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Development of Measurement and Modeling Procedures of Diffractive near-LOS Wireless Links

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Abstract

When deploying a link to provide Internet connection in rural areas it is often necessary to surpass obstacles such as mountains covered by vegetation. However, in many situations, the diffraction angle θ is quite small ($\theta \backsim 1°$), achieving near-LOS (nLOS) links, and the possibility to establish a broadband link exploiting diffraction phenomenon arises. For that matter, a measurement system capable of transmitting and capturing broadband signals has been developed. Moreover, signal processing techniques have been applied to obtain attenuation by diffraction and channel response from the captured signal. To test nLOS links, several experiments and their comparison to propagation models have been carried out.

1 Introduction

Today, network designers rely on Line of Sight (LOS) links, resulting in the need to build repeater sites in difficult locations. This leads to high build costs. However, in many situations, the diffraction angle θ is quite small ($\theta \backsim 1°$), achieving near-LOS (nLOS) links, and the possibility to establish a broadband link exploiting diffraction phenomenon arises. The use of nLOS links can reduce or eliminate the need to build repeater sites to overcome obstacles.

The Project *Over the Horizon Communications* (OTHC) was born to eliminate this need. It has been launched by Facebook Connectivity [1] in collaboration with Universidad Politécnica de Madrid (UPM). For that matter, a measurement system has been developed, and a measurement campaign has been carried out to analyze the channel response and attenuation. By comparing the results with available propagation models, conclusions about nLOS links can be drawn.

Section 2 of this document presents the measurement equipment; Section 3 describes the use of signal processing techniques to obtain excess losses, L_{Excess}, and channel response from the captured signal; Section 4 presents the measurement campaign; Section 5 summarizes the procedures followed to evaluate and predict the propagation losses; and Section 6 shows the results for some outdoor experiments and compares them with the models.

2 Measurement Equipment

The developed system can transmit and capture broadband signals in the 450, 2400 and 5800 MHz bands. 5800 MHz is an unlicensed band often used for outdoor, point-to-point microwave links. Results obtained at 5800 MHz may also potentially be applied to the 6 GHz licensed band, which is often used for licensed point-to-point microwave.

The measurement system is formed by two computing platforms used as transmitter (T_x) and receiver (R_x); both platforms consist of a radio transceiver and an FPGA evaluation board run by a computer. The boards are attached to a transport case and a power supply system is integrated, as shown in Figure 1 (Left). In T_x mode, the platform can transmit either a tone or a broadband signal. In R_x mode, the platform can measure the received power and it can capture the I and Q components with respect to a central frequency.

Three different directive antennas are used for the frequency bands under analysis. Antenna gains, G (dBi), and Front/Back (F/B) ratio are collected in Table 1.

A drone, displayed in Figure 1 (Right), is used in some experiments to vary the T_x height. This drone does not have an antenna-steering mechanism, thus monopole antennas are used instead of directive ones.

Figure 1. Equipment. Transceiver (Left), drone (Right).

Table 1. Antennas specifications.

Parameters	Frequency (MHz)		
	450	***2400***	***5800***
G (dBi)	12.15	24	30
F/B ratio (dB)	>18	≥30	>34

3 Signal Processing Procedures

Two different signals are used for the experiment, a tone and a broadband signal. The tone is processed in real time at the R_x, and provides direct feedback of the received power and approximation of the attenuation. The broadband signal is captured firstly and processed later on. The broadband signal, modulated in BPSK, uses a 100 MHz bandwidth. The modulating signal is an M-sequence [2], which provides a processing gain after the matched filter. Signal processing techniques are implemented to obtain the channel response and attenuation from the captured signal. Moreover, code and carrier synchronization [3] have been applied.

To determine the excess attenuation of the channel, L_{Excess} (dB) are obtained by calculating the propagation losses from the link budget and subtracting the free-space losses. L_{Excess} is produced by diffraction losses, L_D, and multipath.

To determine the channel response, the M-sequence is periodically transmitted several times. Then, the received signal is correlated with the M-sequence, producing a signal with periodic peaks, corresponding to the replication of the code. The different signal replications are then separated using a Hamming window and displaced to the same time instant by calculating the time delay referring to the first peak and eliminating this time delay. These pieces of received signal are transformed to the frequency domain by a Fourier transformation, and are then averaged.

