Multipath modelisation of typical indoor environments optimisation of GNSS based indoor positioning

Anca Fluerasu, Nabil Jardak, Marco Boschetti, Nel Samama

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Optimisation of GNSS Based Indoor Positioning

Anca Fluerasu, *Institut TELECOM, TELECOM & Management SudParis, France*
Nabil Jardak, *Institut TELECOM, TELECOM & Management SudParis, France*
Marco Boschetti, *CNES, Toulouse, France*
Nel Samama, *Institut TELECOM, TELECOM & Management SudParis, France*

BIOGRAPHY

Anca Fluerasu graduated from "Politehnica" University of Bucharest, Romania, in 2000, and received a Ph.D. degree in 2003 from the University of Marne-la-Vallee, France, working on the characterization of millimeter-waves propagation. She is currently an Associate Professor at Institut TELECOM, TELECOM & Management SudParis (IT-SudParis) and member of the Navigation Group in the Department of Electronics and Physics. Her main research interests are in electromagnetic theory, antenna design, and propagation modelling within indoor environments.

Nabil Jardak received his engineering diploma in Telecommunications in 2005, and a Masters degree in the Architecture of Telecommunication Systems in 2006, both from the "Ecole Supérieure des Télécommunications de Tunis", Tunisia. He worked on future GNSS signals and indoor positioning methods. He is currently a Ph.D. student at IT-SudParis and a member of the Navigation Group. His current interests are related to GNSS repeater based indoor positioning and more specifically to GNSS receiver architecture.

Marco Boschetti graduated as telecommunications engineer from UPC (Universidad Politécnica de Cataluña) in Barcelona and aerospace engineer from the ENSAE (Ecole Nationale Supérieure de l'Aéronautique et l'Espace) in Toulouse. He is responsible for GNSS simulation tasks in the Localisation & Navigation System Engineering Department at CNES in Toulouse.

Nel Samama is a member of the Navigation Group at IT-SudParis. He has been working for many years in the GPS field, on projects such as the development of new communication schemes and indoor location techniques. His current interest is to find a simple approach for a standard GPS receiver to enable indoor positioning.

INTRODUCTION

The present paper describes a detailed numerical simulation study of indoor propagation carried out in order to evaluate multipath effects on the GNSS repeater based approach in various environments. Previous work [1] studied multipath effects in a very restricted area of about 50 square meters with metallic walls. The goal of the present paper is to provide the required complementary information to evaluate the multipath problem in typical indoor environments and to propose some directions of optimisation.

The theory of the GNSS repeater based approach, together with experimental results validating its principle, was presented in a previous paper [2]. The main idea of this method consists in using GNSS repeaters in a sequential mode in order to carry out measurements of code phase jumps at the instant of transition from one repeater to the next. Once obtained, three such jumps allow the indoor location calculation, through a classical GNSS computation.

As often in indoor environments, the GNSS repeater based approach is strongly affected by multipath, the main problem being that the multipath effects are difficult to evaluate and/or minimize. In order to carry out multipath evaluation and optimisation, we use a deterministic propagation simulation software called Ergospace. Some extensions and customized features of the simulation package were developed to make the software more suitable for the GNSS repeater approach. For a given receiving position the software calculates all the possible paths (direct, reflected, transmitted and/or diffracted) propagating between each transmitting repeater and the receiving antenna. These simulated paths are furthermore set as input for a Matlab/Simulink GPS receiver simulator which evaluates the error on the code phase jumps caused by the multipath. Direct comparisons between simulated code phase jumps (converted into distance) and the real distance separating the receiver from each transmitting repeater will be presented and discussed in this paper.

The paper is organized as follows. The first section presents the main features of the software used in order to carry out propagation simulations. The use of the two modules of Ergospace (Outdoor and Indoor) will be detailed here, together with the description of the input and output data. Section 2 describes the simulation configurations: first, the indoor environment characterization is presented and then the antennas used for the simulations are described (indoor receiving antenna and repeaters transmitting antennas). Section 3

presents the numerical results. The impact of two different types of repeaters will be compared and discussed. Finally, a possible determination of criteria for an optimised deployment, depending on the environment, for both repeater and receiving antennas will be discussed in conclusion.

MULTIPATH PROPAGATION SIMULATION SOFTWARE

The Ergospace software [3] simulates electromagnetic signal propagation in 3D environments and allows replacing long and expensive measurements campaigns.
The whole propagation environment (outdoor and/or indoor) is completely described using VRML (Virtual Reality Modeling Language), each surface or object being characterized by its geometrical and electrical properties.
The propagation is determined using the deterministic Ray Tracing technique. These "ray-based" deterministic techniques consider that electromagnetic fields propagate along geometrical optics rays, which can be easily reflected or transmitted by infinite plane interfaces. In the presence of obstacles of finite dimensions, additional rays account for diffraction effects, using for instance the uniform theory of diffraction. In free space, only one ray contributes to the field at a receiving point. In a multireflecting environment however, several "rays" or "paths" starting from the same source point can reach the same receiving point, due to the reflections or transmissions on the environment components. Ray Tracing algorithms are evaluating the field at the receiving point by following all the possible rays starting from the source and reaching this point.
Ergospace takes into account all the elements concerning the satellites, the antennas and the environment, and can be used for both static and dynamic simulations. In this paper, only static configurations will be studied.
In order to consider multipath, the interactions (reflections, transmissions and diffractions) between rays and the considered environment are calculated. The maximum number of authorized interactions must be specified at the user level, and Ergospace calculates the multipath which appears as a consequence of these interactions.

