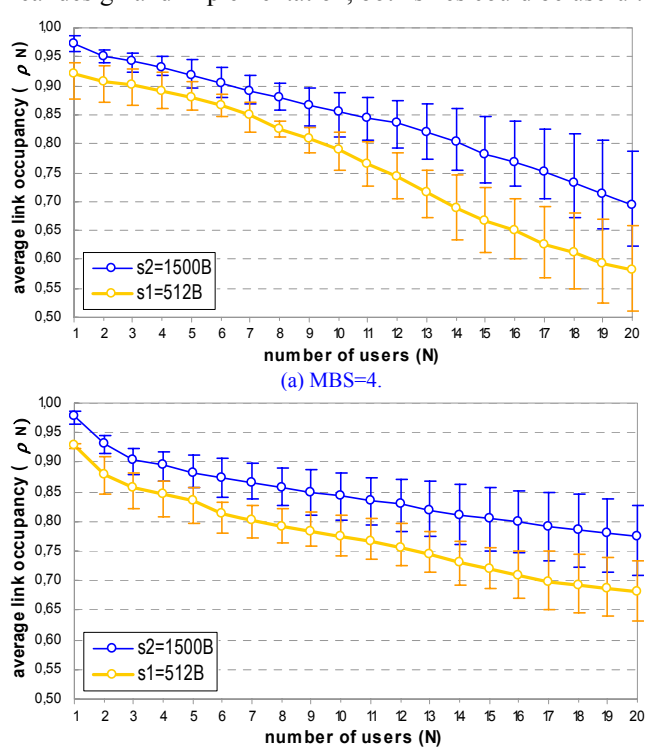
A. UC1 (SF services)

The study of the SF services implies to select the optimum parameters among a large range of specific values. In previous studies of this work [9], focused in UC1, we obtained significant results for the following application parameters: packet size (s), Maximum Burst Size (MBS) and transmission rate ($1/\Delta t$). Thus, in order to provide the best service performance in a rural scenario, the selected values were s_i={512, 1500 (B)}, MBS$_i$={4, 7} and Δt_1=10ms.

Using these values, UC1 was evaluated in order to obtain the maximum number of users that can be simultaneously connected fulfilling the most suitable performance thresholds. These thresholds were obtained as a function of the normalized link occupancy factor (ρ_N), defined in (1).

$$\rho_N = N \cdot \rho = N \frac{C_e}{C} \quad \text{with} \begin{cases} C_e = k_e \cdot 64\text{kb/s} & (k_e \le 1) \\ C = k \cdot 64\text{kb/s} & (k > 1) \end{cases} \tag{1}$$

First, the evolution of ρ_N as a function of N for both values of s_i and MBS$_i$ was evaluated. Fig. 2 shows the average value of ρ_N and its variation range according to the monitored capacity (between the highest, C=2Mb/s, and the lowest, C=64kb/s). ρ_N always decreases in a non-linear way with N and the efficiency is higher with s_2=1500B. In any case, the differences are low $\rho_N(s_2) - \rho_N(s_1) < 0.1$. Thus, for a real design and implementation, both sizes could be useful.



(a) MBS=4.

(b) MBS=7.

Fig. 2. Evolution of the occupancy factor (ρ_N) vs. the number of users for the selected values of packet size (s) and burst size (MBS).

Moreover, the performance depending on MBS is clearly different: MBS_1=4 (Fig. 2(a)) shows better efficiency when the number of users is low (N<14), and MBS_2=7 (Fig. 2(b)) provides better performance if the number of users increases (N>14).

Fig. 3 shows the optimum efficiency areas with this combination. Thus, it could be interesting to monitor the number of simultaneous users and send a *feed-back* message (from the network to the user device) in order to manage the MBS values. This adaptive control, feasible in UC1 and recommended for the design of other RT UCs, is specific for every application. The trends obtained in Fig. 3 allow establishing different recommended performance areas, depending on the link occupancy. Table II presents the maximum number of simultaneous users that fulfill the useful thresholds (ρ > 0.7), depending on the available capacity (indicated by *k*).

In summary, this evaluation also permits to assess service efficiency. For example, for a SF.Test service based on ECG transmissions with a patient test mean size S=40MB, the maximum number of files (n_{SF}) that can be sent from PH centre to the hospital depends on N, ρ and *k*. Following the previous results and considering ρ = 0.8: n_{SF}=5 (N=1, k=1), n_{SF}=17 (N=1, k=4) or n_{SF}=2 (N=4, k=1). This shows the non-proportional trend: a capacity increase of 1:4 implies an efficiency improvement of 5:17; a users' increase of 1:4 implies an efficiency decrease of 5:2.

