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REGULATORY FRAMEWORK FOR INDOOR GNSS PSEUDOLITES

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0 EXECUTIVE SUMMARY

Pseudolites (Pseudo satellites, PL) are ground based radio transmitters that transmit an “RNSS”-like navigation signal that can be received and processed by standard radio navigation receivers compatible to the signals published in the Signal-in-Space Interface Control Documents (SIS-ICD [1]) of the GPS and Galileo systems. They are intended to complement systems in the Radionavigation Satellite Service (RNSS) by transmitting on the same frequencies in the bands 1 164-1 215 MHz, 1 215-1 300 MHz, and 1 559-1 610 MHz.

Since other radio services could also be affected by an uncontrolled use of PL, CEPT conducted sharing studies between PL and other systems on the frequency bands.

The purpose of this Report is to describe guidelines for a regulatory framework under which PL could be operated in CEPT countries. The focus of the report is on PL implemented in indoor environments. CEPT acknowledges that there is planned usage of PL applications for outside environments. A separate CEPT Report on those applications may be developed in the future. Therefore CEPT recommends in the meantime that outdoor use of PL should not be authorised.

The main conclusions and recommendations are:

- It is recommended that, indoor GNSS PL should be authorised in the band 1 559-1 610 MHz;
- It is recommended that PL be operated through individual authorisations in particular so as to ensure that in areas where case by case studies are necessary (i.e., airport areas), no PL should be installed before the completion of those studies;
- Individual authorisations should only authorise PL with dedicated codes. PL with non-dedicated codes should only be authorised, if necessary, in case of temporary experimentation and on a national basis. In terms of this report, PRN codes associated with satellite transmissions are termed “Non-Dedicated PL codes”. PRN codes that are specifically associated with pseudolite transmissions are termed “Dedicated PL codes”;
- Knowledge of the location of GNSS pseudolite installations through licensing is recommended. CEPT administrations should not allow the installation of GNSS pseudolite in mobile vehicles;
- Any authorisations or licenses for GNSS pseudolite installations could include guidance for reduction and reasonable checking of the potential to cause interference;
- Military or other government authorities as well as meteorological services may require specific site limitations.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
ARNS	Aeronautical Radio Navigation Service
CW	Continuous Wave
DME	Distance Measuring Equipment
EC	European Commission
EESS	Earth Exploration Satellite Service
EIRP	Equivalent Isotropic Radiated Power
ESA	European Space Agency
ETSI	European Telecommunications Standardisation Institute
GNSS	Global Navigation Satellite System operating within the RNSS
GPS	Global Positioning System of the United States, a GNSS system
GALILEO	Global Positioning System of the European Union, a GNSS system
ICAO	International Civil Aviation Organisation
ITU-R	International Telecommunications Union – Radio sector
PL	Pseudolites
PRN	Pseudo Random Number
RLS	RadioLocation Service
RNSS	Radionavigation Satellite Service

Regulatory framework for indoor GNSS pseudolites

1 INTRODUCTION

Pseudolites (Pseudo satellites, PL) are defined as a sub-group of equipment that can support operation of GNSS receivers. They transmit GNSS equivalent signals on the same frequency bands allocated to the Radio Navigation Satellite Service. CEPT ECC Report 128 [2] provides detail of the Spectrum Engineering compatibility assessment of PL.

The technologies providing PL signals can help to address indoor coverage and accuracy shortcomings, by providing additional ranging signals and by improving geometry. However, PL are ground based radio transmitters that transmit a GNSS-like navigation signal. It requires users to have modified GNSS-receivers to receive these signals. It is expected that these GNSS receivers have minor changes compared to today's receivers. PL can be used as augmentation to GNSS or stand-alone in an environment where GNSS is not available. It is then possible to extend the service coverage of satellite navigation to difficult propagation environments maintaining high accuracy under attractive cost conditions.

A critical area is the transition zone from GNSS reception outdoor to GNSS and pseudolite reception just inside buildings to pseudolite only reception in the indoor environment, because the navigation performance is affected by the potential interference from PL to direct satellite signals. A typical scenario is where a user is approaching a building with perfect satellite coverage followed by an entrance with degraded satellite visibility and then entering the building with almost no satellites available. The goal for pseudolite usage under these conditions is to provide uninterrupted signal sources for position calculation.

The purpose of this Report is to describe guidelines for a regulatory framework under which PL could be operated in CEPT countries. The focus of the report is on PL implemented in indoor environments.

PL have to be distinguished from GNSS repeaters which are ground based radio transmitters that receive, amplify and re-broadcast signals from existing GPS satellites without changing those signals in any way other than increasing their power. CEPT has adopted ECC Report 145 [3] on "Regulatory Framework for Global Navigation satellite system (GNSS) repeaters".

2 DESCRIPTION OF GNSS AND GNSS PSEUDOLITES

2.1 RNSS/GNSS Systems

Systems using the Radio Navigation Satellite Service (RNSS) or Global Navigation Satellite Systems (GNSS) have developed into indispensable assets for navigation around the globe. They can provide safety related services and they should be carefully protected from interference. Examples are GPS, GLONASS and the future Galileo system that provide data for navigation devices.

A GNSS receiver must lock to the signal of at least three satellites to calculate a 2D position (latitude and longitude) and track movement. With four or more satellites in view, the receiver can determine the user's 3D position (latitude, longitude and altitude) and time. Once the user's position has been determined, the GNSS receiver can calculate other information, such as speed, bearing, track, trip distance, and distance to destination, sunrise and others. This information provides the basic information data for higher-level value-added location based services.