The software is divided in two parts, the Outdoor Module and the Indoor Module.
The first module is used to determine the propagation between satellites and the outdoor receiving antenna. The input parameters are the satellite almanacs, the considered environment and the outdoor antenna characteristics (position, orientation and pattern). At the output of this module we obtain all the geometric and electromagnetic characteristics of each path from the satellites to the outdoor receiving antenna. The signal created by these paths is then transmitted to the repeaters through a sequential switcher.
The propagation between the repeaters and the receiving antenna is determined using the Indoor Module. Indoor transmissions are characterized by numerous errors due to multipath propagation. The electromagnetic model used in this module is more accurate than the one used in outdoor simulations. The input data consists in the parameters characterizing the environment and the characteristics of the repeaters and the indoor receiving antenna (position, orientation, and pattern).

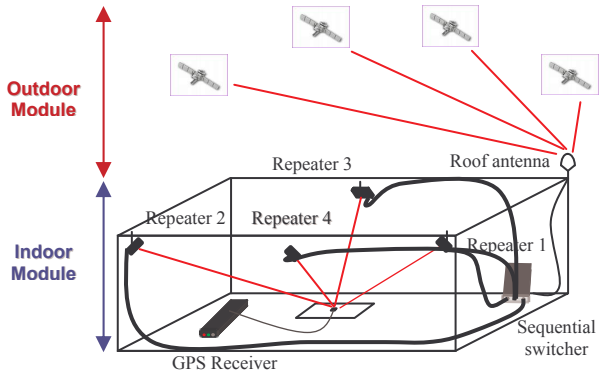

Fig. 1: General architecture of the use of Ergospace

The Ergospace software outputs a file containing the estimates of the multipath parameters values (power level, propagation delay, Doppler shift and carrier phase). This file is used as input for a GPS receiver simulator described in [1]. The GPS receiver simulator, implemented using Matlab/Simulink, is used in order to estimate the error caused by the multipath.

SIMULATION CONFIGURATIONS

Indoor environment characterization

The considered indoor environment is the main hall of the IT-SudParis building, as shown in Fig. 2. The dimensions of the hall are 15m x 70m with a ceiling height ranging between 3.6m (at the extremities) and 7.6m (in the middle). It should be noticed that the environment is quite particular, since there are many metallic objects inside (columns, walls, ceiling, different structures on the ceiling and in front of the windows,…).

Fig. 2: The main hall of the IT-SudParis building

The whole environment was completely described using VRML, each surface encountered (wall, ceiling or floor) being characterized by its geometrical and electrical properties. The most important objects as well as the furniture presented in the environment were taken into account in the description. Fig. 3 shows the global VRML description of the considered environment.

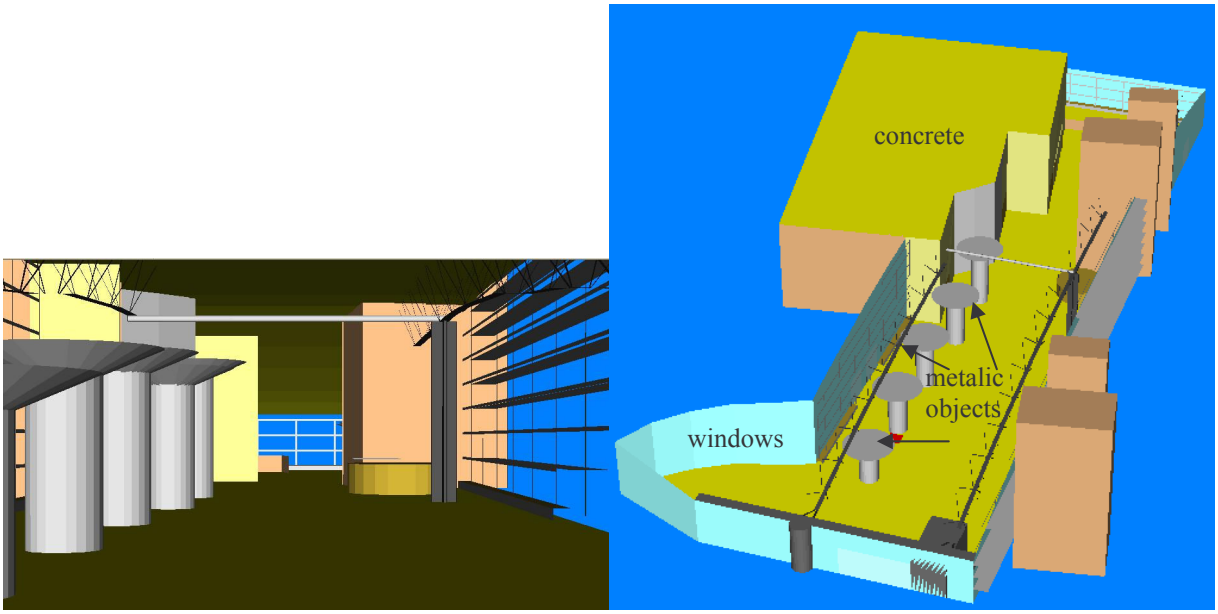

Fig. 3: Global VRML description of the main hall of the IT building

The electrical characteristics of the materials encountered in the environment have been extracted from the literature [4,5], or measured, and are shown in Fig. 4.

