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Simulation study of delay of medical data transmission in bottleneck network

***Abstract**. The article deals with the delay of medical data in queues, caused by a bottleneck in the network. Primarily it focuses on the mathematical basis for defining the entrance traffic based on exponential distribution in the Network simulator. In the simulation part a model of input medical imaging data is implemented, and simulations are performed on a network with a bottleneck, when the delay is measurement for different combinations of active input medical imaging sources.*

***Streszczenie.** W artykule analizuje się opóźnienie w przepływie danych medycznych spowodowanych obecnością wąskich gardeł sieci. Przeprowadzono szereg symulacji dla różnych rodzajów przesyłu obrazu w projekcie MeDiMed. (**Analiza symulacyjna opóźnień przesyłu danych medycznych w projekcie MeDiMed**)*

Keywords: delay, bottleneck network, simulation
Słowa kluczowe: przesył danych, dane medyczne, opóźnienie

Introduction

The rate at which the TCP entity sends data is determined by the arrival rate of confirmation of previously sent segments. In the case of the TCP protocol, the rate of arrival confirmation is affected by a bottleneck between the transmitting and receiving TCP entities, which may be the destination node or the transmission network.

Most often, the bottleneck is caused by data units waiting in long queues of routers, switches or destination node. The total delay caused by waiting in queues then changes in dependence on the amount of traffic in the network, making it significantly more difficult to achieve a steady-state flow of data units.

The massive growth of networking, and especially of the Internet, has been accompanied by a wide range of internetworking problems related to routing, packet losses, delay etc. The study of these problems often involves simulation or analysis using an abstraction or model of the real network. The reason for this is clear: networks that are large enough to be interesting are also expensive and difficult to control; therefore, they are suitable for analysis, modelling and simulation provided the model of the real network [1], [2].

Simulation is a key technology when experimentation with the real network is unfeasible (expensive, difficult to control or without access to the network).

Simulation is widely used within the networking research community to investigate the behavior of many aspects of network performance [3], [4] and [5].

Computer based simulation is widely used in almost all areas of networking research. There are a number of existing network simulation tools. These tools allow researchers to test and validate new and existing protocols under a variety of conditions. An experimental protocol can be shown to work correctly in the presence of packet losses, packet re-ordering and lengthy delays.

Each of these tools has strengths and weaknesses, and no single simulation environment is suitable for all possible simulation requirements. The most popular and widely used simulation tool for networking research [5] is free software *ns2/ns3* [6], [7] or commercial software *OpNet* [8].

For this reason, the article focuses on the delay simulation in the bottleneck network. To determine the most accurate results of the simulation it is necessary to describe the real input data and enter them into the simulator. This article describes possible way of modeling input traffic which corresponds to medical imaging data obtained from various medical modalities.

Our testing bottleneck network provides communication among hospitals via a network, giving the possibility of on-line or time-delay consultations of experts in different hospitals. In this communication, it is necessary to know the value of delay depending on the number of active input medical data sources, network traffic and bottleneck of the network.

The new telemedicine strategies must be introduced not only amongst local radiology departments but also at the global level. The strategies must therefore take into consideration local as well as global aspects. A successful system must be fully integrated into systems that support daily routine procedures and also be able to be integrated into other technologies related to medicine.

Many large-scale healthcare enterprises have been formed around the world [9]. The possibilities of current ICT enable them to operate in a very efficient and cost effective manner even if they are spread over a very large area [10].

The shared regional collaborative environment is more than just a set of computer network applications. Gradually, it changes the thinking of medical specialists and enables them to cooperate and share data about patients in electronic form. It builds a network of medical specialists [11].

Firstly this article describes MeDiMed project, which deals with transmission of medical data. Next, the article describes the analysis of measured data from the most common modalities in medicine. After that, the network bottleneck was defines. Finally, the model of traffic sources and network topology model with bottleneck are designed and the delay simulation results are shown.

