# Study on Radio Link Availability in Millimeter Wave Range

Boncho G. Bonev, Kliment N. Angelov and Emil S. Altimirski

***Abstract*—**In this paper, the link quality in SHF and EHF ranges are studied. In order to achieve high data rate higher frequencies must be used – centimeter waves (SHF), millimeter waves (EHF) or optical range. However, there are significant problem when a radio link work in that diapason – rain attenuation and attenuation in earth's atmosphere. Based on statistical rain rates data for Bulgaria, the link availability can be determined, depending on the working frequency, the path length and the Power Budget of the link. For the calculations of rain attenuation and atmosphere's attenuation the ITU recommendations are used.

***Keywords*—**rain attenuation, atmospheric gaseous attenuation, link availability, link breaking probability

## I. Introduction

THE constant demand of higher data rates in communications requires the use of higher frequencies. That can be achieved by using frequencies higher than 30 GHz [1], [2], [3]. In this frequency range some main problems occur - absorption by the hydrometeors and air molecules. In the Terahertz, infrared and ultraviolet waves range the absorption is so severe, that a communication link using these frequencies is practically impossible. In the visible diapason and specifically –for the infrared waves, when the sky is clear, a link can be made (Free Space Optics - FSO), but when fog or clouds are presented, the link is again impossible [4]. Only with combined usage of the 30-100 GHz range and the transparency windows of infrared range we can achieve high data rate, along with acceptable attenuation – hybrid FSO/RF links.

There is a significant absorption by the atmosphere oxygen at about 60 GHz. Losses in fog and clouds are not high, but the rain causes strong attenuation, which increases with frequency, and when it rains hard, the radio link is seriously jeopardized.

The aim of the present research is to determine a radio link breaking probability, when the Power Budget, respectively the *bit error rate,* is given, using different frequencies of this range and different path lengths, and in the specific Bulgarian climate conditions. In order to make the calculations, the meteorological data, adapted to the needs of the investigation are used and through it the availability of the link can be derived, depending on various link parameters.

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## II. Theoretical Analysis

The received power of a radio link working at frequency $f$ on distance of $d$ can be given by [5]

$$P_r = P_t + G_t - L_{FS} - L_{rain} - L_{atm} + G_r \,, \quad (1)$$

where $P_t$ is the transmitted power in dBm, $G_t$ and $G_r$ are respectively transmitter's and receiver's antenna gain in dBi with transmission line and connectors losses included. Free space losses $L_{FS}$ can be calculated by [6]

$$L_{FS} = 20\lg\frac{4\pi df}{c} \,, \quad (2)$$

where $c$=3.10$^8$ m/s is the light velocity.

The rain attenuation $L_{rain}$ is caused mainly by rain absorption and is expressed as [5]

$$L_{rain} = L_{sp\_rain}.r.d/1000 \,, \quad (3)$$

where $L_{sp\_rain}$ is the specific rain attenuation in dB/km and can be calculated using the ITU model [7] as follows

$$L_{sp\_rain} = k(f).RR^{\alpha(f)} \,, \quad (4)$$

where $RR$ is rain rate in mm/h, $k(f)$ and $\alpha(f)$ are frequency and polarization dependent constants [7].

In (3), distance $d$ is in meters and $r$ is a correction, which renders an account of the fact that the rain falls only on part of the link distance and can be calculated by the expression [5]

$$r = \left(1 + d/35\exp(-0.015RR)\right)^{-1} . \quad (5)$$

The losses by atmospheric gaseous absorption are given by equation

$$L_{atm} = L_{sp\_atm}.d/1000 \,, \quad (6)$$

where the specific attenuation, $L_{sp\_atm}$ in dB/km, can be calculated using the ITU recommendation [8].

The maximum rain losses can be expressed from (1) by using the receiver sensibility $P_{r\_min}$ for a given Bit-Error Rate (*BER*) as follows

$$L_{rain\_max} = P_t + G_t + G_r - P_{r\_min} - L_{FS} - L_{atm} . \quad (7)$$

After substitution of (3 - 5) in (7), the following expression is obtained

$$\frac{RR_{max}^{\alpha(f)}}{(1 + d/35\exp(-0.015RR_{max})} = \frac{1000}{k(f)d}\left(P_t + G_t + G_r - P_{r\_min} - L_{FS} - L_{atm}\right), \quad (8)$$

where $L_{FS}$ and $L_{atm}$ can be calculated from (2) and (6).

