Investigation on Millimeter Waves Usage in Hybrid FSO/RF Communication Systems

Boncho Bonev[1] and Kliment Angelov[2]

Abstract **In this paper the comparative analysis of radio wave attenuation at frequencies of 60 GHz, 93 GHz and 77 GHz has been taken into consideration. The maximum rain range admitting radio connection has been estimated. The possibility of using the radio waves with 77 GHz frequency in hybrid FSO/RF communication systems has been investigated.**

Keywords – **Hybrid FSO/RF, Rain attenuation, Atmospheric gaseous attenuation.**

I. Introduction

Free-Space Laser Communications (Free-Space Optics – FSO) are subject of increasing interest in last ten years. This is caused to a great extent by their technical and economical advantages over cables and microwave networks – quick and easy installation, portability, relatively low price and high speed information flows. Furthermore through FSO the "last mile" problem is resolved.

Despite these advantages, the utilization of FSO is related to some important problems, which decision is subject to a number of researches [1–5]. First of all these problems are due to influence of atmospheric extinction especially in fog and clouds [6–8] and influence of atmospheric turbulence and mechanic vibration of optical antennas [9–12] on link quality of FSO communication systems. Investigation on effect of turbulent medium on laser beam propagation is subject of many publications, where authors suggested some methods and techniques for reducing of this effect – using of partially coherent laser beam [13, 14] or different methods of coding, modulation and detection [15–19]. Decreasing of antennas vibrations influence can be achieved with tracking systems [20]. That leads to significant improvement of link quality on FSO even in case of long distance communication lines. Therefore the main limiting factor on link range of FSO remains atmospheric transmittance [2, 6].

This problem can be resolved with backing up the FSO with RF communication line, which will take up communication when optical connection is down. That is possible because of insignificant attenuation of radio waves in fog and clouds.

The operating frequency of 2,4 GHz for RF part of hybrid FSO/RF communication system is frequently discussed in free-space laser communications literature [21, 22]. The Earth atmosphere is actually transparent for radio waves with this frequency and RF part of hybrid system can work in all kinds of weather conditions. However in this case the communication speed is significantly lower than on FSO. In [23] is examined hybrid FSO/RF system with radio line working on 60 GHz. This frequency is unlicensed in some countries (USA, Canada), because of maximum of oxygen absorption. Some authors are investigated the possibility of using 93 GHz RF line for hybrid systems [24]. Where using these frequencies of MMW band the speed of information flows can be much greater than in 2,4 GHz radio line, but radio waves suffer on significant rain and atmospheric gases attenuation. That cause decreasing of communication links range.

In this paper the comparative analysis of radio wave attenuation at frequencies of 60 GHz, 93 GHz and 77 GHz has been taken into consideration. The possibility of using the radio waves with 77 GHz frequency in hybrid FSO/RF communication systems has been investigated.

II. Theoretical Analysis

Let RF line operates on frequency f, respectively on wavelength λ and has a link range of d. For received power P_r in dBm can be written

$$P_r = P_t + G_t - L + G_r, \tag{1}$$

where P_t is transmitters power in dBm, G_t is transmitters antenna gain in dB with transmission line losses at transmitting terminal included, G_r is receivers antenna gain in dB with transmission line losses at receiving terminal included and L are total propagation losses in dB.

$$L = L_{FS} + L_{rain} + L_{atm}, \tag{2}$$

where

$$L_{FS} = 20\lg\frac{4\pi d}{\lambda} = 20\lg\frac{4\pi df}{c} \tag{3}$$

is free space loss, L_{rain} are rain attenuation losses and L_{atm} is atmospheric gaseous absorption loss. In Eq. (3) $c = 3.10^8\ m/s$ is light velocity.

Rain attenuation losses are given by relation

$$L_{rain} = L_{sp\_r}.d/1000, \tag{4}$$

where L_{sp_r} is specific rain attenuation in dB/km and d is distance in m. L_{sp_r} according [25] can be calculates as follow

$$L_{sp\_r} = a(f).I^{b(f)}, \tag{5}$$

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where I is rain rate in mm/h, $a(f)$ and $b(f)$ are frequency and polarization depending constants.

