Performance Evaluation of FSO and MMW for the Uruguayan Weather Conditions

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Abstract In this work the Free Space Optics (FSO) and the Millimeter Waves (MMW) links are studied for the Uruguayan weather conditions. FSO availability is affected by fog significantly, while MMW availability is mainly affected by rains. Considering visibility and rain intensity data, these availabilities are estimated for the Uruguayan weather conditions. The results are extensible to other areas with similar weather. Finally the use of both links simultaneously, one as a backup of the other, is discussed.

Keywords Free Space Optics · Millimeter Waves · Hybrid links · Backhaul · Last Mile.

1 Introduction

For several reasons FSO and MMW are very interesting candidates to be used as Backhaul or Last Mile. Both technologies support important bandwidths (from the order of hundreds of Mbps or some Gbps) using portions of spectrum unused or scarcely used. Also for these technologies it is easy to reuse frequencies, because these are very directive links in no so large hops. Considering that FSO and MMW are affected by different meteorological phenomena (fog and rain respectively), which not always occur together, to use one technology as a backup of the other is a common idea; it is named as hybrid FSO-MMW link [1]. Some companies are already offering this type of hybrid links [2] (see

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Fig. 1 Hybrid FSO-MMW equipment (source: [2]).

Fig. 1). It is presented as a good alternative for Backhaul and Last Mile, considering the high costs and the time needed for deploying fiber optics networks. These technologies are also good options for Gigabit Ethernet (GE) links for corporative customers.

FSO links are well known for their high bandwidth (up to 10 Gbps [3]), robustness (low probability of being interfered), small dimensions (see Fig. 2) and their no need for licenses or *light-licensing* depending on the country. As a disadvantage, they are very sensible to fog which decreases significantly their availability, specially in cities where the fog is common.

The length of these links depends on the required availability (percentage of time in which the link is up), usually it can reach approximately 2 km. According to MRV (a specialized company in the area) FSO links have an availability near of 99 % for distances of 2,5 km, while it can reach up to 99,999 % for distances of 200 m [3, 4].

MMWs links (60-80 GHz) are another alternative for short range links with high bandwidth. As FSO, MMWs links can achieve also high bandwidths, e.g. 1,25 Gbps [5]. The main disadvantage of MMWs is their attenuation with rain. Nevertheless, their availability is much better than for FSO [5]. The price and maintenance costs (100 USD/year [5]) of these links are low, and their dimensions are small (antenna diameter of 39 cm, see Fig. 3).

Fig. 2 FSO dimensions, approximately 80x40x60 cm (source: [3]).

Fig. 3 MMW dimensions, antenna diameter 39 cm (source: [5]).

Concerning to atmospheric channel effects, as it was previously said, fog affects significantly FSO links, being less important the attenuation produced by rain for these links [6–10]. The rain affects significantly MMW links [11, 12]; being fog less important for MMW than for FSO links. These are the reasons why hybrid FSO-MMW links are considered. In [13], the effects of rain over these hybrid links are analyzed.

Fog is the loss mainly considered in this work for FSO links, because of its importance and variability, but it is not the only one. Other kind of atmospheric loss that affects FSO links is absorption, caused by oxygen, water vapor and aerosols (smoke, dust, etc.). Apart from these losses, FSO links are also affected by: obstructions (e.g., caused by birds), scintillation (caused by the variation of the refractive index of the air), geometric losses (due to the beam divergence [14]), optical losses (due to imperfections in the optical elements), system losses (e.g., in cables and connectors), etc.

Rain is the loss mainly considered here for MMW links, because of its importance and variability. Other kind of atmospheric loss that affects MMW is absorption, caused by oxygen and water vapor. Fog and clouds also affect the MMW links depending on the density and size of its water drops, but its effects are less important than the ones for rain. Also some non atmospheric losses have to be considered for MMW links as Free space loss, system losses, etc.

