Redundant Topology in Computer Network Realized with Millimeter Wave Radio Links

Dragana Perić, Miroslav Perić, Grozdan Petrović

Abstract - **In this paper we analyzed influence on link disconnection caused by unavailability due to rain in a mesh network made of point-to-point high capacity radio links carrying IP traffic, at frequency bands of 26GHz and 38GHz. Main goal of this research is to confirm the redundancy degree in a mesh topology. Knowing that major effect on link unavailability is due to rain, mesh topology and appropriate routing protocols practically represent the use of path diversity technique. Simulation results showed that finite convergency time of realistic routing protocols (OSPF, EIGRP, RIP) can cause in significant network performance degradation, which can especially be critical for modern real-time IP application, such as VoIP or VPN. It is shown that results with EIGRP are closest to ideal protocol, but still are not close enough. Given simulation methodology could be used to find weakness of real network and to improve its performance.**

Index Terms - **computer network performance, millimeter wave radio propagation, redundancy, routing**

I. INTRODUCTION

The usage of radio relay links for router connection has shown as very attractive solution last years, because of low equipment cost and quick installation [1]. Millimeter wave bands practically must be used if data throughputs above 100 Mbit/s are needed, since licenses for such capacities at lower bands are hard to get. Other reason for attractiveness of this band is achievment of relatively high gains and small angle antenna radiation pattern with small dimensions, that make easier realisation of dense metropolitan networks and minimize interference issues. Drawback of these systems is their high susceptibility to rain, that result in temporary link unavailability. The link availability model [2] shows that attenuation due to rain has a major influence at frequency bands above 18 GHz, where percentage of unavailable time round 0.01% could be expected per single hop. As a remedy against this effect it is adviced to use path diversity, which is signal propagation along two uncorrelated paths. It is noted that correlation of attenuation beetween two paths is weaker if they are geographically separated for more than 4 km. Bearing in mind that the hop lenghth of high capacity link at these frequency bands is about 10 km, it practically means that these requirements can be satisfied with multi-hop links.

As a separate problem stands forming of diversity-switch criteria. Classical radio relay systems deploy two mechanisms: receiver power level and error detection [1]. Since links must be multi-hop, in the first case, transmission of a receiver power level should be collected from many hops through the remote monitoring system, which would increase the overall equipment cost.

IP traffic allows for another flexibility, knowing that routers and appropriate routing protocols in fact work as commutators [3]. Another option is possibility of signal transmission over multiple paths, known as load balancing, so that for this nature of traffic mesh topology comes as a logical solution. We must mention that radio relay links at such bands need line-of-sight visibility, so this is the other important reason why mesh topology is attractive.

In this work we analyze two problems that may occur in designing and using mesh topology with millimetric wave links.

First problem would be if the rain cell above the node position should disconnect all links connected to that node, meaning that practical improvement would be negligible. For analisys of this problem two-dimensional rain distribution in space models are used [4][5][6][7][8].

Another problem that appears is the frequent link state changes, that cause huge loss of time on routing protocol convergence, and result in significant traffic loss. Three types of routing protocols are analised: RIP (Routing Information Protocol) [9], OSPF (Open Shortest Path First) [10] and EIGRP (Enhanced Interior Gateway Routing Protocol) [11]. RIP is classical distance-vector protocol based on periodical exchange of complete routing tables between neighbouring routers, so its convergence is very slow and it is expectible that it is inefficient for this application. OSPF is a link-state routing protocol which exchanges link states on their status transition, and every router with Dyjkstra algorithm forms its own network topology, so its convergence is much faster. This algorithm is very CPU-consuming, so it is important to explore its reaction with numerous successive link state changes in mesh network resulting from rain cell moving. EIGRP is Cisco proprietary enhanced distance-vector protocol and for its characteristics it stands beetween two previously mentioned. However, it has implemented a concept of a back-up route that goes active after main route goes down without recalculation of routing table and informing neighbours of network topology change, so it can be appropriate for use in this example.

