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TECHNICAL REPORT

**Railways Telecommunications (RT);
Shared use of spectrum between
Communication Based Train Control (CBTC)
and ITS applications**

Reference

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Contents

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Railway Telecommunications (RT).

Modal verbs terminology

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Executive Summary

The present document summarizes the possible solution for a shared deployment of the CBTC systems for urban rail systems and cooperative ITS systems based on ETSI ITS-G5 in the band 5 855 MHz to 5 925 MHz.

In the band 5 905 MHz to 5 925 MHz all sharing proposals assume that CBTC urban rail safety related applications will have a prioritization over the C-ITS applications. In the band 5 875 MHz to 5 905 MHz C-ITS will have the priority. In the band 5 855 MHz to 5 875 MHz both systems are treated equally.

Different sharing mechanisms are proposed in the present document:

- Implementation of mitigation techniques on the ITS side like detect and avoid or geolocation based solution using 5 MHz CBTC systems.
- Deployment of the ETSI ITS access mechanisms in the CBTC system with 10 MHz channelization.
- Fully integration of CBTC as part of the 10 MHz based ETSI ITS systems with prioritization mechanisms in all protocol layers based on the existing Decentralized Congestion Control mechanism of the ETSI ITS system.

Introduction

The present document has been developed in cooperation with TC ITS in order to present to the Electronic Communications Committee (ECC) of the European Conference of Post and Telecommunications Administrations (CEPT) a common point of view regarding sharing possibilities between CBTC and ITS applications in the 5 875 MHz to 5 925 MHz frequency band.

After having clearly defined CBTC applications, the present document defines first the functional needs of CBTC regarding its communication. From that, technical needs for the communication system are derived, and the scenarios where sharing the spectrum between CBTC application and ITS road applications could be an issue are described. Finally the different technical means of sharing bandwidth are introduced and the next steps including a proposal for short term regulation are defined.

1 Scope

The present document investigates the possibility of shared use of spectrum between CBTC and ITS applications in the 5 875 MHz to 5 925 MHz under the assumption that CBTC applications have priority over ITS-G5 applications.

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

[i.1] ECC/DEC/(08)01: "ECC Decision (08)01 of 14 March 2008 on the harmonised use of the 5875-5925 MHz frequency band for ITS, and subsequent amendments".

[i.2] ETSI TR 103 111 (V1.1.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference document (SRdoc); Spectrum requirements for Urban Rail Systems in the 5,9 GHz range".

[i.3] CENELEC EN 50159: "Railway applications - Communication, signalling and processing systems - Safety-related communication in transmission systems".

[i.4] ETSI EN 302 665 (V1.1.1): "Intelligent Transport Systems (ITS); Communications Architecture".

[i.5] ETSI TR 101 607 (V1.1.1): "Intelligent Transport Systems (ITS); Cooperative ITS (C-ITS); Release 1".

[i.6] ETSI TR 102 638: "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Definitions".

[i.7] ETSI TS 101 556-1 (V1.1.1): "Intelligent Transport Systems (ITS); Infrastructure to Vehicle Communication; Electric Vehicle Charging Spot Notification Specification".

[i.8] ETSI EN 302 637-2 (V1.3.2): "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service".

[i.9] ETSI EN 302 637-3 (V1.2.2): "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service".

[i.10] ETSI TS 103 301 (V1.1.1): "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Facilities layer protocols and communication requirements for infrastructure services".

[i.11] ETSI TS 102 687 (V1.1.1): "Intelligent Transport Systems (ITS); Decentralized Congestion Control Mechanisms for Intelligent Transport Systems operating in the 5 GHz range; Access layer part".

[i.12] ETSI TR 101 612 (V1.1.1): "Intelligent Transport Systems (ITS); Cross Layer DCC Management Entity for operation in the ITS G5A and ITS G5B medium; Report on Cross layer DCC algorithms and performance evaluation".

[i.13] ETSI TS 103 175 (V1.1.1): "Intelligent Transport Systems (ITS); Cross Layer DCC Management Entity for operation in the ITS G5A and ITS G5B medium".

[i.14] ETSI TS 102 792 (V1.2.1): "Intelligent Transport Systems (ITS); Mitigation techniques to avoid interference between European CEN Dedicated Short Range Communication (CEN DSRC) equipment and Intelligent Transport Systems (ITS) operating in the 5 GHz frequency range".

[i.15] ETSI EN 302 571: "Intelligent Transport Systems (ITS); Radiocommunications equipment operating in the 5 855 MHz to 5 925 MHz frequency band; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU".

[i.16] ETSI EN 302 663: "Intelligent Transport Systems (ITS); Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band".

[i.17] IEEE 802.11™: "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".

[i.18] Standardisation mandate addressed to cen, cenelec and etsi in the field of information and communication technologies to support the interoperability of co-operative systems for intelligent transport in the european community (M/453 EN).

NOTE: Available at http://www.etsi.org/about/our-role-in-europe/public-policy/ec-mandates.

[i.19] ETSI TS 103 097: "Intelligent Transport Systems (ITS); Security; Security header and certificate formats".

[i.20] CEPT/ERC Recommendation 70-03: "Relating to the Use of Short Range Devices (SRD)", Tromso 1997, Subsequent amendments 07 February 2014".

[i.21] Commission Decision 2008/671/EC of 5 August 2008 on the harmonised use of radio spectrum in the 5875-5905 MHz frequency band for safety-related applications of Intelligent Transport Systems (ITS).

[i.22] ECC/REC/(08)01: "Use of the band 5855-5875 MHz for Intelligent Transport Systems (ITS)".

[i.23] Commission Implementing Decision 2013/752/EU of 11 December 2013 amending Decision 2006/771 on harmonisation of the radio spectrum for use by short-range devices and repealing Decision 2005/928/EC.

[i.24] IEEE 1474.1™-2004: "IEEE Standard for Communications-Based Train Control (CBTC) Performance and Functional Requirements".

[i.25] Brussels Regional Authority - Institut Bruxellois de Statistique et d'Analyse (IBSA).

3 Definitions and abbreviations

3.1 Definitions

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

data communication system: global communication architecture into which radio communication links are integrated

ITS station: communication equipment implementing an ITS protocol stack according to the ETSI ITS communication architecture

NOTE: Within the present document, this term is more specifically used for on-board units and roadside units transmitting in the ITS-G5 frequency band.

