Urban Rail integration into ITS-G5

CAR 2 CAR Communication Consortium

About the C2C-CC

Enhancing road safety and traffic efficiency by means of Cooperative Intelligent Transport Systems and Services (C-ITS) is the dedicated goal of the CAR 2 CAR Communication Consortium. The industrial driven, non-commercial association was founded in 2002 by vehicle manufacturers affiliated with the idea of cooperative road traffic based on Vehicle-to-Vehicle Communications (V2V) and supported by Vehicle-to-Infrastructure Communications (V2I). Today, the Consortium comprises 88 members, with 18 vehicle manufacturers, 39 equipment suppliers and 31 research organisations.

Over the years, the CAR 2 CAR Communication Consortium has evolved to be one of the key players in preparing the initial deployment of C-ITS in Europe and the subsequent innovation phases. CAR 2 CAR members focus on wireless V2V communication applications based on ITS-G5 and concentrate all efforts on creating standards to ensure the interoperability of cooperative systems, spanning all vehicle classes across borders and brands. As a key contributor, the CAR 2 CAR Communication Consortium works in close cooperation with the European and international standardisation organisations such as ETSI and CEN.

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1 Introduction

1.1 Abstract

In recent years the Urban Rail community has proposed and pushed to use the spectrum allocated to the road ITS systems in the band 5.9 GHz for the use of their systems, mainly metro systems in big cities. The deployed communication systems do not follow any harmonized specification and are based on a set of requirements. The used systems are proprietary and mainly based on 802.11a and a DSSS spread spectrum system. A sharing between these systems and the existing ETSI Road ITS systems can only be reached by complex mitigation and sharing techniques. C2C-CC has proposed to deploy an extended road ITS systems based on the ETSI ITS specifications for the use in Urban Rail. This integrated approach would significantly simplify the sharing operation and could reduce the cost of Urban Rail systems due to the reuse of an existing system.

This report is intended to give an initial evaluation of the required changes and extensions in the ETSI ITS set of standards and specifications in order to support the deployment of this communication standard in the field of rail and urban rail. It can be used as the basis for further development and standardization work in the field of rail communication with the main focus on Urban Rail systems.

1.2 Survey of document

The use and integration of wireless communications to provide railway operators with a means to control and manage the train traffic on their networks is a must to make the train traffic safe and sustainable in the future. In this report, we survey the train communications technologies recently used or under development mentioning the related harmonization and standardization activities. The relation with Cooperative Intelligent Transportation Systems (C-ITS) communications and the possible joint development of the two different, though highly interdependent modes of transportation, is shortly characterized.

In this report we first summarize the basic railway communication solutions which are used already in the practice in urban and also in long-haul line solutions. Then, the Day 1 C-ITS communication solutions are briefly characterized and the idea of the shared use of C-ITS technology between road and rail users is presented in accordance with the recent developments of the standardization activities.

2 Technical overview of railway communication systems

2.1 Introduction

The primary objective of the application of railway communication systems is to provide railway operators with a means to control and manage the train traffic on their networks.

Railway communication systems are varied and can be classified in different application groups, such as safety and control oriented, operator and customer-oriented services and networks. By architecture one can distinguish on-board and inter-vehicle communications. On-board communication networks were installed aboard trains since the end of the 1980s to reduce the cable beams used to transfer information between different devices like human to machine interface (HMI), passenger information system (PSI), or heating, ventilating, and air conditioning systems etc., following the general technology trends of drive-by-wire systems commonly used in aerospace and car industries. This technology is out of the scope of our recent technology review and will not be treated any further.

As to inter-train communication, there is a well-defined technology separation between systems that are being used in Mass transit networks (or urban lines in general) and the ones being used for Mainline (or long-haul lines). *Mass transit* and *Mainline* communication systems evolved along two separate trajectories resulting in the situation in which the two ecosystem approaches coexist in some networks. Moreover, each of these systems has the necessary maturity to step forward to an integrated solution that comprises the best of both worlds. They are the Communications-Based Train Control (CBTC) system and European Rail Traffic Management System (ERTMS). In the following sections we characterize the two distinct technology approaches in a historical perspective.

2.2 Inter-train communication systems

There was the ultimate need to provide railway operators with a means to control and manage the train traffic on their own networks. Obviously, this requirement necessitates the continuous availability of a seamless communication connection between rail vehicles and the control infrastructure. The vehicle to infrastructure communication was deployed for train applications in the past decade. The deployment focus was studiously Train-to-Ground (T2G) communication. Train-to-Train (T2T) communication was not in the foreground until recently.

Rail traffic is characterized by poor braking capabilities of trains and rail vehicles in general, the fixed path, and the inability to avoid obstacles. Maintaining a short following distance between trains and ensuring safe braking distances between rail vehicles on busy commuting lines necessitate the use of safety-related, time-critical train control applications, which are enabling technology parts of the Automatic Train Operations (ATO) networks. Because of the safety requirements, they impose stringent reliability and availability requirements on the radio communication technology used.

T2G connectivity solutions are basically using GSM, IEEE 802.11 and other proprietary technologies and solutions. While GSM-R (GSM for railways) is built on the GSM network infrastructure, the 802.11 microwave (WiFi) solutions make use of the private network of wayside units. Both technologies ensure connectivity of the trains with the control centre in order to send and receive control information. Various application-oriented control networks were defined over those wireless access technologies in the past decades. These are summarised in the following sections.

2.3 Automatic Train Operations (ATO) networks

The basic objective of a railway control system is to prevent trains from colliding with each other and with obstacles and prevent derailing based on various train detection technologies. The detection system combined with a signalling and a communication system makes up the traditional Automated Train Operations (ATO) technology. In communication-based railway signalling, different means of telecommunication are used to transfer train control information between the train and the wayside.

ATO systems still rely on the T2G link to send and receive control signals and monitor train conditions from a central management site. As train operations move towards increasingly automated and even autonomous, Automated (or Unattended) Train Operations (ATO/UTO) solutions perform the following basic functions and are implemented through the interaction with control centres in the rail infrastructure.

- In the first approach, traditional **Automatic Train Stop (ATS)** systems represent the classical safety train control applications which helped to ensure the adherence of requested clearing distances between trains. ATSs were integrated in the rail operation and acted as the interface between the operator and the system, managing the traffic. Other tasks include the event and alarm management as well as acting as the interface with external systems.
- **Automatic Train Control (ATC)** or **Automatic Train Protection (ATP)** is a general class of train protection system for railways that, beyond ATS requirements, involves a speed control mechanism in response to external inputs. The objective of this comprehensive ATC/ATP system solution is to constantly monitor the train speed and compare it to the maximum values that are sent by trackside signalling systems. ATC/ATP is probably the most critical CBTC subsystem, which helps prevent collisions as a result of the driver's failure to observe a signal or speed restriction.

2.4 Communications Based Train Control (CBTC)

Communications-Based Train Control (CBTC) is an advanced ATO system using bidirectional T2G communications to ensure the safe operation of trains and rail vehicles. It is a continuous, automatic train control system utilizing train location determination and continuous, 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 are part of the installations.

CBTC is the enhancement and natural evolution of the wireless Automatic Train Operations (ATO) solutions. It is an enveloping technology term and represents a more flexible and cost-efficient solution than traditional ATC/ATP. CBTC applications and deployments are mainly focused on traditional mass transit networks, such as Automatic People Movers (APMs) and urban rail lines.

Currently over one hundred CBTC systems are installed or being installed worldwide (see Appendix C).

Traditional ATC/ATP control solutions are integrated within most of the newly deployed CBTC systems resulting in a hybrid installation especially regarding the communication technology used. ATC/ATP communications technologies were traditionally based on standard Wi-Fi and assigned to the 2.4 GHz unlicensed radio spectrum, which could be interfered easily. New and advanced CBTC systems are employing IEEE 802.11 communications and tend to operate mostly in the 5 GHz range.

