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Technical Report

Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Technical characteristics for SRD equipment using Ultra Wide Band technology (UWB) Part 1: Communications 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 1 of a multi-part deliverable covering short range devices as identified below:

Part 1: "Communications applications";

Part 2: "Ground and Wall Probing Radar applications".

Introduction

Ultra-Wideband is a new emerging SRD technology with potential benefits for consumers and businesses, including security applications.

UWB technology is undergoing rapid development for a variety of commercial and industrial applications on a global basis.

The present document (Part 1 of TR 101 994) covers UWB communication equipment which is expected to operate between 3,1 GHz and 10,6 GHz with a very high bandwidth and a very low radiated power density.

The report includes 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) for amending the ERC Recommendation 70-03.

The technical characteristics of short range Ground, Wall, and Through-wall Probing Radars using UWB- technology will be covered in part 2 of TR 101 994.

1 Scope

The present document provides information on the intended applications, the technical parameters and the radio spectrum requirements for UWB communication equipment in the frequency range from 3,1 GHz to 10,6 GHz.

Additional information is given in the following Annexes:

- Annex A: Detailed market information;
- Annex B: Technical information;
- Annex C: Expected compatibility issues.

2 References

For the purposes of the present document the following references apply:

[1] CEPT/ERC Recommendation 70-03: "Relating to the use of Short Range Devices (SRD)".

[2] ITU-R SG1 TG1-8 Report from the 1st meeting of ITU-R SG1 TG 1-8, Geneva 21 - 24 January 2003 (Document 1-8/047).

[3] Intel Labs (J. Foerster, A. Stephens): "Response to the "Revision of UWB and FS co-existence report (Annex 5-1)" concerning aggregate UWB interference into FS systems". WGPT SE24 Meeting 18 document M18-14R0.

[4] ITU-R Recommendation M.1454: "E.i.r.p. density limit and operational restrictions for RLANs or other wireless access transmitters in order to ensure the protection of feeder links of non-geo-stationary systems in the mobile-satellite service in the frequency band 5150-5250 MHz".

[5] Domenico Porcino and Walter Hirt: "Ultra-Wideband Radio Technology: Potential and Challenges Ahead". IEEE Communications Magazine, July 2003, Vol. 41, No. 7, pp. 66-74.

[6] IEEE P802.19/019r2, July 2003: Working document UWB.

[7] FCC 02-48: "First Report and Order", February 14, 2002.

[8] "Digital Communications", Second Edition, John G. Proakis, McGraw-Hill 1989.

[9] M.Pezzin, J.Keingart, N Daniele, S. de Rivas, B. Denis, D. Morche, P. Rouzet, R. Catenoz, N. Rinaldi, "Ultra Wideband: the radio link of the future?", Annales des Télécommunications, Mars/Avril 2003.

[10] IEEE 802.15-03/267r5: "IEEE Standard for Telecommunications and Information Exchange Between Systems - LAN/MAN Specific Requirements - Part 15.3: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for High Rate Wireless Personal Area Networks (WPAN)".

[11] IEEE 1394: "IEEE Standard for a High Peformance Serial Bus".

[12] IEEE 802.15.3a "Amendment to Standard for Telecommunications and Information Exchange Between Systems - LAN/MAN Specific Requirements - Part 15.3: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Higher Speed Physical Layer Extension for the High Rate Wireless Personal Area Networks (WPAN)".

[13] IEEE 802.15.4: "STANDARD FOR Telecommunications and Information Exchange Between Systems - LAN/MAN Specific Requirements - Part 15: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low Rate Wireless Personal Area Networks (WPAN)".

3 Definitions and abbreviations

3.1 Definitions

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

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

isochronous: isochronous transmission transmits asynchronous data over a synchronous data link

necessary bandwidth: width of the frequency band which is just sufficient to ensure the transmission of information at the rate and with the quality required under specified conditions

NOTE: The definitions (such as Occupied bandwidth, Necessary Bandwidth, etc.) related to UWB are currently under study in CEPT and ITU-R Recommendation TG 1-8 [2]. Upon completion of this work ETSI will be in a position to update this definition if necessary. Therefore for the time being this definition is not to be added to any ETSI definition database.

3.2 Abbreviations

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

AC3	type of audio application
CDMA	Code Division Multiple Access
CE	Consumer Electronics
CEPT	European Conference of Post and Telecommunications administrations
dB	deciBel
dBi	deciBel relative to an isotropic radiator
dBm	deciBel relative to one milliwatt
DS-CDMA	Direct Sequence-CDMA
DSSS	Direct Sequence Spread Spectrum
ECC	Electronic Communications Committee
eirp	equivalent isotropically radiated power
EMC	ElectroMagnetic Compatibility
ERC	European Radio communication Committee
FCC	Federal Communications Commission
FDMA	Frequency Division Multiple Access
FFH	Fast Frequency Hopping
FHSS	Frequency Hopping Spread Spectrum
HDR	High Data Rate
IEEE	Institute of Electrical and Electronics Engineers
ITU-R	International Telecommunications Union-Radio sector
LDR	Low Data Rate
LOS	Line-Of-Sight
OFDM	Orthogonal Frequency Division Multiplex
PHY	PHYsical layer
PPM	Pulse Position Modulation
PRF	Pulse Repetition Frequency
PSD	Power Spectral Density
QoS	Quality of Service
R&TTE	Radio and Telecommunications Terminal Equipment
RF	Radio Frequency
Rx	Receiver
SDTV	Standard Definition TeleVision
SRD	Short Range Device
TDM	Time Division Multiplex
Tx	Transmitter
UWB	Ultra-WideBand
WPAN	Wireless Personal Area Network

4 Executive summary

UWB technology holds potential for a wide variety of new Short Range Devices (SRD) for communications, measurement, imaging, surveillance and medical systems.

UWB technology is typically used for transmitting short-range digital signals over a wide range of frequencies. High data rate communication with up to 500 Mbps over short distances up to 10 m can be achieved. However, beyond pure high data rate communications (e.g., high speed WLANs, ad-hoc wireless networks, intra-home and intra-office communication), UWB radio can also be used in applications requiring only medium- to low data rates (e.g. in sensor networks for high-resolution indoor positioning and tracking of assets and people, intrusion detection in security systems, obstacle avoidance and motion sensing). Reference [5] describes further envisaged scenarios for such High Data Rate (HDR) and Low Data Rate (LDR) UWB applications.

Existing FCC regulations require UWB to occupy a minimum of 500 MHz of spectrum or the minimal fractional bandwidth should be 0,2, referred to the -10 dB points.

UWB offers many advantages over narrowband technology for certain applications. Improved channel capacity is a major potential advantage of UWB. It is important to note that UWB may provide a significant increase in channel capacity, but only at limited distance. Figure 1 compares theoretical UWB data rates vs distance with one of today's wireless technologies used in communication applications.

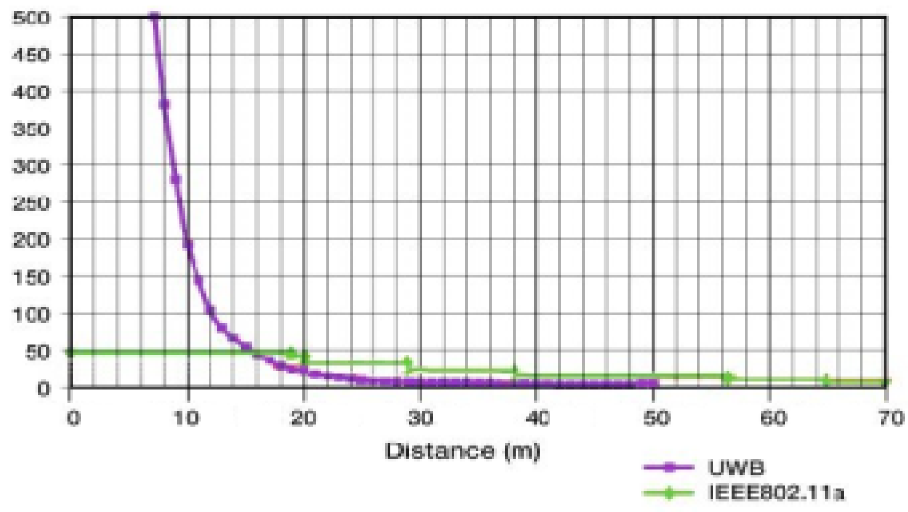

Figure 1: Theoretical data rate (in Mbps) vs distance for different technologies (source: INTEL)

Tables such as table C.4.3/2 show a corresponding set of potential applications. This is further developed in particular in clauses B.1.2 and C.5.4. The potential applications described in the present document are summarized in table 1.

Table 1: Examples of potential applications described in the present document

	Required Bit rates	**Distances as provided in IEEE 802.19 [6] co-existence scenarios**
1. Home usage Streaming video	25 Mbit/s	1 m to 5 m
1. Home usage Streaming MP3 audio	1,5 Mbit/s	5 m to 50 m
2. Home usage	10 Mbit/s (see note 1)	Approx 1m
3. Enterprise usage	1 Mbit/s to 200Mbit/s (see note 2)	1 m to 5 m
4. Kiosk/hot spot usage	160 Mbit/s	0,5 m to 3 m
5. Hotspot	80 Mbit/s	1 m to 25 m
6. Mobile phone with UWB	Up to 2Mbit/s (see note 3)	10 cm
7. Mobile phone image transfer	80 Mbit/s	10 cm
NOTE 1: Data rate available from a high speed ADSL connection to the home. NOTE 2: From table C.4.3/2; consistent with data rates for individual components in table C.4.3/1. NOTE 3: Data rate limited by mobile phone connection.		

Due to the high bandwidth UWB is potentially able to transmit very high data rates. UWB systems offer, in contrast to many traditional narrow bandwidth RF systems, an excellent immunity to multi-path interference. Therefore, the requirement for a margin in the RF link budget is substantially less. Additionally, UWB receivers offer an excellent immunity to interference from other radio systems due to a very high spreading and processing gain.

UWB technology is a technical platform for SRD applications for high bit rate communications. The UWB industry expects it to be implemented by relatively low cost integrated circuits.

UWB communication devices have intentional emissions over a wide frequency range and are for widespread use. All the relevant activity factors as well as realistic deployment scenarios and their impact on total aggregation effects should be considered when calculating the total aggregate interference.

