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Technical Report

**Electromagnetic compatibility
and Radio spectrum Matters (ERM);
System Reference Document;
Short Range Devices (SRD);
Technical characteristics for SRD equipment using
Ultra Wide Band Sensor technology (UWB);
Part 5: Location tracking applications type 2 operating
in the frequency bands from 3,4 GHz to 4,8 GHz and from 6 GHz to 8,5 GHz
for person and object tracking and industrial applications**

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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).

The present document is part 5 of a multi-part deliverable covering Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference Document; Short Range Devices (SRD); Technical characteristics for SRD equipment using Ultra Wide Band technology (UWB) as identified below:

Part 1: "Building material analysis and classification applications operating in the frequency band from 2,2 GHz to 8 GHz";

Part 2: "Object Discrimination and Characterization (ODC) applications for power tool devices operating in the frequency band from 2,2 GHz to 8,5 GHz";

Part 3: "Location tracking applications type 1 operating in the frequency band from 6 GHz to 8,5 GHz for indoor, portable and mobile outdoor applications";

Part 4: "Object Identification for Surveillance applications (OIS) operating in the frequency band from 2,2 GHz to 8,5 GHz";

Part 5: "Location tracking applications type 2 operating in the frequency bands from 3,4 GHz to 4,8 GHz and from 6 GHz to 8,5 GHz for person and object tracking and industrial applications";

Part 6: Void;

Part 7: "Location tracking and sensor applications for automotive and transportation environments operating in the frequency bands from 3,1 GHz to 4,8 GHz and 6 GHz to 8,5 GHz".

Introduction

The original spectrum request for UWB location tracking applications was covered by part 3 of the present multi-part deliverable. This original request is now being enhanced by the proposals covered in the present document (part 5). Therefore, these additional location tracking devices are called type 2. The performance attributes of type 2 devices is the new frequency range from 3,4 GHz to 4,8 GHz in addition to the 6 GHz to 8,5 GHz frequency range. It is foreseen that individual licensing of operators in the range 3,4 GHz to 4,8 GHz on a site-specific basis will be required.

The total addressable market for type 2 devices is expected to be considerable larger than that under the original request.

UWB location tracking is a viable positioning technology that meets industrial requirements in the following markets:

1) Healthcare.

2) Workplace/Office.

3) Public buildings.

4) Security.

5) Defence training.

6) Professional multimedia production.

7) Logistics, warehouses.

8) Manufacturing assembly lines.

9) Prisons and correctional institutes.

10) Large and hazardous industrial sites, such as oil refineries.

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 includes necessary information 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 has been created by ERM TG UWB. It has undergone an ETSI internal consultation and it was approved for publication as ETSI Technical Report by ERM at ERM#42 (November 2010). The present version is now intended for submission to ECC WGFM and ECC WGSE for consideration at their next meetings.

Target version	Pre-approval date version (see note)				
V1.1.1	**a**	**s**	**m**	**Date**	**Description**
V1.1.1	0.0.4			10 January 2008	Approved by TG31C and sent to ETSI ERM for consultation and subsequent approval.
V1.1.1	0.0.5			27 June 2008	Mini ETSI internal enquiry version.
V1.1.1	0.0.6			21st August 2008	Incorporation of comments received during ETSI internal consultation.
V1.1.1	0.0.9			15th October 2008	Version after internal ETSI consultation and rework in TG31c. Approved by TG31c.
V1.1.1	0.0.10			6 November 2008	ERM approved version for publication.
V1.2.1	0.0.1			20th July 2010	Updated Version based on actual ECC SE24 discussion
V1,2,1	0.0.2			3rd August 2010	Approved version TG UWB
V1.2.1	0.0.3			12th August 2010	Check version (edithelp)
V1.2.1	0.04			24th November 2010	Editorial changes after ERM#42
NOTE: See clause A.2 of EG 201 788 [i.13].					

1 Scope

The present document defines the requirements for radio frequency usage for Ultra Wide Band (UWB) location tracking devices type 2. These devices would operate in the frequency ranges from 3,4 GHz to 4,8 GHz and from 6 GHz to 8,5 GHz. Operation is foreseen for indoor and outdoor applications in the range 3,4 GHz to 4,8 GHz and only indoor applications in the range 6 GHz to 8,5 GHz as for the earlier type (i.e. type 1) covered in TR 102 495-3 [i.9]. The operating distance may be limited to about 200 metres. It would include applications from all different markets (see list of markets in introduction). Site-specific licensing of fixed outdoor tracking systems using higher emission levels is possible and proposed by the present document.

The present document covers ultra-wideband location tracking tags which are attached to people or objects. The tags are tracked using a base station infrastructure. Equipment covered by the present document is fitted with an integral or dedicated antenna.

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 specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

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

NOTE: While any hyperlinks included in this clause were valid at the time of publication ETSI cannot guarantee their long term validity.

2.1 Normative references

The following referenced documents are necessary for the application of the present document.

Not applicable.

2.2 Informative references

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] Void.

[i.2] CEPT/ERC Report 25: "The European table of frequency allocations and utilisations in the frequency range 9 kHz to 1000 GHz", Lisboa 02 - Dublin 03 - Kusadasi 2004 -Copenhagen 04 - Nice 07".

[i.3] Void.

[i.4] Void.

[i.5] ECC/DEC/(06)04: "ECC Decision of 24 March 2006 amended 6 July 2007 at Constanta on the harmonised conditions for devices using Ultra-Wideband (UWB) technology in bands below 10.6 GHz".

[i.6] ECC/DEC/(06)12: "Decision of 1 December 2006 on the harmonised conditions for devices using Ultra-Wideband (UWB) technology with Low Duty Cycle (LDC) in the frequency band 3,4-4,8 GHz".

[i.7] Void.

[i.8] ITU Radio Regulations, Geneva, 2004.

[i.9] ETSI TR 102 495-3: "Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference Document; Short Range Devices (SRD); Technical Characteristics for SRD equipment using Ultra-Wideband Sensor Technology (UWB); Part 3: Location tracking applications type 1 operating in the frequency band from 6 GHz to 8,5 GHz for indoor, portable and mobile outdoor applications".

[i.10] EC Mandate M/407: Standardisation mandate forwarded to CEN/CENELEC/ETSI for harmonised standards covering ultra-wideband equipment.

[i.11] Void.

[i.12] EC Mandate: Final and adopted Mandate to CEPT to identify the conditions relating to the harmonised introduction in the EU of radio applications based on ultra-wideband (UWB) technology (Mandate 4).