While CBTC, in acc. with the IEEE standard recommendation [AD-13], is a generic enveloping technology term, today CBTC is used specifically to mean systems used for mass-transit almost exclusively.

In the modern CBTC systems, the trains continuously calculate and communicate their status via radio to the trackside (wayside) equipment distributed along the line. This status includes, among other parameters, the exact position, speed, travel direction and braking distance. This information allows calculation of the area potentially occupied by the train on the track. It also enables the wayside equipment to define the points on the line that must never be passed by the other trains on the same track. These points are communicated to make the trains automatically and continuously adjust their speed while maintaining the safety and comfort requirements. So, the trains continuously receive information regarding the distance to the preceding train and are then able to adjust their safety distance accordingly.

There has been a general lack of standardization efforts for CBTC, the result of which is that nearly all existing CBTC installations are incompatible with each other. Although, performance and functional requirements for CBTC systems are established in [AD-13], it has not gained much attention from CBTC suppliers due to its limited scope. There are currently no independent standards defining the performance and functional requirements to be satisfied by CBTC systems. The system itself as a whole is not fully standardized which means that some parts, and in particular its communication system, are proprietary and regional implementation dependent.

In addition to CBTC functional requirements, IEEE 1474.1 also defines headway criteria, system safety criteria, and system availability criteria for a CBTC system. This standard is applicable to the full range of transit applications including automated people movers as well.

The primary characteristics of a CBTC system include the following, see [AD-13]:

1. **Identification**, where the system identifies the number of the trains and locomotives, the engineer operating each locomotive and also any other mobile railway units that are occupying a main railway track.
2. **Location determination** independent of track circuits in an accuracy, adequate for the needs of train traffic resolution. This is typically in the standard 2-4 m GNSS accuracy which does not pose stringent requirement for precision, at last the requirement is not in the decimetre range.
3. **Detection**, where the system detects railway switches, defective equipment, status of a railway/highway crossing.
4. Continuous, bi-directional train to wayside data **communications for** messaging, **monitoring and control**.

In summary, a CBTC system must be able to determine the accurate location of a train, independent of track circuits, using a bi-directional communication link while keeping the system in a continuously safe status.

In CBTC, compared to the conventional train control systems, the responsibility of determining a train’s location has been moved from the track circuit to the train itself. In previous technologies, the train location was determined by the wayside (with the help of a track circuit), independent of the train. This train-centric location determination results in lower certainty, however, and requires reliable, positioning technologies. In CBTC, the wayside depends on the train to get the validated location information, which, in turn depends on the performance of the communication.

2.4.1 CBTC architecture

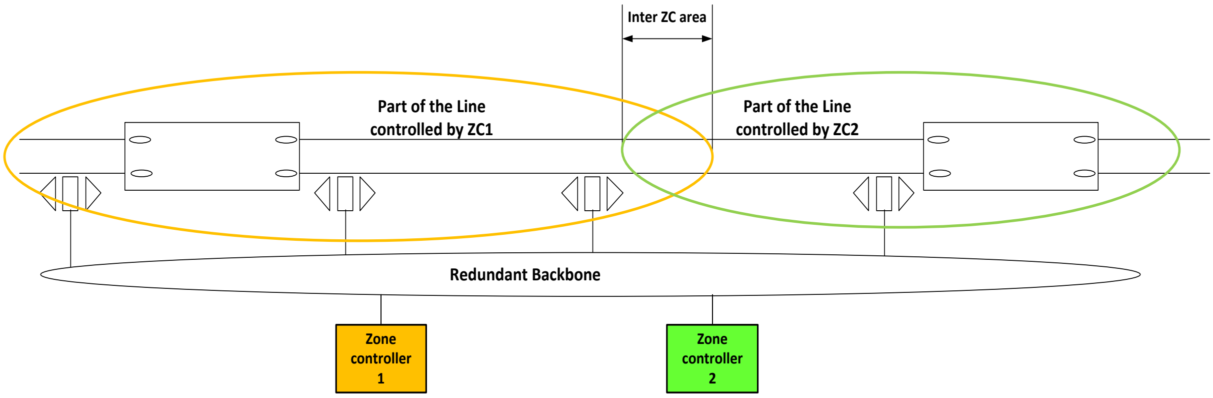

Figure 2-1: Simple zone control with partially overlapped zones

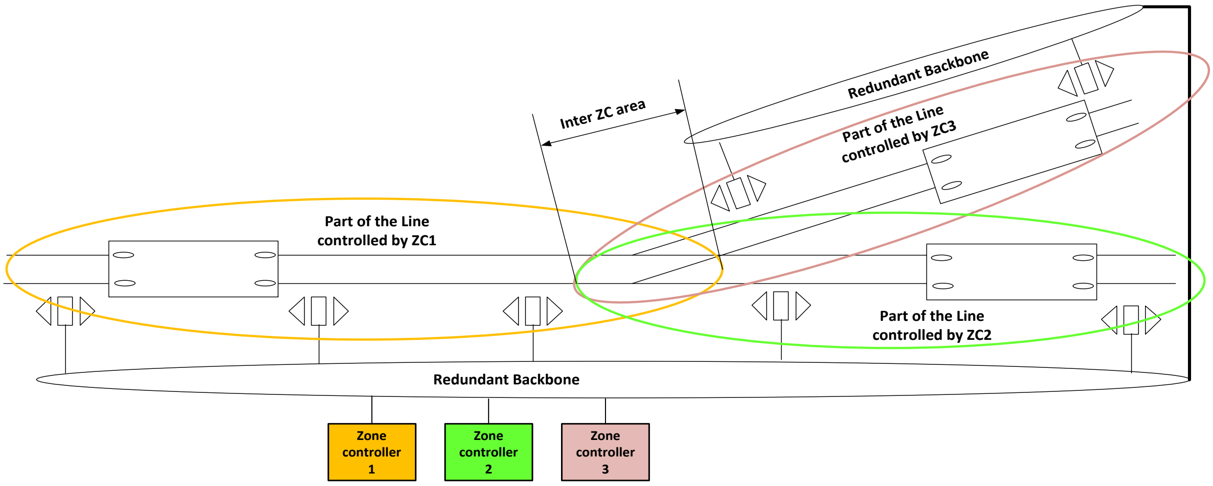

Figure 2-2: Zone control with line crossing and three zone controllers and multiple overlapped zones

2.4.2 The moving block principle

In railway signalling and train automation systems (e.g., in CBTCs) the so-called moving block principle is a concept of primary importance. A moving block is a signalling concept where the blocks are defined as safe zones around each train in real time.

The classical semaphore control system is the earliest form of the moving block principle where the safety zone around trains were static and controlled by fixed railway signals called semaphores. By this concept the safety zone was assigned to the infrastructure and the safety separation of trains was controlled by dividing the railway yard into specific sub regions (named blocks) in order to determine the location of a train and ensuring safe distance between the trains by creating go and no-go zones along the railway yard. This is the classical train separation technique based on the so-called fixed block point of view. A block can be occupied only by one train in the fixed block approach and the distance between trains is considered safe if there is only one train in a particular block. The length of a block depends on location of the railway yard, allowable maximum speed, geographical conditions etc. and the block length may vary from a couple hundred meters to a couple kilometres. It can be asserted that the fixed block systems are not sufficient for high capacity railways.

In contemporary train separation the physical fixed block sections are removed and replaced by virtual moving block sections whose lengths and locations are consistent with instantaneous kinematic conditions of the train. Physically, the railway yard is still divided into regions where each region is supervised by a wayside control unit. The safety zone around trains, however, is calculated dynamically in a way responsive to speed, geolocation (e.g., slopes) and weather conditions, braking characteristics and other meaning the moving block concept is a layer of implementation over the network of wayside units.

