Optimization of link capacity for telemedicine applications

Karol Molnar*, Jiri Hosek*, Lukas Rucka*, Pavel Vajsar* and Otto Dostal†
*Department of Telecommunications
FEEC, Brno University of Technology
Purkynova 118, 612 00 Brno, Czech Republic
Email: molnar@feec.vutbr.cz, hosek@feec.vutbr.cz, rucka.lukas@phd.feec.vutbr.cz, pavel.vajsar@phd.feec.vutbr.cz
†Institute of Computer Science
Masaryk University
Botanicka 554/68a, 602 00 Brno, Czech Republic
Email: otto@ics.muni.cz

***Abstract*—Interactive telemedicine services have become very popular due to their cost efficiency and low response times. On the other hand, several acquisition units connected to a network can significantly increase the network load on communication links connecting hospital facilities to the Internet. Since these links are often leased from commercial ISPs, there is much interest in minimizing the cost, i.e. the capacity of leased links, without a significant degradation of the quality of telemedicine services. The paper presents the results of the initial analysis of network traffic generated by Computed Radiography, introduces the corresponding statistical model, and presents the simulation results obtained by optimizing the network capacity from the point of view of application response time.**

***Keywords*-Computed Radiography; medical image processing; OPNET Modeler; transmission capacity; WFQ;**

I. Introduction

The number of digitized medical facilities which can take advantage of integrated solutions for data handling, storing and transmitting, according to the DICOM standard, is rapidly increasing [1]. The demand of current telemedicine equipment on instantaneous bandwidth varies from tens of kbps to tens of Mbps. It causes that the requirement on the capacity of communication links is highly affected by the type and exact number of such equipment items (modalities) in the medical facility. Usually these facilities are connected to a regional centre for medical image processing and storing, which coordinates data sharing and mutual exploitation of technical resources of the collaborating parties. These centres also provide sophisticated analyses of traffic flows to estimate traffic profiles, time-distributions, delays, etc. This paper presents the results of such an investigation.

The aim of our work was to estimate the minimum link-capacity towards commercial ISPs which still preserves acceptable service quality for telemedicine applications. The quality was expressed as the delay of images transmitted from the medical modality. We also conducted an investigation into differentiated traffic treatment and analysed how significantly preferential treatment of selected traffic-flows affects the response-time in the case of different services.

The methods used for analysis, modelling and evaluation are described in the following structure: section II describes our initial premises, ways of collecting and the methods of statistical processing of measured data. Section III contains the description of the simulation models built based on the statistical description of the modality investigated. This section also evaluates the simulation results with and without preferential traffic treatment. The last section concludes our activities and presents our plans for future investigation.

II. Initial premises and statistical analysis

Current hospital facilities are usually equipped with several modalities such as MRI (Magnetic Resonance Imaging), US (UltraSound), CT (Computed Tomography) or CR (Computer Rentgen/X-ray). The last of these modalities is the most common representative of current telemedicine applications. For this reason our analysis was primarily focused on the CR modality.

Information required for the analysis was obtained by direct measurement of corresponding traffic-flow parameters. To preserve the faithfulness of data, these measurements were conducted between 7 am and 4 pm only. Traffic flows from non-working days were also excluded to avoid additional statistical errors. Additionally, to eliminate the influence of transport network, the measurements were carried out only on modalities which were connected to the regional centre via 100 Mbps or faster links. The whole traffic generated by these modalities was captured by the tcpdump tool and it was then statistically analysed. Pearson's chi-square test [2] was used to validate the fidelity of distribution functions and their parameters, which were chosen to describe traffic flows generated by CT and CR modalities.

A. Computed Radiography Modality

In the case of CR modality there were 392 inter-request times identified and measured between subsequent TCP connections. The values measured ranged from 8s to 25963s. It was also evident that a CR transmission consisted of random

 ISBN: 978-1-61208-166-3

bursts of TCP connections. Each burst contained from one to seven separate connections. Therefore it was desirable to analyse separately the period between subsequent bursts, the number of TCP connections in a burst and the duration between TCP connections within a burst.

