MAN Performance Measurements and Optimization

D. Tomić, D. Žagar and G. Martinović
Faculty of Electrical Engineering, Josip Juraj Strossmayer University of Osijek, Croatia
drazen.tomic@etfos.hr, drago.zagar@etfos.hr, goran.martinovic@etfos.hr

***Abstract* — The general parameters that affect the performance of MANs are physical topology and hierarchical model of the network. The performance of each individual link depends on the type and intensity of network traffic that is characterized by the traffic direction (download/upload), the packet size and the number of packets. If MAN links share a common communication medium, as in case of using the EEE 802.11g technology in the point-to-multipoint mode, the overall performance of MAN will be affected. This paper presents the example of MAN made in IEEE 802.11g technology and describes MAN performance optimization based on measurement and parameters analysis.**

***Keywords*— MAN, optimization, 802.11g**

I. INTRODUCTION

Applying the IEEE 802.11g technology for the construction of a MAN with the aim of linking LAN's in an urban area, enables the user to create his own network infrastructure. The maximum throughput of links is up to 28 Mbps in the manner of connecting points is in the form point-to-point on distances of several hundred meters. With increasing distances between the points, the transferring rate gets reduced so that on a maximum distance of 40 km the transfer rate is 1 Mbps [1]. Such characteristics of IEEE 802.11g technologies allow the construction of MAN with a favorable cost and time term implementation and without additional fees for connected time, the use of available bandwidth or the amount of data transferred as is the case of renting MAN infrastructure. Wireless MAN topology can be realized by installing wireless point-to-point links or merging more links to the central point in the form of point-to-multipoint where the connected links share a common communications medium [10]. The performance of computer networks built using the IEEE 802.11g technology can vary significantly from the theoretical obtained values. The basic problems affecting the reduction of the maximum throughput are inadequate line of sight between points, incomplete fulfillment of the conditions in the Fresnel zone, a bad selection and orientation of antennas and radio-frequency and electromagnetic interference with other signals and devices in the area of operation [7,8,9]. Measuring throughput of each individual link and removing the problems that reduce its bandwidth the link is getting optimized. With measuring the MAN network traffic with changing the size or number of packets, the types of traffic impacts on the network performance are getting analyzed. Analyzing the network in regime of point-to-point work with gradual inclusion of additional points and changing the mode from point-to-point to a new mode, point-to-multipoint, the impact of the sharing medium on the throughput on MAN links is measured. Measuring the changes of the network throughput during the change of the physical network topology and hierarchical network models, their impact on MAN performance is getting analyzed.

II. MAN PERFORMANCE OPTIMIZATION

The MAN network design contains and unites the elements of LAN and WAN networks [2]. When optimizing the MAN model, it is necessary to observe the system as a set of individual links, but also as a whole. This way allows the optimization on two levels:

- *single-link optimization*: every link may have specific input parameters that can cause the selection of the same or different technologies for every link
- *optimization of the system of links*: by optimizing individual links can be obtained solutions that, in the case of various technologies on the individual links, at the level of the group of links lead to appearing of a hybrid model of communication network. It is necessary to further analyze such hybrid model respecting additional elements of the system that may occur at the junction points of various technologies. In the case of a monolith model, the bulk of individual effects can be violated by watching the system as a whole (example of sharing communication media in the case of point-to-multipoint wireless networks).

The optimization of each individual link is a step that leads to the optimization of the overall system. Optimized model of the communication network describes the system that is optimized as a whole where the impact on the performance of MAN are sharing a common communication media, size and quantity of packets on the network, the physical MAN topology and hierarchical model of the network. Selecting proper parameters in MAN model and their configuration can significantly optimize the type and amount of traffic on MAN, which represents the basis of MAN optimization in its entirety.

III. TOPOLOGY OF EXPERIMENTAL MAN

Methods for MAN performance optimization are shown on the example of a MAN built in IEEE 802.11g technology in the point-to-multipoint mode where individual MAN links share a common communications medium.

The experimental MAN network, located in downtown of Osijek (Croatia), is modified according to Figure 2. for the purposes of measuring MAN performances. The network is built from 5 wireless access points that are linked to a central point from which they are maximum 500 meters away.

