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# GNSS transmitter based indoor positioning systems – Deployment rules in real buildings

*Anca Fluerasu, Telecom SudParis, France*  
*Nel Samama, Telecom 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 Télécom, Télécom 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.

**Nel Samama** is 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.

## 1. INTRODUCTION

Indoor positioning appears to be a real challenging topic. Many techniques have been proposed these last ten years, ranging from High-Sensitivity GNSS to sensor networks, through Assisted-GNSS or WLAN based approaches. Nevertheless, no ultimate solution seems yet to provide the answer to the problem, probably crucial to Location Based Services, of continuity of the availability of the positioning from outdoors (where GNSS are such good candidates) to indoors. Current works are mainly oriented towards hybridisation techniques. Our indoor approach is based on a constellation of so-called repeaters transmitting sequentially. Another approach is to implement pseudolite constellations or even what we call repealites (Vervisch-Picois and Samama, 2009).

Since regulations tend to be provided for both repeaters and pseudolites, we carried out indoor propagation simulations, for real environments, in order to define realistic deployments of both systems. Different buildings have been considered and modelled.

Coverage and positioning accuracy results are presented for various hypotheses: full 3D (3D positioning all over the building), 2.5D (2D positioning all over the building and 3D provided only where floor level changes are possible, i.e. near the stairs and the elevators) and only 2D (assuming the floor level is available through another technique). The number of repeaters/pseudolites required for a complete coverage of the buildings is also given and commented (the specific case of the Telecom SudParis campus in France is analysed).

The results presented in the paper are concerning the GNSS transmitter based systems operating in the 1559 – 1610 MHz frequency band (L1).

The paper is organized as follows. Section 2 outlines the main deployment constraints of the GNSS transmitter based indoor positioning system. The repeater situation will be studied here, as well as the pseudolite case. Section 3 presents some first aspects concerning new regulations on GNSS repeaters and pseudolites transmissions. The indoor propagation simulations performed are presented in Section 4. Some particular deployments are studied for the building A of the Telecom SudParis institute and the impact of the new regulatory framework on these solutions is presented and discussed, before concluding.

## 2. GNSS TRANSMITTER BASED INDOOR POSITIONING SYSTEM

### 2.1. Repeaters

The repeater approach is based on the use of GNSS so-called repeaters in order to provide GNSS availability indoors through the way of an amplification of the signals received by an outdoor antenna (typically located on the roof of the building). The complete system, already presented in previous papers (Fluerasu, Jarda, Vervisch-Picois and Samama, 2009), uses four repeaters in order to provide a full 3D 1 to 2 meter accuracy positioning, indoors. The measurements, at

the receiver end, are the pseudo-ranges at the instant of transition from one repeater to the next, the transmission being achieved through a sequential scheme (cycle), with only one repeater transmitting at any given time.

A new receiver architecture was developed in order to improve the accuracy of the phase jump measurements against multipath (Jardak, Fluerasu, Vervisch-Picois, Jeannot and Samama, 2008). The SMICL tracking loop discriminator (Short Multipath Insensitive Code Loop) was developed in order to mitigate the short multipath (with delays of less than 0.5 code chip, 146.5 meters), which are the usual multipath occurring in indoor environments. It has been showed that in order to provide good results, the SMICL loop needs a carrier to noise ratio  $C/N_0 > 40$  dB-Hz.

The deployment of repeater based system should take into account the following main constraints:

A1) At each position within the coverage area the receiver should receive the signals arising from each of the four repeaters in the cycle, in the correct order (Repeater 1 → Repeater 2 → Repeater 3 → Repeater 4).

B1) The received power should be strong enough in order to allow the use in good conditions of the SMICL loop (providing a  $C/N_0 > 40$  dB-Hz).

C1) Outside the coverage area the signals transmitted by the repeaters should not cause harmful interferences with the other GNSS receiver or other systems using the same frequency band. To this end the constraints of the future regulations presented in Section 3.1 should be satisfied.

## 2.2. Pseudolites

From the deployment point of view, the pseudolite based indoor positioning system differs from the repeater based one only in a few aspects.