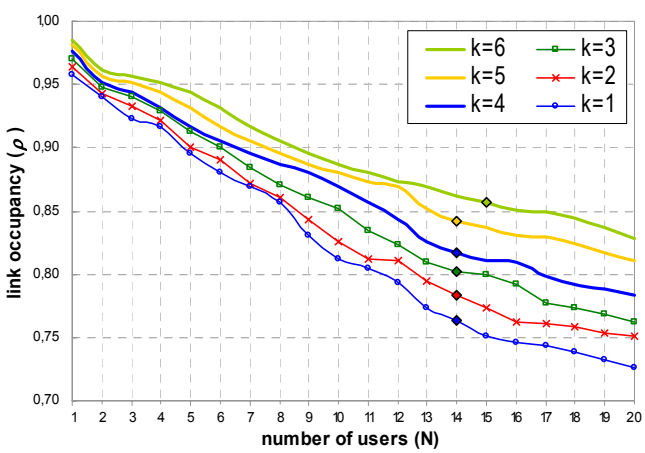


Fig. 3. Recommended performance areas, depending on the useful ρ thresholds, for the variation range of capacity and number of users.

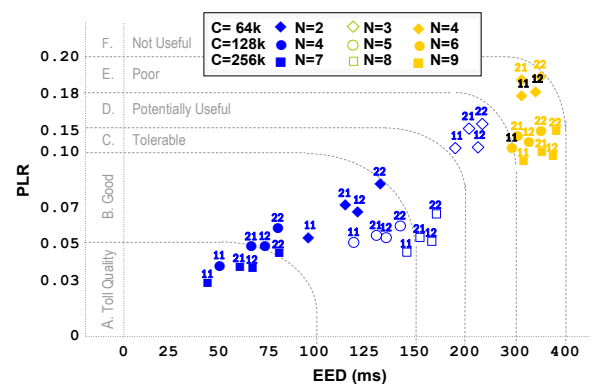
TABLE II.
NUMBER OF USERS THAT FULFILL THE SELECTED PERFORMANCE THRESHOLD DEPENDING ON LINK CAPACITY (*k*·64KB/S).

	ρ=0.95	ρ=0.90	ρ=0.85	ρ=0.80	ρ=0.75
***k*=1**	0	1	5	8	12
***k*=2**	0	2	6	10	13
***k*=4**	1	4	9	14	24
***k*=8**	3	7	16	26	40
***k*=16**	5	14	28	41	76
***k*=32**	9	29	47	77	148

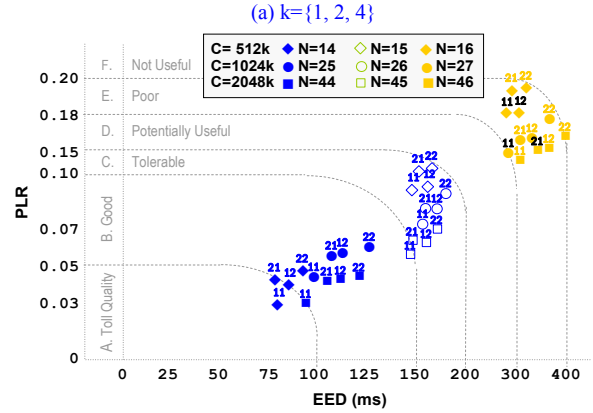
B. UC2, UC3 and UC4 (RT services)

UC2, UC3 and UC4 were analyzed to evaluate the evolution of the service performance obtained in the previous case, but adding the combination of SF and RT services. In previous studies of this work [9], we obtained that the most critical situations depend on the characteristics of the RT.Media applications combined with the RT.Bio communications. In addition, we obtained the best MBS values for the RT.Media services: MBS_{Ai}={4, 7 (packets/burst)} for RT.Audio, and MBS_{Vj}={10, 15 (frames per second, fps)} for RT.Video.

Therefore, in this work the PLR/EED ratio has been evaluated in order to select the best combinations that fit the useful areas (Fig. 3). Each (MBS_{Ai}, MBS_{Vj}) combination is indicated as *ij*={11, 12, 21, 22}. For example, for C=64kb/s in Fig. 3(a), the maximum number of users is N=3 (even N=4, but with large EED and PLR). If the available resources increase, N does not increase proportionally, due to a non-equitable sharing of resources among RT services (for the same QoS requirements). For example, for C=512kb/s in Fig. 3(b), the maximum number of users is N=15 (not 8 times larger). It is also remarkable that the optimal values appear with small burst sizes for RT.Audio (MBS_{A1}=4) and RT. Video (MBS_{V2}=10fps).