ITS-G5A: frequency band from 5 875 MHz to 5 905 MHz

ITS-G5B: frequency band from 5 855 MHz to 5 875 MHz

safety: freedom from unacceptable levels of risks resulting from unintentional acts or circumstances

security: freedom from unacceptable levels of risks resulting from intentional acts or circumstances

3.2 Abbreviations

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

AP	Access Point
ASIL	Automotive Safety Integrity Level
ASIL-A	Automotive Safety Integrity Level
ATC	Automatic Train Control
ATO	Automatic Train Operation
ATP	Automatic Train Protection
ATS	Automatic Train Supervision
C2C-CC	Car to Car Communication Consortium
CAM	Cooperative Aware Message
CBTC	Communication Based Train Control
CEPT	European Conference of Postal and Telecommunications Administrations
C-ITS	Cooperative Intelligent Transportation System
DCC	Decentralised Congestion Control
DCS	Data Communication System
DEC	DECision
DENM	DEN Message
DSRC	Dedicated Short Range Communication
EC	European Community
ECC	Electronic Communications Committee
EDCA	Enhanced Distributed Channel Access
EIRP	Equivalent Isotropically Radiated Power
EM	Electro Magnetic
GN	GeoNetworking
HW	HardWare
IEEE	Institution of Electrical and Electronic Engineers
IP	Internet Protocol
ITS	Intelligent Transportation System
ITS-G	5,9 GHz Cooperative ITS system
ITS-S	Intelligent Transportation System Station
LOS	Line Of Sight
MAC	Medium ACcess
MIMO	Multiple Input Multiple Output
NLOS	Non Line Of Sight
OEM	Original Equipment Manufacturer

OFDM	Orthogonal Frequency Division Multiplexing
OSI	Open Systems Interconnection
QPSK	Quadrature Phase Shift Keying
REC	RECommendation
SIL	Safety Integrity Level
SNR	Signal to Noise Ratio
SW	SoftWare
TAC	Transmit Access Control
TTT	Transport and Traffic Telematics
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
VRU	Vulnerable Road User

4 CBTC description

The primary public objective of this system is to provide urban rail and regional railway operators with a means to control and manage the train traffic on their own networks. Metro lines which are operated at a high level of performance and short intervals between successive trains are now installing Communications-Based Train Control (CBTC) systems.

CBTC is a wireless Automatic Train Control (ATC) system, more flexible and cost efficient than traditional ATC.

CBTC systems are deployed on urban and suburban train on dedicated tracks. Tramways, tram trains and buses are not covered by this system.

The standard IEEE 1474.1™ [i.24] gives the following definition:

A CBTC system is a continuous, automatic train control system utilizing:

- high-resolution train location determination, independent of track circuits;
- continuous, high-capacity, bidirectional train-to-wayside data communications;
- train borne and wayside processors capable of implementing automatic train protection (ATP) functions, as well as optional automatic train operation (ATO) and automatic train supervision (ATS) functions.

CBTC application requirements are defined in the standard IEEE 1474.1™ [i.24].

CBTC systems allow running trains only 90 seconds apart with total safety for the passengers and the staff (or even less, the headway depending upon time spent by the train at every station for passengers to leave and board trains, the distance between stations and profile of the line as well as the possible acceleration, maximum speed and deceleration of the train).

5 Market information

The automation of existing urban rail lines and the development of fully unattended metro operation (no staff on board) are booming and represent tomorrow's challenges in this sector. Millions of passengers use urban public transport every day (in Europe 31,6 million daily passengers in 48 cities only for metro), and the European Union's modal shift objective means more people using public transport. CBTC markets have been presented in ETSI TR 103 111 [i.2].

6 CBTC Technical information

6.1 CBTC Communication needs

Although IEEE 1474.1™ [i.24] defines the CBTC system and its requirements, the system itself as a whole is not fully standardized which means that some parts, and in particular its communication system, are implementation dependent.

The MODURBAN project issued a functional requirement specification for CBTC systems, and a MODURBAN architecture document (partially public), which allocates functions to a system or subsystem level but leaving some open options and without fully specifying in details the interfaces.

As a consequence, the needs for communication and the definition of messages to be exchanged are not standardized, even if some metro authorities promoted interoperability specifications which enable the construction of a complete CBTC system by assembling subsystems from different manufacturers: one company can provide the wayside ATC subsystem, while another one can provide the on-board ATC subsystem, a third one can provide the data communication system, a fourth one can provide the ATS.

Achieving such compatibility of the subsystems require that an interoperability specification fully defines the interfaces, which include, of course, an extensive definition of all the data exchanges through the radio channel: definition of the protocols, list of the messages, size and detailed consist of each message in terms of functional data, performances including rates of emission and reception for each communicating piece of equipment and each type of message. Nevertheless these interoperability specifications, when they exist, are project dependant.

Finally, the level of performances (for example the headway between trains or the guaranteed reaction time of the system to an unexpected safety hazard) highly influences the requirements allocated to the communication system: it drives the amount of data to be transmitted, the frequency at which they need to be transmitted and the quality of the transmission such as the frame error rate and the latency of the transmission.

Therefore it should be pointed out that all the data given below are based on principles and existing implementations and are used as an example to justify the common needs for communication of CBTC, but cannot be seen as characteristics fulfilled by all CBTC systems on the market.

CBTC communications can be classified in different groups based on their conditions for transmission, and also based on their criticality regarding the system performance.

Some messages need to be transmitted and received regularly in order to ensure that on-board and wayside CBTC subsystems are continuously up-to-date (typically while a train is moving and updating its location) and to ensure they can 'monitor' each other for a safe evaluation of critical functions performed by the other interoperable subsystems. Such messages are typically transmitted periodically and are therefore known as "periodic data". Different periods may coexist at the same time on a same interface.

EXAMPLE: From the above-mentioned interoperable CBTC applications, some messages are transmitted at a period of 200 ms while others are transmitted every 360 ms and some others at a period of a few seconds.

The transmission requirement for periodical data generally gives the base for the calculation of the "mean" required throughput for CBTC. The following periodic CBTC messages are transmitted from train to wayside:

- **A 'Location Report' message** sent by the on-board CBTC of each train to the wayside CBTC ('Zone Controller'). These messages help the Zone Controller to continuously track the trains' position on a portion of the metro line designated as its 'territory'. It should be noted that a train generally communicates with one Zone Controller but it may also have to communicate with two Zones Controllers in order to handle smooth transition from one territory to the next one at their common border. It may even have to anticipate communications with 3 Zone Controllers in some specific configurations (for example when the track is subdivided into two diverging branches).

  The 'Location Report" message includes data such as the location of both ends of the train, its speed, the train consist, etc.

  If that message is received with a delay greater than 100 ms, then it is no longer useful and will be considered as lost by the receiver: only fresh messages can ensure the safety of the application. No messages of that type received during N seconds from a train will stop the transmission of the Movement Authority messages authorizing that train to run (N depends on the specified headway, and can be down to 1 second for highly efficient CBTC).