The proposed necessary bandwidth for communications will fall within the range 3,1 GHz to 10,6 GHz. Emissions outside this range can be attenuated via filters and pulse shaping techniques that are still evolving.

The UWB industry within ETSI proposes in-band transmit power density limit which corresponds to the provisional policy [7] which the FCC has adopted.

The aim of the present document is to ask CEPT-ECC to perform the relevant studies to determine whether the above in-band limit is appropriate to protect the other radio services in the band and to propose a more adequate value if necessary. The present document does not propose any values outside this frequency band and asks CEPT-ECC to assess which mask (inside and outside the band) will be the most appropriate to ensure that all the radio services inside and outside the band are fully protected from UWB wanted and unwanted emissions. CEPT is therefore asked to propose an adequate mask and all other practical measures to ensure the protection of all other radio services in and outside the band 3,1 GHz to 10,6 GHz.

4.1 Status of the present document

Version 1.0.0 had been approved by ERM TG31A and submitted to ERM RM # 25 for approval.

Version 1.1.1_1.0.5 was the result of the revision by ERM RM#25 (green text have been reviewed and agreed). That version was sent for a two-week consultation period within ETSI (first deadline 16th of September 2003, 16:00).

Several comments from other ETSI members had been received and discussed at ERM TG31A#6. The version 1.1.1_1.0.6 is the result of the revision by ERM TG31A.

In view of the strong disagreement of TG31A with many comments made during the consultation, version 1.1.1_1.1.1 was prepared by WG ERM RM Secretary to try to consolidate a text acceptable for all parties. This text was offered for a further consultation until 17th of October 2003.

Version 1.1.1_1.2.2 was prepared by WG ERM RM Secretary to be presented to TC ERM#21 on the 29th of October for approval for publication.

Version 1.1.1_1.2.3 was approved by TC ERM#21.

The following comments were received during the two consultation phases from ETSI members but could not be incorporated in the other clauses of the present document:

4.1.1 Comments from Vodafone group plc (supported by Nokia, Deutsche Telekom AG, Ericsson)

While UWB clearly offers the potential for new communications applications, it clearly also has the potential to cause interference to other radiocommunication services. The present document does not provide any justification for the in-band or out-of-band emissions limits contained in clauses B.2 and 4.1.5, respectively.

It is important to recognise that the term UWB encompasses a number of very different technologies, which may have different compatibility characteristics. The present document does not contain sufficient information about the characteristics of UWB Multi-band pseudo-carrier Spectrum to evaluate its compatibility with other systems.

The proponents of UWB claim that only the power levels in table B.2 may enable the expected high rate capability of UWB technology and, therefore, enable successful UWB penetration of the market. However, this claim is not supported by information provided to ETSI, and included in the present document. Figure 1 shows the maximum distance for UWB communications, as a function of data rate. This distance is larger than needed for the envisaged deployment scenarios and applications for UWB. In other words, the power limits for UWB could be reduced without constraining its potential applications.

4.1.2 Further comments from Vodafone group plc

This clause provides explanation of the comments previously made by Vodafone, which were supported by Nokia, Deutsche Telekom AG and Ericsson.

4.1.2.1 In-band power limits

The in-band power limit proposed by ERM TG31A (see clause B.2.1) is greater than is justified by information presented in the present document.

Figure 1 of the present document is a graph of the available data rate of a UWB system (presumably meeting FCC requirements) as a function of range. Clause C.5 contains a number of scenarios that represent current thinking of the industry of typical uses of UWB. Table 1 in the Executive Summary shows that, with one exception, the range available from UWB is significantly higher than required for the scenario. This means that the UWB PSD could be reduced, without impairing its usability. For the one exception, the distance quoted for the scenario is much greater than would seem to be appropriate for the scenario described.

Most studies of UWB compatibility have assumed that a high bit rate UWB signal can be modelled as Gaussian Noise. This is not always the case for UWB multi-band systems. For example, a multi-band system using a single band that hopped over N channels would cause interference to a narrowband digital system for 1/N of the time. This could result in a "plateau" in the uncorrected BER curve, with a BER of 1/2N (corresponding to 50 % BER for the duration of the interference). The power of this carrier could be N times higher than the mean power specified in the emissions limit.

At present, cellular networks and most WLANS operate below 3,1 GHz. However, by the time that UWB may become widespread, WLANs operating at 5 GHz will be commonplace, and WRC-07 may have identified spectrum for the future development of IMT-2000 and systems beyond IMT-2000 that could be above 3,1 GHz.

4.1.2.2 Out-of-band power limits

Vodafone has serious concerns about the out-of-band power limits proposed by ERM TG31A (see clause 4.1.5).

The FCC spectrum mask has an emissions limit of -61,3 dBm/MHz immediately outside of the frequency range for intended emissions (3,1 GHz to 10,6 GHz). However, at lower frequencies (the GPS bands and below), the limit becomes more stringent. Most of the compatibility studies undertaken in Europe have assumed that equipment will have lower emissions below 3,1 GHz, in order to meet the limits in the GPS bands; this is generally represented as a linear interpolation between the limits at 3,1 GHz and for the GPS band. It is believed that this is representative of the emissions from impulse UWB, but may not be the case for other technologies.

The studies conducted in Europe on compatibility between UWB and UMTS have assumed emissions some 13 dB below the FCC limits, due to the linear interpolation between the GPS band and 3,1 GHz limits. Despite this, it has been shown that interference can occur to terminals, especially in indoor (domestic and office) environments. If it could not be relied upon that the UWB emissions would be significantly below the FCC limits, the impact on UMTS networks (and also GSM networks) would be even more serious.

Regulatory action in respect of UWB should not be limited to particular technologies. The assumptions about the out-of-band emissions may not be valid for all future UWB technologies. It is also possible that equipment could be designed that seeks to exploit a constant out-of-band emissions limit.

It is therefore necessary for any European emissions mask for UWB to:

- specify tighter limits for out-of-band emissions at critical frequency bands;
- include slopes between the breakpoints in the limits for out-of-band emissions.

4.1.3 Comments from Nokia (supported by Deutsche Telekom AG)

We propose that the intended frequency range (where -41,3 dBm applies) should NOT include the 5,15 GHz to 5,85 GHz band since this is used by WLAN and CEPT studies have shown that interference would result. Furthermore any use in the range 3,1 GHz to 5,15 GHz band should be on a strict DCA/listen before talk basis, as the band has been proposed for mobile use by some administrations.

Because the noise floor is raised over a large frequency range, reducing the Shannon capacity for existing users, UWB does not always result in efficient use of the spectrum. This is especially so in physically congested areas.

4.1.4 Comments from Siemens MC

Clause B.1.1 contains bullets requirements, taken from FCC regulations, which show a clear contradiction in the three bullets (bullet 1, 6 and 7).

The first one claims for -10 dB bandwidth included within 3,1 GHz to 10,6 GHz, while the last two contradict that statement asking for -20 dB outside that band, making the first bullet meaningless.

We think that is not the case to bring forward a FCC inconsistency into an ETSI document (which, in principle, should formally follow CEPT rules; for which purpose the SRD is made).

Therefore we are of the opinion that either the first bullet is deleted (because unnecessary) or it should be modified asking for "-20 dB bandwidth included within 3,1 GHz to 10,6 GHz". The third option is to add a note highlighting such inconsistency.

4.1.5 Comments from ERM TG31A

In reaction to comment in clause 4.1.3, ERM-TG31A indicated it is of the opinion that UWB can share a congested spectrum better. In reaction to comment in clause 4.1.4, ERM-TG31A indicated clause B.1.1 is for informative purpose only. ERM-TG31A had proposed limits that include 20 dB tighter limits for the unwanted emissions below/above the band edges, 3,1 GHz and 10,6 GHz (staircase-mask).

In a previous stage in the drafting of the present document, ERM - TG31 A had proposed out of band limits as follows:

Parameter	Limit
Unwanted emissions power density outside the frequency range from 3,1 GHz to 10,6 GHz	-61,3 dBm/MHz (see notes 1 and 2)
Unwanted emissions peak power outside the frequency range from 3,1 GHz to 10,6 GHz in 50 MHz bandwidth	-20 dBm/50 MHz
NOTE1: The proposed unwanted emission limits are subject to CEPT review and decision. The proposed mask is different from the current CEPT-mask used in SE24 compatibility studies. NOTE:2 The proposed mask is different from the FCC regulations.	

Recognizing, however, that "slope masks" had also been proposed.

4.1.6 Comments from EP BRAN

A new type of fixed wireless access standard has been developed in ETSI BRAN: HiperMAN. Manufacturers of HiperMAN systems are targeting indoor deployment of the Subscriber Stations, in order to reduce installation costs. UWB devices may be among the types of handheld device used in the same room as a HiperMAN receiver.

We recommend that the present document add HiperMAN to the list of co-existence studies required (annex C).

4.1.7 Comments from INTEL CORPORATION SARL

INTEL CORPORATION SARL provided the following technical justification supporting the proposed UWB in-band level of -41,3 dBm/MHz

In the spread sheet attached to the present document (see annex B.2), a simple link budget table shows that we are just on the border of achieving 110 Mbps at 10 m and 480 Mbps at 4 m, which are desired targets for this technology when the Tx power is -41,3 dBm/MHz.

As an example, if the Tx power is reduced to -51,3 dBm/MHz (this is simulated in the table below and results for this reduced level are indicated in red), the ranges for 110 Mbps becomes less than about 3,5 m and for 480 Mbps becomes less than 2 m. These estimates include realistic implementation losses and margins for multipath/shadowing.

We are, therefore, on the border using the current FCC limits, and the application space for high throughput applications would likely be better served with other technologies if the Tx power is reduced to -51,3 dBm/MHz. Adopting this lower limit would restrict the application area for UWB devices to low data rate/sensor applications. In this latter case, ranges would still be significantly impacted so the usability would still need to be investigated.

With such reduced power levels the affected applications are mainly the consumer electronics and enterprise applications requiring data rates from 100 Mbs to 250 Mbs and representing the mainstream market that would be surely prevented from having any commercial viability.

As an example, detailed UWB link budgets and system performance that received broad industry support and specific to the multi-band OFDM approach, and, that considers different channel models in multipath environments, are also available in the document numbered IEEE 802.15-03/267r5 [10] on the internet site of IEEE. It shows similar numbers of final system performance at -41,3 dBm/MHz, taking into account the losses due to the multiple degradations: front-end filtering, clipping at the DAC, ADC degradation, multi-path degradation, channel estimation, carrier tracking, packet acquisition, etc.

