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Release 2

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Intelligent Transport Systems (ITS).

Modal verbs terminology

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Introduction

Based on the new spectrum regulation framework (ECC Decision (06)04 [i.1]) in Europe the use of UWB technologies in the band 6 GHz to 8,5 GHz ITS has been simplified and the potential applications have been extended. Further extensions of the available spectrum are under investigation in CEPT [i.4]. Material sensing application using UWB which are deployable in vehicular environments are permitted under the ECC Decision (07)01 [i.2].

ECC Decision (06)04 [i.1] may be reviewed (as per its considering mm)) based on the outcome of the World Radio Conferences and/or on the actual UWB deployment, in particular if the deployment of UWB technology can present a significant risk of interference to radio services deployed in the band 6 GHz to 8,5 GHz. It is important to ensure that future ITS applications based on the present document match the assumptions used in ECC Report 327 [i.5] used to develop such ECC decision (e.g. densities of UWB devices, activity factors, etc.) and avoid risk of interference to other services.

The present document analyses the required extension of the ETSI ITS protocol and architecture for inclusion of UWB technologies into the overall C-ITS system.

For these analyses the present document uses example use cases such as:

- VRU detection and clustering
- Tolling based on secure ranging
- Precise cooperative positioning
- Highly automated parking applications

In the present document, some of the use cases are descripted and a potential way to integrate UWB technology in support of these uses cases into the ITS standards framework is considered.

1 Scope

The present document studies the feasibility of using Ultra Wide Band (UWB) technology in ITS.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative 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 referenced document (including any amendments) applies.

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

The following referenced documents may be useful in implementing an ETSI deliverable or add to the reader's understanding, but are not required for conformance to the present document.

[i.1] CEPT ECC/DEC/(06)04: "The harmonised use, exemption from individual licensing and free circulation of devices using Ultra-Wideband (UWB) technology in bands below 10.6 GHz", 24 March 2006 amended 18 November 2022.

[i.2] ECC/DEC/(07)01: "The harmonised use, exemption from individual licensing and free circulation of Material Sensing Devices using Ultra-Wideband (UWB) technology", 30 March 2007.

[i.3] Commission Implementing Decision (EU) 2024/1467 of 27 May 2024 amending Implementing Decision (EU) 2019/785 on the harmonisation of radio spectrum for equipment using ultra-wideband technology in the Union.

[i.4] ETSI TR 103 750 (V1.1.1): "System Reference document (SRdoc); Short Range Devices (SRD) using Ultra Wide Band (UWB); Technical characteristics for UWB operation in the frequency band between 8,5 GHz to 10,6 GHz".

[i.5] ECC Report 327: "Technical studies for the update of the Ultra Wide Band (UWB) regulatory framework in the band 6.0 GHz to 8.5 GHz", 1 October 2021.

[i.6] IEEE Std 802.15.4a™-2015:"IEEE Standard for Low-Rate Wireless".

[i.7] IEEE Std 802.15.4z™-2020: "IEEE Standard for Low-Rate Wireless Networks--Amendment 1: Enhanced Ultra-Wideband (UWB) Physical Layers (PHYs) and Associated Ranging Techniques".

[i.8] ETSI TR 103 579 (V1.1.1): Intelligent Transport Systems (ITS); Pre-Standardization Study on payment applications in Cooperative ITS using V2I communication.

[i.9] ERC Report 25: "The European table of frequency allocations and applications in the frequency range 8.3 kHz to 3000 GHz (ECA table)".

[i.10] ECC CEPT SE24_79: "UWB extension".

[i.11] European Commission: "Road safety statistics 2022 in more detail".

[i.12] Bettina Erdem, regulatory affairs V2X: "Importance of Collective Perception, V2X spectrum needs, expectation on Euro NCAP".

[i.13] Microwaves&RF®: "Revolutionizing Vehicle Safety: The Role of UWB in Modern Automobiles", Qorvo, 2024.

[i.14] ETSI TS 103 300-2 (V2.2.1): "Intelligent Transport Systems (ITS); Vulnerable Road Users (VRU) awareness; Part 2: Functional Architecture and Requirements definition; Release 2".

[i.15] ETSI EN 302 065-1 (V2.1.1): "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU; Part 1: Requirements for Generic UWB applications".

[i.16] ETSI EN 302 065-2 (V2.1.1): "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU; Part 2: Requirements for UWB location tracking".

[i.17] ETSI EN 302 065-3 (V2.1.1): "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU; Part 3: Requirements for UWB devices for ground based vehicular applications".

[i.18] ETSI EN 302 065-4 (V1.1.1): "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU; Part 4: Material Sensing devices using UWB technology below 10,6 GHz".

[i.19] ETSI EN 302 065-4-4 (V1.1.1): "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised Standard for access to radio spectrum; Part 4: Material Sensing devices; Sub-part 4: Exterior material sensing applications for ground based vehicles".

[i.20] ETSI EN 302 065-4-1 (V2.2.1):"Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised Standard for access to radio spectrum; Part 4: Material Sensing devices; Sub-part 1: Building material analysis operating within 30 MHz to 10,6 GHz".

[i.21] ETSI EN 302 065-5 (V1.1.1): "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU; Part 5: Devices using UWB technology onboard aircraft".

[i.22] ETSI EN 302 065-3-1 (V3.2.1): "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised Standard for access to radio spectrum; Part 3: UWB devices installed in motor and railway vehicles; Sub-part 1: Requirements for UWB devices for vehicular access systems within 3,8 GHz to 4,2 GHz or 6 GHz to 8,5 GHz".

[i.23] ETSI EN 303 883-1 (V2.1.1): "Short Range Devices (SRD) and Ultra Wide Band (UWB); Part 1: Measurement techniques for transmitter requirements".

[i.24] ETSI EN 303 883-2 (V2.1.1): "Short Range Devices (SRD) and Ultra Wide Band (UWB); Part 2: Measurement techniques for receiver requirements".

[i.25] Pirch H.-J., Leong F.: "Introduction to Impulse Radio UWB Seamless Access Systems".

[i.26] Inpixon: "Ultra-Wideband RTLS, Positioning, & Sensor Technology".

[i.27] Leoni Elia, et al.: "Validating Vehicular Localization Indoor using UWB: Challenges and Solutions". 2023 9th International Workshop on Advances in Sensors and Interfaces (IWASI). IEEE™, 2023, pp. 27-32.

[i.28] San Martín J., et al.: "Precise positioning of autonomous vehicles combining UWB ranging estimations with on-board sensors". Electronics, 2020, 9(8), 1238.

[i.29] u-blox: "Exploring hybrid positioning solutions to enable future autonomous vehicles".

[i.30] Piavanini Marco, et al.: "Experimental Validation of Vehicle Positioning with Ultra-Wide Band Roadside Infrastructure." 2023 IEEE™ International Workshop on Metrology for Industry 4.0 & IoT (MetroInd4. 0&IoT). IEEE™, 2023, pp. 171-176.

[i.31] FiRa Consortium: "The Present and Future of UWB".

[i.32] European commission: "General Safety Regulation protecting vehicle occupants and vulnerable road users".

[i.33] ETSI TS 103 900 (V2.1.1): "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Cooperative Awareness Service; Release 2".

[i.34] ETSI TR 103 300-1 (V2.3.1): "Intelligent Transport Systems (ITS); Vulnerable Road Users (VRU) awareness; Part 1: Use Cases definition; Release 2".

[i.35] ETSI TS 103 300-2 (V2.3.1): "Intelligent Transport Systems (ITS); Vulnerable Road Users (VRU) awareness; Part 2: Functional Architecture and Requirements definition; Release 2".

[i.36] ETSI TS 103 300-3 (V2.2.1): "Intelligent Transport Systems (ITS); Vulnerable Road Users (VRU) awareness; Part 3: Specification of VRU awareness basic service; Release 2".

[i.37] Genovese A.: "Awareness Messages for Vulnerable Road Users", Politecnico di Torino, December 2023.

[i.38] Xhoxhi E., Schiegg F.A.: "A First Study on the Spectrum Needs for Release 2 V2X Services", IEEE™ VTC-23 Fall.

[i.39] CAR 2 CAR Communication Consortium: "Survey on ITS-G5 CAM statistics CAR 2 CAR Communication Consortium".

[i.40] Renzel T., Stolz M., Watzenig D.: "Looking into the Path Future: Extending CAMs for Cooperative Event Handling", IEEE 92nd Vehiculare Technology Conference, 11/2020.

[i.41] Yonhap News: "'Next-Generation Intelligent Transportation System' Introduced in Sejong City to Ensure Safety on School Commutes".

[i.42] ETSI TR 103 667 (V1.1.1): "Intelligent Transport Systems (ITS); Study on Spectrum Sharing between ITS-G5 and LTE-V2X technologies in the 5 855 MHz-5 925 MHz band".

[i.43] Lisa Ward, Jörg Köpp: "Exploring the Future of UWB Comprehensive insights into IEEE 802.15.4ab", R&S White Paper, 2025.

[i.44] IEEE P802.15.4ab™/D03: "IEEE Draft Standard for Low-Rate Wireless Network Amendment 1: Enhanced Ultra Wide-Band (UWB) Physical Layers (PHYs) and Associated Medium Access and Control (MAC) sublayer Enhancements", September 2025.

[i.45] ETSI TR 103 902 (V2.1.1): "Intelligent Transport Systems (ITS); ITS Framework; Terms, Symbols and Abbreviations; Release 2".

[i.46] draft ETSI EN 302 065-1-1: "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised Standard for access to radio spectrum; Part 1: Generic UWB devices; Sub-part 1: Communication devices within 3,1 GHz to 4,8 GHz using LDC mitigation or within the 6 to 8,5 GHz".

NOTE: Under development at the time of publication of the present document.

[i.47] draft ETSI EN 302 065-2-1: "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 2: Ultra Wide Band location tracking devices; Sub-part 1: Requirements for devices within 6 GHz to 8,5 GHz".

NOTE: Under development at the time of publication of the present document.

[i.48] draft ETSI EN 302 065-2-2: "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 2: Ultra Wide Band location tracking devices; Sub-part 2: Requirements for devices in the frequency band between 3,1 GHz to 4,8 GHz utilizing LDC mitigation technique".

NOTE: Under development at the time of publication of the present document.

[i.49] draft ETSI EN 302 065-2-3: "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 2: Ultra Wide Band location tracking devices; Sub-part 3: Requirements for fixed infrastructure UWB based localization systems in the frequency band between 3,1 GHz to 4,8 GHz deploying Detect-And-Avoid (DAA) mitigation technique".

NOTE: Under development at the time of publication of the present document.

[i.50] draft ETSI EN 302 065-2-4: "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 2: Ultra Wide Band location tracking devices; Sub-part 4: Requirements for fixed outdoor devices within 6,0 GHz to 8,5GHz".

NOTE: Under development at the time of publication of the present document.

[i.51] ETSI EN 302 065-2-5: "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 2: Ultra Wide Band location tracking devices; Sub-part 5: Requirements for enhanced indoor devices within 6,0 GHz to 8,5 GHz".

[i.52] draft ETSI EN 302 065-3-2: "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 3: UWB devices installed in motor and railway vehicles; Sub-part 2: Requirements for location tracking devices installed in rail and road vehicles operating in the frequency range of 3,1 GHz to 4,8 GHz or 6,0 GHz to 8,5 GHz".

NOTE: Under development at the time of publication of the present document.

[i.53] ETSI EN 302 065-3-3: "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 3: UWB devices installed in motor and railway vehicles; Sub-part 3: Requirements for UWB radiodetermination applications operating within 6,0 GHz to 8,5 GHz".