- A **functional status message** sent by each train to the automatic train supervision system, which is less vital but contains more data: it includes information about the train position but also any modifications of the rolling stock which can influence the operation, and the health status of any on-board redundant equipment, to detect latent failures (hardware failures which have no functional impact but reduce the level of redundancy) and fix it before a second failure occurs and many other items of functional information, and, when there is a driver on a train, some reports on his actions.

- Messages necessary to control and ensure safe monitoring of the **platform doors** (where existing), also sent cyclically when the train is at a station. Very short delays of transmission are required to ensure fast passenger exchange at the station.

The following CBTC periodic messages are transmitted from wayside to train:

- Messages informing the trains about the status of the variable elements in the area where the train is and in the area it will reach soon (such as a work zone, a low adhesion zone, a malfunctioning signal, etc.). Such information is common to several concerned trains which are in the same area.

- Messages informing the train about its Movement Authority: this message identifies the zone ahead of the train in which it can safely operate without colliding with a fixed or moving 'obstacle'. Such information is specific to each communicating train. No messages of that type received during N seconds by a train will trigger an Emergency break for that train, and can also have consequences on following trains.

- Messages necessary to control and ensure safe monitoring of the **platform doors** (where any). These messages are also sent periodically when the train is approaching and docked at a station.

In addition, it is also sometimes necessary to send quite a high volume of data to a train to update the track database it is using. To be transparent for train operation, these data are transmitted from the wayside as the train moves forward.

The CBTC payload contains the functional information described above, but also an important amount of data to ensure the security and the safety of the transmitted messages such as safety codes or safety timestamps.

The resulting CBTC payload throughput is therefore between a minimum of 30 kb/s for the periodic data of a train under the responsibility of a single wayside zone controller and without platform doors, and up to 50 kb/s for a train under the responsibility of three zone controllers and with platform doors. With the additional non periodic data, the throughput can be increased by 100 kb/s.

In summary the CBTC train-to-wayside throughput requirements (without redundancy) are between 30 kb/s and 150 kb/s, with typical packet length between 200 bytes and 500 bytes.

In order to allow short headways performances, a low latency of the transmission (less than 100ms) and a very low frame error rate is required. Typically a value of maximum 1 % of frame error rate is taken into account to calculate the performances of the complete CBTC system.

6.2 Simultaneous CBTC communications in a given geographical area

Very often there can be two trains stopped in a station (one on each track) and two trains in each interstation (one on each track) with a typical interstation of 600 meters length. So a density of 6 trains per linear area of 1,2 kilometres length is a minimum to be taken into account.

In the case of a track configuration with two diverging branches, 2 additional trains should be added, so a density of 8 trains is taken into account.

In degraded mode, if congestion occurs, it could happen that 2 trains are in an interstation instead of only one.

Therefore the density of trains per linear area of 1,2 kilometres can reach 12 trains.

Depot and stabling area

In this case, the trains can be parked with only a few meters between them on the same track, and many tracks can be in parallel.

The real density is depending on the train length, but a good order of magnitude is typically 36 trains in an area of 500 m × 20 m.

In case of fully automatic operation, all the trains in the depot continue to transmit the periodic data defined above to a single zone controller, without dataflow for the platform doors. They therefore need to exchange 30 kb/s of periodic data per train.

In addition it should be possible to download log files, or to upload new database to several trains.

As a result the throughput per train is doubled compared to the one of train running on mainline.

6.3 Propagation parameters of CBTC radio communication

6.3.1 General CBTC radio properties

For the 5,9 GHz band, directional antennas are easy to manufacture and are well suited to ensure radio coverage of linear tracks.

At the time the current document was prepared, CBTC did not use a standardized access layer technology. A set of different modulation schemes, MAC and radio bandwidths are used by current implementations.

6.3.2 Propagation in tunnel

Thanks to the attenuation brought about by the tunnel itself, the level of electromagnetic noise seen in the tunnel is much lower than outside. Conversely, the signals transmitted inside of the tunnel are not seen outside. Only the signal transmitted by the wayside radio installed at the entrance of the tunnel can be received outside and can be considered as an outdoor wayside radio.

6.3.3 Propagation Outdoors

6.3.3.1 On line

Directional antennas are employed both on wayside and in the trains. They concentrate the radiofrequency signal along the tracks and therefore increase the coverage distance and the protection against external interferences outside of the axis of the tracks.

Wayside antenna are installed along the tracks and have a gain between 16 dBi and 24 dBi. The distance between successive Access Points has a mean value of 500 m. Therefore the width of the area receiving significant level from the wayside CBTC transmitter is restricted to a maximum width between 90 m and 180 m along the tracks.

With a typical antenna that has a gain of 18 dB and an aperture of 18°, the level that will be received at a distance higher than 180 m from the track is < -90 dBm/MHz for an EIRP of 20 dBm/MHz in the frequency band 5 875 MHz to 5 925 MHz.

Train antennas are also directive, with typical gains between 9 dBi and 12 dBi. They are installed either in the train behind the windscreen, or on the roof of the train. The area receiving significant level from the wayside CBTC transmitter is restricted to a maximum width between 150 m and 250 m along the tracks.

6.3.3.2 In depot or stabling area

To cover depots, antennas with wider aperture are chosen in general, and the coverage is established on a well-defined area.

6.4 Mandatory characteristics to ensure CBTC safety

For CBTC, mass transit operators have critical requirements which are classified at the highest Safety Integrity Level (SIL4). This level is equivalent to the highest one in aeronautics and nuclear plants, and exceeds the current classification of the automotive industry (ASIL-A to D). This level implies enforcing formal methods for specifications, development, and validation of HW and SW parts, then of the whole systems. CBTC systems have been deployed for more than 15 years in several European countries under national exclusive agreements in the upper 5 GHz band.

From a safety point of view, CBTC considers its DCS part as an untrusted means of communication and uses dedicated application protocols to ensure vital exchanges of the application data.

According to CENELEC EN 50159 [i.3] the requirement transferred to the CBTC communication system is to ensure a sufficient level of access control (cyber security): authentication of all participants in the communication system, integrity and confidentiality of the transmitted data have to be ensured.

In addition, the content of the messages and the protocol of data transmission itself have to ensure the safety: the way to timestamp the transmitted information and the evaluation of the possible default of synchronization between CBTC components is a big part of that. The reception of too many stale (or time-expired) messages is considered by the safety applications as an abnormal and potentially dangerous situation, and can lead to a fail-safe reaction (stopping the train). The evaluation of the position of the train also takes into account a lot of criteria, in order to avoid any unsafe decision. Data rate, sampling rate, buffering processes, latency and packet integrity are analysed during the functional safety assessment process and cannot be changed after safety demonstration.

