Application of above 1Gbit/s millimeter wave radio links for realization of IP networks in urban areas

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Abstract. **In this paper network planning example is given for IP network realized with high capacity radio links at millimeter wave frequency band 80 GHz. Using real equipment characteristics taken from links currently available in the market, and network planning procedure, interference and unavailability parameters are calculated and discussed.**

Keywords: **Millimeter wave link, Network planning, Interference, Unavailability**

I. INTRODUCTION

Fixed radio links operating in the 71-76 GHz and 81-86 GHz bands are good solution for the future market demands for increasingly high bandwidth access, in particular for Internet-based applications. They could be deployed much quicker and in certain cases are more cost efficient than the wired networks, and as such these bands provide sufficient bandwidth for terrestrial fixed links to compete or complement the fiber optic based access networks [1].

In the proposed scenario of using the 71-76 GHz and/or 81-86 GHz band for Fixed Services, availability objectives in the order of 99.99% with the average European rain rates may be satisfied by very high capacity (up to 10 Gbit/s) links with some 1-2 km hop lengths (line-of-sight conditions); There is also slight attenuation variation between the two bands (71-76 GHz and 81-86GHz), which make possible their paired use. These systems would allow a rapid and effective deployment of broadband capacity in areas where fiber optic cables are not available or are not cost effective. The main features of operating fixed radio systems in this part of the spectrum may be summed up as follows:

- Availability of wide bandwidths, allowing for the low cost of traffic
- Possibility of multiple channel frequency re-use, thanks to highly directional antenna beams
- Feasibility of deploying radio links is much easier in comparison to alternative wire-bound solutions
- Ability to ensure high security because of low possibility of interference/capture of signals

The use of the spectrum between 70 to 100 GHz is the only viable solution for fixed links to achieve the above objectives.

In following, network planning example is given in network that is realized with 80 GHz radio links with capacity 1 Gbit/s. Links connect IP routers settled in nodes of this network. Attention is paid to the main network planning issues: fulfilling availability objectives and interference influence.

II. NETWORK PLANNING EXAMPLE

A. Millimeter wave links

As an example network we decided to use characteristics of gigabit Bridgewave millimeter wave digital radio AR80 Adapt Rate at 80 GHz frequency band (Table 1) [2] which completely European standards for millimeter wave equipment channel allocation [1], characteristics [3] and antennas [4]. These devices have adaptive rate and can operate at 1Gbit/s or at 100Mbit/s during the rainfalls when received signal level becomes too low.

TABLE 1. EQUIPMENT CHARACTERISTICS

Manufacturer	Bridgewave, USA
Device	AR80
Frequency band	71-74 paired with 81-84GHz
Bit rate	1Gbit/s (adaptive to 100Mbit/s)
Modulation type	DBPSK
FEC	Reed Solomon (204,188)
Hop gain (BER=1E-12)	for 0.3m antenna 166dB (177dB) for 0.6m antenna 180dB (191dB)
Output power	17dBm
Receiver threshold (BER=1E-12)	-63dBm (-74dBm)
Central frequency	72.5 / 82.6GHz
RF bandwidth	1400MHz (140MHz)
Antenna gain	43dBi (0.3m), 50dBi (0.6m)
Adaptive threshold	hysteresis -59/-57dBm

As we can see in Table 1, devices could operate at single Rx/Tx frequency pair and in normal operation they occupy 1400MHz of RF spectra. As a consequence of usage of very powerful FEC we have very small difference between receiver thresholds with different throughputs. Therefore, entire device operation have three states: 1Gbit/s, 100Mbit/s and unavailable without BER degradation.

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According to [4] antennas have considerable gain, and very good side lobes suppression (Fig 1.) which are more than 35dB when angle of arrival is higher than 5°.

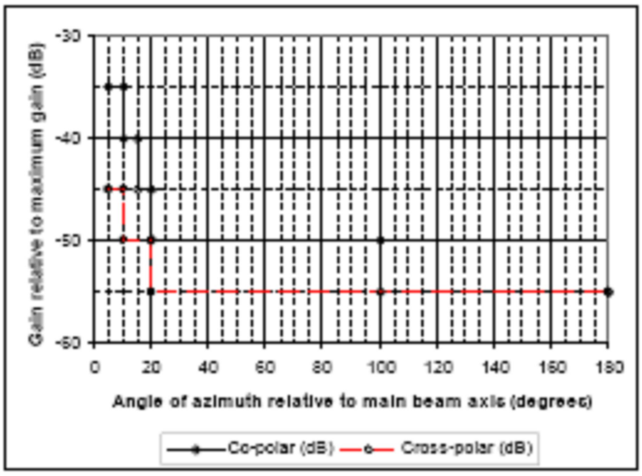

Fig 1. Antenna radiation pattern according to EN302217

B. Network area, topology and interference

Classical approach taken from lower bands [5] suggest that on the same network node all transmitters should operate at the same sub-band to prevent interference in near zone and third order intermodulation. Since there is only single frequency pair available, the crucial in network planning is that on the same node all transmitters should operate at the same frequency. When taking into account line of sight condition, this gives us serious restrictions in selecting possible hops.