MeDiMed project

The MeDiMed project (Metropolitan Digital Imaging System in Medicine) [12] deals with problematic of transmitting, archiving, and sharing medical image data originating from various medical modalities (computer tomography, ultrasound, mammography, etc.).

The realization of the project facilitates fast communication among individual hospitals, allows decision consultations, and brings various other advantages due to direct connections via networks. Additionally, the project is to create conditions for general access to medical imaging data. The data exist already but their use is limited both in scope and time, but it is necessary obtain data in appropriate time without big delay.

Under the term “appropriate time” we understand a situation when the client can, in a reasonable time, store or retrieve a medical image. What is a reasonable time depends on the given application.

The solution of Metropolitan Digital Imaging center in medicine promotes the transfer of medical information between the hospitals that the patient visits during the treatment or which is necessary for consultation of specialists. This solution facilitates and accelerates the formulation of correct diagnoses, the avoidance of repeated testing, saving time of patients and doctors, and thus also financial funds. Fig. 1 shows the hospital - MeDiMed interconnection.

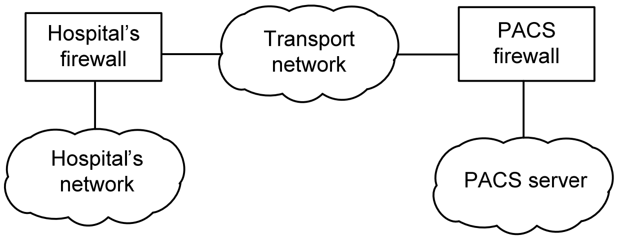

Fig. 1. MeDiMed interconnection

The main principle of the hospital-to-MeDiMed connection is the use of two firewalls. One of them is in front of the MeDiMed PACS (Picture Archiving and Communication System) servers and is under the control of the MeDiMed staff. The second one is the hospital's firewall and is controlled by the hospital staff. More detailed information about regional PACS archive maintained under the MediMEd project is described in [13] and [14].

This principle applies to all types of connections (dedicated fibre optics, phone lines, wireless connection, satellite, etc.) between the MeDiMed servers and the hospital. Anywhere in network be occur bottleneck, which delay the data transmission.

Probability distribution of input sources

In our measurement were chosen two most common used modalities, computer tomography and computed radiography.

From the data size measurement we have 401 TCP connections. In 301 case, the data size was 10,25 MB and in 100 case, was the data size 8,25 MB. From these value is obvious that it is alternative distribution of probability, where the data size is 8,5 MB with probability 0,25 and data size 10,25 MB with probability 0,75.

The measurement sample is shown in Table 1. The sample contains start and finish time of computed radiography connection. From Table 2 is obvious the method of determining of distribution and distribution parameters.

Table 1. Measurement time of transmitting and data size from computed tomography

Start-time [hh:mm:ss]	Time-diff [hh:mm:ss]	Time-diff-int [s]	Finish-time [hh:mm:ss]	Data size [B]
11:03:14			11:03:17	10249511
11:05:51	00:02:38	158,00	11:05:54	10249513
11:07:46	00:01:55	115,00	11:07:49	8581189
…				
09:37:42	00:03:18	198,00	09:37:45	10249509
09:38:13	00:00:31	31,00	09:38:18	8581199
09:39:36	00:01:24	84,00	09:39:38	10249489

We investigate the difference between the connection Start-time, which means the Time-diff value and Time-diff-int value. Time-diff-int value means the time from previous connection in seconds.

Whole sample of measurement values in Table 1 has 46 values with Time-diff-int range from 7 to 7752 seconds. The two lowest and biggest values were excluded. From 42 values in range 84 - 5494 seconds, the mean value of Time-diff-int is 1387,4 seconds and the standard deviation is 1169,69 seconds. The regularity or clusters of similar data is not evident in the sample of measured values.

The Time-diff-int value has exponential probability distribution. Exponential distribution often represents a period during which the phenomenon under study can occur. The necessary parameter is the mean waiting time λ.

The mean value of measured values Time-diff-int is 1387,4 seconds and represent the λ parameter of exponential distribution.