Furthermore the communication system should not create any additional risk of intrusion into the CBTC system which could create a possibility of a secondary level of attack such as software or configuration modification after illicitly obtaining a password.

Finally, from a more general point of view, proper functioning of CBTC and therefore efficiency of the transport system and the safety of passengers are based on highly reliable communication links between wayside and on-board CBTC. External interference on the frequency band used by CBTC can cause repeated disturbances making the transport system inoperable. This was demonstrated on the occasion of the introduction of new mobile communication services on a Chinese public metro network when traffic was completely stopped.

6.5 Mandatory characteristics derived from the CBTC availability needs

In any place on a metro line, CBTC train and wayside applications exchange information. In case of loss of connection, the train will stop automatically. This situation can have a strong impact on safety of passengers, as any situation leading to passenger evacuation could possibly generate panic movement.

To maximize the availability of connections between train and wayside applications, path diversity is required. Each train has a minimum of two radio paths with the wayside radio infrastructure. Each radio path operates on two channels with a different carrier frequency.

In most cities which have a metro network, some lines cross each other, or can have some tracks in parallel in some areas (common stations, for example).

Lines are working with completely independent systems, which can come from different manufacturers. Therefore, to keep the independence and performances in that situation, 2 pairs of channels are required.

Service availability requires redundancies and their management from the applicative level. Redundancies are relevant for control equipment, networking units and transmitting devices as well. It is comprehensive to add redundancies at network level, using switches, multiple links or meshed sub-networks. At transmitting level, redundancy is not enough. A high grade of diversity is required, in order to cope with the weakness of EM propagation in various physical environments: LOS, NLOS, with multi-path, multi-mode and spatial filtering.

It is common to combine 3 to 4 types of diversity. One type is generally kept for redundancy, e.g. a whole communication channel. The other types are devoted to improving availability: frequency diversity, polarization diversity, MIMO, spatial diversity (head & end of train) and macro diversity using simultaneous connections to several successive AP's. The last one is very efficient in tunnels, when trains are masking each other at a moderate distance from the current AP. All types of diversities being combined, a train can maintain more than 4 simultaneous links with wayside, and the wireless coverage should be continuous.

6.6 Summary of CBTC communication requirements

Table 1 summarizes the communication needs of a typical CBTC system.

Table 1: CBTC communication requirements

Criteria	Value
Payload throughput	Between 30 kb/s and 150 kb/s per train on a channel (but this data should be sent redundantly in parallel on 2 different channels by the two train ends)
Typical train density	12 trains for 1,2 km length of double track 36 trains in depot
Minimum number of channel needs	4
Maximum frame error rate or frame loss when the communication is available (a message received after too much delay is considered lost)	1 %
Availability of the communication	99,999 % (as a consequence of a high level of redundancy)
Maximum delay (end to end transmission between CBTC application devices)	100 ms
Data security to ensure train safety	Compliant with CENELEC EN 50159 [i.3]. See also clause 6.4.

6.7 CBTC typical line description

6.7.1 In tunnel

- Brussels: 68,7 km of tunnel tracks: 88,7 % of total track length (77,44 km).
- Paris: 187,9 km of tunnel tracks: 91,4 % of total track length (205,8 km).
- Madrid: 276 km of tunnels tracks: 94,2 % of total track length (293 km).
- Vienna: 30,2 km of tunnels tracks: 38 % of total track length (78,5 km).

6.7.2 Outside

Tables 2, 3, 4 and 5 show the line description for the Brussels, Paris, Madrid and Vienna networks.

Table 2: Line description for the Brussels network

Total Track length	77,44 km		% 400 km big road length
Outside: Track and road at the same level	4,019 km	5,2 %	1,009 %
Outside: Track and road at a different level (open trench)	4,692 km	6,1 %	1,173 %
Tunnel length	68,73 km	88,7 %	

Table 3: Line description for the Paris network

		% of total track length
Total Track length	205,8 km	
Outside: Track and road at the same level	9,6 km	4,6 %
Outside: Track and road at a different level (viaduct)	8,3 km	4 %
Tunnel length	187,9 km	91,4 %

Table 4: Line description for the Madrid network

		% of total track length
Total Track length	293 km	
Outside: Track and road at the same level	17 km	5,8 %
Tunnel length	276 km	94,2 %

Table 5: Line description for the Vienna network

		% of total track length
Total Track length	78,5 km	
Outside: Track and road at the same level	48,3 km	62 %
Tunnel length	30,2 km	38 %

7 ITS Technical information

7.1 ITS description

In response to the EU standardization request M/453 [i.18], ETSI has issued a first release of the standards to enable the deployment of a set of Cooperative ITS applications. In particular, a set of ITS G5 access layer specifications in the 5 GHz frequency band have been published.

NOTE: The documents that form Release 1 of Cooperative ITS (C-ITS) are listed in ETSI TR 101 607 [i.5].

The applications specified in release one focused on Vehicle to Vehicle and Vehicle to Infrastructure applications, as defined in ETSI TR 102 638 [i.6]. Among multiple applications, road safety applications are most demanding in terms of data quality, communication reliability and management performance in network congested situations. For instance, the road hazard signalling applications ETSI TS 101 556-1 [i.7] specifies the application requirements and data transmission requirements for V2V and V2I road safety applications that enables the detection in real time of a road hazard or a dangerous driving behaviour of a vehicle, and in accordance triggers the transmission of warning messages to other traffic participants. ETSI EN 302 637-2 [i.8] and ETSI EN 302 637-3 [i.9] specify high layer message sets and protocols for the road safety applications, enabling vehicles to exchange high dynamic information with other ITS stations in the ITS network. Typically, vehicle ITS station broadcasts the Cooperative Awareness Messages (CAM) at maximum rate of 10 Hz, providing real time high dynamic information of the vehicle, such as position, time, basic sensor data, vehicle type, size, etc. In addition, when an ITS-S detects an abnormal road hazard situation, such as potential collision, stationary vehicle, emergency vehicle approaching, hazardous weather situations etc., it triggers the transmission of a Decentralized Environmental Notification (DENM) messages to other ITS-Ss located in the relevant geographic area ranging from several hundred meters to several kilometres. The transmission of DENM may persist at a typical transmission rate of 10 Hz, as long as the detected event persists.

