Periodica Polytechnica
Electrical Engineering
and Computer Science

60(1), pp. 44-50, 2016
DOI: 10.3311/PPee.8644

RESEARCH ARTICLE

Rain Effects on 5G millimeter Wave ad-hoc Mesh Networks Investigated with Different Rain Models

Ákos Faragó[1], Péter Kántor[1], János Z. Bitó[1*]

Received 06 October 2015; accepted 18 December 2015

Abstract
Substantial growth of mobile data and rapidly increasing spread of smartphones nowadays present major challenge for mobile service providers. The allotted spectrum for the currently operating mobile communicating systems have been saturated in the last years by such considerable rate that the future's fifth generation network would not be able to fulfil its requirements without applying new frequencies. In accordance with the concept of 5G, millimeter wave spectrum will also be used along with the current frequency bands.

This spectrum however, introduces meteorological effects as a new and significant attenuation factor. In this paper millimeter wave propagation affected by precipitation will be investigated and a simulation environment (written in Matlab) used for the 5G mm-wave mesh networks statistical investigation will be presented.

Keywords
millimeter wave propagation, 5G, cellular, mesh network, mobile communication, rain attenuation

[1] Department of Broadband Infocommunications and Electromagnetic Theory,
Faculty of Electrical Engineering and Informatics,
Budapest University of Technology and Economics,
H-1111 Budapest, Egry József utca 18, Hungary
[*] Corresponding author, e-mail: bito@mht.bme.hu

1 Introduction

Current mobile communication services (3G and 4G as well) use carrier frequency spectrum ranging between 700 MHz and 2.6 GHz for mobile data traffic. The several different communication systems however, cover this spectrum with disjoint frequency bands leaving narrow pieces of unused frequencies scattered in this 2 GHz range. In case we needed to operate new mobile service in this well-known albeit fragmented spectrum, either utilizing these scattered bands or waiting a decade of administration through regulatory bodies such as the International Telecommunication Union (ITU) and the U.S. Federal Communications Commission (FCC) to finally procure spectrum are the possibilities [1]. Although there is an issue with operating in this spectrum: as the number of subscribers grows, demand on capacity and global bandwidth also grows – this unambiguously visions the requisite of wide and joint frequency bands for the 5G mobile networks.

One logical step is the augmenting the currently saturated radio spectrum with untapped mm-wave bands allowing much wider spectrum allocation. This spectrum however, holds a new attenuation factor, the precipitation to be investigated as well as different propagation characteristics. Figure 1 shows the rain attenuation in dB/km across frequency at different rainfall rates.

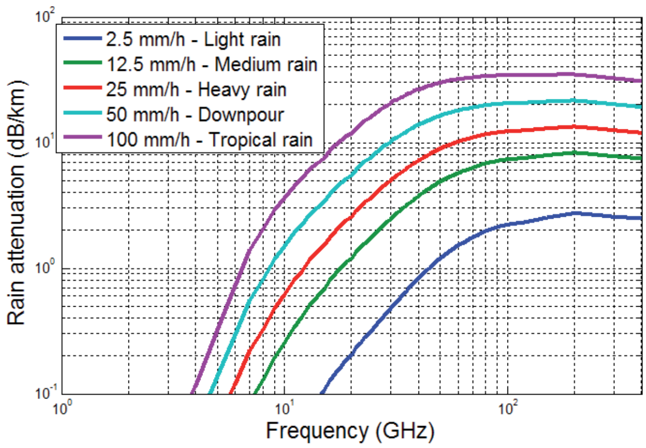

Fig. 1 Rain attenuation in dB/km across frequency at different rainfall rates. Curves are generated based on [2]

According to the ITU curves a heavy rainfall (25 mm/h) would cause around 5 dB/km attenuation at 28 GHz for homogeneous rain intensity distribution.

Multi-path propagation characteristics on mm-wave is another drawback to be addressed, most probably it will be compensated with highly directional beam-forming antennas at both the mobile device and base station [1]. Despite these disadvantages the use of millimeter wave in backhaul networks of 5G seems to be imperious by the day and will essentially extend cellular technology with rapidly deployable (ad-hoc) mesh-like networks [3].