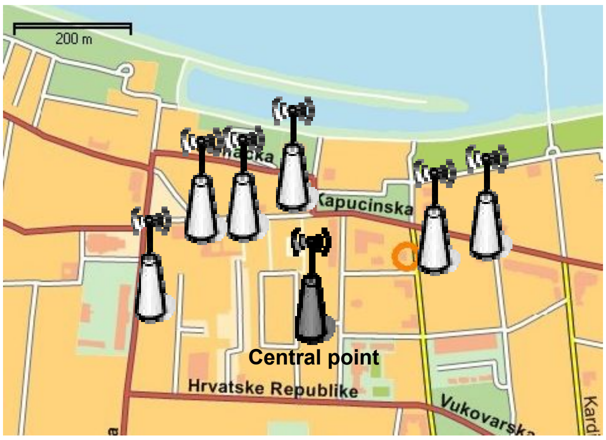

Figure 1. Geographical distribution of Access Points

All wireless access points are Cisco Aironet 1300 in bridge mode with enabled Cisco Aironet extensions [11]. The data rate for all access points is 54 Mbps. To avoid the impact of additional traffic that is generated in real network and proceed with measuring only controlled sources of network traffic, instead of distribution layer routers, which connects some LAN's on MAN, laptops (HP NX6310 T5500 – Intel Core 2 Duo 1.66 GHz, RAM 512 MB, HDD 60 GB, LAN 10/100, Windows XP SP2) are connected as the peripheral points PC1 to PC5.

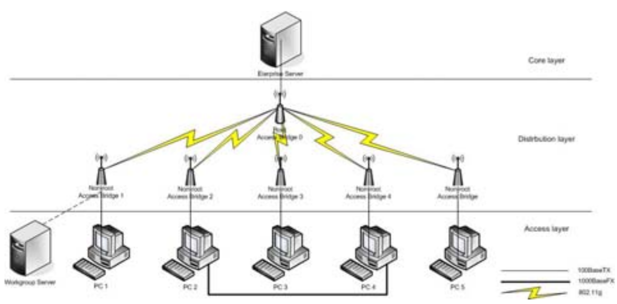

Figure 2. The structure of MAN adapted for measurement purpose

For purposes of measuring a laptop is connected on the Root Access Bridge in the function of a Enterprise server (Toshiba Satellite Pro M70 – Centrino 2.13 GHz, RAM 1,5 GB, HDD 80 GB, LAN 10/100, Windows XP SP2).

IV. MEASUREMENT METHODOLOGY AND TOOLS FOR ANALYSIS

In order to get results that will less affect the higher OSI layers, the measurements were made with generating UDP packets. The basic advantage of the UDP in relation to the TCP is smaller UDP header size and property that does not seek to establish initial bidirectional connections (three-way handshake) and confirmation of receipt segments transferred after a certain quantity of data (positive acknowledgment) that, for the purposes of this measurement, is the unnecessary traffic that enters an error in the results of the measurements. Because of reducing the influence of devices buffers there is 5 seconds of link inactivity between the traffic generated within each measurement [4,5].

As UDP is a „connectionless“ protocol it is necessary to generate UDP packets that will enable the tracking UDP segment generated by the number of segments, the order of receipt and time of sending and receiving for each segment [6]. A tool to generate UDP packet with these properties is the Multi-generator (MGEN) developed by the Naval Research Laboratory (NRL) PROTocol Advanced Software Engineering (PROTEAN) group as open source software. The version used for measurement is mgen 4.2 for Windows platform. The program allows generating UDP packet flow of arbitrary packet size and arbitrary number of packets per second according to the arbitrary number of recipients and supports three types of traffic generated. For the purposes of measurement a periodic traffic pattern that enables the constant load of a link was selected. A support for creating scripts was built in the program which defines the activities in the time domain. Parameters of received segments can be logged on the side of recipients for the purpose of further analysis. If the real-time clocks on the side of the sender and recipient are synchronized (with using the NTP protocol for example) the information about the time of segment travel - delay (defined by difference between the time stamp of sender and recipient) has an absolute value, in contrary it is observed as relative value.