4.2 Technical system description

For detailed technical UWB information, see annex B.

4.3 Market information

For detailed market information, see annex A.

4.4 Impact on radio services inside and outside the proposed frequency band

ETSI fully supports the actions of CEPT to allow the operation of UWB in Europe while insuring the compatibility with the other services. ETSI is also asking that due care be also given to the implication on the other radio services outside the band.

Information on the implication on mobile services and radio navigation satellite services, is available in clause C.1.2.

5 Current regulations

There are no current regulations permitting the operation of UWB in Europe.

Article RR No. 4.4 has been relied upon by national administrations (and CEPT as well) in many contexts to authorize applications not conforming with the Table of Frequency Allocations in the Radio Regulations (e.g. Short Range Devices which are operated in ISM frequency bands). UWB communications systems might also be operated under Article RR No. 4.4.

6 Main conclusions

From the market information collected from the UWB industry, it is clear that there is a potential for a variety of UWB communication applications as well as an increasing number of (indoor) sensing and positioning applications. Technology is still advancing, so that it is at the moment not possible to describe a single modulation scheme with related spectrum characteristics that is appropriate for all suppliers and applications. In fact, it is very unlikely, that only a single type of signalling and modulation scheme will be used for the large variety of potential UWB radio applications (see also annex B).

Manufacturers indicated that UWB equipment will become available in 2004 with first products to be ready to be placed on the market by the end of 2004.

7 Expected ECC actions

Mandate M/329 covering UWB calling for completion of Harmonized Standards for UWB by the end of the year 2004 was received by ETSI. ETSI accepted this mandate (see ETSI Work Item DEN/ERM-TG31A-0112-1).

Therefore, ETSI requests ECC to consider the present document which includes 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) for, in fine, amending the ERC Recommendation 70-03 [1].

Therefore, ETSI asks CEPT-ECC to perform the relevant studies to determine whether the mask described in the present document is appropriate to protect all the other radio services and to provide the most adequate mask and all other practical measures to ensure the protection of all other radio services inside and outside the band 3,1 GHz to 10,6 GHz, while permitting the introduction of UWB communication devices in Europe.

It should be stressed that the present document contains information not yet considered in the currently on-going co-existence studies within WGSE PT SE24.

Annex A: Detailed market information

A.1 Applications

UWB devices can be used, for example, for a variety of communications applications involving the transmission of very high data rates over short distances without suffering the effects of multi-path interference. The potentially low supply power requirement of this technology makes it very suitable for products with limited battery capacity.

For communications systems, there are three overlapping target areas that will benefit from short-range wireless connections: PC, mobile and consumer electronic devices (see table A.2.2 Step 1 for examples within these three categories). Each of these target areas can be considered as a cluster, where surrounding devices need to communicate large amounts of data over fairly short ranges. For example, a digital still camera, with a large storage capacity, may require a high-speed connection to the PC to transfer images. At the time of transfer, the distance between the PC and the camera is typically a few meters at most. UWB allows us to create a wireless link by enabling the necessary data rates in a radio suitable for cost sensitive, battery powered mobile devices, such as a camera or PDA. Similar examples are smart phones, printers, handheld computers, camcorders and MP3 players.

UWB communication devices could be used to wirelessly distribute services such as phone, cable, and computer networking throughout a building or home. UWB has potential in both home and business markets, based on its low cost as well as high-speed data transmission capability (100 Mbps - 500+Mbps), and could be well suited to for various video distribution applications (DVD player/recorder to TV or transmitting images/video from digital camera/camcorder to TV) and, generally, new high-speed consumer SRDs such as:

- PVP/PVR/Personal movie players;
- Digital Camera;
- MP3 players;
- Internet Connections (tablets);
- Peer-to-peer file sharing;
- External Hard-drive for backups;
- HDTV streaming from set-top boxes;
- Remote Monitors;
- Business Video projectors;
- Videophones, Scanner;
- Laser Printers;
- PC speakers;
- Video projectors and surround speakers for home theatre;
- Video Game Consoles;
- Mice/tracking ball/pointers;
- Keyboards;
- Joysticks;
- Headset;
- PDAs for file downloads (calendar/email synchronization);

- Desktop;
- Notebook PCs and peripherals;
- Access Points;
- Cellular Handsets; and
- many other applications.

Particularly, UWB technology is a potential cable replacement for applications where USB 2.0/Firewire resides e.g.:

- USB 2.0 allows data rates up to 480 Mbps;
- IEEE 1394 [11] (Firewire 400 Mbps and 800 Mbps); and
- USB 1.1 at 12 Mbps.

Other UWB applications are low data rate and with very low activity factors, and are typically used in sensor networks and RFID (radio frequency identification) systems. For example, the FCC recently approved a tagging system for UWB precision asset location systems.

A.2 Market size

A method used by Intel to determine the UWB market size for the initially expected more common, medium to high data rate communication applications is shown in the following steps below:

1) Step 1:
   - Estimate the volume worldwide for the target addressable market i.e. devices such as CE (Consumer Electronics), PC (Computer and Peripherals) and Mobile Devices that are potentially UWB enabled. This is readily available (over 5 years) in external market research.
2) Step 2:
   - Make growth rate assumptions for the uptake of UWB over 5 years using for UWB adoption time periods: early; leadership; mainstream; late.
3) Step 3:
   - Make geographical breakdown assumptions for the European market by identifying one specific device forecast for Europe to use as a representative distribution for the aggregate UWB device volume from 2.

A.2.1 Markets covered

Although only the US market is currently available for UWB devices, enabled by the current FCC regulations for UWB, there is high interest for this technology in many other countries and steps are being taken by the UWB industry to explore a number of markets and regulatory processes.

A.2.2 Market forecast

The market forecasts provided in the following clauses assume that all country regulations will enable (from 2004) the same or very close power levels as those allowed under current FCC regulations.

Step 1: Worldwide Addressable Device Unit Volume for UWB.

Table A.2.2 represents the worldwide forecast unit volumes for the potential UWB enabled Consumer Electronics (CE), PC (Computer and Peripherals) and Mobile Devices. The table actually represents the addressable market for the UWB technology.

Table A.2.2 (Step 1): Addressable Worldwide Market for UWB

Device Units (1000s)	2002	2003	2004	2005	2006	2007	2008	2009
Digital Camcorders	8 100	9 450	10 350	12 600	14 500	15 200	*15 934*	*16 703*
Video Game Consoles	41 430	46 050	49 100	45 900	50 900	55 100	*57 855*	*60 748*
DVD Recorders	1 425	3 630	8 300	17 400	31 600	45 600	*60 648*	*69 139*
DTT/DBS/Cable Set Top Boxes	40 549	38 338	40 952	46 431	53 472	57 972	*62 262*	*66 869*
DVCRs / PVRs	840	1 355	1 945	2 340	2 730	*3 208*	*3 529*	*3 882*
TV Front Projector Displays / PDPs	10	20	35	70	150	*338*	*844*	*1 898*
Digital Televisions	5 384	8 671	12 837	20 000	33 930	57 925	*98 473*	*157 556*
Digital Still Cameras	22 800	28 100	34 100	40 200	46 900	51 800	*58 016*	*64 978*
Digital Home Audio Electronics	165	365	710	1 195	1 620	*2 106*	*2 527*	*2 780*
Portable Digital Music Players	3 295	3 920	4 950	5 750	6 430	7 200	*7 776*	*8 398*
Total CE Devices	**123 998**	**139 899**	**163 279**	**191 886**	**242 232**	**296 449**	**367 863**	**452 951**
Desktop PCs / Adapters	101 195	107 486	119 949	126 583	134 303	142 547	*152 525*	*163 202*
Notebook PCs / Adapters	28 455	32 161	37 329	42 962	49 424	56 898	*64 864*	*73 945*
Printers (Inkjet, Laser, MFDs)	79 450	81 850	84 250	86 500	88 800	90 850	*96 301*	*102 079*
PC Cameras	5 400	6 200	6 600	7 100	7 700	8 300	*9 296*	*10 226*
Scanners	28 500	32 500	37 000	42 000	45 500	47 500	*52 250*	*57 475*
Enterprise Display Projectors	1 200	1 550	2 075	2 925	4 100	*5 740*	*7 749*	*10 074*
Ext Storage (HDD, Disk, CD-RW, DVD-R, Flash)	21 032	23 350	26 776	30 453	33 470	31 500	*34 650*	*38 115*
External Digital Modems	17 459	21 937	21 242	19 798	17 871	15 730	*9 438*	*5 663*
Flash Card Readers	2 450	2 900	3 450	4 050	4 550	4 900	*5 782*	*6 823*
Input Devices (Mice, Keyboards, Game Controllers)	288 805	305 727	335 112	350 717	368 459	388 206	*407 616*	*427 997*
Total PC & Peripheral Devices	**573 946**	**615 661**	**673 783**	**713 088**	**754 177**	**792 171**	**840 471**	**895 598**
PDAs	11 000	14 000	16 000	20 000	22 000	25 000	*26 500*	*27 560*
Cellular 2.5G Handsets	436 897	467 167	502 482	527 707	562 013	*702 516*	*772 768*	*811 406*
Cellular 3G Handsets	202	2 018	5 045	12 108	22 198	*35 517*	*46 172*	*55 406*
Total Mobile Devices	**448 099**	**483 185**	**523 527**	**559 815**	**606 211**	**763 033**	**845 440**	**894 372**
Total CE/PC/Mobile Device Unit Volume (1000s)	**1 146 043**	**1 238 745**	**1 360 589**	**1 464 789**	**1 602 620**	**1 851 653**	**2 053 774**	**2 242 921**

NOTE: Source: In-Stat MDR, (Numbers in italic indicate extrapolated data estimates beyond published report timeframe)

Step 2: Estimated Worldwide UWB Enabled Devices.

In table A.2.2 Step 2 the devices from table A.2.2. Step 1 are regrouped according to their speed of adoption by the market: early adopter, leadership adoption, mainstream adoption, and late adopting. The CE devices are shaded in yellow, the PC & peripheral devices in pink, and the mobile devices in blue. The number of addressable unit volumes (same figures as in table A.2.2 Step 1) is given for each CE device, PC and peripheral devices, and mobile devices for the years 2002 through 2009. The total number of UWB enabled devices per adoption period is calculated by summing the addressable unit volumes of devices in that category and multiplying by the attach rate.