This paper will present extended version of our previous investigations [4] in this field and will be structured as follows; in Section 2 simulation assumptions will be introduced along with the applied rain models, test mesh network, etc., in Section 3 the simulation results in homogenous case while in Section 4 the results in inhomogeneous case will be presented. The paper will be concluded in Section 5.

2 Simulation assumptions

2.1 Rain cell models

The simulations were conducted with two distinct rain models: a homogeneous and an inhomogeneous one. According to the first model, rain intensity is assumed to be constant across the whole investigated area which is called a *homogeneous rain cell*. The *inhomogeneous rain cell* model however, utilizes measured data e.g. rain intensity and wind speed data to create a rain cell model. Basically if at a specific location one measures these two data (point rain rate and wind speed), the rain event can be modeled by transforming the rain cell's velocity (corresponding to the wind speed) and sampling time of the measuring system to distance. In-between measured rain intensity values, samples have been determined by linear extrapolation generating a second based rain event. The model obtained this way shall be called as a *rain front.*

Figure 2 and Figure 3 depict two reproduced rain fronts (coming from minute based measurements) I applied for the simulation: both last for approximately 10 minutes however, the first event has a peak intensity of 58 mm/h while the second one has 82 mm/h.

Regarding further investigations inhomogeneous rain cell model can also be generated using a given distributions in space for rain intensity (e.g. Gaussian) and utilizing empirical models in order to determine the expanse of the rain cell. Such model is specified by Goldhirsh [5], which determines the diameter of rain cell in function of rain intensity and other empirical parameters (α and β).

$$D(R) = \alpha * R^{\beta} \qquad 2 \le R \le 50 mm/h \tag{1}$$

D indicates the diameter in km, *R* is rain intensity in mm/h while α = 12.43 and β = –0.553. Figure 4 depicts how the diameter varies in function of rain intensity.

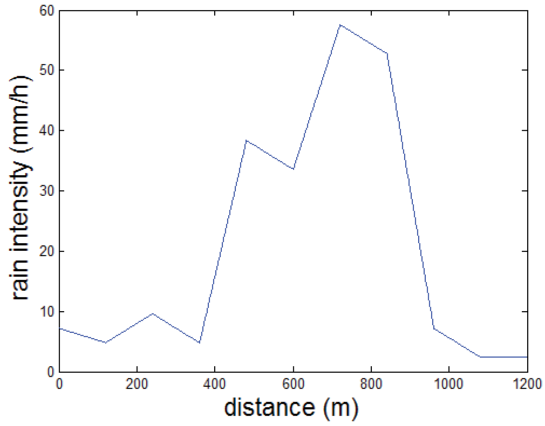

Fig. 2 First reproduced rain front with the peak intensity of 58 mm/h

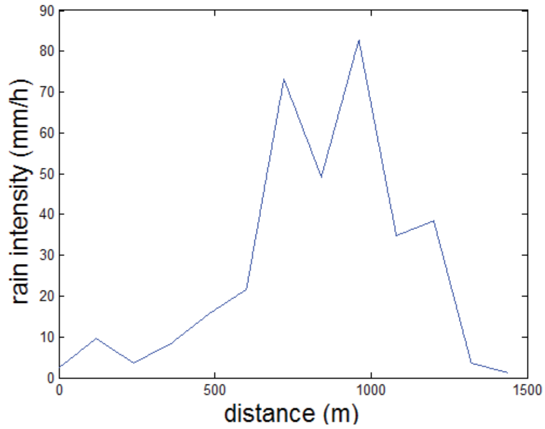

Fig. 3 Second reproduced rain front with the peak intensity of 82 mm/h

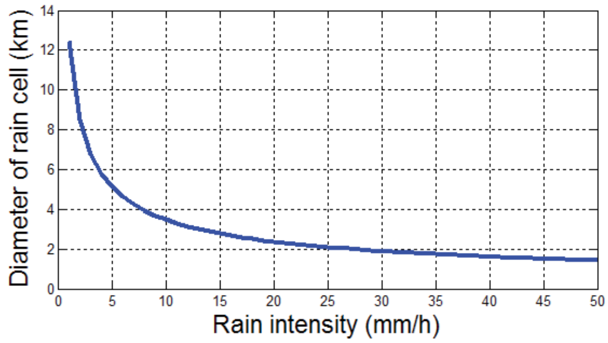

Fig. 4 Diameter of rain cell based on the Goldhirsh model

2.2 Rain attenuation

The formula of rain attenuation is the following:

$$A^{[dB]} = \int_L kR^{\alpha}(l)dl \tag{2}$$

where k and α are frequency and polarization dependent empirical parameters with ITU recommendations [6], L is the length of the communication link in meter and R is rain intensity in mm/h. Obviously in case of the homogeneous rain cell model, the integral becomes a simple multiplication.