This requires both knowledge of the exact location and speed of all trains at any given time, and continual *communication* between the central signalling system and the train's vehicle signalling system. The moving block is also a concept of virtual coupling of rail vehicles which allow trains to run closer together, while maintaining required safety margins, thereby increasing the line's overall capacity. The close analogy with the concept of platooning in road vehicle automation is obvious.

2.4.3 CBTC Characteristic #1

The main feature which differentiates a CBTC system from conventional signalling is the ability to determine the location of a train independent of track circuits.

Typically, this is done using transponder tags or beacons installed along the track. The tags/beacons provide the train borne unit with a course position. The tachometers installed on the axles provide the fine position.

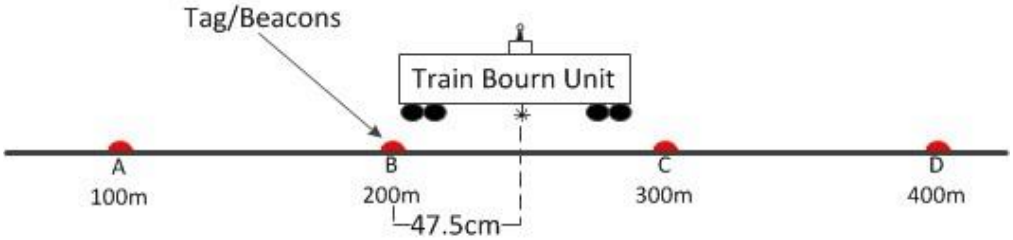

Figure 2-3: Location determination of trains by means of traditional CBTC technology

As the train crosses tag/beacon B, the train borne unit is aware that it's located at the 200-meter mark (course position). As the train moves away, the tachometers will count how far the train has moved (fine position). Taking the course and fine position together, the train borne unit will be able to determine that the centre of the train is located 247.5m away from the zero-reference point.

2.4.4 CBTC Characteristic #2

Once the train is able to accurately determine its location, this information must be relayed to the wayside unit in a timely fashion.

There are various methods to accomplish this. In the past inductive loop was utilized as a communication medium but recently over the past ten years, radio has become the technology of choice for the majority of suppliers. As the technology matures, radio will become the default standard for the rail industry.

For a railroad application, access points are installed along the track. As the train comes within range of an access point, the train borne radio will lock onto its signal and disconnect from the previous access point.

The communication protocols utilized in this medium is usually the standard Ethernet TCP/IP or UDP/IP protocols. This gives the solution flexibility and expandability.

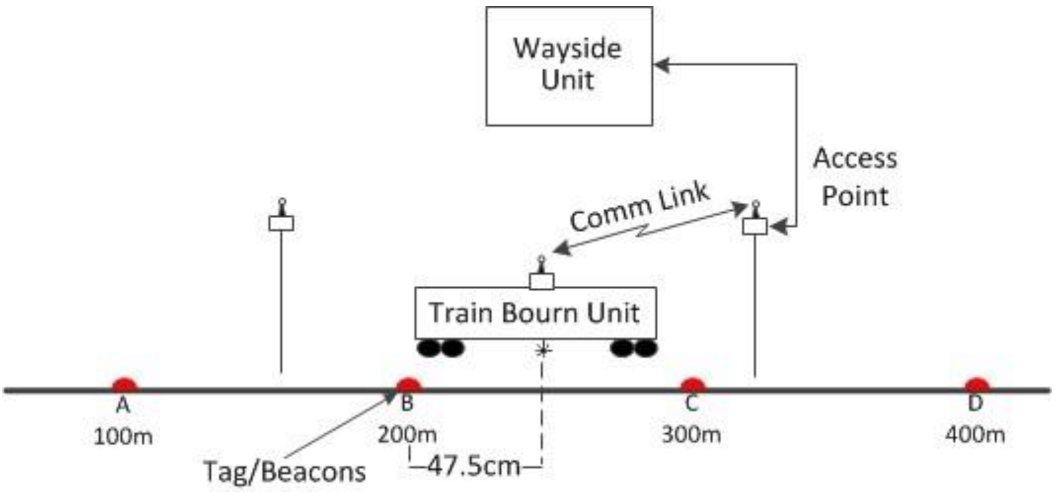

Figure 2-4: Traditional CBTC communications function blocks

All data (vital and non-vital) is sent through this medium but this link is considered non-vital (TCP/IP and UDP/IP are not considered vital protocols). To maintain safety integrity, end to end vitality must be ensured. This means, the train borne and wayside unit must guarantee the information they receive is not corrupted or stale through various mechanisms (CRC, sequence numbers, Tx ID, Rx ID etc).

2.4.5 CBTC Characteristic #3

It's not enough that a CBTC system is able to accurately determine the location of a train it also has to protect that train from all types' failures.

The vital functions a CBTC system must perform can be classified into three categories: collision avoidance, over speed protection and miscellaneous protections. The basic definitions of these functions are as follows:

Collision avoidance – Is the ability of the CBTC system to keep trains safely separated from one another and from other obstacles.

Over speed protection – Is the ability of the CBTC system to accurately determine the speed of the train and to control the speed within a tight tolerance.

Miscellaneous protection – These are functions that don't fit into any generalized category and are not a fundamental part of a CBTC system (but IEEE 1474.1 has listed them as features that a CBTC system should protect against).

However, CBTC has come to mean much more recently. When the term CBTC is used, it is commonly defined as a highly automated system.

IEEE 1474.1 recognizes that there are different CBTC configurations. A CBTC system may:

1. Provide ATP functions only, with no ATO or ATS functions.

2. Provide ATP functions, as well as certain ATO and/or ATS functions, as required to satisfy the operational needs of the specific application.
3. Be the only train control system in a given application or may be used in conjunction with other auxiliary wayside systems.

At the high end (configuration 3) one has a completely automated CBTC system with ATP (Automatic Train Protection), ATO (Automatic Train Operation) and ATS (Automatic Train Supervision) functionality. At the low end (configuration 1) is the ATP only solution as defined by the primary characteristics in section 4.1 (ATO functional requirements are described in the 1474.1 standard).

The type of configuration a property needs depends on the problem they are trying to solve. If the desire is to increase throughput, then a completely automated system might be needed (Configuration 3). If the desire is to add another layer of safety protection, then an ATP only solution may suffice (Configuration 1).

The point here is that CBTC does not mean “driverless” or fully unattended. At its most basic form, a CBTC system provides automatic protection (ATP) only. More elaborate systems may provide ATO and ATP functionality but it’s not a requirement in order to apply the label “CBTC”.

2.5 European Railway Traffic Management Systems (ERTMS)

CBTC deployments fragment the European railways technology field into local solutions. In the European Union, more than 20 different CBTC-like train control systems are operated and supported. These systems are non-interoperable, meaning extensive measures must be taken for trains to be able to run across system borders.

In Europe, where cross-border interoperability is particularly important the International Union of Railways (UIC) and the European Rail Research Institute (ERRI) began the search for a common European operation management platform for railways, titled European Rail Traffic Management System or ERTMS. ERTMS is a project conducted by European Union Agency for Railways (ERA). By its objective, the ERTMS is the system of standards for management and interoperation of signalling for railways in the EU. Ten years after the initial start of the ERTMS initiation, the ERTMS standard was devised. It consisted of two parts: ETCS and GSM-R and ERTMS became the organisational umbrella for the two separately managed technology platforms of

- GSM-R communication,
- European Train Control System (ETCS).

In fact, ERTMS = GSM-R + ETCS. ETCS (or simply TCS in a more general context in the sequel) is for railway safety and on-board train control that always involves the communication with a management or control centre.

GSM-R is used for all sorts of communications in and around the train and railway track; this includes the communication necessary for ETCS to function. GSM-R thus plays a vital role in train safety, this is why GSM-R and ETCS are the two central concepts in ERTMS. It is important to note, however, that the fundamental needs of TCSs include voice and video transmission.