Table A.2.2 (Step 2): Estimated Worldwide UWB Enabled Device Total

Device Units (1000s)	2002	2003	2004	2005	2006	2007	2008	2009
Early Adopter Devices								
Attach Rate (% of unit total)	*0,0%*	*0,0%*	*0,5%*	*8,0%*	*25,0%*	*55,0%*	*80,0%*	*95,0%*
Digital Camcorders	8 100	9 450	10 350	12 600	14 500	15 200	*15 934*	*16 703*
TV Front Projector Displays	10	20	35	70	150	*338*	*844*	*1 898*
Enterprise Display Projectors	1 200	1 550	2 075	2 925	4 100	*5 740*	*7 749*	*10 074*
Early Adopter UWB Enabled Devices (1000s)	**-**	**-**	**62**	**1 248**	**4 688**	**11 703**	**19 621**	**27 241**
Leadership Adoption Devices								
Attach Rate (% of unit total)	*0,0%*	*0,0%*	*0,2%*	*5,0%*	*10,0%*	*25,0%*	*40,0%*	*50,0%*
Digital Televisions	5 384	8 671	12 837	20 000	33 930	57 925	*98 473*	*157 556*
DVD Recorders	1 425	3 630	8 300	17 400	31 600	45 600	*60 648*	*69 139*
DTT/DBS/Cable Set Top Boxes	40 549	38 338	40 952	46 431	53 472	57 972	*62 262*	*66 869*
Digital Still Cameras	22 800	28 100	34 100	40 200	46 900	51 800	*58 016*	*64 978*
Notebook PCs / Adapters	28 455	32 161	37 329	42 962	49 424	56 898	*64 864*	*73 945*
PDAs	11 000	14 000	16 000	20 000	22 000	25 000	*26 500*	*27 560*
Cellular 3G Handsets	202	2 018	5 045	12 108	22 198	*35 517*	*46 172*	*55 406*
Leadership UWB Enabled Devices (1000s)	**-**	**-**	**309**	**9 955**	**25 952**	**82 678**	**166 774**	**257 726**
Mainstream Adoption Devices								
Attach Rate (% of unit total)	*0,0%*	*0,0%*	*0,0%*	*1,0%*	*5,0%*	*15,0%*	*25,0%*	*30,0%*
Video Game Consoles	41 430	46 050	49 100	45 900	50 900	55 100	*57 855*	*60 748*
DVCRs / PVRs	840	1 355	1 945	2 340	2 730	*3 208*	*3 529*	*3 882*
Portable Digital Music Players	3 295	3 920	4 950	5 750	6 430	7 200	*7 776*	*8 398*
Digital Home Audio Electronics	165	365	710	1 195	1 620	*2 106*	*2 527*	*2 780*
Desktop PCs / Adapters	101 195	107 486	119 949	126 583	134 303	142 547	*152 525*	*163 202*
Printers (Inkjet, Laser, MFDs)	79 450	81 850	84 250	86 500	88 800	90 850	*96 301*	*102 079*
Scanners	28 500	32 500	37 000	42 000	45 500	47 500	*52 250*	*57 475*
Ext Storage (HDD, Disk, CD-RW, DVD-R, Flash)	21 032	23 350	26 776	30 453	33 470	31 500	*34 650*	*38 115*
External Digital Modems	17 459	21 937	21 242	19 798	17 871	15 730	*9 438*	*5 663*
Mainstream UWB Enabled Devices (1000s)	**-**	**-**	**-**	**3 605**	**19 081**	**59 361**	**104 213**	**132 702**
Late Adopting Devices								
Attach Rate (% of unit total)	*0,0%*	*0,0%*	*0,0%*	*0,0%*	*0,0%*	*1,0%*	*4,0%*	*10,0%*
PC Cameras	5 400	6 200	6 600	7 100	7 700	8 300	*9 296*	*10 226*
Flash Card Readers	2 450	2 900	3 450	4 050	4 550	4 900	*5 782*	*6 823*
Input Devices (Mice, Keyboards, Game Controllers)	288 805	305 727	335 112	350 717	368 459	388 206	*407 616*	*427 997*
Cellular 2.5G Handsets	436 897	467 167	502 482	527 707	562 013	*702 516*	*772 768*	*811 406*
Late UWB Enabled Devices (1000s)	**-**	**-**	**-**	**-**	**-**	**11 039**	**47 818**	**125 645**
Estimated WW UWB Enabled CE Device Total (1000s)	-	-	244	7 767	23 337	72 012	143 103	219 685
Estimated WW UWB Enabled PC Device Total (1000s)	-	-	85	5 435	21 965	70 615	135 344	201 007
Estimated WW UWB Enabled Mobile Device Total (1000s)	-	-	42	1 605	4 420	22 154	59 979	122 624
Estimated Worldwide UWB Enabled Device Total (1000s)	**-**	**-**	**371**	**14 808**	**49 721**	**164 781**	**338 426**	**543 315**

Figure A.2.1, the estimated number of UWB enabled devices worldwide is presented from 2004-2009. (These numbers correspond with those in the last row of table A.2.2 Step 2.)

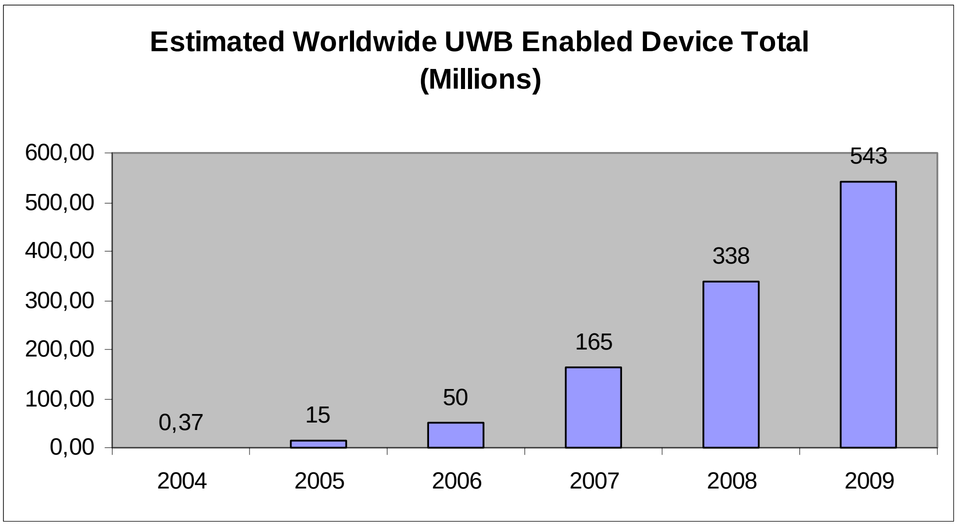

Figure A.2.1

Step 3: Estimated European UWB Enabled Devices.

Table A.2.2 (Step 3): Total Estimated European UWB Enabled Devices

Devices Units (1000s)	2002	2003	2004	2005	2006	2007	2008	2009
Germany	-	-	16	617	2 508	6 705	13 209	21 914
UK	-	-	13	481	1 940	5 208	10 298	17 150
France	-	-	10	397	1 643	4 427	8 788	14 693
Russia	-	-	9	358	1 563	4 427	9 238	16 235
Italy	-	-	7	289	1 265	3 450	6 932	11 730
Spain	-	-	5	202	845	2 278	4 528	7 579
Netherlands	-	-	5	187	768	2 018	3 908	6 372
Poland	-	-	4	139	583	1 627	3 345	5 790
Sweden	-	-	3	110	448	1 172	2 259	3 668
Switzerland	-	-	2	86	357	1 042	2 237	4 045
Belgium	-	-	2	76	316	846	1 670	2 776
Ukraine	-	-	2	101	477	1 562	3 770	7 662
Denmark	-	-	1	52	215	651	1 452	2 728
Austria	-	-	1	52	215	586	1 176	1 989
Turkey	-	-	1	58	247	651	1 265	2 069
Norway	-	-	1	51	204	521	979	1 551
Finland	-	-	1	52	215	586	1 176	1 989
Greece	-	-	1	49	212	586	1 195	2 053
Czech	-	-	1	50	217	586	1 163	1 945
Hungary	-	-	1	48	200	521	997	1 608
Portugal	-	-	1	40	172	456	891	1 469
Ireland	-	-	1	31	130	391	865	1 613
Other	-	-	10	436	1831	4492	8 354	13 084
Total	**-**	**-**	**98**	**3 962**	**16 571**	**44 789**	**89 695**	**151 712**

In figure A.2.2, the estimated number of UWB enabled devices in Europe is presented from 2004-2009. (These numbers correspond with those in the last row of table A.2.2 Step 3.)

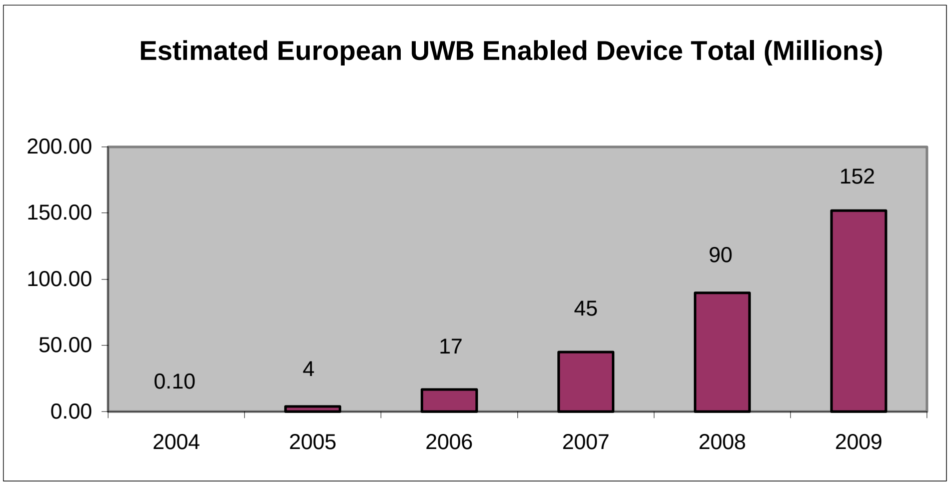

Figure A.2.2

Annex B: Technical information

B.1 General UWB characteristics for communications

In the context of a communications system application, the UWB technology may be considered in relation to the theoretical capacity of the channel. The system capacity may be calculated from the "Shannon" relation. This relation shows that the channel capacity (bit/sec) equals the channel bandwidth multiplied by the logarithm (base 2) of one plus the signal to noise ratio. This relation offers a theoretical capacity advantage to wide band systems. UWB offers many advantages over narrowband technology in certain applications. Improved channel capacity is one major advantage of UWB. The channel is the RF spectrum within which information is transferred. Shannon's capacity limit equation shows that increasing channel capacity requires linear increases in bandwidth, under certain conditions, while similar channel capacity increases would, under certain other conditions, require exponential increases in power.