4 Measurement Campaign

In the measurement campaign, systematic measurements of nLOS links are taken covering different path lengths, θs, obstacles and vegetation. Two different scenarios are defined: Mast-Mast (M-M) and Drone-Mast (D-M).

For the M-M scenario, the T_x and the R_x are placed at fixed points. The advantage of this scenario is that both sites use directive antennas, which increase the system range, but only a few values of θ can be analyzed, corresponding to the antenna heights. To carry out the measurements, a tone is first transmitted and the antennas are initially pointed to the mountain peak. After that, both antennas are slightly moved manually in azimuth and elevation until the directions yielding maximum power are found. Finally, the broadband signal is transmitted, captured and processed.

For the D-M scenario, the T_x location is a mobile point while the R_x is at a fixed point. The T_x node consists in a drone supporting the platform and a monopole antenna, shown in Figure 1 (Right). The advantage of this kind of measurement is that various θ can be analyzed but, in contrast, only one site uses a directive antenna, which decreases the maximum range. For the D-M scenario, the drone is transmitting the tone along 160 m and the R_x antenna is pointing to the mountain peak.

An M-M preliminary experiment and a total of seven measurement experiments, in different rural areas around Madrid, are carried out. Five of them correspond to the M-M scenario and two to the D-M scenario.

5 Methods to Predict the Propagation Losses

The ITU-R diffraction models described in [4] have been used in this project. The shape of the obstacles must be idealized, either as a knife-edge or as a thick smooth obstacle with a radius of curvature;

For a long distance, tens of km, the variation of the atmospheric refraction index causes a curvature in the trajectory of the ray. It can be modeled by an Earth modified radius through what is call k factor, which is a multiplier for the Earth radius [5]. When the terrain is not smooth, but has a certain profile, the variations of k also produce variations of the heights of the terrain profile with the consequent influence on the link clearance. The k factor is obtained from local information data.

In [6, 7] becomes clear that the different environments and variety of foliage challenge the prediction procedures. For this Project, it has been assumed that, in the case of presence of vegetation in the obstacle summit, the signal can travel through and over the vegetation. In that sense, the vegetation is considered as an extra height over the obstacle, since the signal travelling over the vegetation mass is likely to be dominant. The averaged vegetation height, h_v, is obtained from local information data.

6 Outdoor Experiments Analysis

6.1 Preliminary Experiment

This is accomplished to assure that the measurement system and procedures can adequately characterize the link. This was performed at Escuela Técnica Superior de Ingenieros de Telecomunicación (ETSIT-UPM). Figure 2 presents the geometrical layout of the experiment. The T_x and R_x, are on the roof of two buildings (*D* and *C*) while another building acts as an obstacle, building *B* corner *O*. The results must be obtained for different θ, which is achieved by switching the R_x mast height, h_{MC}, and letting the height of the T_x mast fixed, h_{MD}.

As seen in Figure 3, the single knife-edge analysis [4] is underestimating L_D, while the rounded obstacle model [4] has better agreement with measurements; the radius *R* of the rounded obstacle is around half of the building *B* width. Notice that the link distance is 150 m, and the obstacle width is 16.6 m (more than 10% of the distance).

Figure 4 presents the relative channel response for 450 MHz; it is used to validate the measurements through the location of the scatterers, *Scs*, in the surroundings show in Figure 5. Table 2 collects the distance travelled by the indirect signals in excess of the direct path, d_{dp}, length produced by the *Sc* through the echoes registered.

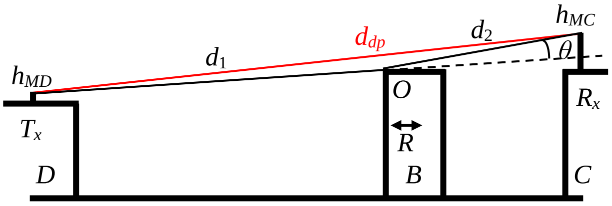

Figure 2. Preliminary experiment, d_1 and d_2 are the distances from the two ends of the path to the top of the obstacle (corner O) and the red line is the d_{dp}. While corner O is below d_{dp} θ<0° and when it is above d_{dp} θ>0°, following the sign criteria defined in [4].