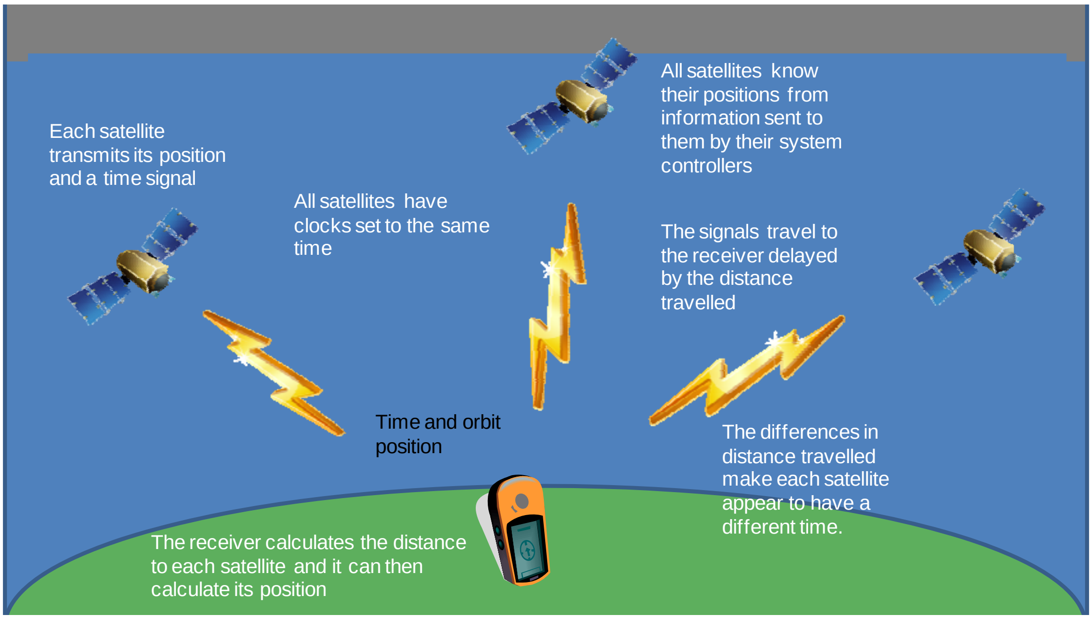

Figure 1: RNSS/GNSS functionality

2.2 Pseudolite description details

For many years, PL have been investigated for a wide variety of applications. In the beginning, they were used to test GPS when no satellites were available. Then their usage evolved to augmentation of GPS and finally extended during the last years to pseudolite-only and indoor navigation systems.

In the course of development of the Galileo satellite navigation systems PL were defined as part of the Galileo architecture

There are two basic cases where PL might be used. These are considered representative for a wide range of applications:

Case 1: "areas where RNSS satellite signals are partially available or with a weak signal", such as in urban canyons and light indoor environment.

Case 2: "Deep Indoor", where signals from RNSS satellites are blocked.

The above classification is important in view of the definition of regulatory framework and interference issues between PL and Radio Navigation Satellite Services (RNSS) on the one hand, and PL and other services on the other hand. The main system parameters defining a Pseudolite network are:

- Carrier frequencies - It is assumed that all the GNSS frequency bands will be used in order to cover all the existing and upcoming GNSS services. This also includes GPS, and Galileo;
- Modulation & PRN codes: It is assumed that PL will use dedicated PRN codes separately identifiable from those PRN used by GNSS satellites. PL with non dedicated codes should not be authorised except on a national basis and for temporary experimental purpose only;
- E.I.R.P.:Effective Isotropic Radiated Power, some typical powers are given in ECC Report 128 [2];
- Antenna characteristics: Can be designed to reduce unwanted effects outside of coverage area;
- Pulse shaping: Ensures the correct derivation of timing from GNSS signals or the reduction of unwanted out of band emissions because of the rise time for the pseudolite transmit power;
- Applied duty cycle: Continuous or pulsed;
- Number: Pseudolite transmitter number dependent on area of coverage;
- Pseudolite Locations: Indoor area;
- The PL fall into at least two categories to cater for the above mentioned cases;
- Pulsed PL: - whose transmit power is driven by a duty cycle and;

- Continuously transmitting: -whose transmit power is constant over time.

Pulsed PL have to be implemented to overcome the so-called "near-far" effect due to specific geometrical configuration. One option is to use pulsed signals, taking into account that the duration of the pulse is a criteria to be taken into account to ensure the lack of such near-far effect.
PL would usually transmit in the relevant GNSS frequency bands, though there are some PL today that transmit in other non-GNSS frequency bands, the prime example is the Industrial Scientific Medical (ISM) band where devices with proprietary signal specifications (sold as "Synchrolites") have been developed

The number of PL actually implemented at a site also depends on the purpose to be achieved and the overall propagation characteristic of the desired service area. PL in Case 1 are assumed to enhance the associated GNSS system. In this case, it is not necessary to ensure visibility of at least four PL for a full positioning capability. The number of implemented equipments should be driven to avoid hot spots. In other words, a distributed network of low power devices would be preferable than the implementation of a few high power transmitters. In Case 1, non participative RNSS receivers shall not be jammed or spoofed by the PL (this could happen in case PL use non-dedicated codes).

2.3 Indoor GNSS applications

GNSS applications are numerous and are usually divided in various categories such as:

- Governmental usage, dedicated to security and military usage;
- Professional usage, in particular for the logistics of professional vehicles;
- Mass market usage, in particular for car or pedestrian navigation.

Mass market usage is developing at a high growth rate, with numerous new applications, that use location knowledge to map local information for a user and the development of these applications rely on reasonable levels of GNSS signals, but some areas may be partially unavailable as they have weak signals.

In principle, PL can replace the satellite constellation wherever the satellite signals are completely unavailable due to high attenuation or shadowing, such as in the case of urban canyons, indoor reception, in road tunnels, and other areas.

Other options such as Assisted (A-) GNSS have been developed that can be used in areas of weak reception level by transferring the content of the navigation data message through other means of communication (GSM, local broadcast and others).

High sensitivity receivers that use available GNSS multipath signals have also been developed to improve the lack of a good quality GNSS signal, but only partial coverage ("light indoor") can be achieved.

A comprehensive summary of the pseudolite technology and applications can be found in the revised ECC Report 128 [2].

Information on A-GNSS is available through the 3GPP standards forum and through the developed corresponding ETSI Technical Specification 136 171 [4].

2.4 Benefits of pseudolites

PL are intrinsically complementary to GNSS systems and can offer a transition between outdoor and indoor environments, namely by maintaining a continuous synchronisation of the GNSS chipset.

The radiated power of pseudolite signals could offer a good EMC environment due to the low radiated power necessary for making the chipset work.

PL rely on timing measurements, i.e. they intrinsically show good and constant accuracy performance.