Shannon's Capacity Limit Equation:

$$C = BW \times \log_2(1 + SNR)$$

where:

- C = Channel Capacity (bits/s);
- BW = Channel Bandwidth (Hz);
- SNR = Signal to Noise Ratio;

and

$$SNR = P/(BW \times No);$$

where:

- P = Received Signal Power (watts);
- No = Noise Power Spectral Density (watts/Hz).

However, in the case of systems using a large BW, where BW>>P/No (i.e. characterized by operation at SNR<<1, i.e. negative SNR values in dB), Shannon's equation will simplify to the following:

$$C \approx BW \times P/(BW \times No) / \ln(2) = P/(\ln 2 \times No).$$

This is described on page 136 of [8] and other literature in information theory.

This simplified relation for large BW systems shows that capacity is "saturated" in terms of BW. This means that, after some point, a bandwidth increase gives no further channel capacity, while channel capacity will increase linearly with transmitter power.

Therefore, UWB technology is capable of transmitting very high data rates using very low power densities and allows for a very wide spreading of the emission spectrum resulting in a very low power interfering spectral density, which thereby may allow operation across existing radio services.

B.1.1 Current UWB devices design

B.1.1.1 FCC requirements

UWB communications devices that have been implemented or designed so far meet FCC rules for UWB handheld systems.

These rules (implemented from FCC 02-48 [7]), of informative character in the present document, are summarized below:

- -10 dB bandwidth must be within 3,1 Ghz to 10,6 GHz;
- the emissions below 960 MHz must not exceed the general limits (rule 15.209);
- the emissions between 960 MHz to 1 610 MHz must be attenuated below the general limits by 34 dB;
- the narrowband emission in the GPS bands must be attenuated below the general limits by 44 dB;
- the emissions between 1 610 MHz to 1 990 MHz must be attenuated below the general limits by 22 dB;
- the emissions between 1 990 MHz to 3 100 MHz must be attenuated below the general limits by 20 dB;
- the emissions above 10 600 MHz must be attenuated below the general limits by 20 dB.

The general radiated power density limit is equivalent to -41,3 dBm/MHz, and it is also required that the digital circuitry that operates the associated UWB transmitter also respects the general limit; the digital circuitry is not required to respect the transmitter limit.

The UWB communications devices that have been implemented or designed so far only need the spectrum from 3,1 GHz to 10,6 GHz for communications, and this band may therefore be described to contain the necessary bandwidth.

B.1.1.2 Work done in IEEE

IEEE 802 is investigating various applications for UWB:

a) Medium to high data rate:

   - During the year 2003, the IEEE 802.15.3a [12] standards group is examining and implementing a selection process for an UWB standard for short range, high bit rate communications devices. The various proposals for the standard all meet the above FCC requirements, and in general they use necessary emission that meets the following criteria:

     - The minimum limit of the necessary bandwidth is 500 MHz, wanted emission in the frequency range from 3,1 GHz to 10,6 GHz

NOTE: For the purpose of conducting coexistence studies this should be understood to be the -10 dB bandwidth limits of the wanted emission.

b) Low data rate:

   - In the year 2003, the IEEE 802.15.4 [13] standards group chartered to investigate a low data rate solution with multi-month to multi-year battery life and very low complexity has formed a new Study Group 4a (SG4a). This group is working to define a project for an amendment to 802.15.4 [13] for an alternative PHY, where to date, the principle interest has been in providing high precision location capability and high aggregate throughput, as well as adding to data rates, range, power consumption, and cost. These additional capabilities over the existing 802.15.4 [13] standard are expected to enable significant new applications operating in an unlicensed, international frequency band. Potential applications are sensors, interactive toys, smart badges, remote controls, and home automation; the informal but strong consensus is that UWB radios operating in the 3,1 GHz to 10,6 GHz at FCC power density levels (-41,3 dBm/MHz) will likely be used to support these applications.

- One specific example for a low-data rate / extremely low activity factor UWB precision asset location system which was recently approved by the FCC has the following parameters:
    - Centre frequency of operation: 6,2 GHz;
    - Instantaneous -10dB bandwidth: 1,25 GHz;
    - Antenna: broadband monopole;
    - Peak power: less than 0 dBm / 50 MHz;
    - Burst length (see note 1): 72 pulses (bits);
    - Pulse repetition frequency (PRF): 1 MHz;
    - Update rate (see note 2): 1 Hz (i.e. once per second).

NOTE 1: Includes synchronization preamble, tag ID, optional data field and forward error correction and control bits.

NOTE 2: In most cases of practical interest, one tag update per second is very high, typical update rates are more likely to be from once every 5 s to once per hour.

B.1.2 UWB communications system principles and features

As an example, the activities of the IEEE 802.15 High Rate Alternative PHY Study Group (Study Group 3a) for Wireless Personal Area Networks (WPANs) can be used to illustrate the expected features and possible techniques for UWB communications systems. This group is tasked with standardizing an UWB high bit-rate WPAN PHY (physical layer), in conjunction with the IEEE 802.15.3 MAC (media access control) for applications that involve video and multimedia.

The technical requirements set in December 2002 are as follows:

- Bit rate of at least 110 Mbps at 10 m. An additional higher bit rate of at least 200 Mbps at 4 m is required. Scalability to rates in excess of 480 Mbps is desirable even if at reduced ranges.
- Isochronous capable (to support streaming video).
- Support for 3 piconets (non-overlap channels), with minimum effective throughput of 50 Mbps each; also calls for support for 4 piconets to 8 piconets, with up to 300 Mbps shared capacity.
- Addressing of up to 127 devices per host.
- Uses existing 802.15 MAC.
- Robust multipath performance (using agreed channel models).
- Co-exists and operates within 1 m of 802.11, Bluetooth, Cellular, PCS, and GPS.
- Power consumption less than 100 mW for 110 Mbps and less than 250 mW for 200 Mbps.
- Physical form factor can easily be integrated into consumer equipment devices, especially portable devices.

Two approaches for UWB implementation are contained in the IEEE 802.15.3a [12] proposals and are shown in table B.1.2.

Table B.1.2: IEEE 802.15.3a approaches for UWB implementation

Approach	Variants	No. of sub-bands	Sub-band bandwidth
Single impulse	Bi-phase pulses. Pulse position modulation. DS-CDMA	1 to 2	1,8 GHz to 4,6 GHz
Multi-band OFDM pseudo-carrier	"Time-frequency" coding (i.e. Fast Frequency Hopping (FFH))	13	500 MHz

The single impulse and multi-band pseudo-carrier approaches are further explained in clauses B.1.2.1 and B.1.2.2 respectively.

B.1.2.1 Single impulse approach

UWB waveforms in realizations made up to early 2003 have typically been single impulses (e.g. "Gaussian Mono Cycle Pulses") in the time domain. By varying the impulse characteristics, the characteristics of the energy in the frequency spectrum may be defined. There are three parameters of interests when defining the properties of energy filling a specified frequency spectrum. The first is in defining the intended bandwidth of the transmitted energy. The second is in limiting energy to within the specified spectrum. The third is defining where generated energy should centre within the spectrum of interest. Impulse duration, in the time domain, determines bandwidth in the frequency domain (1/duration ~ bandwidth).

Impulse frequency is one characteristic that may determine the centre frequency of a band of transmitted energy. Impulse shape determines the characteristics of how the energy occupies the frequency domain. UWB impulse technology is designed to use required bandwidth with respect to the intended application.

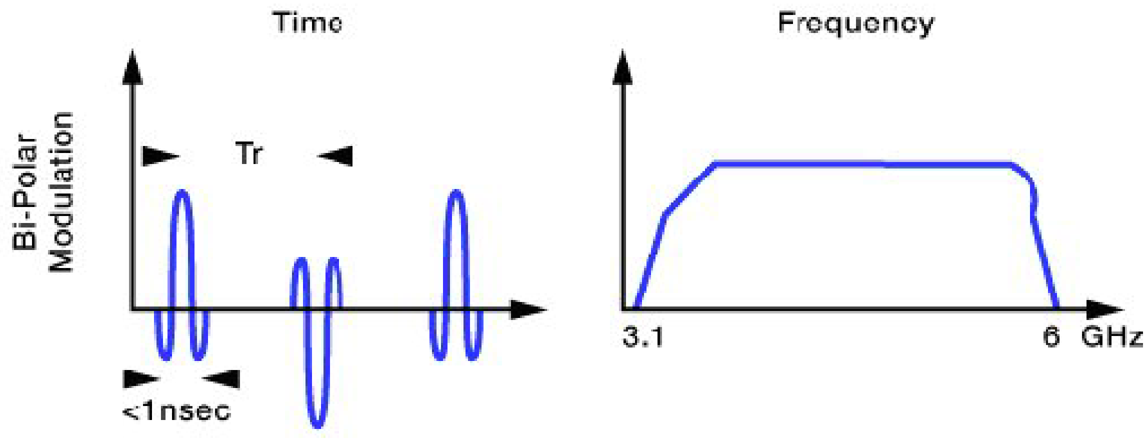

Figure B.1.2.1/1: Sketch of impulse Bi-Polar Modulation shape and frequency spectrum

As with traditional radio architectures, data can be modulated on the impulses in a number of ways, including amplitude, phase, time position, or any combination of these.

By implementing a flexible pulse generator, the shape of the transmitter pulse can be modified according to the spectrum that needs to be covered. Figure B.1.2.1/2 displays a pulse shape with its corresponding spectrum [9].

