IMPROVEMENT OF WIRELESS NETWORK PERFORMANCE BY POLARISATION DIVERSITY

Simulation from Measurement Results at only One Polarisation

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Abstract: The use of polarisation diversity techniques in reception could be adequate to improve the performance of the wireless networks operating in deep multipath fading environments. This paper explores this possibility, and presents a procedure to estimate the received cross-polarised power from wide band measurements performed at just one polarisation. Three different strategies have been tested, and the results are presented and analysed, detecting improvements even when the multipath is low in the channel. In highly multipath rooms, the improvement in terms of received power reaches 21%.

1 INTRODUCTION

The deployment of wireless local area networks is determined, in most situations, by the strong multipath effect that could degrade the performance of the complete communication system. This multipath effect appears as frequency selective fast fading events along the receiver path, when it is moved; or as very low coverage at some locations that could coincide with receiver position. In both situations, the connection possibilities of the network nodes may be reduced or even unavailable.

The multipath is present in most of the environments where a radio communication system is installed. However, it is at indoor scenarios where the effects of multipath resulted to be more hazardous for the performance of the system. This is the reason why different indoor environments have been used to check the proposal of this paper.

The work in this paper is centred in the 5.8 GHz band, one of the assigned to wireless networks (Dutta-Roy, 1999) (IEEE802.16, 2003) (Eklund et al, 2002). Results of several measurement campaigns performed in both line of sight (LoS), non LoS (NLoS), and obstructed LoS (OLoS) indoor environments have been used as a basis to check the options of implementing a solution to reduce the multipath consequences. These data are radio channel responses, with transmitters at fixed locations and receivers measuring along linear paths, as explained in the second section. As we get complex responses, we can analyse the multipath effect, and we can try to reduce the influence of their costs.

Among the various procedures that have been tested to mitigate the multipath consequences, different diversity techniques have been proposed. The general solution of such techniques is to provide two different propagation paths, with almost uncorrelated received signals. Thus, the alternate use of both signals, or the combination between them, provide a final signal with better relation SNR than that obtained with only one standard propagation path.

Diversity techniques could be applied following several strategies: frequency, space, time, angle, polarisation, and hybrids that combine some of the previously indicated (Dietrich et al, 2001) (Turkmani et al, 1995).

Among the diversity techniques, the polarisation diversity is analysed along this paper: two orthogonally polarised signals at the same frequency are used as inputs in the diversity receiver. In this case, the pair of propagation paths is provided by the pair of orthogonal polarisations. This technique has been selected because the indoor environments presents both multipath phenomenon and depolarisation by transmission and reflection on the walls, ceiling, floor, and so on. Thus, a certain percentage of the transmitted signal would arrive the

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receiver orthogonally polarised. Moreover, the spectrum consumption is reduced compared to frequency diversity, as no new bands are occupied by the second propagation path. Depending on the amount of depolarised signal, the application of polarisation diversity at reception could be more or less advantageous.

The depolarisation indexes depends on the building material of the wall, specifically on the electromagnetic behaviour of the different constructive elements, as previously studied in (Cuiñas et al, 2009). Results presented in that paper have been applied in the computation of the improvement by polarisation diversity. The information related to depolarisation is the aim of the third section.

The computation procedure begins with the data provided by the wide band measurement campaign, which represent the channel response in just one linear polarisation. Based on the depolarisation indexes induced by each reflection or transmission phenomena, the cross-polarised signal could be obtained by analysing separately each multipath contribution. The actual copolar contribution and the synthesised cross-polar one are then the inputs of the diversity device, which provides the combination of both contributions. All the procedure to obtain the final signal is explained in detail along section fourth.

Three different strategies are then applied to the couple of signals to be combined into the final result: sum, maximum and average diversity. The performance of the application of such strategies are related and analysed in section five.

The paper is organised, then, into six sections. The second section is devoted of the measurements, and the third one is focused on the fundamentals of depolarisation indexes. Sections four and five are centered in the results: the fourth on the way to compute them, and the fifth in the analysis. Finally, the sixth section summarises the conclusions.

2 MEASUREMENTS

A large wide band measurement campaign was designed with the aim of obtaining the co-polar response of the radio channel in several indoor environments, both LoS, and OLoS or NLoS. The campaign involved five different environment configurations. The band of interest is centred in 5.8 GHz, as it is focused on propagation aspects for wireless networks.