[i.13] ETSI EG 201 788: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Guidance for drafting an ETSI System Reference document (SRdoc)".

[i.14] Void.

[i.15] CEPT Report 34: "Report B from CEPT to European Commission in response to the Mandate 4 on Ultra-Wideband (UWB); Final Report on 30 October 2009 by the Electronic Communications Committee (ECC) within the European Conference of Postal and Telecommunications Administrations (CEPT)".

3 Definitions, symbols and abbreviations

3.1 Definitions

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

activity factor: effective transmission time ratio, actual on-the-air time divided by active session time or actual on-the-air emission time within a given time window

duty cycle: defined as the ratio, expressed as a percentage, of the transmitter "on" relative to a given period as specified in the technical requirements

fixed equipment: UWB location tracking device on a fixed position

mobile equipment: UWB location tracking device to be used while in motion or during halts at unspecified points

portable equipment: UWB location tracking device normally used on a stand-alone basis and to be carried around

range resolution: ability to resolve two targets at different ranges

tag: mobile or portable UWB location tracking device

3.2 Symbols

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

c	velocity of light in a vacuum
δR	range resolution or multipath rejection resolution
dBm	deciBel relative to 1 mW
T_P	pulse width

3.3 Abbreviations

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

2D/3D	Two Dimensional/Three Dimensional
CEPT	Conference Europeenne des Administrations de Postes et des Telecommunications
DCR	Duty Cycle Restriction
e.i.r.p.	equivalent isotropically radiated power
ECC	Electronic Communications Committee
ERC	European Radiocommunications Committee
ERM	Electromagnetic compatibility and Radio spectrum Matters
FS	Fixed Service
FSS	Fixed Satellite Service
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ITU	International Telecommunication Union
LAN	Local Area Network
LDC	Low Duty Cycle
LORAN	LOng RAnge Navigation
LT2	Location Tracking devices type 2
NRA	National Regulatory Authority
PSD	Power Spectral Density
RF	Radio Frequency
SRD	Short Range Device
TPC	Total Power Control
UWB	Ultra Wide Band

4 Comments on the System Reference Document

No statements have been received on the present document so far.

5 Executive summary

5.1 Background information

The present document describes devices using Ultra Wide Band sensor technology for location tracking applications.

In UWB location tracking, small mobile or portable tags, operating as either transmitters or receivers, or both, are attached to the objects to be located, or are carried by personnel within an area under surveillance. A network of fixed equipment around the area to be covered, communicate with the tags. By analysing, e.g. the time-of-arrival and/or angle-of-arrival of the radio signal relative to the known reference stations, the 2D/3D position of the tag can be found. Typically, the range between a tag and a reference station might be up to 200 m, depending on the area to be observed.

There is evidence that these devices can address versatile industrial requirements in many different markets and therefore, a socio-economic benefit is given.

It is also possible that such a system will significantly enhance the security and safety of persons monitored in different applications such as process industries, healthcare, prisons (guards) and lone workers.

A high precision in range measurement is required. This means that the signals necessarily have a very large bandwidth to provide the required accuracy.

5.2 Market information

The proposed changes will lead to a greater addressable market that also includes new location tracking applications not considered before.

Detailed market information is given in annex A.

5.3 Technical system description

Small UWB transmitter tags are attached to the objects to be located, or are carried by persons.

A tracking system in the present document can be realized in 3 different ways:

- **Transmitting tags and receiving fixed equipment** (see figure B.1)
  The UWB signals emitted by a small transmitting tags (carried by persons or attached to the objects to be located) are detected by a network of receiving fixed equipment placed at known, fixed points around the area to be covered. By centralized computational means the location of the tags can be determined. Typical application.

- **Receiving tags and transmitting fixed equipment** (see figure B.2)
  The UWB signals emitted by a network of transmitting fixed equipment are detected by receiving tags, which need to have computational means to a detect their own position. Comparable to a GPS system.

- **Receiving/transmitting tags and receiving/transmitting fixed equipment** (see figure B.3)
  A combination of 1 and 2; both the tag and the fixed equipment can receive and transmit UWB-signals.

The 3D position information / position can be calculated by detecting the UWB signal at a number of receivers (system set-up 1 or 3) or by detecting different (known) information from different transmitters at one receiver (system set-up 2 or 3), and analysing the time-of-arrival and/or angle-of-arrival of each radio signal.

In a typical application (system set-up 1), the range between a tag and the fixed equipment might be between 10 m to 200 m, depending on the level of building obstruction between the two.

Since the transmitting tags can only work in combination with the fixed equipment, a useful activity-control strategy could be to only allow the tags to transmit when they are ordered to do so, or when they receive a "system heartbeat". For receiving such a command or heartbeat the tags should also have a receiving part (not necessarily on UWB-basis).

Detailed technical information is given in annex B.

5.4 Regulations

5.4.1 Current Regulations

The current regulation (amended ECC/DEC(06)04 [i.5] and ECC/DEC(06)12 [i.6]) excludes fixed outdoor installations.

5.4.2 Radio spectrum requirements and justification

The addition of the lower frequency ranges (i.e. 3,4 GHz to 4,8 GHz) is attractive due to the availability of chipsets having lower costs and higher antenna efficiency but also because of the lower propagation losses.

A detailed description of the emissions levels is added in clause B.2.2.

The following requirements are proposed for Location Tracking Type 2 applications as shown in table 5.1. These proposed limits broaden the set of applications which can be addressed by UWB location tracking systems, by increasing the emissions levels applicable to indoor systems (but with additional duty-cycle restrictions), and by enabling fixed outdoor systems (with both duty-cycle restrictions and a requirement for individual licensing which ensures compatibility with existing users of the radio spectrum).

Table 5.1: Proposed regulation for outdoor location tracking type 2 applications

	Outdoor (note 2)		
Frequency (GHz)		**Present regulation**	**New regulation requested**
3,4 < f ≤ 4,8	Mobile / nomadic	≤ -41,3 (note 1) and implementation of LDC (note 3) as per ECC/DEC(06)12 [i.6]	**DCR - parameters:** • Ton max ≤ 25 ms • Σ Ton < 5 % per second
	Fixed transmitters		≤ -41,3 (note 1) **DCR - parameters:** • Ton max ≤ 25 ms • Σ Ton < 5 % per second
6 < f ≤ 8,5	No fixed outdoor use! Indoor use only, see table 5.2		
NOTE 1: Maximum value of mean power spectral density (dBm/MHz) and the maximum peak e.i.r.p. (in 50 MHz reference bandwidth, as in ECC/DEC(06)04 [i.5] will be limited to 40 dB higher than the maximum mean e.i.r.p. spectral density (dBm/MHz). NOTE 2: An individual site licensing / outdoor installation registration will be discussed in ECC FM47 (May 2010). NOTE 3: LDC - parameters (as in ECC/DEC(06)12 [i.6]): 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.			