A2) First, as the pseudolites transmit the signal at the same time, there is no transmission cycle anymore. In these conditions, the equivalent of the A1 constraint of the repeaters deployment is to ensure, at each position within the coverage area, the reception of the signals arising from any four transmitters.

B2) A signal to noise ratio greater than 40 dB-Hz in reception is needed in order to allow the use in good conditions of the SMICL loop, providing an efficient elimination of multipath.

C2) It should take into account the future regulations concerning the emission of GNSS pseudolites.

## 3. REGLEMENTATIONS ON GNSS TRANSMISSIONS

In order to protect the users of various in-band and adjacent band systems, a new regulatory framework on the use of GNSS repeaters and pseudolites is currently discussed.

### 3.1. Reports and regulations on repeater transmission

Regarding the repeater transmissions, a few documents can be found, and are listed below, together with the main suggested limitations.

The 129 ECC (Electronic Communications Committee) Report of the ERO (European Radiocommunications Office), last updated in January 2009 during the Dublin meeting, treats the “Technical and operational provisions required for the use of GNSS repeaters” (see the reference Draft ERO). It is mentioned that in the considered frequency band (1559 - 1610 MHz) there are no other systems and services sharing the band, so a protection should be provided only to the non-participating GNSS users. The most important limitations proposed are the following:

- The overall gain of a repeater (including all the amplifier gains, the outdoor receiving antenna gain, the indoor transmitting antenna gain and the losses) should be limited to a maximum of 45 dB where the indoor transmit antenna gain is limited to +3dB.
- Filtering operations should be performed (with a response centred on the transmitted signal and the half-power points at  $\pm 20$  MHz), providing at least 10 dB of attenuation at the 1610 MHz band-edge.
- It is considered that the repeater system has no effect on the non-participating users if the signal level is less than -140 dBm/24MHz at a distance of 10 meters from the building housing the repeater.

The first limitation gives an idea of the maximum allowed emission power level, which is of about -77 dBm (corresponding to a repeater overall gain of 45 dB), while the last condition indicates the maximum allowed received power level at the protection distance.

In the minutes of the 10<sup>th</sup> FM PT44 meeting held in June 2009 in Mainz (see reference Draft FM PT44), it is mentioned that progress had been made on the development of a regulatory framework for GNSS repeaters, and a new draft report will be submit at a future meeting. Ideas like individual and site-specific licensing for the repeaters operations are under study.

The ETSI (European Technical System Institute) EN 302645 draft on the standardization of the GNSS repeater operation is based on the ECC 129 report and imposes the same limitations about the repeater total gain and the output power limitation (see reference Draft ETSI 302645). Its goal is to fulfil the requirements of the R&TTE directive (see reference R&TTE directive) and to protect the primary service and the radio services in adjacent frequency bands.

The US policy regarding the repeater operations is presented in the NTIA Manual (National Telecommunications and Information Administration)

edited in 2008 and revised in January 2009: “Manual of regulations and procedures for federal radio frequency management” (See reference NTIA Manual). Sections 8.3.28 and 8.3.29 present the regulations concerning fixed and respectively mobile devices re-radiating GPS signals. It is mentioned that only the following parties are allowed to re-radiate GPS signals (under conditions) at  $1575.42 \pm 12$  MHz (L1):

- the agencies and departments of the US Federal Government or under their direction
- parties that have received a license under the Federal Communications Commission rules (see reference FCC rules)
- parties that will be operating GPS repeaters in a shielded room

GPS repeaters are thus not legally sold in the US since the frequency bands they are meant to use are restricted.

### 3.2. Reports and regulations on pseudolite transmission

Regarding the pseudolite operation, ERO (European Radiocommunications Office) provided the 128 ECC Report on compatibility studies between pseudolites and the other services in the RNSS band (see reference Draft ERO). The report analyses the impact of continuously transmitting (cwPLs) and pulsed (pPLs) pseudolites.

It is concluded that, in the 1559 – 1616 MHz frequency band, coexistence between cwPLs and RNSS is feasible under power limitations. The cwPL transmitting power should be adjusted in order to have a received power of less than -120 dBm at the near boundary. This limitation will allow non-participating receivers to operate outside this boundary (it is assumed the area inside the near boundary is not accessible to the non-participating users).