Atmospheric gaseous absorption losses are due to oxygen and water vapor absorption and are specified as [26]

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

where L_{sp_atm} is specific atmospheric gaseous attenuation in dB/km and d is distance in m.

For the total propagation losses after substitution of Eq. (3-6) in Eq. (2) are obtained the expression

$$L = 20\lg\frac{4\pi df}{c} + a(f).I^{b(f)}.\frac{d}{1000} + L_{sp\_atm}.\frac{d}{1000} = = L(f,d,I)\,, \quad (7)$$

or they depend of frequency, distance and rain rate.

The maximum value of rain rate that has been admitted connection can be given by

$$I_{\max} = \left\{\frac{1}{a(f)}\left[\frac{1000}{d}\left(L_{\max} - 20\lg\frac{4\pi df}{c}\right) - L_{sp\_atm}\right]\right\}^{1/b(f)} \quad (8)$$

In Eq.(8) maximum admissible total losses L_{max} can be expressed from Eq. (1) as

$$L_{\max} = P_t + G_t + G_r - P_{r\_\min} \quad (9)$$

where $P_{r\_\min}$ is receivers sensibility in dBm.

III. Numerical Results

Equations (7) – (9) are used for an example investigation on total losses and maximum admissible rain rate for frequencies of 60 GHz, 77 GHz and 93 GHz. The following input data (the same for all frequencies) has been assumed: P_t=10 dBm; G_t=G_r=43 dB; $P_{r\_\min}$= – 60 dBm; d=var.

In that case the maximum admissible total losses from Eq. (9) are calculated as L_{max}=156 dB.

The constants $a(f)$ and $b(f)$ for examined frequencies has been taken from [25] and are given in Table 1 and Table 2. The specific atmospheric attenuation [26] for examined frequencies is given in Table 3.

Table 1
Specific rain attenuation constants for horizontal polarization

Frequency, GHz	*a(f)*	*b(f)*
60	0,8606	0,7656
77	1,132	0,7177
93	1,3089	0,6901

Table 2
Specific rain attenuation constants for vertical polarization

Frequency, GHz	*a(f)*	*b(f)*
60	0,8515	0,7486
77	1,1276	0,7073
93	1,3083	0,684

Table 3
Specific atmospheric gaseous attenuation

Frequency, GHz	L_{sp_atm}, dB/km
60	16
77	0,26
93	0,37

The results for maximum admissible rain fate for horizontal and vertical polarization are illustrated on Fig. 1 and Fig. 2 respectively. The total losses for 77 GHz and 90 GHz for horizontal polarization are given on Fig. 3.

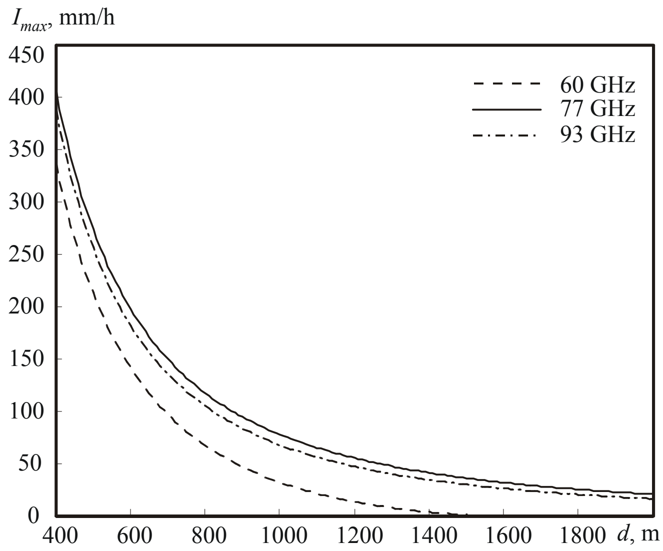

Fig. 1. Maximum admissible rain rate I_{max} as function of distance d for horizontal polarization