The measurement system was based on a vector network analyser (VNA). The wide band condition of the measurements is a key factor in this work, as it allows the transformation to time domain and, once moving to time, also the identification of different multipath contributions. These contributions could then be individually considered when processing the cross-polar response of the channel.

Along the following subsections, the setup used during the measurements, the environments where the experiments were performed, and the applied procedure are described.

2.1 Measurement Setup

As previously commented, the measurement system is based on a VNA Agilent 8510-C, which can perform measurements up to 50 GHz, so far away our needing. Both transmitting and receiving antennas were connected to the ports 1 and 2 of the VNA, which acts as signal generator and as receiver.

The transmitter end was placed in static locations at each environment, whereas the receivin antenna was installed on the top of a engineered mast, which moved the receiver along a linear track, by means of a neverended screw. Figure 1 shows the setup for the receiver.

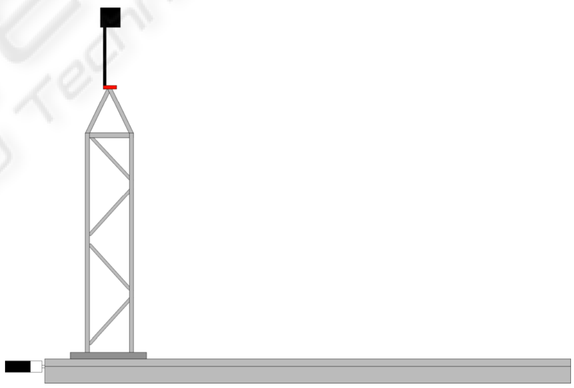

Figure 1: Receiver setup.

This positioning system, which consists of a 2.5 meter long linear table with a millimetre screw along it, improves the precision of the positioning compared to moving the antenna by hand.

Both antennas, Electro Metrics EM-6865, present omni-directional radiation patterns. This kind of pattern is interesting in order to get all the multipath contributions with approximately the same antenna gain, when dealing with receiver end. And this pattern is also important in the transmitter, to generate the maximum amount of multipath components.

The radiation pattern of such antennas was measured within the anechoic chamber of the Radio Systems Research Group, being the 3 dB beam width larger than 50 degree around the horizontal plane, in elevation, at 5.8 GHz. Whereas, the azimuth radiation pattern resulted to be aproximately omnidirectional. Figure 2 depicts the radiation pattern in elevation.

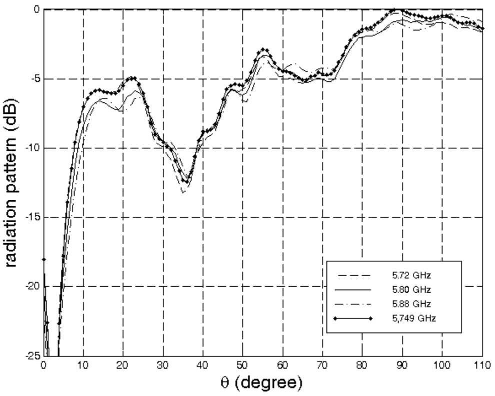

Figure 2: Radiation patttern at 5.8 GHz, in elevation.

2.2 Indoor Environments

Various series of indoor radio channel frequency response were measured in five different environments, some in LoS condition, one in NLoS and the other in OLoS situation. The measurements were taken in research laboratories, with both computers and electronic equipment. The furniture, when it is present, is the typical of this kind of rooms: office tables and chairs, and laboratory benches. The positions of transmitter and receiver are depicted at Figures 3, 4 and 5, at different rooms. During the measurement campaign, the transmitter was fixed at positions Tx*n*, being *n* a natural number between 1 and 5 devoted to the five environments, and the receiver was moved along the lines labelled as Rx*n*.

The five environments was selected trying to represent a great variety of rooms: we can compare results at large and small rooms, at furnished and empty places, at square and rectangular spaces, in LoS and NLoS conditions, and so on.

The points and paths labelled as "1" correspond to LoS situation within a large room (more than 100 square meter) and the labelled as "2" to NLoS within the previously commented room and an adjacent saloon. Both plans can be observed at figure 3. The wall that obstructs the propagation channel between both antennas in the second situation is made of bricks and concrete.