Material	Conductivity	Permittivity
Aluminium2	5e+007	1
Aluminium3	5e+007	1
Beton	0.0389	7
Brick2	0.001	4.44
Concrete2	0.2	4.53
Glass2	0.35	6.06
Glass3	0.35	6.06
Metalic Wall2	3000	1
Plasterboard2	0.01	2.02
Steel	4.8e+006	1
Wood2	0.2	2.88

Fig. 4: Material characteristics used in the VRML description

Antenna characterization

Indoor receiving antenna

The indoor receiving antenna is a typical omidirectional automotive Trimble active antenna with a magnetic mounting (more details are given in [1]). The maximum gain is 29 dB, including the Noise Amplifier.

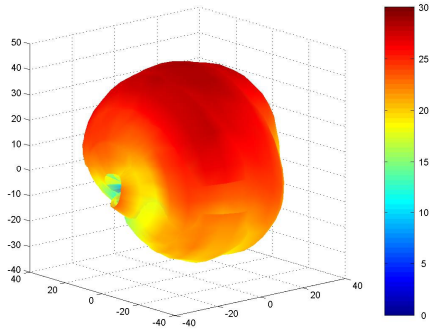

Fig. 5: Measured 3D radiation pattern of the indoor receiving antenna

Repeater antennas

The two sets of repeaters used in the simulations are composed of four identical antennas, and are described below.

Patch repeater antennas

The first set of repeaters is composed of 4 passive Macon antennas, each one mounted on a ground plane of 10 by 10 cm, in order to avoid cable effects and backward radiation (for more details see [1]).
Antenna pattern measurements performed at 1575.42 MHz in anechoic chamber show a maximum gain of 4 dB, and a radiation concentrated upwards (due to the ground plane effects).

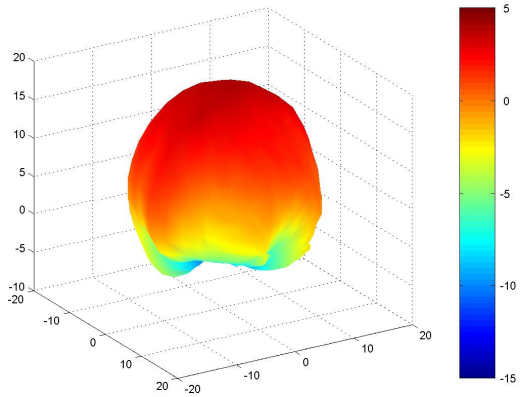

Fig. 6: Measured 3D radiation pattern of a patch repeater

Helical repeater antennas

The second set of repeaters used in the simulations is composed of 4 Tecom helical antennas (see Fig. 7), more directive than the patch antennas. The maximum gain is 13.2 dB, with a 32° half-power beamwidth.

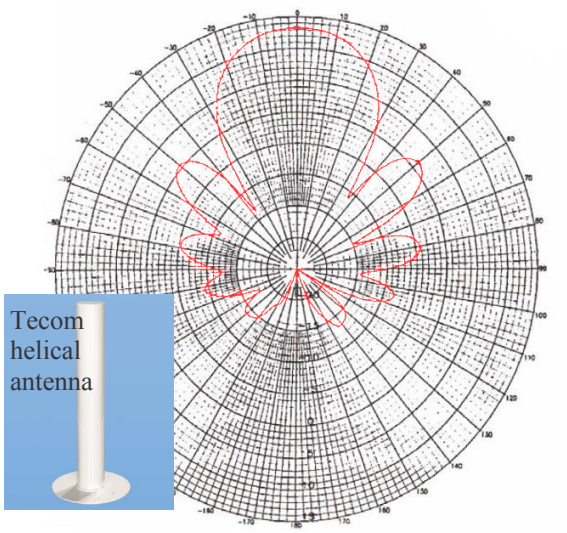

Fig. 7: Tecom directional helical antenna repeater and radiation pattern

NUMERICAL RESULTS

In order to study the influence of the repeater antenna pattern on the positioning precision we compared the results obtained using two different types of repeaters (the patch and the helical antennas described above). Fig. 8 shows the comparison between the patch and the helical repeaters antenna pattern. One can clearly observe on the figure that the helical pattern is more directive than the patch pattern (with a 32° half-power beamwidth compared to approximately 120° half-power beamwidth for the patch antenna).

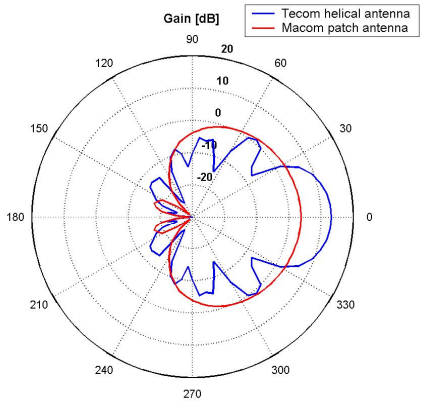

Fig. 8: Helical and patch repeater antenna pattern

We performed indoor propagation simulations at 1575.42 MHz in the main hall environment presented in Section 2. The indoor receiving antenna is the Trimble active antenna and the emission power of the repeaters is set to -60 dBm. The simulation analysis considers all combinations of reflections (between walls, objects surfaces, floors and ceilings) and transmissions until a maximum number of interactions is reached. We set the maximum number at 2 reflections and 2 transmissions per path.

The repeaters are located at different heights (Tx1, Tx2, Tx3 and Tx4 in Fig. 9) in order to provide a good VDOP, and are pointing towards the direction represented by the blue arrow in Fig. 9 (downwards for Tx1 and Tx4, and at a 45° angle with respect to the vertical direction for Tx2 and Tx3).

