Network Optimization for Interactive Telemedicine Services

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***Abstract*—In medical environment, there is a fundamental demand to transfer and store large volumes of image data generated by modern medical devices and interactive telemedicine services. Currently the majority of the medical facilities spread around the country have quite limited Internet access, so these facilities require additional observation and network optimization for transfer of high load traffic generated by medical applications such as Computed Radiography or Computed Tomography. That is why we focused our work on this issue and this paper presents our result – optimal solution to transfer large volumes of image date over low-capacity links with regarding to minimum response-times. First we statistically described the traffic generated by the corresponding medical equipment and then evaluated the behaviour of these mathematical models in the OPNET Modeler discrete event simulation environment.**

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

I. INTRODUCTION

Regional medical image data processing systems are servicing many medical facilities. Mass of data originated by cooperating medical facilities are stored in the central node. The sources of data, called modalities, are obviously MRI (Magnetic Resonance Imaging), CT (Computed Tomography), US (Ultra-Sound) or CR (Computed Radiography) devices.

The usage of optical networks can provide sufficient bandwidth capacity for medical facilities, [1], [2]. Difficulties occur in medical facilities which are connected by alternative technologies with limited data-rate. The aim of this article is to find a solution which can compound the demands of hospital workers on the volume of required data and maximum acceptable delay.

The main goal is to find an optimal relation between a channel capacity and delay of images transmitted by various types of acquisition devices (modalities). Preferential treatment of some selected traffic-flows can also significantly affect the response-time of the evaluated services. Preferential treatment has its reason because not all of modalities are used for acute cases, so these modalities can have limited resources, e.g. data-rate in comparison with those used instantly. The simplified scheme of medical data transfer architecture is shown in the Figure 1.

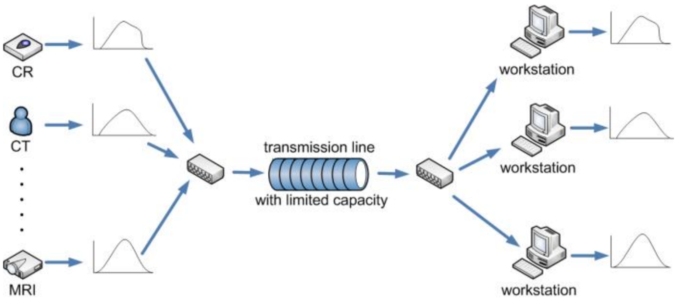

Figure 1. Simplified scheme of medical data transfer architecture

II. INITIAL PREMISES AND STATISTICAL ANALYSIS

The system in the scope of our evaluation uses TCP (Transmission Control Protocol) as a transport protocol, so the transfer time of image data can be affected by channel capacity, performance of the TCP transmitter and the receiver subsystem and by application functionalities.

We have experimentally verified that channel throughput is not limited by the size of socket-buffer neither in the transmitter nor in the receiver. So, there is no TCP window reduction caused by the lack of buffer capacity on the receiver or the transmitter side. We also assumed that the channel throughput was not influenced neither by the application behaviour such as the data storage and organization method. The parameters of a statistical model were specified based on the measurement and analysis of real traffic. The measurement was provided during traffic peaks, which is the time since morning 7 AM till 4 PM. The traffic from CT and CR modalities has been chosen as a source of investigated data. Three key traffic parameters have been identified which were required to model the traffic: inter-request time, size of transmitted data and number of repetitions. Since all of these parameters are random variables each of them were described by a corresponding probability distribution. The probability distributions of the corresponding traffic parameters have been tested by the Pearson's chi-square test with a significance level of 5%. The independence of the volume of transmitted data and the intervals between transmissions was verified by a contingency table.

To obtain the precise traffic-profile of the corresponding acquisition modality a precise long-term measurement has been carried out. Modalities connected at speed of at least of 100Mbps have been selected for this purpose. The whole traffic from these modalities was captured using the tcpdump utility and subsequently analysed. The results of the analysis of the selected modalities are presented in the following chapter.

We have observed two main traffic patterns in the captured data flows. The first traffic pattern type is a set of separate TCP connections. A typical modality generating such type of traffic is CT. The example of a CT image is shown in the Figure 2. First of all we have analysed the inter-request time, e.g. whether during a given period of time the acquisition modality is transmitting data or not. From a practical point of view we found more useful to work with the periods between the establishments of the subsequent TCP connections instead of the time between the end of a TCP connection and the setup of the following TCP connection. The reason is that the end of the connection depends on the capacity of the transmission links which is the parameter we want to optimize in our simulations.

The time interval *DT* between establishment of two subsequent TCP connections can be described by exponential distribution with parameter $\lambda = 1387.40$. The volume of data *V* transmitted by the CT has combined probability distribution. It is a combination of two uniform distributions: uniform distribution in range <11; 14> and uniform distribution in range <20; 95>. Values *DT* and *V* are independent.

