Influence of wind power plants on power system operation – Part one: Wind power plant operation and network connection criteria

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OPTIMIZATION OF LAN/MAN NETWORK MODEL BASED ON EXPERIMENTAL MEASUREMENTS

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Original scientific paper

MAN design includes elements of LAN and WAN design. A model of MAN design presented in this paper describes a methodological approach to MAN modeling and necessity for single link optimization and link system optimization in case of common communication link sharing. MAN optimization methods are presented using experimental MAN made in IEEE 802.11g technology and a point-to-multipoint operation mode where wireless links share a common communication medium. Results of measurements confirm the influence of communication media sharing as well as the size and the number of packets and a hierarchical MAN network model on MAN throughput.

Keywords: *MAN, modeling, optimization, IEEE 802.11g*

Optimizacija modela LAN/MAN mreže temeljena na eksperimentalnim mjerenjima

Izvorni znanstveni članak

Dizajn MAN-a uključuje elemente LAN i WAN mreža. Model dizajna MAN-a predstavljen ovim radom opisuje metodološki pristup modeliranju MAN-a i potrebu za optimizacijom pojedinačnog linka kao i sustava poveznica u slučaju dijeljenja zajedničkog komunikacijskog medija. Metode optimizacije MAN-a predstavljene su na primjeru eksperimentalne MAN mreže izgrađene IEEE 802.11g tehnologijom u načinu rada točka-više točaka u kojemu bežične poveznice dijele zajednički komunikacijski medij. Rezultati mjerenja potvrđuju utjecaj dijeljenja zajedničkog komunikacijskog medija, veličine i broja paketa te hijerarhijskog modela mreže na propusnost MAN-a.

Ključne riječi: *MAN, modeliranje, optimizacija, IEEE 802.11g*

1 Uvod
Introduction

MAN covers geographical areas between LAN and WAN and includes both LAN and WAN characteristics and technologies. With disappearing of differences between LAN and WAN technologies MAN is in expansion. A typical LAN is built on the property infrastructure in contrast to WAN technologies which very often rely on the service provider's infrastructure.

IEEE 802.11g technology, working at 2,4 GHz, provides an opportunity to build a proprietary MAN infrastructure at a reasonable cost and network time implementation with throughput of up to 28 Mbps for the point-to-point operation mode at a distance of up to few hundred meters. Maximal distance between peers can be 40 km with a 1 Mbps transfer rate [1].

The main goal of building a MAN network is usually to connect LAN's on the metropolitan area. As a result, the MAN model should contain network communication technology, analysis of the existing LAN infrastructure and specification of user requirements. Networking communication technologies should be determined with specific properties, availabilities of technologies and with duration and cost of implementation. User requirements should be determined with a type of network services in the MAN and a demand for time and area availability of services.

The proposed MAN model and model optimization applied on wireless networks presented in this paper expands a throughput analysis perspective of TCP/UDP traffic flow in 802.11 WLAN presented in [9] and [10]. The conducted measurement observes the influence of single link optimization, link system optimization, size of packets, number of packets and hierarchical MAN topology on MAN throughput.

The paper is organized as follows: in section II design and optimization method of the MAN model is described, section III present optimization of MAN's parameters based on experimental measurements and the conclusion is given in section IV.

2 MAN modeling
Modeliranje MAN-a

Computer network design consists of defining three fundamental elements and their optimization through service/price relationship [2]:

- environment settings: includes locations of workstations, servers, terminals and other equipment; planned traffic; planned charges for different levels of services provided
- performance demands: includes data about reliability and the available bandwidth; computer' performance
- network connections elements: network topology, links capacity and traffic shape on the connections links.

The goal of network design is to minimize costs based on these elements with insurance of a service level that will not jeopardize defined requirements for service availability. Availability of services and their prices represent mutually dependent and related elements [3].

According to the model in Figure 1 design and optimization of the MAN model is conducted in three phases as an iterative process:

- *Creating a general model of communication network*: begins with analysis of the existing infrastructure and definition of user requirements on the system which include information about planned development. At this stage it is necessary to define the type, quantity and time periods of traffic on connection links.