Table 5.2: Proposed regulation for indoor location tracking type 2 applications

	Indoor	
Frequency (GHz)	**Present regulation**	**Proposed LDC changes for location tracking applications**
3,4 < f ≤ 4,8	≤ -41,3 (note 1) and implementation of LDC (note 2) as per ECC/DEC(06)12 [i.3]	**DCR - parameters:** • Ton max ≤ 25 ms • Σ Ton < 5 % per second
	≤ -41,3 (note 1) (implementation of LDC as per ECC/DEC(06)12 [i.3]	**DCR - parameters:** • Ton max ≤ 25 ms • Σ Ton < 5 % per second
6 < f ≤ 8,5	≤ -41,3 (note 1)	No changes requested
NOTE 1: Maximum value of mean power spectral density (dBm/MHz) and the **maximum** peak e.i.r.p. (in 50 MHz reference bandwidth, as in ECC/DEC(06)04 [i.5] will be limited to 40 dB higher than the maximum mean e.i.r.p. spectral density (dBm/MHz). NOTE 2: LDC - parameters (as in ECC/DEC(06)12) [i.3]: 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.		

LDC - parameters (as in ECC/DEC(06)12 [i.3]**):**

- 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.

DCR - parameters:

- Ton max ≤ 25 ms.
- Toff mean ≥ 38 ms (averaged over 1 s).
- Σ Toff ≥ 950 ms per second.

Peak power limitation

Maximum peak e.i.r.p. (in 50 MHz reference bandwidth, as in ECC/DEC(06)04 [i.5]) will be limited to 40 dB higher than the maximum mean e.i.r.p. spectral density (dBm/MHz) defined in table 6.1 for the various cases.

The proposed individual licensing approach is outlined in clause 5.4.3.

5.4.3 Proposal for individual site specific licensing approach

National Regulatory Authorities (NRAs) may establish individual licensing requirements for the use of the radio spectrum by LT2 systems with fixed outdoor base stations as part of conditions for the efficient use of radio spectrum.

The purpose of this clause is to provide an example for the establishment of these individual licensing provisions so as to facilitate the work of both administrations and LT2 professional users in Europe.

It is recommended that the individual licensing regime include the following individual requirements:

- operator registration;
- exact location and information on the area covered (geographical coordinates, radius and indoor or outdoor operation);
- co-ordination with services potentially affected (e.g. FSS and FS receivers) on the basis of fixed terminal location, antenna orientation, and possibly frequency;
- the specific combination of mitigating factors to be implemented (e.g. antenna pattern, sub-bands avoided, and TPC as well as low duty cycle).

If NRAs will require applicants to perform some of the co-ordination tasks, e.g. to identify specific service users to be assessed, they may need to create a database for LT2 operators to consult.

6 Expected ETSI Actions

It is expected to create a new Harmonized Standard for location tracking type 2 devices. EC Mandate M/407 [i.10] and [i.12], [i.15] was accepted by ETSI, and calls for the preparation of Harmonized Standards for UWB.

7 Requested ECC Actions

ECC is requested to study the proposal covered in present document.

It is noted that limits for fixed outdoor unlicensed usage have already been discussed in ECC TG3, but not licensed usage.

The proposed site-specific individual licensing approach for fixed outdoor transmitters, as well as the proposed DCR, specific Low Duty Cycle for Location Tracking Applications at the frequency band 3,4 GHz to 4,8 GHz should be taken into account for an amendment of the UWB regulatory framework.

It is recommended that the ECC Decision to be made by end of 2010 to allow manufacturers sufficient time to have equipment in the market as of 2011.

Annex A: Detailed market information

A.1 Range of applications

Applications of UWB location tracking technology are many and varied. Within hospitals, equipment, patients and doctors can be located quickly to speed up response to an incident. In the workplace, computers and communications systems can be shared between personnel, and automatically configured for a particular user as they walk up to equipment. In high-security environments, authorized personnel can be tracked, and unauthorized persons quickly identified when passive sensors (e.g. infra-red sensors) detect the presence of a person who is not located by the tracking system. Additionally, in industrial and agricultural environments the system can be used to track products through an assembly line and to monitor animal behaviour (e.g. in the dairy industry).

The list in the following clauses indicates some of the many applications of UWB Location Tracking technology in each of a number of environments - it is in no way intended to be an exhaustive list. Any one installation may serve more than one of these purposes.

A.1.1 Category 1: Personnel applications

Offering help to personnel during daily work and emergencies (e.g. position finding in case of a no-move or man-down situation and/or location tracking of a person in an alarm situation).

NOTE: Personnel can also work outdoor (but on-site).

- Streamlining hospital processes (locating staff, finding wandering patients), figure A.1.

Figure A.1: People working in (psychiatric-) hospitals

- Personnel Security:
    - Safety (panic alarms with position-finding capability).

Figure A.2: Guards

Figure A.3: Lone workers

Figure A.4: Service personnel

- Control the workflow of employees. For example there are rules on how long employees are allowed to work in high radiation environments in a nuclear plant. The integration of a tracking system combined with a radio-dosimeter enables accurate and reliable tracking of the workers in radioactive areas gathering dosimeter readings.

Figure A.5: People working in potentially dangerous environments

- For the largest sites, such as an oil refinery several kms across, it will be necessary to install systems with a long free-space range, able to operate in a very adverse propagation environment, where plant, buildings, and other structures both obstruct the signal and cause multipath. This environment rules out GNSS as a site-wide location solution, since the errors are too large, though a combined system using both forms of location does have a better coverage than either on its own.

- The operators of such large industrial sites often need to know the whereabouts of all staff and vehicles on site (and some other objects as well) for safety reasons. This is most obviously true for hazardous sites like oil refineries and storage depots, chemical works including some kinds of food processing, or ports and docks; but there are many others. In order to co-ordinate a rapid response to a hazardous chemical leak, for example, it is vital to locate the staff who form the rapid response team as well as any others working in the vicinity who might need rescuing.