From (8) the maximum value of rain rate $RR_{max}$, which guarantees link availability can be determined. This action is impossible with mathematical transformations because the left side of (8) is very complicated expression of $RR_{max}$ and therefore for its determination computing methods must be used.

Furthermore, if the rain rate statistic $p(RR)$ (the probability $p$ that rain rate is greater than $RR$) is known, the probability of link breaking can be obtained.

## III. Results and Discussion

Equation (8) is used for study on link availability depending on frequency, distance and power characteristics of the radio link. In this investigation, the common values of radio link characteristics and the rain rate statistic in Bulgaria, which is given in Fig. 1, have been used.

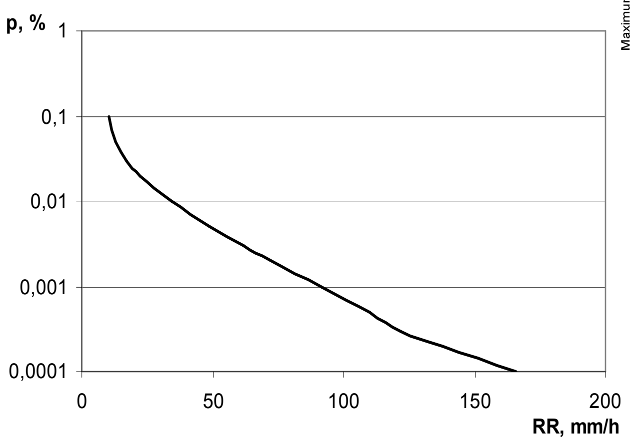


Fig. 1 Rain rate statistic for Bulgaria

The function from Fig. 1 has been interpolated with the following expression

$$p,\% = 10^{A.RR^6 + B.RR^5 + C.RR^4 + D.RR^3 + E.RR^2 + F.RR + H}, \quad (9)$$

where the values of the constants *A, B, C, D, E, F* and *H* are given in Table 1. The error of this approximation is calculated to be 0.15%.

TABLE I
VALUES OF APPROXIMATION CONSTANTS

| A | B | C | D | E | F | H |
|---|---|---|---|---|---|---|
| *4.87E-12* | *-2.79E-9* | *6.36E-7* | *-7.3E-5* | *4.426E-3* | *-0.1507* | *0.1082* |

In Fig. 2 - Fig. 7 are presented the values of maximum rain rate and the values of link breaking probability depending on frequency *f*, link distance *d* and power characteristics ($P_t$, $G_t$, $G_r$ and $P_{r\_min}$) of the radio link. In this figures $L_{max}$ is given by relation

$$L_{max} = P_t + G_t + G_r - P_{r\_min} . \quad (10)$$

It is well known that high data rates can be obtained mainly by using higher frequencies. That in other hand allows to be achieved the higher antenna gain with the same antenna diameter as in low frequencies. Therefore, we will analyze mainly the frequencies above 50 GHz, where with relatively smaller antennas high data rate can be provided.

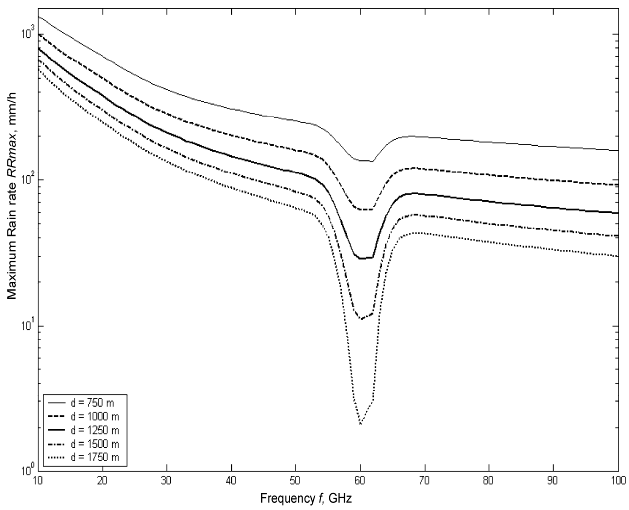


Fig. 2 Maximum rain rate depending on frequency for different link distances and $L_{max}$=162 dB ($P_t$=10 dBm; $P_{r\_min}$=-60 dBm, $G_t$=$G_r$=46 dBi)