As for the pPLs, the coexistence with the RNSS is possible if the duty cycle of all pulsing pseudolites seen by the RNSS receiver is less than 20%.

The 128 Report was last updated during the meeting in Dublin, in January 2009, but the discussion about the pseudolite operation was opened also during the 10<sup>th</sup> FM PT44 meeting (June 2009), where it was suggested the development of the Report in order to take into consideration new aspects.

## 4. INDOOR PROPAGATION SIMULATIONS

In order to define realistic deployments of both repeater and pseudolite systems and to obtain coverage results, we carried out indoor propagation simulations. Ergospace, the propagation simulation software used, is based on the deterministic Ray tracing technique in order to determine the electromagnetic signal propagation in 3D environments.

### 4.1 Simulation setup

Propagation simulations were performed using Ergospace in the Building A of the Telecom SudParis Institute. The building, of dimensions 34.3 x 16 x 13.3 meters (length - width - height), is composed by 4 floors and is shown in Fig.1. The environment contains all the typical materials (brick, concrete, metal, plasterboard, wood, glass ...).



Fig.1. Building A of the Telecom SudParis Institute

The considered propagation environment is completely described using VRML (Virtual Reality Modelling Language), each object encountered in the environment (wall, ceiling, floor or furniture) being characterized by its geometrical and electrical properties.

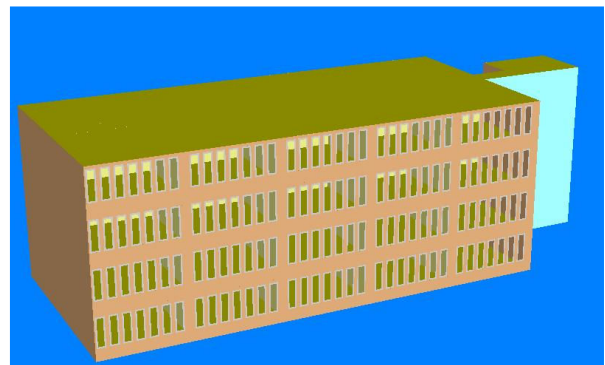


Fig.2. VRML description of the Building A

The software takes also into account all the information about the antennas: position, orientation and patterns of the transmitting and receiving antennas. The considered transmitting antennas are four identical Macon patch antennas, with a maximum gain of approximately 4 dB. The indoor receiving antenna is a typical Trimble active antenna, with a maximum gain of approximately 29 dB, including the Low Noise Amplifier.

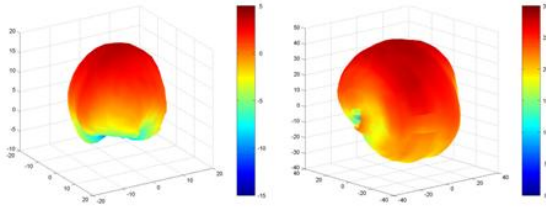


Fig.3. Transmitting and receiving antenna patterns

#### 4.2 Simulation results – Coverage of the building with 4 transmitters

As a first step we will study the feasibility of the coverage of the whole Building A with only four transmitters. We will take into account, for the moment, only the first two main constraints of the deployment: A1 and B1 for the repeaters, and A2 and B2 for the pseudolites. The impact of the future regulations on the GNSS transmitters will be presented and discussed later.

As the Ergospace software presents the simulation results in terms of received power, and the constraint of the SMICL loop is given in terms of carrier to noise ratio, we had to find the equivalence between these two variables.

Considering only the thermal noise we obtain:

$$N_0 = -174 \text{ dBm} / \text{Hz}$$

To satisfy the SMICL constraint, we obtain the following theoretical limitation of the carrier strength:

$$\frac{C}{N_0} > 40 \text{ dBHz} \Rightarrow C_{\text{theoretical}} > -134 \text{ dBm}$$

Measurements performed in our laboratory showed that, in practice, the values of the received power corresponding to a given carrier to noise ratio  $C/N_0$  depend on the receiver.