2.3 Link outage

Both multi-path propagation and rain attenuation on mm-wave restrict radio links to be limited in length, only few hundred meters long depending on the density of environment (reflective surfaces e.g. buildings). Studies suggest that in a highly residential area a radio link beyond 200 meter is not recommended to use [3], therefore in the presented simulation no link with the length of more than 200 meter is applied. The main scope of the simulation is investigating the base station (node) outages assuming both homogenous and inhomogeneous rain intensity distribution with static path loss exponent (PLE = 2.55) and using only LOS (Line-of-sight) connections [1]. Nevertheless one important task is determining the condition when a link is unable to operate due to rain attenuation. As the formula of free space path attenuation is known along with the maximum allowed length of a link, we are able to determine the maximum value of attenuation that can appear on an arbitrary long radio link without obstructing the communication (n is identical with PLE, d_{max} equals 200 m and λ is the wavelength):

$$\mathrm{PL}[\mathrm{dB}] = 10n\log_{10}\frac{4\pi d_{max}}{\lambda} \quad (3)$$

As path attenuation for an arbitrary link distance d is known and it is trivially lower than in case of the link with 200 m, it becomes easy to determine the fade margin for compensating rain attenuation in case of any shorter link than 200 meter and clearly also lets us decide whether the link remains operable or not (4).

$$10n\log_{10}\frac{4\pi d_{max}}{\lambda} - 10n\log_{10}\frac{4\pi d}{\lambda} < \int_L kR^{\alpha}(l)dl \quad (4)$$

Using this inequality we can depict the maximum rain attenuation across length of link without obstructed communication (Fig. 5) and also the maximum length of link across homogenous rain intensity (Fig. 6). Short (60-100 m) links will always operate as rain attenuation can almost never be that high on such short distance while long (180-190 m) links have barely any fade margin compensating the effects of rain.

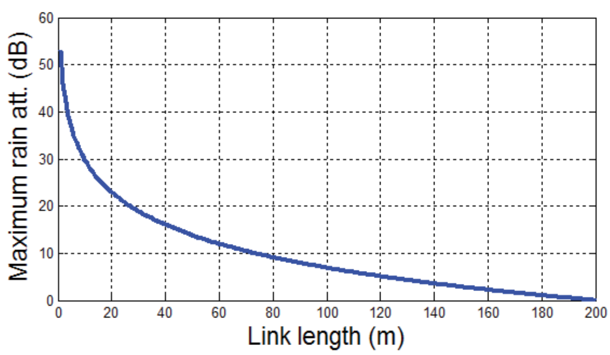

Fig. 5 Maximum tolerable rain attenuation across length of (operable) link

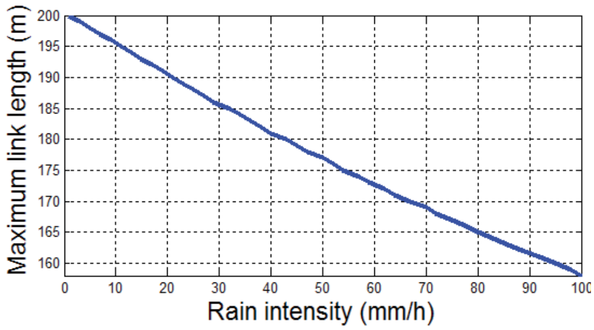

Fig. 6 Maximum length of (operable) link across homogenous rain intensity

2.4 Simulation environment and test mesh network

The investigated area was chosen to be 800x800 m with 10 randomly located nodes and a drain in the center that can be considered as a connecting point of an optical backbone network. In case of no rain a correct set-up enables each node to communicate with the drain either directly or via hopping through other nodes. The simulation hence required to implement an ordinary path-finding algorithm in order to properly investigate node outage. The test mesh network with numbered links is depicted in Fig. 7 along with their distance and azimuth angle collected in Table 1.