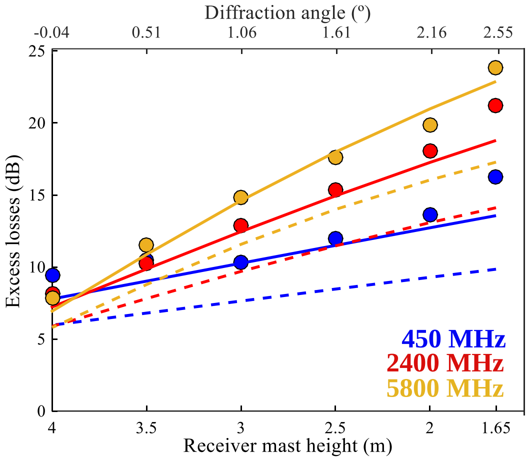

Figure 3. Preliminary experiment, L_{Excess}. Measurements (dots), knife-edge (dashed) and rounded (solid).

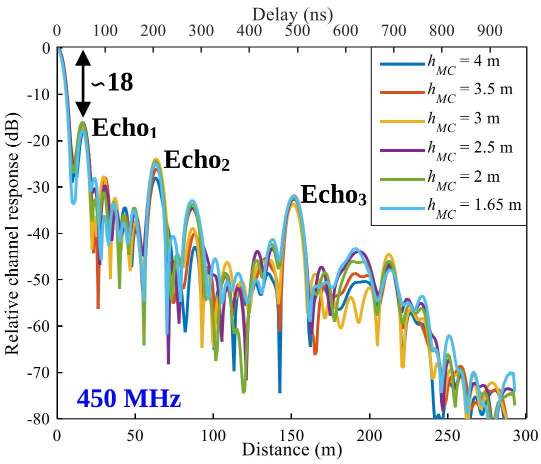

Figure 4. Preliminary experiment, relative channel response, 450 MHz.

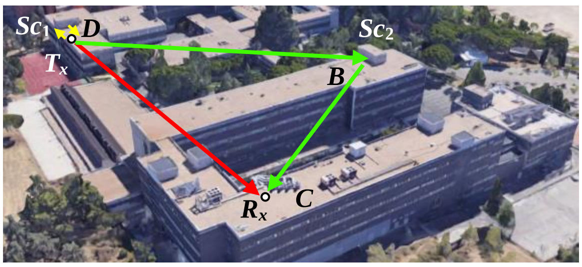

Figure 5. Preliminary experiment, d_{dp} (red), reflections produced by Sc_1 (yellow) and by Sc_2 (green).

Table 2. Preliminary experiment, echo identification.

Frequency (MHz)	Distance (m)		
	Echo₁	***Echo₂***	***Echo₃***
450	16.6	64.45	153.3
2400	11.72	59.57	150.4
5800		65.43	

Echo₁ comes from the structure behind the T_x that can act as a Sc_1 (Figure 5, yellow). Since the distance from the antenna to the structure is ∽8 m, the total increment of the d_{dp} (Figure 5, red) is ∽16 m. Also, the difference between the main peak and this echo presented in Figure 4 is ∽18 dB, which is of the order of the *F*/*B* ratio (Table 1, 450 MHz). Echo₂ comes from the structure located on one of the edges of building *B*, Sc_2, since the total covered distance is ∽210 m (Figure 5, green) and the d_{dp} is ∽150 m. This means that the new ray travelled ∽60 m more than the ray in the d_{dp}. Echo₃ is difficult to identify. The different directivity of the antennas, higher for 5800 MHz and lower for 450 MHz, produces different echoes.

6.2 Mast-Mast Scenario

This scenario has fixed and directive antennas. Table 3 presents the L_{Excess} prediction error for one of the five M-M scenarios. The k factor used is 1.22, θ = 0.78 and θ_v = 1.03. θ_v is the diffraction angle considering h_v = 12.62. The frequency band of 450 MHz could not be measured correctly, due to the high level of interference and multipath (due to the low directivity of the antenna) in that band in rural areas around Madrid.

Table 3. M-M scenario, 11.8 km, prediction error (dB), difference between measurements and models.

Frequency (MHz)	Knife-edge	Vegetation	Rounded
2400	1.62	-0.79	-3.90
5800	3.68	1.24	-5.34

Table 3 shows that the single knife-edge analysis is underestimating L_D. However, the simulated L_D produced by the curvature of the top of the obstacle (Rounded) overrates the measurements; we believe this is due to the obstacle shape and its location along the link. The better approximation is obtained by considering the knife-edge model with vegetation as an extra height h_v (Vegetation).