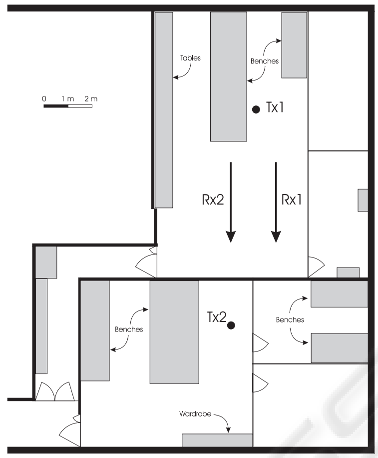

Figure 3: Map of the measured environments. LoS is defined as situation 1, and OLoS as situation 2.

The walls at both rooms are built by bricks and concrete, except the fine line parallel to Rx1, which is made of chip wood, and the upper wall (opposite to the place where the measurements took place) that contains a large window.

Figure 4 depicts the third environment, which is again a LoS situation in a smaller square room, with approximately 45 square meters.

The walls of such room are also brick made, except the wall opposite to the transmitter, which contains a large window.

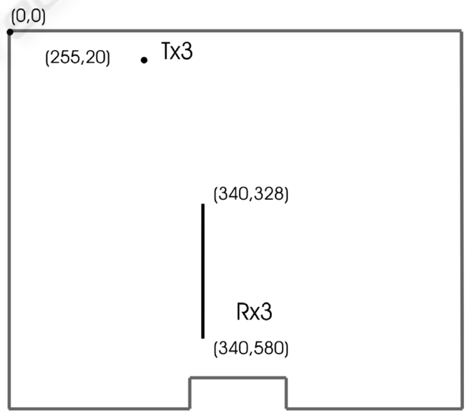

Figure 4: Map of the third measurement environment (dimensions in centimeter).

Finally, figure 5 depicts the situation for both fourth and fifth environments. Both are placed in a long room of 36 square meters. Whereas the fourth environment consists of a completely empty room, with perfect LoS conditions, the fifth consists of a furnished office room, in OLoS conditions. When furnished, office elements were placed within the radio channel: desks, chairs, closets, etc.

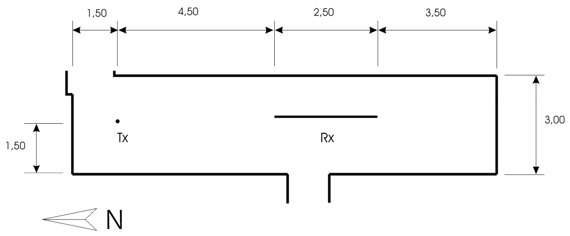

Figure 5: Map of the fourth and fifth measurement environment.

This environment is more complicated: both North and South walls are made of brick, the West wall is made of chip wood in its North half, and brick the South half, and the East wall is brick constructed, but it contains a window.

2.3 Measurement Procedure

The transmitting antenna was kept stationary at a height of 1.8 meter. This location guaranteed that the radiating element was approximately equidistant from floor and ceiling.

The receiving antenna was moved along 2.5 meter long linear paths by means of the automatic positioner. Data were taken every one-eighth of a wavelength (Dossi et al, 1996), which represent a *de facto* standard when measuring radio channels, as adjacent samples are far enough to be uncorrelated and they are near enough to keep all fade event.

At each position, complex frequency responses have been measured in a 160 MHz band around 5.8 GHz, with a resolution of 200 kHz, due to the 801 points in the frequency scan. As a consequence, the sounder resolution in the delay domain is 6.25 ns, while the maximum measurable delay is 5 µs.

The measurements were taken following a procedure “measure-move-stop-measure-...” in order to avoid Doppler effects within the data.

3 DEPOLARISATION

Indoor environments typically present large multipath phenomena, which are the main trouble when planning a wireless network. However, the depolarisation induced by transmission of waves across the walls (or by reflection on the walls) is not commonly taken into account during the planning procedure. And it could be useful to improve the performance of the receiving signal if a polarisation diversity technique is implemented at the reception end.

This section deals with the fundamentals of depolarisation and the depolarisation indexes used to processing the results.

3.1 Depolarisation Phenomenon

A phenomenon associated to reflection, the depolarisation that could be generated when a wave beats a flat obstacle, appears to be not so fine defined and modelled as the reflection itself. This is probably because typical planning tools, as ray-tracing, were initially created to be used at frequencies corresponding to cellular phone or television broadcasting, at which the typical obstacles (walls) are electrically flat enough to provide strong specular reflections.