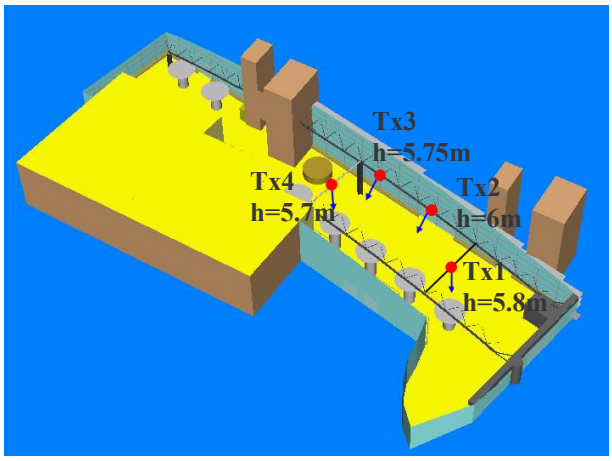

Fig. 9: The repeaters antenna positions

The receiving antenna is located at 1.6 meters above the floor, fixed on a plastic mounting and pointing towards the Oz axis (upwards), as shown in Fig. 10.

Fig. 10: Mounting of the receiving antenna

The receiving antenna positions studied for this configuration are denoted by Rx1 to Rx11 in Fig. 11. The main reason for choosing these positions was to provide a large variety of propagation scenarios. We have for example situations where the receiving antenna is close to a very reflecting object (as in the Rx5, Rx9 or Rx10 positions), or where the receiving antenna is close to a repeater but far away from the others (like Tx2 who is pointing directly towards Rx4 and Rx2).

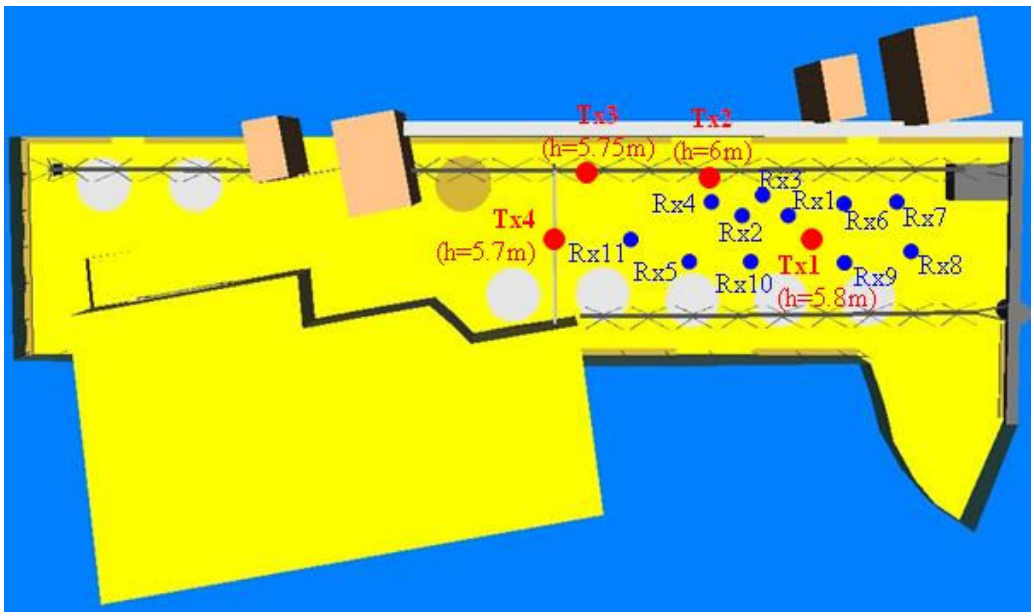

Fig. 11: The receiving antenna positions

Multipath propagation simulations were performed for each of the 11 receiving positions described in Fig. 11 (Rx1 to Rx11), using the Indoor Module of Ergospace. As explained before, the software outputs a file containing the characteristics of the paths propagating between each repeater and the receiving antenna. In post-processing, using Matlab, we obtain the power-delay profile for each configuration "repeater Tx_i – receiving antenna" (i ranging from 1 to 4). Taking the dimensions of the environment into consideration, some preliminary simulations showed that significant multipath components have excess delay (delay beyond the LOS delay) less than 150 ns (propagation along a 45 meters path). The power-delay profiles obtained using Matlab will be thus represented below over a 50 meters spread.
The power, propagation delay, Doppler shift and carrier phase of each path are used as input for the simulated Matlab/Simulink GPS receiver described in [1] in order to estimate the error on the distance prediction caused by the multipath.

Table 1 shows the simulated distances between each repeater and the indoor receiving antenna. We denote here with *di* the distance between the repeater Tx_i (i=1:4) and the indoor receiving antenna. The results are presented for both patch and helical antenna repeaters.

The error between simulations results and the real distance between the repeater Tx_i (i=1:4) and the receiving antenna is given by

$$dist\_error = (d_i)_{sim} - (d_i)_{real} \qquad (1)$$

and is presented in Fig. 12, for each receiving position (Rx1 to Rx11).