2.5 Requirements for GNSS Receiver to operate with pseudolites

The development of PL needs to be compatible with current GNSS receivers. In particular, GNSS receivers not designed to use pseudolite signals (non-participative receivers) shall not suffer interference from pseudolite emissions. Compatibility with other services has also to be ensured.

2.6 Examples of the need for indoor GNSS pseudolites

Overview of typical applications, key applications for the use of PL are:

- Government associated agencies, including law enforcement, fire and rescue organizations and the contractors supporting them;
- Manufacturing, production and test facilities where GNSS is an integral part of the finished product;
- Operators of indoor parking facilities where emergency services need to continue tracking GNSS where it is otherwise unavailable;
- High-precision applications for professional users;
- Mass market consumer applications for covering indoor retail environments.

These applications are further discussed in the following sections.

2.6.1 Mass market: indoor navigation

Many issues arise from the lack of appropriate location information in large sites, such as:

- In an airport, finding a boarding gate and getting there on time;
- In an exhibition, avoiding to lose a friend or a children;
- In a museum, following a guided tour efficiently.

The demand for location-based-services in indoor environments is now very high as mobile users get more and more used to have such services outdoor. Mobile phone terminals using GNSS receivers with assisted GPS signals are rapidly growing in use, they now employ such technology for Location Base Services with internet enabled mobile phones.

2.6.2 Car: navigation in tunnels and parking

Tunnels and parking are places where continued location information would be very useful due to drivers enter these areas while using a GPS device. This will allow continue accurate navigation, to find free parking lots, remember the place where the car is parked afterwards, and also to enhance security.

2.6.3 Industry: worker security

Accurate indoor location is a key mean to ensure security of workers in dangerous and/or isolated situations. Devices that can detect abnormal situation (long immobility, shock) can therefore deliver location-aware alerts to monitoring centres and very efficiently contribute to save lives at work. A European directive (89/391/EEC of 12 June 1989, modified in 2003) on Lone Worker Protection and GNSS PL are an efficient solution to comply with it.

2.6.4 Machinery: high accuracy positioning

Ensure centimetre-level positioning with the use of PL allows a fast evolving geometry to solve for phase ambiguities. Such a high accuracy allows for high levels of security and integrity, opening the door for automatic vehicle guidance or machine-to-machine positioning.
Positioning capability in important areas can be easily denied by intentional or unintentional jamming of GNSS. PL can serve as a indoor local backup positioning system with higher transmit power than a jammer and thus ensure positioning of e.g. emergency staff in a local protected environment.

2.7 Potential candidate frequency bands for supporting pseudolite implementations in RNSS frequency spectrum

Frequency bands allocated to the radionavigation-satellite service as listed in the ITU-R Radio Regulations frequency allocation table are shown in table 1. It is important to consider each of the bands as potential candidate bands for supporting pseudolite implementations.
The different sharing conditions for each band listed might necessitate particular licensing conditions for the operation of co-channel PL.

1 164-1 215	AERONAUTICAL RADIONAVIGATION 5.328 RADIONAVIGATION-SATELLITE (space-to-Earth) (space-to-space) 5.328B 5.328A
1 215-1 240	EARTH EXPLORATION-SATELLITE (active) RADIOLOCATION RADIONAVIGATION-SATELLITE (space-to-Earth) (space-to-space) 5.328B 5.329 5.329A SPACE RESEARCH (active) 5.330 5.331 5.332
1 240-1 300	EARTH EXPLORATION-SATELLITE (active) RADIOLOCATION RADIONAVIGATION-SATELLITE (space-to-Earth) (space-to-space) 5.328B 5.329 5.329A SPACE RESEARCH (active) Amateur 5.282 5.330 5.331 5.332 5.335 5.335A
1 559-1 610	AERONAUTICAL RADIONAVIGATION RADIONAVIGATION-SATELLITE (space-to-Earth) (space-to-space) 5.208B 5.328B 5.329A 5.341 5.362B 5.362C

Table 1: RNSS/GNSS frequency bands

2.8 Radio regulatory status of pseudolites sharing RNSS frequency spectrum

As can be seen in the ITU-R frequency allocation table there are primary allocations for the radionavigation-satellite service (space-to-Earth) but no allocations exist for pseudolite operation under a general terrestrial radionavigation allocation except for the band 1599-1610 MHz for PL in the aeronautical domain operated under the Aeronautical Radionavigation Services (ARNS).

GNSS PL will, therefore, operate according to national licensing conditions and this should be on a non-interference non-protected basis.

As a first stage, the operation of GNSS PL is considered within the following RNSS allocations: 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 MHz. – subject to studies in each band.

3 CEPT SPECTRUM ENGINEERING CONCLUSIONS

3.1 Pseudolite Application

3.1.1 PRN Code Introduction

To understand the issues associated with PRN codes, this report must explain first the association of Pseudo Random Number and the associated transmitted RNSS signals. For example, the “C/A” code of GPS is a random set of bits, 1023 bits long. Each PRN code is associated with one specific arrangement of those 1023 bits. There are many possible arrangements of these bits. However, not all arrangements are good in terms of their cross correlation co-efficient, i.e. if we cross compare two codes to each other, what is the power ratio of that arrangement compared to one code itself correlated with the same code. Families of codes with good cross correlation co-efficient (the so called, “Gold Codes”) have been found, one of the PRN codes from such a family uniquely identifies it. For the RNSS constellations, each satellite operator assigns a different Gold Code family to each satellite.
Some RNSS operators have identified a limited number of PRN Codes in their code family specifically for pseudolite (PL) functions.

In terms of this report, PRN codes associated with satellite transmissions are termed "Non-Dedicated PL codes". PRN codes that are specifically associated with pseudolite transmissions are termed "Dedicated PL codes.
RNSS receivers designed to include knowledge and the use of PL transmissions termed "participative RNSS receivers", and those that not designed to cope with PL transmissions are termed "non-participative RNSS receivers".