In this work the availabilities for FSO and MMW are studied, considering meteorological data for the city of Montevideo, Uruguay. There are several regions in the world with similar rates of rain[1] and fog, where these results could be useful. The novelty of this work in the area of MMW and FSO is to provide information about link length versus availability for regions with similar weather conditions to those of Uruguay. For the country and also for regions with similar weather conditions it is important to know what to expect from MMW and FSO techniques. The results provided in this paper can be useful for telecommunications companies working in these regions. This information is a useful input to decide when and where to use each one of these technologies. In the following sections, each technology is analyzed for these weather conditions.

2 Free Space Optics

To study the FSO availability, visibility data from Montevideo were used. The visibility is defined as the greatest distance under given weather conditions to which it is possible to distinguish an obscure object during the day [15] or a light source during the night [9]. The visibility measures were provided by the Dirección Nacional de Meteorología (DNM). These measures were obtained in their meteorological stations of: International Carrasco Airport, Melilla and

[1] http://www.climate-charts.com/World-Climate-Maps.html#rain.
http://uy.kalipedia.com/graficos/distribucion-mundial-precipitaciones.html?x=20070418klpcnaecl_56.Ees.

Table 1 Meteorological Stations, their coordinates and elevations.

Station	Coordinates	Elevation (m)
Carrasco	34 50’ S, 56 00’ W	32
Melilla	34 47’ S, 56 15’ W	54
Prado	34 51’ S, 56 12’ W	16

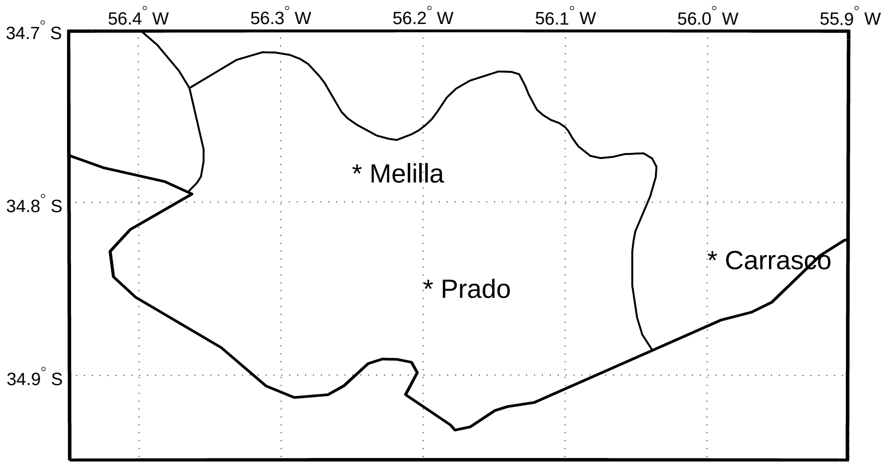

Fig. 4 Location of the used stations in the area of Montevideo.

Prado, these are the meteorological stations of this institution, where visibility is measured. These measures are visually taken by an observer, using reference points at known distances. These measures can be affected e.g. by rains, but these ones were the only measures that could be obtained as fog indicators. Also it was verified, that this kind of measures (visually taken) are often used to study FSO links [4].

By using the visibility to estimate the availability, the availability for different weather conditions as “light fog”, “thin fog”, “haze”, etc. is obtained; because each one of these weather conditions correspond to different visibility levels.

The data used goes from 23/04/2010 up to 11/02/2011. The measures were taken each one hour, during 24 hours for Carrasco station and only from 9 to 19 hours for the other two stations. In Table 1, the geographical coordinates and the elevation -relative to the see level- are presented (source [16]). In Fig. 4 the location of these stations is shown.

In Table 2 the distances between these stations are shown. Nevertheless these stations are quite near between them (some kilometers), the measures are quite different. As an example, in Fig. 5, the data for these three stations on May 2, 2010 is presented.

It is known, that the fog depends on the geographical conditions, e.g. for a valley the presence of fog can be more probable. Then it is not useful to

Table 2 Distances between the meteorological stations.