Position	Real distance [m] Simulated distance [m] (patch repeaters) Simulated distance [m] (helical repeaters) d1	d2	d3	d4
Rx1	4.6615	8.6835	15.5027	17.0226
	5.0991	9.9638	19.5466	38.1554
	5.6676	9.9052	22.2720	35.1077
Rx2	7.0520	5.3294	10.8782	12.2788
	3.9855	5.6266	13.2460	14.4475
	6.6757	5.3294	5.3336	14.8871
Rx3	6.2394	6.8119	13.3767	15.4974
	7.9710	8.5571	11.3118	15.2387
	10.4034	8.4692	10.9308	16.0300
Rx4	8.9404	4.5280	8.9014	10.6850
	9.0553	4.5280	6.7402	4.8148
	3.5518	4.5280	17.2901	3.0184
Rx5	9.7739	8.3488	10.9834	9.8168
	9.7739	10.9015	14.0665	14.0665
	13.9786	10.8429	15.1215	22.4185
Rx6	5.4342	10.2520	17.2868	19.0885
	4.8295	13.2753	15.1215	23.8545
	12.3463	16.5868	15.7662	24.0304
Rx7	9.2698	15.8588	23.1351	24.9233
	4.4603	14.3596	30.6533	27.5469
	16.6747	15.5904	26.4626	25.6128
Rx8	9.8656	17.8438	24.9627	25.8064
	11.9272	12.3082	24.8215	26.9608
	13.1580	22.6529	24.4699	26.3747
Rx9	5.4342	12.3977	18.8318	19.0885
	12.6305	13.7735	6.9746	21.8324
	12.3375	12.2203	32.8219	22.4478
Rx10	6.7179	8.9052	13.7926	13.4004
	8.3227	3.1357	16.8798	14.5647
	11.1360	5.8610	14.8578	15.4731
Rx11	11.1234	6.6032	7.8061	7.6007
	15.1215	3.0829	10.9895	11.3411
	19.0191	3.9738	9.7879	14.1837

Table 1: Distances between the transmitting repeaters and the receiving antenna

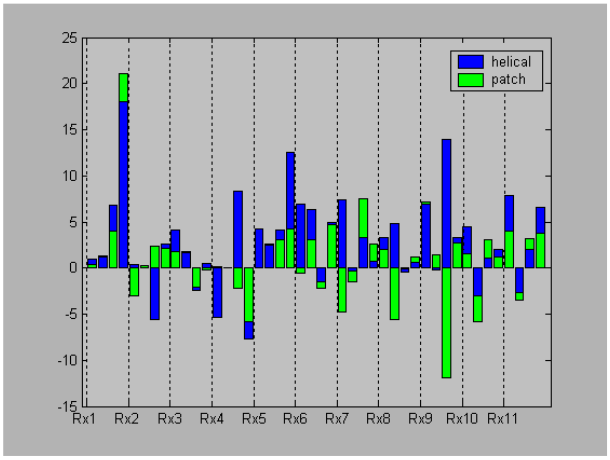

Fig. 12: Error on distance given by Eq. 1

From Fig. 12 one can draw some conclusions.

First, we can notice that in general the patch antenna repeaters seem to give better results in terms of positioning precision. The error obtained while using the helical repeaters is often very important. If we study repeater by repeater the error on the prediction of the distance, we can see that the error is generally minor while the repeaters Tx2 and Tx1 are transmitting. On the contrary, the error is very important while the repeater Tx4 is transmitting, since all the receiving points are distant. We study below some particular situations.

- *situations where both patch and helical repeater antennas give good results*

We can observe from Fig. 12 that in general both repeater antennas give good results while the repeater Tx2 is transmitting. The average error obtained while Tx2 is transmitting is 2.5m/receiving position for the patch repeater situation, and 2.1m/receiving position for the helical repeater situation. We present in Fig. 13 the power-delay profile for a typical "good" configuration, where the error on the prediction of the distance is negligible.

It's obvious from Fig. 13 that this situation is an "easy" case, since the only significant path is the direct one. A minimal error on the estimation of the distance is then expectable, and can be verify on Fig. 12.

We can also observe that in this configuration the power level of the direct path is quite similar between the simulations with the patch repeaters and the simulations with the helical repeaters. This appears as a consequence of the high-directivity of the helical antenna, and of the fact that the maximum gain direction is pointing towards a 45° angle with respect to the vertical direction (while the receiving position Rx4 is in a 15° direction). We have thus a transmitting helical antenna gain of 1.5dB – corresponding to a 30° direction (instead of 13.2 dB in the maximum direction, as can be seen in Fig. 7). The patch antenna gain in the 30° direction is 1dB higher than the helical antenna gain in this direction (see Fig. 8), so the power level of the direct path is 1dB higher while using the patch antennas.

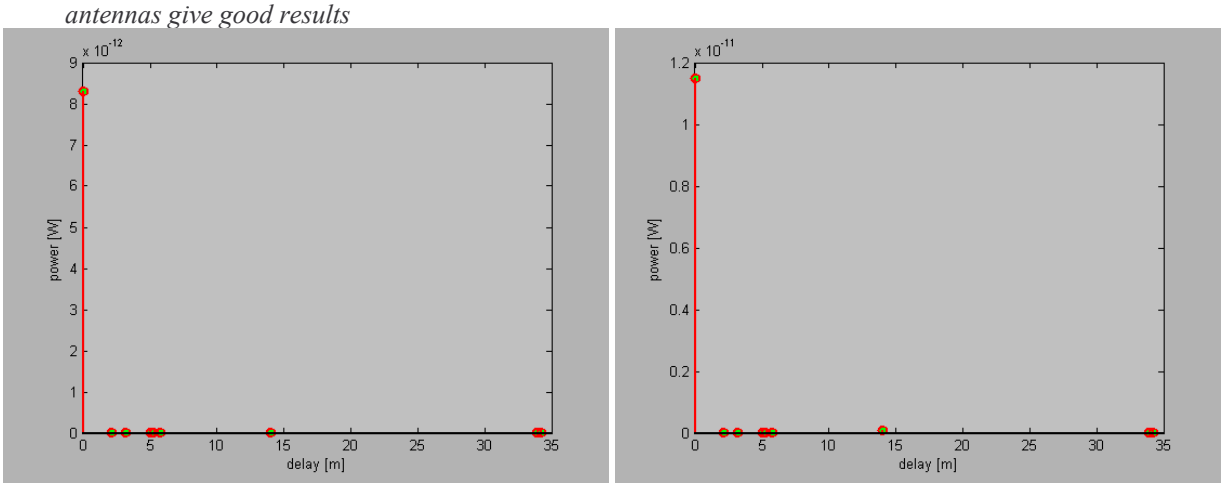

Fig. 13: Power-delay profile for the position Rx4 while repeater Tx2 is transmitting (left – helical; right – patch)

