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Technical Report

Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference Document; Short Range Devices (SRD); Technical characteristics for Location tracking Applications for Emergency Services (LAES) in disaster situations operating within the frequency range from 3,4 GHz to 4,8 GHz

Reference

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Contents

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Electromagnetic compatibility and Radio spectrum Matters (ERM).

Introduction

Ultra Wide Band (UWB) technology enables a new generation of Location Tracking and Sensor devices and opens new markets with very different applications. UWB radio location and sensor devices with an operating bandwidth of several hundreds of MHz up to more than one GHz allow tens of centimetre-level localization and positioning even in the presence of severe multipath effects caused by walls, furniture or any other harsh radio propagation environments.

The applications described in the present document are intended to become an essential part of the Public safety operations.

The purpose of producing the present document is to lay a foundation for industry to quickly bring innovative and useful products to the market.

The present document has been developed to support the co-operation between ETSI and the Electronic Communications Committee (ECC) of the European Conference of Post and Telecommunications Administrations (CEPT).

Status of pre-approval draft

The present document was developed by ERM_TG31C.

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V2.1.1	0.4.13			4 September 2008	Clean version of v2.1.1_0.4.12 plus deletion of extra "for" in sentence above table 3
NOTE: See clause A.2 of EG 201 788 [i.14].					

1 Scope

The present document defines the requirements for radio frequency usage for short range Ultra Wide Band (UWB) location tracking devices to be used only by emergency services (e.g. fire workers, police, civil protection authorities) in critical situations or in surveillance operations and operating within the frequency range from 3,4 GHz to 4,8 GHz. A licensing approach is suggested for these applications.

Additional information is given in the following annexes:

- detailed market information (annex A);
- technical information (annex B);
- expected compatibility issues (annex C).

2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific.

- For a specific reference, subsequent revisions do not apply.
- Non-specific reference may be made only to a complete document or a part thereof and only in the following cases:
    - if it is accepted that it will be possible to use all future changes of the referenced document for the purposes of the referring document;
    - for informative references.

Referenced documents which are not found to be publicly available in the expected location might be found at http://docbox.etsi.org/Reference.

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2.1 Normative references

The following referenced documents are indispensable for the application of the present document. For dated references, only the edition cited applies. For non-specific references, the latest edition of the referenced document (including any amendments) applies.

Not applicable.

2.2 Informative references

The following referenced documents are not essential to the use of the present document but they assist the user with regard to a particular subject area**.** For non-specific references, the latest version of the referenced document (including any amendments) applies.

[i.1] CEPT/ECC Report 64 (February 2005): "The protection requirements of radiocommunications systems below 10,6 GHz from generic UWB applications"; Helsinki.

NOTE: Available at http://www.ero.dk/doc98/Official/pdf/ECCREP064.pdf.

[i.2] CEPT/ERC Report 25: "The European table of frequency allocations and utilisations in the frequency range 9 kHz to 3 000 GHz". (Lisboa 02, Dublin 03, Kusadasi 04, Copenhagen 04, Nice 07).

NOTE: Available at http://www.erodocdb.dk/docs/doc98/official/pdf/ErcRep025.pdf.

[i.3] Document TG3#7-19R0 (1-3 March 2005): "Effects of PSD limits on UWB positioning systems"; submitted to ECC TG3 meeting, Brest.

[i.4] FCC 03-33: "Revision of Part 15 of the Commission's Rules Regarding UWB Transmission Systems".

[i.5] ECC/DEC/(06)04 of 24 March 2006 on the harmonized conditions for devices using Ultra-Wideband (UWB) technology in bands below 10,6 GHz.

[i.6] Revised Terms of reference for ECC TG3 (July 2006).

[i.7] ECC/DEC(06)04 - update June 2007, /DEC/(06)04 amended 6 July 2007: "ECC Decision of 24 March 2006 amended 6 July 2007 at Constanta on the harmonized conditions for devices using. Ultra-Wideband (UWB) technology in bands below 10,6 GHz".

[i.8] Commission Decision 2007/131/EC, 23rd Feb 2007 allowing the use of the radio spectrum for equipment using ultra-wideband technology in a harmonized manner in the Community.

[i.9] ECC/DEC/(06)12: "ECC Decision of 1 December 2006 on the harmonized conditions for devices using Ultra-Wideband (UWB) technology with Low Duty Cycle (LDC) in the frequency band 3,4 GHz to 4,8 GHz".

[i.10] Draft ECC Recommendation (08)05 on the identification of frequency bands for the implementation of Broad Band Disaster Relief radio applications in the 5 GHz frequency range.

[i.11] ECC Report 102 (January 2007): "Public protection and disaster relief spectrum requirements"; Helsinki.

[i.12] Report ITU-R Recommendation M.2033: "Radiocommunication objectives and requirements for public protection and disaster relief".

[i.13] ETSI TR 102 491: "Electromagnetic compatibility and Radio spectrum Matters (ERM); TETRA Enhanced Data Service (TEDS); System reference document".

[i.14] ETSI EG 201 788 (V1.2.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM) Guidance for drafting an ETSI System Reference Document".

[i.15] ETSI EN 302 500 (all parts): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD) using Ultra WideBand (UWB) technology; Location Tracking equipment operating in the frequency range from 6 GHz to 8,5 GHz.

[i.16] ETSI EN 302 435 (all parts): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Technical characteristics for SRD equipment using Ultra WideBand technology (UWB); Building Material Analysis and Classification equipment applications operating in the frequency band from 2,2 GHz to 8 GHz".

[i.17] ECC Decision (07)01: " ECC Decision of 30 March 2007on Building Material Analysis (BMA) devices using UWB technology ".

[i.18] IEEE 802.15.4a: "IEEE Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements; Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs); Amendment 1: Add Alternate PHYs".

[i.19] ECC Report 64: "The protection requirements of radiocommunications systems below 10,6 GHz from generic UWB applications"; Helsinki, February 2005.

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

activity factor: reflects the effective transmission time ratio

maximum mean e.i.r.p. spectral density: highest signal strength measured in any direction at any frequency within the defined range

NOTE: The mean e.i.r.p. spectral density is measured with a 1 MHz resolution bandwidth, an RMS detector and an averaging time of 1 ms or less.

maximum peak e.i.r.p.: highest signal strength measured in any direction at any frequency within the defined range

NOTE: The peak e.i.r.p. is measured within a 50 MHz bandwidth centred on the frequency at which the highest mean radiated power occurs.