The sample in Table 1 is divided into five groups with 800 seconds interval range in Table 2. The empirical and theoretical frequency of particular groups and calculation of Pearson statistic are shown in Table 2. The calculate value of Pearson statistic is lower than critical value χ_3^2 (0,05) = 7,815. Therefore the hypothesis, that the file has exponential distribution with λ parameter = 1387,4 is not refuse on 5 % significance level.

Table 2. Verify of exponential probability distribution of Time-diff-int values

Group [seconds]	Empirical frequency	$F(x)$	P_n	Theoretical frequency	χ^2
800	14	0,4382	0,4382	18,40	1,054
1600	15	0,6843	0,2461	10,33	2,100
2400	7	0,8226	0,1383	5,80	0,244
3200	3	0,9003	0,0776	3,26	0,021
4000	3	1	0,0996	4,18	0,334
Sum	42		1	42	3,755

Network bottleneck

A network bottleneck refers to a discrete condition in which data flow is limited by network resources. The flow of data is controlled according to the bandwidth of various system resources. If the system working on a network is delivering a higher volume of data than what is supported by the existing capacity of the network, then a network bottleneck will occur [15].

Fig. 2 shows a situation when the bottleneck is in the transmission network. The transmission network can be power lines [1], [2], WAN [16] or GSM [17] network. The transmission path is shown as a pipe between the transmitter and the destination, and its thickness is proportional to the bandwidth. When the segment is transmitted via a slower connection, it must be stretched in time, which is seen in the shape of the rectangle in Fig. 2.

P_b interval is the minimum distance between segments of the slowest link. This interval has an influence on the minimum distance between segments in networks. Nevertheless, the data rate here is higher, the interval in a network will be the same, i.e. $P_r = P_b$.

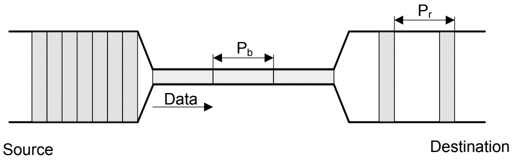

Fig. 2. Example of bottleneck network

Traffic source modeling

NS2 (Network Simulator) [18] was chosen for source modeling and delay measurement. Traffic source modeling is necessary for modeling real medical input traffic and then to calculating the delay from traffic trace.

Fig. 3 shows the interconnection of medical modalities in one hospital with another hospital communicating over a PACS server through transport network with bottleneck.

We can say that MeDiMed is based on a client-server model. Clients are modalities and diagnostics/viewing stations. Servers are PACS servers and other servers used to store and retrieve medical images.

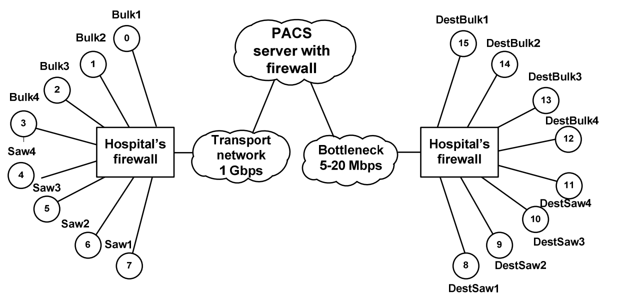

Fig.3. Topology of modeled MeDiMed network with bottleneck

Input sources are divided into two types, Bulk sources with 10 MB data size and Saw sources with 8 MB data size, the size of the data is based on measurement describe in [12]. Between hospitals it is necessary to build a network or hire a connection from the provider. The best network selection between hospitals would be a line with the highest possible data rate, to avoid delays. Higher data rates cost more and more must be paid to the provider and therefore it is necessary to find a compromise between the connection cost, i.e. choosing the data rate and the value of allowable delays.

The goal of simulation is to obtain delay values for various input combinations of active sources, namely the combination of Bulk x Saw - 1x1, 2x2, 4x4 and 8x8 active sources.

Each source is defined as exponential traffic (describes and verifies in previous section). The calculation of exponential parameter and model design for Bulk and Saw traffic can be found in [19].