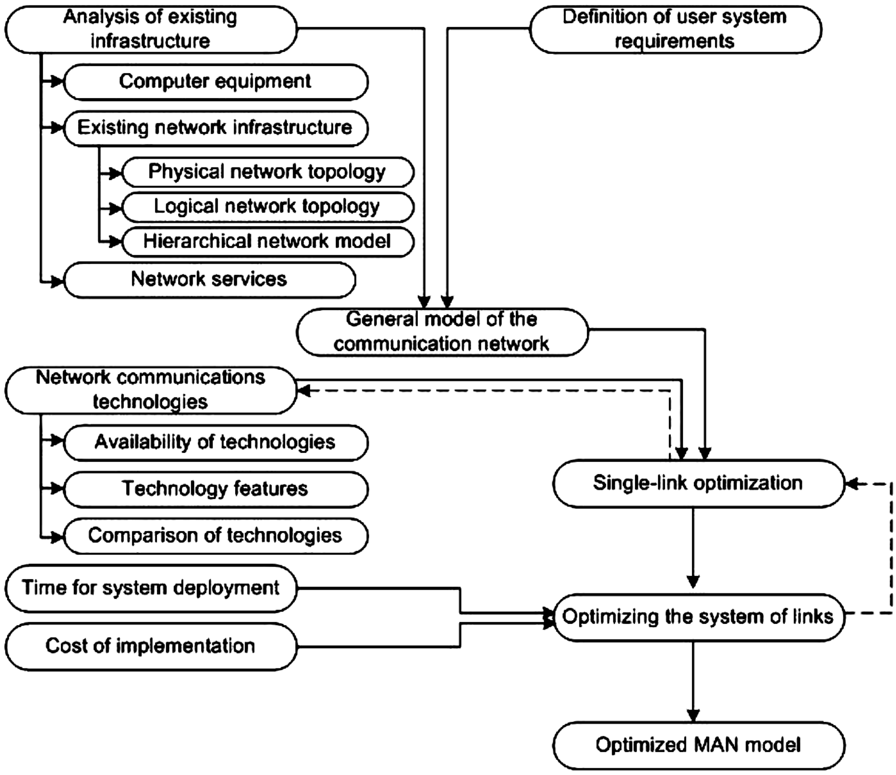

Figure 1 *MAN modeling and optimization*
Slika 1. *MAN modeliranje i optimizacija*

- *Single-link optimization*: a general model of a communication network sets requirements for connections links. According to defined requirements the analysis of network communication technologies determines the technologies which meet specified requirements.
- *Optimizing the system of links*: connecting optimized individual links in the system of links represents a point of re-optimizing. The set of optimized individual links usually does not lead to a generally optimized system. It is necessary to determine whether it is possible to optimize the whole system by replacement of technologies on a particular link, which is set as optimal in previous step. This is especially necessary for the technologies that share a common communications medium (e.g. IEEE 802.11g).

2.1
The analysis of the existing infrastructure
Analiza postojeće infrastrukture

The initial infrastructure represents an existing state. It consists of computer equipment, network infrastructure and computer services.

Computer equipment includes overall equipment in the computer network that is or will become part of the network and includes personal and portable computers, network servers, networked and shared printers, data storage systems and other equipment connected directly to the network or terminal equipment users can use in LAN. It is also necessary to make the list of active network equipment.

The existing network infrastructure, which is mostly comprised of local, unrelated computer networks built on certain locations, is characterized by physical network topology, logical network topology and a hierarchical model of the network. The above elements are also possible points for optimization of the existing infrastructure in order to facilitate their mutual connectivity and/or optimization of a new network in terms of enhancing the performance of each individual network and system as a whole.

Hierarchical network model represents layout of available resources on the network - network services and devices. Proper layout of network resources can significantly optimize traffic at the local and connecting network. The basic rule for network hierarchy modeling is that local traffic should stay local.

Network services: type and quantity of network services and their properties are directly related to the possibility and implications of applying specific technologies: bandwidth of communication channels, the amount of transferred data, period of time availability of the communication link, the source and destination of generated traffic, availability and reliability of network connections and network link security. Proper settings of network services on the hierarchical model of the network can significantly affect optimization of traffic on the network.

2.2
Definition of user system requirements
Definicija sustavskih zahtjeva korisnika

User requirements define basic parameters which selected technologies must meet and they should include:
- detailed description of existing and planned online services that will be available in the system
- definition of area and time availability of network services
- network services access security scheme.