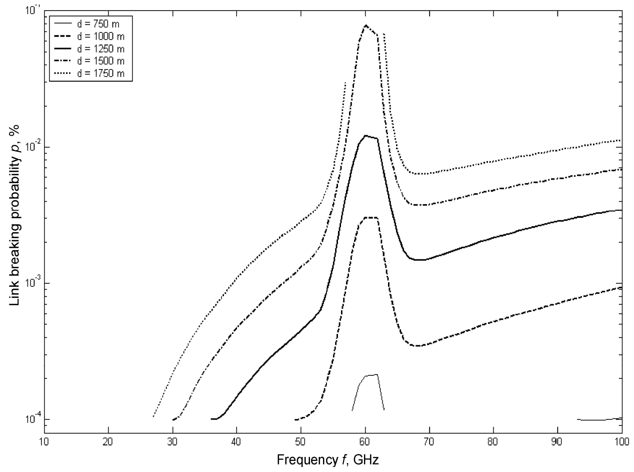


Fig. 3 Link breaking probability in %, depending on frequency for different link distances and $L_{max}$=162 dB ($P_t$=10 dBm; $P_{r\_min}$=-60 dBm, $G_t$=$G_r$=46 dBi).

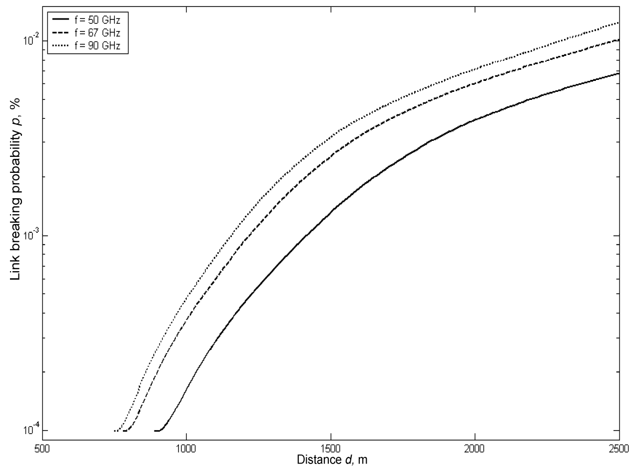


Fig. 5 Link breaking probability in %, depending on distance for different frequencies and $L_{max}$=162 dB ($P_t$=10 dBm; $P_{r\_min}$=-60 dBm, $G_t$=$G_r$=46 dBi).

Fig. 2 and Fig. 3 show that the minimum breaking probability for link distances from 750 m to 1750 m is achieved at frequencies from 50 to 55 GHz and from 65 to 70 GHz. But even at frequencies higher than 70 GHz, $RR_{\max}$ and the link breaking probability remain of the same order.

Fig. 4 and Fig. 5 show that if a link availability greater than 99.999% (link breaking time less than 5.25 minutes per year) is required, the link distance is limited to 1200 – 1400 m for the studied frequencies. For link availability of 99.99% (link breaking time 52.5 minutes of 1 year) these distances are 2.5 – 3 km for the frequencies examined in Fig. 5.

On Fig. 6 and Fig.7 the maximum rain rate and breaking probability, depending on the distance $d$, with fixed frequencies (67 GHz and 95 GHz), respectively $L_{\max}$ are shown. When the frequency is higher with a $\sqrt{2}$, the total gain of the transmitter's and receiver's antennas is increased twice (or by 3 dB), when the size of the antenna stays the same. From these figures, it is clear that when we use the same sized antennas, working on these frequencies, the breaking probability for the higher frequency is slightly better. Furthermore, in this case, the data rate would be significantly higher.