Upon reception of CAM, DENM, an ITS-S processes the information for the application usage such as detection of potential collision risk. Typically, in order to correctly evaluate the relevance of the message and to determine the probability of the collision, the receiving ITS-S should reconstruct the itinerary of the counterpart vehicle by the received CAM or DENM messages.

The European Industrial Consortium C2C-CC is currently developing the profile standards for ETSI ITS release one standards. In C2C-CC profile standards, CAM transmission is started as long as vehicle ignition is on, and as long as the position and time information is available. Therefore, CAM transmission will persist when vehicle is in the proximity of an urban rail vehicle.

Meanwhile, road side ITS-S provides road side information to road users using ITS networks, such as road signage information, traffic light phase and timing information (including the level crossing light information) and road topology data. At the reception of the road side information, vehicle ITS-S or mobile ITS-S may process the information for application usage, such as informing driver of the road signage information (e.g. speed limit) or adjust the speed to pass the intersection (Green Light Advisory Speed Information). The transmission behaviour and protocols for the message handling of the infrastructure messages are specified by ETSI TS 103 301 [i.10].

The ITS G5 and protocol stack has been subjected to several national and European large scale Field Operational Test projects e.g. DRIVE C2X, SCOREF. Currently, pilot projects are ongoing in Europe, involving both the Original Equipment Manufacturer (OEM) and Road Operators for a regional scope deployment and pilot tests. For instance, the Corridor project is realizing a large scale pilot in Germany, Austria and the Netherlands. The French SCOOP project is setting up a pilot test places in multiple regions in France, including the Paris region, Grenoble, Bordeaux, etc.

Since 2014, ETSI TC ITS has triggered the standardization work of its release 2 specifications. This standardization work is currently ongoing, with main focus on C-ITS for future autonomous driving applications, and other ITS applications for smart cities and for personal mobility. For instance, new Work Items have been set up in ETSI TC ITS for Cooperative Adaptive Cruise Control, Platooning, and Vulnerable Road User safety applications. The application requirements defined by these applications will bring inputs to future standardization work of the communication protocol stacks at lower layer. It is foreseen that communication requirements for such new applications may be more demanding, in terms of message transmission frequency, data quality, or message reception success rate etc. In addition, the Vulnerable Road User (VRU) applications would implement ITS applications on personal portable devices, and enables communications between these devices, between personal devices to/from vehicles, and to/from road side infrastructure.

7.2 Intelligent Transport System communication architecture

ETSI EN 302 665 [i.4] has defined a communication architecture for ITS derived from the OSI model.

This is an open standard supporting GeoNetworking (GN) IP stack and multiple access technologies, including G5.

7.3 Networking and transport

The C-ITS messages of ITS-G5 use the GeoNetworking (GN) protocol in the networking and transport layer.

The GeoNetworking protocol supports the following communication routing:

- point to point;
- point to multi point;
- message dissemination with a defined hop count;
- message dissemination within a defined geographic area;
- multi hop routing to a geographic area;
- transport of IPv6 packets over GeoNetworking.

ITS-G5 also supports a plain IPv6 networking and transport layer, but the use of IPv6 is not standardized for C-ITS specific messages at the time of publication of the present document.

7.4 Access

The radio interface of ITS-G5 is specified in ETSI EN 302 571 [i.15] and ETSI EN 302 663 [i.16]. It is based on IEEE 802.11™ [i.17] and uses a 10 MHz channel bandwidth OFDM signal. The default configuration uses a QPSK modulation of the OFDM carriers with a coding rate of 1/2. The resulting data rate is 6 MBit/s. A lot of other configurations are supported and specified in ETSI EN 302 663 [i.16]. The transmit power level is limited by regulation to 33 dBm, and the default value is 23 dBm.

ITS-G5 uses the CSMA/CA MAC protocol as specified in IEEE 802.11™ [i.17]. Packet prioritization is done by the EDCA mechanism with four different access categories as specified in IEEE 802.11™ [i.17].

7.5 Security

ITS G5 security is specified in ETSI TS 103 097 [i.19].

7.6 Decentralized Congestion Control

Decentralized Congestion Control (DCC) is a mandatory component of ITS-G5 stations operating in ITS-G5A and ITS-G5B frequency bands to maintain network stability, throughput efficiency and fair resource allocation to ITS-G5 stations. A set of access layer DCC mechanisms has been specified in ETSI TS 102 687 [i.11]. It should be noted that DCC functionalities reside in different layers, and are jointly managed by DCC management plane. An operational requirement of DCC is to keep the actual channel load below predefined limits. The element DCC_access control maintains a state machine of DCC level that is transit among RELAXED state, RESTRICTIVE state and ACTIVE state depending on the measured channel load. The ETSI TS 102 687 [i.11] specifies a reference model for channel measurement. According to the channel load, one or more than one DCC mechanisms may be combined at per-channel and per-packet base, reflected by setting of access layer parameters:

- Transmission power control: adjusting of the transmit power parameter based on DCC state.
- Transmission rate control: adjusting the packet transmitting timing parameter based on DCC state. Timing thresholds are divided into packet duration thresholds and packet interval thresholds.
- Transmission data rate control: adjusting of transmission data rate based on DCC state.
- Transmit Access Control (TAC): it is the DCC_access mechanism that supports the operational requirement of fair channel access. In case of high channel load the TAC is more restrictive to ITS-stations that transmit many packets.

ETSI TR 101 612 [i.12] further introduces Cross Layer DCC Management Entity for operation in the ITS-G5A and ITS-G5B medium. This Technical Report specifies DCC overall functional architectures and data exchanged between different layers and DCC management plane. In addition, ETSI TR 101 612 [i.12] provides a guideline for the channel load measurement and test procedure, as well as the evaluation metrics. The output of the present document has triggered a related Technical Specification (ETSI TS 103 175 [i.13]).

7.7 CEN DSRC co-existence mitigation

The band 5 795 MHz to 5 815 MHz has been harmonized for the use by Transport and Traffic Telematics (TTT), also called CEN DSRC, by the EC decision 2013/752/EU [i.23] and the ECC recommendation ECC/REC/70-03 [i.20], which is primarily used for road charging systems in Europe and elsewhere. With ECC/DEC/(08)01 [i.1] and ECC/REC/(08)01 [i.22], ECC has recommended the band 5 855 MHz to 5 875 MHz (REC 08/01) and decided 5 875 MHz to 5 925 MHz (DEC 08/01) to be used for Intelligent Transport Systems (ITS). In addition, the band 5 875 MHZ to 5 905 MHz has been harmonized for the use in the EU according to EC decision 2008/671/EC [i.21]. These documents recommend ITS systems to be designed and to be operated in a way to avoid harmful interference to TTT. In 2012, ETSI has published ETSI TS 102 792 [i.14] which specifies necessary measures to avoid such harmful interference. For ITS stations, the mitigation mainly consists of complying with some transmission restrictions in the immediate vicinity of the position of CEN DSRC tolling stations, denoted as protected zone. The goal is to restrict the unwanted emissions of an ITS station within the vicinity of a CEN DSRC tolling zone.