2.3
General model of the communication network
Opći model komunikacijske mreže

Analysis of the existing infrastructure and user requirements provide the knowledge of all relevant data as prerequisites of successful system modeling. In this phase network model is only general because it does not contain information about communication technologies. In the next phase we should determine the optimal model of communication technologies and thus define the model of the communication network.

2.4
Network communications technologies
Mrežne komunikacijske tehnologije

Rapid development of technologies improves the possibility for connecting LAN's on separated locations in the metropolitan area in a form of MAN. Different technologies have significantly different characteristics, requirements and opportunities. By knowing available technologies and by comparing their various properties we could select an optimal technology that will satisfy requirements of the general model of the communication network.

Availability of technologies is defined by geographical, location, legal and technological restrictions of implementation. Prior to consideration of the matching technology it is necessary to check the possibility of implementation in the MAN area.

Technology features are defined by its standards. The maximum possible data rate, the type of medium, the maximum distance between connecting points and the price and model of fee calculation for certain technologies are the most important parameters that cause selection of specific technologies in a particular case.

Comparison of technologies can be accomplished using different criteria, depending on the general model of the communication network. Basic criteria for comparison of technologies are bandwidth and throughput, the type of connection (temporary or permanent connections), independent or shared use of communication media, the maximum distance between communication points, ownership of infrastructure, mobility of infrastructure, a model of fee calculation for the cost of a rented connectivity service (according to the period of use, achieved data traffic or amount of leased bandwidth or according to combination of the above criteria), a level of technology security, availability, reliability and the total price.

2.5
Single-link optimization
Optimizacija jednog linka

The general model of the communication network defines requirements for communication links. According to requirements analysis of network communication technologies determines technologies that meet specified requirements. For each technology it is necessary to meet the demands from the general model of the communication network and to determine properties under which the technologies will be compared in the process of optimization for each individual link.

2.6
Time for system deployment
Vrijeme razvoja sustava

During MAN modeling it is necessary to calculate the total time for implementation of each technology. In addition, it is necessary to express time for the system testing phase after which the system will be fully operational.

2.7
Cost of implementation
Troškovi ugradnje

Cost of implementation affects determination of an optimal MAN model. Cost could be expressed in several terms:

- cost of system implementation: consists of the total cost of all activities on the design, implementation and system testing, including building of infrastructure and cost of equipment
- cost of system maintenance: includes costs of permanent, regular maintenance of the system (hardware, software) and equipment amortization
- cost of system exploitation: includes fixed and variable costs, which charge a service provider according to the type of technology.

Calculation of costs is based on user demands on the system for each considered technology. Cost of the system implementation and the permanent monthly cost (the sum of the price of monthly system maintenance and the cost of system exploitation) should be calculated separately. Since cost of system implementation and permanent monthly cost can differ significantly in different technologies, it is recommended to make system cost analysis for a period of time by summing the cost of system implementation and permanent monthly cost for that period.

$$C_t = C_s + n \cdot C_m \tag{1}$$

C_t - total cost
C_s - cost of system implementation
n - total number of months in the observed period
C_m - monthly cost.

By calculating the ratio of the total cost and link bandwidth we could express link cost per bandwidth and determine the optimal bandwidth in relation to the price of technology and simplify comparison of prices for links with a different bandwidth:

$$C_b = \frac{C_t}{BW} \tag{2}$$

C_b - cost per unit of bandwidth
BW - bandwidth.

2.8
Optimization of the system of links
Optimizacija sustava veza

Connecting individual links in the system of links provides a possibility for system re-optimization. Because the set of optimized individual links is not obligatorily