Within ERTMS, the European Train Control System (ETCS) is a signalling, control and train protection system based on GSM-R that replaces many incompatible (legacy and mostly analogue) safety systems which were previously used in and around Europe, in particular on high-speed routes.

GSM-R has several limitations, mainly with respect to available bandwidth and latency and a more compliant technology is needed. The larger part of the related work is performed under a standardisation project (led by UIC) called FRMCS (Future Railway Mobile Communication Systems), aimed at replacing the existing GSM-R that is expected to be phased out by 2030.

As a summary, ERTMS is the European standard for ATOs that achieve rail interoperability on the Mainlines throughout Europe, which relies fundamentally on GSM-R communication. It allows a train equipped with an ERTMS onboard device made by any supplier to run on track sections, equipped with ERTMS devices made by other suppliers. This also implies the ability for any onboard equipment installed on any train to behave in exactly the same way under the same circumstances. ERTMS is specified in several layers and is not yet fully defined. ERTMS is currently adopted in various levels by the railway companies in most European countries.

1. Level 1 involves continuous supervision of train movement while a non-continuous communication between train and trackside (normally by means of Euro-balises). Lineside signals are necessary and train detection is performed by the trackside equipment out of the scope of ERTMS.
2. Level 2 involves continuous supervision of train movement with continuous communication, which is provided by GSM-R, between both the train and trackside. Lineside signals are optional in this case, and train detection is performed by the trackside equipment out of the scope of ERTMS.
3. Level 3 is also a signalling system that provides continuous train supervision with continuous communication between the train and trackside. The main difference with level 2 is that the train location and integrity is managed within the scope of the ERTMS system, i.e. there is no need for lineside signals or train detection systems on the trackside other than Euro-balises.
4. In addition, there are two more levels defined: Level 0, which is meant for trains equipped with ETCS running along non-equipped lines; and Level STM, which is meant for trains equipped with ETCS running on lines where the class B system needs to be operated. Regarding the STM level, the ETCS acts as an interface between the driver and the national ATP.

2.6 GSM-R communication

GSM-R is the most known system based on the GSM standard (phase 2) with major modifications to fulfil railway needs. As the third generation of GSM evolved towards LTE, GSM-R is expected to evolve as well. The radio sub system of the GSM-R network is typically implemented using base transceiver stations (also called balises in the rail context) and communication towers with antennas which are placed next to the railway with intervals of approximately eight to twenty kilometres. Through GSM-R, trains establish a constant circuit switched digital modem connection to their respective train control centre. If the modem connection is lost, the train must automatically stop. This modem operates with higher priority than normal users.

By the Commission Decision 1999/569/EC GSM-R uses a lower extension of the 900 MHz frequency band: 876 MHz – 915 MHz for uplink and 921 MHz – 960 MHz for downlink. In Europe, the 876 MHz to 880 MHz and the 921 MHz to 925 MHz bands are used for data transmission and data reception respectively. Channel spacing is 200 kHz.

Non-harmonized spectrum of 873-876 MHz and 918-921 MHz for downlink and uplink respectively, is used in Germany, Switzerland and Liechtenstein.

The access layer of GSM-R is based on standard GSM (it uses Time Division Multiple Access - TDMA method for channel access), but only uses the 876-880 MHz frequency band for data transmission, and the 921-925 MHz band for data reception and used exclusively for railway applications.

GSM-R is able to guarantee performance at speeds up to 500 km/h, without communication loss. This is a huge advancement of the use of cellular technology as this type of communication is excessively prone to doppler. In order to provide a high degree of availability and reliability, the base stations are located very close to the train yard at a distance of 7-15 km between each other. There are two redundant communication links to be maintained in each particular time. In case the GSM-R connection is lost (i.e., both links lost), the train will automatically stop for safety reasons.

EU Decision on Short Range Radio Devices (SRD) in 874-876 MHz / 915 – 921 MHz is shown in Figure 2-5. [see RD-1].

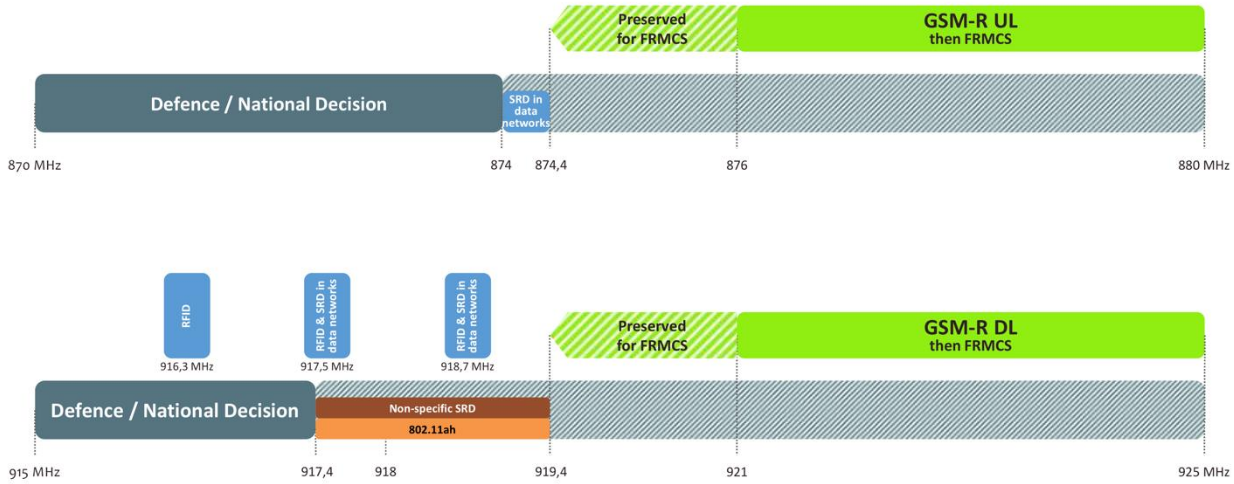

Figure 2-5: EU Decision on SRD devices in 874-876 MHz / 915 – 921 MHz [RD-1]

2.7 CBTC vs ERTMS

It is important to note that recent CBTC systems are considered distinct from the European Rail Traffic Management System (ERTMS), which is another modern, communication-based signalling system, targeted towards mainline railway operations. Still, however, there are similarities between the two technologies and, generically, they are actually fairly similar.

CBTC and ERTMS architectures can be divided into four main components. The systems are typically constituted by

1. onboard and wayside communication equipment,
2. control and command centre with traffic management facilities,
3. trackside or signalling equipment, moreover,
4. the core communication system.

Mainline railway operations make use of wide area network technologies (GSM-R). CBTC is based on short and medium range solutions. The convergence of CBTC and ERTMS solutions would be highly beneficial which is a primary focus of the development of both fields. While CBTC is fragmented but existing and more or less complete set of technologies, ERTMS (level 3 and above) is mostly the collection of harmonizing ideas. The communication system is the basis for providing a sustainable, safe operation and ensuring long term interoperability. GSM-R, from many reasons, represents a bottleneck in development of future rail systems and it will be phased out by 2030.

The following table compare the main differences of the two approaches regarding interoperability and flexibility of the recent solutions and the critical set of implemented features such as ATOs and the moving block principle. The communication technology used is also rather diverse.

	Interoperability	Flexibility	Automatic Train Operation (ATO)	Moving block principle	Communication technologies
CBTC	–	+	+++	+++	GSM-R IEEE 802.11
ERTMS Level 3	+++	+++	–	–	GSM-R

Table 2-1: CBTC and ERTMS system similarities and differences

Due to the big number of stakeholders involved and the wide European heterogenicity of the affected railways technologies harmonization in standardization is ultimately required. Future systems must be flexible enough to support these differences without compromising the features already achieved by each of the individual systems (i.e., ERTMS & CBTC) and everything will converge towards the standardization of the operational requirements of CBTC and ERTMS platforms to achieve a seamlessly interoperable European train control system.