In the second traffic pattern we can identify significant bursts of TCP connections. A typical modality producing this type of traffic is CR. Bursts of TCP connections established by observed CR were consisting of one up to seven TCP connections. Therefore, the time interval *DT* between bursts, the number *NB* of the TCP connections in the burst and the time interval *DB* between TCP connections in the burst were analyzed separately. A time interval of 150 seconds was set up as an upper time limit after which a TCP connection is no longer considered to be a part of the investigated burst.

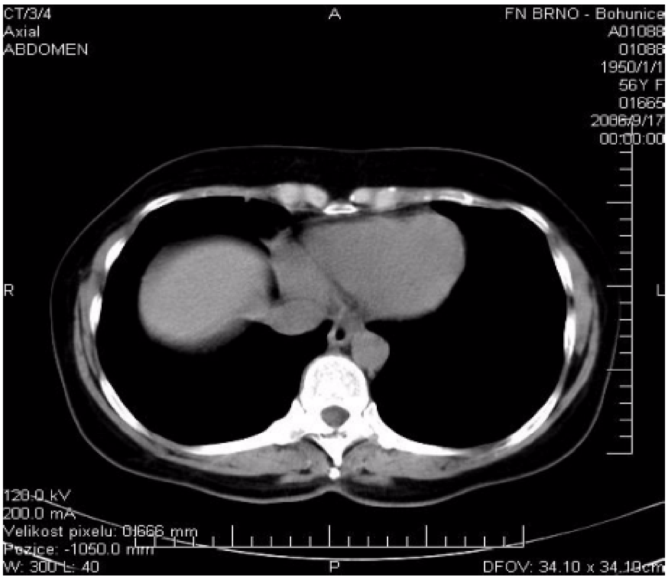

Figure 2. One of the slices of the CT modality

The time interval between establishment of subsequent TCP connections *DT* has exponential probability distribution with parameter $\lambda = 837.63$. The time interval between TCP connections within one burst *DB* is in range from 8 to 150 seconds and has normal probability distribution with parameters $\mu = 57.87$ and $\sigma = 27.88$. Burst of the TCP connections contains from one to seven connections. The number of TCP connections in the burst *NB* has Poisson probability distribution with parameter $\lambda = 1.45$. The volume of data *V* transmitted *V* in every TCP session has an alternative probability distribution. The volume of transmitted data is 8.5MB with probability 0.25 and 10.25MB with probability 0.75.

III. SIMULATION RESULTS

Due to timing constraints in practical implementations we examined the impact of total link capacity and differentiated queue management on the response-time of the modalities. For this purpose a simulation model has been built in OPNET Modeler simulation environment [3]. The model consisted of two types traffic sources modelling the CT and CR modalities. The topology of the simulation scenario in case of four CT and four CR sources is shown in the Figure 3.

During the simulations the application-level response-time has been evaluated. Because of a very close behavioural analogy, the FTP (File Transfer Protocol) protocol has been used to model both of the modalities. To simulate limited link capacities rate-limiting was applied on the common communication link. All the other communication links operated with full-speed 1Gbps. The inter-request time, file size and number of repetitions were configured according to the results obtained by statistical analysis of the captured traffic. The following figures show the most important simulation results.

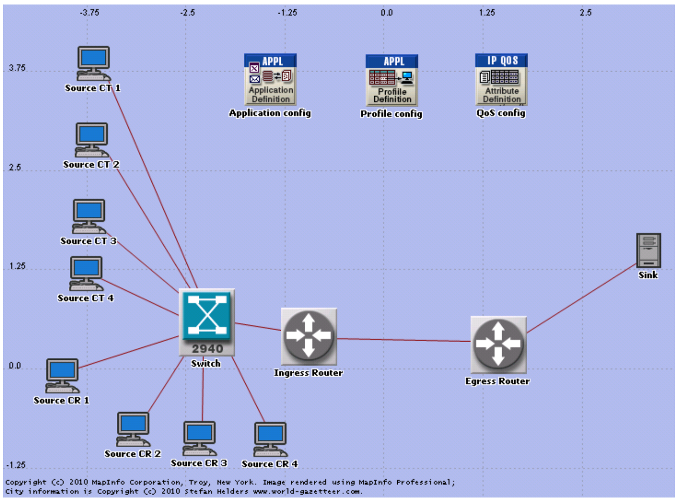

Figure 3. Topology of simulation scenario (4x CT source, 4x CR source)

Figures 4 to 7 show the dependency of the average response-time of the CT modality on the number of stations. There were four scenarios with different combinations of modalities, more exactly 1 + 1, 2 + 2, 4 + 4 and 8 + 8, involved in our analysis. Fig. 4 shows that at lower speeds the response-time is significantly influenced by the particular characteristics of the traffic (the amount of data transferred). In other scenarios according to our expectations the response-time is decreasing by the increasing the link-capacity. From the results it is also evident, that a slow connection of 5Mbps noticeably limits the communication even in the case of 1 + 1 combination. The increase of the link-capacity to 10Mbps gives acceptable results also for the combination of 4 + 4 and stops to be usable for the 8 + 8 scenario. In the case of 20Mbps link-capacity the average link-capacity is fully sufficient and practically the same for each of the scenarios evaluated.