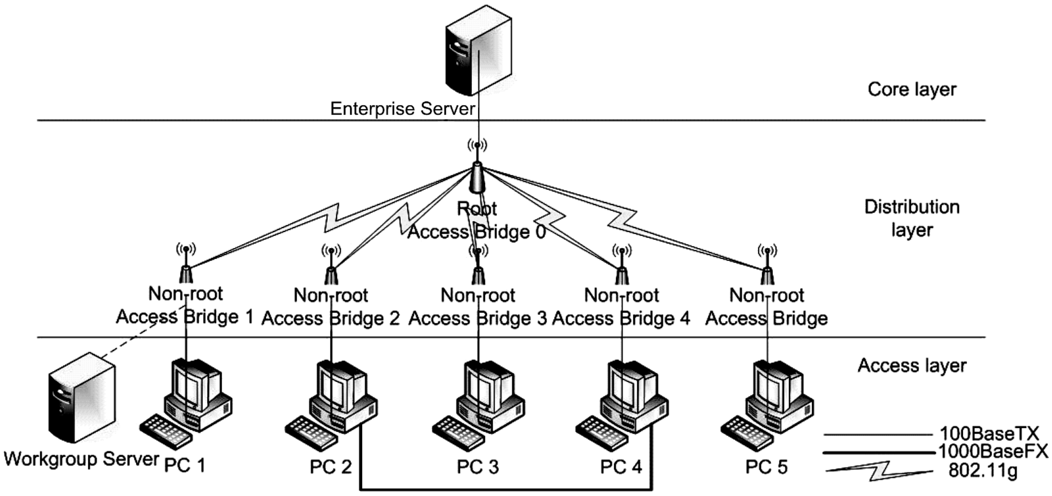

Figure 2 *Structure of experimental MAN*
Figure 2. *Struktura eksperimentalnog MAN-a*

optimized as a whole, it is necessary to determine whether connecting individual links in a system of links could provide a possibility for optimization, which ultimately may lead to replacement of technology on a particular link which is in the previous step determined as optimal. Generally, the model should be optimized to enable maximum throughput of MAN per lowest price.

3
Experimental Optimization of MAN's parameters
Eksperimentalno modeliranje parametara MAN-a

During optimization of the MAN model it is necessary to observe connection links as a set of individual links but also as a whole - system of links. That allows optimization at two levels:

- optimization at the level of an individual link: every link may have specific input parameters that can cause selection of the same or different technologies for every link;
- optimization of the system of links: optimizing at the level of an individual link can obtain solutions that, in the case of various technologies for individual links, at the level of the system of links lead to the appearance of a hybrid model of communication network.

Optimization of each individual link is the first step for optimizing the overall system. An optimized model of the communication network describes the system that is optimized as a whole.

3.1
Test topology
Ispitna topologija

Methods of optimization of a individual link and the system of links are experimentally tested in the MAN network built in IEEE 802.11g technology in the form of a point-to-multipoint wireless network. The MAN network is located in Osijek (Croatia) and all 5 wireless access points are in radius of 500 m of the central spot (Figure 2).

Wireless access points are Cisco 1300 in the bridge operation mode (AB) with enabled Cisco Aironet extensions. Transmission rate for all access points is 54 Mbps. For the purpose of testing on the LAN interface of each AP only one PC is connected.

For traffic generation and logging the program Multi-generator (MGEN) v 4.2 is used. A tool TRace Plot Real-team (TRPR) v2.0b2 and GnuPlot v4.0 are used for the analysis of logs and for a graphic data display, respectively. UDP traffic is generated for measurements because UDP throughput link measurement does not enter the error of communication protocol itself [4, 5, 6].

3.2
Single-link optimization
Optimizacija jednog linka

A single link can be optimized by generating packets whose number and size will enable its maximum throughput.

3.2.1
Number of packets optimization
Optimizacija broja paketa

To determine an optimal number of packets for achieving maximum throughput of the link with the maximum size of packets of 1500-bytes 10 measurements were performed from the central point towards PC1 with a different number of packets (Figure 3).

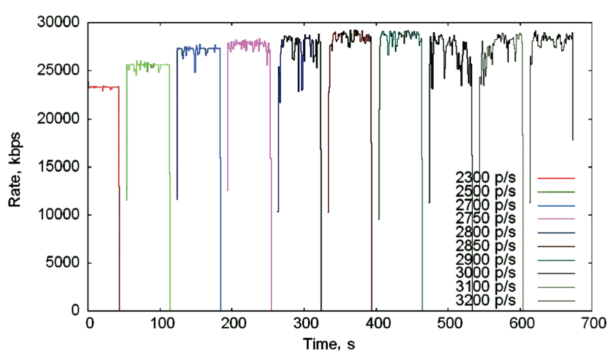

Figure 3 *Link throughput in relation to the number of packets*
Slika 3. *Propusnost linka u ovisnosti o broju paketa*

Table 1 shows a statistical analysis of link throughput in relation to the number of packets generated in 1 second. For the load of 2900 packets in second, with a packet size of

1500 bytes, the largest average throughput of 27,76 Mbps is achieved, and therefore it is the number of packets that is optimal for achieving maximum throughput on the link.