- Security applications. Since September 11th security is a number one topic in public places. "Command & Control" systems, that know where operational personnel are, can raise an alarm if they enter critical zones. Integration with camera tracking, resource management for rapid response are examples of applications where mixed indoor/outdoor usage is necessary

- Person tracking for public events:

  - Some information about the location of the artists is desired in theatres and movie production enterprises. To achieve this the artists and the stage facilities are equipped with localization equipment. Based on given localization information it is possible to control:

    - spot beams;

    - camera devices;

    - beam forming for microphone receiver antennas and their audio back links.

  - The project focus contains fixed based and non fixed based installation concepts. It probably is a professional application operated by staff that has had the relevant introduction.

A.1.2 Category 2: Industrial & logistics asset tracking

- People and asset tracking in public places.

- Collision avoidance between container wagons.

- Workflow management and quality control: There are very stringent requirements regarding who is allowed to execute maintenance work at an aircraft. Location tracking enables control of these requirements in real time and the documentation of completed work steps.

As the capability of UWB devices for tracking becomes more well-known, many further applications will be identified.

Industrial factories and logistics distribution centres usually consist of a set of buildings and an open (outdoor) area. For the Location tracking of high value assets, pallets or fork-lifts a central requirement is that the tracking is not limited to one building but to every possible location in the whole area. Therefore a limited outdoor usage is necessary. But the technology still relies on a fixed infrastructure. In addition, the halls are typically very large and installation of infrastructure (network, cabling and sensors) is very expensive. It can be shown that the required number of base stations increases rapidly as the PSD limit decreases. Therefore a slightly higher PSD will be very beneficial for these applications.

Examples are shown in figures A.6 and A.7. In figure A.6 the position of the goods is tracked indirectly with every movement of the pallet by the corresponding fork-lifts. High precision (30 cm) is required to have the proper identification which pallet gets moved by which fork-lift.

Figure A.6: Example for a tracking application in a workflow situation

The second example (figure A.7) shows the combination of an asset tracking system with a video camera system.

The system locates the shipment on arrival and subsequent transport of goods to within 50 cm in order to select the corresponding video frame.

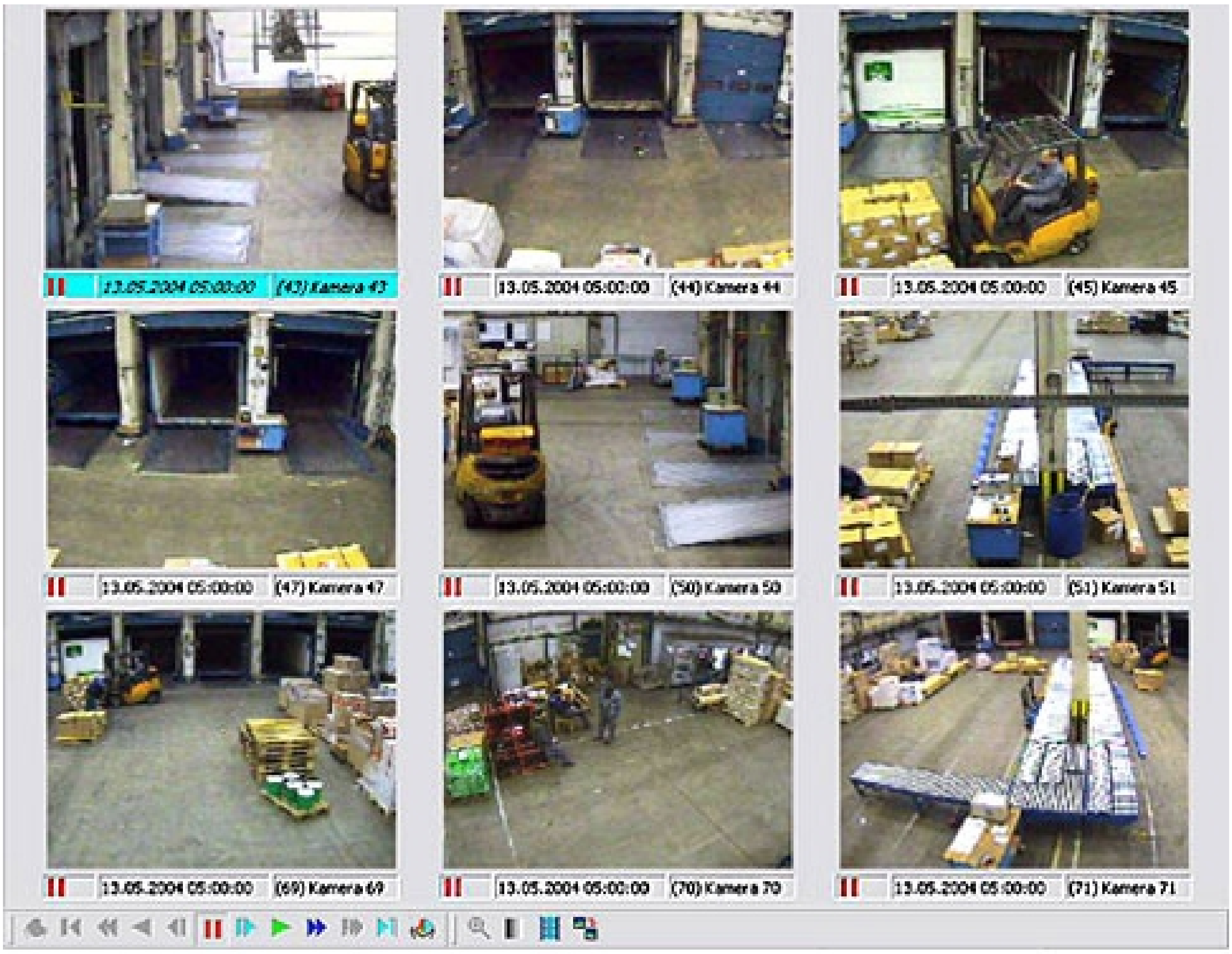

Figure A.7: Example of UWB tracking in combination with video tracking

In production line assembly, cars on computer-assisted process systems (power screwdriver systems, testing systems and pick-to-light systems) are often still identified by scanning the car ID manually using a barcode scanner. The corresponding assembly order is then automatically loaded to the process system to be carried out. Scanning manually is both laborious (many tens of thousands of times every day) and error-prone. The aim is to enable the cars to be identified and assigned to the process system fully automatically. The assembly order - unique to the car and the process system - should be loaded reliably, in real-time and without manual interaction.