CEN DSRC stations may enhance their adjacent channel rejection (blocking) capabilities such that the interference from the ITS stations is reduced.

When an ITS station is close to a CEN DSRC tolling station (entering the protected zone), it operates in coexistence mode:

- transmit duty cycle is limited; and/or
- output power level and unwanted emissions are reduced.

Four coexistence modes are defined, specifying which combinations of transmit power limits and duty cycle restrictions are possible. At low transmit power, duty cycles are not restricted; at maximum output power, duty cycle limits are more strict. Duty cycle restrictions are defined by specifying the required minimum idle time (T-off), which depends on the maximum transmission time (T-on). One co-existence mode is used by an ITS-S, as long as it is located in the protection zone.

In addition, ETSI TS 102 792 [i.14] further specifies means to enable ITS-S to detect a CEN DSRC protection zone. It may be determined by radio detection of the CEN DSRC tolling signal or by a search among all stored protected zone centre positions. These positions were either received by CAM messages or are stored in a database.

8 Sharing Issue

8.1 Sharing scenarios

The sharing scenarios between CBTC application and ITS applications are limited to geographical area where:

- CBTC transmission devices could receive signal from ITS devices and be disturbed; and/or
- ITS transmission devices could receive signal from CBTC devices and be disturbed.

In other areas, both applications are not disturbing each other.

Considering that both kind of application have to share the same frequency band, the definition of these areas is determined by the set of following parameters for each application:

- maximum transmitted power (EIRP);
- antennas diagrams;
- minimum signal to be received;
- maximum signal to interference ratio supported;
- attenuation brought by the environment (e.g. tunnel walls attenuation).

The sharing scenarios taken into consideration are limited to the following:

- Parallel CBTC tracks and roads.
- Crossing CBTC tracks and roads at different level (viaduct, etc.).
- Road in the axis of a track until a certain distance (bridge, curve of the track).
- Entrance of CBTC tunnels.
- Around CBTC depot or stabling area.

Sharing with personal ITS-G5 devices inside trains are not considered in the present document since specifications are not defined.

To illustrate the fact that these areas are limited, a detail case study of the Brussels Metro has been made (see annex A).

8.2 Technical Sharing Solution

8.2.1 Different sharing proposals

One of the following sharing proposals should be considered to avoid interference between ITS-G5 and CBTC systems.

It is necessary to distinguish between different mitigation methods and methods to detect a mitigation area.

The following mitigation methods can be identified:

- Avoiding interference by geographic separation.
- Changing the transmit parameters including transmit power control, duty cycle restrictions and vacating the channel.
- Packet collision avoidance on a common ITS-G5 access layer protocol.
- Channelization and dynamic channel/frequency selection.

Methods to detect a mitigation area are:

- Geographic database.
- Detection of the CBTC signal.
- Warning beacon: message transmitted by CBTC system to ITS to inform this one about its presence in order to activate mitigation.

The avoidance of interference by geographic separation is possible only for fixed services and therefore it is not applicable to ITS-G5.

Sharing the bandwidth without the need for a detection method is possible if duty cycle restrictions or a common access layer with sharing mechanisms are applied. Duty cycle restrictions allow channel sharing in a less coordinated way, at the cost of more frame collisions. Frame collision can also occur when using the same MAC layer.

All other mitigation methods need to detect the mitigation area with one of the above mentioned methods.

8.2.2 Mitigation methods

8.2.2.1 Changing the transmit parameters

If a CBTC mitigation area is detected, any ITS radio devices could use one or more of the following techniques to mitigate interference by reducing the number of channel access attempts:

- Stop communication in the channel until the mitigation area is left. This will prevent the use of some ITS applications.
- Reduce the frame rate to ensure that the minimum CBTC frame rate requirement is satisfied even in the worst case scenario (highest possible number of ITS transmitters in the area).
- Reduce the frame rate to ensure that the minimum CBTC frame rates is satisfied based on the level of load of the channel locally (e.g. the ITS radio devices could reduce for a certain time their number of attempts to access the channel. by changing the values of various DCC parameters).

The following parameters should be reconfigurable depending on the mitigation technique:

- Threshold level for Detection.
- Period during which an ITS radio device should not use a channel where a CBTC signal has been detected.
- Percentage of reduction for the number of channel access attempts.

A mechanism should be made available to update the value of these parameters over time. The purpose of this update mechanism is to allow progressive adjustment based on gained experience.

In summary this approach needs some more detailed investigations to test its feasibility, like some investigations whether ITS-G5 safety services can reduce their output power level and/or their transmit duty cycle when they are close to CBTC installations. Also it should be investigated how large the protection areas need to be.

In order to define the needed transmit parameters the following information is necessary:

- An analysis of received levels by the CBTC radio system from the ITS radio systems for the different sharing scenarios defined in clause 8.1. These levels will be compared to acceptable SNR for CBTC radio devices.
- A traffic model of the ITS radio system to model the impact of ITS traffic on CBTC communication and define the worst case.

8.2.2.2 Harmonized access layer protocol

If both ITS and CBTC appear as different applications using the same ITS-G5 access layer protocol, each device is able to receive all the messages and distinguish between CBTC and ITS messages without specific physical measurement.

To reduce hidden node problems, the transmit power level of both technologies should be the same. If they are different, then the devices using higher transmit power will have a higher chance to obtain access to the channel and transmit its packets.

The CSMA/CA MAC of ITS-G5 avoids packet collisions very efficiently when the radio channel is not overloaded. To avoid a channel overload, all ITS-G5 devices implement a decentralised congestion control (DCC). This ensures low packet loss rates for high priority packets (EDCA access class "video"). The DCC reduces automatically the ITS-G5 transmission rate when the channel gets highly loaded.

If CBTC is transmitting its packets with a higher priority than ITS-G5, then it will have more channel access opportunities with minimum delay. This requires that both ITS-G5 and CBTC do not saturate the channel. DCC can avoid channel saturation, if implemented by all systems using the channel.

This approach needs some investigations regarding the ITS-G5 DCC configuration to meet the CBTC requirements.

8.2.3 Methods to detect a mitigation area

8.2.3.1 Geographic database

While all the channels are available for ITS applications outside of CBTC territory without restriction, mitigation techniques are necessary within the area where both systems can share the spectrum. One possibility to detect the mitigation area is to use a database where all the information related to the channel usage is stored.