[i.54] draft ETSI EN 302 065-6-1: "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised Standard for access to radio spectrum; Part 6: Ultra Wide Band radio-determination for radar sensing devices; Sub-part 1: Requirements for presence detection applications within 6,0 GHz to 8,5 GHz".

NOTE: Under development at the time of publication of the present document.

[i.55] draft ETSI EN 302 065-6-2: "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 6:Ultra Wide Band radio-determination for radar sensing devices; Sub-part 2: Requirements for generic UWB through-air non-contact vital signs applications within 6,0 GHz to 8,5 GHz".

NOTE: Under development at the time of publication of the present document.

[i.56] draft ETSI EN 302 065-6-3: "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 6: Ultra Wide Band radio-determination for radar sensing devices; Sub-Part 3: Requirements for fixed outdoor presence detection devices within 6,0 GHz to 8,5 GHz".

NOTE: Under development at the time of publication of the present document.

[i.57] draft ETSI EN 302 065-6-4: "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 6: Ultra Wide Band radio-determination for radar sensing devices; Sub-Part 4: Requirements for fixed outdoor through-air non-contact vital signs applications within 6,0 GHz to 8,5 GHz".

NOTE: Under development at the time of publication of the present document.

[i.58] draft ETSI EN 302 065-6-5: "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 6: Ultra Wide Band radio-determination for radar sensing devices; Sub-Part 5: Requirements for enhanced indoor presence detection devices within 6,0 GHz to 8,5 GHz".

NOTE: Under development at the time of publication of the present document.

[i.59] draft ETSI EN 302 065-6-6: "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 6: Ultra Wide Band radio-determination for radar sensing devices; Sub-Part 6: Requirements for enhanced indoor through-air non-contact vital signs applications within 6,0 GHz to 8,5 GHz".

NOTE: Under development at the time of publication of the present document.

[i.60] FiRa Consortium: "Annual Report 2025".

[i.61] Car Connectivity Consortium: "Digital Key V3.1.4 & V4.1.0".

[i.62] IEEE Std 802.11™-2024: "IEEE Standard for Information Technology--Telecommunications and Information Exchange between Systems Local and Metropolitan Area Networks--Specific Requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications".

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the terms given in ETSI TR 103 902 [i.45] apply.

3.2 Symbols

Void.

3.3 Abbreviations

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

AoA	Angle of Arrival
BPM	Burst Position Modulation
BPSK	Binary Phase-Shift Keying
CPD	Child Presence Detection
DS-TWR	Double-Sided Two-Way Ranging
ETC	Electronic Toll Collection
FEC	Forward Error Correction
HRP	High-Rate Pulse
ICRW	Intersection Collision Risk Warning
LRP	Low-Rate Pulse
PDoA	Phase Difference of Arrival
PRF	Pulse Repetition Frequency
RHS	Road Hazard Signalling
RTLS	Real-Time Location Systems
SFD	Start-of-Frame Delimiter
SHR	Synchronization Header
STS	Scrambled Timestamp Sequence
TDoA	Time Difference of Arrival
ToF	Time of Flight
TWR	Two-Way Ranging
UWB	Ultra-Wide Band

4 Ultra-Wide band technologies

4.1 Overview

With the arrival of UWB in mainstream consumer products, standardized solutions for UWB products are becoming more important and prevalent. While the previous IEEE 802.15.4 [i.6] standard was only used by a number of manufacturers, its successor IEEE 802.15.4z [i.7] has been adopted by car manufacturers and mobile phone makers. Two industry consortia, Car Connectivity Consortium and FiRa Consortium, are building standardized solutions on top of this latest IEEE standard. This interest has led to a major increase of chip manufacturers providing standard compliant silicon. The availability of cheaper chipsets for consumer applications means that also other applications areas such as industrial location tracking are switching to standard compliant transmissions. Several applications of UWB in the automotive domain are under deployment and additional applications will follow soon.

By integrating these applications and used devices into the intelligent transport systems architecture can lead to significant synergies, providing complementary applications to the 5,9 GHz band ITS.

In this clause, a short introduction to the basic characteristics and standard of Ultra-Wide band technologies will be given.

4.2 Basic characteristics

In Europe, depending on the application, ultra-wide band devices are allowed to operate anywhere between 3,1 GHz to 4,8 GHz and 6,0 GHz to 9,0 GHz. Some UWB material sensing application can also operate in lower frequency ranges down to 30 MHz with very low emission levels of down to -85 dBm/MHz e.i.r.p. To qualify as ultra-wide band, the 10 dB bandwidth of the emissions needs to be higher than 50 MHz. In practice, to fit worldwide regulations and to fully exploit the advantages of ultra-wide band signals, most signals have a bandwidth of at least 500 MHz to maximise worldwide compliance, devices tend to operate in the spectrum between 6,0 and 8,5 GHz.

In CEPT work to extend the usable spectrum for UWB applications up to 10,6 GHz is ongoing with the goal to have an updated regulation including automotive applications until the beginning of 2027.

Given that these devices operate in spectrum assigned and licensed to many other applications, UWB operates on a non-protected, non-interfering basis. To prevent interference to other applications, the UWB transmit power is limited to a very low mean power spectral density of -41,3 dBm/MHz, equivalent to the limit for unintentional radiation of 500 microvolts/meter measured at 3 m that these applications would have to deal with anyway. To prevent very short, high powered energy pulses from causing interference, an additional 0 dBm peak power limit in 50 MHz was added. Recent European regulations allow 'enhanced indoor power' levels of -31,3 dBm/MHz mean EIRP, 10 dBm in 50 MHz peak EIRP for some UWB applications operating between 6,0 and 8,5 GHz. The details of how to determine the indoor conditions in line with the regulation for a specific ITS application is out of the scope of the present document.

The wide bandwidth available under the UWB regulations allows for very steep rising and falling edges in the time domain, typically combined to form very short RF pulses with durations in the order of 1 or 2 nanoseconds. In the frequency domain, multipath fades are averaged, so the received signal power tends to be very constant.

Many applications use these short pulses to obtain high resolution estimates of the channel impulse response. Sensing applications evaluate characteristics and changes in the channel impulse response to extract features of the environment in which the device is operating. Ranging applications aim to identify the time of arrival of the first path in the channel impulse response as a measure of the distance between two devices. In practice, they are able to do so with centimetre level precision. Location tracking systems built on this ranging capability to position devices in a network.

Communication applications benefit from the lack of multipath fading and exploit the fact that the multipath components can be resolved to ensure robust communication in highly reflective environments. The short symbol duration made possible by the high bandwidth also means that packets can be very short, resulting in low latency.

4.3 UWB regulation overview

4.3.1 Regulatory framework

The UWB regulatory framework in Europe can be mainly split into two categories:

- UWB Sensor application in ECC Decision (07)01 [i.2], covering the harmonised use, exemption from individual licensing and free circulation of Material Sensing Devices using Ultra-Wide Band (UWB) technology.
- General UWB in ECC Decision (06)04 [i.1], covering the harmonised use, exemption from individual licensing and free circulation of devices using Ultra-Wide Band (UWB) technology in bands below 10,6 GHz including location tracking, communication and radio determination (radar like applications).

On EU level these applications are harmonized in an Decision (EU) 2024/1467 [i.3]. UWB applications are always operating under a non-interference and non-protected rules thus the applications have to accept interference from other services and applications and are not allowed to create harmful interreference into services and applications in the operational band and in any adjacent bands.

4.3.2 Operating frequencies

4.3.2.1 IEEE channels

IEEE defines UWB channels as discrete frequency ranges of 499,2 MHz, 1 331,2 MHz or 1 354,97 MHz. Industry has mostly been focusing on 499,2 MHz channels. Table 1 provides description of these channels in the range 3 GHz to 10,6 GHz, reporting the regions where each channel can be used.

Table 1: IEEE UWB channels

UWB channel	Channel bandwidth (MHz)	Center Frequency (MHz)	Frequency range (MHz)	Regions
1	499,2	3 494,4	3 244,8 to 3 744,0	USA, Europe
2	499,2	3 993,6	3 744,0 to 4 243,2	USA, Europe, Japan, Korea
3	499,2	4 492,8	4 243,2 to 4 742,4	USA, Europe, Japan, Korea
4	1 331,2	3 993,6	3 328,0 to 4 659,2	USA, Europe
5	499,2	6 489,6	6 240,0 to 6 739,2	USA, Europe, China
6	499,2	6 988,8	6 739,2 to 7 238,4	USA, Europe, China
7	1 081,6	6 489,6	5 948,8 to 7 030,4	USA
8	499,2	7 488,0	7 238,4 to 7 737,6	USA, Europe, Korea, China
9	499,2	7 987,2	7 737,6 to 8 236,8	USA, Europe, Japan, Korea, China
10	499,2	8 486,4	8 236,8 to 8 736,0	USA, Europe, Japan, Korea, China
11	1 331,2	7 987,2	7 321,6 to 8 652,8	USA, Japan, Korea
12	499,2	8 985,6	8 736,0 to 9 235,2	USA, Japan, Korea
13	499,2	9 484,8	9 235,2 to 9 734,4	USA, Japan, Korea
14	499,2	9 984,0	9 734,4 to 10 233,6	USA, Japan, Korea
15	1 354,97	9 484,8	8 807,3 to 10 162,3	USA, Japan, Korea

4.3.2.2 Frequency bands available in Europe

ECC Decision (06)04 [i.1] covers frequencies up to 10,6 GHz and provides maximum mean and peak e.i.r.p. limits for different device types (e.g. general case, vehicular applications, etc.).

ECC Decision (06)04 [i.1] regulates under its section A1.2 the use of UWB in a number of bands up to 10,6 GHz for vehicular applications, including UWB devices installed in road and rail vehicle.

The frequency range 6 GHz to 8,5 GHz is considered by ITS industry as the frequency band for UWB applications in Europe, without the need to implement active mitigation techniques like "detect and avoid" or "listen-before-talk" to protect other services. However, this does not relief the ITS UWB applications operating in Europe from the obligation not to cause interference to other radio services.

ECC Decision (06)04 [i.1] may be reviewed (see considering mm in [i.1]) based on the outcome of the World Radio Conferences and/or on the actual UWB deployment, in particular if the deployment of UWB technology can present a significant risk of interference to radio services deployed in the band 6 GHz to 8,5 GHz.

It is important to ensure that future ITS applications based on the present document match the assumptions used in ECC Report 327 [i.5] used to develop such ECC decision (e.g. densities of UWB devices, activity factors, etc.) and avoid risk of interference to other services.

In contrast, frequencies above 8,5 GHz yield very low maximum e.i.r.p. limits (e.g. ≤ -65 dBm/MHz), do require mitigation techniques and can thus be considered as not suited. In the band 3,1 GHz to 4,8 GHz UWB is allowed with -41,3 dBm/MHz but requires either DAA or a stringent version of LDC. Furthermore, not all applications are allowed in this band.

An extension of the usable band up to 10,6 GHz is under investigation within ECC CEPT SE24 under Work item 79 [i.10].

4.3.2.3 Other services operating on similar frequency ranges

The set of frequency allocations and applications for Europe is provided by the ECA table [i.9]. Applications include for example "UWB applications" (to which UWB ITS belongs), or "Fixed", "RLAN", "PMSE", "Passive sensors (satellite)". Figure 1 provides a simplified view of the spectrum in Europe.