Dragana Perić - *dragana@insimtel.com*
Miroslav Perić - *micha@insimtel.com*
are with IMTEL Institute, Bulevar Mihaila Pupina 165b, 11070 Novi Beograd, Serbia and Montenegro
Grozdan Petrović - *gpetrovic@etf.bg.ac.yu*
is with Faculty of Electrical Engineering Belgrade, Bulevar Kralja Aleksandra 73a, 11000 Beograd, Serbia and Montenegro

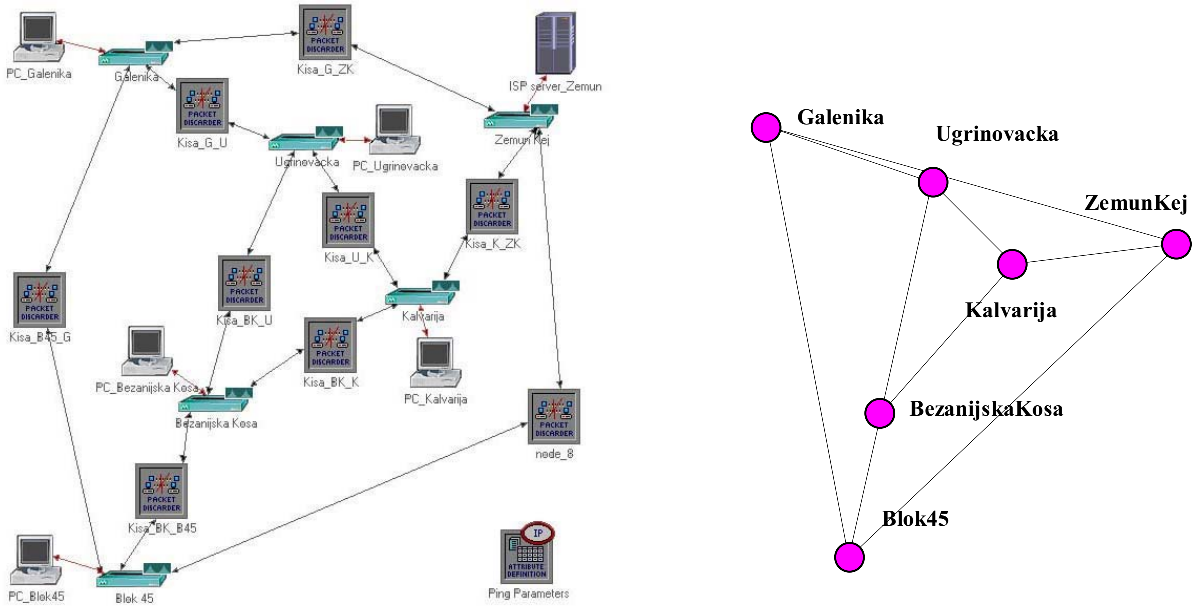

Fig. 1. Topology of one Internet service provider network segment

II. Methodology

A. Network topology

This problems are explored on a fictive Internet service provider computer network segment located in Zemun and New Belgrade. Network consist of six nodes: Galenika, Ugrinovacka, Zemunski kej, Kalvarija, Bezanijska Kosa, Blok 45, which are suitable for antenna positions for their geographical location. Area on which nodes are settled spans within 5x5 km.

Nodes are interconnected with 26GHz or 38GHz radio links. Network topology is formed in the following manner:

- As an input parameter, a maximum number of WAN links per one node is taken. We assumed it was three.
- Nodes are initially connected by tree that require minimum link energy for a given individual link unavailability. As rain is the major reason of unavailability on millimetric wave band, and its attenuation is proportional to path lenght, this criterion is equal to minimum path lenght.
- Then, redundant paths are added to the nearest nodes respecting the number of WAN links from one node limit. Structure of redundant paths generated in this way is dependant of node order, so we opted for sorting based on distance from network geographical center.

Following described procedure all nodes were connected with nine links. Each node contains one router, with links on WAN serial ports. Ethernet router port is for the purpose of simulation connected to workstation or ISP server in one of the nodes.

B. Rain model

Attenuation due to rain can be defined as in Eq.1 [2].

$$\gamma_R = K \cdot R^{\alpha} \qquad (1)$$

where R is rain intensity (mm/h), K and α are parameters dependant on frequency and polarisation.