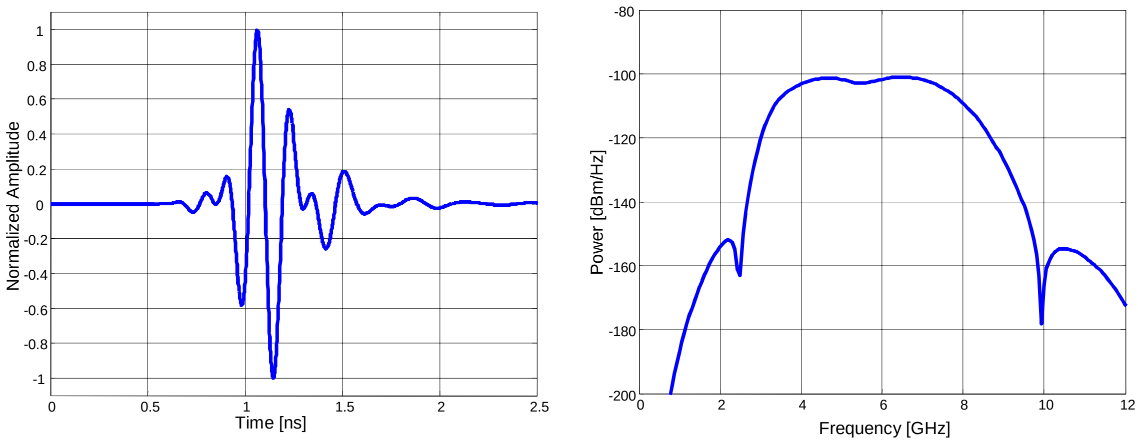

Figure B.1.2.1/2: Pulse shape with corresponding spectrum

Sometimes, pulse shaping on the transmitter side may not be enough to reduce the emission to a tolerable interference level. In this case, notched filters at the emission can be implemented. The resulting modified pulse shape will not affect the receiver performance in a well designed receiver.

Single pulse architectures can also cope with narrowband interference, by using dynamic notched filtering in the receiver.

Single pulse systems can also be flexible regarding data rate. For example, if low data rates are desired, the pulse repetition frequency can be dropped accordingly, thus providing possibilities to low-rate devices to co-habit with high-rate devices.

By reducing the bandwidth covered by a UWB system implementing a single pulse architecture, its performance will naturally be degraded due to reduced multipath immunity. However, its raw data rate is independent of this and will remain constant because the modulation does not determine the amount of bandwidth utilized. Single pulse systems perform with satisfactory performance under severe multipath conditions as long as the bandwidth is not too restricted.

Although it is best to conserve as wide a transmit bandwidth as possible, implementations using one or two sub-bands are also possible within the 3,1 GHz to 10,6 GHz frequency band. Energy may be emitted in specific non-overlapping sub-band simultaneously or using only one of the defined sub-bands.

Single pulse UWB radio design can be implemented at very low cost and with low power consumption.

B.1.2.2 UWB Multi-band OFDM pseudo-carrier approach

"Multi-band OFDM pseudo-carrier" modulation is another approach to UWB proposed in the IEEE. Multi-band pseudo-carrier UWB modulation is a method where the 7,5 GHz of permitted spectrum is split into multiple smaller frequency bands. The number of bands varies in the various proposals, with emission bandwidth usually in the 500 MHz to 800 MHz range.

Impulse shape is the primary characteristic that determines the distribution of energy within the frequency domain. Properly shaping the impulse will concentrate more of the energy in the centre of the frequency band and reduce out-of-band energy.

To effectively fill the specified spectrum, multiple frequency bands of energy must be generated with different centre frequencies spaced across the spectrum. A method for shaping an impulse that enables centre frequency definition is shown in figure B.1.2.2/1. The centre frequency selection is accomplished using a pseudo-carrier oscillation in generating and shaping the required UWB impulse. The frequency of the pseudo-carrier oscillation determines the centre frequency of the band, while the impulse shape defines the bandwidth.

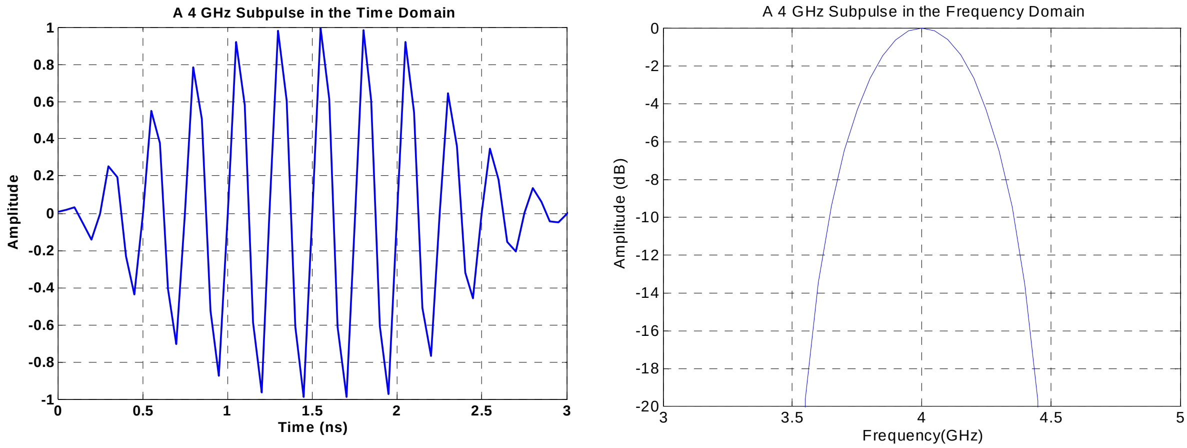

Figure B.1.2.2/1: Amplitude and frequency spectrum characteristics for a pseudo carrier oscillation

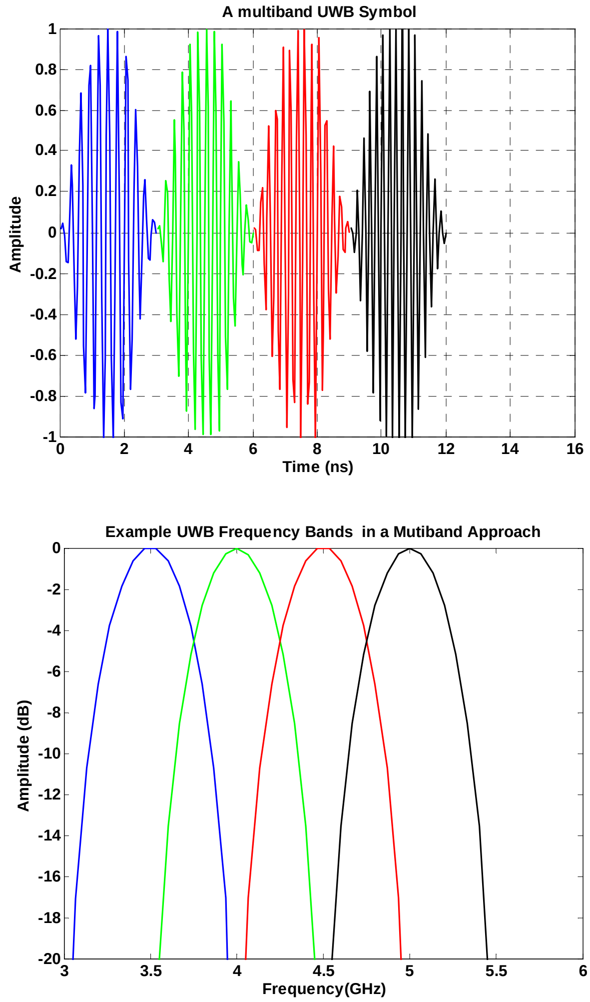

Figure B.1.2.2/2: Amplitude and Frequency spectrum characteristics for a multi-band symbol

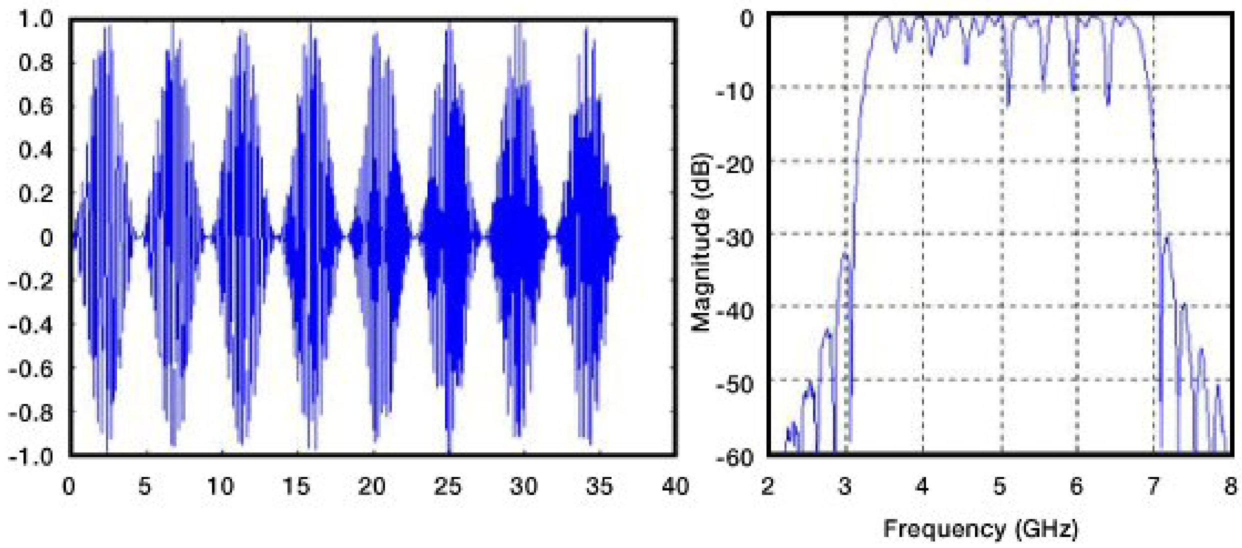

Figure B.1.2.2/3: Amplitude and frequency spectrum characteristics for an overall multi-band implementation

A feature of this method is that separate bands stacked across the available spectrum may be treated independently, allowing a level of flexibility that may be exploited for different purposes.

The multi-band approach could provide performance scalability from very low-speed devices (that might use only one or two bands, keeping implementation costs down) to very high-speed devices (requiring the entire bandwidth of available spectrum).