For illustration planning of small network is presented. Network consists of 11 nodes and 14 links. Nodes are chosen to be located on the highest buildings in Novi Beograd and Zemun, and therefore network is from "real world" (Fig. 2.). On this area of the city live about 400000 people. Each node should be connected to the at least other two nodes, so there should be at least one the backup route.

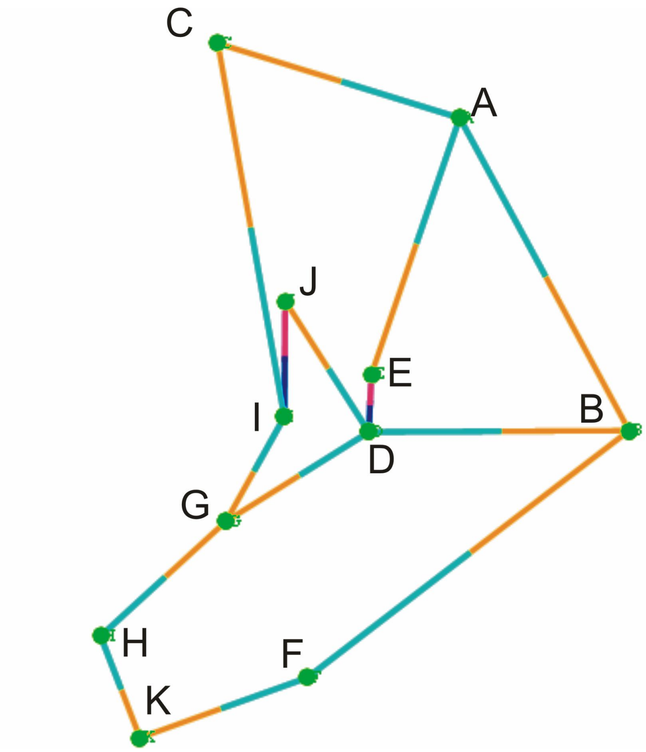

Fig.3. Network topology

One possible solution is given in Fig. 3. where nodes A,

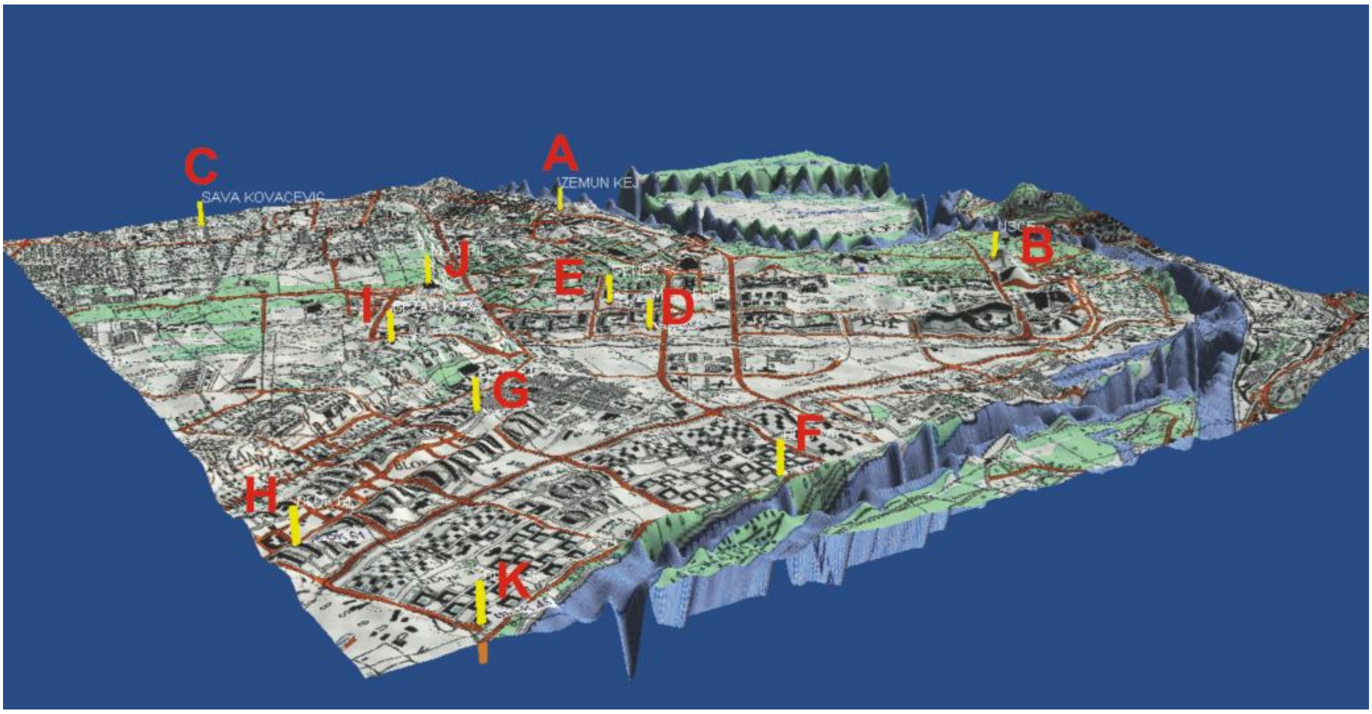

Fig. 2. Node locations on Novi Beograd and Zemun

D, F, H and I have transmitters at 72.5GHz while the rest have transmitters at 82.5GHz. The short hop E-D, on which both nodes are located on very high buildings, has very important role in solving these problem. However short hop is potentially very strong interference source and it should operate at different polarization from the rest of the network.

Classical interference calculation that takes into account only antenna radiation patterns in azimuth plane and 3D terrain model without buildings [6] in this 80GHz urban case gives very pessimistic calculation. However it could be used for the first approximation, since if networks operate in this model they will certainly operate in practice. Such calculation shows that I-J hop is also very strong interferer, and should operate at different polarization.