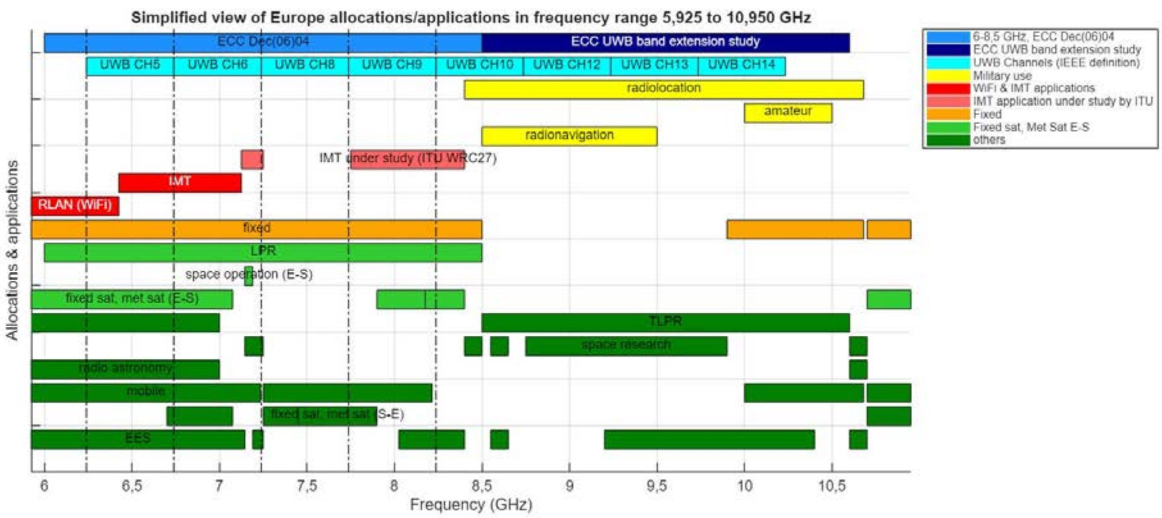

Figure 1: Simplified view of the spectrum in Europe

While ECC Report 327 [i.5] studied coexistence between UWB devices in the 6 GHz to 8,5 GHz band and a number of incumbents, it did not study coexistence with IMT operation which was identified in the 6 425 MHz to 7 125 MHz band during WRC23 under primary mobile allocation. Studies are of importance considering that the ECC Decision (06)04 [i.1] may be reviewed (as per its considering mm) based on the outcome of the World Radio Conferences and/or on the actual UWB deployment, in particular if the deployment of UWB technology can present a significant risk of interference to radio services deployed in the band 6 GHz to 8,5 GHz.

In addition to the already operational services and applications in the relevant band new allocations and investigations planned for WRC-27 and beyond based on the WRC-23 outcome should be considered. Here the studies for IMT in 7,125 GHz to 7,250 GHz and 7,750 GHz to 8,4 GHz are of importance. These band are also depicted in the Figure 1.

4.3.2.4 Possible frequencies for "UWB ITS"

ITS applications by essence require a coordinated utilisation of the spectrum, so that the different ITS-stations can transmit and receive ITS messages on a common frequency range. Stemming from the regulatory landscape and from the use of the spectrum by other applications, it appears that there is spectrum available for UWB ITS, and that several deployment options exist. Lower UWB channels 5 and 6 do not seem appropriate to host ITS applications due to deployment of Wi-Fi® and IMT applications. In the scope of the band extension work up to 10,6 GHz in CEPT additional channel and band will potentially be available in the future.

NOTE: It is however not the goal of the present document to define the frequency used by UWB ITS. It might be the topic of a dedicated study.

4.3.3 Transmit requirements

ECC Decision (06)04 [i.1] describes transmit requirements in the band 6,0 GHz to 8,5 GHz, for "vehicular applications" (vehicle-to-vehicle and infrastructure-to-vehicle) as well as for "general use". Table 2 provides a synthetic view of the transmit requirements depending on the device type.

Table 2: UWB ITS Transmit requirements

<table>
<tr><th colspan="2">Requirement
Device type</th><th>Relevant section in ECC Decision (06)04 [i.1]</th><th>Max mean e.i.r.p. PSD</th><th>Max peak e.i.r.p. (meas. in 50 MHz)</th><th>Max short-term duty-cycle (1 second)</th><th>Additional requirement</th></tr>
<tr><td colspan="2">Infrastructure outdoor (fixed)</td><td>A1.2.3</td><td>-41,3 dBm/MHz</td><td>0 dBm</td><td>5 %</td><td>• down tilted antennnas
• antenna max 10 m height</td></tr>
<tr><td colspan="2">Infrastructure indoor (fixed) (see note)</td><td>A1.3.2 "Specific applications involving enhanced indoor devices"</td><td>-31,3 dBm/MHz</td><td>10 dBm</td><td>5 %</td><td></td></tr>
<tr><td colspan="2">Road & rail vehicles (e.g. passenger cars, trucks, buses, trams, motorcycle, e-bikes, etc.)</td><td>A1.2.3 "applications involving infrastructure to vehicle and vehicle to vehicle communications"</td><td>-41,3 dBm/MHz</td><td>0 dBm</td><td>1 %</td><td>• antenna max 4 m height</td></tr>
<tr><td rowspan="2">VRU ("portable devices")</td><td>Bikes (e.g. cyclists)</td><td colspan="5">road & rail vehicles or general case</td></tr>
<tr><td>pedestrian</td><td>A1.1 "General case"</td><td>-41,3 dBm/MHz</td><td>0 dBm</td><td>No limit</td><td></td></tr>
<tr><td colspan="7">NOTE: The details of how to determine the indoor conditions in line with the regulation for a specific ITS application is out of the scope of the present document.</td></tr>
</table>

Additional frequency bands beyond 8,5 GHz up to 10,6 GHz are under investigation in CEPT.

4.4 Standards

4.4.1 IEEE 802.15 standards

Many applications build upon the impulse radio physical layer and medium access control provisions standardized in IEEE 802.15.4 [i.6] and its amendment. The recent uptake of UWB in automotive and consumer electronics in particular is based on IEEE 802.15.4z [i.7], which introduced secure ranging capabilities. Further development, in particular to improve ranging link budgets and to include sensing applications are included in the latest IEEE P802.15.4ab amendment [i.44], as further described in clause 4.5.

4.4.2 Industry consortia

These IEEE specifications are used by industry consortia such as the Car Connectivity Consortium, Fine Ranging (FiRa) Consortium and omlox (industrial localisation) to ensure interoperable applications.

4.4.3 ETSI standards

For UWB applications, ETSI harmonised standards are part of the ETSI EN 302 065 series. It comprises active harmonised standards and harmonized standards under development. The current structure of the series comprises parts (such as ETSI EN 302 065-X) and sub-parts (such as ETSI EN 302 065-X-Y). In the future only the sub-parts version of the harmonized standards will be valid. These list of standards will be updated based on the further development of the EU spectrum regulation.

Table 3: ETSI standards related to UWB

Part	Sub-part
ETSI EN 302 065-1 [i.15] Requirements for Generic UWB applications	ETSI EN 302 065-1-1 [i.46] Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised Standard for access to radio spectrum; Part 1: Generic UWB devices; Sub-part 1: Communication devices within 3,1 GHz to 4,8 GHz using LDC mitigation or within the 6 to 8,5 GHz
ETSI EN 302 065-2 [i.16] Requirements for UWB location tracking	ETSI EN 302 065-2-1 [i.47] Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 2: Ultra Wide Band location tracking devices; Sub-part 1: Requirements for devices within 6 GHz to 8,5 GHz
	ETSI EN 302 065-2-2 [i.48] Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 2: Ultra Wide Band location tracking devices; Sub-part 2: Requirements for devices in the frequency band between 3,1 GHz to 4,8 GHz utilizing LDC mitigation technique
	ETSI EN 302 065-2-3 [i.49] Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 2: Ultra Wide Band location tracking devices; Sub-part 3: Requirements for fixed infrastructure UWB based localization systems in the frequency band between 3,1 GHz to 4,8 GHz deploying Detect-And-Avoid (DAA) mitigation technique
	ETSI EN 302 065-2-4 [i.50] Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 2: Ultra Wide Band location tracking devices; Sub-part 4: Requirements for fixed outdoor devices within 6,0 GHz to 8,5GHz
	ETSI EN 302 065-2-5 [i.51] Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 2: Ultra Wide Band location tracking devices; Sub-part 5: Requirements for enhanced indoor devices within 6,0 GHz to 8,5 GHz
ETSI EN 302 065-3 [i.17] UWB devices installed in motor and railway vehicles	ETSI EN 302 065-3-1 [i.22] Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised Standard for access to radio spectrum; Part 3: UWB devices installed in motor and railway vehicles; Sub-part 1: Requirements for UWB devices for vehicular access systems within 3,8 GHz to 4,2 GHz or 6 GHz to 8,5 GHz
	ETSI EN 302 065-3-2 [i.52] Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 2: Ultra Wide Band location tracking devices; Sub-part 5: Requirements for enhanced indoor devices within 6,0 GHz to 8,5 GHz
	ETSI EN 302 065-3-3 [i.53] Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 3: UWB devices installed in motor and railway vehicles; Sub-part 3: Requirements for UWB radiodetermination applications operating within 6,0 GHz to 8,5 GHz

Part	Sub-part
ETSI EN 302 065-4 [i.18] Material Sensing devices	ETSI EN 302 065-4-1 [i.20] Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised Standard for access to radio spectrum; Part 4: Material Sensing devices; Sub-part 1: Building material analysis operating within 30 MHz to 10,6 GHz
	ETSI EN 302 065-4-4 [i.19] Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised Standard for access to radio spectrum; Part 4: Material Sensing devices; Sub-part 4: Exterior material sensing applications for ground based vehicles
ETSI EN 302 065-5 [i.21] Devices using UWB technology onboard aircraft	
ETSI EN 302 065-6 series Ultra Wide Band radio-determination for radar sensing devices	ETSI EN 302 065-6-1 [i.54] Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised Standard for access to radio spectrum; Part 6: Ultra Wide Band radio-determination for radar sensing devices; Sub-part 1: Requirements for presence detection applications within 6,0 GHz to 8,5 GHz
	ETSI EN 302 065-6-2 [i.55] Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 6:Ultra Wide Band radio-determination for radar sensing devices; Sub-part 2: Requirements for generic UWB through-air non-contact vital signs applications within 6,0 GHz to 8,5 GHz
	ETSI EN 302 065-6-3 [i.56] Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 6: Ultra Wide Band radio-determination for radar sensing devices; Sub-Part 3: Requirements for fixed outdoor presence detection devices within 6,0 GHz to 8,5 GHz
	ETSI EN 302 065-6-4 [i.57] Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 6: Ultra Wide Band radio-determination for radar sensing devices; Sub-Part 4: Requirements for fixed outdoor through-air non-contact vital signs applications within 6,0 GHz to 8,5 GHz
	ETSI EN 302 065-6-5 [i.58] Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 6: Ultra Wide Band radio-determination for radar sensing devices; Sub-Part 5: Requirements for enhanced indoor presence detection devices within 6,0 GHz to 8,5 GHz
	ETSI EN 302 065-6-6 [i.59] Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised standard for access to radio spectrum; Part 6: Ultra Wide Band radio-determination for radar sensing devices; Sub-Part 6: Requirements for enhanced indoor through-air non-contact vital signs applications within 6,0 GHz to 8,5 GHz

Measurement procedures (for instance total emission, TX spurious and unwanted emission not belonging to the UWB emissions) are specified in ETSI EN 303 883-1 [i.23] (transmitter) and ETSI EN 303 883-2 [i.24] (receiver).