B.1.2.3 Typical utilization characteristics

The activity factor averaged over a large user base during a typical busy hour has been calculated taking into account the various utilization scenarios for UWB [3]. Similar studies for the activity factor for WLAN [4] systems provide comparable conclusions. Considering usage models and activity factors for the home and office, results show that the average UWB device "on-air" time will be typically less than 5 %.

Detailed information on usage patterns, unit densities, and estimated activity factors, which are suitable for co-existence investigations are given in clause C.4.

B.1.3 UWB receiver characteristics

Since, as the name implies, UWB technology inherently employs wide acceptance band receiver front ends, it is a necessary design objective to cope with potential interference within the capture range. Robustness to interference is not achieved by adjacent channel rejection but by other means specific to UWB technology. The technology is still advancing and various strategies may emerge.

For example, one UWB receiver implementation exploits multipath in indoor environment as a result of coherent interaction of signals arriving from many paths with differential delays. In fact, the multiple delayed replicants can be integrated or Rake-received to provide gain over a single direct path in the multipath environment.

In another example, where it is a requirement for the devices to co-exist in close proximity to other narrow band emitters (e.g. 5 GHz WLAN) there may be a need to employ narrow band filters in the UWB receiver to protect against receiver overload. Such means or requirements are however determined per use-case and are not necessarily universal requirements demanding any specific attention in spectrum regulations or a Harmonized Standard.

B.2 Limits for RF parameters

B.2.1 In-band

ETSI is not in position to propose a consensus on limits within the band 3,1 GHz to 10,6 GHz. The values given in Table B.2 are supported by the UWB industry within ETSI as the starting point for studies by CEPT. Several ETSI members or Technical Bodies have expressed concerns (see clause 4.1) with the proposed values. Therefore this will require attention by CEPT. ETSI is asking CEPT to perform the relevant studies and to propose more adequate levels, if necessary, that will be able to offer full protection of all other radio services in the band.

Table B.2: UWB industry proposal for UWB transmitter parameters

Parameter	Limit
Frequency range for intended emissions	3,1 GHz to 10,6 GHz
Radiated Power density	-41,3 dBm/MHz
Peak power (EIRP) in 50 MHz bandwidth	0 dBm/50 MHz

NOTE: A limitation on the Pulse Repetition Frequency (PRF) values of UWB devices is governed by the peak power limit.

One ETSI member (see also clause 4.1.7) has provided a simple link budget for justification of the required in-band level. The spread sheet can be found attached to the present standard.

B.2.2 values outside the band 3,1 GHz to 10,6 GHz

ETSI understands that there is currently no clear definition of out-of-band emissions and spurious emissions for UWB. The present document is not dealing with just one modulation specification therefore details concerning OOB are not easy to be dealt with.

ETSI is not in a position to propose any specific value for emissions outside the band. It is within the scope of CEPT to study what those limits should be from the point of view of co-existence. Different shapes of masks have been proposed: stair-case mask, slope masks, etc.

Due to possible interference from UWB to other services (GPS, Galileo, Mobile, RLANs, ...) the discussion is ongoing on adequate limits for UWB in Europe.

B.2.3 other considerations

A view also expressed is that:

- strictly speaking, this is not a "transmitter mask" since it represents general emission level PSD limits that are requested for UWB devices to operate under, rather than a specification corresponding to a particular modulation scheme. There are several modulation methods that could operate within the above overall limits that have been proposed and investigated for example for UWB communications systems.
- The important parameter, for UWB to be able to achieve the desired performance, is the PSD in the 3,1 GHz to 10,6 GHz range.
- Another consideration here is that very low levels of OOB will not be easy to measure since the wanted PSD is already below the general limit for unwanted emissions from conventional modulations, or the general limit from unintentional radiators.

Annex C: Expected compatibility issues

C.1 Coexistence studies required

C.1.1 Current allocations in the frequency band from 3,1 GHz to 10,6 GHz

The following radio services are allocated in the frequency band proposed for UWB communications devices, and hence are areas that have been identified for study by CEPT:

- Aeronautical Radio navigation Service.
- Amateur Service.
- Amateur Satellite Service.
- Earth Exploration Satellite Service (active).
- Fixed Service (including Fixed Wireless Access and HiperMAN).
- Fixed Satellite Service.
- Land Mobile Service (including 5GHz Radio LAN).

NOTE: WRC'07 is expected to identify spectrum for the future development of IMT-2000 and systems beyond IMT-2000 which may be operated in the frequency range above 3,1 GHz

- Mobile Satellite Service.
- Radio Astronomy.
- Radio Determination Service0
- Radio Navigation Service.

A preliminary draft new Recommendation ITU-R SM.[UWB.COMP] - Compatibility between devices using UWB technology with radiocommunications services is being prepared by TG 1 - 8 available in [2].

Valuable Information about results from preliminary sharing studies can be found in the report from the 1st meeting of ITU-R SG1 TG 1-8, Geneva 21 - 24 January 2003 (Document 1-8/047) [2].

C.1.2 Implication on radio services outside the proposed frequency band for UWB communication devices

An UWB transmitter can be characterized by the pulse repetition frequency, radiated power density (per 1 MHz) and peak power in a 50 MHz bandwidth. In actual practice, a specific UWB transmitter will be subject to the average limit or to the peak limit but not both. Systems with low PRFs will be governed by the peak limits and systems with high PRFs will be governed by the average limits.

Since the main deployment of UWB devices will be indoors, this bears inherently conflict potential with mobile communication applications like cellular networks and WLANs due to the close vicinity of mobile terminals to UWB devices. A UWB radio interface could even be integrated in a mobile terminals. This has to be taken into account when specifying the unwanted emission limits for UWB communication applications.

In addition, effects of interference from narrow pulses into digital communications systems have not been thoroughly studied. In particular, CDMA cellular systems do rely on fast power control for their operation. This is usually signalled over the radio interface by using a few data bits which are not interleaved because of the need for a fast response time.

For this reason, the effect on digital mobile communication systems needs to be studied in detail before any peak emission limits for UWB applications are concluded on.

In addition, concerns have also been raised on GPS (and in future Galileo) receivers that could result from specific PRF values (and fluctuations).

C.2 Current ITU-R allocations

There is no current ITU-R allocation corresponding to UWB communication devices. The present document assumes operation according to a provision of the Radio Regulations, that does not require any new allocation (see clause 7).

C.3 Sharing issues

Sharing is required with all radio services allocated within the frequency range of 3,1 GHz to 10,6 GHz.

C.4 Usage scenarios

Typically expected usage scenarios for UWB Communication devices are described in this clause. The proposed user density, geographic distribution and traffic parameters can be used for co-existence studies.

C.4.1 Introduction

UWB Communications devices are foreseen to be used essentially in small portable or handheld equipment. The majority are expected to be personal devices, which are frequently in different positions/locations, and operated only intermittently, with activity factors (i.e. actual on-the-air time divided by active session time) that vary according to the application. In order to simplify the analysis of the impact on other services, three model scenarios that are considered to be representative - Home, Office, Public Kiosk - are proposed. The parameters for each of these models are population density and geographic distribution with respect to a victim receiver and the traffic generated on the UWB radio transmitter by typical applications and use patterns. These are discussed in the clauses below and finally parameters for the representative models are derived.

C.4.2 Single interferer and aggregate interference

Two extreme situations can occur when assessing interference to a victim receiver: either the signal from a single nearby device dominates, or the aggregation from many devices a considerable distance away only has to be considered (there is no one device near enough to dominate). Other situations can also be envisaged such as interference from two devices nearby the victim receiver.

It is important to consider for aggregation all the relevant parameters, total device numbers in interfering range, distribution in time of the emissions of each device (determined by medium access and traffic characteristics), propagation characteristics and geographic distributions.

Below is more detailed information in regards to activity time sharing within a piconet of UWB devices, or between different piconets. These are the current channel access method approaches planned for UWB applications at IEEE.

A) WITHIN A PICONET OF UWB DEVICES.

Within a single piconet, devices will time share the channel.

B) FOR DIFFERENT PICONETS OF UWB DEVICES.

Another piconet could show up in close proximity of a piconet, and use a different "code" (either a direct sequence code or time-frequency interleaving code). These codes are limited to how close the devices can operate without causing significant interference.

EXAMPLE: A piconet trying to operate at 10 meters will, at best, only be able to handle interference from another uncoordinated piconet operating 5 m away. For different piconets it's possible to have different piconets operate at the same time, but not when they are really close to each other. In this case, reasonable separation distance between piconets is needed before simultaneous usage of the frequency band can take place. This will also impact the total aggregate power.

If different piconets operate in close proximity such that the code separation is not strong enough, then they must coordinate. This could mean time-sharing the channel or splitting up the frequency bands over which they operate.

C.4.3 Traffic types

Example types of use and traffic are summarized in table C.4.3/1, where the typical data rates, activity factors and length of sessions are given as guidelines. The activity factor is the actual on-the-air emission time within a given time window. It is a statistical parameter that is averaged in C.4.3/1 assuming a data rate of 110 Mbps and an estimated MAC throughput efficiency of 70 %. The latter parameters also vary statistically in reality and also developing standards may support multiple rates but table C.4.3/1 represents the best estimate of the overall average available currently that should provide an illustration of the statistics of potential interference to other devices within range. Session duration is described as the length of time a device would be in use for the given application. For example, image transfer would occur at the peak available PHY rate and might last 1 s to 60 s depending on the file(s) size.

Table C4.3/2 is a more complete description of the applications represented in table C.4.3/1.

Table C.4.3/1: PHY Layer utilization in time

Application	Ave. Data Rate	Peak Data Rate	QoS	PHY Activity Factor (see note)	Session duration
Digital Video Distribution					
SDTV , DVD, MPEG-2	6 Mbps	10 Mbps	yes	8 %	1,5 h
Dig Camcorder		60 Mbps	yes	78 %	30 min
HDTV	20 Mbps	25 Mbps	yes	25 %	1 h to 3 h
Digital Image Transfer, HD connection		77 Mbps	no	100 %	1 s to 60 s
High Quality Audio	1,5 Mbps	2 Mbps	yes	2 %	1 h
Data Network (Printer, Internet)	0,5 Mbps	10 Mbps	no	1 %	1 h
PC Graphics Distribution	4 Mbps	100 Mbps	yes	5 %	1 h
Video Conferencing	1 Mbps	1,5 Mbps	yes	1 %	30 min
NOTE: Estimated average fraction of time the PHY emits assuming 110Mbps rate and that max throughput = 0,7 × (bit rate).					