	Distance (Km)
Carrasco-Prado	18
Melilla-Carrasco	22
Prado-Melilla	10

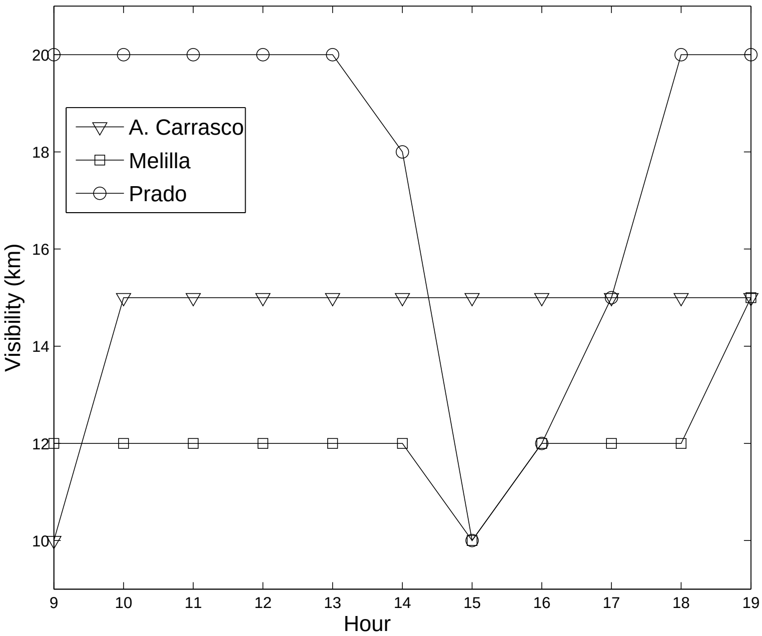

Fig. 5 Comparison of visibility data for these three stations on May 2, 2010.

interpolate the visibility data between the meteorological stations to estimate the data for other points of the city. Also for this reason, the data for these three meteorological stations could be not representative for all the areas in the city. If fog is a local phenomena, then it induces to think that a ring topology can be a good alternative for this technology. The idea is that an intensive fog able to affect a hop in a ring, not necessarily should be present in other hops of the same ring. Then a ring topology would improve the availability of the communication system.

In order to model the link attenuation with meteorological data, the model proposed by Kruse [9,17,18] was used. Several models were analyzed, Kruse [17], Kim [15], Naboulsi [7], etc. Finally in this work Kruse model was used, because it is a basic and quite used model. Also Kim model was tested, and it produces similar results than Kruse model for a link length of 1 km.

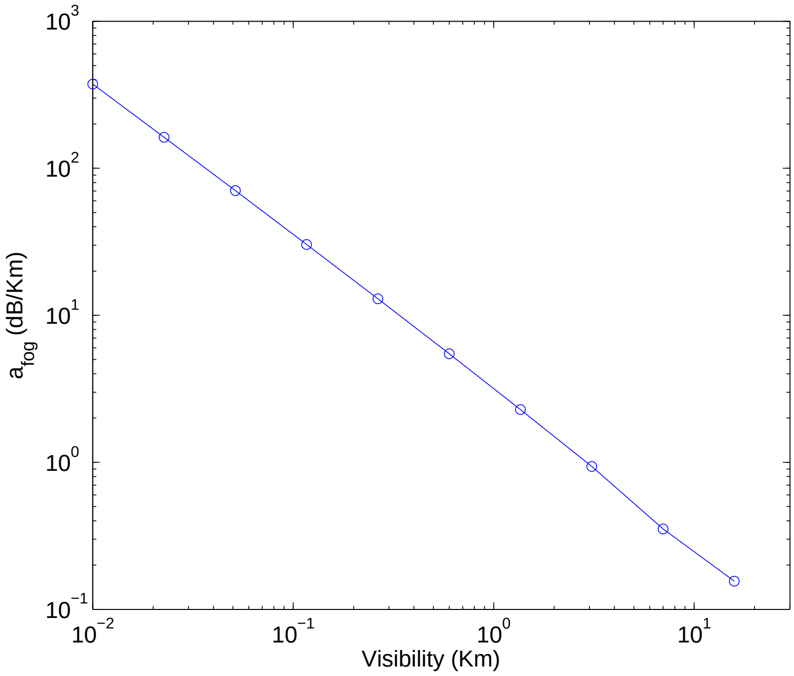

Fig. 6 Attenuation due to fog versus visibility.