3.1.2 Indoor Pseudolite Scenarios

The applications described in section 2.6 were combined into three scenarios and the technical compatibility assessed as part of ECC Report 128 [2]. The ECC Report 128 [2] considered PL compatibility and interference concerns for the participating receiver, but also for non-participating receivers, such as A-RNSS or civil aircraft at low altitude, when they are local to an area using PL. Scenario A from ECC Report 128 [2] is relevant to this Report:

Scenario	**Description**	**Service Area**	**EIRP**	**Remarks**
A	Indoor	Building	Low (-50 dBm to -59 dBm)	PL only

Table 2: Generic Pseudolite scenario

It was assumed in the engineering studies that following operational requirements have been established for PL:

- all PL in an area are controlled by the same entity;
- the PL coverage for each scenario is limited to a maximum set radius;
- that 1 to 6 PL might be seen at any one location;
- that the signals must be positively monitored, i.e. that the PL system do not use codes used by satellite in visibility (this criteria is not relevant when PL use dedicated codes).

The next section presents technical analyses undertaken by the CEPT WG Spectrum Engineering concerning scenario A, i.e. PL for indoor use.

3.1.3 Power and Allocation PRN

The impact of PL on outdoors non-participative receivers differs depending on the type of PRN codes that is used by the PL (i.e. dedicated pseudolite PRN code or non-dedicated codes usually associated with GNSS satellites).
In case of experimentation on a national basis of PL using non-dedicated PRN codes, it is recommended to broadcast on the PL a modified navigation message to ensure that the signal is declared "UNHEALTHY" by some non participating receiver.

Finally, it is necessary to ensure that a failure of the software management system used to allocate the satellite PRN codes to the PL will never occur.

It can be noted that, the use of longer pseudo random codes will also improve the compatibility with non participative receivers as well as the performance of participative receivers.

3.1.4 Aggregate effect – aeronautical/airport protection

The aggregate effect should be negligible on non-participative receivers operated on the ground. Additional spectrum engineering assessment work has been conducted on the aggregate interference of PL on airborne non-participative receivers. In that case, some mitigation techniques would be necessary (see section 4.2).

3.2 Compatibility between GNSS pseudolites and other services and applications

PL should not create harmful interference to other receivers used in the same and in the adjacent bands. ECC report 128 [2] provides the compatibility studies carried out to assess any potential harmful interference. Its determination must take typical receiver performance parameters into account that the receivers will have in the different market segments, These range from consumer products to high-end equipment for geodesy, safety of life or Governmental usages.

The RNSS band 1 215 - 1 300 MHz, is also used by primary surveillance radars in the Radionavigation Service (RNS), by Earth observation systems in the Earth Exploration Satellite Service (EESS) and by Wind Profiler radars in the Radiolocation Service (RLS). Pseudolite signals may cause false targets inside a radar clutter zone or interfere with the radar signals of EESS satellites.

Galileo and GPS both use the band 1 215-1 300 MHz for secure services as well as providing additional signals to help correct Ionospheric propagation effects.

Aeronautical Distance Measuring Equipment (DME) uses the ARNS band, 1 164-1 215 MHz.

In the case of the band 1 559-1 610 MHz, only the ARNS and RNSS are concerned.

Since the adoption of the first version of ECC Report 128 [2], a proposal for higher e.i.r.p. PL (from -59 to -50 dBm) has been received from CEPT. The technical studies have been reviewed accordingly.

It is necessary to consider the transmissions of PL that apply duty cycle (pulsing). Pulsing schemes will vary for different GNSS systems, i.e. the pulsing scheme for a GPS PL is a different one than for Galileo or Compass. It is expected that new and improved pulsing schemes will be developed.
Different compatibility criteria will result from consideration of whether a Pseudolite transmits continuously or uses higher power pulsed signals.

3.2.1 Co-frequency compatibility with GNSS

3.2.1.1 Band 1 164-1 215 MHz, RNSS

Radio Navigation Satellite Systems are spread spectrum systems. Because of the similarities between RNSS and PL systems, the RNSS receiver tolerates more or less the PL wideband interference depending on the nature and characteristics of the PL signal.

The RNSS receiver tolerates also to some extent pulsed interference. The RNSS receiver saturates during the interfering pulse, but after short recovery time can receive the slightly degraded satellite signals. However, the maximum acceptable pulse duty cycle for all pulsing pseudolites in the vicinity of RNSS receiver still has to be determined.

Sharing/compatibility between continuously transmitting Pseudolites and RNSS is feasible under the following conditions:

a) A specific attention should be given to the use of pseudolites operating in light indoor environment, i.e. close to large apertures (e.g. doors, windows, …). In this case, in the absence of mitigation techniques and assuming an e.i.r.p. of -59 dBm, a separation distance of up to 190 m can be necessary to ensure the protection of non-participative receivers. In order to reduce the potential interference level for lower separation distances, the following measures could be taken:

- Reduce the PL e.i.r.p. to -65 dBm above 0°elevation;
- Avoiding PL deployment close to large aperture or implementing additional attenuation with shielding material;
- Reducing the PL maximum e.i.r.p.;
- Optimisation of the pseudolite signal.

b) In the case non-dedicated PRN codes are used, this area of potential performance degradation is much more important since without any mitigation technique, separation distances up to 1.5 km are necessary to guarantee the integrity of non-participative receivers (those used for safety applications). The impact in this area is an increase of the Time-To-First-Fix of non participating receivers in cold start.

In order to reduce the potential interference level for lower separation distances, the following measures could be taken:

- ➢ Reduce the PL e.i.r.p. to -65 dBm above 0°elevation;
- ➢ Avoiding PL deployment close to large aperture or implementing additional attenuation with shielding material;
- ➢ Reducing the PL maximum e.i.r.p

In addition, in order to avoid non-participating receivers using the RNSS code allocated to other systems (i.e. satellites), it is recommended to broadcast on the PLs a modified navigation message to ensure that the signal source validity is identified.

Moreover, PL signals can monopolize some reception channels of non participative receiver, even after the acquisition resolved. Therefore, non participative receiver could have an insufficient number of available channels to receive satellite signals. It is recommended to limit the number of different non dedicated PL codes to 6, and in case of dedicated PL code to develop the associated receiver with an increased number of reception channels.
Finally, it is necessary to ensure that a failure of the software management system used to allocate the satellite PRN codes to the PLs will never occur. For use in any area where safety is an issue, this software must be proven to be using well known safety case assessment procedures.

Therefore, the use of non dedicated code should only correspond to experimental purpose for a limited duration under specific regulation approval. The implementation of dedicated code for pseudolite is part of the modification of firmware expected from chipset manufacturer to meet mass market requirements.