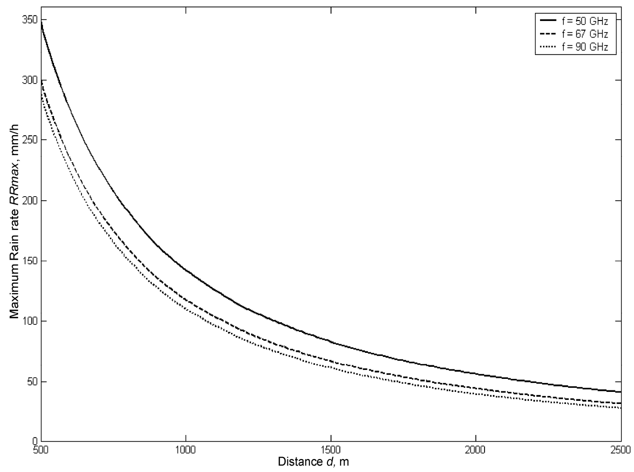


Fig. 4 Maximum rain rate depending on distance for different frequencies and $L_{max}$=162 dB ($P_t$=10 dBm; $P_{r\_min}$=-60 dBm, $G_t$=$G_r$=46 dBi)

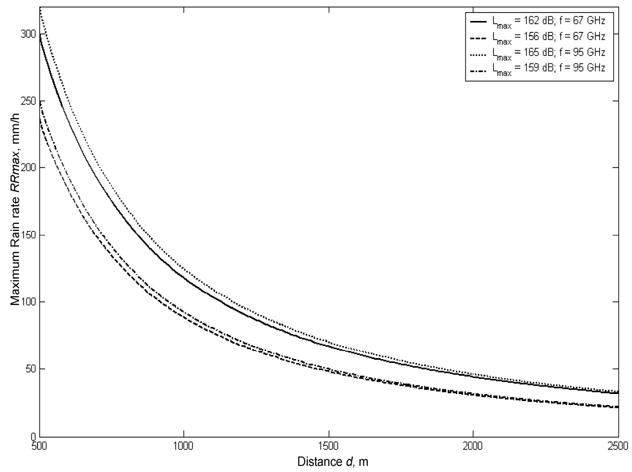


Fig. 6 Maximum rain rate depending on distance for different values of $L_{max}$ at frequencies of 67 GHz and 95 GHz

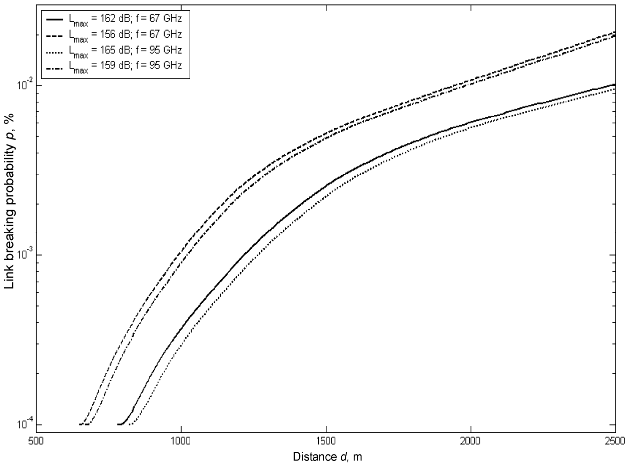


Fig. 7 Link breaking probability in % depending on distance for different values of $L_{max}$ at frequencies of 67 GHz and 95 GHz.

## IV. Conclusion

The frequencies in the 65 GHz – 100 GHz diapason can be used for secured radio link with narrow antenna beams (less than 1°) and high data rates on distances of about 1 km with link availability greater than 99.999%, which is sufficient enough for that type of radio links. The attenuation at higher frequencies is greater, but in this case a narrower beam, and respectively the higher antenna gain can be produced with the same sized antenna as for the lower frequencies. Furthermore, in this case, the link distance is slightly better than in lower frequencies if the same sized antennas are used. If the greater than 1 – 1.5 km distances or greater than 99.999% link availability have to be achieved, the hybrid Free-Space Optics/Radio Frequency (FSO/RF) communication links can be used.

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