Figure A.8: UWB tracking in car manufacturing

The solution can be based on UWB location tracking systems to track cars (see figure A.8) and tools with high resolution. The assignment of a process system (e.g. power screwdriver) to an individual car is made by evaluating the spatial relationship between the system component and the car in real time. The manual scanning process can be entirely dispensed with: the trigger by which the assembly order is loaded to the relevant system is the entry of the tool or test component into one of the zones assigned to the car.

A.2 Market size and value

As described above, UWB location tracking systems will have a direct impact in a number of markets, such as healthcare, workplace, security, entertainment, defence training, warehousing, and manufacturing. The market size estimates in figure A.9 show the projected combined value of hardware, software and professional services for the UWB location tracking industry from 2005 to 2012 (with a combined market size estimate of 1 500 Million Euro in 2012). Development of this market will depend on the high accuracy and reliability provided by UWB systems.

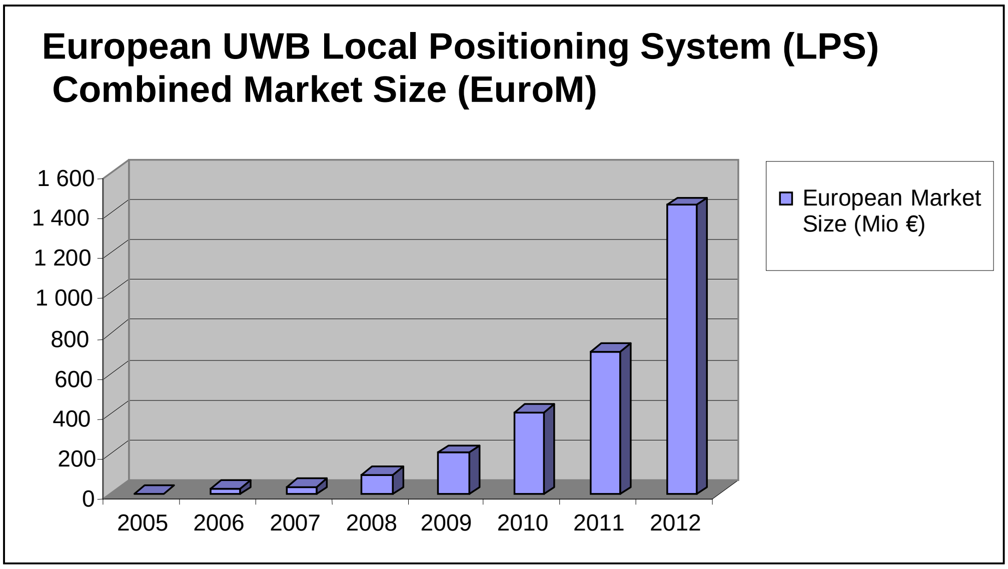

Figure A.9: European Location Tracking Systems Combined Market Size per year (2005-2012) in millions of Euro

A.3 Traffic evaluation

The likely modes of deployment and activity factors of UWB Location Tracking systems are discussed below:

- UWB location tracking systems provide a powerful capability for industry to build automated process management and resource management systems. There is no equivalent technology that can match the accuracy and reliability of UWB for location tracking in a number of key applications.
- These industrial and professional applications will allow tracking of assets and critical resources.
- UWB location tracking systems for smaller buildings are already permitted, unlicensed, as "Type 1" devices.
- The present document is concerned with larger buildings, and mixed indoor/outdoor operating areas. These Type 2 systems are operated by or for the site owner, and are "closed". That means that its operators do not want it to work with a mobile unit not provided as part of the system, even if that is technically possible, except perhaps to locate and intercept such a "stranger". While the sites may be large, the number of people and tracked objects in them is relatively small per unit area.

- Given that the user base of UWB location devices will be limited to such a closed group, rather than the public at large, the **expected number of location tracking devices will be relatively low** even if "hot-spot" situations (already taken into account by compatibility studies) may be present (e.g. large storage areas, both indoor and outdoor), Thus, it is very unlikely that the worst-case numbers of active devices used in previous UWB compatibility studies for UWB communications devices will be approached by UWB location systems.

- For fixed outdoor systems subject to site-specific licensing as proposed in the present document, the maximum number of tags can be included in the assessment process for licensing, and made a license condition if this is found to be appropriate. The concept of "aggregation", as used in the studies on unlicensed UWB, does not apply to such systems.

Location system devices are generally required to be very low powered and zero-maintenance (with battery lifetimes of years), and so tend to have **relatively low activity factors.** Assuming a typical pulse train length of 25 milliseconds (used by a representative type 1 device) and a location update frequency of 1 Hz, the resulting duty cycle of a device in normal operation is about 5 %.

In summary, therefore, these type 2 UWB location tracking systems are to be used in defined buildings or large sites, by a closed group of users, and are likely to have relatively low activity factors.

Annex B: Technical information

B.1 Detailed technical description

Small UWB transmitter tags are attached to the objects to be located, or are carried by persons.

A tracking system in the present document can be realized in 3 different ways:

- **Transmitting tags and receiving fixed equipment** (see figure B.1).
  The UWB signals emitted by a small transmitting tags (carried by persons or attached to the objects to be located) are detected by a network of receiving fixed equipment placed at known, fixed points around the area to be covered. By centralized computational means the location of the tags can be determined. Typical application.

- **Receiving tags and transmitting fixed equipment** (see figure B.2).
  The UWB signals emitted by a network of transmitting fixed equipment are detected by receiving tags, which have to have computational means to detect their own position. Comparable to a GPS system.

- **Receiving/transmitting tags and receiving/transmitting fixed equipment** (see figure B.3).
  A combination of 1 and 2; both the tag and the fixed equipment can receive and transmit UWB-signals.

For options 1 and 3, the signals emitted by a UWB transmitting tag in the system are detected by a network of receivers placed at known, fixed points around the area to be instrumented. For options 2 and 3 the signals emitted by a set of fixed UWB transmitters are detected by a mobile tag (which has the information where the fixed base stations are placed - furthermore the tag has to detect signals from more than one base station).

The 3D position information / position can be calculated by detecting the signal at a number of receivers or detecting different (known) information from different transmitters at one receiver, and analysing the time-of-arrival and/or angle-of-arrival of each radio signal.

A diagram illustrating the components of a UWB location tracking system (option 1) is shown in figure B.1.