At higher frequencies, the electrical size of a given obstacle becomes larger. At 5.8 GHz, as an example, some simulation tools could not work as well as expected, because when a wave reaches an obstacle, several reflection paths are generated in any directions, not only the specular direction (Cuiñas et al, 2007). And moreover, the obstacle depolarises the wave in a certain percentage, which is not commonly considered in such prediction tools.

3.2 Depolarisation Indexes

The depolarisation index, for any material, at any angle of incidence and any polarisation of the transmitted waves is the fraction of the power of this wave that is received in the orthogonal polarisation. From this definition, depolarisation indexes may be computed by means of a matrix procedure (Cuiñas et al, 2009).

The depolarisation indexes for the reflection mechanism, computed in the specular direction, are summarized in table 1. The values depend on the polarisation of the incident wave, which is denoted by “h” when it is horizontal and “v” when vertical. The specular situation is adequate to define very good reflectors, which reflect most of the incident wave towards the opposite direction, being the normal to the surface the axis of symmetry.

The results of table 1 indicate that brick wall provides reduced depolarised waves compared to the co-polar reflected waves in the specular direction. The other considered materials provide depolarised waves up to 9.8% compared to the co-polar one.

But when a more complex analysis is expected, as it is the situation of the present paper, all scattering directions have to be considered, and not just specular one, because the reflector could be randomly located and oriented.

Table 1: DI (%) induced by reflection, in the specular direction of observation.

Material	Incidence angle (deg)	DIh	DIv
Brick wall	10	0.31 %	0.48 %
	20	0.66 %	0.19 %
	30	0.67 %	0.65 %
	40	0.72 %	0.75 %
Chip wood	10	4.57 %	4.66 %
	20	9.80 %	8.20 %
Stone and concrete facade	10	2.12 %	1.57 %
	20	5.31 %	1.27 %
	30	1.80 %	3.60 %
	40	5.27 %	3.74 %
	50	9.27 %	8.38 %

With this aim, median depolarisation indexes for each material at all pair of angles of incidence and observation are provided in table 2.

Table 2: Median DI (%) induced by reflection.

Material	DIh	DIv
Brick wall	23%	30%
Chip wood	18%	18.5%
Stone and concrete facade	4.5%	4%

Once the complete (180 degree) observation arc, not just the specular angles, is introduced, the depolarisation indexes grow, and differences between incident polarisations also appear in the brick wall case. The brick wall is the more non isotropic material among the considered, as it presents a clearly oriented structure, whereas the chip wood panel and the stone and concrete facade are the result of the solidification of a mass, which is expected to present a more isotropic behaviour. The high median values of depolarisation indexes indicate that high depolarised waves could be generated when several scatterers are present in an environment, which is the case of indoor scenarios.

Furthermore, the transmission mechanism across walls induces depolarisation. In this case, and focused on the environments under test, the interest is mainly the depolarisation by transmission across a brick wall with normal incidence. The measured value for DI at such situation was 9.4 %, considering transmission with vertical polarisation.

4 PROCESSING

As measurements have been done following a wide band scheme, information about the multipath components can be obtained from the outcomes. Knowing the multipath scheme, or the power-delay profile (PDP) in the co-polar installation, it is possible to compute a synthetic mirror (another PDP) in the cross-polar domain.

Then, each couple of PDPs (co-polar and cross-polar) could be the input of a diversity block, which provides a new received signal with better performance than just the co-polar one.

The following subsections contain the computation of these cross-polar PDPs as well as the results of applying different diversity techniques at the reception end.

4.1 Effect of the Multipath in the Total Received Power

The receiving antenna at each measuring location is reached by the direct ray, which links the transmitting and the receiving antennas following the shortest path. But that antenna is also reached by several contributions coming from paths generated by reflections on the walls and, perhaps, transmissions across some wall. The received power from each contribution, associated to the time delay relative to the direct ray arrival time, construct the PDP. This profile defines the multipath environment at each reception location.

Commonly, this PDP is shaped by the antenna pattern. In this case, with azimuth omnidirectional antennas, most of the PDP is due to the multipath, and only a few part could be defined by the elevation pattern of the antenna. Consequently, the PDP used along this work could be assumed as the product of the environments where the measurements were performed.