(a) k={1, 2, 4}



(b) k={8, 16, 32}

Fig. 3. PLR/EED ratio for different (MBS_{Ai}, MBS_{Vj}) combinations, as a function of the number of users (N) and the link capacity (C), in order to evaluate which cases fulfill the recommended QoS thresholds.

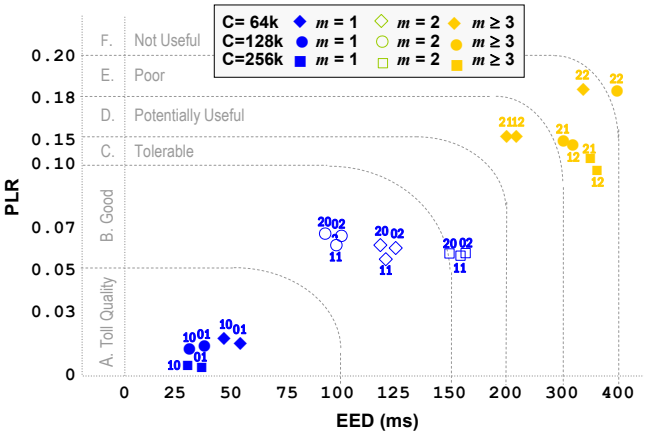
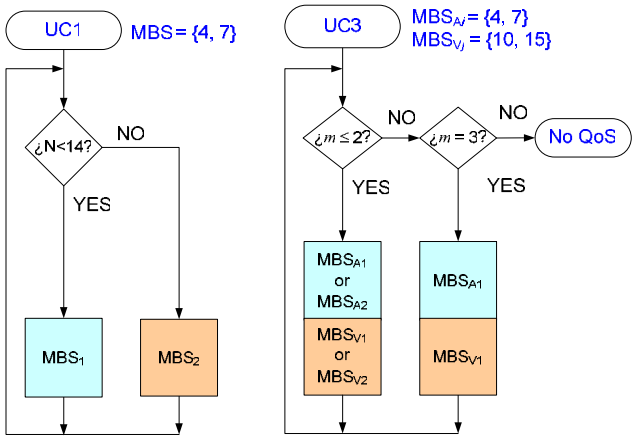


Fig. 4. PLR/EED ratio for the most critical situations of the multiplex factor (m) as a function of link capacity (C), in order to evaluate which combinations fulfill the recommended QoS thresholds.



(a) UC1 (b) UC3

Fig. 5. Decision trees in order to select the best MBS values in the applications used for e-Health services in rural environments.

Finally, we defined a multiplex factor (m) as the addition of simultaneous RT services (including RT.EPR, RT.Media and RT.Bio) for each user access connection. Fig. 4 shows the PLR/EED for the most critical situations, closer to QoS thresholds. These worst cases occur when a variable number of RT services (n_{RT}) are combined. As every possible combination includes services of each type, m is indicated as $\{n_{RT.Media}\ \ n_{RT.Bio}\}$ in Fig. 4 (i.e. m=1 corresponds to {10} and {01}, m=2 for {11},{20}, etc.).

Results obtained conclude, in generic terms for C=k·64kb/s, that all the cases allow m=k simultaneous RT services and no case allows m=4k services. That means that the maximum number of RT services that the same PH centre can establish with the hospital varies between 2 and 3, for each 64kb/s. In those cases, the QoS is always guaranteed with m=2, and m=3 can be permitted depending on specific application parameters.

In summary, these results permit to establish several good-performance areas and to select the maximum number of simultaneous users, according to the available resources, in order to guarantee QoS.

Moreover, the evaluation allows selecting the best application parameters in each case. An example of the adaptive selection of access parameters, depending on the number of connected users and the available link capacity, is shown in Fig. 5. For UC1, Fig. 5(a) shows the described *feed-back* decision, according to the monitored number of users, in order to select the best MBS value. For UC3, Fig. 5(b) shows a representative example of MBS_{Ai} (for RT. Audio) and MBS_{Vj} (for RT.Video) selection according to the monitored number of users, with C=64kb/s. For other UCs more complicated, decision trees can be configured.

IV. Conclusions

This work studies the maximum number of simultaneous users and the efficiency obtained for each one in rural communications, in order to improve QoS management. The results obtained from the technical evaluation permit to establish several good-performance areas depending on network conditions. In addition, the best application parameters have been selected for each use case, according to the available resources, in order to guarantee the QoS of the global e-Health service.

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