For the analysis of logs generated with the mgen program, a tool, TRace Plot Real-team (TRPR) version 2.0b2 for the Windows platform was used, also developed by the Naval Research Laboratory. The program enables analysis of throughput, loss and packet delay in the form suitable for graphic display. Furthermore, the program allows defining the size of sampling data from log files, the separation of only certain types of traffic and defining time frame analysis.

Graphic display of data processed with the trpr program was enabled by program GnuPlot v 4.0 for Windows platform.

V. Performance Measurment and Analysis

The basic parameters that significantly affect the results of measuring are the type of traffic, the size of the IP packet (UDP segment) and a number of generated segments in one second:

- type of traffic: for the type of traffic a periodically sample is selected that during the entire time generates identical UDP traffic, which allows a permanent link load with same type of traffic
- maximum MTU for Ethernet technology, which is generated by a computer connected to the network, is 1500 bytes. As the size of the IP header is 16 bytes and the size of a UDP header is 12 bytes, UDP segment size to achieve MTU should be 1472 bytes. Choosing the size of the packet same as MTU for particular LAN technology allows maximum efficiency and avoids packet problems associated with the fragmentation of the IP packet if the packet size is larger than MTU (UDP unlike TCP doesn't segment the packets, it lets the IP protocol to do that). When the data is transferred between 802.11 and 802.3 technologies, size of 1500 packets is the maximum that can be transferred without fragmentation
- number of packets generated per second along with the size of a packets define the number of bits that are in one second put on the link. By selecting the number of generated packets greater than theoretical maximum throughput, it is possible to generate traffic which will in 100% load the link and lead to its saturation. Theoretically, for the maximum load of the wireless link, for throughput of 28 Mbps packets with the size of 1500 bytes, link would require 2500 generated packets in one second that would create a load of 28.6 Mbps.

The maximum load of the wireless access point is realized when the access point always has a frame ready to transmit and represent maximum throughput possible to achieve in the 'downlink' scenario, when the traffic is generated on the Ethernet side of the access point and transferred to the client with a wireless link.

A. Optimizing the number of packets for the maximum link load

To determine a necessary (optimum) number of packets generated in one second for achieving maximum throughput of link with the maximum size of packets of 1500 bytes (which do not lead to fragmentation) it was performed 10 measurements from the central point towards the PC1 with a different number of packets generated in one second (from 2300 to 3200). Duration for each measurement is 60 seconds. Interval between measurements is 10 seconds.

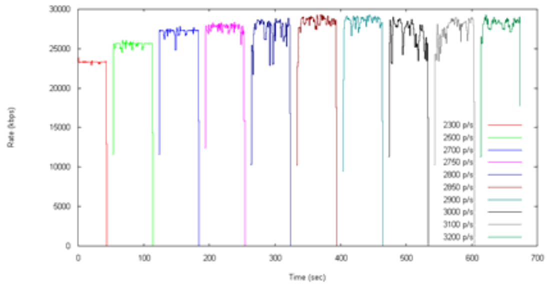

Figure 3. Link bandwidth in relation to the number of packets generated in 1s

TABLE 1
STATISTICAL ANALYSIS OF LINK BANDWIDTH IN RELATION TO NUMBER OF PACKETS GENERATED IN 1 SECOND

Number of packets	Average bandwidth	Minimal bandwidth	Maximal bandwidth	Standard deviation
2300	23323.48	22916.09	23858.17	122.21
2500	25565.28	24576.51	26083.84	294.40
2700	27189.36	24823.80	27838.46	427.82
2750	27673.80	25553.92	28368.38	487.87
2800	27374.12	21714.94	28851.20	1598.11
2850	28321.68	23198.72	29310.46	1083.92
2900	28426.04	21173.24	29228.03	1137.72
3000	27068.47	23104.51	29016.06	1533.36
3100	27220.12	12105.72	29180.92	2372.22
3200	28153.97	25648.12	29228.03	2681.05

From Figure 3. it's visible that Cisco Access Bridge Series 1300 shows very good characteristics for a large load when the input buffer receives significantly more data than they can pass it because they do not come up with throughput degradation due to overloading.