We obtained, for two different receivers, the following limitations:

- NordNav R30 receiver  
 $C/N_0 > 40 \text{ dB-Hz} \Rightarrow Pr > -123 \text{ dBm}$
- uBlox 5 receiver  
 $C/N_0 > 40 \text{ dB-Hz} \Rightarrow Pr > -129 \text{ dBm}$

To evaluate the necessary emission power in order to cover the entire building, we considered the following statements:

- maximum distance between 2 points within the building:  $d_{\text{max}} \sim 40 \text{ meters}$
- maximum attenuation within the building (from the ceiling of the last floor until the ground level):  $L \sim 28 \text{ dB}$
- maximum combined gain of the transmitting and receiving antenna:  $Ge + Gr \sim 33 \text{ dB}$

It should be noticed that the value of the maximum attenuation within the building presented before is a simulation result. Measurements performed in the same environment showed that in some particular cases (especially in the stair case at the end of the corridor) the attenuation can be more important, sometimes reaching 40 dB. This difference between measurements

and simulations can be explained by the infrastructure in the walls, which was not taken into account in the VRML model. In order to have a more precise description of the materials composing the environment, complementary measurements should be performed in a future work.

Using the Friis equation

$$P_r = P_e + G_e + G_r - Att - L$$

where

$$Att = 20 \cdot \log\left(\frac{4\pi \cdot d_{\text{max}}}{\lambda}\right)$$

and imposing the conditions:

$$Pr > -123 \text{ dBm (NordNav receiver)}$$

$$Pr > -129 \text{ dBm (uBlox receiver)}$$

we obtain the minimum (approximate) power necessary in order to cover the whole building, over four floors:

$$Pe > -59 \text{ dBm (NordNav receiver)}$$

$$Pe > -65 \text{ dBm (uBlox receiver)}$$

Simulations were performed in the Building A using four transmitters. Three of them are located at the last (3rd) floor, just under the ceiling, and are pointing downwards, as showed in Fig.4. The fourth transmitter is located in the corridor of the ground level, on the floor, and is pointing upwards. These positions were chosen in order to ensure a good DOP (vertical and horizontal) at each floor of the building.

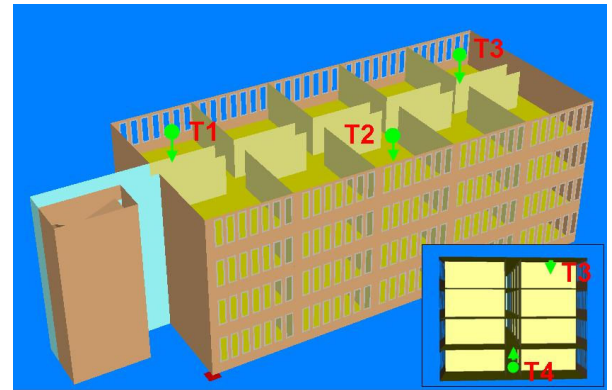


Fig.4. Transmitters positions and orientations in the building.

The figures below represent the received power over the whole building, arising from each one of the four transmitters. In Fig.5 the received power is obtained considering a transmitted power  $Pe = -59 \text{ dBm}$  and a threshold level of  $-123 \text{ dBm}$  (for the NordNav receiver). Fig.6 represents the received power considering the uBlox receiver (transmitted power  $Pe = -65 \text{ dBm}$  and threshold level of  $-129 \text{ dBm}$ ).

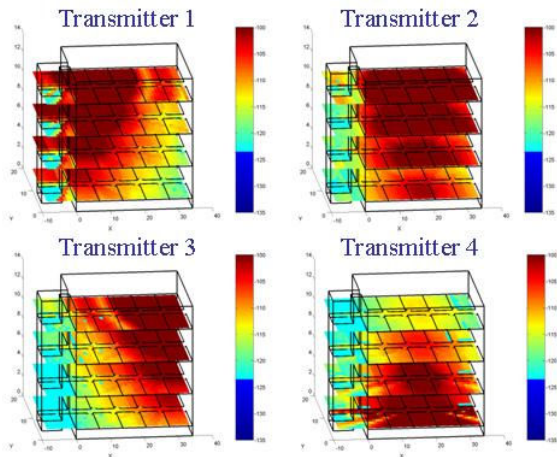


Fig.5. Received power considering the NordNav receiver ( $P_e = -59$  dBm)