TABLE 2. INTERFERENCE CALCULATION

General					Interference			Strongest interferer		
Rx	Tx	d (km)	n_{r0} (dBm)	a_{FM} (dB)	I (dBm)	a_{FMI} (dB)	Δa (dB)	Tx	Rx	I_i(dBm)
F	B	3.8	-38.8	24.2	-80.9	20	4.2	K	F	-82.9
B	F				-82.3	20.8	3.4	D	B	-85.5
I	C	3.3	-37.6	25.4	-75.3	17	8.4	J	I	-77.2
C	I				-83.6	22.7	2.7	A	C	-85.1
A	B	3.1	-37	26	-80.2	21.4	4.6	E	A	-84.8
B	A				-81.4	22.1	3.9	D	B	-85.5
D	B	2.6	-35.5	27.5	-74	18	9.5	E	D	-76.2
B	D				-81.6	23.7	3.8	A	B	-87
C	A	2.5	-35.1	27.9	-81.9	24.3	3.6	A	E	-85.1
A	C				-80.9	23.7	4.2	E	A	-84.8
E	A	2.4	-34.8	28.2	-75.1	19.6	8.6	D	E	-76.2
A	E				-79	22.7	5.5	G	I	-82.4
F	K	1.7	-31.8	31.2	-81	27.1	4.1	K	H	-81.8
K	F				-76.2	23.6	7.6	H	K	-77.2
H	G	1.6	-31.3	31.7	-77.3	25	6.7	G	D	-81.9
G	H				-76.8	24.6	7.1	I	G	-79.2
G	D	1.6	-31.3	31.7	-74.6	22.7	9	I	G	-78
D	G				-73	21.3	10.4	E	D	-76.2
J	D	1.4	-30.1	32.9	-76.9	25.8	7.1	D	G	-80.1
D	J				-74.8	24.1	8.8	E	D	-76.2
I	G	1.1	-28	35	-74.6	26	9	G	D	-78
G	I				-75.5	26.8	8.2	I	C	-80.8
H	K	1	-27.2	35.8	-76.7	28.6	7.2	K	F	-77.2
K	H				-78.9	30.3	5.5	F	K	-81.8
I	J	1	-27.2	35.8	-81.6	32	3.8	G	I	-83
J	I				-84.6	33.5	2.3	D	J	-85.1
E	D	0.5	-21.2	41.8	-88	40.6	1.2	A	E	-89.8
D	E				-81.5	38	3.8	J	D	-85.1

In Table 2., results of simplified interference calculation are given. We can notice that the strongest interference comes from hops that share the same node.