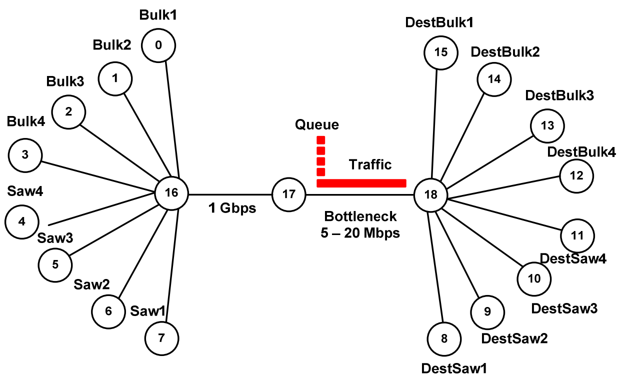

Fig.4. Bottleneck network for 4x4 sources in Network Simulator

Delay simulation results

Simulations were run for various combinations of input sources, and delays were measured separately for Bulk and Saw sources; the resulting delay is the average value of active Bulk and Saw sources. Data measured from Bulk and Saw sources are from simulations in NS2 (see Fig. 4) processed using the awk programming language [20], which parse the trace file into a file containing two columns (simulation time and delay); these data are then processed and the results of delay simulation are shown in Fig. 5 to Fig. 12.

The delay for 8x8 and 4x4 active sources had a relatively large value in the start. Therefore these values are not shown. In some cases the delay for a link with 5 Mbps was very high, therefore is not shown. For some combination of active sources was simulated delay for a link with 15 Mbps.

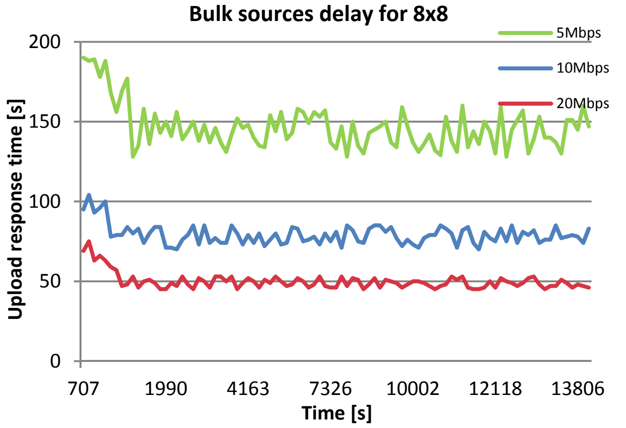

Fig.5. Simulation results for 8x8 active Bulk sources

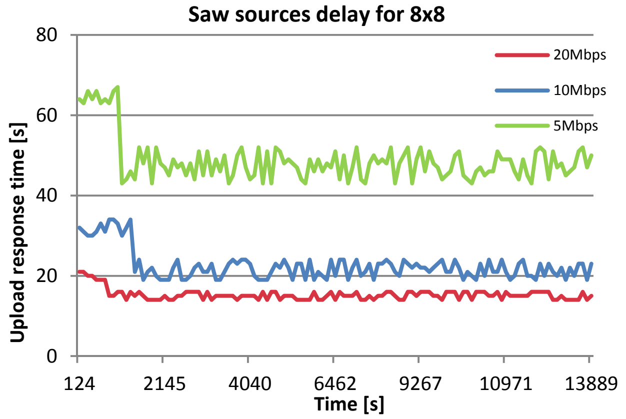

Fig.6. Simulation results for 8x8 active Saw sources

The delay for 8x8 active Bulk sources for a link with 5 Mbps bandwidth is between 130-160 seconds. The link with 10 Mbps bandwidth has delay about 80 second and the link with 5 Mbps bandwidth has delay about 50 second. The connection speed of 10 Mbps and lower ceases to be sufficient for 8x8 active Bulk sources.

Saw sources generate lower traffic than the Bulk sources. From the waveform of 8x8 active Saw sources in Fig. 6 is visible that the delay with connection speed 10 Mbps and 20 Mbps is in some case, for applications like Saw, usable. The problems with delay occur mainly with 5 Mbps bandwidth.