Figure 6 shows the relative channel responses for the five M-M experiments, classifying them by their length and h_v, for 2400 MHz; this figure reveals the presence of multipath with small delays which are probably produced by the obstacle. Values of RMS delay spread about 4–10 ns arise for obstacles with scarce vegetation (39.7 km and 40.6 km) which rise to 10–20 ns when vegetation is denser and higher (11.8 km, 21.2 km and 65 km). Further, there are softer values of echoes for obstacles with scarce vegetation.

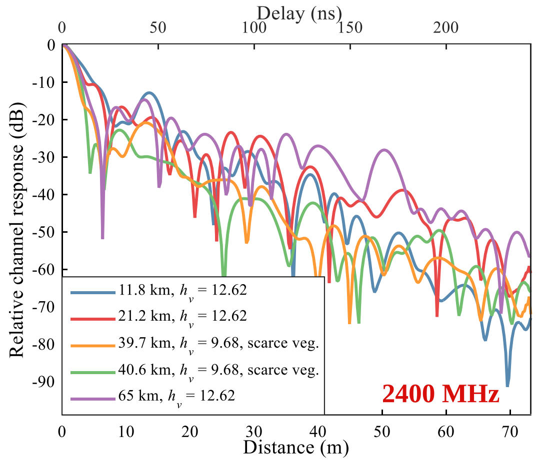

Figure 6. M-M scenarios, relative channel response, 2400 MHz.

6.3 Drone-Mast Scenario

As an example, Figure 7 shows the surroundings of one of the D-M scenarios. Figure 8 presents the measurements collected by the drone and the model results; in this figure, the variability in the measurements for a small drone height probably corresponds to the multipath produced at the obstacle summit. This multipath effect is more noticeable than the one discussed for the M-M scenario (Figure 6), since the drone carries an omnidirectional antenna. Besides, Figure 8 shows how the knife-edge model considering vegetation height reaches good agreement with the measurements, as revealed by the mean error and typical deviation values between measurements and models. Where $\theta_v = \theta$ (°) + 0.24°.

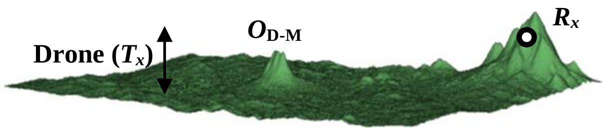

Figure 7. D-M scenario, 9.4 km, $O_{\text{D-M}}$ obstacle.

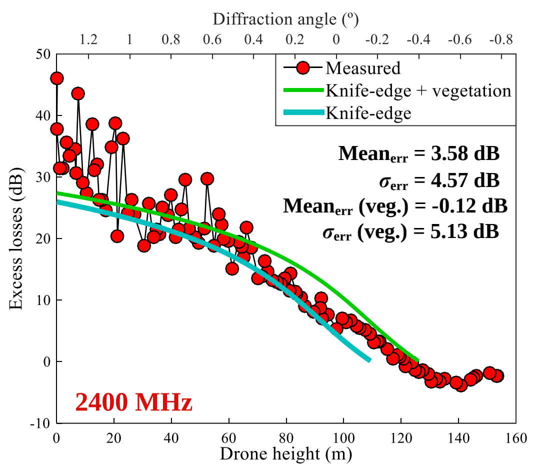

Figure 8. D-M scenario, 9.4 km, L_{Excess}. Measurements (dots), knife-edge and vegetation (green), knife-edge (cyan), k = 1.19, h_v = 9.68 m, 2400 MHz.

7 Conclusions

Under the Project *Over the Horizon Communications*, a measurement system capable of transmitting and capturing broadband signals for 450, 2400 and 5800 MHz has been implemented, as well as signal processing techniques to obtain L_{Excess} and channel response.

The preliminary experiment confirms that the measurement system and procedures can measure the channel correctly. The M-M and D-M experiments show that the multipath propagation, produced by the obstacle, depends on the density and height of the vegetation. Furthermore, the diffraction propagation model matches the measurements with good agreement for both scenarios. The importance of considering obstacle vegetation as an extra height over the obstacle summit should be stressed, since its impact could be determinant to provide a better estimation.

As stems from above, the losses produced by nLOS links with obstacles like mountains covered by vegetation, with low θs, can be predicted, with a good accuracy, using the propagation models considered in this study. We believe that the use of nLOS links can reduce or eliminate the need to build repeater sites to overcome obstacles.

8 Acknowledgements

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9 References

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