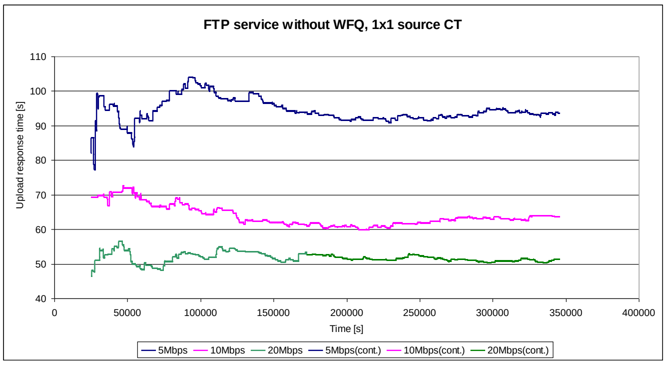

Figure 4. Dependency of the average response-time of the CT modality in the case of 1 CT and 1 CR modalities

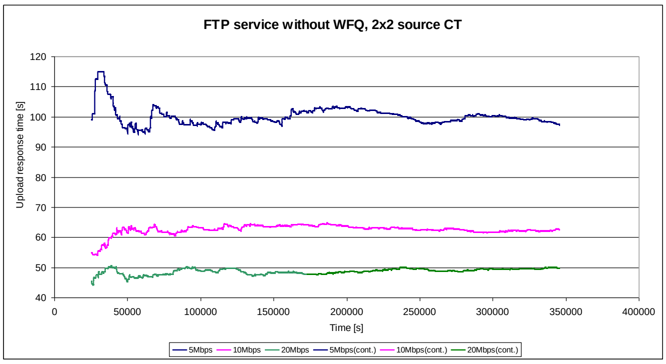

Figure 5. Dependency of the average response-time of the CT modality in the case of 2 CT and 2 CR modalities

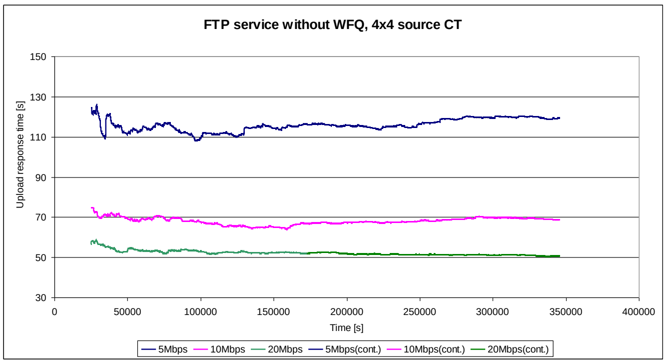

Figure 6. Dependency of the average response-time of the CT modality in the case of 4 CT and 4 CR modalities

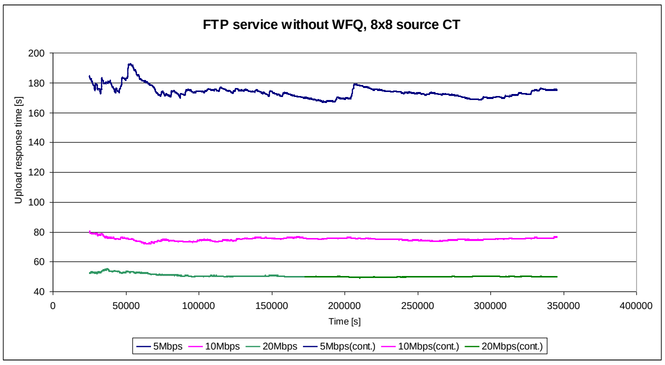

Figure 7. Dependency of the average response-time of the CT modality in the case of 8 CT and 8 CR modalities

Similarly to the previous case Figures 8 to 11 show the dependency of the average response-time of the CR modality on the number of stations. Also for this modality the 1 + 1, 2 + 2, 4 + 4 and 8 + 8 combinations were investigated. Since this modality generates smaller amount of data than CT in this case, the resulting curves are smoother, but the conclusions derived for the CT modality are applicable also here. However, the positive effect of higher link-capacity on the response-time of the CR modality is more remarkable. The results show, that in some cases the 5Mbps link is also sufficient for this type of modality.