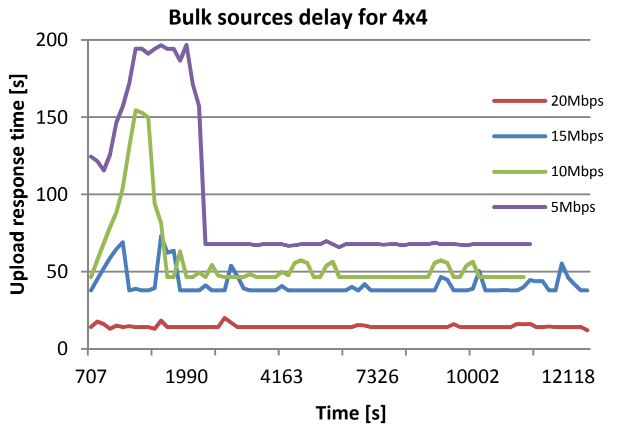

Fig.7. Simulation results for 4x4 active Bulk sources

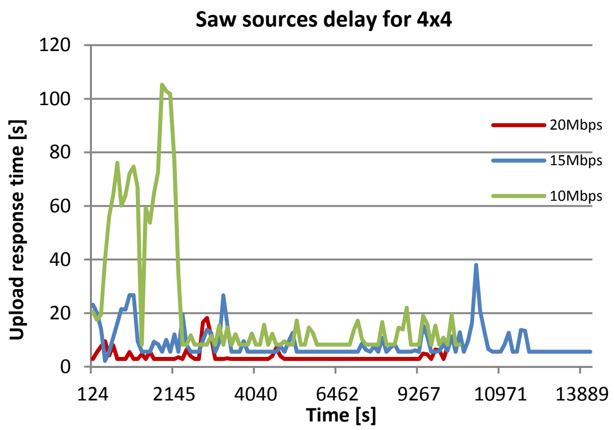

Fig.8. Simulation results for 4x4 active Saw sources

For the 4x4 active Bulk sources, the delay for a link with 20 Mbps bandwidth is between 15-20 seconds. The link with 15 Mbps bandwidth has a delay of about 40 seconds. The delay for links with a bandwidth of 5 Mbps and 10 Mbps attains a relatively large value in the start.

For the 4x4 active Saw sources is seen that increasing of connection speed from 5Mbps to 10Mbps or from 10Mbps to 20Mbps causes only a relatively small improvement in average response times. The increase in connection speed to 10Mbps gives acceptable results for the combination of 4x4 active Saw sources.