Table 1. shows that for the load of the 2900 packets in second, and packet size of 1500 bytes, is achieved the largest average throughput of 27.76 Mbps, and therefore that is the number of packets that is optimal for achieving maximum throughput of the link.

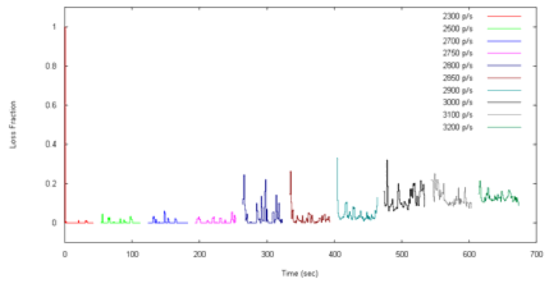

Figure 4. The relation between packet size and the number of lost packets

Figure 4. shows expected behavior of the link that on the increasing amount of packets reacts with their dropping. The higher the number of packets, and thus the greater link load above the maximum possible throughput, the greater number of packets will be dropped, which means that the increasing size of a packet with the same link load reduces link throughput.

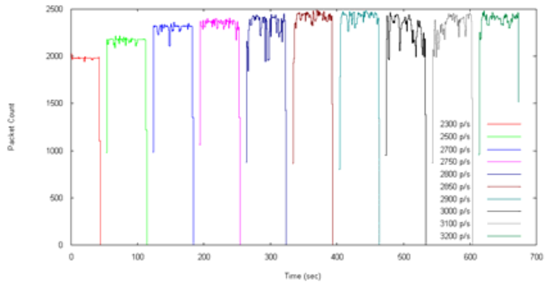

Figure 5. Number of received packets

The number of packets received (Figure 5.), with the same size of packets for different measurements, directly affects the link throughput and therefore the number of received packets graph follow the link throughput graph.

B. The impact of the media sharing to network throughput

Determination of the impact of shared communication media on the link throughput was done by measuring throughput of individual links in the point-to-point mode and then by measuring throughput in the point-to-multipoint mode with gradual inclusion of access points into the system.

1) Point-to-point mode

The influence of the media sharing to network throughput was measured in a manner that the first was measured maximum throughput in the point-point mode for every link (PC1 to PC5). Packet size was 1500 bytes, number of bytes per second was 2900. Measurement for each link takes 300 seconds.

PC1 and PC2 have the bandwidth/throughput which is very near to maximum throughput defined by manufacturer's documentation (28 Mbps, Figure 6.). PC4 has the worst throughput.

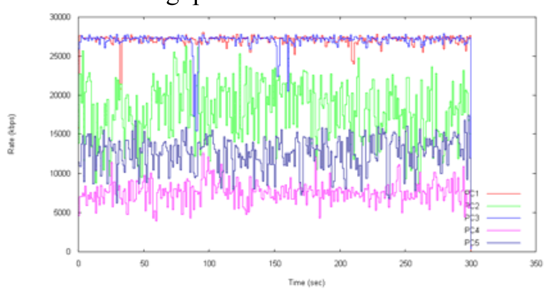

Figure 6. Links throughput for computers PC1 to PC5 in the point-to-point mode

TABLE 2
STATISTICAL ANALYSIS OF LINKS THROUGHPUT FOR COMPUTERS PC1 TO PC5 IN POINT-TO-POINT MODE (KBPS)

PC	Average throughput	Minimal throughput	Maximal throughput	Standard deviation
PC1	26985.19	105.98	28015.10	1782.24
PC2	18107.96	859.64	26272.25	3799.76
PC3	26925.29	341.50	27897.34	1909.70
PC4	7606.63	683.008	12576.76	1452.07
PC5	12615.38	600.57	17381.37	2167.08

Access Bridges have enabled Cisco Aironet extensions, which result in higher maximum bandwidth in bridge operational mode. As the 802.11 standard requires that each unicast frame is confirmed, reducing the time duration of DIFS (Distributed Interframe Space) - the time it takes to channel becomes free before active station begins broadcasting and SIFS (Short Interframe Space) - the time between the frame receipt and transmission of frame for a confirmation of receipt. Cisco has modified 802.11 standard to allow greater link bandwidth.