In view of the unknown effect to all non participating receiver designs associated with the use of non visible satellite PRN codes by pseudolites, this method is not recommended for operational use.

c) Using dedicated code will avoid the type of impact described in b) and is thus recommended as soon as possible (as soon as mass market chipsets are able to process such dedicated codes). Moreover, the use of longer codes will also improve the compatibility with non participative receivers as well as the performance of participative receivers. In case of mass market deployment, the use of dedicated code is the solution to grant no interference described in b) with non participative GPS receiver

d) It is not possible to determine a reasonable separation distance (i.e. much lower than the building dimensions) between the pseudolites and a non participative GNSS receiver located in the same building. Therefore, this kind of non participative GNSS receiver cannot be protected.

e) The studies of the aggregate effect of PL on aeronautical receivers show that in average, the PL density should be limited to 6 PL/km² if the e.i.r.p is -59dBm and 24 PL/km² if the e.i.r.p is limited to -65dBm (or if equivalent mitigation techniques are applied) under the assumption of a uniform distribution of these PL over very large areas (more than 1 000 km²). It should be noted that these values should not be taken as regulatory limitations since they correspond to average numbers, which may be exceeded locally.

In sensitive areas like airport, the studies show that mitigation techniques should be applied. Moreover, since the aggregated effect really depends on the real deployment conditions, case by case studies may be necessary.

It is expected that the use of pulse transmitting Pseudolites will improve the compatibility with RNSS systems.

3.2.1.2 Band 1 215-1 300 MHz, RNSS

Radio Navigation Satellite Systems are spread spectrum systems. Because of the similarities between RNSS and PL systems, the RNSS receiver tolerates more or less the PL wideband interference depending on the nature and characteristics of the PL signal.

The RNSS receiver tolerates also to some extent pulsed interference. The RNSS receiver saturates during the interfering pulse, but after short recovery time can receive the slightly degraded satellite signals. However, the maximum acceptable pulse duty cycle for all pulsing pseudolites in the vicinity of RNSS receiver still has to be determined.

Sharing/compatibility between continuously transmitting Pseudolites and RNSS is feasible under the following conditions:

a) A specific attention should be given to the use of pseudolites operating in light indoor environment, i.e. close to large apertures (e.g. doors, windows, …). In this case, in the absence of mitigation techniques, and assuming an e.i.r.p. of -59 dBm, a separation distance of up to 185m can be necessary to ensure the protection of non-participative receivers. In order to reduce the potential interference level for lower separation distances, the following measures could be taken:

- Reduce the PL e.i.r.p. to -65 dBm above 0°elevation
- Avoiding PL deployment close to large aperture or implementing additional attenuation with shielding material;
- Reducing the PL maximum e.i.r.p
- Optimisation of the pseudolite signal

b) In the case non-dedicated PRN codes are used, this area of potential performance degradation is much more important since without any mitigation technique, separation distances up to 1.5km are necessary to guarantee the integrity of non-participative receivers (those used for safety applications). The impact in this area is an increase of the Time-To-First-Fix of non participating receivers in cold start.

In order to reduce the potential interference level for lower separation distances, the following measures could be taken:

- Reduce the PL e.i.r.p. to -65 dBm above 0°elevation;Avoiding PL deployment close to large aperture or implementing additional attenuation with shielding material;
- Reducing the PL maximum e.i.r.p

In addition, in order to avoid non-participating receivers using the RNSS code allocated to other systems (i.e. satellites), it is recommended to broadcast on the PLs a modified navigation message to ensure that the signal source validity is identified.
Moreover, PL signals can monopolize some reception channels of non participative receiver, even after the acquisition resolved. Therefore, non participative receiver could have an insufficient number of available channels to receive satellite signals. It is recommended to limit the number of different non dedicated PL codes to 6, and in case of dedicated PL code to develop the associated receiver with an increased number of reception channels.
Finally, it is necessary to ensure that a failure of the software management system used to allocate the satellite PRN codes to the PLs will never occur. For use in any area where safety is an issue, this software must be proven to be using well known safety case assessment procedures.
Therefore, the use of non dedicated code should only correspond to experimental purpose for a limited duration under specific regulation approval. The implementation of dedicated code for pseudolite is part of the modification of firmware expected from chipset manufacturer to meet mass market requirements.

In view of the unknown effect to all non participating receiver designs associated with the use of non visible satellite PRN codes by pseudolites, this method is not recommended for operational use.

c) Using dedicated code will avoid the type of impact described in b) and is thus recommended as soon as possible (as soon as mass market chipsets are able to process such dedicated codes). Moreover, the use of longer codes will also improve the compatibility with non participative receivers as well as the performance of participative receivers. In case of mass market deployment, the use of dedicated code is the solution to grant no interference described in b) with non participative GPS receiver.

d) It is not possible to determine a reasonable separation distance (i.e. much lower than the building dimensions) between the pseudolites and a non participative GNSS receiver located in the same building. Therefore, this kind of non participative GNSS receiver cannot be protected.

e) The studies of the aggregate effect of PL on aeronautical receivers show that in average, the PL density should be limited to 12 PL/km² if the e.i.r.p is -59dBm and 48 PL/km² if the e.i.r.p is limited to -65dBm (or if equivalent mitigation techniques are applied) under the assumption of a uniform distribution of these PL over very large areas (more than 1 000 km²). It should be noted that these values should not be taken as regulatory limitations since they correspond to average numbers, which may be exceeded locally.

In sensitive areas like airport, the studies show that mitigation techniques should be applied. Moreover, since the aggregated effect really depends on the real deployment conditions, case by case studies may be necessary.

It is expected that the use of pulse transmitting Pseudolites will improve the compatibility with RNSS systems

3.2.1.3 Band 1 559-1 610 MHz RNSS

Radio Navigation Satellite Systems are spread spectrum systems. Because of the similarities between RNSS and PL systems, the RNSS receiver tolerates more or less the PL wideband interference depending on the nature and characteristics of the PL signal.

The RNSS receiver tolerates also to some extent pulsed interference. The RNSS receiver saturates during the interfering pulse, but after short recovery time can receive the slightly degraded satellite signals. However, the maximum acceptable pulse duty cycle for all pulsing pseudolites in the vicinity of RNSS receiver still has to be determined.