4.5 UWB packet structure

IEEE 802.15.4 [i.6] provides two physical layers (PHY) options, High-Rate Pulse frequency (HRP) and Low-Rate Pulse (LRP). The HRP PHY uses Burst Position Modulation (BPM) and Binary Phase-Shift Keying (BPSK) modulation. Each symbol is divided into two BPM intervals, and depending on the bit value to transmit, the first or the second interval contains a burst of UWB pulses. As receiver technology evolved, transmitted pulses became phase modulated to carry a second bit of information per symbol. Different numerologies exist for the number of pulses per burst and Pulse Repetition Frequencies (PRF). More details can be found in IEEE 802.15.4 [i.6], section 16.2.

The UWB packet comprises different fields, as illustrated by Figure 2:

- The Synchronization Header (SHR), further divided into:
    - The Preamble, a ternary coded predefined sequence with a repeating pattern.
    - The Start-of-Frame Delimiter (SFD).
- The PHY Header (PHR).
- The transmitted payload (PSDU), encoded as per the rate indicated in PHR.

Figure 2: HRP PHY packet structure (copy pictures courtesy of NXP Semiconductors)

The IEEE 802.15.4z [i.7] amendment improves ranging capabilities of the mentioned PHYs and enhances the MAC to support those PHY improvements. It also introduced new features, such as new PRF and data rates (up to 27 Mbit/s), new ternary preamble sequences, a more advanced (K=7) convolutional encoding based Forward Error Correction (FEC) scheme, as well as new Scrambled Timestamp Sequence (STS) field which is designed for support of accurate range measurements. The STS can be located at different positions of the packet, defined by the STS packet configuration, as shown by Figure 3.

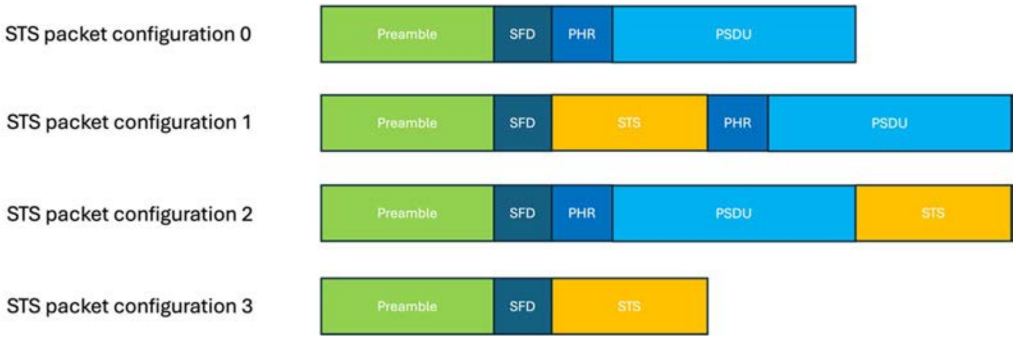

Figure 3: STS packet configurations (copy pictures courtesy of NXP Semiconductors)

IEEE P802.15.4ab amendment [i.44] intends to substantially improve the performance of UWB, and introduces a number of changes [i.43] in the PHY, MAC and upper layers. The standard is available as draft version and is intended to be published in 2026.

For example, enhancements include:

- Three HRP-EMDEV modulation modes (one with long symbol time for longer distances, two with shorter symbol times with 2 and 4 pulses per symbol, to enable higher data rates).
- Additional data modulation rates (higher data-rates for higher throughput and lower latency, and lower data-rates for improved sensitivity in noisy environments).
- LDPC channel coding for improved sensitivity (LDPC code lengths of 648, 1 296, 1 944).
- Assistive Narrow Band (NB) radio, enabling power saving and longer range for acquisition and ranging poll & response messages, in particular for ranging applications.
- Multi-Millisecond (MMS) packet structure, for link budget enhancement for two-way ranging, driven either by UWB or NB-assisted. Fragmenting a long packet into multiple smaller fragments separated by at least 1 ms allows a higher transmit power, thereby increasing achievable range, as regulations define the maximum transmit power in form of PSD measured over a 1 ms measurement window (e.g. reducing the air-time by half within a 1 ms window allows a 3 dB higher transmit power). Figure 4 provides an exemplary view of how the different fragments are scheduled over time.

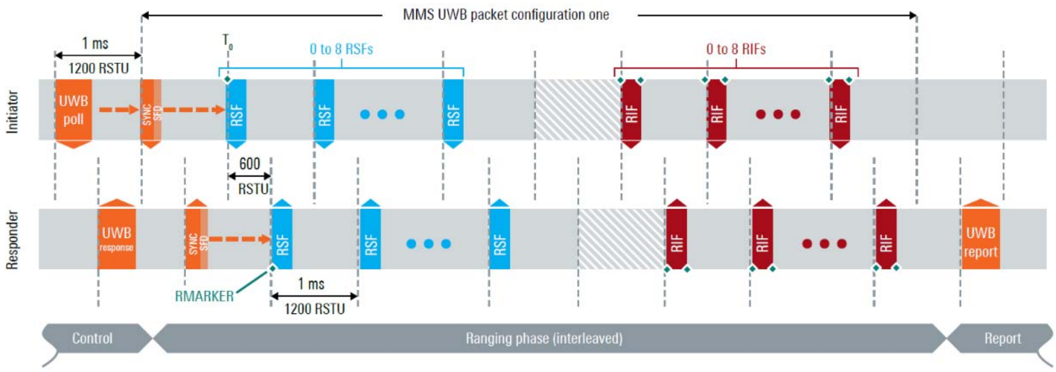

Figure 4: Illustration of IEEE 802.15.4ab UWB-driven MMS feature (copy pictures courtesy of R&S [i.43])

- Introduction of a new and dedicated field "SENS" and associated packet formats for sensing & radar applications. Three different configurations are defined, as shown by Figure 5.

Figure 5: SENS packet formats (copy pictures courtesy of NXP Semiconductors)

- Finer grain channel definition and frequency stitching, intra-packet and inter-packet, primary designed to enable improved sensing (providing a larger signal bandwidth), as illustrated by Figure 6.

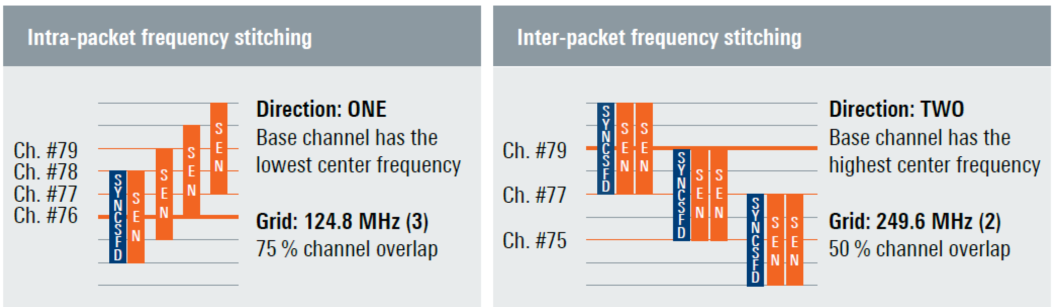

Figure 6: Illustration of IEEE 802.15.4ab Extended channel supporting frequency stitching feature (copy pictures courtesy of R&S [i.43])

- Wake-up radio messages for power saving.

4.6 Technical capabilities

4.6.1 Data communication

UWB system is maybe the oldest form of radio transmission, with experiments from Heinrich Hertz dating as far as 1887 [i.25], and continued by Guglielmo Marconi in the beginning of the 20th century.

IEEE 802.15.4 [i.6] and IEEE 802.15.4z [i.7] define nominal data rates ranging from 0,11 Mbps to 27,24 Mbps. IEEE P802.15.4ab [i.44] defines nominal data rates up to 124,8 Mbps.

Achievable ranges depend on variety of factors, including data-rates and the presence or absence of clutter and/or line-of-sight or non-light-of-sight situations, but ranges of up 50 m have been reported [i.26].

4.6.2 Sensing

UWB technology enables scanning of material (for instance for wall and floor scanners detecting presence of metallic water pipes or other material behind visible surface), and proximity sensing of surrounding objects.

In this mode, acting in a similar way was a monostatic radar, a UWB device transmits a sounding signal. This signal may be reflected by an object or a surface, and part of it returns to the UWB device which captures it. By analysis of the Channel Impulse Response (CIR), different material types can be distinguished, and/or distances towards targets can be derived.

4.6.3 Positioning and localisation

UWB technology is widely used for Real-Time Location Systems (RTLS) applications. Several topologies using different schemes exist, including:

- Uplink Time difference of arrival (Uplink TDoA)
- Downlink Time difference of arrival (Downlink TDoA)
- Two-way ranging (TWR)
- Angle of Arrival (AoA) Uplink Time Difference of arrival (Uplink TDoA)

In this topology, multiple synchronized anchors (AP) are deployed at known locations, and are capturing the signals sent by one or more mobile tags (the so-called 'blink' messages), and the timestamps can be processed to derive the location of the tags. In this topology, the location information is known by the infrastructure:

- Downlink Time Difference of arrival (Downlink TDoA)

In this 'GPS-like' topology, also sometimes referred to as "Reverse Time Difference of arrival", multiple synchronized anchors (AP) are deployed at known locations, and sending signals which are received by the mobile tags. Based on the known position of the signal sources, the tags can derive their own location. In this topology, the location information is known by the tags:

- Two Way Ranging (TWR)

This method is based on the accurate measurement of the Time of Flight (ToF) between peers, such as between a tag and an anchor, or between two tags. This is typically the mode used by the car-access system. The ranging measurement is initiated by one of the devices (e.g. a smartphone), by sending a poll type of message directed to a specific receiver (e.g. a fixed anchor), which then sends a response message following a strict timing, denoted as T_{reply} in Figure 7. When the initiator of the ranging process receives the response, it timestamps it, and derive the round trip Time of Flight (ToF), denoted as T_{loop} in Figure 7, which is then converted to a distance information. This distance information can possibly be sent to the second device by means of a final message.

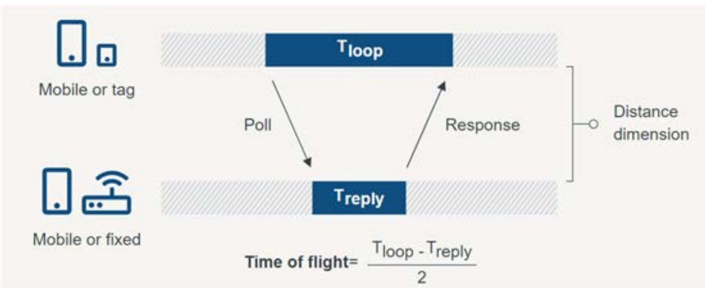

Figure 7: TWR principle
(copy pictures courtesy of NXP Semiconductors)

TWR measurements exist in form of Single-Sided Two-Way Ranging (SS-TWR), as per the above description, or Double-Sided Two-Way Ranging (DS-TWR) in which two round-trip time measurements are used and combined to reduce the measurement error.

- Angle of Arrival (AoA)

A variation of this mode is the called Phase Difference of Arrival (PDoA), made possible when the UWB devices have multiple receive antennas. The perceived phase difference at the different receive antenna, for the incoming signal can be processed and translating into an angle information for the incoming signal, i.e. AoA calculations.

Experiments carried in [i.27] indicated that in most cases, the ranging error is below 0,2 m. Experiments carried in [i.28] indicated a max distance error of 140 cm (raw) or 55 cm (post processed) and that using on-board IMU odometry data, RMSE of the positioning distance error over the whole trajectory was 18,56 cm, with a maximum positioning distance error of 46 cm.