3.2 Symbols

For the purposes of the present document, the following symbols apply:

Toff	the time interval between two consecutive bursts when the UWB emission is kept idle
Ton	the duration of a burst irrespective of the number of pulses contained
δR	Range resolution

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ABL	Anchor Based Localization
AFL	Anchor Free Localization
BBDR	Broad Band Disaster Relief
BU	Base Units
CEPT	European Conference of Post and Telecommunications administrations
CU	Control Unit
DAA	Detect and Avoid
DBPSK	Differential Binary Phase Shift Keying
DCLG	Department of Communities and Local Government
DR	Disaster Relief
DUs	Usually Dropped Units
e.i.r.p	equivalent isotropically radiated power
ECC	Electronic Communications Committee
FHUWB	Frequency-Hopping UWB
GNSS	Global Navigation Satellite System
GPS	Global Positionning System
HSN	High Speed Network
INS	Inertial Navigation Systems
IR-UWB	Impulse Radio UWB
ITU-R	International Telecommunications Union - Radio sector
LAES	LocationTracking Applications for Emergency Services
LBT	Listen Before Talk
LDC	Low Duty Cycle
LOS	Line Of Sight
MU	Mobile Units
NLOS	Non Line Of Sight
PN	Pseudo Noise
PP2	Public Protection situations

PPDR	Public Protection and Disaster Relief
PRF	Pulse Repetition Frequency
PSD	Power Spectral Density
RF	Radio Frequency
SSDI	Social Security Disability Insurance
TDMA	Time Division Multiple Access
UWB	Ultra Wide Band

4 Comments on the System Reference Document

Comments received during the internal ETSI enquiry have been incorporated.

5 Executive summary

5.1 Background information

The present document describes new short-range location applications based on UWB technology which will be used in emergency situations. For these systems, no fixed installations are available to perform the localization as the place of events are not known in advance.

The system is composed of a set of nodes deployed as an ad-hoc network. It will provide accurate positioning information of objects or persons which are inside the building which is affected by the event. This means that the required signals necessarily demand a high bandwidth to provide the required accuracy which is better than one metre.

Two systems architecture can be used for such applications:

- Anchor Based Localization (ABL); and
- Anchor Free Localization (AFL).

For the systems based on Anchor Based Localization (ABL) at least three reference points which are inside or outside the building located in the sensitive area are needed. For Anchor Free Localization (AFL) systems, there is no need of reference points but a sufficient connectivity between the nodes inside the building is needed in order to obtain ranging information between all nodes. This implies that a high signal power is required in order to enable the penetration of obstacles (walls, etc.) and to enable a sufficient link distance between nodes inside the building. Based on these requirements, an increased power compared to current regulations of the UWB devices that will be used in such situation is needed and is discussed in the present document.

The users of the proposed system will be government agencies responsible for public safety primarily and so would be clearly defined organizations. It is suggested in the proposed regulation that users should be licensed, but not sites, since the equipment would only be operated when and where an emergency situation occurs. As described in [i.12], applications are used temporarily by emergency services in all aspects of disaster situations, including disaster prevention.

There is evidence that such a system will significantly enhance the security and sustainability of life of persons and therefore will provide a socio-economic benefit.

5.2 Market information

The intended market for this equipment is government agencies responsible for public safety: primarily fire and rescue services, but also including police and other services. (Note that the organization and names of these services vary between European states.) The members of these services work in dangerous environments and put their own lives at risk in order to protect the public, and being able to locate and track them makes their work safer. As a result of being safer, these workers can be more effective at saving the lives of the public.

This enhanced protection for public safety workers yields benefits over the full range of emergencies, so the market is potentially a large one.

The detailed market information are given in annex A.

5.3 Technical system description

The short-range location application described in the present document uses UWB waveforms with bandwidths of over 500 MHz within the frequency band 3,4 GHz to 4,8 GHz. The application calls for accurate positioning inside buildings, where radio signals will suffer severe losses and multi-path. By using a very wide bandwidth, good range measurement can be achieved even in such difficult environments. It has a position accuracy of objects or people inside buildings of better than one metre.

The link distance that is required in-buildings by emergency services is about 50 m corresponding to a link distance of 500 m in LOS conditions.

As these systems are used in emergency situations, they do not require any infrastructure and so they operate as ad-hoc networks with mesh networking capabilities.Two systems architecture can be used for such applications:

- Anchor Based Localization (ABL) systems for which Anchors are used in order to determine the location of the nodes in the network. Usually, anchor nodes are equipped with GNSS in order to obtain an absolute position.
- Anchor Free Localization (AFL) systems for which there is no need of anchors. For this solution real-time ranging information are spread all over the network allowing to construct a relative 3D positioning of all nodes. The peer-to-peer distance information are used to determine node coordinates even without any referenced node. This solution can be used even if all nodes are in deep indoor environment preventing any GNSS use.

The choice of system architecture is independent of the waveform that is used for the UWB devices. Many physical layers can be applied such as Impulse Radio, chirp waveform or a frequency hopping technique in a large bandwidth.

In the present document two waveforms are detailed: the Impulse Radio based on IEEE 802.15.4a [i.18] standard and the less conventional approach called Frequency-Hopping UWB (FHUWB).

The Impulse Radio solution has a typical data rate of 500 kbps which is needed especially for AFL system architecture and to transmit small amount of data between users. For this solution an increased RF power compared to current regulations is needed in order to compensate the losses implied by severe NLOS environments and to get the link distance.

The other solution is to use a much less usual Frequency-Hopping UWB (FHUWB) signal with a very much reduced data capacity (15 kb/s) in order to maximize the penetration for a given transmitted power level. However, as stated previously, for AFL systems a greater amount of ranging data has to be exchanged and the data rate transmission has to be increased.

In annex B, a detailed description of the localization techniques, the link budget and the UWB signals is given.

5.4 Regulations

5.4.1 Current regulations

The current regulation for generic UWB devices are included in ECC/DEC(06)04 as amended in July 2007 [i.7].

Table 1 summarizes the authorized power limits for generic licence free UWB devices.

Table 1: Current power limits for generic licence-free UWB devices

Frequency range	Maximum mean e.i.r.p spectral density (dBm/MHz)	Maximum peak e.i.r.p (measured in 50 MHz)
Below 1,6 GHz	-90 dBm/MHz	-50 dBm
1,6 GHz to 2,7 GHz	-85 dBm/MHz	-45 dBm
2,7 GHz to 3,4 GHz	-70 dBm/MHz	-36 dBm
3,4 GHz to 3,8 GHz	-80 dBm/MHz	-40 dBm
3,8 GHz to 4,2 GHz	-70 dBm/MHz	-30 dBm
4,2 GHz to 4,8 GHz (see notes 1 and 2)	-70 dBm/MHz	-30 dBm
4,8 GHz to 6 GHz	-70 dBm/MHz	-30 dBm
6 GHz to 8,5 GHz	-41,3 dBm/MHz	0 dBm
8,5 GHz to 10,6 GHz	-65 dBm/MHz	-25 dBm
Above 10,6 GHz	-85 dBm/MHz	-45 dBm
NOTE 1: UWB devices placed on the market before 31st December 2010 are permitted to operate in the frequency band 4,2 GHz to 4,8 GHz with a maximum mean e.i.r.p. spectral density of -41,3 dBm/MHz and a maximum peak e.i.r.p of 0 dBm measured in 50 MHz. NOTE 2: In case of devices installed in road and rail vehicles, operation is subject to the implementation of Transmit Power Control (TPC) with a range of 12 dB with respect to the maximum permitted radiated power. If no TPC is implemented, the maximum mean e.i.r.p. spectral density is -53,3 dBm/MHz.		