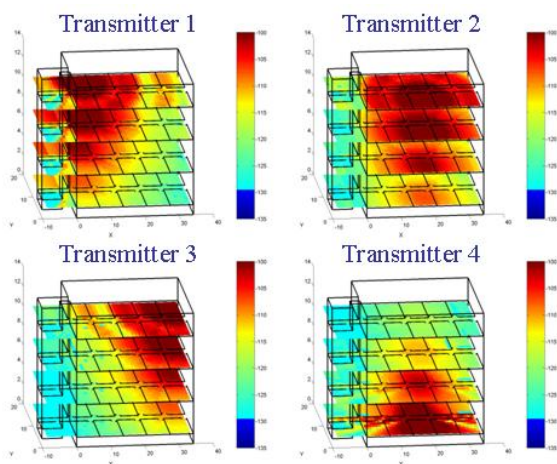


Fig.6. Received power considering the uBlox receiver ( $P_e = -65$  dBm)

The above conditions for the transmitted power and the threshold level (for both the NordNav and the uBlox receivers) are sufficient in order to ensure the visibility of all the four transmitters everywhere in the building, and give access thus to a full 3D positioning.

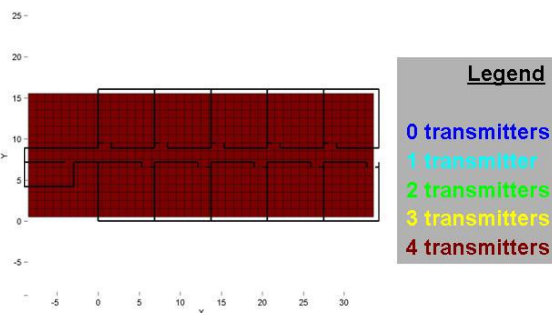


Fig.7. Number of transmitters in visibility in the whole building

If we take into account the repeater regulations, it is obvious that with a transmitted power of  $-59$  dBm, and respectively  $-65$  dBm the received power at 10 meters from the building will be more important than the  $-140$  dBm and the system will not fulfil the requirements of the Report 129 (see Section 3.1). Actually, as mentioned in Section 3.1, a transmitted power of less

than approximately  $-77$  dBm is necessary in order to satisfy the condition on the repeater overall gain:  $G_{\text{repeater}} < 45$  dB.

Fig.8. shows the power received from all the four repeaters in the building, at a distance of 10 meters from the building, considering a transmission power of  $-65$  dBm (uBlox receiver).

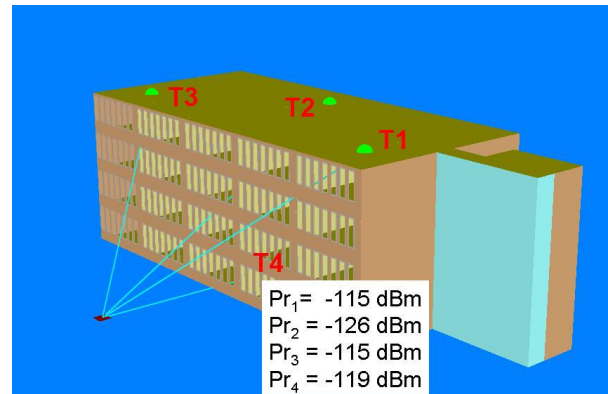


Fig.8. Received power at 10 meters from the building, assuming an emission power  $P_e = -65$  dBm

In these conditions, the protection limit at 10 meters from the building is not satisfied, but opens new investigation fields. As is shown in Fig.9, the receiving position at 10 meters from the building A (housing the transmitter antennas) is in the middle of an inner yard, part of the Telecom SudParis campus. If we consider that the protection criterion for the non-participating users is applicable outside the campus, then the power limitations are satisfied.