4.6.4 Possible usage for ITS applications

ITS applications using UWB could be adopting all of the abovementioned mechanisms, including hybrid solutions, depending on the type of device, the application, the scenario and its requirements. For UWB ITS location and tracking applications, TDoA could be deployed when either synchronized fixed infrastructure or multiple synchronized UWB devices on a car, train, ship or airplane are available. ToF could be the method for relative ranging between traffic participants, e.g. cars, pedestrians, bicycles, etc. Passive sensing could be a could solution for dense environments involving also non equipped objects. Sensing capabilities could also be a solution for dense environments involving non-equipped objects.

For ITS applications, UWB positioning systems can also be combined with GNSS information to obtain even more accurate measurements. [i.29] reports approximately 10 cm precision reported in this case. Alternatively, leveraging TDoA and AoA, [i.30] indicates that UKF+ Interactive Multiple Model (IMM) emerges as a valid alternative to conventional GNSS-RTK vehicle positioning since, for each tag, the mean mismatch is below 16 cm, and below 30 cm in 95 % of the occurrences.

4.7 Market overview and growth

4.7.1 Overview

UWB technology has developed extensively over the past years and is used within a variety of applications and devices. This includes for example smartphones, automotive, IoT, wearables, smart home, or industrial applications. According to FiRa [i.60], the yearly number of UWB enabled devices shipments will grow from nearly 400 million to more than 1,4 billion by 2030, as shown by Figure 8.

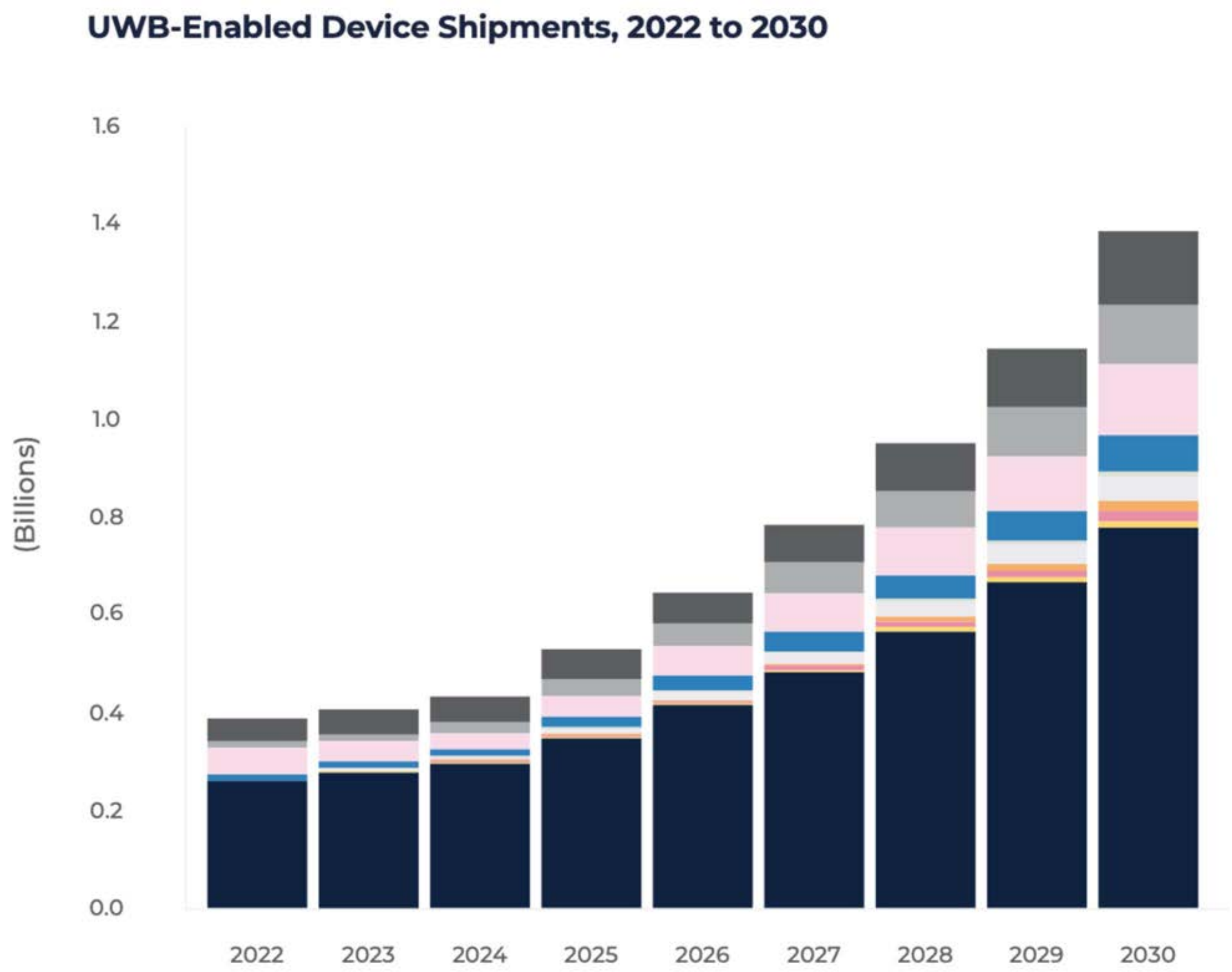

Figure 8: Yearly number of UWB-enabled device shipments (Source: FiRa Consortium [i.60])

4.7.2 Smartphones and accessories use cases and deployments

A large number of smartphones and related accessories are nowadays equipped with UWB technology, offering new end-user applications. According to FiRa [i.31], "*in 2022, 21 % of smartphone shipments included UWB technology...*".

This number is expected to even grow up to 100 %, meaning more than 800 million of smartphones equipped with UWB technology sold every year in 2030 [i.60].

The UWB technology is used for example to accurately locate smartphones accessories (UWB is also used for precise asset tracking devices or applications).

4.8 Automotive use cases and deployments

4.8.1 Keyless entry systems

The Car Connectivity Consortium (CCC), a group of automotive and smartphone companies, has created a specification called Digital Key (CCC DK 3.1.4 & 4.1.0 [i.61]). The DK 3.1.4 and DK 4.1.0 specification [i.61] allows drivers to use their smartphones to securely unlock and start their cars. It leverages Ultra-Wide Band (UWB) technology to precisely determine the distance between the phone and the vehicle. Figure 9 provides an exemplary view of this deployment scenario. The system ensures the smartphone is in close proximity to the car before granting access, and employs encryption to prevent unauthorized relay attacks. By using a mobile app as a digital key, offering the added convenience of easily sharing and revoking virtual keys as needed, this technology is poised to replace traditional physical car keys in the coming years. According to the FiRa consortium [i.31], by 2028, one third of new vehicles are expected to use UWB as secure access technology.

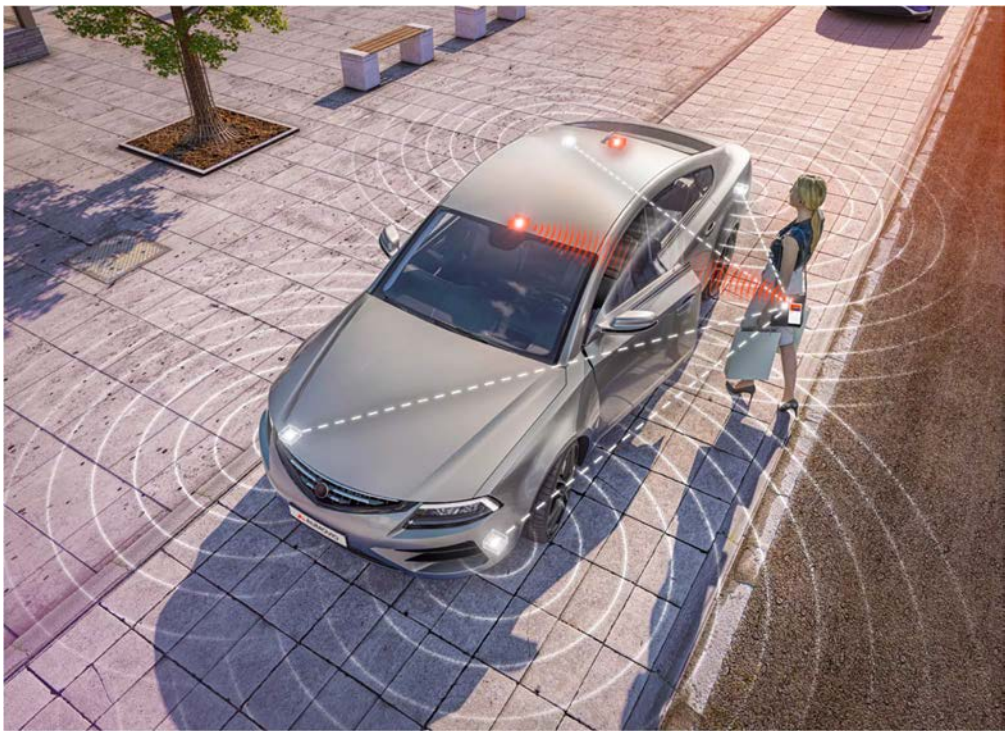

Figure 9: Typical set-up for UWB based hands-free access systems with smartphone (copy pictures courtesy of AUMOVIO)

4.8.2 In-cabin sensing and occupant presence detection

In-cabin sensing is a fast-growing market, with driver and passengers monitoring applications are becoming mandatory in Europe (as defined by the GSR 2 Regulation [i.32]) and in the USA, while safety consortia like EuroNCAP are pushing carmakers to switch to direct detection starting 2025 for Child Presence Detection (CPD).

In-cabin sensing covers a broad set of safety applications, and some of them can be covered by UWB technologies, including occupants detection and tracking such as Child Presence Detection (CPD), while vital signs monitoring (respiration and/or heart rates) is crucial for drowsiness detection.

One important future use case for Ultra-Wide Band (UWB) technology is detecting the presence of children inside vehicles Child Presence Detection (CPD) to prevent tragic hot car deaths. By installing UWB sensors in the car, the system can accurately identify if a child has been accidentally left behind by tracking their breathing and movements. This child presence detection feature can be integrated into digital vehicle access platforms, working in conjunction with secure ranging for keyless entry. This combination of technologies enables a comprehensive solution that enhances vehicle security while also providing crucial safety alerts to prevent leaving children unattended in cars. Figure 10 provides an exemplary view of this deployment scenario.

Figure 10: Child Presence Detection (CPD) application using UWB (copy pictures courtesy of AUMOVIO)

4.9 Summary

In this clause several UWB use cases in the automotive environment have been presented. Most of these use cases are already deployed or under development. UWB technology thus is not new to the automotive industry. Based on that experience UWB applications can be extended in the future. The reuse of existing UWB devices installed in a car can simplify the cost-efficient adoption of new use cases.

5 UWB in support of ITS use cases

5.1 Introduction

Cooperative Intelligent Transport Systems (C-ITS) defines a comprehensive framework, as illustrated by Figure 11, which allows road users of different types as well as infrastructure equipment and traffic managers to share information in a quest to increase road safety and comfort, as road traffic fatalities in Europe are still at a high level of approximately 20 000 fatalities per year as of 2022 [i.11].