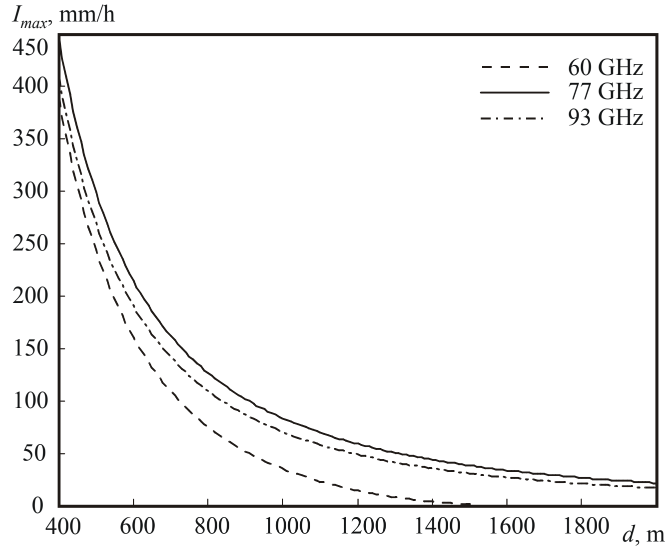

Fig. 2. Maximum admissible rain rate I_{max} as function of distance d for vertical polarization

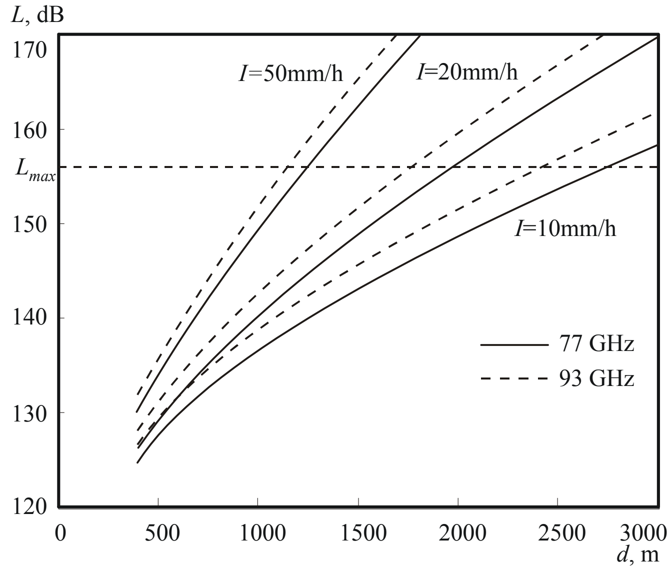

Fig. 3. Total losses L for 77 GHz and 93 GHz as function of distance d for horizontal polarization

IV. CONCLUSION

Fig. 1 and Fig. 2 show that the connection on RF line working on 60 GHz will interrupt at considerably lower values of rain rates than in 77 GHz and 93 GHz lines, because of very high oxygen absorption for that frequency. Nevertheless the radio line on frequency of 60 GHz can be used in short range (up to 800 – 1200 m) hybrid FSO/RF systems.

On the other hand the 77 GHz RF line will be available for rain rate 10-20 mm/h greater than 93 GHz one (Fig. 1 and Fig. 2) and can be used for back-up connection for FSO systems with range of about 2000 – 2500 m, while 93 GHz RF line for distances to 1800 – 2200 m. That is clearly shown on Fig. 3 with drawings for rain rates of 10 mm/h and 20 mm/h. The total losses for 77 GHz are 3-5 dB lower than on 93 GHz. For rain rate of 50 mm/h link range is shorter, but in that case hybrid system can connect on FSO, because optical waves attenuate insignificantly in rain, and heavy rain and fog don't appear simultaneously.

In addition Eq. (8) can be used in future works for estimation of link availability of hybrid FSO/FR networks for some regions if probability density function of rain rate *pdf(I)* is known.

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