In 1962 Paul W. Kruse [17] based on Mie theory and experimental results, proposed a simplified equation (1) to relate the dispersion coefficient a_{fog} with the visibility V and the wave length λ.

$$a_{fog} = \frac{3.912}{V} \left(\frac{\lambda}{\lambda_0} \right)^{-q} \tag{1}$$

$$q = \begin{cases} 1.6 & V > 50\ km \\ 1.3 & 6\ km < V < 50\ km \\ 0.585\ V^{1/3} & V < 6\ km \end{cases} \tag{2}$$

where a_{fog} is the attenuation of the link in dB/km (dispersion coefficient), V the visibility in km (for visible light), λ the operation wavelength, λ_0 the wavelength of the visible light -in average 550 nm-, and q was heuristically determined. In Fig. 6 the relation between attenuation and visibility is presented.

According to [2] the relation between the received and the transmitted power is:

$$P_{\text{received}} = P_{\text{transmitted}} \frac{A_{\text{receiver}}}{(\theta \times L)^2} \exp\left(-a_{fog} L\right) \tag{3}$$

Being:

- A_{receiver}: Receiver area
- θ: Beam divergence (in radians)
- L: Link length

As specifications for the FSO equipment, the specifications of TereScope 3000 from MRV were used in order to compare the results with the ones provided by this company [19].

Specifications for the FSO equipment:

- $\lambda = 785\ nm$
- $P_{\text{transmitted}} = 21\ mW$
- $\theta = 2.5 \times 10^{-3}\ rad$
- $A_{\text{receiver}} = 0.021\ m^2$
- $P_{\text{received\_min}} = 100\ nW$ (With BER $= 10^{-9}$)

In order to calculate the relation between the length of the link and the availability, the received power (for a given length of the link) was estimated using the visibility data. After that, the number of intervals (all of them of 1 hour) for which the received power was greater than the minimum (for a given length of the link) was counted, and finally the availability was estimated as the ratio between this quantity and the total number of time intervals considered.

In Fig. 7, the availability results versus link length, with the data from Carrasco station are shown. These results are shown together with data provided by MRV [4] for the cities of San Diego and Las Vegas in USA and St. Johns in Canada (Newfoundland island in the northeast). According to MRV these availability results also were obtained by using visibility data visually measured in airports.

As it can be seen in Fig. 7, the availability results for Montevideo (considering the measures for Carrasco during 24 h) are quite similar to the ones corresponding to San Diego, which is described by MRV as an average city in terms of availability, far away from Las Vegas (almost without fog) and St. Johns (very foggy).

In order to decide if the availability calculated for one station is representative for the whole city, the availability for the three stations was compared. In Fig. 8, the availability for Prado, Melilla and Carrasco from 9 am to 7 pm is shown. The data comparison from the three meteorological stations (only considering the day measures) shows important differences between them (see the respective "availability versus link length" curves in Fig. 8). It suggests that the FSO link could have a quite different performance in different points of the city at the same time.

In Fig. 8, the difference between the availability considered from 9 to 19 h and the one obtained considering 24 h for Carrasco station, can be observed. It suggests that it is not enough to consider only visibility data for daily hours to study the general availability (it can decrease by night).