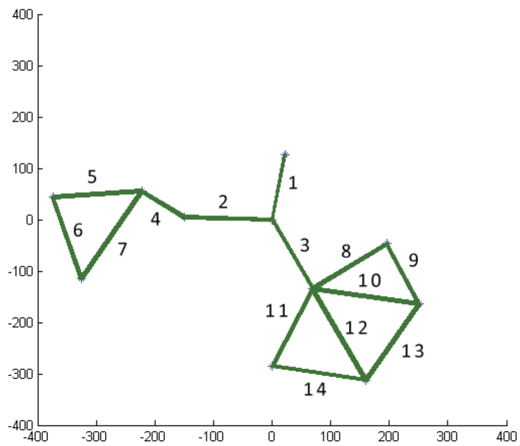

Fig. 7 Test mesh network with numbered links

2.5 Node outage

Nodes are connected to each other via links. Rain attenuation can be high enough to obstruct communication on every link connected to one of the nodes causing that node's connection with the drain broken. In worse cases, critical links responsible for connecting the drain and a smaller part of the mesh network (which consists of 2 or more nodes) can also break resulting significant node outage.

Table 1 Links with distances and azimuth

Link number	Distance (m)	Azimuth (degree)
1	127.9	80.1
2	148.1	178.1
3	150.7	117.3
4	88.5	145.6
5	152.4	4.1
6	166.4	107.1
7	198.7	58.8
8	153.9	34.4
9	128.3	115.3
10	184.3	170.9
11	166	65.5
12	199.9	117
13	174.6	58.6
14	162.2	170.4

3 Investigation in homogeneous case

3.1 Average node outage

The MilliProp measuring system [7] provided monthly rain intensity data allowing more realistic simulation. The CCDF (Complementary Cumulative Distribution Function) of rain intensity shows the probability of the rain intensity exceeding an arbitrary value in Fig. 8.

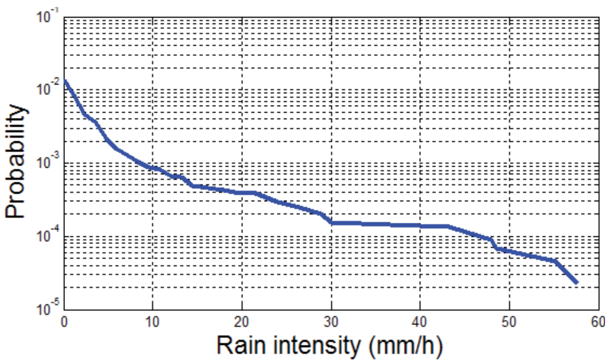

Fig. 8 Rain intensity CCDF calculated from monthly measured intensity data (Miskolc, May 2005)

Since short links are in our scope, investigating rain attenuation on these links by applying the measured rain intensity data on them is also worth considering. Figure 9 shows the rain attenuation CCDF for 50-100-200 m long links calculated from the measured rain intensity distribution [3]. With $2.5 \cdot 10^{-4}$ probability (cca. 132 minutes a year) a 200 m long link will suffer 0.9dB rain attenuation which corresponds to the ITU curves in case of heavy rain (25mm/h). Applying the known rain intensity data the average node outage – of 500 randomly generated mesh networks – can be calculated. Figure 10 shows that, on the average, 2 or more nodes suffer outage with $3 \cdot 10^{-4}$ probability.