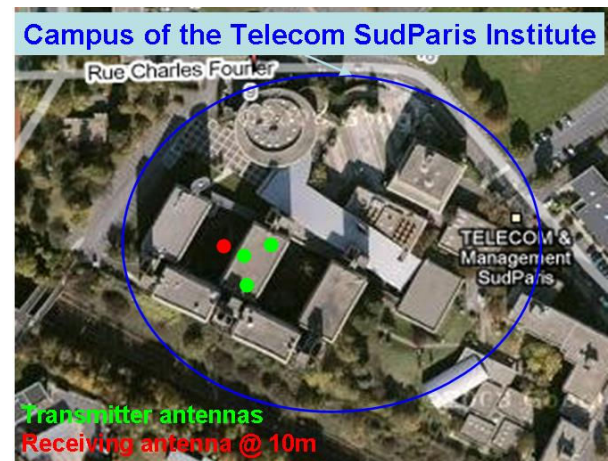


Fig.9. Campus of the Telecom SudParis Institute

An alternative solution to the repeater regulatory limitations is to use more than four transmitters in order to cover the whole building, and is discussed in the next section.

### 4.3. Deployment taking into account the repeater regulation restrictions

If more than four transmitters are used to cover the considered building, the emission power can be less

important, as the action ray of each transmitter will be less important (e.g. 2 floors instead of 4 floors). For this study the emission power of the transmitters was set to  $-77$  dBm to fit with the repeater regulatory limitations.

In this section will be shown the results corresponding only to the uBlox receiver, as it has a more convenient dynamic range.

Test simulations showed that with a  $-77$  dBm transmitted power in the considered environment, the maximum coverage area of one transmitter is usually between two and three floors, in the direction of the maximum radiation. Also, in order to obtain a 3D positioning in the building, four transmitters are needed every 2 floors. Of course, there are possibilities to optimise the deployment by reusing some transmitters for different coverage area.

In order to obtain a full coverage of the 2<sup>nd</sup> and 3<sup>rd</sup> floor of the building, four transmitters were used, and their location and orientation is shown in Fig.10. T1, T2 and T3 are located at the 3<sup>rd</sup> floor, under the ceiling, and are pointing downwards. T2 is located at the 2<sup>nd</sup> floor, and is pointing upwards (in order to have a better visibility, the roof of the building as well as the floor between 2<sup>nd</sup> and 3<sup>rd</sup> floor are not showed in the figure).

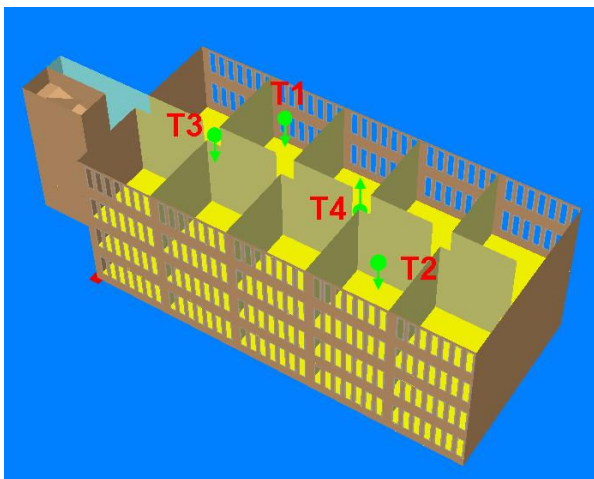


Fig.10. Transmitters positions for the coverage of the 2<sup>nd</sup> and 3<sup>rd</sup> floor

Fig.11. shows the received power at the considered levels (2<sup>nd</sup> and 3<sup>rd</sup> floors) for each of the four transmitters in Fig.10. The transmitted power is  $-77$  dBm, as discussed before.

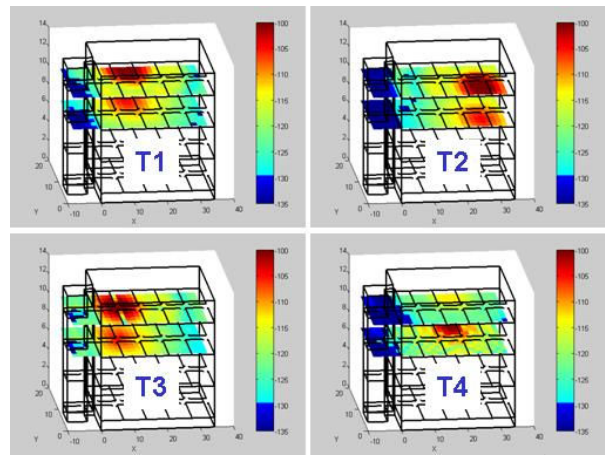


Fig.11. Coverage of each transmitter over the 2<sup>nd</sup> and 3<sup>rd</sup> floors of the building

The ground floor and the 1<sup>st</sup> floor were covered using another four repeaters, T5 to T8, whose locations are the same as the ones of T1 to T4 (see Fig.10), shifted with two floors.