Therefore, overall attenuation due to rain with variable intensity along the path is:

$$A_R = \int_0^L K \cdot R(l)^{\alpha} \cdot dl \qquad (2)$$

When calculating percentage of unavailable time for a single hop, it is of interest to have rain intensity cummulative distribution which has local character. When these values are not available, data from the Rec. ITU-R 837 [12] are used, where areas worldwide are divided into rainfall zones. In Rec. ITU-R P.530 cumulative rain distribution is approximated in respect to one value of rain intensity exceeded in 0.01% time, so rain intensity exceeded in other percentage of time can be estimated, and therefore can be determined attenuation due to rain and needed fading margin. It is also possible to calculate inverse problem, ie finding percentage of unavailable time for a given attenuation due to rain. Fact that rain does not fall with the same intensity is modeled with effective path length, that represent factor of path shortening.

$$d_{eff} = \frac{d}{1 + d/(35 \cdot e^{-0.015R(0.01\%)})} \qquad (3)$$

where d is real path length, and R(0.01%) rain intensity exceeded in 0.01% time.

There are many other rain models in literature, apart from this which is legitimate for calculation of radio relay link performance. In [6][7] comparison is made between given model and several previously used models with experimental results and it is shown that differencies can be significant (even to 5 dB in fade margin on eight different locations).

For the task of determining the rain influence on mesh topology two-dimensional rain structure is needed. In literature [4] it is shown that there are two types of rain cell called *stratiform* - which has small rain intensity (below

10mm/h) and predominantly constant in space and *convective* - heavy rain with intensity decreasing as leaving rain cell center. In the same paper it is shown that space distribution function of rain intensity can be:

$$R(r) = (R_{\max} + R_{low})e^{-r/\rho 0} - R_{low}, r < \rho_{\max}$$
$$\rho_{\max} = \rho_0 \ln((R_M + R_{low})/R_{low}) \quad (4)$$

where R_M is maximum, ρ_0 reference cell radius, R_{low} - rain intensity at the cell periphery. Medial cell radius D_M is a key parameter of this distribution and based on measurements in Europe, East Asia and East coast USA lead to conclusion that it can be taken for *Rmax>50mm/h* to be *1.2km*, *Rmax* beetween 30 and 50mm/h to 2km, beetween 20 and 30mm/h 4km, beetween 14 *and* 20 8km. For smaller values rain character is no longer convective. This type of rain cell is moving with a wind [5] and typical speed is round 10m/s. In [5] results are given for fitting data taken from metheorological radar into described convective rain model.

Another rain structure model found in literature is Gaussian rain cell model [8], whose parameter standard deviation can be calculated based on medial rain radius as:

$$R(r) = R_{\max} e^{-(r/r_{ref})^2}$$
$$r_{ref} = D_M \Big/ \sqrt{\ln 2} \quad (5)$$

Rain model that should be used for analysis in ISP network is formed from the given facts. It is adopted that rain intensity exceeded in 0.01% time is 42mm/h (ITU-R Rec. P.837 zone K, at which area geographically belongs to). Network behaviour is examined under the influence of rain cell with maximum intensity which is equal 42mm/h, and medial radius of 2km, wind speed 10m/s and direction north-east.

Fading margins of all links are dimensioned according to the model in ITU-R P.530 to have unavailability of 0.01% time, and that disconnection starts when rain intensity of 42mm/h is present along the effective path length. In this case, certain links will be down for a short time depending on the rain cell movement.

Bit error ratio (BER) dependance of receiver power level is modeled as complete link disconnection when rain attenuation exceeds fading margin and errorless transmission when it is below fading margin. Modern radio relay systems with forward error connection (FEC) behave similar to this simplified model, as difference in receiver power level between disconnection and BER<10^{-10} is 1 to 2 dB. This behaviour can be modeled with an object called Packet Discarder [13] that has defined start and end time of time interval in which packet are dropped (Table I).

It is noticable that under given assumptions there are no significant differences beetween packet discarder definitions for bands 26GHz and 38GHz, because parameter α from Eq.1 is very close to one [12], so that value of attenuation integral practically gives equal results for fading margin exeeeding. Since the same assumptions are made for dimensioning of fading margins in both cases, some links are not realizable at 38GHz due to requirement for very high fading margin (Table I).