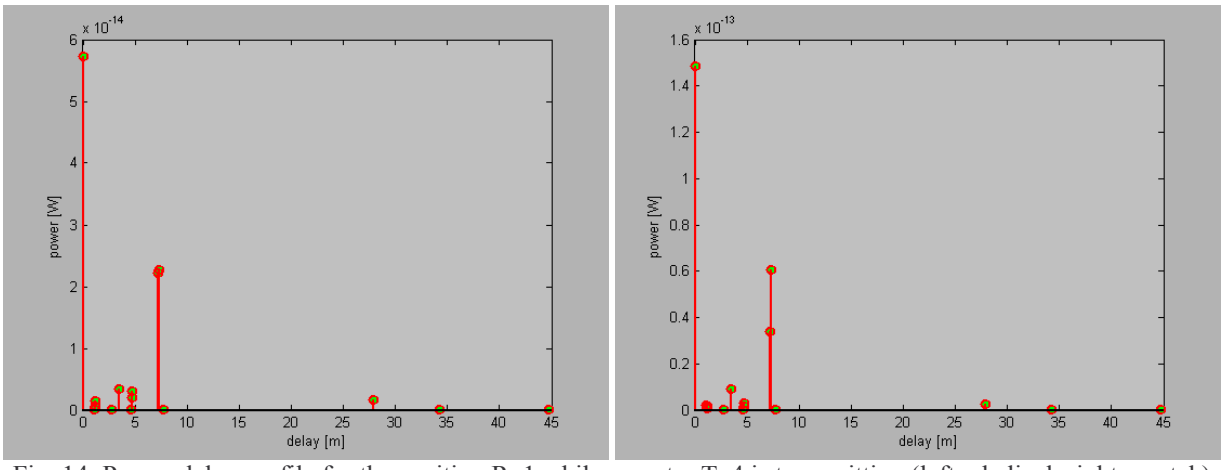

Fig. 14: Power-delay profile for the position Rx1 while repeater Tx4 is transmitting (left – helical; right – patch)

- *situations where both patch and helical repeater antennas give bad results*

We can see from Fig 12 that in some configurations, both patch and helical repeaters create an important error on the prediction of the distance. Two examples of such a situation are the position Rx1 while repeater Tx4 is transmitting and the position Rx9 while repeater Tx3 is transmitting.

We can see from the power-delay profiles in Fig. 14 that two strong multipath with a short delay (approximately 7 meters) occur in both situations. Previous work [1] showed that a multipath with short delay (ranging between 1 and 6 meters) creates an acceptable error if the power level is small enough compared to the level of the direct path (approximately 10dB less). But in the present situation the power level of the multipath is quite important (3dB less that the direct path power level), and the error on the prediction of the distance is very important (approximately 20 meters, less in the case of helical repeaters).

The receiving antenna at the position Rx9 is close to a metallic column, as can be seen in Fig. 11, so multipath will be reflected on the surface of the column and thus they will have a significant power level (see Fig. 15). The error on the prediction of the distance is then important.

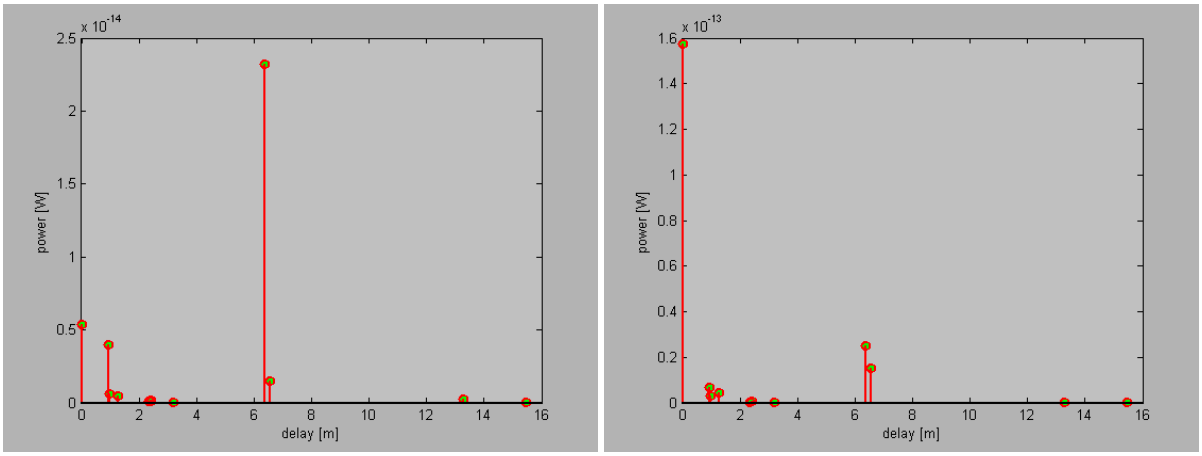

Fig. 15: Power-delay profile for the position Rx9 while repeater Tx3 is transmitting (left – helical; right – patch)