Without a detailed semantic analysis of the traffic-flows it is quite difficult to specify the boundaries of the bursts and decide if a given TCP connection belongs to the current burst or represents the beginning of the next burst. We empirically chose a period of 150 seconds to limit the length of each burst. After excluding the extremely outlying values, the periods between subsequent bursts were ranged in the interval from 150s to 3986s with a sample mean of 837.63s and a sample standard deviation of 840.01s.

We assumed that the length of the period between bursts was of exponential distribution with probability density according to (1).

$$f(x) = \frac{1}{\lambda} e^{-\frac{x}{\lambda}} \quad (1)$$

for x > 0, where $\lambda > 0$ is the parameter to be specified based on the measurement results.

In the case of exponential distribution parameter λ equals the mean-value of the random variable. The sample counterpart of the mean is the average of the values in the selective statistical population, which means that the period between the beginnings of two subsequent TCP bursts can be described by exponential distribution with parameter λ = 837.63s.

The period between subsequent TCP connections within a burst ranges from 8s to 150s. After excluding the most outlying values, we obtained 150 values between 8s and 116s. These values were symmetrically centred around an obvious mean. A random variable with normal probability distribution was therefore assumed with the probability density according to Eq. (2):

$$f(x) = \frac{1}{\sqrt{2\pi\sigma}} \exp(-\frac{(x-\mu)^2}{2\sigma^2}), \quad (2)$$

$-\infty <$ x $< \infty$, where $\mu \in (-\infty, \infty)$ and $\sigma > 0$ are constants and can be derived from the values measured.

The mean value of a random variable with normal distribution is equal to parameter μ and the standard deviation is equal to parameter σ. The selective counterpart of the mean is the average of the values in the statistical population. The selective counterpart of the standard deviation is represented by the sample standard deviation according to Eq. (3):

$$\overline{\sigma} = \frac{1}{n-1} (\sum (x_i - \overline{x_s})^2)^{\frac{1}{2}}. \quad (3)$$

After applying these presumptions on the values measured we found that the period between the beginnings of two subsequent TCP connections within a burst is normally distributed with parameters μ = 57.87s and σ = 27.88s.

Each of the bursts examined contained a random number of TCP connections, from one to seven. Based on an empirical evaluation we assumed that the number of TCP connections in a burst has a Poisson probability distribution with the following probability function Eq. (4):

$$P(x) = \lambda^{\chi} e^{-\lambda} / x!. \quad (4)$$

The mean value of a random variable with the Poisson distribution is equal to parameter λ. The selective counterpart of this mean is the average of the values in the statistical population.

In our analysis we dealt with a total of 225 values of one to four connections and found that the number of TCP connections in a burst can be described by the Poisson probability distribution with parameter λ = 1.45s.

Finally we had to statistically describe the amount of data transmitted within the TCP connections. In total we had 401 TCP connections captured for the CR modality. From these connections, 301 represented a transmission of 10.25MB of data and the remaining 100 cases corresponded to a transmission of 8.5MB each. This behaviour can clearly be described by an alternative distribution of probability 0.25 for 8.5MB and 0.75 for 10.25MB.

B. Final notes on statistical analysis

For any of the CR modalities neither the beginnings of the TCP sessions nor the amount of transmitted data shows any sign of dependence, which means that in the simulation model we can consider the beginnings of the TCP sessions and the amount of data to be independent. We used the pivot table to verify the independence of these parameters.

III. Simulation of telemedicine application

A. Description of the simulation model

Within our simulations we examined the impact of total link capacity and differentiated queue management on the response-time of the CR modalities. For this purpose a simulation model was built in the OPNET Modeler simulation environment [3]. The model consisted of 8 traffic sources with CR traffic-profile. Additional background traffic was modelled by TCP sources generating traffic bursts with Poison distribution. During the simulations, the application-level response-time was evaluated. Because of close behavioural analogy, the FTP (File Transfer Protocol) protocol was used to model the TCP communication of the modalities. To simulate limited link capacities, rate-limiting was applied to the common communication link. All the other communication links operated at a full speed of 1Gbps. The inter-request time, file size and number of repetitions were configured according to the results of the statistical analysis. The influence of controlled queue management was verified by using the WFQ (Weighted Fair Queuing) [4], [5] scheduling scheme. This scheduling scheme was chosen due to its frequent use in real networks installations.