C. Simulation tools

Two types of simulation were done, first, using assumed ideal routing protocol which forwards packets without loss due to network convergence in real case, were done in programming package Mathematica.

Second, simulation of expected real network performances was done in OPNET IT Guru - Academic Edition software that is free-downloadable version of OPNET software package. Link unavailability is simulated with object Packet Discarder, that was previously mentioned and explained.

D. Traffic description

For traffic flow test ICMP command is used: ping demand, which is used for testing of traffic beetween workstation and ISP server. For its description object *IP Ping Demand* is used. Parameters that are given here are

TABLE I
PARAMETERS OF LINKS

Node A	Node B	Hop length (km)	26GHz			38GHz		
			Fading margin (dB)	Packet discard. start (s)	Packet discard. stop (s)	Fading margin (dB)	Packet discard. start (s)	Packet discard. stop (s)
Blok 45	Bežanijska Kosa	2.12	12.45	-	-	30.73	-	-
Bežanijska Kosa	Kalvarija	2.55	14.7	470	640	36.26	470	650
Kalvarija	Ugrinovačka	1.44	8.75	360	550	21.6	360	560
Ugrinovačka	Galenika	1.78	10.57	190	410	26.33	190	420
Bežanijska Kosa	Ugrinovačka	2.1	18.98	370	600	46.82*	360	510
Kalvarija	Zemun Kej	1.62	9.79	520	630	24.15	510	630
Zemun Kej	Galenika	4.34	23.05	290	540	56.87*	280	550
Blok 45	Galenika	6.35	30.98	-	-	76.87*	-	-
Zemun Kej	Blok 45	5.6	28.18	570	760	69.52*	550	770

* link is practically unrealisable at 38GHz because it demands too large fading margin

that workstation requests unlimited number of pings every 30s, starting from 100s.

Modeling of IP ping traffic is done with object *IP Ping Parameter* which sets traffic duration to 1s and traffic is made of one packet 64 bytes length.

As a quality criterion of protection given by mesh topology number of succesful interworkstation pings in case of ideal routing protocol are discussed. Under term ideal routing protocol, we assume that link beetween nodes A and B is available if given nodes are connected in a network graph of available links.

III Results

Results are presented in Fig. 2. At the moment T=180s first link collapse occur. Since this link exist in routing tables of all three routing protocols its absence result in a traffic drop.

Routing protocols with triggered updates successfully recover from this event in a following way: EIGRP recovers after 20s, and OSPF takes about 40s to recover. RIP is not able to regain its convergence in a short time since next routing table update comes in another 30s. Next link drops 100s later (about T=300s). Reactions after this event are following: OSPF recalculates topology again, but EIGRP does not since this link is no longer in its routing table. Packet loss in case with RIP increase, since algorithm is too slow to track the changes.

Next link failure happens at T=370s, and is fatal because it completely isolates node "Ugrinovacka", actually dissconnects network graph which is noticable even in the