3 Urban Rail communication systems

3.1 CBTC/ERTMS status

One the one hand, the trend of applying wireless communication systems in railways – apart from legacy systems (which are usually analogue) that started their development in the early 1980s – is still in its very beginning. In the control and signalling field, several non-harmonized wireless solutions, such as the use of IEEE 802.11-based radio for CBTC/ETCS needs exists in several deployments since several years.

In contrast, ERTMS specification for long haul rails combines the GSM-R for internal voice and data communication in the railway environment and the existing ETCS solutions.

Harmonization of CBTC in the framework of ERTMS is in a very early stage and the integration of rail systems with other modes of transportation such as with road transportation systems was not considered until recently. As the harmonized European CBTC solutions will be part of final ERTMS specification, the technical work on closing the gap between the road and rail technology domain is an urgent harmonization task.

3.2 Basic CBTC communication requirements

Challenges with CBTC stem from the demanding railway application and the special mobility requirements of moving trains. CBTC is ultimately relies on the performance of the communication system. Poor T2G communication performance can result in temporary reduction in speed, a complete train stop, or a train operating in a degraded mode until communications are restored.

- **Latency and handover time:**

Basic requirements of radio transmission for CBTC, therefore, are dependability, high priority, the capability of low-to-medium latency communication (latency is in the range of 100 ms and not much higher) and the full-service coverage.

Communication holes must be less than 500 msec meaning that if trains lose the connection with the operation (control) centre (i.e., they cannot exchange messages), they will not be authorised to move and must stop in emergency. A roaming handover time of less than 50 ms is essential. From similar reasons a packet loss of less than 0.1 percent is required.

- **Bandwidth:**

The typical size of a CBTC control message is 400-500 bytes. A message transmission time of shorter than 100 milliseconds is normally supported.

Otherwise, CBTC communications are not specifically bandwidth demanding, they typically generate low data throughput (per train). Given that the typical frequency of messages is about 100-600 milliseconds, data requirement for a CBTC system is typically in the range of 20-40 kbps, but not more than 100 kbps.

CBTC is typically a scattered and diverse technology. IEEE 1474.1™ [AD-13] defines a few key and relevant requirements for the CBTC system, however the system itself as a whole is not fully standardized, 1474.1 serves as mere guidelines, and is not strictly followed by the suppliers which is one reason why different CBTC solutions are highly incompatible. In particular its communication system solution is highly implementation dependent.

CBTC does not use a standardized access layer technology neither. A set of different modulation schemes, MAC and radio bandwidths are used by current implementations.

Though it uses many different technologies: DSSS/TDMA (the CBTC systems installed on the RATP lines (Paris subway) are based on DSSS proprietary system and TDMA access to channel), full or modified IEEE 802.11 technology (OFDM based) in various frequencies, nearly all CBTC installation today work in one of the three, unlicensed ISM bands: 900 MHz, 2.4 GHz, and 5 GHz. 900 MHz is only used in the US. 3GPP TD-LTE (experimentally used in China at 1.8 GHz, not implemented in Europe yet). Still, however, 802.11 remains the preferred choice since it defends deployments against obsolescence. Some restrictions on the transmission power do apply, however.

Using a license-exempt spectrum increases the probability of interference from other users (*c.f.* with the widespread proliferation of smartphones and other handheld devices) in the band. The increasing use of the 2.4 GHz band for CBTC systems by railway operators has therefore raised concerns and not supported in the future deployments.

3.3 Messages in safety related CBTC (Urban Rail) systems and their requirements

CBTC communications can be classified in various categories 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. For a list of messages see the Table below.

The main CBTC message types exchanged are:

- **A 'Location Report' message** (Uplink) 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 up to 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 composition, etc.
- A **functional status message** (Uplink) 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 (Downlink) informing the trains about the **status of the variable elements** in the area where the train is, and in the area that 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** (downlink): 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.
- 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 (downlink).

Furthermore, when the track is equipped with platform doors, additional messages are exchanged. These messages necessary to control and ensure safe monitoring of the **platform doors** (where existing), also sent periodically when the train is at a station (uplink) and when the train is approaching and docked at a station (downlink). Very short delays of transmission are required to ensure fast passenger exchange at the station.

It appears that uplink messages carry status information, in a similar way as C-ITS CAM messages do. The downlink direction contains different types of messages: status messages (objective similar to CAM), notification about the area location (objective similar to DENM), information about Movement of authority ZC (objective similar to SPAT messages) and update of track database (objective similar to MAP messages).

Direction	CBTC application services	Period (msec)	Similar C-ITS message
Uplink	Location Report to one ZC	200	CAM
	Periodic Train Functional Status message	300	CAM
	On demand specific status message	300	CAM
	Platform Screen Door monitoring and control approaching, in station and leaving station	100	CAM
Downlink	Movement of authority from ZC	600	SPAT
	Information about Line from ZC	400	DENM
	Track data base update (File transfer)	100	MAP
	Request for Health train status	500	DENM
	Platform Screen Door	100	CAM

Table 3-1: List of messages used in the CBTC system

According to the topology, the train CBTC system can report to up to three ZCs (Zone Controllers) simultaneously. The density of the trains depends on several factors such as the train length or the track configuration of the area, but a good order of magnitude varies typically from 2 to 36 trains in the communications area. Some of the messages exchanged are sent with an identical content to multiple destinations. Each train receives all the data sent by wayside. CBTC protocol allow to distinguish between data to be used by all trains and data to be used for a specific train (constraint for CBTC). They would thus benefit from a broadcast or multicast transmission (one-to-many).

Throughput requirements for generic CBTC systems

The size of a CBTC control message is typically around 400-500 bytes. A message transmission time of shorter than 100 milliseconds is normally supported. Given that the typical frequency of the generation and sending of these messages is about 100-600 milliseconds, data throughput requirement for a CBTC system is in the range of 20-40 kbps, but not more than 100 kbps.

Throughput requirements have been provided in ETSI contribution [AD-14] based on the assumptions of messages from [AD-15].

The evaluation has been made for 3 radio transmission speed: 1.5 MBits/s, 2.25 MBits/s and 3 Mbits/s. It is based on the IEEE 802.11 protocol with parameters applicable in a channel of 5 MHz. It assumes that all packets exchanged between Trackside and Train CBTC applications are UDP Packets.

	Average	Max
Uplink Throughput	34666 Bits/s	85334 Bits/s
Downlink Throughput	17467 Bits/s	54933 bits/s
Total throughput on channel	52133 Bits/s	140267 Bits/s
% Time channel occupancy for 1.5 Mbits/s Radio Transmission speed	6%	12%
% Time channel occupancy for 2.25 Mbits/s Radio Transmission speed	4,65%	9%
% Time channel occupancy for 3 Mbits/s Radio Transmission speed	4%	6%

Table 3-2: CBTC Application services Uplink and Downlink Throughput requirements communication with one ZC

	Average	Max
Uplink Throughput	50666 bits/s	149334 bits/s
Downlink Throughput	37467 bit/s	110933 bits/s
Total throughput on channel	88133 bits/s	260267 bits/s
% Time channel occupancy for 1.5 Mbits/s Radio Transmission speed	9,94 %	25,45 %
% Time channel occupancy for 2.25 Mbits/s Radio Transmission speed	7,65 %	17,98 %
% Time channel occupancy for 3 Mbits/s Radio Transmission speed	6,52 %	14,32 %

Table 3-3: CBTC Application services Uplink and Downlink Throughput requirements communication with three ZC