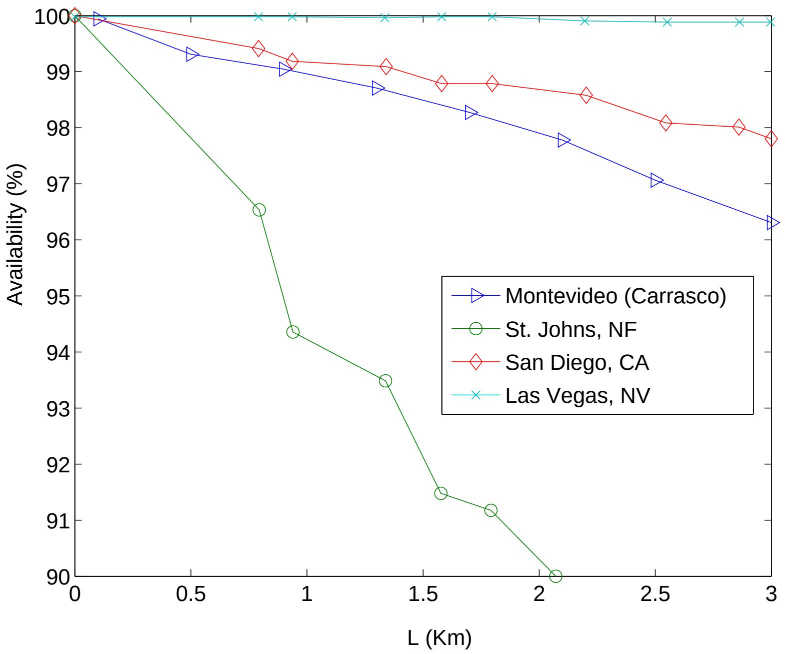

Fig. 7 FSO availability versus link length.

3 Millimeter Waves Links

In order to model the attenuation suffered by MMWs due to rains, to know the rain intensity (R, measured in mm/h) is necessary. Unfortunately it was not possible to obtain -up to now- this information, the DNM does not have records of rain intensity for none of the stations; it only has a register of the total rain by day (rainfall records). Then it is not possible to use this data to estimate the MMWs availability.

By this reason, data provided by the International Telecommunication Union (ITU) was used (Recommendation ITU-R P.837, "Characteristics of precipitation modeling"). This recommendation provides statistic information about the rain intensity for the whole world. This information is presented in tables beside of a Matlab script to allow an easy access to the information. With this data base, the value R exceeded -given a fraction of the year (in %) and the geographic coordinates- can be obtained.

To calculate the attenuation due to rains, also recommendation ITU-R P838, "Specific attenuation model for rain for use in prediction methods" was used. This recommendation provides the equations and tables of recommended values to calculate the attenuation up to 400 GHz. Also a script for Windows, which simplifies the calculations, is provided. It calculates the attenuation for

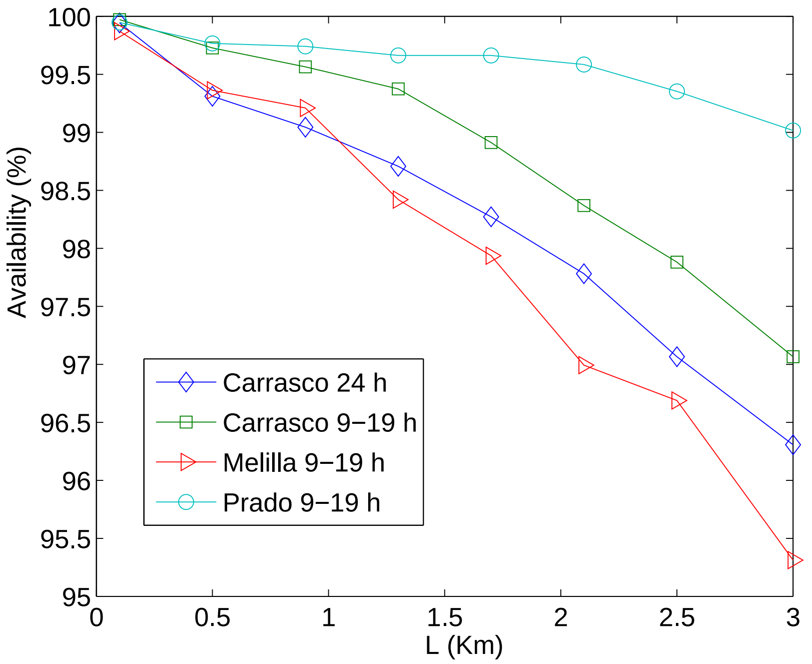

Fig. 8 FSO availability comparison between Carrasco and the other two stations where there is not visibility data for the whole day.

a set of R values (up to 200 mm/h), starting from the link length and the frequency.