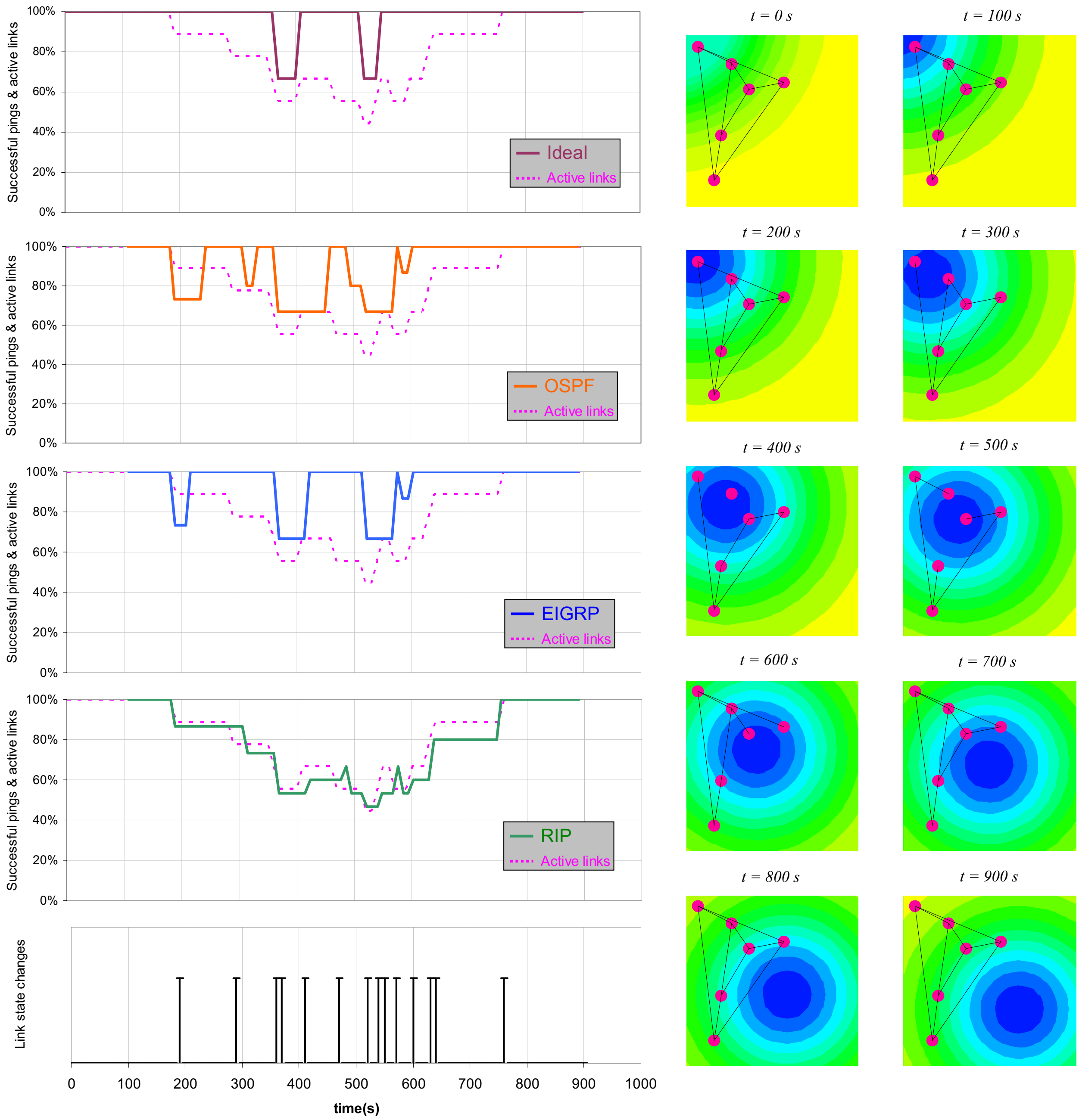

Fig. 2. Network behaviour under NE rain cell influence

ideal routing protocol case. This node reconnects after 30s, but routing protocols wait some time before putting them into traffic transmission again. Similar behavior is met at time round T=550s.

The last link restores at the moment T=770s, and RIP routed network finally functions properly.

Finally, simulation results showed that interval between the first link failure and the last link recovery lasted for 590s. During this time, 14 link state changes occured.

IV Conclusion

Simulation results have shown that partial mesh topology could be used as a protection mechanism in a millimetre wave radio-relay network. The protection is better if hop lengths are higher than median rain cell diameter (about 2km in the most interesting cases) and the individual link fading margins are properly design. Shorter hops could be used with higher fading margin than necessary, so they act as network links that are not susceptible to rain influence.

The huge number of link state changes caused by rain presents very serious problem, which is why standard routing protocols behave far away from ideal. RIP could not be used at all, OSPF could be used but suffers from significant availability loss, and EIGRP could be the best available solution. However, we think that much could be done in improvement of routing protocols for such application since link failure could be predicted.

Described simulation of moving rain cell influence could be done in real networks to find its weakness since two dimensional statistical data could be very rarely find for specific geographical area. The dimensioning of rain cell parameters could be estimated by local single point data, or by ITU-R rec. P.837.

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