	Average	Max
Uplink Throughput	50666 bits/s	149334 bits/s
Downlink Throughput	37467 bit/s	110933 bits/s
Total throughput on channel	88133 bits/s	260267 bits/s
% Time channel occupancy for 1.5 Mbits/s Radio Transmission speed	10,99%	25,73%
% Time channel occupancy for 2.25 Mbits/s Radio Transmission speed	8,58%	18,26%
% Time channel occupancy for 3 Mbits/s Radio Transmission speed	7,39%	14,59%

Table 3-4: CBTC Application services Uplink and Downlink Throughput requirements communication with three ZC and one PSD

3.4 Spectrum requirements for a CBTC system

The parameters needed to evaluate the spectrum requirements for a given set of application are mainly:

- Message size ($L_{message\_aver}$,$L_{message\_max}$)
- Message periodicity (P)
- Range requirements
  - Modulation scheme
  - Coding scheme
- Spectrum efficiency of the access layer (Eff_{access})
- Density of the communication nodes (N_{nodes}), for Urban Rail N_{nodes} is 1.
- Congestion control level/maximum channel load ($C_{channel}$)

The message sizes and periodicity are given in the tables from Table 3.1 to Table 3.4 in the previous section. In order to fulfil the range requirements a QPSK modulation scheme and a coding rate of R = ½ will be assumed in the following calculation. The spectrum efficiency of the access layer takes into account the control overhead of the system including the required pilot symbols and guard bands. In the calculation the modulation and coding scheme and the overhead has been combined into one figure (Eff_{access} = 0,55). A wireless communication system can only load the channel up to a limit before the channel congestion will significantly reduce the performance and the Quality-of-Service requirements can no longer be fulfilled. Here we have taken a value of $C_{channel}$ = 0.8 for the further calculations.

The average spectrum requirement Req_{spec_aver} and the maximum spectrum requirement Req_{spec_max} in MHz for each of the message sets can then be calculated by:

$Req_{spec\_aver} = (L_{message\_aver} * 8 * 1/P * N_{nodes} * Eff_{access} * C_{channel}) /1000000$ or

$Req_{spec\_max} = (L_{message\_max} * 8 * 1/P * N_{nodes} * Eff_{access} * C_{channel}) /1000000$

Environment	Parameter	Value	Comment
Urban_aver	Packet size (byte), $L_{message\_aver}$	200,0000	
	TX periodicity (Hz), 1/P	15,0000	Message to three Zone Controllers
	ITS stations in relevance area, N_{nodes}	1,0000	
	spectrum efficiency(bits/Hz), Eff_{access}	0,5500	pay load bit per Hz QPSK, R =1/2
	maximum channel load, $C_{channel}$	0,8000	LTE assumption for V2X
	Spectrum requirements (MHz), Req_{spec_aver}	**0,0545**	

Urban_Max	Packet size (byte), $L_{message\_max}$	800,0000	
	TX periodicity (Hz), $1/P$	15,0000	Message to three Zone Controllers
	ITS stations in relevance area, N_{nodes}	1,0000	
	spectrum efficiency(bits/Hz), Eff_{access}	0,5500	pay load bit per Hz QPSK, R =1/2
	maximum channel load, $C_{channel}$	0,8000	
	Spectrum requirements (MHz), Req_{spec_max}	**0,2182**	

Table 3-5: Average and maximum spectrum requirements calculation for Location report three ZC

As an example for the calculation in Table 3-4, the calculation of the spectrum requirement for the location report in a three zone controller set-up is given based on the figures in Table 3-6 below. The calculations for all messages in Table 3-1 are given in Annex D.

Message type	**Urban_average in MHz**	**Urban_max in MHz**
Location Report three ZC (UL), LR	*0,0545*	*0,2182*
Periodic Functional Status message (UL), PFS	*0,0303*	*0,0606*
On-demand specific status messages (UL), OSS	*0,0182*	*0,0605*
Movement of authority from ZC (DL), MoA	*0,0060*	*0,0241*
Line information from ZC (DL), L-info	*0,0682*	*0,1909*
Track data base update (DL), TDBU	*0,0091*	*0,0273*
Request for Train health status (DL), RqTH	*0,0218*	*0,0273*
Platform Door monitoring and control, PDM	*0,0091*	*0,0273*
TOTALS for a single connection (single link)	**0,2172**	**0,6089**
TOTALS for a redundant connection (dual link)	**0,4344**	**1,2179**

Table 3-6: Average and maximum spectrum requirements for all messages in Urban Rail CBTC systems

A summary of the results is given in Table 3-6. It can be seen that the maximum spectrum requirement for a system using a redundant communication set-up is in the range of 1,22MHz. A single channel has a spectrum requirement of 0,61MHz.

In this calculation a TDD based system has been considered thus one channel is used for the uplink and the downlink communication.

Higher spectrum requirements can be envisaged at specific operational points of an Urban Rail system. These points could be:

- **Line crossing:** For the case of a line crossing the given spectrum requirements need to be doubled. In case the two lines use different systems a separate set of channels will have to be considered. In a standardized and interoperable system this will not be necessary
- **Maintenance areas and depots**: In depot area the trains equipment will be parked and maintained. Here a significantly higher requirement related to the spectrum capacity is given. Due to the structure with several parallel tracks and a high number of rail vehicles the wireless network planning in these areas is complicated. The capacity needed in these areas is significantly higher than in the normal line operational areas.

4 Regulation in the 5.9 GHz band

4.1 Existing status

The road ITS V2X technology, to be thought of in this document, is a microwave radio technology composed of latency critical communication methods, such as the one being developed under the standard IEEE 802.11 [AD-17] on automotive focus with operation OCB (outside the context of a Basic Service Set (BSS)), and, in special cases, cellular microwave technologies. 802.11(OCB) is meant to be the complement to cellular communications by providing relatively high data transfer rates in circumstances where minimizing latency in the communication link and isolating relatively small communication zones are important.

The EC Decision [AD-18] (in accordance with the ECC Decision (08)01 [AD-19] and ECC Recommendation (08)01 [AD-20] was made to make available and create the efficient use of the frequency band 5.875-5.905 GHz for safety related applications of ITS (Road ITS) on a non-exclusive base. The usage of this spectra over 802.11(OCB) access mode is defined in ETSI standard [AD-5] as ITS-G5 A, D, B and C for safety critical, non-safety critical and general traffic applications, respectively

ITS-G5A	• 5.875 GHz to 5.905 GHz – ITS safety (not limited to road safety)
ITS-G5B	• 5.855 GHz to 5.875 GHz – ITS non-safety
ITS-G5D	• 5.905 GHz to 5.925 GHz – other future ITS applications
ITS-G5C	• 5.470 GHz to 5.725 GHz – RLAN

ITS safety applications pose severe requirements on the reliability and the latency of the data transmission. Due to the MAC protocol of IEEE 802.11 and the limited bandwidth of ITS-G5 in Europe, the data load on the wireless channels may exceed the available capacity in some situations. Therefore, congestion control as specified in TS 102 687 and implemented as Decentralized Congestion Control (DCC) is required in ITS-G5 stations in order to control the channel load and avoid unstable behaviour of the system.

Deployment of electronic fee collection (EFC) in Europe was predominantly based on the European DSRC 5.8 GHz technology (CEN DSRC). Tough, this technology is now considered legacy, its coexistence with road-ITS systems resulted in the frequency limitation in the lower part of the ITS-G5 range (in contrast to US and Asia) and make the total usable spectra 70 MHz wide in Europe. Moreover, mitigation techniques are required to avoid interference with CEN DSRC. Transmit power of an ITS-G5 station operating in the ITS-G5A, ITS-G5B or ITS-G5D frequency bands shall be controlled by mechanism based on the DCC as defined in ETSI TS 102.792 and clause 5.