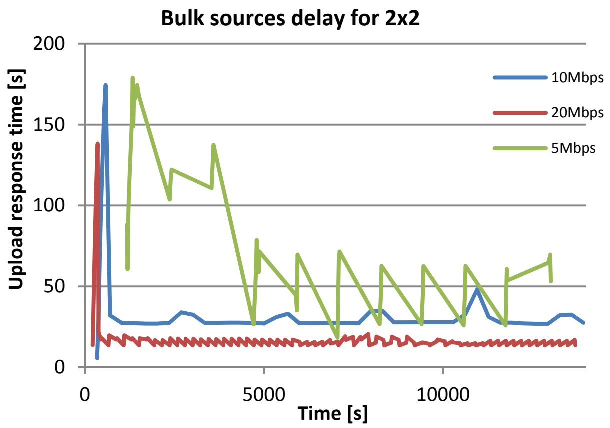

Fig.9. Simulation results for 2x2 active Bulk sources

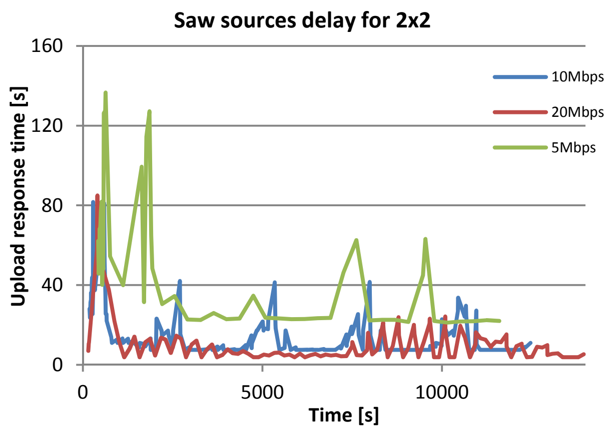

Fig.10. Simulation results for 2x2 active Saw sources

For the 2x2 active Bulk sources, the delay for a link with a bandwidth of 20 Mbps is about 15 seconds, and a link with a bandwidth of 10 Mbps has a delay of about 27 seconds. The delay for a link with a 5 Mbps bandwidth is over 40 seconds.

For the 2x2 active Saw sources, the delay for a link with a bandwidth of 20 Mbps is about 7 seconds and a link with a bandwidth of 10 Mbps has a delay of about 9 seconds, with occasional jumps to 20 up to 30 seconds. The delay for a link with a 5 Mbps bandwidth is over 27 seconds.

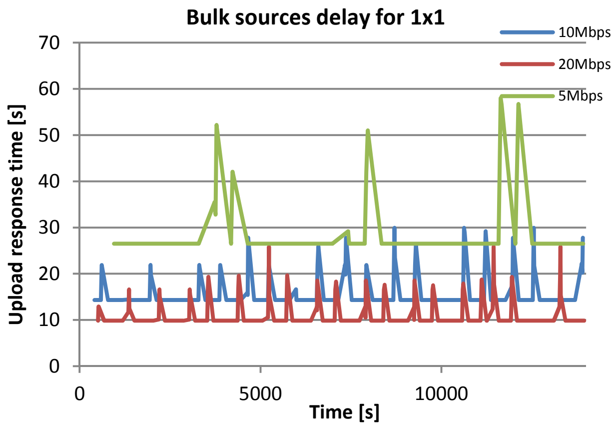

Fig.11. Simulation results for 1x1 active Bulk sources

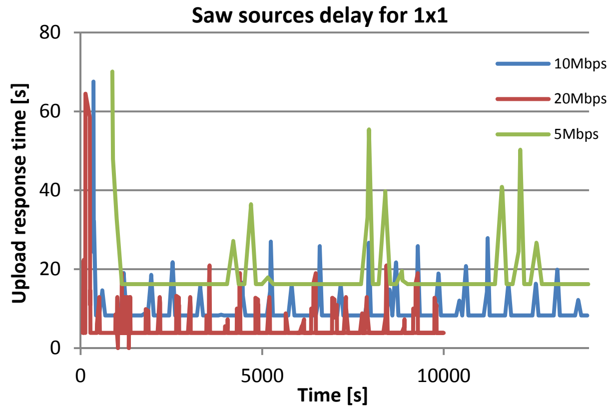

Fig.12. Simulation results for 1x1 active Saw sources

From the results of the simulations for Bulk and Saw sources is evident the limitation of slow connections 5Mbps, where a combination of 1x1 active sources have relatively high response times.

Conclusion

The delay in telemedicine may be very critical and it is therefore important to determine the value of delay in dependence on the transmission speed in the bottleneck. Therefore for the simulation issue is necessary to determine probability of input sources distribution. In the article, based on the measured are designed real input sources of medical modalities.

Based on the measured or simulated results a corresponding transmission speed can be selected, which ensures the value of delay within appropriate limits and simultaneously ensures that the bandwidth is not wasted. The choice of transmission speed in the bottleneck is a question of the cost-to-delay ratio.

The problems with delay occur mainly when large numbers of sources are active, that's mean combination of 4x4 and 8x8. The simulation results show a major increase in the delay with decreasing connection speed from 10 Mbps to 5 Mbps for both types of traffic. The simulation results shows that the capacity of the chosen configuration of network connection should not drop below 10 Mbps, otherwise the response time significantly reduce the quality of operated services.

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