Further investigation to define the structure and management of this database is recommended.

8.2.3.2 Detection of the CBTC signal

A detect and avoid mechanism could be used when CBTC and ITS radio systems are operating on same channels but with two different channel bandwidths: 5 MHz for CBTC and 10 MHz for ITS.

The detect and avoid mechanism should be based on existing mechanism with minimum adaptation.

For the detection, a part of the CSMA/CA mechanism can be used.

Since the packets transmitted by CBTC radio devices in a channel bandwidth of 5 MHz will not be recognized by the ITS radio devices a detection should be performed. An ITS radio device should measure the received level and should also estimate the bandwidth to make a difference between an ITS transmission and a CBTC transmission.

Since the access layer of CBTC is proprietary, it should be investigated how to detect all possible CBTC signals. Otherwise this could be a severe safety issue, since the ITS-G5 safety service could be blocked by any interference signal.

8.2.3.3 CBTC warning beacon

CBTC warning beacons would inform ITS devices about their entry into a CBTC area where they need to adapt their behaviour.

These beacons would use ITS communication protocol and therefore ITS devices would not need to implement a specific measurement mechanism.

Deployment of the warning beacons would be CBTC's responsibility.

A viable mitigation system could include both a geographic database and warning beacons.

8.3 Security concern

Sharing the same channel between two applications with different needs based on a supposed priority scheme respected by both application devices introduces new risks which need to be covered.

- Risk for CBTC:
  - Modified ITS device which would not reduce their usage of the channel in which CBTC has priority when they should (either due to failure of detection or on purpose as attack).
- Risk for ITS:
  - False "CBTC" transmitter, forcing unnecessary reduction of transmission for ITS application where not necessary.

In any case, a mechanism preventing any modifications of the device using the ITS and CBTC channels should be put in place.

8.4 Sharing conditions

8.4.1 ITS Conditions

It is recommended that ITS-G5 safety critical communication should not be disturbed by providing to ITS-G5 the highest priority in the frequency range from 5 875 MHz to 5 905 MHz.

If the mitigation technique does not allow ITS to access the frequency band 5 905 MHz to 5 925 MHz then this can only be accepted for very limited areas in cities.

In the present document only Urban Rail is studied. The use of the same CBTC technology for main line and suburban trains could increase the area for band sharing because many rail tracks run in parallel with roads, and would require the use of mitigation techniques that allows ITS to use the same channels and ensures ITS service availability on roads and highways.

Different mechanisms are required for applications using the ITS frequency bands. Based on this, a harmonized access protocol benefits from established methods for channel load balancing among applications within the ITS band (i.e. DCC) and coexistence with other applications (e.g. DSRC/tolling).

8.4.2 CBTC Conditions

It is recommended that CBTC safety critical communication should not be disturbed by providing to CBTC the highest priority in the frequency range from 5 905 MHz to 5 925 MHz.

Conditions to be taken into account to be compliant with CBTC security and safety recommendations:

- Data communication system does respect CENELEC EN 50159 [i.3].
- Data communication system does not modify the content of application message.
- Data communication system does not affect message integrity.
- Data communication system performances for CBTC fulfil the parameters given in table 1, even in the worst case situation regarding the number of ITS devices in the area.

9 Conclusion

The present document presents different approaches for achieving sharing between CBTC and ITS application which are summed up in the tables 6 and 7.

The following different approaches for detection and mitigation (see tables 6 and 7) can be used for a shared spectrum access between ITS and Urban Rail:

- ITS systems stop transmitting in the mitigation area of Urban Rail.
- ITS systems reduce duty cycle in the mitigation area of the Urban Rail system.
- DCC based duty cycle reduction in the mitigation area.
- Harmonized access layer, e.g. CBTC system use extended ITS protocol with the highest priority allocated to CBTC applications in the band 5 905 MHz to 5 925 MHz, lower priorities in the rest of the ITS bands (5 855 MHZ to 5 905 MHz).

Further investigations need to be made to better understand the feasibility of all the proposed approaches including the CBTC protection area size.

A fully integrated CBTC solution as part of ITS (harmonized access layer) could be considered for a long term solution in order to further improve the spectrum efficiency. This solution might severely impact existing CBTC implementations. For this solution an update of the existing ETSI ITS set of standards would be required to include the specific requirements of the CBTC communication system.

Without a harmonized access layer, an additional mitigation technique on the ITS side might lead to a reduced usability of the band for safety related ITS operations. For such an approach no or only limited changes to the existing CBTC implementation would be required. Additional requirements for mitigation on the ITS side are not today integrated in the current spectrum regulation and respective harmonised standards.

Table 6: Possible mitigation methods

	Changing the ITS transmit parameters when inside a mitigation area			**Harmonized access layer protocol**
	Stop transmitting	***Reduce fixed duty cycle limit***	***Reduce duty cycle limits based on the channel load***	
Technical implementation	ITS G5 stop transmitting.	ITS G5 reduce duty cycle.	ITS G5: Measure the channel load. Change the duty cycle according to channel load.	CBTC implement ITS G5 access layer protocol and encapsulate its messages.
CBTC channel definition	Free channelization within 5 905 MHz to 5 925 MHz.	Free channelization within 5 905 MHz to 5 925 MHz.	Free channelization within 5 905 MHz to 5 925 MHz.	Same as ITS with 10 MHz channels. Full possible use of all ITS channel in 5 855 MHz to 5 925 MHz (70 MHz).
Impact on CBTC	Compatible with existing systems.	Compatible with existing systems.	Compatible with existing systems.	Implement harmonized protocol Not compatible with existing systems. Update/extension of ETSI ITS standard required.
Impact on ITS	ITS not allowed to use shared channels in the mitigation area. No safety related operation possible in the shared band.	Always use of very low duty cycle in the mitigation area. No safety related operation possible in the shared band.	Use of very low duty cycle when high channel load. No safety related operation possible in the shared band.	Use of lower priority level in shared channels when capacity is required by CBTC. No detection needed. Slightly reduced capacity in the shared band.
Work to be done	Specification, test and implementation of the ITS systems. See also Regulation section of table.	Specification, test and implementation. of the ITS systems. See also Regulation section of table.	Investigate if necessary and how to measure CBTC channel load. Specification, test and implementation of the ITS systems. See also Regulation section of table.	Specification, test and implementation of the CBTC system and update of the ETS ITS standard.
Regulation requirements/ Standardization	New regulation for CBTC required, New harmonised standard for Urban Rail required. Update of ITS regulation required. Update of ITS harmonised standard required.	New regulation for CBTC required, New harmonised standard for Urban Rail required. Update of ITS regulation required. Update of ITS harmonised standard required.	New regulation for CBTC required, New harmonised standard for Urban Rail required. Update of ITS regulation required. Update of ITS harmonised standard required.	Extension of ITS regulation could be beneficial to have an harmonized spectrum up to 5 925 MHZ No new regulation needed. No new harmonised standard needed.