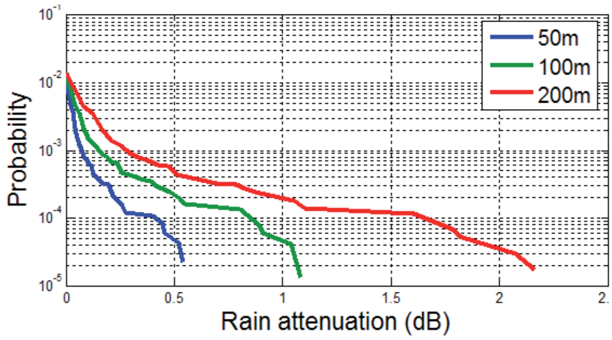

Fig. 9 Rain attenuation CCDFs with homogeneous rain intensity on 28 GHz

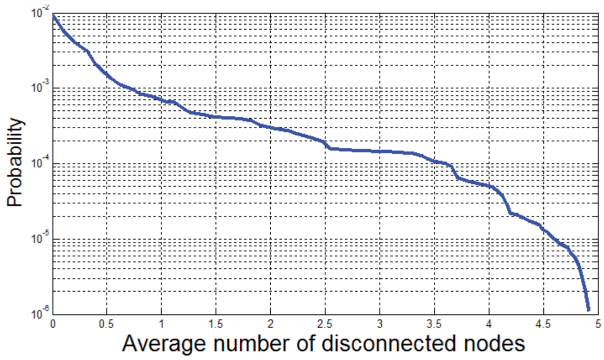

Fig. 10 Node outage probability

3.2 Simulation in homogeneous case

As rain intensity increases across the investigated area from 0 to 100 mm/h the expected behavior happens: at low rain intensity only the longer (190-200 m) links are affected, while heavy rainfall breaks also 165-170 m links making one or more nodes completely disconnected (Fig. 11). At 90 mm/h rain intensity (Fig. 11d) 3 nodes out of 10 are unable to communicate with the drain which is equivalent to 30 % node outage.

4 Investigation in inhomogeneous case

4.1 Investigation basics

The investigation conducted the following way: both of the reproduced rain front (see Section 2.1) passed through the test mesh network in two different directions: from west to east (or from left to right on the MATLAB generated plot and referring it hereafter „horizontally") and from north to south („vertically"). Trivially the same links have been affected differently in the two cases thus link outage, and inherently node outage differed. The question is whether the deployment of a mesh-like network's links can be optimized to decrease foreseeable link outage by adjusting their orientation or not?

The effect of rain front on a link which is nearly in line with one of the applied directions will obviously have a greater dissimilarity in the two cases than investigating links with arbitrary azimuth. In accordance with the aforementioned assumptions link 2 with azimuth of 178.1 degree (see Table 1) would be plausible to investigate although its length is not enough to measure link outage (rain attenuation never exceeded the corresponding fade margin), hence a longer link, number 14 could be a good candidate for further investigation.

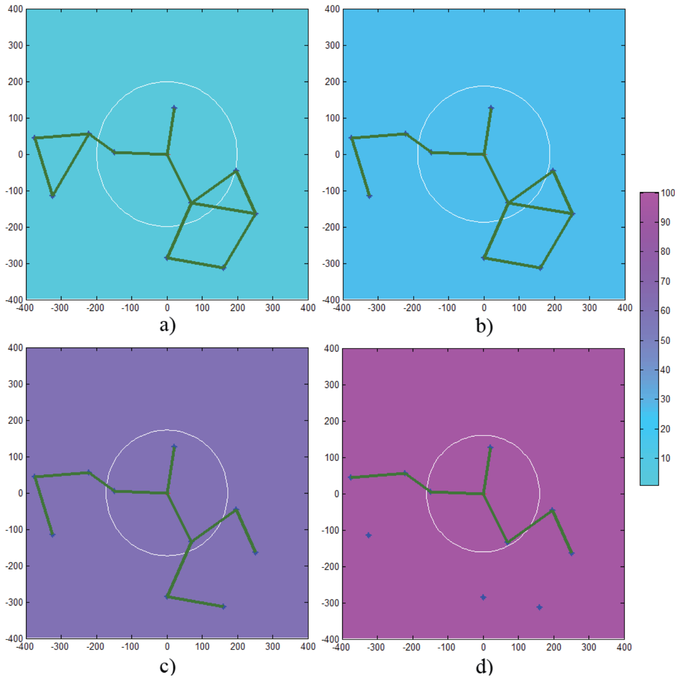

Fig. 11 Test mesh network affected by homogeneous rain intensity: (a) 5 mm/h, (b) 25 mm/h, (c) 55mm/h, (d) 90mm/h. The decreasing radius of the white circle indicates the limit of an operable link

4.2 Link outage differences

At first, the rain event depicted at Fig. 2 passed over the test network. Link availability values are collected in Table 2 in case of both horizontal and vertical directions (100 % means there was no outage).