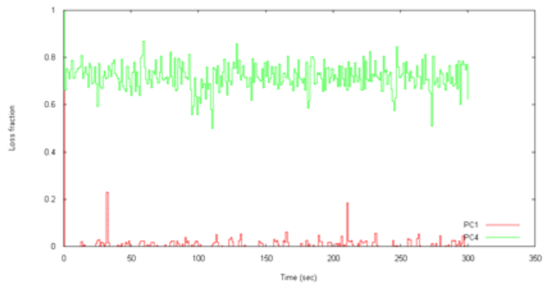

Figure 7. An overview of lost packets for PC1 and PC4

Figure 7. shows that the reduced throughput has been caused by increasing loss of packets in transfer. As all Access Bridge's have the power of signal between -60 dBm and -70 dBm, measured by the Root access Bridge's, we can conclude that the losses are primarily caused by interference. Scanning has shown a big number of AP's working on the same and near channels that proves interference with the MAN network working channel.

2) point-to-multipoint mode

Measuring throughput in the point-to-point mode and comparison with the results of the measurements for point-to-multipoint mode (and with each other) is method to determinate an impact of media sharing on network throughput. We have firstly measured link throughput for PC1 and after that we have added other computers, one by one, ending with PC5. The packet size was the same, 1500 bytes, and the starting number of packets per second of 2900 is reduced so that it is divided with the number of active links:

- 1450 for two computers (two links),
- 970 for three computers,
- 725 for four computers
- 580 for five computers.

In this way it is assured that Root Access Bridge in every measurement, regardless the number of active access points, always generates maximum traffic on the network. Each measurement takes 300 seconds with an interval between the measurements of 10 seconds. Total duration of the test was 1540 seconds. In 1295's second was simulated breakdown of link toward PC5.

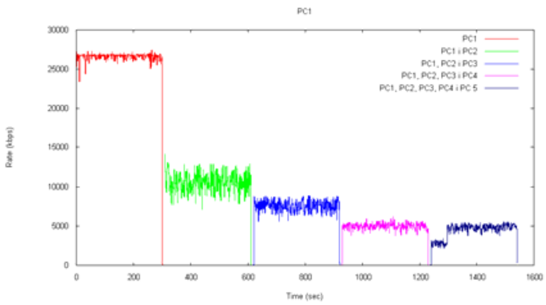

Figure 8. An overview of the parallel work of PC1

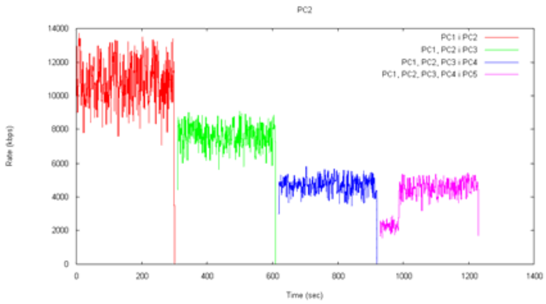

Figure 9. An overview of the parallel work of PC2

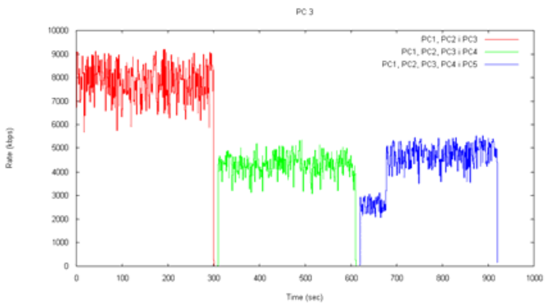

Figure 10. An overview of the parallel work of PC3

Due to point-to-multipoint mode in which the central point was generated the traffic on the network (downlink scenario), all links were equally treated and had equal ability to access media, and therefore have approximately the same channel bandwidth (Figures 6. to 9.).