European ITS frequency allocation scheme is shown in Figure 4-1. Channel allocation is according to Figure 4-2. The usage of G5-CCH and G5-SCH1 to G5-SCH2 are dedicated basically for ITS road safety.

The PHY in 802.11 OCB is OFDM (detailed in clause 18 of 802.11). OFDM supports three different frequency channel bandwidths, i.e., 5 MHz, 10 MHz and 20 MHz. Coding schemes and channel spacing are tabulated for 10 MHz channels for vehicular use (5 MHz and 20 MHz is for WLAN at 2.4 GHz and 5 GHz).

In 2017 ECC/CEPT proposed revision of ECC Recommendation 08(01) [AD-19] and instructs ETSI to find an agreement by end of 2018. Joint taskforce between TC RT and TC ITS: TC RT JTFIR was created. ETSI will finalize the documents until March 2019.

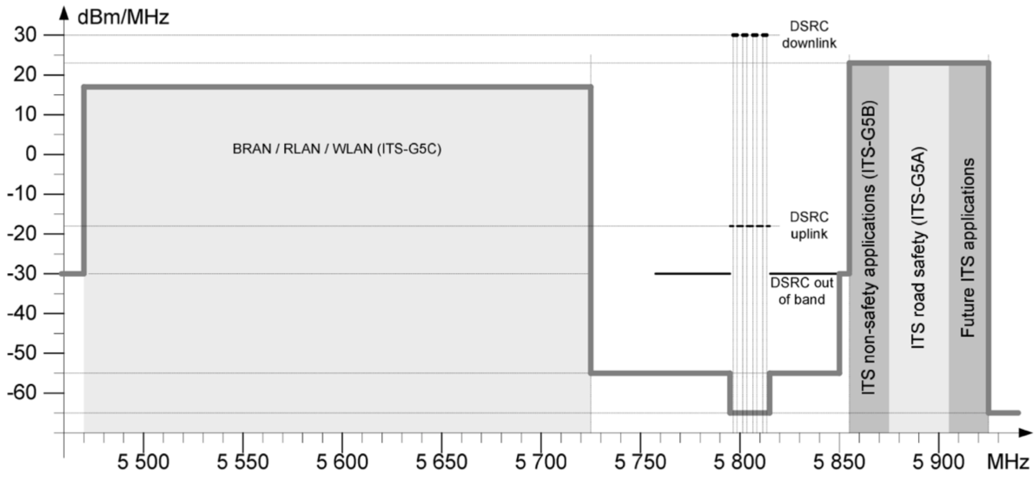

Figure 4-1: European road ITS frequency allocation scheme [see AD-5]

Channel type	Centre frequency	IEEE 802.11 channel number	Channel spacing	Default data rate
G5-CCH	5 900 MHz	180	10 MHz	6 Mbit/s
G5-SCH2	5 890 MHz	178	10 MHz	12 Mbit/s
G5-SCH1	5 880 MHz	176	10 MHz	6 Mbit/s
G5-SCH3	5 870 MHz	174	10 MHz	6 Mbit/s
G5-SCH4	5 860 MHz	172	10 MHz	6 Mbit/s
G5-SCH5	5 910 MHz	182	10 MHz	6 Mbit/s
G5-SCH6	5 920 MHz	184	10 MHz	6 Mbit/s
G5-SCH7	As described in ETSI EN 301 893 for the band 5.470 MHz to 5.725 MHz	94 to 145	Several possibilities	dependent on channel spacing

Figure 4-2: European road ITS channel allocation scheme

4.2 Proposed changes

The Urban Rail proponents in ETSI and CEPT are claiming a spectrum need of 20 MHz split into 4 x 5 MHz channels. It has been agreed between the communities that the Urban Rail application will have a certain prioritisation in the upper 20 MHz of the ITS band (5905 MHz to 5925 MHz) as long as the planned ITS application can still use the bands with only limited restrictions.

Figure 4-3 depicts the proposed prioritisation of the spectrum.

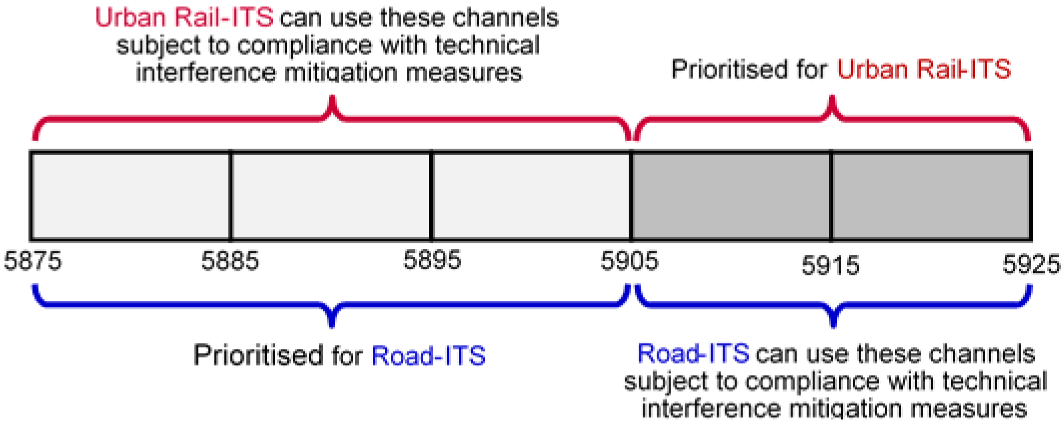

Figure 4-3: JTFIR proposal for prioritisation mechanism [AD-10]

The prioritisation of Urban Rail and Rail applications in the band 5905 MHz to 5925 MHz can be performed using different methods and techniques:

- Duty cycle limitations
- Power reduction
- Exclusion of Urban Rail and Rail applications from the DCC algorithm and decrease of the DCC load limits in Road ITS (e.g. increase load headroom from 10% to 40% channel load).

In order to be able to limit this prioritisation to the area where it is required (operational area of an Urban Rail and Rail system) and to the time frame where a prioritisation is needed, it is important that a Road ITS system gets the dynamic information about the sharing needs of Urban Rail and Rail based on the actual traffic situation. This information can be transmitted using a dynamic beacon solution which is only active where and when sharing is required.

The proposal of is to advertise the presence of Urban Rail by the dissemination of CAM messages, similar to those used for protecting tolling zones (see Appendix A). This solution is considered in the draft LS to be sent to ECC as a promising sharing technique for coexistence of Road-ITS and Rail-ITS systems for two reasons:

1. This solution is considered as technology-neutral (CAM messages can be sent and decoded on any technology)
2. There is no impact on CBTC system behaviour. The only impact to UR operators is the necessity to deploy beacons close to each CBTC AP. If more than one Road-ITS technology is used at a single location, several beacon solutions must be deployed (one for each Road-ITS technology).

In this schema, however, the question can be raised about which band would be prioritised for Urban-Rail ITS. It can be a decisive factor that current implementations of urban rail radio systems in the 5.9 GHz range under individual authorisations are already existing in Denmark and Finland, France, Spain and Sweden with some more on-going implementation projects in Europe (and also outside of Europe, e.g. in China) using the 5.915-5.935 GHz bands.

In the meantime, CEPT WG FM agreed to take urban rail systems into account and set out in ETSI SRdoc TR 103 111 in the ongoing studies regarding compatibility between WAS/RLANs and public transport automation systems in the 5.915-5.935 GHz band. The ECC (mentioned also by ANFR) has indicated that it supports to study also the range 5 925 – 5 935 MHz for Urban-

Rail-ITS (CBTC) and consider it for future ITS mandate. If mandated, it would preserve an additional 10 MHz channel (SCH5) for Road-ITS.

The band 5.925 GHz to 5.935 GHz is an exclusive, not license exempt Rail band with no Road ITS system sharing requirements.