Table C.4.3/2: Applications

Digital Video Distribution
External sources: coming into the home via a set-top-box (HDTV or SDTV MPEG2 or MPEG4 format) Internal sources: from sources like DVD players, digital camcorders Expected throughput: 3 - 200+ Mbps (6 Mbps required for high action video such as sports, up to 10Mbps for DVD players, up to 60Mbps for digital camcorders, approximately 20 Mbps for HDTV) with support for multiple streams. QoS required.
Digital Image Distribution
Download/upload from digital still camera Expected throughput: 100 Mbps or greater for multi-megapixel cameras. QoS not required.
High Quality Audio
Surround sound systems (AC3 at a minimum) Hi-Fi, Dolby, etc. (CD quality) Expected throughput: 1,5 Mbps QoS required.
High Speed Data
External sources: xDSL, Cable Internal sources: peripheral sharing (e.g. hard disk drive, high speed printers, scanners) Expected throughput: 1 Mbps to 200 Mbps QoS may be required.
PC Graphics Distribution
Using TV or webpad as a PC terminal Game consoles receiving graphics from a central PC (I/O latency is a critical factor that must be met here. Expected throughput: 2 Mbps to 5 Mbps with compression, > 100 Mbps without compression
Video and high quality Voice Communication
Video conferencing (room to room to hand-held device) Expected throughput: 1 Mbps to 2 Mbps per session (Requires symmetric bandwidth and a maximum 30 ms latency)

C.4.4 Device density and geographic distribution

UWB Communications devices are foreseen to be used mainly in the circumstances described in the preceding clauses, and are essentially in small portable or handheld equipment. The majority will be personal devices, operated in different positions/locations frequently, and intermittently, with the activity factors that vary according to application as above. In order to simplify the analysis the model scenarios that are considered representative - Home, Office, Public Kiosk - are proposed. The population density and geographic distribution parameters for the model scenarios are discussed in this clause.

C.4.4.1 Home (residential) population

For single interferer interference, the active UWB devices in one room will dominate. Hence the important parameter for this case is the distance to the victim receiver located in the same room, and a minimum distance is chosen that will have high probability of being LOS propagation in a home environment.

For aggregate interference estimates, the population in a residential zone of defined size has to be defined. The population density in towns and countries varies considerably. Monaco has one of the world's highest population densities of 16,670 people/km2. Basle in Switzerland may be more typical with 5,100 /km². A value 10,000 /km2 may be a high-side average to take, giving a mean density over the area of a town equal to 0,01 /m². However the population is actually not spread uniformly, but within buildings most of the time. A ten-storey apartment building could contain 3 apartments per floor and consist of 6 similar apartment buildings side by side. Average household size is not more that 3 people. Such a building would have:

- 3 apt/storey × 10 storeys/apt. building × 6 apt. building × 3 residents/apt = 540 residents.

With an average apartment size of 100m2 the density within the building is 3/100 per m² i.e. 0,03 /m² of building floor area but 0,3 /m² of ground area. Hence the geographical distributions have a granularity that depends on the point of observation and typical numbers are summarized in table C4.4.1.

Table C.4.4.1: Residential population parameters

Granularity Level	Area	Population	Population density	Population density
Major City	1000 km²	10 M	10,000 pop/km²	0,01 pop/m²
Large Town	50 km²	0,5 M	10,000 pop/km²	0,01 pop/m²
Dense Residential zone	1 km²	10,000 M	10,000 pop/km²	0,01 pop/m²
Apartment building per block	300 m²	90 M	300,000 pop/km²	0,3 pop/m²
Single Apartment floor	100 m²	3 M	30,000 pop/km²	0,03 pop/m²

C.4.4.2 Office population

In order to simplify the calculations, the following model has been used.

The office population of a town consists of residents who are in the office for the working day, meaning that office and home activity are not simultaneous. Also the geographic distribution is still within the town or city but in different buildings. Therefore considering table 3, the first two lines remain the same in the case of offices but any UWB device activity at this level of granularity will not change: office and home use are not additive since users are not in two places at once! From the point of view of a building, the density of workers in an office space may be somewhat higher than for a typical apartment. An office of 100 m² may accommodate 6 workers, double the residential density. On the other hand, office properties cover normally less of the urban area that residences cover. Table C.4.4.2 is the suggested list of parameters for the office scenario.

Table C.4.4.2: Office population parameters

Granularity Level	Area	Population	Population density	Population density
Major City	1000 km²	10 M	10,000 pop/km²	0,01 pop/m²
Large Town	50 km²	0,5 M	10,000 pop/km²	0, 01 pop/m²
Dense office urban zone	0,33 km²	10,000 M	30,000 pop/km²	0,03 pop/m²
Office building per block	300 m²	180 M	600,000 pop/km²	0,6 pop/m²
Single office floor	300 m²	18 M	60,000 pop/km²	0,06 pop/m²

C.4.4.3 Public space population

The public spaces where UWB usage and interference potential are expected to be greatest are where people are shopping or waiting for transport etc. Examples are shopping malls, airport halls and lounges, hotel foyers. Such spaces are less frequent than homes or offices but the population densities in these areas can fluctuate and increase significantly for short periods, such as in a waiting lounge just before departure. For interference calculations they may be treated as totally singular and isolated, containing a specific maximum number of people. There are no typical data available on the numbers of people temporarily localized and capable of using a UWB device, so the proposal is to use a round number of 100 people, considered to be within a zone of about 300 m² in a lounge, hall or mall public area where congregation can be observed.

Table C.4.4.3: Public space population parameters

Granularity Level	Area	Population	Population density
Public floor gathering zone	300 m²	100 M	0,3 pop/m²

C.5 Possible interference scenarios and parameters

Interference from one device to a victim receiver is a fairly trivial calculation, but valid for certain scenarios such as the case of an UWB device operating within the same room as another handheld/portable device such as a PDA. For the case where aggregate interference needs to be estimated the correct tool to use is a statistical Monte-Carlo method. Ideally the individual interferer parameters such as path loss, activity factor, are assigned and summed according to the population density and market penetration. This requires fairly intensive compute time and a suitable program. If the aggregate interference emanates from a defined geographic zone it may be sufficiently accurate to treat that zone as a cluster and apply simple statistical factors to estimate the average aggregate interference to a victim located some distance away. This method might be expected to give good average figures. Estimating the dispersion that results from the combined dispersion of all the parameters used however may be difficult without further study of these parameters in real situations.

The following simplified scenarios for co-existence studies in relation to victim receivers may give useful estimates for comparison:

C.5.1 Home A/V cluster co-existence scenario

Table C.4.5.1

Description	Ave data rate	Activity factor over 1 h	Penetration	Aggregation factor
Streaming HDTV video with audio and web	~ 30 Mbps	40 %	15 %	0,06 × Pop ÷ 3

When aggregation needed, Pop = total population divided by 3 in interfering zone from table 3. Division by 3 is needed since this scenario assumes one cluster per household of Table C.4.5.1.

C.5.2 Office co-existence scenario

Table C.4.5.2

Description	Ave data rate	Activity factor over 1 h	Penetration	Aggregation factor
Streaming video presentation to projector, video conference	~ 20 Mbps	5 %	15 %	0,0075 × Pop

When aggregation needed, Pop = total population in interfering zone from table C.4.5.2.

C.5.3 Public kiosk co-existence scenario

Table C.4.5.3

Description	Ave data rate	Activity factor over 1 h	Penetration (%)	Aggregation factor
Kiosk file upload	~ 80 Mbps	100 × 1/60 %	10 %	0,16 × Pop

When aggregation needed, Pop = total population in interfering zone from table C.4.5.3.

C.5.4 IEEE 802.19 co-existence scenarios

The following scenarios have been envisaged by IEEE 802.19 [6] in order to study single interferer co-existence issues for UWB PHY layer devices. They represent current industry thinking on the typical uses and scenarios for the various types of equipment that will be in widespread use.

Home usage

1. A UWB digital video camera streams video to a multimedia hub in the home that also forwards the stream to an HDTV monitor, while the same multimedia hub is streaming MP3 audio to a remote audio terminal.

Devices: DVC, A/V hub (WLAN/WPAN bridge), HDTV monitor, MP3 player.

Distances: Video: 1 m to 5 m, Audio: 5 m to 50 m.

2. The multimedia hub in a home is located 1 meter away from a cellphone or WLAN base station. The user may be talking on the phone or the hub is supporting web browsing or email while uploading video or still images.

Devices: DSC, DVC, cordless phone.

Distances: approx 1 m.

Enterprise usage

0. A UWB video projector is used in a conference room to allow attendees to stream their presentations from their laptops, but all attendees want to use the corporate network simultaneously using 802.11b/g/a/n.

Devices: Dual mode laptop, video projector.

Distances: 1 m to 5 m.

Kiosk/hot spot usage.

1. A laptop computer equipped with 802.11b/g/a/n uploads photos to a kiosk while a DSC with an UWB device also uploads photos to the same kiosk.

Devices: laptop w/WLAN, DSC, dual mode AP (WLAN/WPAN), possibly WLAN or WPAN printer.

Distances: 0,5 m to 3 m.

2. In an airport hot spot, several users upload their DSC/DVCs to their laptop computers, then forward these images via WLAN to a central server for storage.

Devices: DSC/DVC, dual mode laptop, WLAN AP.

Distances: 1 m to 25 m.

Mobile usage

1. Mobile phone incorporating UWB technology and GPS.

Devices: Mobile phone with E911 capability.

Traffic: GSM/GPRS/EDGE, WCDMA, or CDMA/CDMA2000 and GPS.

Distances: < 10 cm.

2. Mobile phone with either DSC or DVC capability that uploads video or still images to kiosk or A/V hub while maintaining 3G connection.

Devices: Mobile phone with digital camera (video or still).

Distances: < 10 cm.

Annex D: Bibliography

- James M. Wilson: "Ultra Wideband Technology Update at Spring 2003 IDF', Intel Developer Update Magazine"
- ITU-Radio Regulations Article RR No. 4.4
- ITU-R Recommendation SM.[UWB.COMP]

History

Document history		
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