Sharing/compatibility between continuously transmitting Pseudolites and RNSS is feasible under the following conditions:

a) The increase of the PLs e.i.r.p from -59 dBm to -50 dBm will create additional interference on outdoor non-participative receivers. A specific attention should be given to the use of pseudolites operating in light indoor environment, i.e. close to large apertures (e.g. doors, windows). In this case and in the absence of mitigation techniques, with a maximum PL e.i.r.p of -50 dBm, a separation distance of up to 350 m can be necessary to ensure the protection of non-participative receivers. In order to reduce the potential interference level for lower separation distances, the following measures could be taken:

- Reduce the maximum PL e.i.r.p. by 6dB above 0° elevation;
- Avoiding PL deployment close to large aperture or implementing additional attenuation with shielding material;
- Reducing the PL maximum e.i.r.p
- Optimisation of the pseudolite signal

Under these conditions, and with a more typical receiver sensitivity of 25 dBHz, a separation distance of between 18m and 51m (corresponding to PLs maximum e.i.r.p of -59 dBm and -50 dBm respectively) will have to be maintained between any PL and outdoor non-participative receivers.

b) In the case non-dedicated PRN codes are used, this area of potential performance degradation is much more important since without any mitigation technique, separation distances of 1.1 km to 2 km are necessary to guarantee the integrity of non-participative receivers (those used for safety applications). The impact in this area is an increase of the Time-To-First-Fix of non participating receivers in cold start.

In order to reduce the potential interference level for lower separation distances, the following measures could be taken:

- Reduce the maximum PL e.i.r.p. by 6 dB above 0° elevation.
- Avoiding PL deployment close to large aperture or implementing additional attenuation with shielding material;
- Reducing the PL maximum e.i.r.p.

Under these conditions, and with a more typical receiver sensitivity of 25 dBHz, a separation distance of between 143m and 403m (corresponding to PLs maximum e.i.r.p of -59 dBm and -50 dBm respectively) will have to be maintained between any PL and outdoor non-participative receivers. In some sensitive areas like airports, a case-by-case interference analysis is recommended to evaluate the potential risk associated to a PL deployment proposal.
In addition, in order to avoid non-participating receivers using the RNSS code allocated to other systems (i.e. satellites), it is recommended to broadcast on the PLs a modified navigation message to ensure that the signal source validity is identified.
Moreover, PL signals can monopolize some reception channels of non participative receiver, even after the acquisition resolved. Therefore, non participative receiver could have an insufficient number of available channels to receive satellite signals. It is recommended to limit the number of different non dedicated PL codes to 6, and in case of dedicated PL code to develop the associated receiver with an increased number of reception channels.
Finally, it is necessary to ensure that a failure of the software management system used to allocate the satellite PRN codes to the PLs will never occur. For use in any area where safety is an issue, this software must be proven to be using well known safety case assessment procedures.
Therefore, the use of non dedicated code should only correspond to experimental purpose for a limited duration under specific regulation approval. The implementation of dedicated code for pseudolite is part of the modification of firmware expected from chipset manufacturer to meet mass market requirements.
In view of the unknown effect to all non participating receiver designs associated with the use of non visible satellite PRN codes by pseudolites, this method is not recommended for operational use.

c) Using dedicated code will avoid the type of impact described in b) and is thus recommended as soon as possible (as soon as mass market chipsets are able to process such dedicated codes). Moreover, the use of longer codes will also improve the compatibility with non participative receivers as well as the performance of participative receivers. In case of mass market deployment, the use of dedicated code is the solution to grant no interference described in b) with non participative GPS receiver.

d) It is not possible to determine a reasonable separation distance (i.e. much lower than the building dimensions) between the pseudolites and a non participative GNSS receiver located in the same building. Therefore, this kind of non participative GNSS receiver cannot be protected.

e) The studies of the aggregate effect of PL on aeronautical receivers show that in average, the PL density should be limited to 2.5 PL/km² if the e.i.r.p is -50 dBm and 11.8 PL/km² if the e.i.r.p is limited to -59 dBm (or if equivalent mitigation techniques are applied) under the assumption of a uniform distribution of these PL over very large areas (more than 1 000 km²). It should be noted that these values should not be taken as regulatory limitations since they correspond to average numbers, which may be exceeded locally.

In sensitive areas like airport, the studies show that the e.i.r.p should be limited to -59 dBm and mitigation techniques applied. Moreover, since the aggregated effect really depends on the real deployment conditions, case by case studies may be necessary
It is expected that the use of pulse transmitting Pseudolites will improve the compatibility with RNSS systems.

3.2.2 Compatibility with other co-frequency or adjacent band services detail

3.2.2.1 Band 1 164-1 215 MHz, ARNS

Aeronautical Radio Navigation Service (ARNS) is a safety related service and should be carefully protected from interference. The protection criterion is I/N = - 23 dB and does not include any relaxation for example as function of time (Fractional Degradation of Performance, FDP). The ARNS receivers are located on board aircraft on all altitudes up to 12000 meters and the radio propagation environment is already rather difficult.

An aggregated PFD limit of -144.5 dBW/m²/MHz to protect ARNS from RNSS was assumed.

Sharing and/or compatibility between continuously transmitting Pseudolites and ARNS would not be easily feasible, and in particular around airports areas.

Sharing/compatibility between Pulse transmitting Pseudolites and ARNS are not feasible.

3.2.2.2 Band 1 215-1 300 MHz, RDS

Radiodetermination Service (RDS) is a safety related service and should be carefully protected from interference. The protection criterion considered is I/N = - 6 dB to be met 100% of the time.

Due to the high antenna gain and sensitivity of radars the separation distances are rather large already in the case of continuously transmitting Pseudolites, becoming unacceptable in the case of pulse transmitting Pseudolites.

Sharing/compatibility between Pseudolites and Radio determination Service is possible if

1) There is a frequency separation between Pseudolites and radars

or

2) There is a separation distance between Pseudolites and radars.

3.2.2.3 Band 1 215-1 300 MHz, EESS

An EESS system scans the surface of the Earth with its antenna main beam. During scan the antenna footprint is about 20 km x 20 km area. One single pulse transmitting Pseudolite in the antenna footprint can not cause interference to EESS systems. If the number of Pseudolites in the footprint increases aggregated average interference power level in the EESS receiver may be exceeded.