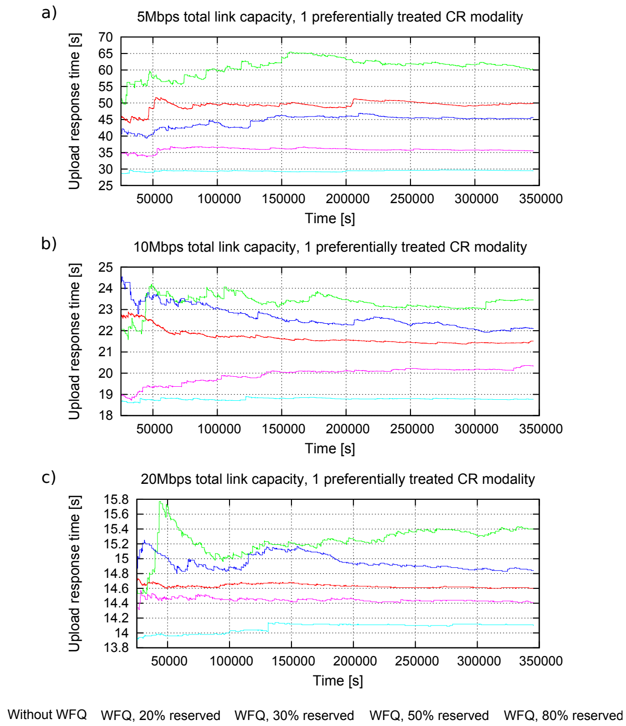

Figure 1. Impact of the relative distribution of link-capacity between WFQ queues for 5Mbps (a) 10Mbps (b) and 20Mbps (c) links in the case of 8 CR modalities

B. Simulation results

The impact of the bandwidth distribution between WFQ queues on the response time of one preferentially treated CR modality is shown in Fig. 1a) to 1c). The background traffic is processed by the second queue, which can use the remaining capacity of the communication link. It is evident that for the CR modality the bandwidth guarantee has a clearly positive impact on the response time. It is also evident that the resulting effect of WFQ scheduling depends on the total link capacity. More exactly, in the case of the 5Mbps total link-capacity at least 50% of the capacity must be guaranteed for the selected CR modality to achieve a shorter response time than without the use of WFQ. For higher link capacities already the guarantee of 20% of capacity brings improvements. Simulation results show that the improvement is relative and the absolute response times are dependent on the actual connection speed.

IV. CONCLUSION

After a comparison of the simulation results with the network administrators' practical experience we found that our simulation model showed very good matching with the measurement results obtained from real networks. It means that the simulation model can be used to estimate the required link capacity if we know the type and number of corresponding modalities.

The simulation scenarios clearly showed that for a given combination of devices it is possible to specify a minimum data rate for which the average response time will remain within the required limits. It was also found that preferential treatment can decrease the response time for Computed Radiography.

We have for some time been working on the statistical models for the remaining modalities. If completed, they will also be integrated into the simulation model and used for the optimization.

ACKNOWLEDGMENT

This paper has been supported by the Grant Agency of the Czech Republic (Grant No. GA102/09/1130) and the Ministry of Education of the Czech Republic (Project No. MSM0021630513).

REFERENCES

[1] K. Slavicek, M. Javornik, O. Dostal, ”Technology background of international collaboration on medicine multimedia knowledge base establishment”, Proc. 2nd WSEAS International Conference on Computer Engineering and Applications (CEA'08), Acapulco, Mexico, pp. 137-142, 2008.

[2] P. E. Greenwood, M. S. Nikulin, *A guide to chi-squared testing*, Wiley-Interscience, New York, 1996.

[3] OPNET Technologies, *OPNET Modeler Product Documentation Release 15.0*, 2009.

[4] K. I. Park, *QoS in Packet Networks*, Springer, New York, 2004.

[5] L. Rucka, J. Hosek, K. Molnar, ”Advanced Modelling of DiffServ Technology”, Proc. 32nd International Conference on Telecommunications and Signal Processing, Budapest, Hungary, pp. 1-6, 2009.