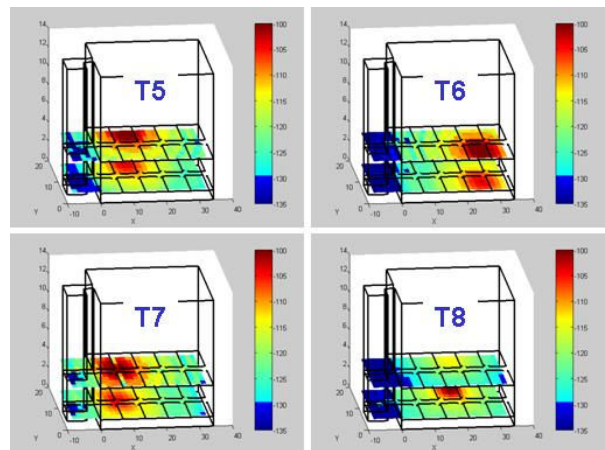


Fig.12. Coverage area of each transmitter over the ground level and 1<sup>st</sup> floor of the building

With this deployment of the transmitters, we obtain almost a full 3D coverage of the whole building (except 1.5% of the total amount of considered positions, where only three transmitters are in visibility, allowing a 2D positioning).

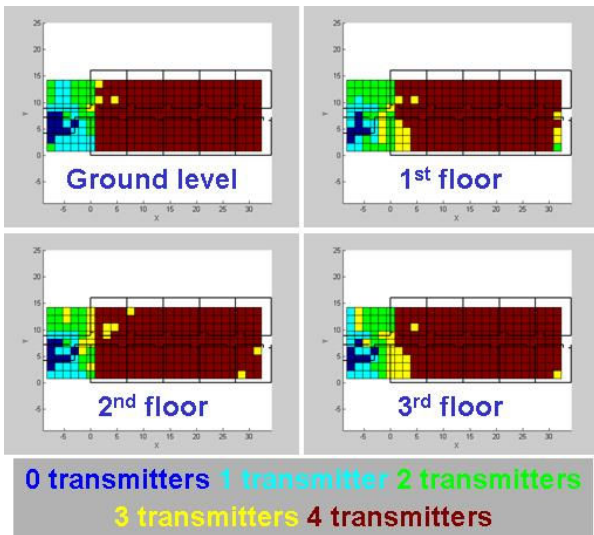


Fig.13 Number of transmitters in visibility at the four floors of the building, considering 8 transmitters ( $P_e = -77$  dBm)

It should be noticed that it should be possible to cover the building with only six repeaters instead of the eight presented before. An example of deployment is to locate two transmitters at the third floor, two at the ground level, and two in the middle which will be shared between the two cycles, for the coverage of the two upper levels as well as the first two levels. This is feasible if the transmitter antenna have a more isotropic pattern. In the actual configuration, the patch antennas used are mounted on a ground plane of 10 x 10 cm in order to avoid backward radiation and cabling effects. Eliminating the ground plane will transform the pattern antenna and will allow a better coverage in all directions.

### 4.3. Deployment taking into account the pseudolite regulation restrictions

Eight transmitters (2 cycling sets) used in order to obtain a coverage of the building A is a quite important deployment, especially that the stairs at the end of the corridor are not well covered (see Fig.13).

To overcome this problem we took advantage of one of the main features of our GNSS transmitter based approach, which consists in the possibility of using any type of signal to aliment the transmitters. We can thus use a pseudolite-type of signal instead of the signals arising from satellites, collected by the roof antenna. It should be noticed that with this approach only one signal is necessary, since all the transmitters send the same signal during the cycle.

In this section is considered the use of a pseudolite-type signal generator which aliment the transmitters who are thus not anymore re-radiators of GNSS signals. Consequently, the pseudolite operation regulations should be considered, instead of the repeater one.