Sharing/compatibility between one continuously transmitting Pseudolites and EESS is feasible.

Sharing/compatibility between one pulse transmitting Pseudolites and EESS is also feasible due to the high processing gain of the SAR system.

However, aggregated effect should be considered carefully.

3.2.2.4 Impact on RAS in the adjacent band 1 610-1 613 MHz

The Radio Astronomy Service plays a key role in increasing our understanding of the universe in which we live. It is a passive service that does not cause interference to other users of the electromagnetic spectrum. It is important to protect radio astronomy operations from interference as use of the electromagnetic spectrum by both terrestrial and space-borne active services increases. For indoor PLs:

1. **Sharing/compatibility between indoor CW PLs and the Radio Astronomy Service in this band is feasible.**
2. **Sharing/compatibility between indoor pulsed PLs and the Radio Astronomy Service in this band is feasible if a co-ordination zone is adopted around observatories of the RAS and deployment of pulsed indoor PLs within that zone is assessed on a case by case basis for non-interference.** Deployment of indoor pulsed PLs in the vicinity of a station of the RAS may be possible by considering:

- Terrain and clutter effects between the pulsed indoor PL and RAS station.
- Reduction in transmitter pulse power, careful choice of physical location in the building, manipulation of the transmit antenna pattern in situ (additional shielding), reduction in duty cycle, etc. used in combination.

For both cases (1) & (2) above, it is assumed that the unwanted out of band emission power falling into the Radio Astronomy band is limited as described in ECC Report 128 [2].

4 REGULATORY ASPECTS FOR INDOOR GNSS PSEUDOLITES

4.1 Proposed regulatory regime

As a rule, the use of radio frequencies is subject to either a general authorisation, in particular if the risk of harmful interference is negligible, or the grant of individual rights of use, issued to each operator of PL. Within the framework of a general authorisation, the use of radio frequencies is free, in compliance with conditions included in such an authorisation.
Those two options are examined in this section, considering that authorisation regime for the use of radio frequencies by PL shall ensure that no harmful interference to other services could result from the use of these devices, protection of both GNSS systems and non-GNSS systems should be considered.

4.1.1 General authorisation option

Adopting general authorisation for the use by PL of radio frequencies in RNSS bands would raise a number of issues:

- use of radio frequencies without individual authorisations would cause a potential increase in the risk of interference caused to adjacent GNSS receiver applications in some situations and in particular if the PL is using non-dedicated codes, as well as interferences between non-coordinated pseudolite systems themselves;
- a general authorisation regime will increase the likelihood that there is an unknown GNSS PL adjacent to other legitimate GNSS uses, which would result in potentially significant interference issues if the PL is using non-dedicated codes;
- aviation users are particularly concerned as unknown GNSS PL using non-dedicated codes operating nearby to an aircraft as this could cause errors or stop the aircraft acquiring and tracking GNSS;
- Government users are also concerned that uncontrolled use of these devices might negate the trust in the use of GNSS and therefore undermine the regulatory basis of any location-based applications.

With these factors in mind, this Report does not recommend general authorisation regime for these devices.
On a national level, if an administration makes the use of radio frequencies subject to a general authorisation, it is accepted that such an authorisation should be subject to approval by the national civil aviation administration.

4.1.2 Individual rights of use option

Due to the importance of ensuring compatibility with GNSS systems, the use by PL of radio frequencies in RNSS bands should be subject to individual authorisations. Such individual authorisations should be granted to operators of PL, and may be subject to technical and operational conditions necessary for the avoidance of harmful interference. Those conditions should define physical implementation of PL, in order to properly assess the compatibility with GNSS systems for a given site, and to be able to determine if any local pseudolite is responsible for any harmful interference.

4.2 Technical and operational conditions which may be attached to rights of use for radio frequencies

Rights of use for radio frequencies for indoor GNSS PL should ideally be restricted to applications listed in section 2.6 (“Examples of the need for indoor GNSS PL”). The authorisation should provide specific guidance for installation.
On the basis of the conclusions of the technical studies, the following CEPT recommendations related to technical and operational conditions for indoor PL have to be taken into account:

- GNSS PL should only use dedicated codes;
- GNSS CW and pulsed-PL should be authorised in the 1 559-1 610 MHz band.

Mitigation techniques such as the following should be implemented:

- Using PL antennas tilted toward the ground and pointing inside the building. The e.i.r.p above elevation angles higher than 0 degree should be reduced by at least 6dB compared the maximum e.i.r.p;

- Avoiding PL deployment close to large aperture or implementing additional attenuation with shielding material;
- Reducing the PL maximum e.i.r.p.;
- GNSS PL e.i.r.p. should be limited to – 50 dBm in the general cases;
- GNSS PL e.i.r.p. should be limited to – 59 dBm in airport areas and the installation of PL in such areas should be subject to case by case studies.

In addition, the following elements should be taken into account:

- Transmit antenna patterns have to be adapted according to the site requirements and coverage areas. Antenna patterns should be designed to minimize impact on non-participating receivers and focus only on the operations area;
- Site installations should be conducted by professional installers only. This should include e.g. appropriate measures to avoid unauthorised insertion of additional RF power amplifiers between signal generator and antenna and others.

4.3 Protection of non participating GNSS receivers

Pseudo Random Number (PRN) codes are the identification code by which GNSS signals are associated with individual satellites and their different signals. Using different PRN codes in a RNSS family of codes will minimise the impact on receiver design. Using a different PRN code family should be avoided to minimise receiver design modifications.

Except for experimental situations which have to be dealt with at national level, only PL using dedicated codes should be used in deployed PL systems. The national administration must have a confirmation from the licence applicant that the PRN code requested is one of those that are dedicated to PL.

4.4 Development of a Harmonised European Standard

As there are no standards for PL, it is anticipated that ETSI may be requested in near future to develop a harmonised standard for indoor PL.

4.5 Enforcement

A malfunctioning or a badly installed GNSS pseudolite system could affect the performance of non participating GNSS receivers operating in areas near to the devices coverage area.

A malfunctioning or an unprofessionally installed GNSS pseudolite could cause irritations or inaccuracies in participating or non-participating GNSS receivers operating in areas near the coverage area.