TABLE 3
STATISTICAL ANALYSIS OF LINK THROUGHPUT FOR COMPUTER PC1 WITH GRADUALLY INCLUDING REMAINING LINKS (KPBS)

Active links	Average throughput	Minimal throughput	Maximal throughput	Standard deviation
PC1	26596.98	23410.68	27461.63	408.19
PC1+PC2	10625.18	7077.37	14437.37	1276.58
PC1+PC2+PC3	7598.85	211.96	8890.88	819.00
PC1+PC2+PC3+PC4	4997.90	3756.54	6217.72	392.06
PC1+PC2+PC3+PC4+PC5 (before breakdown)	3761.45	1846.05	2893.42	1805.59
PC1+PC2+PC3+PC4+PC5 (after breakdown)	4572.80	2202.11	5522.94	788.98

TABLE 4
STATISTICAL ANALYSIS OF THROUGPUT FOR PC1 AND PC2 (KBPS)

PC	Average throughput point-to-point	Average throughput point-to-multipoint PC1+PC2
PC1	26596.98	10625.18
PC2	18107.96	10833.72
∑(PC1,PC2)	44704.94	21458.90
Δ(PC1,PC2)	22352.47	10729.45

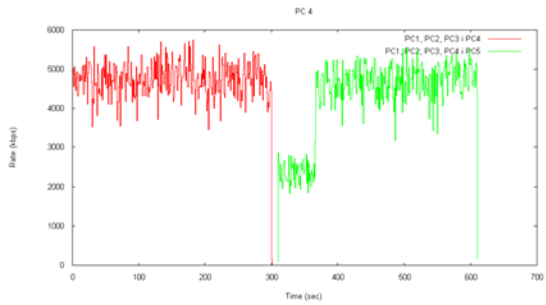

Figure 11. An overview of the parallel work of PC4

The links to PC1 and PC2 show that the average throughput of both links in the parallel mode is reduced to half in comparison with the highest throughput in point-point mode (throughput with 22352.47 kbps fell to 10729.45 kbps). Throughput is almost equally balanced (10625.18 kbps by PC1 and 10833.72 kbps by PC2) regardless the fact that the link to a computer PC1 in the point-to-point mode had greater throughput in relation with link to a computer PC2 (26596.98 kbps by PC1 in relation with 18107.96 kbps by PC2).

3) Network behavior in case of one point breakdown

At the time of 1295th second after generating traffic to PC1 (Figure 8.), the Access bridge of PC5 was turned off and a breakdown of link 5 was simulated. Although the program continued to generate traffic to PC5, the Root Access Bridge stopped to transmit traffic and reallocated that part of throughput equally to other channels.

C. Optimizing link bandwidth by changing the packet size

The influence of the packet size to the network bandwidth was measured with gradually reducing the size of a packet for 50% compared to the previous measurement. For a link bandwidth measured from the central point towards a PC size of packets was decreased in four steps:

1. step: 1500 bytes,
2. step: 750 bytes,
3. step: 375 bytes and
4. step: 188 bytes.

Total measurement time was 1230 seconds and consisted of 4 measurements per 300 seconds and three intervals between the measurements of 10 seconds each (Figure 12.).

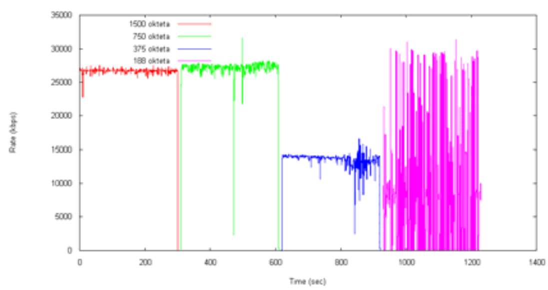

Figure 12. The influence of the packet size to link bandwidth

TABLE 5
STATISTICAL ANALYSIS OF THE INFLUENCE OF THE PACKET SIZE TO LINK BANDWIDTH (KBPS)

Packet size (B)	Average bandwidth	Minimal bandwidth	Maximal bandwidth	Standard deviation
1500	26579.61	26579.61	27496.96	854.02
750	26467.32	358.11	31970.16	2011.55
375	13378.78	460.81	17077.95	1390.20
188	8411.97	0.00	31909.12	9806.82

The results show that reduction of the packet size for 50% does not affect the average throughput although further reductions significantly decrease the link bandwidth. For a packet size of ¼ MTU is evident that the data transfer takes place with large oscillations between the maximum and minimum link bandwidth because the packet size is too small and does not lead to permanent link saturation.