The mitigation techniques such as LDC in the lower bands are included in ECC/DEC(06)12 [i.9]. Table 2 summarizes the current decision on LDC in the lower band.

Table 2: Summary of ECC/DEC(06)12

All kind of devices except: - installations in vehicles; - installations at fixed outdoor location; - installations in aircrafts.	**Technical requirements for LDC in the band 3,4 GHz to 3,8 GHz** UWB devices implementing LDC will be permitted to operate at a level of -41,3 dBm/MHz in the frequency band 3,4 GHz to 4,8 GHz with the following requirements: - Ton max = 5 ms; - Toff mean = 38 ms (averaged over 1 s); - Σ Toff > 950 ms per second; - Σ Ton < 5 % per second and 0,5 % per hour.

Concerning the use in vehicles as stated above, the updated ECC/DEC/(06)04 allowed the use with TPC implemented.

ECC/DEC/(06)04 includes location applications, and EN 302 500 [i.15] applies to such applications with emissions that conform to the generic licence free UWB limits. Other non-communications applications of UWB have been considered as "specific applications", with different frequency and emissions limits. ECC/DEC(07)01 and EN 302 435 [i.16] apply to devices for building material analysis. Work is proceeding on object detection and classification, and while an ECC report is in preparation.

5.4.2 Proposed regulation and justification

The following limits in table 3 are proposed for UWB devices used in emergency situations to provide precise localization. An important point to be raised is that these devices will be used only in critical PPDR situations by users that are clearly identified.

Indeed, users would be clearly defined organizations responsible for public safety. It is suggested that users should be licensed, but not sites, since the equipment would only be operated when and where an emergency calls for it. Since the usage of the system is considered mission critical, locally and temporary, this application would fit in the PP2 and DR categories as defined in Report ITU-R Recommendation M.2033 [i.12]. However the proposed licensing will also depend on the specific requirements and organizational structures of individual states.

Emergency management or disaster response/recovery agencies use the system to provide accurate indoor location and tracking information. They will need this technology for emergency management and disaster services that are characterized by a very low usage pattern during routine operations and high but localized usage patterns during major disasters or events. Special operational needs include responding to an incident requiring specialized training for safe and effective operations, such as a hazardous materials leak and/or spill remediation, mountain rescue and associated technical rescue, collapse search and rescue, swift water rescue, blue water rescue, trench and confined space rescue, and heavy rescue.

Since the system is used to save lives and should have a rapid deployment, it is not appropriate for it to check for other spectrum users before operating at all (as in "LBT" or some forms of "DAA").

However, it should be noticed that the activity factor of a single device will not exceed 1 % which should be sufficient for the operation of the location tracking process itself and the transmission of a small amount of communication data. As for LDC defined for generic applications, Ton max = 5 ms and Toff mean = 38 ms (averaged over 1 s).

Table 3: Proposed limits for UWB devices used in emergency situations

Frequency range	Maximum mean e.i.r.p. spectral density	Maximum peak e.i.r.p. (measured in 50 MHz)
Below 1,6 GHz	-90 dBm/MHz	-50 dBm
1,6 GHz to 3,4 GHz	-85 dBm/MHz	-45 dBm
3,4 GHz to 4,8 GHz	-21,3 dBm/MHz	20 dBm Maximum Activity factor is 1 %
4,8 GHz to 6 GHz	-70 dBm/MHz	-30 dBm
6 GHz to 8,5 GHz	-41,3 dBm/MHz	0 dBm
8,5 GHz to 10,6 GHz	-65 dBm/MHz	-25 dBm
Above 10,6 GHz	-85 dBm/MHz	-45 dBm

The increase of 20 dB for power with respect to current limits in the frequency range 3,4 GHz to 4,8 GHz will extend the protection range but the size of operation is limited and the users will use it mainly in indoor and also in deep indoor environment. The system proposed in the present document with this proposed regulation would help to save lives of citizens and people involved in the action. As a number of lives can be saved with the system, it can be accepted that civilian services in this band could be potentially degraded during the duration of the operation.

6 Expected ETSI actions

It is envisaged that a Harmonized Standard will be prepared in ERM TG31C, should the proposal contained in the present document be adopted.

7 Requested ECC actions

ETSI requests ECC to consider the present document, which includes the necessary information to support the co-operation under the MoU between ETSI and the Electronic Communications Committee (ECC) of the European Conference of Post and Telecommunications Administrations (CEPT).

ECC is requested to undertake studies on the proposal covered by the present document. A European harmonized regulatory solution is envisaged that would also facilitate international circulation of this PPDR equipment and systems.

The creation of a new ECC recommendation or revision of an existing one is envisaged.

It is recommended that ECC deliverable be completed by middle of 2009 to allow manufacturers to have sufficient time to have equipment on the market as of the beginning of 2010.

Annex A: Detailed market information

A.1 Range of applications

The proposed system will be used in situations where lives are at risk, from a small house fire up to major disasters.

Disasters, which call for Disaster Relief (DR) operations, can be caused by either natural or human activity. Natural disasters include a earthquakes, major tropical storms, major ice storms, floods, etc. Examples of disasters caused by human activity include industrial accidents, large-scale criminal incidences, or situations of armed conflict. Generally, both the existing PP2 communications systems and special on-scene communications equipment brought by DR organizations are employed. The applications are used temporarily by emergency services in all aspects of disaster situations, including disaster prevention.

There can also be large-scale emergency events (e.g. large fire in a large city), or events that threaten public order, both national and international (such as the G8 Summit and the Olympics).

Most deployments will be for the kind of small-scale emergencies that occur every day, and are dealt with by the emergency services almost as a matter of routine. However, in such emergency situations, particularly within smoke filled, partially or completely collapsed large buildings, communications with rescue personnel can be difficult. Safety and coordination of the operations is hampered by a lack of knowledge of the location of emergency staff.

The use of Ultra-WideBand (UWB) radio, to allow the precise location of personnel to be measured and displayed in a control centre, will make a real contribution to saving lives. It can also support an increase in the communication between emergency personnel, where the system is able to handle localization and communications. The data carried could range from the health and equipment status of individual personnel, to image data of particular disaster scenes (thus providing the control centre staff with a better insight into the operation, enabling them to provide more informed feedback and assistance to personnel on the ground).