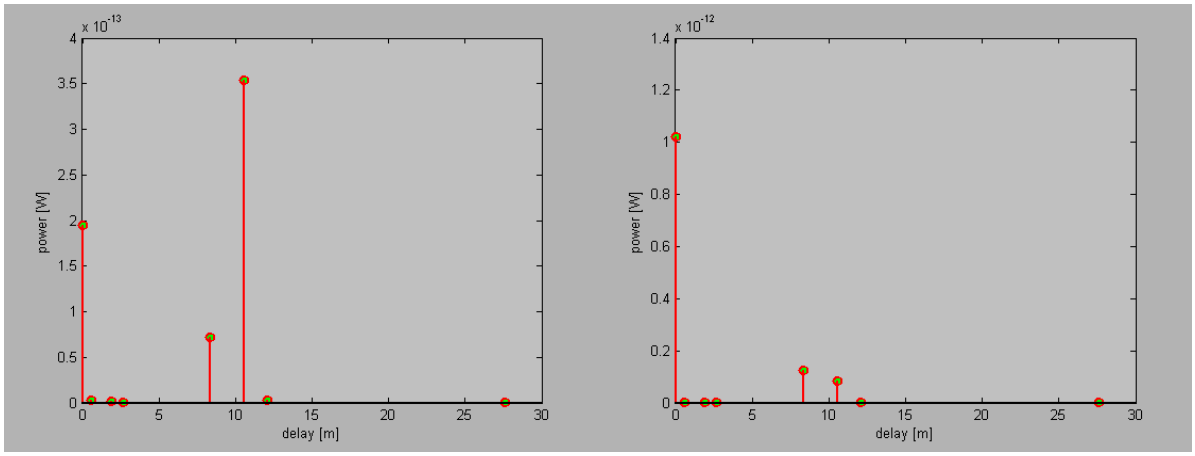

Fig. 16: Power-delay profile for the position Rx4 while repeater Tx1 is transmitting (left – helical; right – patch)

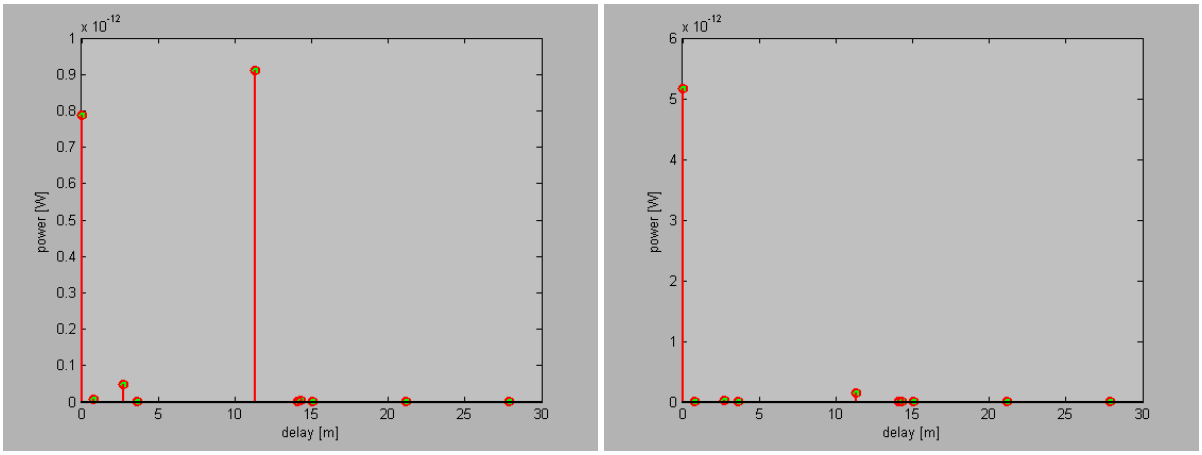

Fig. 17: Power-delay profile for the position Rx6 while repeater Tx1 is transmitting (left – helical; right – patch)

- *situations where the patch repeaters give better results than the helical repeaters*

This is the case for most of the configurations presented above, especially while the repeater Tx1 is transmitting. Fig. 16 and 17 show the power-delay profiles in two such situations.
In both configurations we can observe a significant multipath around 10 meters in the case of helical repeaters, while the power-delay profile for patch repeaters presents only the direct path and some low power multipath. The error on the prediction of the distance is then important for the helical repeaters, and minor for the patch repeaters, and can be seen in Fig. 12.
The higher directivity of the helical repeaters can be useful in order to minimize the multipath effects if they are used in a good way. In order to obtain a good accuracy the receiving position should be located in the area covered by the major lobe of the antenna pattern. The simulation presented in Fig. 18 illustrates this fact. We performed a simulation in the same configuration as in Fig. 17 (position Rx6 with helical repeater Tx1 transmitting), but the repeater was pointing directly towards the receiving position.