Table 1 *Statistical analysis of link throughput (kbps) related to number of packets in 1 second*
Tablica 1. *Statistička analiza propusnosti linka (kbps) povezane s brojem paketa u 1 sekundi*

Number of packets	Average throughput	Minimal throughput	Maximal throughput	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

1500 bytes, the largest average throughput of 27,76 Mbps is achieved, and therefore it is the number of packets that is optimal for achieving maximum throughput on the link.

3.2.2
Optimizing link throughput by changing the packet size
Optimiziranje propusnosti linka promjenom duljine paketa

The influence of the packet size to the network throughput is measured by gradually reducing the size of a packet for 50 % compared to the previous measurement. For a link throughput measured from the central point toward a PC1 the size of packets is decreased in four steps: Step 1: 1500 bytes, Step 2: 750 bytes, Step 3: 375 bytes and Step 4: 188 bytes (Figure 4).

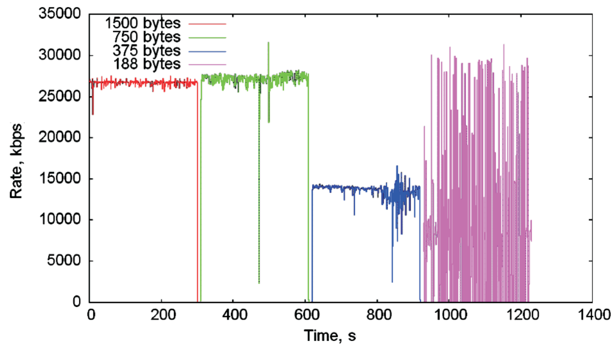

Figure 4 *The influence of the packet size to link throughput*
Slika 4. *Utjecaj duljine paketa na propusnost veze*

Table 2 *Statistical analysis of the influence of the packet size to link throughput (kbps)*
Tablica 2. *Statistička analiza utjecaja duljine paketa na propusnost linka (kbps)*

Packet size (B)	Average throughput	Minimal throughput	Maximal throughput	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

Results in Table 2 show that reducing the packet size for 50 % does not affect the average throughput, but further reductions significantly decrease the link throughput. For a packet size of ¼ MTU it is evident that the data transfer takes place with large oscillations between the maximum and minimum link throughput because the packet size is too small and does not lead to permanent link saturation.

3.3
Link system optimization
Optimizacija sustava linkova

Determining the impact of shared communication media on the link bandwidth/throughput was performed 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.

3.3.1
The influence of media sharing to throughput
Utjecaj dijeljenja medija na propusnost

The influence of media sharing to network throughput is measured so that first maximum throughput in the point-to-point mode was measured for every link (Figure 5).

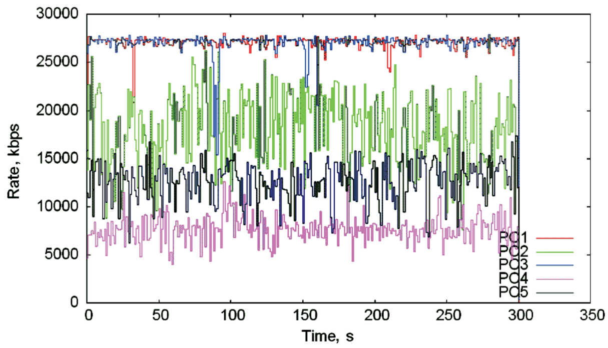

Figure 5 *PC1 to PC5 throughput in the point-to-point mode*
Slika 5. *Propusnost od PC1 prema PC5 u načinu rada točka-točka*

Table 3 *Analysis PC1 to PC5 throughput in point-to-point mode (kbps)*
Tablica 3. *Analiza propusnosti od PC1 prema PC5 u načinu rada točka-točka (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	683,01	12576,76	1452,07
PC5	12615,38	600,57	17381,37	2167,08

Pc1 and PC2 have the bandwidth/throughput which is very near to the maximum throughput defined by manufacturer's documentation (28 Mbps). PC4 has the worst throughput. Access Bridges have enabled Cisco Aironet extensions, which result in a higher maximum throughput in the bridge operational mode [7]. Measuring throughput in the point-to-point mode and comparison with the results of measurements for the point-to-multipoint mode is a method for determining the impact of media sharing on network throughput. It has measured link throughput for PC1 and then individually added other computers, ending with PC5 (Figure 6).