UWB radio access technology offers the possibility of a reliable and pervasive wireless system by extending coverage to these difficult propagation environments for both communication and localization purposes. Some solutions focus on relatively low data rates (around 20 kbps), in order to ensure high reliability in urban/indoor environments, and carrying mainly the system's internal data used for localization. Other solutions focus on higher data rates (up to 1 Mb/s with a typical value of 400 kb/s) for data transmissions from fire-fighters to the Control Unit, coupled with high precision localization. For these systems to achieve the required range a range, higher transmitted power is needed for communication in the harsh environment, even if some mesh networking is implemented.

There are two main groups of applications for the solutions described in the present document to be used by emergency services (fire workers, police, civil protection authorities, etc.):

- indoor positioning even in hazardous environments;
- wireless sensor networks for surveillance in critical situations.

The main benefits for these authorities who use them are:

- high indoor availability within buildings affected by disaster;
- high positioning accuracy even in this indoor environment;
- no fixed installations required (only ad-hoc reference stations);
- high positioning accuracy for sensor networks deployed in critical situations.

One scenario that is foreseen for fire-fighter users is a building that has collapsed due to fire (which will be the most common case), terrorist attack or earthquake. Each emergency worker is equipped with a small unit which allows transmission and reception of UWB signals and allows the localization of the rescuers even in indoor harsh environment. The localization information can be displayed in a Control Unit in order to take quick decisions if some people are in danger. In this scenario first the UWB devices are mainly used indoor.

Figure A.1 illustrates this first scenario for fire-fighters.

Figure A.1: Fire-fighters in a building that has collapsed due to fire, terrorist attack or earthquake

The fire-fighter who is in danger can be precisely located in relative positioning thanks to the ranging information that is transmitted in the UWB network. In order to have an absolute positioning, as explained in annex B several solutions can be envisaged:

- With an Anchor Based Localization (ABL) system. In this case, anchor nodes can be put outside the building in rescue vehicles or just at the entrance of the building if anchor nodes are dropped portable UWB units. The absolute position can be obtain thanks to GNSS information.

- With an Anchor Free Localization (AFL) system. In this case, all rescuers have a relative 3D positioning. As an example they are able to know if there is a fireman behind a wall and to rescue him if necessary.

For this first scenario, UWB devices are used mainly indoor. Fire-fighters need to go in a deep indoor environment in which propagation is difficult and need to have localization information in all cases.

Another scenario would be the use of UWB devices in a sensor network application. In this application, UWB devices will be used indoors and outdoors. This application is beneficial in order to secure critical installations such as oil and chemical works. In this case some UWB Low Data Rate devices can be deployed in order to collect the information of the various sensors (PIR, seismic, infra red cameras, etc.) in a Control Unit.

All together, based on figures from insurance agencies for several metropolitan areas in Europe, it can be forecast that the application might save up to hundreds of lives per annum Europe-wide, taking into account fire-fighters and police deaths, and also civilian deaths as fire-fighters would be able to go deeper in the indoor environment if they know that they can be localized and quickly rescued in case of problems.

A.2 Expected market size and value

The volume of the European target addressable market is estimated to be in the range of 500 000 systems per year. Most of this demand is for replacements of units lost or damaged in use, which will be a common occurrence in such applications.

A.2.1 Markets covered

The primary market targeted is the EU market; UK, Germany, France, Italy, Austria and Netherlands expressed their interest for these applications. Further discussions have already shown that there is high interest for this technology in many other countries such as Singapore, USA and Australia and some regulatory provisions should also be put in place in these countries for the use of UWB in emergency situations.

Typical market segments have been chosen in order to clarify the numerous application possibilities. The market can be divided into:

- fire brigades;
- police and civil protection.

A.2.2 Market forecast

A.2.2.1 Fire Brigades

Fire services in Europe are provided by a mixture of employed professional staff and part-time volunteers. However, not only do the organization and responsibilities of these services vary between countries, but the statistics are also collected and presented in different ways, which makes it difficult to aggregate them. Some examples from individual countries are given here.

A.2.2.1.1 Statistics for the UK

Statistics for the UK (in practice England and Wales), from the relevant department (DCLG), distinguish primary, secondary, and chimney fires, plus false alarms. "Primary" means there is a risk to life, or valuable property, or this cannot be ruled out since the building or vehicle is or may be in use. However, "secondary" includes not just fires in heathland and derelict vehicles, but also derelict buildings - presumably when fire-fighters arrive they make an assessment of how abandoned the building is. In round numbers, in England each year, there are 350 000 fires, a similar number of false alarms, and 150 000 non-fire incidents. The fires break down as: buildings fires 90 000, vehicles and other outdoor 60 000, abandoned vehicles and rubbish, etc., 120 000, other secondary fires (some of which may actually be quite dangerous) 80 000, road accidents 40 000, other non-fire 110 000.

Casualties from fires are about 1 death per 100 000 of population in the UK, and similar over most of Europe). Fire-fighters' deaths are more erratic, and have been about 3 per year on average in the UK.

For the population of about 50 million as in the UK, there are about 30 000 professional fire-fighters, at 1 300 stations (less than half of them manned full-time) with 3 000 "front-line" vehicles (depending on the definition of this term). There are more volunteers (on "retained duty"), but as they are on stand-by and rarely called out the numbers are hard to use.

Full-time fire stations are usually crewed by four shifts ("watches"), but allowing for other absences, roughly six staff are needed for one fire-fighter on duty per watch. This leads to a figure of 5 000 on duty at a time. We might assume one UWB equipment is needed per fire-fighter on duty, but in practice this is too low. The expected method of keeping the terminals ready is to place them in a rack in the vehicle, which keeps their batteries charged, and for each fire-fighter to take one, personalize it (with the equivalent of a personal SIM card), and put it in the appropriate place in their clothing. As there are more places in vehicles than crew members on duty, because they have a choice of vehicle suitable for different call-outs, the total of vehicle places is the higher, at about 10 000 rather than 5 000.

In order to reinforce the network connectivity between the fire fighters, some dropped units can also be used. Each dropped unit is a UWB transceiver in a slightly different housing from the units that the fire-fighters placed in their clothing. The dropped units will often not be recovered after use, and we can expect that twice of these drop units will be lost during rescue operations. With a hypothesis of three dropped units used by the fire-fighters on duty, we can evaluate the number of dropped units which is around 30 000.

So, in the UK, the minimum number of UWB devices in use is estimated to be about 45 000. A replacement rate of one per year for UWB devices used on fire-fighters' clothing, and ten per year per fire-fighter for dropped units seems reasonable. Table A.1 gives an overview of the UK envisaged market.

Table A.1: Overview of the UK envisaged market

Unit	In use	Per year	In ten years
Units on fire-fighter clothing	10 000	10 000	110 000
Dropped units for network connectivity	30 000	100 000	1 030 000
Total	40 000	110 000	1 140 000

A.2.2.1.2 Statistics for France

In France the report of the SSDI in 2006 (source Ministry of the Interior, statistics report 2007), shows that the total number of interventions for the fire brigades and ambulances services is around 3 827 300. This number includes several types of intervention as depicted in figure A.2.