A typical system of this nature will include a number of power-saving features which are primarily intended to reduce the activity levels of the battery-powered mobile tags. Of course, this reduction in activity levels is also advantageous in terms of reducing the impact of these systems on other radio services:

- The mobile tags in a location system of this kind often include a vibration sensing switch, which is used to deactivate the tag (or switch it into a low-activity mode) when the tag is stationary. This is a viable method of reducing activity because if a tag is stationary there is no need to locate it. In the quiescent state, where the tag location is known from previous UWB beacons, the tag may emit UWB only infrequently, if at all.

- The mobile tags in a location system of this kind often include a mechanism to turn off the tag when it is not in range of a location system. This is a viable method of reducing tag activity because if a tag is not within range of UWB receivers, then there is no point in it beaconing UWB. A separate RF channel (such as a low-power, short-range 2,4 GHz channel) is typically used to indicate the presence of UWB receiver infrastructure - in the absence of this signal the tag will not transmit UWB.

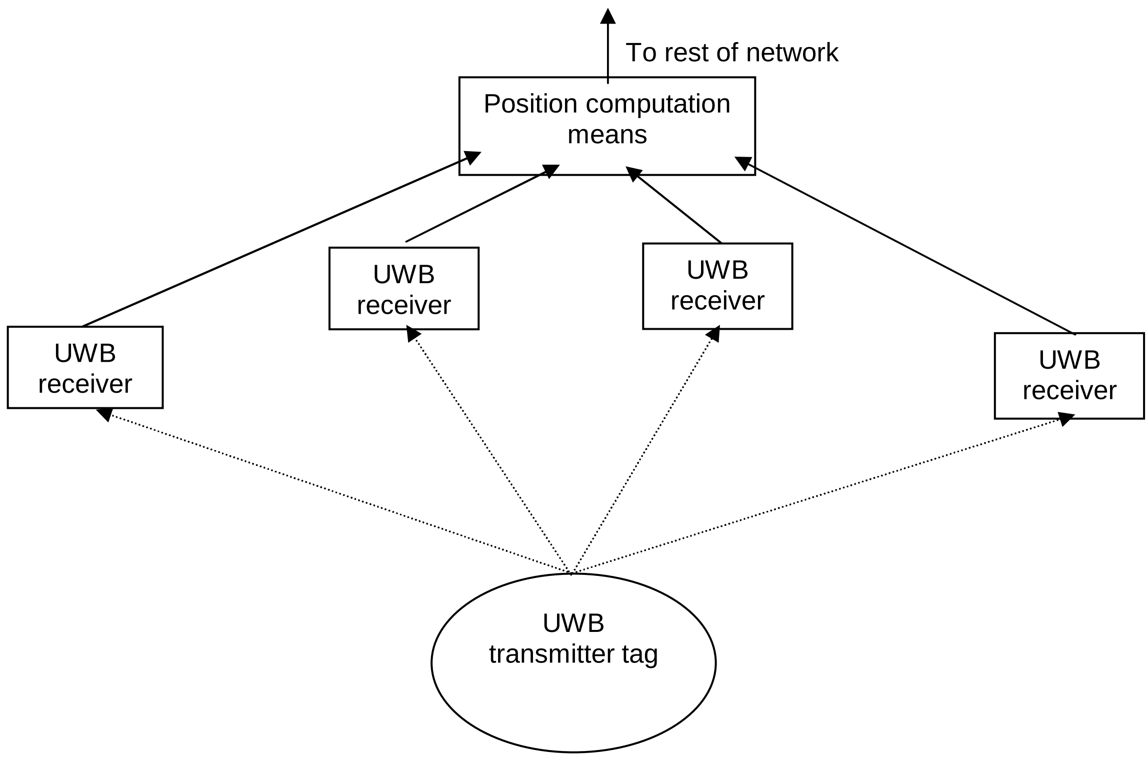

Figure B.1: Components of a UWB location tracking system (option 1)

A diagram illustrating the components of a UWB location tracking system (option 2) is shown in figure B.2.

In this option the position will be calculated in the tag. The position information can be sent to the system/network (if necessary) by another technology (e.g. SRD at 868 MHz, GSM, etc.)

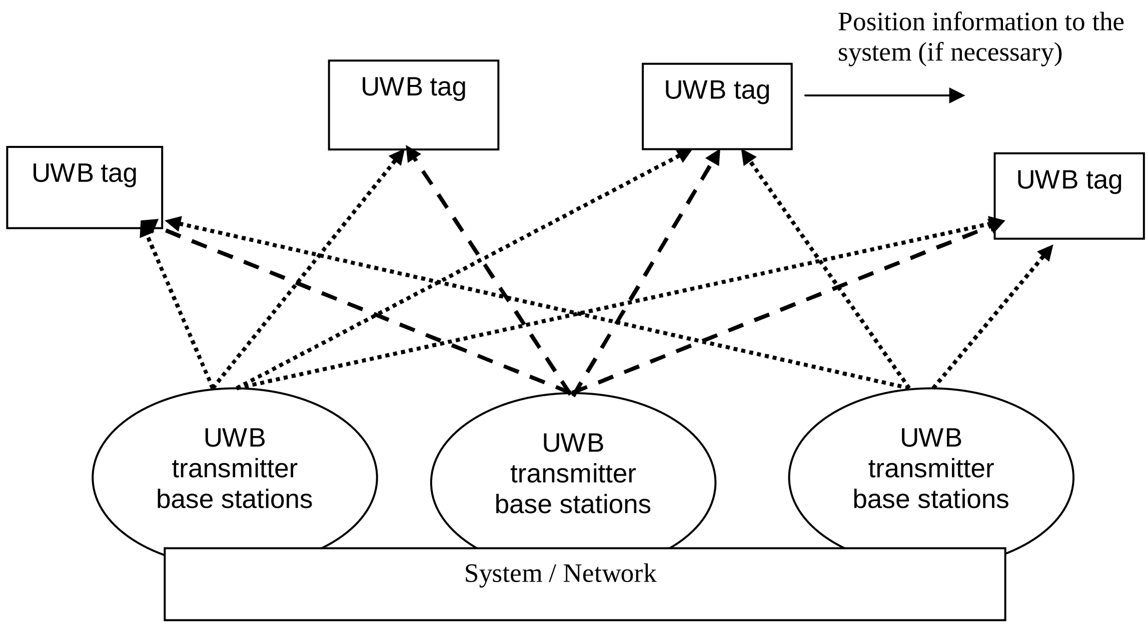

Figure B.2: Components of a UWB location tracking system (option 2)

A diagram illustrating the components of a UWB location tracking system (option 3) is shown in figure B.3.