D. The impact of changes to the physical network topology

The impact of changes to the physical network topology is measured in a way that links between the computer PC2 and PC4 are loaded at the same time. After that, the network was reconfigured so that both computers were directly connected and link of computer PC2 was used as common link load. Measurements were made with following parameters: 2900 packets length of 1500 bytes in duration of 300 seconds.

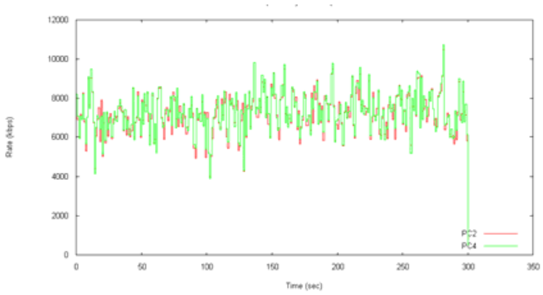

Figure 13. Parallel load of links toward PC2 i PC4

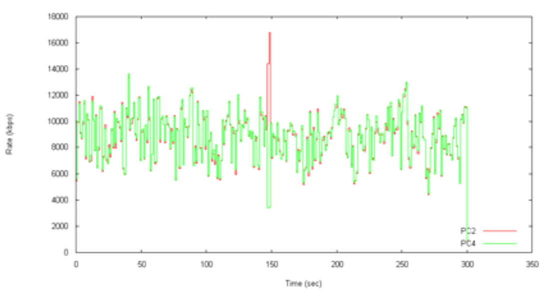

Figure 14. PC2 link load for common transfer of data to PC2 and PC4

In the first case, the average throughput of both links was 7234.16 kbps (7203.93 kbps for PC2 and 7264.38 for PC4, Figure 13.). In the second case, when the traffic was released from PC2 link to PC2 and PC4, the average link throughput of PC2 is 8888.00 kbps (8896.20 kbps for PC2 and 8879.80 kbps for PC4, Figure 14.). The results indicate a better throughput in the case when using a smaller number of WLAN links to transfer the same amounts of data. It was also confirmed that the result indicates an equal distribution of traffic between the links.

E. The influence of changes to the hierarchical network model

By moving location of traffic generator (enterprise server) from Root Access Bridge in a PC1 place and generating traffic to a computer PC3 is simulated change of network hierarchical model when the enterprise server is located in position of workgroup server. It is also a test for throughput between two workstations on the network. In this case first was generated uplink and after that downlink traffic. Measurement takes 300 seconds with the 2900 packets in seconds and with packet length of 1500 octets.

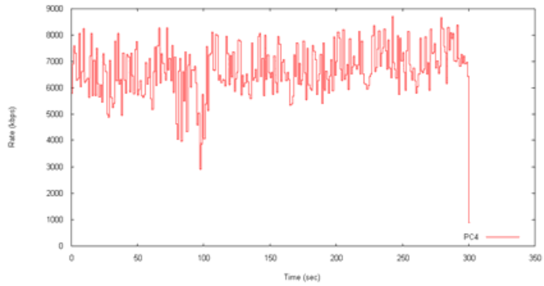

Figure 15. Link throughput for data transfer between PC1 and PC4

Measurements show that the average throughput is 6662.67 kbps. Because the average throughput of each individual is greater than 26 Mbps, it is evident that this method of data transmission is unfavorable. This measurement has confirmed that choice of network hierarchical model can significantly optimize MAN because traffic on communication links significantly depends on location of enterprise servers in the hierarchical model of the network.

VI. CONCLUSIONS

The results of measurements confirmed the influence of the size and number of the packets, sharing communication media, physical topology and hierarchical models of network on MAN performance. The number of packets received, with the same size of packets for different measurements, directly affects the link throughput. The results indicate a better throughput in the case when using a smaller number of WLAN links to transfer the same amounts of data. The measurement has also confirmed that choice of network hierarchical model can significantly optimize MAN because traffic on communication links significantly depends on location of enterprise servers in the hierarchical model of the network.

The proper selection of MAN parameters and their configuration can significantly optimize the types and amount of MAN traffic, which represents the base for optimization of MAN as a whole. During all the measurements, the network showed the stability and repeated tests gave the same results.

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