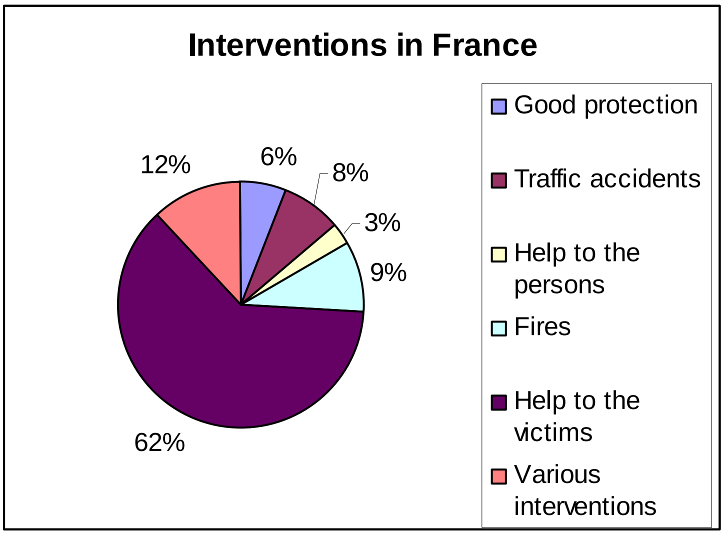

Figure A.2: Types of intervention in France

In round numbers, in France, there are 380 000 intervention for fires which is quite similar to the numbers in England.

Concerning the number of people working in France (source Ministry of Interior, statistics report 2007) for the fire brigades or the rescue services they are given in table A.2.

Table A.2: Number of people working in France for the fire brigades or the rescue services

Total Number	Professional	Volunteers	Military
252 400	38 100	201 800	12 200

In France there are around 38 000 professional fire fighters and around 200 000 volunteers.

A.2.2.1.3 Statistics for various European countries

Some statistics are published concerning the number of fire fighters in the different European countries, as shown in table A.3. In all countries, professional fire-fighters as well as volunteers operate in harsh environments.

Table A.3: Number of fire-fighters in different European countries

Country	Total Number	Professionnal	Volunteers
Germany	1 383 730	24 000	1 300 000
Austria	247 227		
Belgium	17 000	5 000	12 000
Denmark	6 500	1 700	3 400
France	229 000	39 000	190 000
Luxembourg	9 219	178	9 041
Netherland	26 512	4 253	22 259
England + Walls	58 000	35 500	16 500
Switzerland	115 500	1 400	113 700
Total	**2 092 688**	**111 031**	**1 666 900**

Taking into account that for 30 000 fire fighter in UK, there is a need of 100 000 units per year; these numbers show the huge market in order to have UWB localization-communication devices operated in each intervention in Europe.

All these numbers suggest that units will be regarded as disposable items (especially for dropped units), and for that to be acceptable, the price per unit should be low - a figure of €100 to €200 has been discussed as the upper limit for this.

A.2.2.2 Police and civil protection

In UK, the other service that has been identified as a potential user is the police, though we do not yet know how many incidents they expect to have for which the indoor localization is important. For police, the kind of operation that would call for such a system might be considered paramilitary, or even military, in some countries. Actions against terrorists or armed criminals would be prime candidates (these have a special status in Britain, where police are not routinely armed).

The changing threat from man-made disasters and the ever bigger natural disasters are forcing governments to utilize their resources in a different manner. An aspect of importance of these changing threats is that military forces will work also for peace keeping missions. In this context, there is a need in Europe for an increased cooperation between police, Fire departments, rescue and health organizations and military forces. It has to be noticed also that the environment in which all these organizations are working has changed. Indeed, the deployments are more and more in urban areas and inside buildings. For all these organizations, there is a need of location information and situation awareness even in these environments.

A.3 Traffic and equipment density forecast

The modes of deployment for LAES applications are not deterministic. However based on previous experiences, UWB LAES systems will be used mainly indoor in order to locate precisely objects and people. **LAES UWB systems will be used by professional groups (fire brigades, police and civil protection) in a precise area.**

A first estimation of the nodes density in a precise location would be to use for example the statistics (for classical events) published in France in 2007 (source Ministry of the Interior, statistics report 2007), shown in table A.4.

Table A.4: Statistics from France

Interventions	Number of men/hour
Fires	15 (could be 22 for fire forest)
Help to victims	5
Help to persons	4
Traffic accidents	13
Protection of goods	6
Diverse operations	5
Mean over all operations	8

As an example, 3 men operating during 2 hours will correspond to 6 men/hour.

Given these numbers and the users for UWB LAES devices, **the expected number of location tracking devices used in an area will be low**. It is very unlikely that the worst-case numbers of active devices used in previous UWB compatibility studies for UWB communications devices will ever be approached by UWB location systems.

LAES UWB systems will have a **low activity factor**. Assuming of location update of 5 Hz, a three way ranging procedure and 10 neighbours in the vicinity of the node, the activity factor is less than 1 %. Details are given in clause B.2.3.

LAES UWB systems will be used mainly indoors, by professional users (firemen, civil protection) with a low activity factor.

Annex B: Technical information

B.1 Detailed technical information

The short-range location application described in the present document uses UWB waveforms with bandwidths of over 500 MHz within the frequency band 3,4 GHz to 4,8 GHz. It has a position accuracy of objects or people inside buildings of better than one metre. The link distance that is required in-buildings by emergency services is about 50 m corresponding to a link distance of 500 m in LOS conditions.

The application calls for accurate positioning inside buildings, where radio signals will suffer severe losses and multipath. By using a very wide bandwidth, good range measurement can be achieved even in such difficult environments. To be used in emergencies, these systems are required to be used without any infrastructure, so they operate as ad-hoc networks with mesh networking capabilities.

There are a number of common principles that underlie the design of such systems:

- The system measures ranges between neighbouring nodes, where the path between them permits, by exchanging radio messages.
- Position information may or may not be displayed on a mobile device, but is almost always required at a central Control Unit external to the danger area (e.g. an incident control vehicle).
- The relative position of a node among its neighbours can be computed locally (in that node) or centrally.
- Data is also exchanged between nodes that can communicate, either in the same messages or with data and ranging done separately.

Then mainly two approaches are possible:

- Anchor Based Localization systems (ABL) using anchor nodes (having an absolute position i.e. relative to an Earth-fixed frame of reference) for the localization computation and using GNSS coordinates. For this solution anchors can be outside of the building or can be deposed by the fire-fighters when entering in the building as dropped units. Different systems can be defined with anchors nodes for precise localization. In all cases, at least three, and generally 4 anchors to 6 anchors in the system need to be at known positions.
- Anchor Free Localization systems (AFL) for which no anchors are used. In that case, the local distance information are used to determine node coordinates even when no nodes have pre-defined positions. The ranging information are shared between all nodes allowing to have relative localization information between all the nodes. The coordinates obtained with AFL can be embedded in a global coordinates system like GNSS. However when rescuers will be in deep indoor environment and when the transmission even with the proposed regulation will not be possible with nodes having GNSS information, AFL systems will still allow to locate nodes in its own coordinates.