The results show that, due to the point-to-multipoint mode with a downlink scenario, all links were equally treated and had the same ability to access media, and therefore have approximately the same channel bandwidth [8].

Table 4 *Statistical analysis of link throughput for computer PC1 with gradual adding of remaining links (kpbs)*
Tablica 4. *Statistička analiza propusnosti linka za računalo PC1 s postupnim dodavanjem preostalih linkova (kpbs)*

Active links	Average throughput	Minimal throughput	Maximal throughput	Standard deviation
PC1	26596,9	23410,6	27461,6	408,1
PC1+PC2	10625,1	7077,3	14437,3	1276,5
PC1+PC2+PC3	7598,8	211,9	8890,8	819,0
PC1+PC2+PC3+PC4	4997,9	3756,5	6217,7	392,0
PC1+PC2+PC3+PC4+PC5 (before breakdown)	3761,4	1846,0	2893,4	1805,5
PC1+PC2+PC3+PC4+PC5 (after breakdown)	4572,8	2202,1	5522,9	788,9

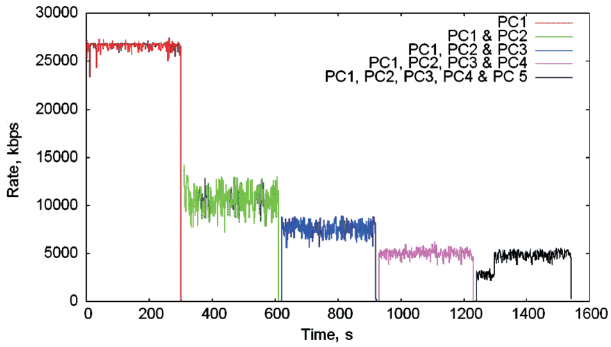

Figure 6 *Link throughput toward PC1*
Slika 6. *Propusnost veze prema PC1*

3.3.2
The influence of changes to the hierarchical network model
Utjecaj promjena na hijerarhijski mrežni model

By moving the traffic generator (enterprise server) from Root Access Bridge to PC1 location and by generating traffic to computer PC3 we have simulated the change of the network hierarchical model when the enterprise server is located in the position of the workgroup server (Figure 7).

The average measured throughput was 6662,67 kbps since the average throughput of each individual was greater than 26 Mbps, it is evident that this method of data transmission is unfavorable. This measurement has confirmed that the choice of the network hierarchical model can significantly optimize MAN because the traffic on communication links significantly depends on the location of enterprise servers in the hierarchical model of the network.

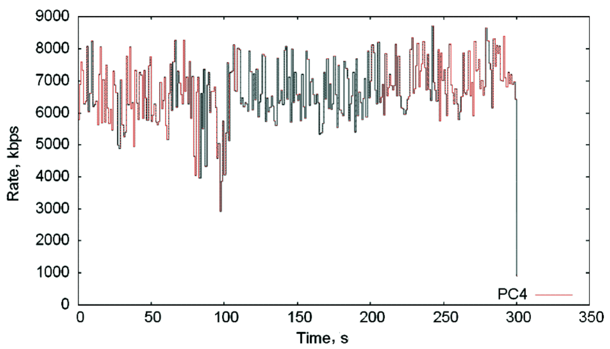

Figure 7 *Link throughput for data transfer between PC1 and PC4*
Slika 7. *Propusnost veze za prijenos podataka između računala PC1 i PC4*

4
Conclusion
Zaključak

This paper presents the model of MAN design and introduces a methodological approach of MAN modeling and the need for single link optimization and link system optimization in case of common communication link sharing. Optimization methods were presented and experimentally tested by using MAN in IEEE 802.11g technology and the point-to-multipoint operation mode where wireless links share a common communication medium.

Measurements results confirm the influence of communication media sharing, the size and number of packets and hierarchical models of the network on MAN throughput. It is confirmed that proper selection of MAN model parameters and their configuration can significantly optimize the type and amount of MAN traffic which leads to overall performance optimization. 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 wireless links to transfer the same amounts of data. Link throughput increases with the increasing number of packets but it is necessary to determine the maximum number of packets that lead to link saturation. The hierarchical model of the network has a significant impact on network throughput because locations of network servers in the MAN hierarchical model affect the size and direction of traffic at connection links. Optimized hierarchical network model optimized number of wireless links and internal (LAN) and external (MAN) network traffic.

5
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