Table 7: Methods to detect a mitigation area

	Geographical data base	Detection of CBTC signal	CBTC warning beacon
Technical implementation	A data base in the ITS devices specifying CBTC areas.	ITS radio device detects a CBTC signal.	Informs ITS devices about their entry into a CBTC area by using ITS messages.
Impact on CBTC	Provide updated areas information.	None.	Deploying the beacon.
Impact on ITS	Implement data base and geolocation checking. Download updated database.	Implement a CBTC receiver. Depending on detector implementation, there is a risk for false alarms.	Decoding the warning message.
Work to be done	Specification, test and implementation.	Specification, test and implementation.	ITS warning beacons to be adapted for CBTC protection areas. Specification, test and implementation.

Annex A: Case Study of Brussels Metro

A.1 General

As any other city, the underground part of the Brussels metro system is mainly located in the centre and densely populated areas. The tracks only come outside a tunnel in the suburb areas.

To allow a clear differentiation between underground places where almost no interference can occur and outside of the tunnel, it has been decided to investigate the following cases:

- track and road at the same level;
- track and road at a different level;
- track/road crossing, the road is on top.

As the second and the third cases are almost similar, they will be studied like a single case.

On average, the level difference between track and road is around 6 m and the slope of the gap is very steep.

The length of a single track is taken into account.

That means that when there are two tracks, each going in the opposite direction of the other, two units of track length have been considered.

Table A.1 shows the outcome of the analysis.

Table A.1: Brussels metro analysis

		% track length	**% road length**
Total Track length	77,44 km		
Track and road at the same level	4,019 km	5,2 %	0,19 %
Track and road at a different level (open trench)	4,692 km	6,1 %	0,23 %

The potential conflict zones are shown in figure A.1.

The colour of the surfaces (style) is based on the type of proximity between track and road:

- track and road at the same level (ex: near Erasmus metro station);
- track and road at a different level (ex: between Demey and Herrmann-Debroux and on line 2-6 between Simonis and Belgica);
- track/road crossing, the road is on top.

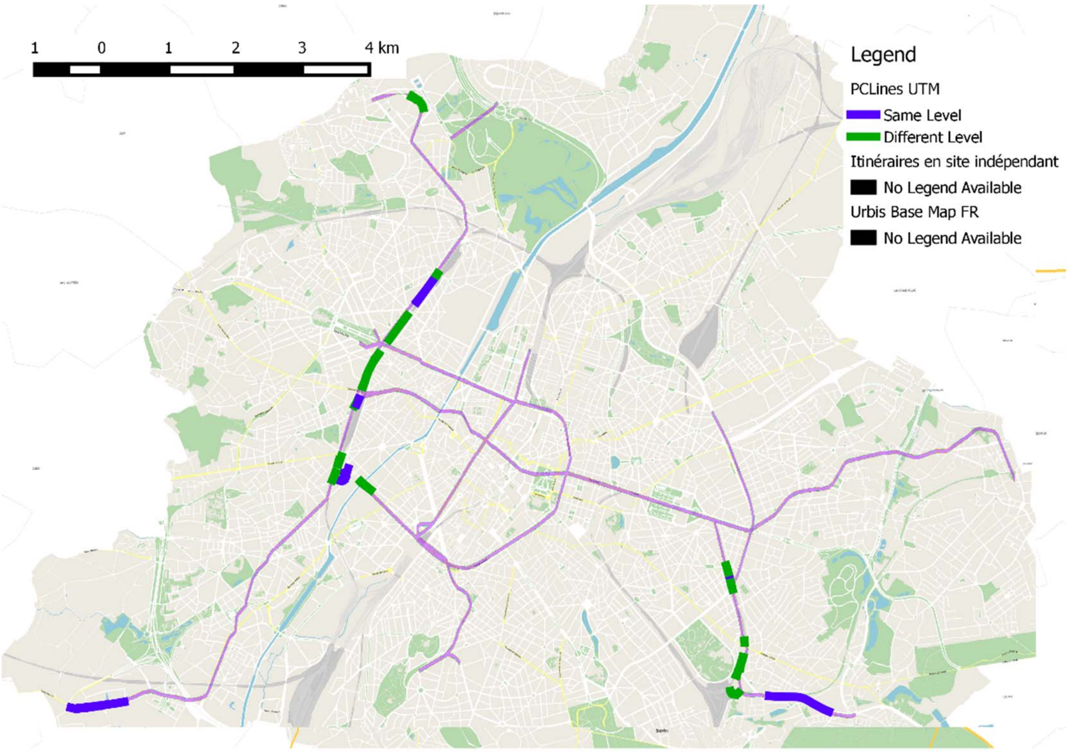

Figure A.1: Brussels area

Data has been mapped on a local knowledge of the situation.

The potential conflicts are located at these places:

- at some places between Thieffry and Herrmann-Debroux on line 5;
- between Eddy Merckx and Erasmus + shunting positions in Erasmus on line 5;
- around Gare de l'Ouest and the depot Brel;
- at numerous places along the line 2-6 between Beekkant and Heysel.

To have a good idea about the possibility of cohabitation percentage regarding the total of road length in Brussels, table A.2 shows the last records of road type.

Table A.2: Road length

Road length in km in October 2015			
Reference: Méthodologie Bruxelles Mobilité [i.25]			
Speed roads	**Regional roads**	**Community roads**	**Total**
30,0	535,1	1 448,4	2 013,5

Table A.3 shows the possible interference percentage regarding the road length in Brussels.

Table A.3: Interference percentage

		% track length	% road length
Total Track length	77,44 km		
Track and road at the same level	4,019 km	5,2 %	0,19 %
Track and road at a different level (open trench)	4,692 km	6,1 %	0,23 %

A.2 Conclusion

The following can be inferred from this case study:

- The position and length of possible perturbation areas between CBTC and ITS are well known and restricted.
- Influences of the position where level difference exists should be technically evaluated but they should be low.
- Only 5,2 % of the overall track length of Brussels metro line is close to roads.
- Related to the road length in Brussels, the percentage of chance to be in a coexistence scheme is reduced to 0,19 %.
- Their areas are well defined and represent five locations.
- When metros and cars are at the same level, the influence is minimized by use of directional antennas.

History

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