The used specifications for MMWs, were the ones provided in [5], which have the following characteristics:

- Frequency: 71-76/81-86 GHz (Downlink/Uplink)
- Transmitted power: 18 dBm
- Antennas Gain ($G_{\mathrm{TX}}, G_{\mathrm{RX}}$): 43 dBi
- Sensibility: -58 dBm (BER 10^{-12})

The MMWs link was modeled by the Friis transmission equation in logarithmic scale.

$$P_{\mathrm{RX}} = P_{\mathrm{TX}} + G_{\mathrm{TX}} + G_{\mathrm{RX}} - 20\log_{10}\left(\frac{4\pi L}{\lambda}\right) - a_{\mathrm{rain}} L \qquad (4)$$

In the same way than for FSO, it was defined the maximum distance L as the one for which the received power is equal to the sensibility (minimum detectable power). Solving (4) for this case, the maximum distance for the link was obtained for each attenuation value a. Then, relating the attenuation a to the intensity R, and then this one to p (the percentage of the year in which

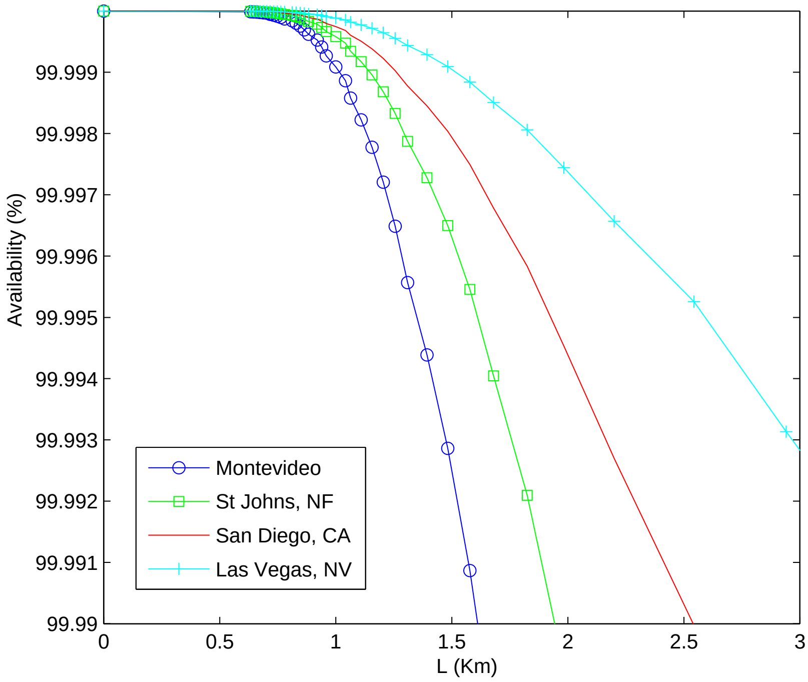

Fig. 9 MMWs availability versus link length.

this R value is exceeded), the availability $P = 100 - p$ is obtained as a function of the distance. The described relation is graphically represented as follows: $L_i \leftarrow a_{\mathrm{rain}\,i} \rightarrow R_i \rightarrow p_i \rightarrow P_i$.

In Fig. 9 the availability versus link length is shown. To compare with other regions, these curves were obtained for the cities previously considered for FSO (using their geographical coordinates). One result is that the availability for MMWs is quite greater than the one for FSO for the same distance. Also the smaller maximum link length for Montevideo -compared with the other three cities- can be observed. The lower availability for Montevideo, compared with the other three regions, can be explained by a higher intensity rain for Montevideo than for the others.

In order to obtain this result for the whole area of Uruguay, the maximum link length for an availability of 99,999 % was calculated for the area between lattitude -35°and -30°and longitude -59°and -53°. In Fig. 10 this result can be observed. A maximum link length between 930 m and 1030 m, for all the country, can be considered when an availability of 99,999 % is required.