Link number 7, 10, 12, 13 are experiencing mediocre to heavy link outage, but barely any differences can be observed when the direction of front is changed by 90 degrees. On one hand it is reasoned by the significantly larger expanse of the reproduced rain event than any link in our network and on the other one the peak intensity of 58 mm/h is simply not enough for deeper investigation. Nevertheless these percentage values are worth understanding with numbers: the simulation – from the moment when the rain front starts affecting the network until it fully passes it – lasted for 2420 seconds in which 3 % drop in case of link number 12 means approx. 72 seconds less operating time. Our possible candidate to demonstrate the influence of link orientation, link 14 does not show anything particular.

Link outage values for the second rain event are collected in Table 3 where the affected number of links increases (6, 7, 10-14) due to 82 mm/h peak intensity.

Table 2 Link availability values when the first rain front passed the test network

Link	Horizontal	Vertical
1	100 %	100 %
2	100 %	100 %
3	100 %	100 %
4	100 %	100 %
5	100 %	100 %
6	100 %	100 %
7	50 %	50 %
8	100 %	100 %
9	100 %	100 %
10	79 %	79 %
11	100 %	100 %
12	46 %	43 %
13	90 %	91 %
14	100 %	100 %

Table 3 Link availability values when the second rain front passed the test network

Link	Horizontal	Vertical
1	100 %	100 %
2	100 %	100 %
3	100 %	100 %
4	100 %	100 %
5	100 %	100 %
6	89 %	88 %
7	47 %	47 %
8	100 %	100 %
9	100 %	100 %
10	74 %	76 %
11	90 %	90 %
12	43 %	41 %
13	83 %	83 %
14	94 %	86 %

None of the links except number 14 shows significant difference when moving the rain front in two different directions, its availability lasts 8 % (or equally 3.5 minutes) less when rain moves vertically. As it was detailed before, this link is nearly in line with the horizontal moving direction and nearly orthogonal with the vertical one – the explanation of 8 % more outage directly comes from this link orientation.

When the orientation is in line with the rain front's moving direction various rain intensity values are affecting the link meaning even if there is an exceptionally intense part of the rain present at one side of the link, the other side might suffer much lighter rain attenuation, eventually having sufficient fade margin to compensate attenuation throughout the total length. This complies with the fact that rain intensity fluctuates inside a rain cell.

Figure 12 illustrates a moment with a very intense part of the rain front present on the left side of link 14 but still having sufficient fade margin since the right side is barely affected. Moments later on Fig. 13, rain attenuation cannot be compensated causing the link unable to communicate. When rain comes from the other direction, link is affected by the very same intensity values in its total length and even a mediocre rain can trigger link outage (Fig. 14) resulting 8 % lower availability in total time.

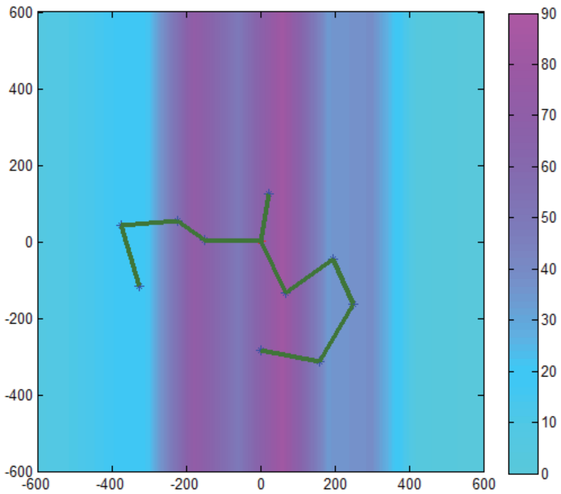

Fig. 12 The fade margin is just enough to compensate the joint rain attenuation, link 14 stays operable