For Galileo, ESA and EC are introducing PL in the definitions and assignments of the Galileo SIS ICD [1]. This includes PRN allocations for PL as well as Navigation Message content.

For GPS, Pseudolite PRNs are already allocated in SIS ICD IS-GPS-200D [1]. As some transport vehicles use GNSS receivers for accurate positioning, there is a need for rapid enforcement actions if interference is caused and reported to GNSS services. However, due to the low level of received GNSS signals, there might be a problem in locating any interference. Consequently, administrations are reliant on the reports of interference to begin to find these. Low-level signals may not be easily detected.

If an installation is found to cause interference conditions, this should be rectified, by comparing the installed equipment against the technical and operational conditions attached to the licence and perhaps including measured results of the affect on other non-participating GNSS receivers in the local vicinity. If necessary, make suitable adjustments to any installation or methods of interference assessment. If no licensed installation was faulty, identification and resolution of an unlicensed GNSS pseudolite or other source of harmful interference is required.

As knowledge of the location of GNSS pseudolite installations through licensing is recommended, CEPT administrations should not allow the installation of GNSS pseudolite in mobile vehicles.

4.6 Additional guidance for a regulatory approach for indoor pseudolite systems in RNSS bands

Unlike mobile telecommunication network operators such as GSM or 3G, GNSS operators such as GPS and Galileo have no licence coverage and no obligation to provide location services in every environment. This obviously applies in particular to indoor environment.

It is assumed that systems delivering indoor location services will be operated by "location system operators". They may rely on various technologies, including or not PL.

Pseudolite system operators wishing to operate pseudolite systems in a building will have the obligation to get an authorisation from the national regulatory authority of the country where they are operating (see section 2).

Pseudolite system operators will have to guarantee that their systems comply with European/CEPT and national regulatory constraints regarding potential interferences with non participative GNSS receivers operating outdoor, in the vicinity of the building.

It is highlighted that PL are aimed at complementing GNSS systems that suffer from poor performances indoor. PL, among other systems, provide accurate location services that will allow building managers to fulfil future needs in location services for commercial services as well as security related services.

Pseudolite systems cannot guarantee a total absence of interference with non participative GNSS receivers relying on satellite signals for indoor operations ("indoor satellite services"), an analysis is given below for each player that is potentially involved in the chain (therefore, the potential interference from pseudolite systems to non participative GNSS receivers operating outside is not addressed in the following analysis):

- For the GNSS operator (operating GPS, Galileo and other present or future satellite systems), it is expected that the impact of PL on indoor satellite services be limited, due to the poor performance of indoor satellite signals and since no obligation applies for indoor coverage for this GNSS operator;
- It is not possible to determine a reasonable separation distance (i.e. much lower than the building dimensions) between the PL and a non participative GNSS receiver located in the same building. Therefore, this kind of non participative GNSS receiver cannot be protected. For the building manager, implementing an indoor pseudolite system will be inherently subject to its agreement, and will require that the pseudolite system operator is authorised by the national regulatory authority of the country where they are operating.

5 CONSIDERATION OF MOBILE PSEUDOLITES

Mobile PL should not be authorised because they may enter areas where case by case studies are necessary (e.g., airport areas). This report considers the regulatory factors of fixed indoor GNSS PL and provides some technical and other licensing conditions that could be applied for the implementation of GNSS pseudolite devices.

6 CONCLUSIONS

6.1 Technical conclusions and recommendations

As a first stage, it is recommended that, indoor GNSS PL should be authorised in the band 1 559-1 610 MHz. Studies have been carried out for CW PL with e.i.r.p. of -50 dBm and -59 dBm.

In order to reduce the potential interference level for lower separation distances, the following measures should be taken:

- Using PL antennas tilted toward the ground and pointing inside the building. The e.i.r.p above elevation angles higher than 0 degree should be reduced by at least 6 dB compared the maximum e.i.r.p;
- Avoiding PL deployment close to large aperture or implementing additional attenuation with shielding material;
- Reducing the PL maximum e.i.r.p.

In case of temporary experimentation on a national basis of PL using non-dedicated PRN codes, it is recommended to broadcast on the PL a modified navigation message to ensure that the signal is declared "UNHEALTHY" by some non participating receiver.

It is necessary to ensure that a failure of the software management system used to allocate the satellite PRN codes to the PL (in case the latter uses non-dedicated codes) will never occur.

Moreover, the use of longer pseudo random codes will also improve the compatibility with non participative receivers as well as the performance of participative receivers.

The regulation should only authorise PL with dedicated codes. PL with non-dedicated codes should only be authorised, if necessary, in case of experimentation and on a national basis.

In addition, in airports areas, the studies shows that the e.i.r.p. should be limited to -59 dBm and mitigation techniques applied to protect those aeronautical receivers when the aircraft is at its parking stand. Moreover, since the aggregated effect really depends on the real deployment conditions, case by case studies are necessary before any deployment in the airport areas, or in the vicinity of them.

6.2 Licensing conclusions and recommendations

It is recommended that PL be operated through individual authorisations so as to ensure that no PL will be installed in areas where case by case studies are necessary (i.e. airport areas).

As knowledge of the location of GNSS pseudolite installations through licensing is recommended, CEPT administrations should not allow the installation of GNSS pseudolite in mobile vehicles.

Any authorisations or licences for GNSS pseudolite installations could include guidance for reduction and reasonable checking of the potential to cause interference.

Military or other government authorities as well as meteorological services may require specific site limitations.

ANNEX 1: LIST OF REFERENCES

[1] The GPS ICD 200D is now IS-GPS-200E, http://www.losangeles.af.mil/shared/media/document/AFD-100813-045.pdf and the Galileo ICD is http://ec.europa.eu/enterprise/policies/satnav/galileo/files/galileo-os-sis-icd-issue1-revision1_en.pdf

[2] ECC Report 128: "Technical and operational provisions required for the use of GNSS pseudolites"

[3] ECC Report 145: "Regulatory Framework for Global Navigation satellite system (GNSS) repeaters"

[4] ETSI TS 136 171 V9.1.0 (2010-07): "Requirements for Support of Assisted Global Navigation Satellite System (A-GNSS) (3GPP TS 36.171 version 9.1.0 Release 9)