As expected, hops J-I and C-I are critical due to small angle between routes, and receiver threshold degradation is very high, without influence of different polarizations. This would have very strong influence on C-I hop performance due to its significant length. Similar situation happens on node D and node G.

Interference at hops that share the same node could be reduced by careful installation of antenna system, with usage of additional protection at antenna tower of building like wall or metal shield. As we notice from table 2. around 10dB of additional attenuation is sufficient.

Next hop overreach case like H-G-D-B in this topology is present, but less significant. When effects of urban area are taken into account (Fig 2), next hop overreach hardly could happen. Considering total amount of interference and the strongest interferer, we see that it frequently differs for more than 2dB, that means that more than one significant interference source effect is very present in this network. In this case area coverage by buildings and trees could be of great help since they provide additional attenuation in this cases.

We must notice that only azimuth antenna radiation pattern is used, and not 3D model. Such additional attenuation due to different antenna elevations unfortunately could not be much significant. Only for very short hops this could give significant attenuation of more than 10dB (e.g. on 0.5km hop antenna height difference of about 30m gives about 3.5° which is for sure more than 10dB of additional attenuation).

Therefore real link performance should be calculated for both cases with and without interference, and in many cases link behavior would be much closer to without interference case. Therefore light licensing method is welcome. Some countries have already adopted it.

C. Network performance

We can notice that receiver level in absence of fading n_{r0} is much higher than usually at lower bands, and fading margins without interference is considerably high from 24 to more than 40dB.

Classical method for hop availabilities calculation is described in [8]. We assumed rain rate 42mm/h to be exceeded in 0.01% of time, which is according to [7] the worst case for Serbian territory. At that rain rate specific attenuations are 16.4 dB/km and 15.1 dB/km for horizontal and vertical polarization at 72.5GHz and 17.1dB/km and 15.9dB/km at 82.5GHz. For both frequencies atmosphere attenuation is slightly less than 0.5dB/km. Under these assumptions we calculated hop availabilities in both directions for individual links.

TABLE 2.PERCENTAGE OF UNAVAILABLE TIME PER HOPS AND DIRECTIONS

Node		Without interference		With interference	
1	2	2→1	1→2	2→1	1→2
F	B	5.96E-02	5.30E-02	9.12E-02	7.46E-02
I	C	4.06E-02	3.59E-02	1.00E-01	4.67E-02
A	B	3.38E-02	2.99E-02	5.33E-02	4.39E-02
D	B	2.03E-02	1.79E-02	5.59E-02	2.58E-02
C	A	1.58E-02	1.80E-02	2.23E-02	2.70E-02
E	A	1.40E-02	1.60E-02	3.45E-02	2.74E-02
F	K	5.26E-03	4.53E-03	7.80E-03	9.86E-03
H	G	4.27E-03	3.67E-03	8.35E-03	7.57E-03
G	D	3.67E-03	4.27E-03	9.43E-03	1.28E-02
J	D	2.25E-03	2.64E-03	4.67E-03	6.57E-03
I	G	1.03E-03	8.61E-04	2.72E-03	2.10E-03
H	K	6.91E-04	5.71E-04	1.50E-03	1.04E-03
I	J	8.97E-04	7.73E-04	1.32E-03	9.78E-04
E	D	1.34E-05	1.83E-05	1.67E-05	3.45E-05

Without interference condition of less than 0.05% unavailability time (ITU-T G.826, access level) is satisfied for almost all hops shorter than about 3km. In these cases operation at lower bit rate (100Mbit/s), in order to reduce receiver threshold, would happen very rarely (less than one hour annually).

For longer hops and in presence of interference such cases would happen much frequent, and therefore usage of adaptive modulation and bit rate is highly recommended.

We also should note that since the network is used for IP traffic there is possibility of usage of path diversity [5] and routers could act as protection devices. However all commonly used routing protocols like RIP, OSPF and EIGRP does not have fast enough reaction time [9], and there is space for more improvements [10].

III. Conclusion

Described planning and analysis of hypothetical network at urban area shows that there is great potential of usage 80GHz band for very cost effective method for realization of Gbit/s IP network. The most important thinks that network planner should take care is interference at hops that share the same node. Despite of very high antenna side lobes attenuation, high interferer level is still very present, and additional counter-measurements like usage of buildings concrete blocks as obstacle between interfering link antennas.

Performances of hops shorter than about 3km satisfies ITU-T access level requirements without additional protection method like adaptive bit rate and/or modulation. For longer hops such methods are highly recommended.

Addition performances could be gain at network level by path diversity, for which IP routers, running link state routing protocols, could acts as protection devices.

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