The near boundary represents the limit between the region where the pseudolites jams the satellite signals and the region where pseudolites and satellites can both be tracked. The condition imposed to the continuously

transmitting pseudolites is that the received signal level at this boundary is less than -120 dBm, as is presented in Section 3.2. We consider the same limit from which the GNSS users should not be disturbed as for the repeaters, i.e. 10 meters from the building housing the pseudolites.

Preliminary simulations showed that this condition is satisfied for an emission power  $P_e \leq -70$  dBm.

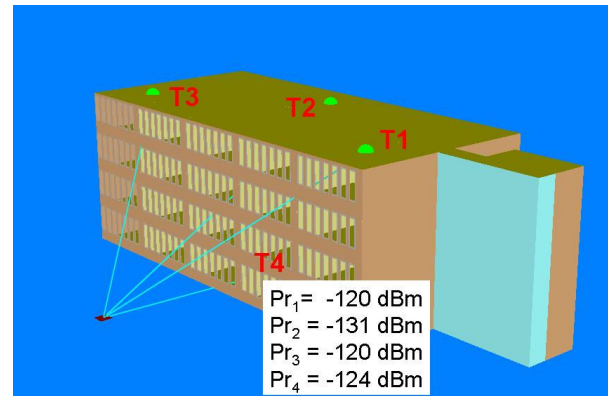


Fig.14. Received power at 10 meters from the building, assuming an emission power  $P_e = -70$  dBm

Considering the deployment of the transmitters presented in Fig. 4 and an emission power of -70 dBm we obtain the coverage results below.

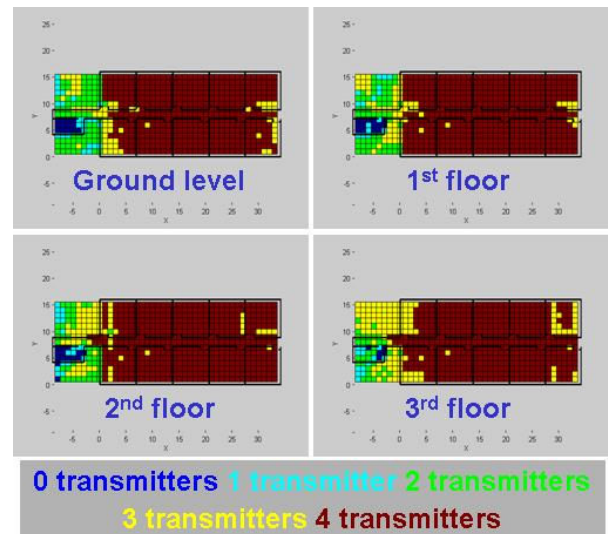


Fig.15 Number of transmitters in visibility at the four floors of the building, considering 4 transmitters ( $P_e = -70$  dBm)

With this deployment we obtain a 3D coverage of the building at 95% of the considered receiving positions (in 5% of the positions only a 2D positioning is available).

## CONCLUSION

This paper presented coverage results in the building A of the Telecom SudParis institute. First, simulations results showed that the whole building can be covered with only four transmitters, under the constraint of a minimum emitted power of -65 dBm. The “under discussion” regulatory framework for the repeater and



pseudolite transmissions was taken into account furthermore.

Results showed that the necessary emission power in order to use only four repeaters is too strong, and can cause interferences to the other GNSS users. A solution to this problem is to use more than four repeaters in the building, with a reduced transmission power. The deployment presented showed that using eight repeaters in the environment, with a power of -77 dBm (which is in conformity with the regulations limitations), a full 3D positioning is available at most receiving positions. It is possible to reduce the number of necessary repeaters by using antennas with more convenient radiation patterns.

The use of a pseudolite-type signal generator alimentering the transmitters was found to be convenient for a coverage of the building using 4 transmitters with an emission power of -70 dBm, since the pseudolite regulations are more flexible.

It is also possible to consider that the GNSS should provide only a 2D positioning, if the level information is available through other technique.

It should be noticed that it can be interesting to locate the transmitters outdoors, over the roof of the building for example. In this situation, more directive antenna patterns are suited. Such deployment could reduce the minimum number of transmitters necessary to cover the whole building, including the stairs. Of course, the limitations of the emitted power should be taken into account, and this type of deployment would be useful for larger areas.

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