These two systems have different needs in term of data throughput. However for both systems a mesh network is needed in order to allow to transport the ranging information along the network.

One possible system architecture, for ABL solution consists of:

- Base Units (BU) - generally located outside the building(s) on the emergency service vehicles. They are in principle, self locating with differential GPS (visibility to GNSS is needed) and are linked to each other and to the Control Unit via a High Speed (non-UWB) radio Network (HSN). They also contain an Ultra-WideBand (UWB) transceiver used for ranging and communication with other units (Base Units, Mobile Unit and Dropped Units).
- Mobile Units (MU) - the units worn by the emergency service personnel. They contain a UWB transceiver used for ranging and communication with other units (Base Units, Mobile Units and Dropped Units).

- Usually Dropped Units (DUs) are deposited by emergency service personnel as required to maintain the UWB network connectivity. In all respects except for the user interface and possibly packaging, they are the same as MUs.
- The Control Unit (CU) provides the main display to the emergency services co-ordinators, showing the position and status information for all emergency service personnel.

Figure B.1 shows an overview of a possible system architecture for an ABL system.

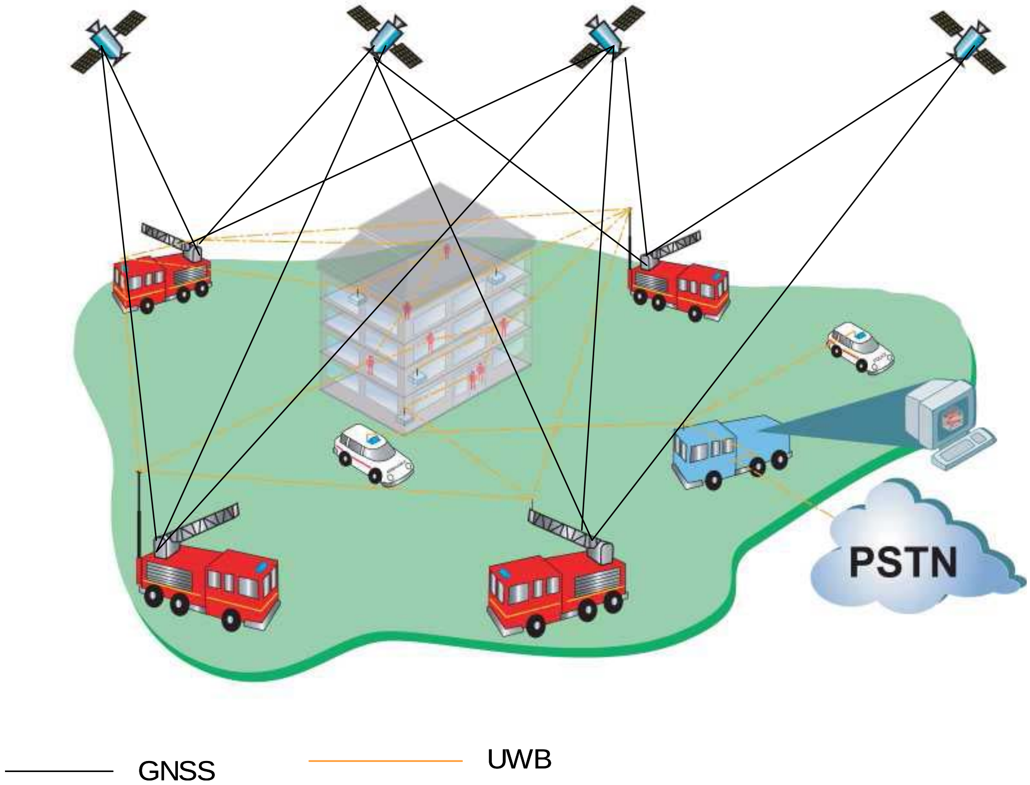

Figure B.1: Overview of a possible system architecture for an ABL system

One possible system architecture for AFL systems consists of:

- Mobile Units (MU) which are the units worn by the emergency service personnel. They contain a UWB transceiver used for ranging and communication. All mobiles nodes have the relative positioning information.

Figure B.2 gives an overview of the AFL system in a deep indoor environment (basement).

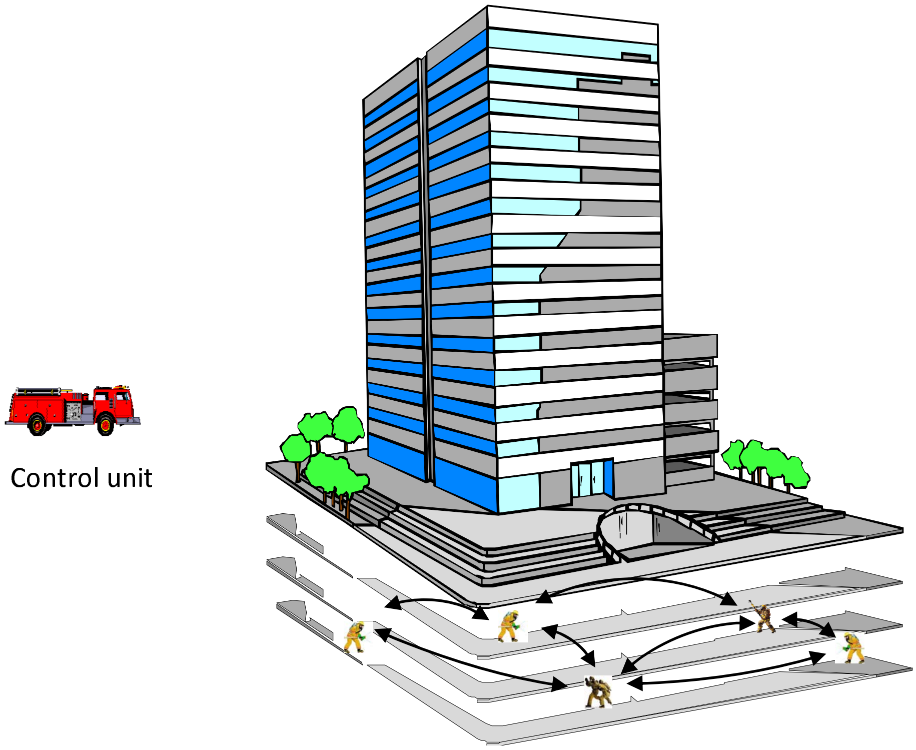

Figure B.2: Overview of the AFL system in a deep indoor environment (basement)

In the AFL system, the coordinates are relative ones and do not use an absolute GNSS positioning.