In this option the position information can be calculated:

a) in the tag and sent back by UWB to the base station;

b) in the base station (the UWB channel to the tag can be used for data transmitting);

c) in tag and base station and then the information can be compared.

In this option it is possible to use mobile or temporarily static tags as references in addition to the base stations. It is also possible to convey all the information needed by the system, including positions, over the UWB network.

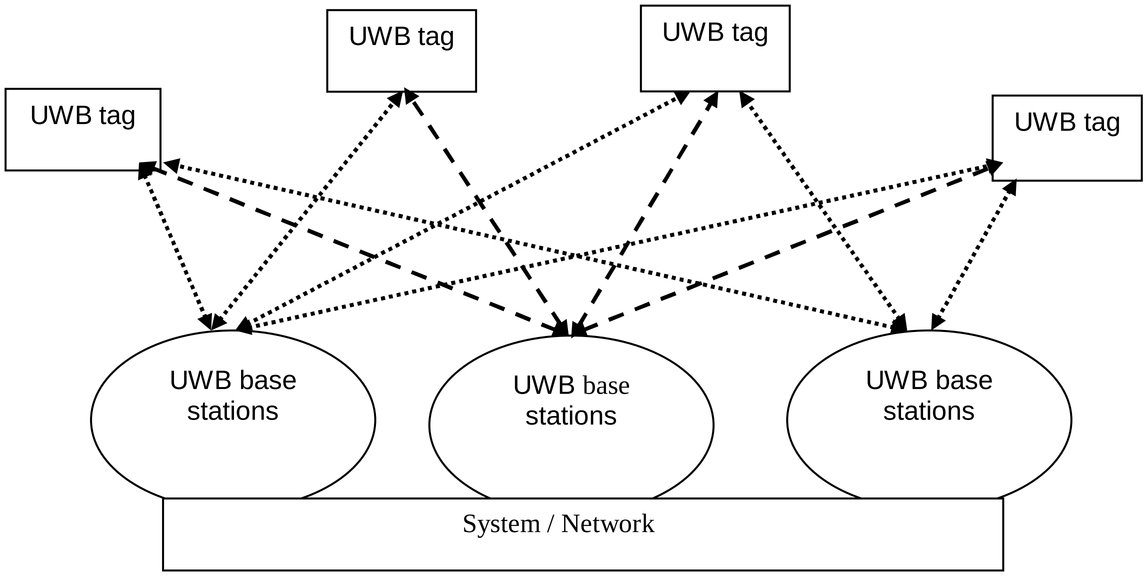

Figure B.3: Components of a UWB location tracking system (option 3)

Typically, the range between a tag and a receiver might be between 10 m to 1 000 m, depending on the level of building obstruction between the two. The number of base stations depends on the system design, as well as the size of the site or building. For example, the main occupied areas of a hospital could be covered by a set of base stations placed with roughly the same density as a wireless LAN installation, but outdoor areas of a large site would need a lower receiver density.

It is likely that the range of frequencies and power levels used for UWB tracking systems will be closer to those of communications systems than those of imaging systems. However, user demographics, deployment density, activity factors and modulation schemes will be significantly different for UWB location tracking systems and UWB communications systems.

Since a tracking system devices cannot be located in the absence of supporting surveyed infrastructure, the usefulness of such devices would not be limited if UWB location tracking transmitter activity were tied to particular sites. This step would decrease the risk of uncontrolled proliferation of transmitters and would stop transmitter activity when it was not required (i.e. outside of the operating range of the infrastructure).

- In option B.1, one way of implementing a system that conformed to this requirement would be to ensure that UWB location tracking transmitters do not transmit if they fail to receive a "heartbeat" signal from the sensor infrastructure. The heartbeat signal could be transmitted in one of a number of ways: over a UWB channel, a conventional RF channel, an infra-red channel, etc. By ensuring (during the installation of the location system infrastructure) that the heartbeat signal was not detectable outside the area in which the system was operating, one could assure that UWB transmitter tags meet the aforementioned requirement.

- In option B.2 this is guaranteed.

- In option B.3 it is natural to arrange that tags never transmit unless they can receive signals from at least one base station, or from another tag that is linked by a chain of communicating tags back to a base station. That guarantees that tags do not transmit outside a region close to the site boundaries.

B.2 Technical justification for spectrum

UWB Location tracking technology present a viable solution because of the reliable operation, precision and functionality for the applications as noted under "Introduction" such as:

- Healthcare.
- Workplace/Office.
- Public buildings.
- Security.
- Defence training.
- Entertainment.
- Logistics, warehouses.
- Manufacturing assembly lines.
- Prisons and correctional institutes.

and in more detail as listed under clause A.1.

A number of radio technologies have been developed for locating objects in the wide area to an accuracy of a few metres (such as GPS, Galileo and LORAN). For a number of reasons, these systems are of little value indoors (and in other high-multipath environments):

- The radio signals used by satellite and ground-based systems do not penetrate the structures of buildings sufficiently.
- Multipath effects within buildings, and the "urban canyon" environments that surround them, substantially degrade the nominal accuracy of present location tracking systems. Factories and other sites full of pipes, machines, gantries, etc. are especially difficult for accurate positioning by GNSS or other non-UWB methods.
- At best, in ideal conditions, the accuracy of these existing systems is no better than a few metres. Several applications of in-building tracking technology require knowledge of where a person or object is to the granularity of a room or a floor within a building. Even under ideal conditions, it is questionable whether wide-area systems can provide the required accuracy: if a person stood next to a wall, a location system with an accuracy of a few metres could easily record them as being on the other side of the wall, in another room. Once the nominal accuracy of the wide-area systems is degraded due to attenuation and multipath effects, it becomes clear that they cannot support indoor applications.

In contrast, a UWB location tracking system can position objects within a building to an accuracy of 10 cm to 15 cm in 2D/3D - the wide bandwidth of UWB signals significantly improves the system's robustness to in-building multipath effects. Over a wider area it can position to an accuracy of about 1 m, comparable with the size of structures and rooms, passageways, roads etc.

B.2.1 Technical justification for bandwidth

UWB location tracking devices operate by radiating a short pulse from a transmitter which is then detected by one or more receivers. By measuring the time-of-arrival (or time-difference-of-arrival) of the signal at one or more receivers, ranges between the transmitter and receiver(s) can be determined, and the position of the transmitter can be found by triangulation.