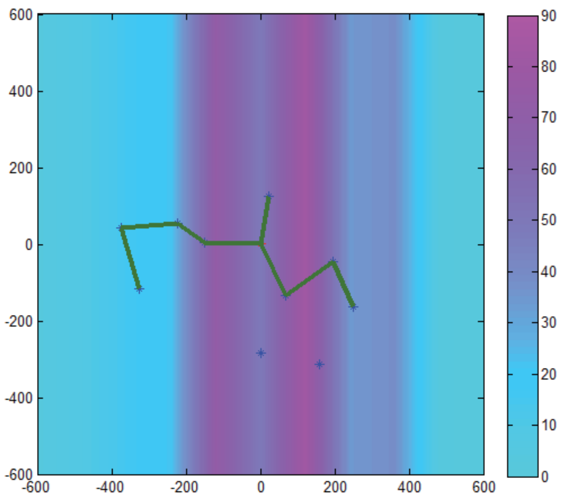

Fig. 13 Attenuation exceeds fade margin making two nodes unable to communicate

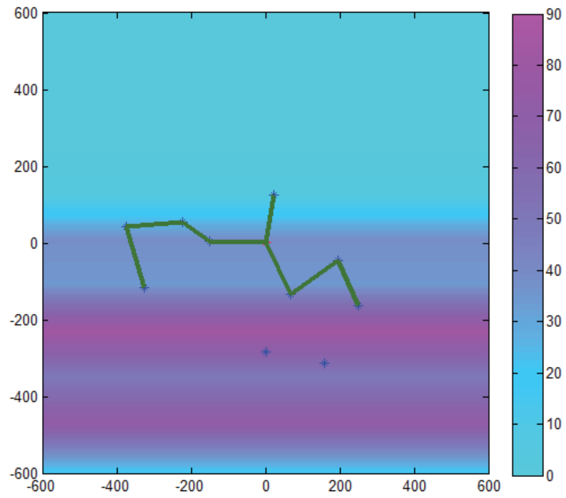

Fig. 14 In case of vertical direction, the same rain intensity values affect the link in its total length, the simulation indicated 8 % lower availability in time

Obviously long-term consequences cannot be drawn based on this one simulation, but should these results be persistent for further investigations, deployment of 5G access points can be optimized taking one of the characteristic of area into consideration: *dominant wind direction*. As a result, longer links' orientation with less fade margin should be as parallel as possible with the dominant wind direction while shorter links able to compensate heavier rain attenuation might be oriented without recommendations.

5 Conclusion

The issue of currently saturated radio spectrum undoubtedly leads us to its augmentation with mm-wave frequencies if the concept of 5G is on the table. Regarding the relatively small amount of research conducted on mm-wave propagation, simulative investigations of reliability of millimeter wave ad-hoc mesh networks in 5G systems was performed. However, the simulation needs to be extended with further improvements to reach a much more precise simulator such as investigation of different rain cell models, propagation models (other PLE values), larger areas with more base stations, other frequencies, Non-Line-of-Sight links etc. However, our presented results already show that by future 5G short range mm-wave mesh backhaul network the orientation of the composing radio links should be carefully deployed; longer links should be parallel with dominant wind direction while shorter ones do not have such recommendations.

References

[1] Rappaport, T. S., Sun, S., Mayzus, R., Zhao, H., Azar, Y., Wang, K., Wing, G. N., Schulz, J. K., Samimi, M., Gutierrez, F. "Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!." *IEEE Access*. 1. pp. 335-349. 2013. DOI: 10.1109/access.2013.2260813

[2] ITU-R P.838-3, "Specific attenuation model for rain for use in prediction methods." p. 1. 2005.

[3] Kantor, P., Drozdy, A., Bito, J. "Effects of rain fading in ad-hoc microwave 5G mesh networks." *10th IC1004 MC and Scientific Meeting*. Aalborg. 26-28 May 2014.
[4] Farago, A., Bito, J., Kantor, P. "Investigation and simulation of meteorological effects on millimeter wave ad-hoc mesh networks in 5G systems." In: *Proceedings of the 13th MICROCOLL Conference*. Budapest. July 2015.
[5] Goldhirsh, J. "Rain cell size statistics as a function of rain rate for attenuation modeling." *IEEE Transactions on Antennas and Propagation*. 31 (5). pp. 799-801. 1983. DOI: 10.1109/tap.1983.1143133
[6] P.530-14, ITU Recommendations, "Propagation data and prediction methods required for the design of terrestrial line- of-sight systems." September 2013.
[7] Babits, L., Bitó, J., Frigyes, I., Kormányos, Zs., Moen, A. E., Sagot, C., Tanem, T., Tjelta, T. "Measurements and Statistical Analysis of Millimetre Wave Propagation in Feeder Links of Cellular Mobile Systems: Preliminary Results of the MilliProp Project, Hungary, Norway, Ireland." In: *Proceedings of the 10th MICROCOLL Conference*. Budapest. pp. 67-70. March 1999.