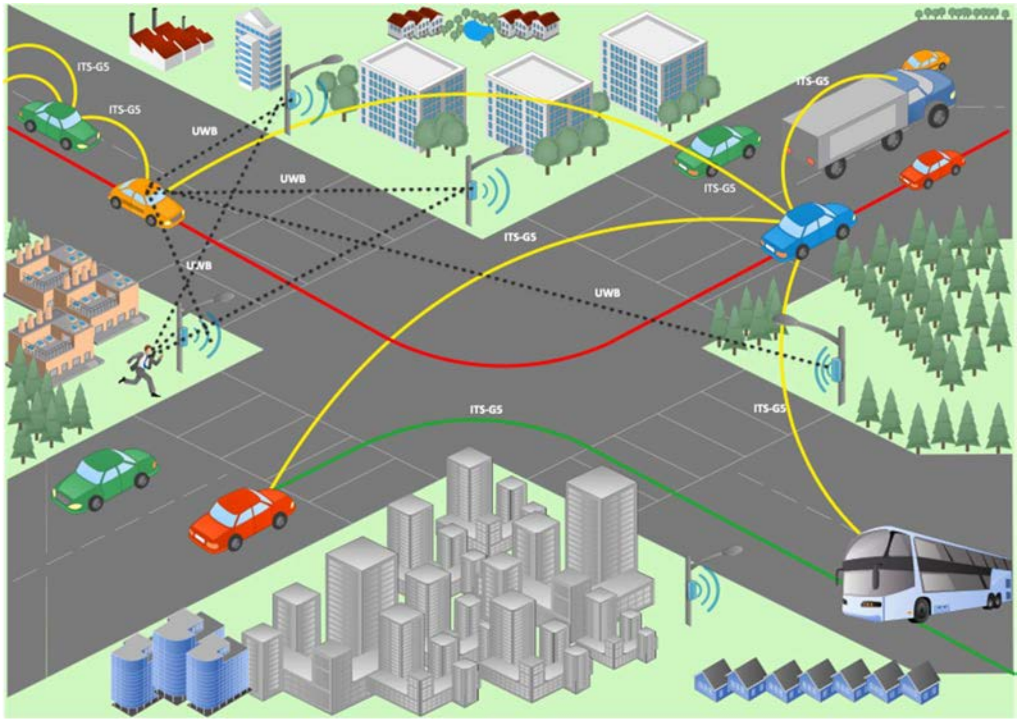

Figure 11: High precision positioning in ITS [i.5]

The connectivity between ITS participants, also referred to as Vehicle-to-everything (V2X), is based in Europe on the ETSI ITS-G5 standard and set of technical specifications, which includes two access-layer technology options (IEEE 802.11p/bd [i.62] and C-V2X), operating in the 5,9 GHz ITS band, as depicted by the spectrum view shown in Figure 12.

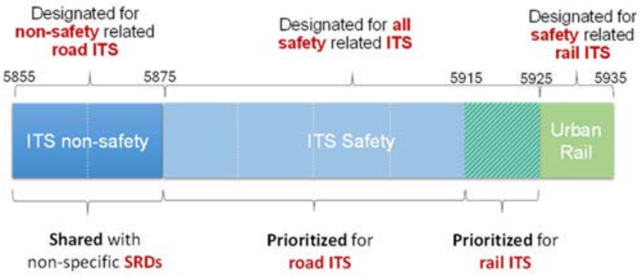

Figure 12: ITS 5,9 GHz frequency band organization in Europe (ETSI TR 103 667 [i.42])

V2X comprises a number of sub-use cases:

- V2V: Vehicle to vehicle
- V2I: Vehicle to Infrastructure (e.g. traffic lights)
- V2B: Vehicle to Bicycle
- V2P: Vehicle to Pedestrian

Most of the 5,9 GHz ITS messages (i.e. CAMs) are essentially periodic beacons indicating vehicle dynamics such as its coordinates, speed, headings, broadcasted a transmit frequency between 1 and 10 Hz.

5.2 Vulnerable Road User protection

As of today, ITS-G5 has been deployed mostly on vehicles and infrastructure. However, vehicle to vehicle accidents only represent a part of the problem, as most of the road fatalities unfortunately involves Vulnerable Road Users (VRUs), e.g. meaning pedestrians, cyclists, moped riders and motorcyclists): 54 % of the fatalities in Japan [i.12] and 48 % of the fatalities in the EU in 2023 [i.11] as shown by Figure 13.

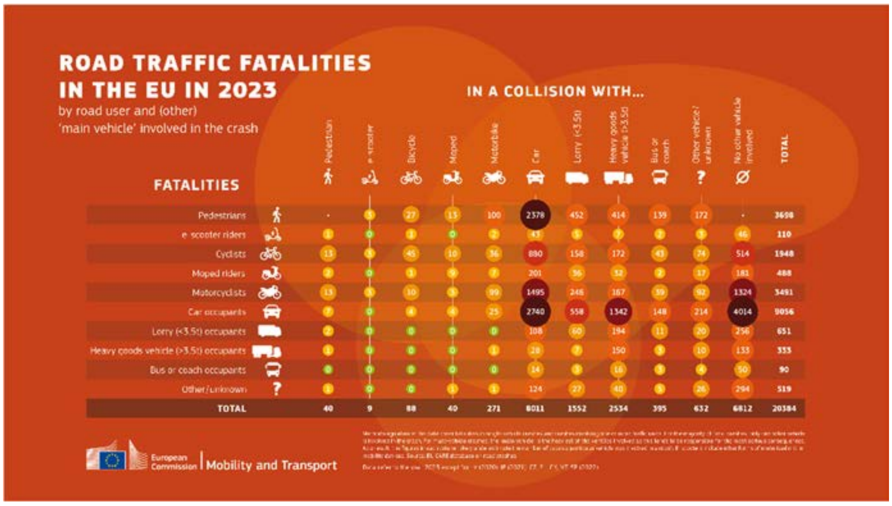

Figure 13: Road Fatalities distribution in the EU in 2023 [i.11]

Leveraging the high penetration of the UWB technology in both smartphones and vehicles, UWB could be used as a bridge to include VRUs in the ITS framework. VRUs are often not identified by vehicles early enough, and UWB technology could help inform vehicles about their presence and localization of approaching VRUs, by means of V2B or V2P communications, as illustrated by Figure 14 and explained in [i.13].

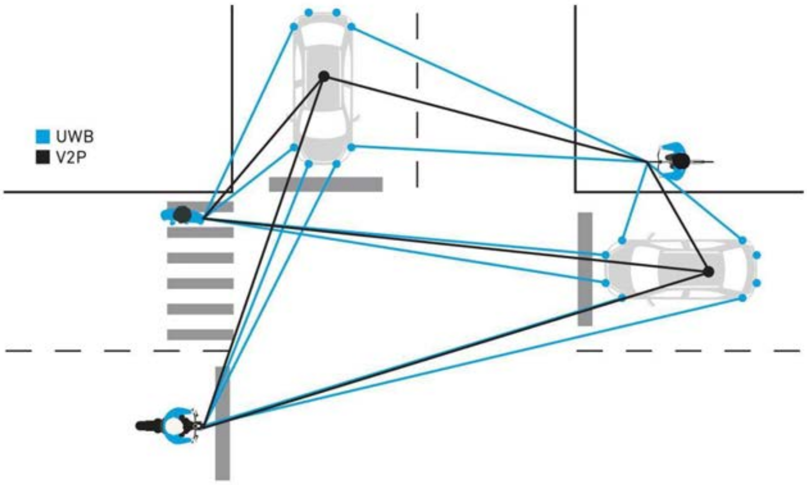

Figure 14: Illustration of UWB used for V2P
(copy pictures courtesy of Qorvo [i.13])

UWB-based ITS messages for VRUs may comprise both broadcasting type of data communication, potentially based on the ETSI ITS VAM (VRU Awareness Messages) format [i.14], as well as secure positioning and localization.

Range requirement: approximately 30 m in LOS conditions.

Accuracy requirement: 1 m.

Requirements on security and trust.

5.3 VRU protection via UWB-connected infra

In a Korean national project in the City of Seyong [i.41], the deployment of UWB in a C-ITS infrastructure based system has been implemented and tested. UWB performs various functions through the exchange of information between UWB located at a specific fixed reference point and UWB attached to an object whose position is constantly moving (e.g. various types of VRU). When installed at a fixed location, it can be connected by various connection methods (e.g. short-range communication, cellular network communication) in addition to UWB connection. UWB information received from a moving object can be processed more efficiently by utilizing other connected infrastructure. UWB-connected infra plays a key role, and can be installed in areas where VRU protection is important (e.g. school zones). Figure 15 shows a system configuration scheme for providing VRU protection through UWB-connected infra.

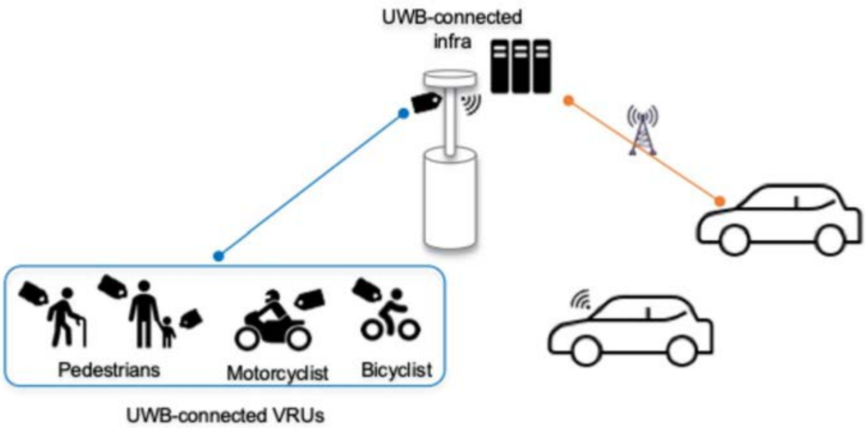

Figure 15: UWB-connected infra and VRUs system configuration

The UWB-connected VRU transmits essential information required for position measurement to the UWB-connected infra installed at a fixed location as a UWB signal. In addition, auxiliary information (e.g. ID value, etc.) can be additionally transmitted. The UWB-connected infra measures the position of a moving UWB object, collects all essential and auxiliary information received from them, and processes them more efficiently based on high performance. In this way, it has the effect of improving the battery performance efficiency of the UWB device mounted on the moving object. In addition, the UWB-connected infra can notify a vehicle entering the vicinity of a collision risk with the UWB-connected VRU or the location of the UWB-connected VRU through various connection methods. The UWB-connected VRU can receive a UWB signal from the UWB-connected infra and notify of a collision risk through sound or vibration. Figure 16 provides an example information flow for this deployment scenario.

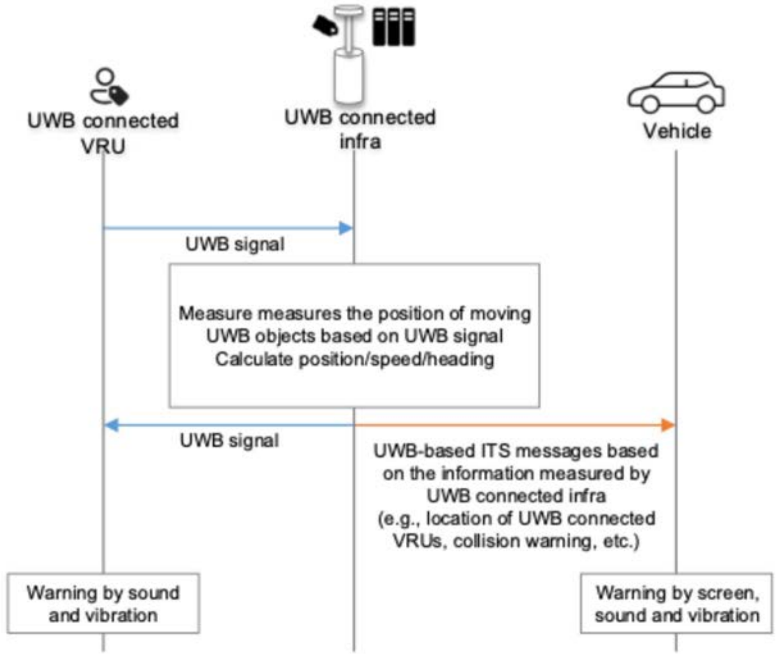

Figure 16: Example information flow

UWB-based ITS messages based on the information measured by UWB connected infra (e.g. location of UWB connected VRUs, collision warning, etc.) may comprise broadcasting type of data communication, potentially based on the ETSI ITS Decentralized Event Notification Message (DENM) format.