In this approach there could be also a Control Unit providing the display to the Emergency services co-ordinators if one of the rescuers can be in the range of the control unit.

It has to be noticed that both localization techniques can be used with different UWB radio communications systems. The UWB waveforms can be the waveforms specified in IEEE 802.15.4a [i.18] standard (pulse solution or chirp solution) or a less conventional approach called Frequency-Hopping UWB (FHUWB).

B.2 Technical parameters and justifications for spectrum

B.2.1 Transmitter parameters

The transmitter power requirement is dictated by the losses incurred in penetrating buildings. Indeed, the system provides ranging and communications over paths within buildings and from outside to inside, passing through the structure (walls, floors, etc.) and the contents of the buildings. Such paths will have significant excess losses relative to an unobstructed (or "free space") path of the same length.

It is not possible to give a single figure for the required range and excess path loss, as buildings vary too much. However, we can adopt a base level of performance, for comparison purposes, while saying that such a performance does not cover enough buildings. The greater the margin of performance over that base level, the more buildings the system can be used in with success.

While building methods are very variable, it is possible to give some typical losses due to walls and floors as a guide:

- outer and major structural walls: 20 dB;
- internal partition walls: 10 dB;
- windows (unless heavily metallized): 5 dB; and
- floors (reinforced concrete): 20 dB to 30 dB.

These figures include normal internal components: not only structural (reinforcing bars), but also service (pipes, cable, conduits, etc. The contents of buildings, such as furniture, machinery, business stock, vehicles, animals, and everything else, will have an additional obstructing effect that is even more unpredictable.

Two factors of signal and receiver design can be applied to do this: increasing the transmitted power, and decreasing the data capacity, which in turn means increasing the coherent integration time in the receiver.

One of the solutions is to use a relatively familiar pulsed UWB (IR-UWB) signal design as described in the IEEE 802.15.4a [i.18] standard for which an increased power is needed to provide penetration. For this approach, localization and data transmission are both transmitted by UWB devices with a typical data rate of 500 kb/s. These devices are also designed in order to obtain a very low power consumption.

Another possible solution is to use an unusual wide band Frequency-Hopping UWB (FHUWB) signal which maximizes the penetration for a given transmitted power level but with a very much reduced data capacity (20 kbps) largely incompatible with data exchanges in the AFL method in deep indoor.

In table B.1 is a typical Impulse Radio link budget in LOS conditions based on channel models developed in IEEE for Low Data Rate systems. With the PSD of -41,3 dBm/MHz in the lower band, the link margin is -16 dB for a link distance of 500 m in LOS conditions. This link budget does not take into account implementation losses. Consequently an increase RF power of 20 dB is necessary in order to reach this link distance of 500 m in LOS conditions with a minimum margin (1 dB or 2 dB).

Table B.1: Typical Impulse Radio link budget in LOS conditions based on channel models developed in IEEE for Low Data Rate systems

Parameter	Value	Unit
PSD	-41,3	dBm/Mhz
fc (arithmetic center frequency)	4000	MHz
Bandwidth @ -10dB	680	MHz
Peak Payload bit rate (Rb)	0,500	Mbps
Distance (d)	500	m
Maximum Tx Power (PT)	-12,97491087	dBm
Pulse shaping losses	2	dB
Power backoff	1,5	dB
Tx Power (PT)	-16,47491087	dBm
Tx antenna gain (GT)	0	dBi
f'c: (geometric center frequency)	3985,5	MHz
Path Loss @ 1m: L1 = 20log10(4.p.f'c / c)	44,45	dB
Path loss exponent after 1 meter (Alpha)	2,00	-
Path Loss @ d m: L2 = 10*Alpha*log10(d)	53,98	dB
Total Path Loss : L= L1+L2	98,43	dB
Rx Antenna Gain (GR)	0	dBi
Rx Power (PR = PT + GT + GR – L)	-114,90	dBm
Average noise power per bit : N = -174 + 10log10(Rb)	-117,01	dBm
Rx noise figure (NF)	6	dB
Average noise power per bit (PN = N + NF)	-111,01	dBm
Minimum required Eb/N0 (S)	12	dB
Link Margin (M = PR - PN – S – I)	-15,89	dB
Proposed Min. Rx Sensitivity Level	-99,01	dBm

With regard to the interference and the mean power over the air, the two solutions mentioned previously are equivalent.

Indeed with an IR-UWB solution, we have a duty cycle which corresponds to the ratio between the pulse burst duration (the pulse burst duration is typically 4 × 2 ns), and the PRF (typically 4 × 240 ns). This ratio is then equal to 120 (i.e. 21 dB). On the one hand, the potential interference occurs during the pulse so during a very short amount of time; on the other hand the average RF power is 21 dB below the RF peak power.

Both UWB signals can be designed to meet the same mean PSD limit, but they will have different distributions of energy in time and frequency. The IR-UWB signal is present over the whole RF band when it is on, and it is on for a slot at a time. The mean PSD is (P(on) / BW) × (burst duration/PRF).

For the FH-UWB signal, the signal is a carrier with a 20 MHz modulation bandwidth, and moves in 10 MHz steps. Thus the mean PSD is P(on) × (1/20 MHz) × (T(hop)/T(cycle)) × Nh, where Nh is the effective number of hops that contribute to the PSD in the 1 MHz band being considered. Nh is between 2 and 3, and is a function of the filtering applied to the skirts of the modulation spectrum of a single hop. The peak power is the carrier power P(on), and is present in a 1 MHz band of measurement for less than 24 μs (three hops) during a cycle of 1 ms length.

By consequence, the energy received in an elementary filter of, let us say, 1 MHz are exactly the same.

B.2.1.1 Operating Frequency

The possible frequency bands in Europe for UWB systems are the lower band from 3,4 GHz to 4,8 GHz or the upper band from 6 GHz to 8,5 GHz. The higher band imposes extra losses that are serious. The extra loss above 6 GHz is partly because of the higher penetration losses of building materials and contents at these frequencies, but the $1/\lambda^2$ effect of doubling the RF is at least as large (at 6 dB). Thus the lower band is much more preferable than the higher band for the foreseen applications and the link budget calculated in the present document are based on this band (3,4 GHz to 4,8 GHz).

B.2.1.2 Bandwidth

The bandwidth requirement is driven by the need to measure range accurately in a dense multipath environment. This application calls for an accuracy of about 1 m in absolute position, and the terminals should usually be attached to fire-fighters' clothing so that their local RF environment will effect radio propagation.

There are several ways to use radio signals to find the relative positions of terminals, primarily by measuring time delay, amplitude, or angle of arrival. All of these suffer errors when the radio signals are obstructed by and scattered off the building and its contents. However, time delay measurement can still be effective if the signal has a wide enough bandwidth. There are several ways of using time delay measurements, such as to give true range (preferred here), range differences (as in hyperbolic systems), or pseudoranges (as in a GNSS), but all require the same bandwidth and very similar signals.