The accuracy of the location process and its resistance to multipath effects in indoor environments are determined by the coherently processed bandwidth of the UWB signal. For a very short pulse of unmodulated carrier, this bandwidth is simply related to the pulse width. For example, if the device is to reliably measure different transmitter-receiver ranges when the transmitter is moved from one point to another, the difference in the travel time of the signal from the transmitter to the receiver at the two different positions has to be greater than the pulse width. Similarly, a direct path signal and a reflected multipath signal can be separated if the extra time interval required for the signal to travel the reflected path rather than the direct path is greater than the pulse width.

The bandwidth BW required to generate a pulse with a pulse width T_P is approximately $\left(\frac{1}{T_P}\right)$.

Therefore, for a range resolution or multipath rejection resolution of δR, the bandwidth requirement for the UWB location tracking devices is given by:

$$BW = \frac{c}{(\delta R)}$$

where *c* is the velocity of light in a vacuum.

For a range resolution of 10 cm, this gives a bandwidth requirement of around 3 GHz to 4 GHz, and 1,25 GHz gives a resolution of about 30 cm. In clear conditions the range measurement accuracy will be better than the resolution, but in severe multipath it is about the same or a little worse. If ranging signals have to penetrate walls (or any other solid objects), the accuracy will be degraded by this, though typically only by 10 cm to 20 cm. When several ranges are combined to produce a location, the position accuracy will depend on the geometry of the ranged paths, and can be significantly poorer than the range accuracy.

B.2.2 Technical justification for proposed DRC limits

To justify the DRC limits and to show the activity of such location tracking application the following two examples (represantive) are given:

System 1: passive base stations / active nomadic tags, see figure B.1.

Example 1: personnel tracking

The system measures both the time- and angle-of-arrival of the incoming UWB signal at the receiver, so as to maximise the amount of information gathered from each tag->sensor. To do this, the tag has to transmit a 25 ms-long signal, which gives the receiver time to acquire the incoming signal and measure its properties. In order to maximise battery lifetime, the tag has an on-board motion-sensing jitter switch which disables the tag when it is stationary, and the tag also has a additional narrowband radio transceiver which disables the device when it is out-of-range of the UWB receiver infrastructure. The system is average-power limited, rather than peak-power limited. Clearly, the activity level of a nomadic tag will depend on a number of factors - what update rate the tag is set to, what fraction of time it spends in motion, and what fraction of time it spends within range of the system. For example, at one end of the spectrum of possibilities, a tag could be set to update twice a second and could be in continuous motion within range of the system - in this case, the potential long-term duty-cycle of the device might be (0,025 s × 2 Hz) = 5 %, but it is hard to envisage a use-case of this kind. For example, a similar device assigned to an employee for a personnel-tracking application, tracking them twice a second, would be in use approximately 240 days/year, 8 hrs/day (since the person would only be on-site for this time), and so the activity factor of the device would be scaled by a further fraction of (240 / 365) × (8 / 24) = 0,22 to around 1 %.

Summary:

- The typical duty cycle factor of a single UWB device (tag / nomadic) attached to a location Tracking System (in and outdoor):

  Duty Cycle: 5 %/s (Ton: 25 ms, two updates per second).

- Typical deployment duration in a day: average **8 h** (activity factor of the nomadic tag).

- total duration of operation of UWB device in a day for interference assessment: 0,05 × 8 × 3 600 = **1 440 s.**

- Time percentage of potential interference occurrence to FSS earth station near the vicinity in 24 hours: **1,67 %.**

Table B.1: Estimation of interference duration from LT2 devices in example 1

Summary example 1: Personal Tracking	
The typical duty cycle factor of a single UWB device attached to a fixed outdoor location	5 % / over 8 h
Typical deployment duration in a day	24 hours
Total duration of operation of UWB device in a day for interference assessment	1 440 s
Time percentage of potential interference occurrence to FSS earth station near the vicinity in 24 hours	1 440 / (24 × 3 600) i.e. 1,67 %

Example 2: industrial equipment tracking

A more realistic example might be an item of equipment which is used exclusively within an industrial plant, and which is located once every 5 s. This item of equipment might be in motion only 5 % of the time - the rest of the time it is stationary and the tag's motion-sensing vibration switch will disable it. The long-term duty-cycle of the device would therefore be ((0,025 s × 0,2 Hz) × 0,05) = 0,025 %. The duty-cycle would be reduced even further, of course, if the equipment was ever taken off-site.

Summary:

- The typical duty cycle factor of a single UWB device (tag / nomadic) attached to a location Tracking System (in and outdoor):
  Duty Cycle: **2,5 %/s (Ton: 25 ms, one updates per second)**

  Long Term Duty Cycle (one update over 5 s) is equal to (25 ms / 5 s) = 0,005 = **0,5 %**

- Typical deployment duration in a day: average **24 h** (activity factor of the tag / nomadic)

- Total duration of operation of UWB device in a day for interference assessment:
  0,005 × 24 × 3 600 = **432 s**

- Time percentage of potential interference occurrence to FSS earth station near the vicinity in 24 hours: **0,5 %**

Table B.2: Estimation of interference duration from LT2 devices in example 2

Summary example 2: industrial equipment tracking	
The typical duty cycle factor of a single UWB device attached to a fixed outdoor location Only 25 ms Ton in a period of 5 sec	2,5 % / sec 0,5 % / 5 sec
Typical deployment duration in a day	24 hours
Total duration of operation of UWB device in a day for interference assessment	432 s
Time percentage of potential interference occurrence to FSS earth station near the vicinity in 24 hours	432 / (24 × 3 600) i.e. 0,5 %

Annex C: Expected compatibility issues

C.1 Current ITU 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 [i.8] (RR4.4) that does not require any new allocation (i.e. on a non-protected basis and causing no harmful interference).

Due to the broad range of frequencies covered, an excerpt of the European Common Allocation Table [i.2] is not reproduced here. Please see [i.2] for further details.

C.2 Coexistence and Sharing issues

The acceptance of the individual site licensing scheme for fixed outdoor location tracking systems within the frequency range 3,4 GHz to 4,8 GHz needs to be assessed.

Several issues have to be taken into account, which will decrease the probability of interference with the existing radio services.

The following technical aspects (mitigation factors) need to be taken into account as these will decrease the probability of interference with the existing radio services in a suitable manner:

- Used in a confined usage area, for fixed outdoor installations an individual site licensing is proposed.
- Location tracking tags are normally battery-operated and the overall transmitter activity is certainly less than 10 % (even much lower on average), also to safe battery-life. This leads to possibility of LDC and DCR restrictions.

Annex D: Bibliography

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History

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