Range requirement: approximately 30 m in LOS conditions.

Accuracy requirement: 1 m.

Requirements on security and trust.

5.4 Positioning and control for autonomous parking and highly accurate vehicle positioning

Autonomous parking, sometimes also referred to as Automated Valet Parking (AVP), intends to increase safety and practicality when parking vehicles in indoor or outdoor facilities. Autonomous parking helps optimizing vehicles' placement, potentially significantly increasing the parking lots capacity. The automated parking operation removes stress from the drivers, risks of scratches on the car bodies and risk of collisions with pedestrians while manoeuvring.

The parking infrastructure is equipped with UWB anchors providing ranging functionality (e.g. TDOA, TWR), guiding the vehicle from the parking entrance to its specific parking location (for example a parking place with electric charging capability for electric vehicles or the cleaning station). For most-advanced systems, the parking operation can be fully automated and orchestrated by the parking infrastructure, as illustrated by Figure 17 and Figure 18.

Range requirement: 10 m to 20 m, depending on the deployment scenario.

Accuracy requirement: 10 cm.

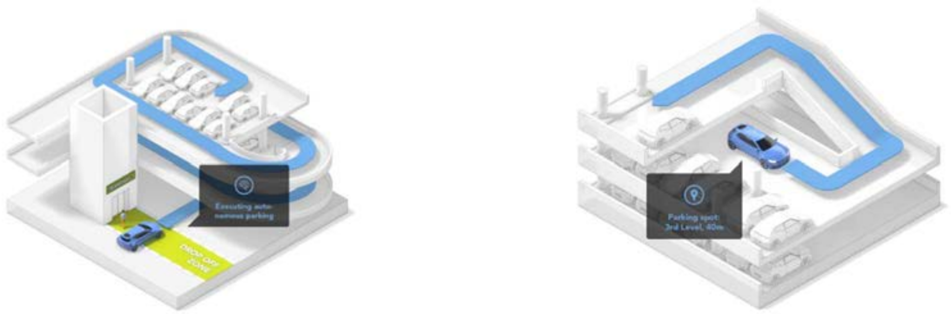

**Figure 17: Autonomous parking positioning (left) and parking marshalling (right)
(copy pictures courtesy of NXP Semiconductors)**

Beside the presented specific use case of parking highly accurate vehicle positioning is the broader generic use case. Highly accurate vehicle positioning defines the ability for a passenger car or other ground-based vehicles to locate itself or being located by the infrastructure very accurately, for situations such as narrow passages, tunnels, road-work situations, very sharp turns, entrance of parking lots, or trailer attachment. Highly accurate vehicle positioning can also be used for trucks approaching charging docks or buses entering depot or stopping at a bus stop.

Highly accurate vehicle positioning can be enabled by different ranging schemes, as well as leveraging the sensing capability of the vehicle to detect proximity obstacles such walls, curbs, etc.

Range requirement: 10 m

Accuracy requirement: 10 cm.

**Figure 18: Automotive use cases
(copy pictures courtesy of NXP Semiconductors)**

5.5 Secure payment and tolling applications

UWB-based payment and tolling applications cover a broad panel of deployment scenarios, including payment for electric car charging, payment on parking lot exit, and highway free-low tolling, as illustrated by Figure 19, Figure 20 and Figure 21.

Exchange between the vehicle (or motor bicycle) and the infrastructure can be based on secure ranging and/or secure data-communication. A more detailed analyses of using ITS-G5 as the basis for road tolling has been published in ETSI TR 103 579 [i.8]. The deployment of a secure ranging based in UWB can significantly improve this operation.

Figure 19: Toll plaza with non-stop ETC lane (far left), stop&go ETC (centre lanes) and automatic lane (right) (ETSI TR 103 579 [i.8])

Figure 20: Toll plaza with non-stop ETC lanes (left), stop&go ETC and automatic lanes (right) (ETSI TR 103 579 [i.8])

Figure 21: Payment and tolling applications (copy pictures courtesy of NXP Semiconductors)

5.6 Summary

Table 4 provides a summary of the use cases system-level technical requirements.

Table 4: UWB ITS use cases requirements summary

Use case	Range required	Accuracy required	Information available at which side
Vulnerable Road User secure positioning	30 m	1 meter	Both at VRU and vehicles
Positioning and control for autonomous parking	10 m to 20 m	10 cm	Vehicles And optionally at infrastructure side
Highly accurate vehicle positioning	10 m	10 cm	Vehicles And optionally at infrastructure side
Payment and tolling applications	10 m to 30 m	20 cm	Both vehicles and infrastructure side

6 UWB in ITS Architectural considerations

6.1 Overview

Intelligent Transportation Systems (ITS) aim to provide services relating to different modes of transport and traffic management, enable users to be better informed and make safer, more coordinated and 'smarter' use of transport networks. They include advanced telematics and hybrid communications including IP based communications as well as Ad-Hoc direct communication between vehicles and between vehicles and infrastructure.

The ETSI ITS stack is often represented in form of various layers, as illustrated by Figure 22. The green-coloured boxes represent possible new building blocks for UWB usage.

- The "applications" layer describes the application requirements specification for use cases like Road Hazard Signalling (RHS), Intersection Collision Risk Warning (ICRW) etc. In order to support the use cases identified in earlier clause 5 of the present document, new application requirements may have be defined.
- The "Facilities" layer describes the messages format, including fields and contents. For instance the Cooperative Awareness Messages are described in ETSI TS 103 900 [i.33], the "VAM" Vulnerable Road Users (VRU) messages are described in ETSI TS 103 300 series (ETSI TS 103 300-1 [i.34], ETSI TS 103 300-2 [i.35] and ETSI TS 103 300-3 [i.36] and may provide a good foundation, although it would also be possible to define yet new messages formats.
- The "Network & Transport" layer controls dissemination and relaying of the messages.
- The "access layer" is tasked to send and receive messages. The UWB access layers comes in addition to the 5,9 GHz access layer, bringing complementary capabilities (as described in clause 4.6).

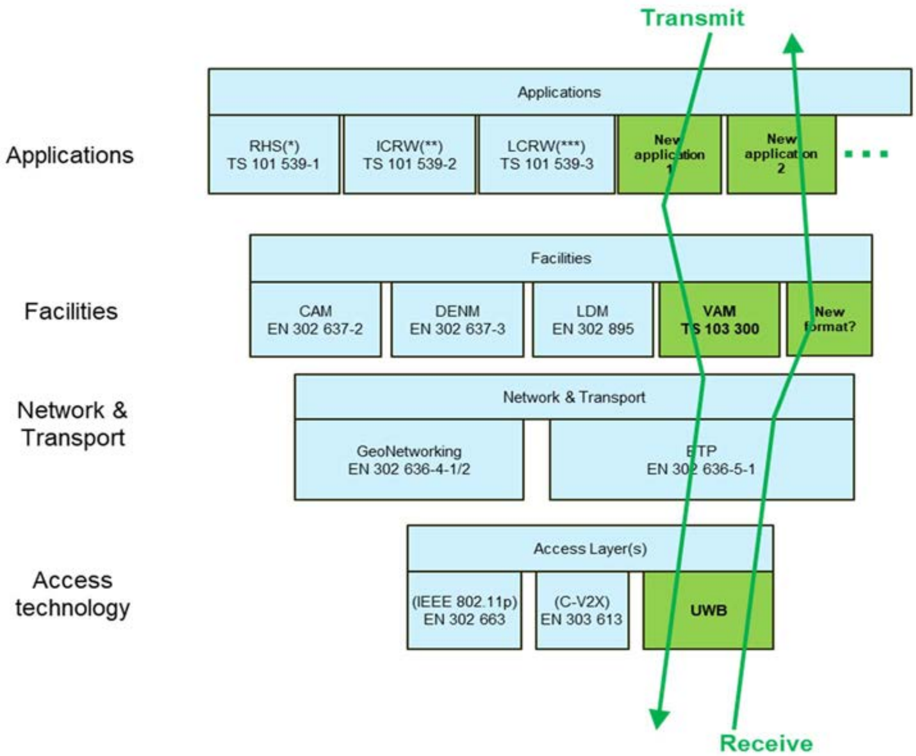

Figure 22: Possible augmentation of the ITS stack with UWB access layer support

6.2 Existing message containers

6.2.1 CAM

6.2.1.1 Scope

CAM is the most common type of messages within ITS. As described in ETSI TS 103 900 [i.33], Cooperative Awareness Messages (CAMs) are messages exchanged in the ITS network between ITS-Ss to create and maintain awareness of each other and to support cooperative performance of vehicles using the road network. A CAM contains status and attribute information of the originating ITS-S. The content varies depending on the type of the ITS-S. For vehicle ITS-Ss the status information includes time, position, motion state, activated systems, etc. and the attribute information includes data about the dimensions, vehicle type and role in the road traffic, etc.

6.2.1.2 Container structure and size

In Figure 23, the structure of the CAM Packet Data Unit (CAM PDU) is shown. There are both mandatory and optional fields. The fields which are always present are:

- ITS PDU header
- Basic container
- High Frequency container, which is highly dynamic data

On the contrary, other fields may not be present. These are typically:

- Low frequency container, which is low-dynamic or static data
- Special vehicle container, which is specific for sender role

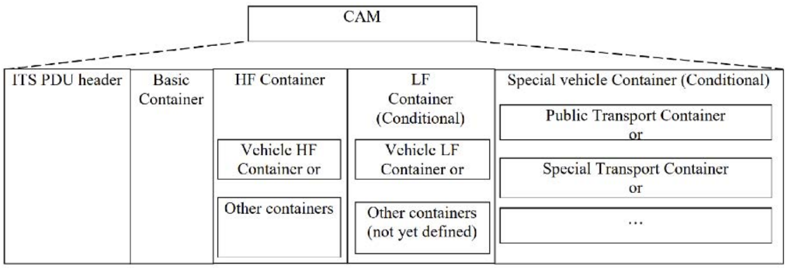

Figure 23: CAM PDU container (ETSI TS 103 900 [i.33])

CAM messages are non-deterministic in time and size. Their period varies from 1 Hz to 10 Hz depending on the dynamics of the vehicle. The average CAM sizes is around 350 bytes for vehicles [i.39], starting from 190 bytes and going to 800 bytes in some cases, as shown by Figure 24.