4.2 Computation of Cross Polar Received Power

The measurement outcomes are complex frequency responses between 5.72 and 5.88 GHz, and they have a shape as depicted in figures 6 and 7, which contain the amplitude and the phase respectively.

If only waves following the direct path arrived the receiving antenna, the amplitude of the frequency response would be approximately flat. In fact, it would be locally flat, but it would be smaller at higher frequencies than at lower. The behaviour of the phase would be expected to be linear. Evidently, if we observe figures 6 and 7, the amplitude is not flat and the phase is not linear, which indicates the presence of multipath components.

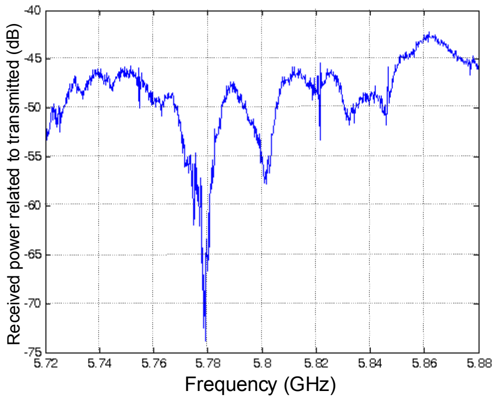

Figure 6: Example of the amplitude of the complex frequency response.

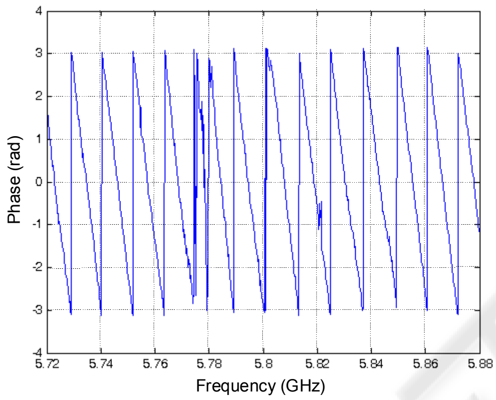

Figure 7: Example of the phase of the complex frequency response.

Applying an inverse fast Fourier transform to each complex frequency response, this can be turned to the time domain, with a resolution of 6.25 ns between adjacent samples. Figure 8 depicts an example.

At this time response, the different contributions after one, two, three, or more reflections can be identified, using an inverse ray tracing procedure. Once the contributions have been classified in terms of the number of reflections on the walls before they reach the receiving antenna, the orthogonal contributions at each delay can be computed.

Firstly, the path followed by each multipath contribution has to be identified, and the walls that generated each reflection or transmission mechanism have to be categorised. Depending on the material that constitutes the wall, the angle of incidence and the frequency, a total depolarisation index (TDI) can be obtained. Mean values, used along computation, are summarised in table 3.

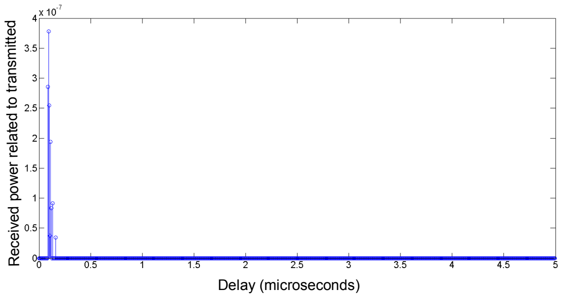

Figure 8: Example of time response.

The direct path contribution TDI needs a supplementary comment. In LoS conditions, this TDI depends on the depolarisation induced by both antennas. In NLoS conditions, and additional depolarisation due to the transmission across the wall separating both rooms has to be considered. When dealing with OLoS (furnished) environments, we decided to take into account only the effect of the antennas.

Table 3: Mean TDI (%) at different environments.

Environment	Multipath contribution			
	Direct	1 ref	2 ref	3 ref
1, LoS	1.8	0.75	1.5	24.6
2, NLoS	9.4	15.8	24	32.2
3, LoS	1.8	0.75	1.5	24.6
4, LoS	1.8	8.2	16.4	24.6
5, OLoS	1.8	8.2	16.4	24.6

If the total power ariving the receiver antenna at each time delay represents 100%, the co-polar contribution would be (100-TDI)%. The collection of co-polar contributions represent the measured PDP, which is the basis to compute the cross-polar PDP. Obviously, the cross-polar contributions at each delay would be TDI %.