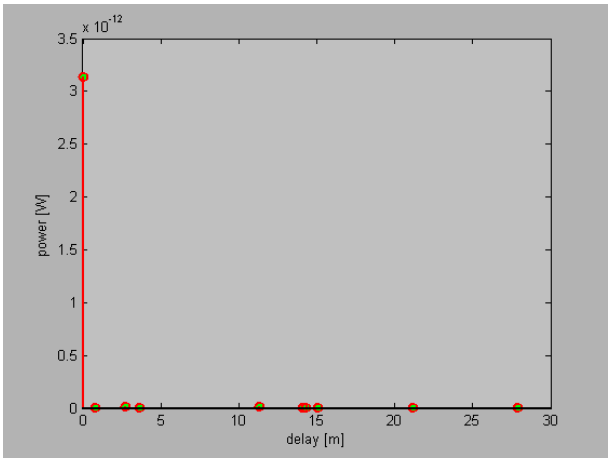

Fig. 18: Power-delay profile for the position Rx6 while repeater Tx1 is transmitting (helical antenna pointing towards the receiving position)

One can clearly see that the multipath occurring in Fig.17 became negligible, and the only path with a significant level is the direct path. The error on the prediction of the distance will thus be improved.

- *situations where the helical repeaters give better results than the patch repeaters*

There are only a few such configurations, occurring especially while repeaters Tx2 or Tx3 are transmitting. The helical repeaters can give better results if the receiving antenna is located in the area covered by the major lobe of the antenna pattern, or if the higher directivity of the pattern decreases the effect of some important multipath. One example of such situation is the Rx7 position of the receiving antenna while the repeater Tx3 is transmitting (Fig. 19). In this configuration the repeater emits the power in the direction of the receiving antenna according to an angle of 80°. We can see from Fig. 8 that in this direction the patch antenna gain is more important than the helical antenna gain (approximately 5dB of difference). This difference can be seen in Fig. 19 if we compare the power level of the direct path on the two power-delay profiles. But the most important here is that the helical antenna pattern, due to its shape, minimizes the multipath at 10 meters, which allow to decrease substantially the error. This multipath arises from the transmitter along a 65° direction. It can be seen in Fig. 8 that in this direction the helical antenna gain is less important than the patch antenna gain (with approximately 15dB of difference). We obtain in the case of helical repeaters a multipath with a power level of 15dB lower than in the case of patch repeaters, and consequently a less important error on the prediction of the distance (3 meters instead of 7.5 meters for the patch antennas).

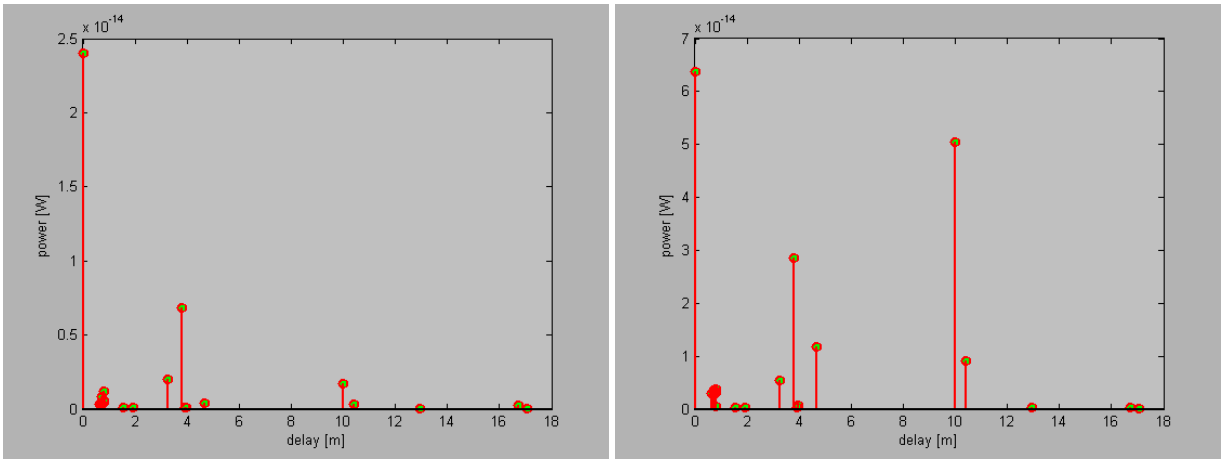

Fig. 19: Power-delay profile for Rx7 position while repeater Tx3 is transmitting (left – helical; right – patch)

CONCLUSION

This paper presents a numerical study of multipath effects on the GNSS repeater based approach. Multipath propagation simulations were performed at 1575.42 MHz in a large hall environment, in order to provide complementary information to the work presented in [1]. Four repeater antennas are transmitting successively, and the paths propagating between each repeater and the indoor receiving antenna were set as input for a simulated GPS receiver. The distance and the power-delay profile were obtained for each configuration "*repeater i – receiving antenna*" (*i* ranging from 1 to 4). We studied a few specific positions of the receiving antenna, and performed comparisons between the results obtained while using patch antennas and helical antennas (with a higher directivity) as repeaters.

The simulations show that in the configurations studied, the patch antennas give in general better results in terms of precision of the positioning. However, this conclusion can not be generalized because it strongly depends on the environment and on the relative position between the receiving and the transmitting antenna, as discussed above.

This results, together with those presented in [1], can be used in order to optimize the deployment of the GNSS repeaters in a given environment. By performing preliminary propagation simulations we can obtain the power-delay profile for a given receiving antenna position. The study of the power-delay profile allows to predict the accuracy of the positioning at the given location. The only required input is the VRML description of the indoor environment and the characteristics of the antennas used. This issue will be studied in more detail in future work.

Similar propagation simulations can also be used to study different configurations, e.g. a situation where the repeaters are located outside the building and are transmitting indoors. Such a deployment can be useful for instance in a situation of emergency for fire brigade or police operations in a building where no on-site repeaters are available. The effect of limited displacements around a given location is also under study in order to evaluate the small scale variations of the multipath. The propagation simulation technique presented here will allow such issues to be studied in a timely and effective manner.

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