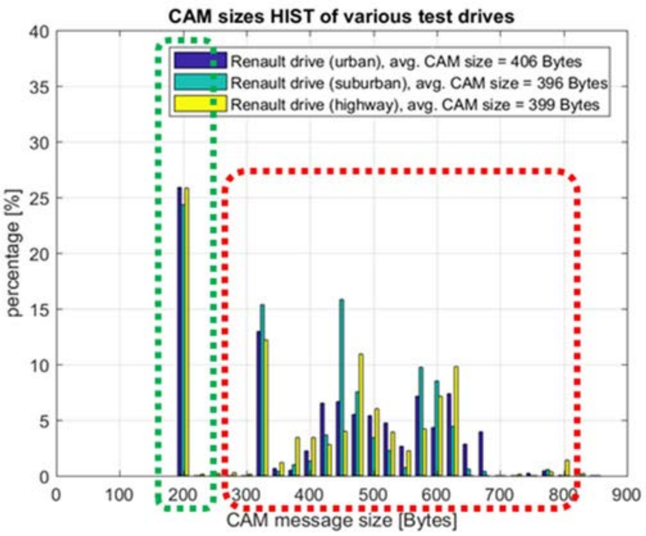

Figure 24: Distribution of the CAM size for an example real-life recording (Source: CAR 2 CAR Communication Consortium [i.39])

Amongst the heaviest fields, ITS certificates are transmitted once per second, or on request from an infrastructure equipment such as an RSU, and account for approximately 100 bytes to 150 bytes. Within the Low-frequency-container, the pathHistory field can also be heavy, providing information on up to 40 previous path points reflecting from 200 m to 500 m of trajectory history (8 bytes per path point).

According to [i.40], the minimum size of CAM packets is 41 bytes when including only the "ITS PDU Header", the "Basic container", and the minimum fields within the "High Frequency Container", e.g. speed, heading and acceleration.

6.2.1.3 Triggering mechanism

New CAMs are generated when there is enough change compared to the previous CAM. Thresholds are defined as:

- A position change ≥ 4 m
- A heading change of direction ≥ ±4°
- A Speed change ≥ 0,5 m/second
- Otherwise: generate a message after 1 second maximum

6.2.2 VAM

6.2.2.1 Scope

Vulnerable Road Users messages (VAM) are described in ETSI TS 103 300 series (ETSI TS 103 300-1 [i.34], ETSI TS 103 300-2 [i.14] and ETSI TS 103 300-3 [i.36]). VAM messages can be seen as adaptation of CAM containers for VRU-related use cases, as illustrated by Figure 25 (Table 2 from ETSI TS 103 300-2 [i.35]).

15 ETSI TS 103 300-2 V2.2.1 (2021-04)

Table 2: C-ITS messages for ETSI TR 103 300-1 [i.1] use cases

UC-	Description	Existing standard messages							Comments
		CAM	DENM	SPaT	MAP	CPM	MCM	VAM	
A1	Sharing sidewalk between pedestrian and cyclists		X					X	VAM is used for awareness between VRUs, DENM is used for warning of a potential risk of collision (applies to all use cases below)
A2	Pedestrian crossing a road with an e-scooter approaching		X					X	
B1	Active Roadwork	X	X					X	
B2	VRU crossing a road	X	X				X	X	
B3	Rider is separated from his motorcycle	X	X				X		
B4	Emergency Electronic Brake Light (EEBL)	X	X						This UC is already covered by existing C ITS messages
B5	Motorcycle Approach Indication (MAI) /Motorcycle Approach Warning (MAW)	X							CAM extended with complementary VAM information
C1	Signalling VRU hidden by an obstacle	X	X			X		X	
D1	Signalled few VRUs in a protected area	X	X			X	X	X	
D2	Non equipped VRUs crossing a road	X	X			X	X		
D3	VRUs crossing at a zebra protected by a traffic light	X	X	X		X	X	X	
D4	Scooter/bicyclist safety with turning vehicle	X	X			X	X		VAM is not used because it is an unequipped VRU
E1	Network assisted vulnerable pedestrian protection	X	X			X	X	X	
E2	Detection of an animal or pedestrian on a highway		X			X	X	X	
F1	Signalled many VRUs in a protected area	X	X		X	X	X	X	
F2	Intelligent traffic lights for all (P2I2V)	X		X			X	X	
NOTE: For UC-E2, the CAM is not used as it is not involved in the described use case. It could be present in an alternative use case when the central station disseminates a warning only in the case when it has detected an actual risk of collision, using the CAMs transmitted by the vehicles for this evaluation.									

Figure 25: ITS use cases supported by VAM

ETSI TS 103 300-2 [i.14] defines several types of VRU "profiles":

- VRU Profile1 - Pedestrian (e.g. human being moving without mechanical device, including children).
- VRU Profile2 - Bicyclist (includes e-bikes, e-scooters, skaters, etc.).
- VRU Profile3 - Motorcyclist (e.g. full-powered two-wheelers).
- VRU Profile4 - Animal presenting a risk to the other users.

6.2.2.2 Container structure and size

VAM and CAM have similar mandatory fields. The VAM container structure differs from CAM in the optional fields, with the introduction of "Cluster-Information", "Cluster-Operation" and "Cluster-Prediction" containers, as can be seen in Figure 26.

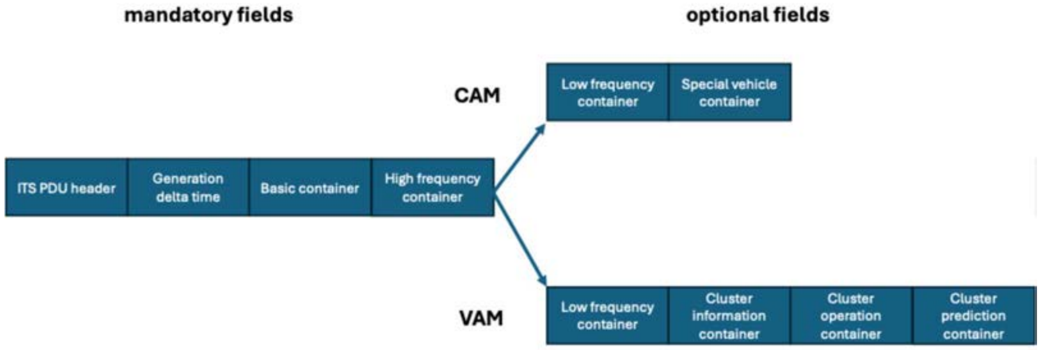

Figure 26: CAM and VAM mandatory and optional packet fields

Referring to VAM, there are two types of message:

1) Individual VAM, containing information about an individual VRU.

2) Cluster VAM, combining information of multiple VRUs.

As described in ETSI TS 103 300-3 [i.36], within a cluster, one VRU device takes the role of leader, and the others are members of the cluster. Leaders send VAMs containing cluster information and/or cluster operations, while members only send VAMs containing cluster operation container to join/leave the cluster.

A cluster is homogeneous if it contains devices of only one profile, e.g. only VRU profile 1 'pedestrian', it is heterogenous otherwise. This is an example of information contained in the cluster information container sent by the leader of the cluster. Any VRU device can lead a maximum of one cluster.

In general, the contents of VAM messages vary depending on the VRU profiles. General information includes position, time, and heading. This is shown more in detail in Figure 27.

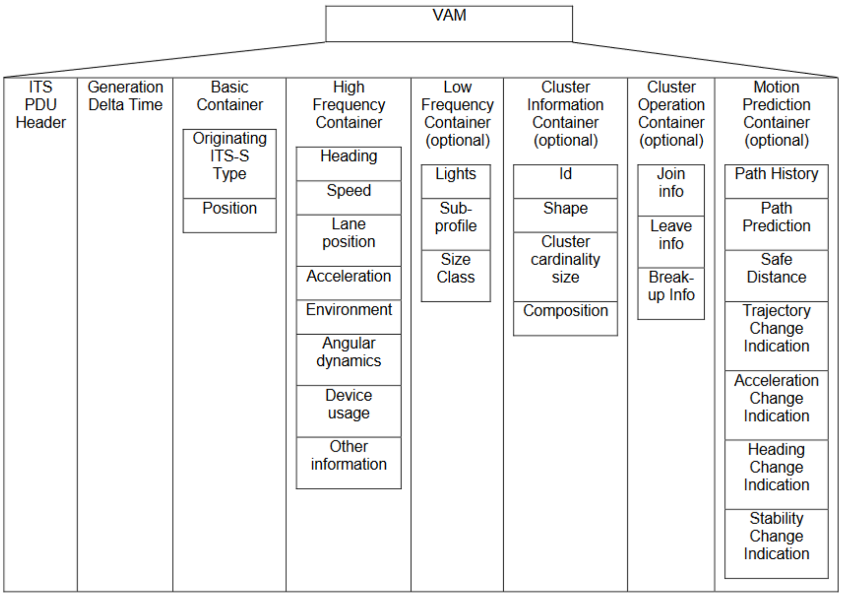

Figure 27: VAM container structure (ETSI TS 103 300-3 [i.36])

VAM containers, as defined in ETSI TS 103 300-3 [i.36], in ASN.1 format is available from ETSI forge repository, see Annex A of ETSI TS 103 300-3 [i.36].

VAM containers size is 114 bytes (using optional fields) according [i.37], and from 261 bits (~33 bytes) to 434 bits (~54 bytes) according to [i.38].

6.3 UWB as Access layer in ITS

6.3.1 Maximum transmit power within 1 ms and duty cycle

The allowed maximum transmit power levels described in clause 4.3.3, Table 2, are maximum mean e.i.r.p. PSD measured over a 1 ms average window (detailed procedure described in ETSI EN 303 883-1 [i.23], clause 5.3.2.3).

Thus, short messages can be transmitted at a higher instantaneous power (for example 1 ms packet at -44,3 dBm/MHz yields same PSD as a 0,5 ms packet at -41,3 dBm/MHz). Therefore, it is desirable to keep the UWB-ITS messages as short as possible to maximize range.

Regarding duty-cycle, the VRU type of devices have no restrictions, while vehicular devices are limited to 1 % duty-cycle and infrastructure devices are limited to 5 % duty-cycle, as further described in Table 2.

6.3.2 UWB ITS packets configuration profiles

For all the participating devices to be able to send and receive the UWB-based messages, a common set of UWB packet configurations, i.e. "profile" would have to be defined, for example defining the transmission mode and the PRF (for instance "HRP 124,8 MHz"), the preamble sequence, the SFD and PHR format, as well as the PSDU modulation and data-rate.

6.4 Resource management considerations

The UWB air interface represents an additional resource available for the use by ITS applications. It can be smoothly integrated into the general ITS Resource Management (RM) framework. By providing the specific services and capabilities of UWB to the applications and the RM entity in the facilities layer, they can be used by the applications requiring either high accurate positioning, low latency communication or ranging capabilities provided by the UWB technology.

In future work on RM these UWB capabilities may be considered.

7 Conclusion and outlook

UWB technologies provides a set of capabilities which can be used to enhance the existing ITS capabilities including communication, location/tracking and sensing. A standardized approach to introduce these capabilities as integral part of the ITS standard landscape would be very beneficial and cost saving.

Several use cases presented in the present document are already integrated into modern cars. Some of these uses cases already require a standardized approach in order to allow for a cross-sector usage, e.g. Key Less Entry systems using smart phones. Other uses cases like sensing applications can be based on proprietary solution.

An integration of UWB into ITS standards could significantly increase the advantages of the technology for safety related applications, especially to protect VRUs.

The definition of UWB messages for the different use case would be required. The starting point could be a UWB CAM/VAM messages format. Some of the presented applications (tolling, charging applications) will require the definition of a secure peer-to-peer protocol as part of the ITS protocol stack. In this case existing solutions in the UWB domain like secure keyless entry systems could be a starting point.

From the set of available UWB bands up to 8,5 GHz, the IEEE channel 9 (7 737,6 MHz to 8 236,8 MHz) seems to be the most promising target for an interoperable ITS UWB solution. A broader adoption of UWB in the automotive domain will require the addition of extension bands potentially above 8,5 GHz as under specification in CEPT.

Annex A (informative): Bibliography

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Annex B:
Change history

Date	Version	Information about changes
June 2023	V0.0.1	Initial version of TR
February 2026	V0.0.12	Version for approval

History

Version	Date	Status
V2.1.1	May 2026	Publication