Consequently, the procedure to compute the cross-polar contribution is:

1. Compute the co-polar PDP from the measured frequency response.
2. Calculate the total power at each delay, based on the correspondent TDI.
3. Obtain the cross-polar power at each delay.
4. Combine the collection of delays to obtain the cross-polar PDP.

4.3 Polarisation Diversity at Reception

Once the co-polar and cross-polar PDPs have been computed at each receiving location, different polarisation diversity technique schemes have to be applied to each couple of data.

The three tested combination schemes are:

1. Sum, where the final signal could be the sum of both input signals.
2. Mean, where the final signal is the average of both inputs.
3. Switching, where the diversity device swicths between both channels in order to get the maximum at each instant.

After application of these diversity schemes at all the receiving locations, the results are prepared to be analysed.

5 RESULTS ANALYSIS

The application of diversity techniques provides improvements in the received power signal. Among the three considered schemes, the combination by sum appears to perform better than the other pair, and it offers enhancements as summarised in table 4.

Table 4: Estimation of the mean improvement by polarisation diversity at different environments.

Environment	Improvement (%)
1, LoS	17.89
2, NLoS	23.29
3, LoS	10.18
4, LoS	18.51
5, OLoS	21.23

Considering each environment separately, the maximum improvement receiving location, the minimum, the mean and the range of improvements along the receiving path can be analysed.

Table 5 contains the data for the environments 1 and 2, which allows the comparison between LoS and NLoS situations within similar rooms. The improvement in terms of received power appears to be larger when there is no line of sight between transmitter and receiver, with a mean of 23.29%. Analysing the maximum and minimum improvements, the application of polarisation diversity appears to be more advantageous in NLoS conditions: the enhancement is, at some points, only 2% in LoS conditions.

Table 6 makes available the data to compare the effect of polarisation diversity at reception as a function of the size of the indoor environment, in LoS conditions (environments 1, 3, and 4). The first comment is that improvements are detected at every room, but the performance of the networks installed in large, and even long, rooms appears to be more enhanced than in small rooms. Besides, the receiving locations where less enhancement has been detected present values under 4%.

Table 5: Comparison between LoS and NLoS.

Environment	Improvement (%)			
	Mean	Max.	Min.	Range
1, LoS	17.89	32.28	2.00	30.28
2, NLoS	23.29	37.23	10.38	26.85

Table 6: Comparison among different size rooms.

Environment	Improvement (%)			
	Mean	Max.	Min.	Range
1, large	17.89	32.28	2.00	30.28
3, small	10.18	31.94	1.60	30.34
4, long	18.51	56.04	3.46	52.58

Table 7 contains the comparison between furnished (OLoS) and empty (LoS) environments performance. Both data come from the same room, but changing the contents. In presence of furniture, the polarisation diversity technique works better, as it provides larger signal enhancements, even although no obstacles block the line of sight between transmitting and receiving antennas.

Table 7: Comparison between empty (LoS) and furnished (OLoS) situations.

Environment	Improvement (%)			
	Mean	Max.	Min.	Range
4, LoS	18.51	56.04	3.46	52.58
5, OLoS	21.23	32.01	5.28	32.01

6 CONCLUSIONS

The improvement in the performance of wireless networks by polarisation diversity has been estimated from radio channel measurements in the 5.8 GHz band. Measurements at only one polarisation were carried out. The cross-polar responses of the channels have been computed from these co-polar data, using depolarisation indexes.

The newness of the proposal is the analysis of polarisation diversity at several scenarios based in just one polarisation measurements.

Although three possible strategies for implementing the polarisation diversity have been taken into account, the main improvements were provided by combination by sum scheme.

The presence of obstacles (when dealing with obstructed line of sight situations), and mainly the absence of line of sight (NLoS situations), leads to larger improvements in the performance provided by the polarisation diversity. Even in LoS situations, the improvements are noticeable. They are over 23% in terms of power at NLoS environments, but the minimum mean improvement has been estimated in 10%, which are interesting values for planning.

The proposal of using polarisation diversity in reception could be of interest for network designers, mainly in such environments where fading due to multipath is especially deep.

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