Problems occur when more devices are communicating, i.e. in combinations of 4 + 4 and 8 + 8. The comparison of these four graphs show that if the link-capacity is doubled, e.g. from 5Mbps to 10Mbps or from 10Mbps to 20Mbps, the improvement of the response-time is visible, but relatively small.

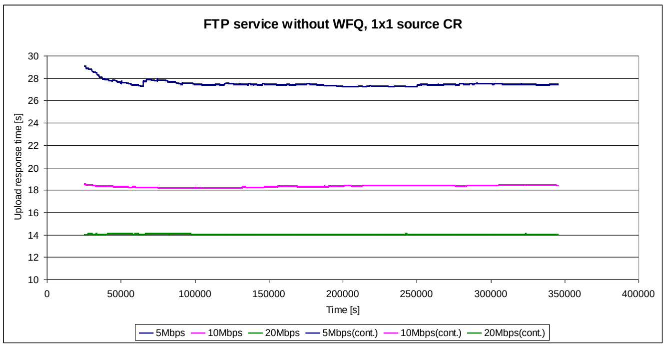

Figure 8. Dependency of the average response-time of the CR modality in the case of 1 CT and 1 CR modalities

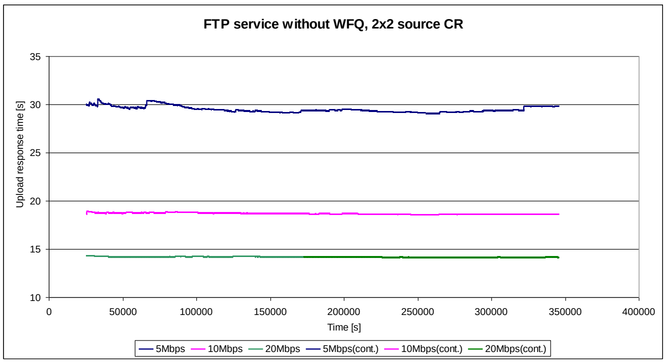

Figure 9. Dependency of the average response-time of the CR modality in the case of 2 CT and 2 CR modalities

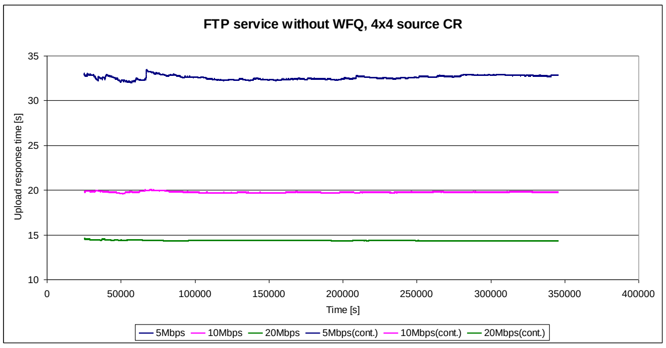

Figure 10. Dependency of the average response-time of the CR modality in the case of 4 CT and 4 CR modalities

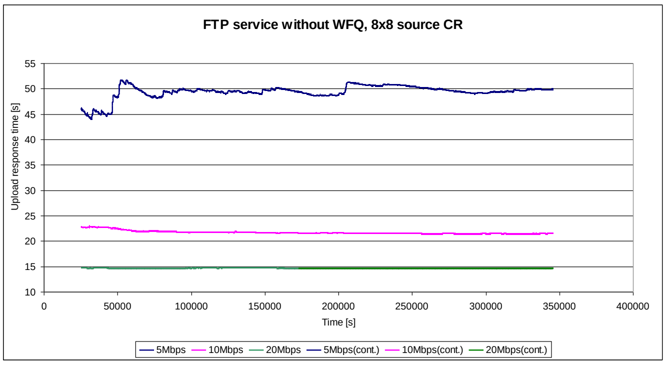

Figure 11. Dependency of the average response-time of the CR modality in the case of 8 CT and 8 CR modalities

IV. CONCLUSION

We can conclude that the objectives of our work were successfully achieved. We derived a statistical model of network traffic generated by the two most often used medical systems – Computed Radiography and Computed Tomography. The evaluation of these models in a simulation environment showed very good matching with the measurement results obtained from real networks. Using these statistical models we evaluated the application level response-times in several simulation scenarios with different numbers of medical equipment, with different data-rates on the common communication link.

The simulation scenarios clearly showed that for a given combinations of devices it is possible to specify a minimum data-rate for which the average-response time will remain within the required limits. Recently we work on the statistical models for the remaining modalities. If completed, they will be used in the simulation environment to specify the minimum required data-rate for Internet connection based on the knowledge of the exact number and type of devices in the given facility. Because it can save money for the hospitals there is already a growing practical interest about our results.

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