Provided the whole bandwidth is processed coherently (inherently true for a pulse), it is the occupied bandwidth that determines the resolution in the time domain. "Range resolution" (δR) can be defined in terms of occupied bandwidth (B) in a number of ways, using different values of the factor "k" in the formula below (c is the speed of light). The appropriate definition will depend on the function and design of the system, as well as the propagation conditions. For a power spectrum that is nearly rectangular, typical values of k are from 0,8 to 1,4.

$$\delta R = \frac{k \cdot c}{B}$$

The relationship between the resolution and the measurement accuracy depends somewhat on the processing and on the path itself, but in practice it is not the RMS value of noise-like range errors that matters most in such systems; the presence of range measurements that do not correspond to the direct path (i.e. "multipath") is more important.

For a range resolution of 10 cm, this formula gives a bandwidth requirement of around 3 GHz. Resolution is not the same as accuracy, and the relationship between them depends on the quality of the signal. With little multipath or with a single ground reflection, code-only GNSS receivers can achieve a high accuracy: an error of less than 1 % of the range resolution (which is set by the code length). However, in the dense multipath environments of the LAES application, the errors are about one third of the range resolution. Thus for an accuracy of 10 cm, a range resolution of 30 cm and a BW of around 1 GHz are needed.

B.2.1.3 Unwanted emissions

In common with other UWB regulations, access to spectrum is granted on the basis of not causing harmful interference, whether within the occupied bandwidth or outside it. The normal distinction between out of band (i.e. within the allocation) and spurious domains is not relevant, and the relevant ECC (and EC) Decisions make no such distinction. The general principle of minimizing unwanted emissions outside the occupied bandwidth still applies.

Unwanted and spurious emission limits of other UWB emitters are defined in EN 302 500 [i.15]. It is proposed that the same limits should be applied in this case, with no increase to correspond to the increased mean power spectral density.

B.2.2 Receiver parameters

The first solution presented above based on Impulse Radio (IR-UWB) has minimum receiver sensitivity of -99 dB (indicated in the link budget) which is higher than the IEEE 802.15.4a [i.18] specifications. As stated before, the potential interferences occur during a very short amount of time.

Concerning, the FHUWB solution, as a hopping narrow-band receiver, it will only suffer interference from one source of moderate bandwidth in two or three adjacent hop bands out of 124. Thus it is relatively robust. However this will occur continuously over the time.

As noticed in the previous clause, the energy received in an elementary bandwidth of 1 MHz are exactly the same for IR-UWB and FHUWB.

B.2.3 Channel access parameters

For an Impulse Radio solution, each elementary pulse has a typical duration of 2 ns with a repetition period of 240 ns. Based on the IEEE 802.15.4a [i.18] standard, the proposed solution uses a DBPSK modulation and a PN length of 12 giving a symbol length of 2 880 ns.

The pulse system has been designed in order to allow location and data transmission in a same frame.

The number of slots dedicated to location and data transmissions is completely variable and the MAC layer has been designed in order to have a maximum flexibility. Thus for applications such as disaster relief, the number of ranging slots needed to perform the localization can be much higher than the data slots.

For the proposed system, the data slot duration is 3,68 ms. In order to optimize the use of the slots, sub slots have been defined in the MAC layer. As ranging packets are shorter than other packets such as data packets, a half slot is used. So, ranging packets are sent in 1,84 ms. This duration corresponds to a number of 640 symbols. In each symbol there is a transmission of 12 pulses having a duration of 2 ns. Then in one ranging slots (1,84 ms) there is a Ton which is:

$$\text{Ton} = (640 \times 12) \times 2 \text{ ns} = 15\,360 \text{ ns}$$

For the ranging procedures, two modes are possible in the MAC layer: a two way ranging or a 3 way ranging. For a 2 way ranging, 2 consecutive ranging slots are needed whereas for a 3 way ranging procedure 3 consecutive ranging slots are needed.

Assuming a three way ranging procedure, three consecutive ranging slots are needed for a peer to peer ranging measurement:

then the Ton resulting of a single 3 way ranging is 46,08 µs.

Assuming that each node has 10 neighbours and has to perform the 3 way ranging measurement with these 10 nodes implies a Ton per device which is 460 µs. If the ranging estimation has to be performed with a rate of 5 Hz (5 measurements per second), then the Ton value for a single node is 2,304 ms per second.

This leads to an activity factor which is below 1 % per node for the ranging procedure. As small amount of data has to be exchanged between nodes and has AFL localization techniques may need more important refreshing ranging estimations, an activity factor of 1 % per node seems to be reasonable.

Furthermore, retransmissions have been handled in the MAC layer and these retransmissions have also to be taken into account in the activity factor for each node.

For an FHUWB solution, each frequency hop cycle (actually it is a linear stepped sweep) takes 1 ms, with 125 hops of 8 µs duration each. The signal in each hop is modulated with a binary code, occupying 6,5 µs (including lead-in and lead-out shaping to control sidebands).

Consequently the duty factor of the signals received in a bandwidth of 10 MHz or less is less than 2,5 % during a 1 ms hop cycle.

Communication uses packets that may use more than one slot, but short messages and ranging transactions use a single slot. Data is carried by phase modulation of the coded signals, at a relatively low rate. In a ranging slot, the initiating unit transmits in some cycles, and listens in others; its chosen ranging partners use these to reply with some cycles of their own. This provides the two-way ranging, or the effect of so-called "three-way ranging" since the initiator sends several cycles per measurement.

All the units in a system lock themselves to one master unit, either directly or by locking to a sub-master if they cannot receive the master. Collisions do happen, and the MAC protocol is designed to cope with these collisions.

Access control operates on the basis of a frame of 40 slots of 25 ms, so each slot contains 25 hop cycles of RF emissions. Any one terminal only uses a few slots per frame, so typically with two slots its received duty factor would be only 0,125 %.

A complete system never operates with all its slots filled. Thus the overall duty factor of a whole system will be limited to 2 %, of which only a few nodes will be outdoors.

Annex C: Expected sharing and compatibility issues

C.1 Current ITU and European Common Allocations

There is no current ITU-R allocation corresponding to these devices. The present document assumes operation according to a provision of the Radio Regulations (RR4.4), that does not require any new allocation (i.e. on a non-protected basis and causing no harmful interference).

C.2 Sharing and compatibility studies (if any)

This specific application has not been the subject of coexistence studies in ECC or elsewhere yet. The studies of ECC Report 64 and other more recent studies of UWB applications based on them are likely to be relevant and useful for conducting the studies on this application. The acceptance of the light licensing scheme needs to be assessed. However, the limited time and extent of deployments will greatly alter the impact assessments.

The application described in the present document is used locally and temporarily which reduces the probability for causing or getting interferences significantly.

History

Document history		
V1.1.1	June 2005	Publication
V2.1.1	May 2009	Publication