The "rain rate model" and "rain prediction model" proposed in [20] and [21] could be another approach to obtain the rain levels for a region in order

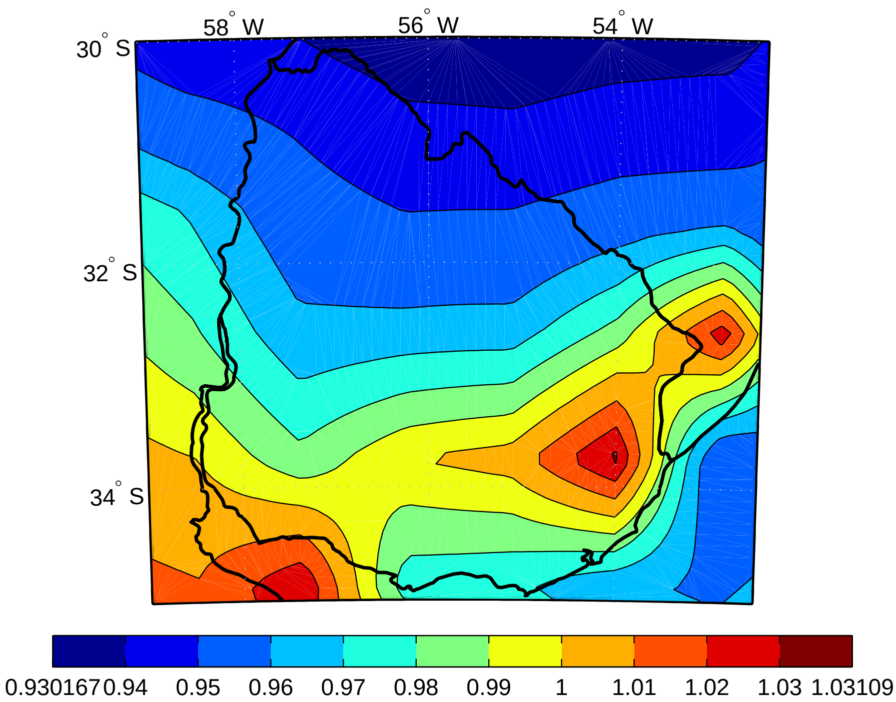

Fig. 10 Maximum link length (km) for 99,999 % of availability with MMWs in Uruguay.

to calculate the attenuations and availability for MMW. This approach can be considered in future works.

4 Conclusions

The objective of this work was to estimate the availability for FSO and MMW systems for the region of Uruguay (South America). Using visibility data from the DNM, the FSO links were evaluated for this country. To study the MMW availability, statistical weather data from ITU was used, due to DNM does not have data from the rain intensity (mm/h).

Concerning to FSO, the availability obtained in Montevideo (the capital of Uruguay) was approximately 99 % for links between 1 and 2 km. Then Montevideo is an average city for FSO deployment, near from to the availability of San Diego (California, USA), and far away of the availability values for Las Vegas (Nevada, USA) where the availability is excellent and St. John's (Newfoundland, Canada) where the availability is very low.

Also it was verified the convenience of using ring topologies for the FSO link, because fog is a local phenomena, as it was seen from comparing the visibility data for the same time in different meteorological stations.

For MMWs, it was found that an availability of 99,999 % can be achieved in Uruguay with link lengths of approximately 1 km. Then the availability for MMWs is much better than the one for FSO for the weather conditions of this region.

Although more precise data about visibility and rain intensity could permit to obtain more precise results, the authors consider these first results as an interesting advance, considering that it is the first study of this kind made in the country as far as the authors know. These results were confirmed and extended by a second work in this area, which will be published in a near future.

Another approach to calculate or verify the results presented in this paper, is to measure directly the availability of this kind of links, once that exists access to this kind of links installed in Uruguay or regions with similar weather conditions. There are good tools to monitor the performance of wireless links as Cacti[2] that could be used for this purpose.

Concerning to the availability of a hybrid FSO-MMW link for this region, although it is true that a hybrid system will improve the link availability, considering the good results for MMW and the extra costs of a hybrid system, it could be avoided.

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