5 Integration of Urban Rail and Rail systems in C-ITS and ITS-G5

5.1 Main concept overview

Section 5 proposes the integration of the Urban Rail and Rail systems in the Cooperative ITS architecture standardised at ETSI. This proposal should be seen as a first “tool box” proposed by road ITS for a possible long-term evolution of both ITS applications.

This concept cannot be considered as a short-term solution, as it would impose a specific technology to CBTC, and for option 2 would require modification of how the CBTC application interacts with the lower layers responsible to transport its messages on the network. Accordingly, such a concept would not fit with the guidance given by ECC in its LS FM(18)190 -Annex 44 : “ Solutions for the coexistence between Road ITS and Urban Rail ITS applications should not impose the use of a specific radio technology, topology or a specific protocol for railway signalling.” However, it should be noted that the concept proposed in this section is agnostic of the access technology used below the network layer and could be seen as a long-term solution that would allow using common components and entities for both ITS systems.

The concept introduces several new technical principles in the CBTC application itself such as a new way to transmit messages (leveraging the use of broadcast and message repetition), together with a new way to define localization (CBTC defines a position based on segment of track and offset on these segments, in road ITS several methods such as GNSS is open sky conditions or any other method like a beacon based solution like it is done in Rail systems can be used), leveraging the use of GeoNetworking to address the controlled zone, etc.

Moreover, the fine analysis of this concept in terms of safety has not been performed in this preliminary version. For any ITS road solution to achieve the same level of safety currently existing in the railway domain, the principles of block (strictly only one vehicle in a block at any time) and failsafe logic (any failure of any element in the chain places the system in its most restrictive state, usually resulting in stopping the train) must be adopted.

According to the concept presented below, the integration of an Urban Rail and Rail communication system into an ITS-G5 based safety related communication system can be done in two steps with different levels of integration:

1 – **Connection (or unicast)-based solution:** use an architecture similar to existing Urban Rail systems using communication in the context of a BSS. This solution leverages the ITS-G5 Access layer only with 10MHz channel bandwidth.

2 – **Broadcast-based solution:** Use broadcast based ITS-G5 system including update of the protocol using communication outside the context of the BSS (OCB). This solution leverages the whole ITS-G5 protocol stack.

Solution described by Step 1 would allow for a smooth introduction of the system into the existing backbone architecture of the CBTC systems already under deployment. The used message set including the PHY/MAC headers would support the detection of the messages and the inclusion of the CBTC load into the operation of the Road ITS system.

Both solutions could be covered by EN 302 571 and the existing regulatory framework without introducing any changes.

5.1.1 Option 1: Connection-based solution

This first solution proposes short and medium-term arrangements that enable Urban Rail systems to work in a manner very close to their existing operation. It uses ITS-capable transceivers to deploy 10MHz channels and headers in compliance with ITS-G5 (802.11 header). The architecture and protocol remain connection-based, using unicast communication and operation in the context of a service set (ISS operation of 802.11 standard). The sharing is done mainly at the access layer level and relies on mechanisms available in the ITS-G5.

- ITS Stations are informed about close-by Rail/Urban Rail operation using protected zone CAMs, as described in more details in Appendix 1;
- A mechanism identical to the one used for DCC mitigation is required for Rail/Urban Rail systems for Safety related communication with limited Duty Cycle.

5.1.2 Option 2: Broadcast-based solution

This second option proposes a more future-proof solution. It also makes use of 10 MHz channels and ITS capable transceivers but it integrates the CBTC communications in the ITS-G5 architecture and relies on the broadcast capabilities of IEEE 802.11-OCB mode. Rail communication is transported in specific messages, which need to be added to existing ITS standards. The sharing is thus done at the entire system level. The Urban Rail AP becomes an ITS Station (hereafter named TS-ITS-S for Track Side ITS-S), while the equipment in the trains becomes also an ITS station (hereafter named T-ITS-S for Train ITS-S) (for detailed nomenclature and symbiosis with road ITS station architecture, see section 5.4.1).

5.2 Description of Option 1: Connection-based solution

In this option, the operation is performed in the context of a BSS, as in standard WiFi operation. It does not require any change in the overall CBTC architecture or communication scheme. Because the communications now use 10 MHz channels to comply with existing regulation, the duty cycle is significantly lower than in 5 MHz channels and can be estimated to be around 50% of existing duty cycle, while respecting the time between messages imposed by the safety.

ITS-enabled radio transmitters guarantee robust communication with enhanced link budget. Typical multipath fading results are available in Annex 1. Using these radios ensures that the CBTC system complies with existing EN and regulation, while no further change is necessary for CBTC. Under assumption of reduced duty cycle, CBTC could operate without implementing the DCC algorithms. This would give CBTC an inherent level of prioritisation.

Furthermore, CSMA/CA based systems can detect each other and an ITS-G5 station is able to perform mitigation when needed using DCC-like mechanism, meaning that Road ITS stations would decrease the transmission power from e.g. 60% load down to 50% and thus give the other systems without DCC reasonable capabilities to access the channel. The limitation similar to DCC limits is deployed only when protected zone CAM is received.

This solution is considered as a transition evolution towards a fully integrated system.

5.3 Description of Option 2: Broadcast-based solution

As this option is fully based on a (modified) version of recent ITS-G5 solution, in the following sections the corresponding technology elements are first reviewed shortly.

5.3.1 ITS-G5: Nomenclature and main properties

ITS applications make use of wireless communications between mobile ITS stations (vehicles), or V2V, and between mobile ITS stations and stationary ITS stations (roadside installations), or V2I / I2V, with single-hop or multiple hops between the source and destination.

ITS-G5 technology and architecture is ultimately based on the harmonized content of the generalized notion of ITS communication station (referenced as ITS-S in the sequel), which can be implemented in various forms with different functionality and configurations. ITS-S is the actual implementation of a communication station concept with particular functionality providing the complete feature set of the C-ITS communications protocol stack. A specific implementation of an ITS-S is referenced as roadside station (R-ITS-S) providing direct access to the infrastructure, central station (C-ITS-S) providing server functionality in the infrastructure, moreover, vehicle station (V-ITS-S) or onboard unit, which are the most frequently used devices in the architecture. An ITS-S is specified as a secured managed domain in the standards in order to lower the risk of unauthorized or illegal usage. This nomenclature is compliant with [AD-5], [AD-21] and with other documents regarding Cooperative Intelligent Transportation Systems (C-ITS) Communications Architecture standards.

ITS-G5 is based on the IEEE 802.11p amendment to IEEE 802.11-2007, and is considered the evolution of the 802.11a amendment that introduced 10 MHz channels and OCB mode to be able to support the high-speed mobility of stations. It uses a higher throughput (6 MBit/s versus 3 MBit/s for QPSK ½).

ITS-G5 was designed to meet V2X application requirements with the most stringent performance specifications and robustness. The technology is required to support many safety-related and non-safety-related use-cases for the ITS ecosystem. Safety-critical and life-saving applications remain at the core of vehicle communications and strictly require the technology to efficiently operate in absence of a network. ITS-G5 technology, which is based on IEEE 802.11 OCB mode was developed for scenarios which must be supported in absence of a network infrastructure that is ideal for safety critical applications.

Furthermore, ITS G5 was optimized for mobile conditions in presence of disturbances and obstructions, handling dynamically varying multi-path reflections and Doppler shifts generated by relative speeds as high as 500 km/h providing sufficient robustness against frequency and timing errors.

It needs to operate robustly in a very dynamic environment with high relative speeds between transmitters and receivers, and support the extremely low latency of the safety-related applications in highways, urban intersections and tunnels.

The typical Line-Of-Sight (LOS) range is 1 km, but, in optimal conditions, larger ranges of even several km's are routinely achievable.

Consistent with the above, communication between ITS-Ss can be classified as safety and non-safety critical one.

So far, all operation under ITS-G5 safety mode is broadcast operation that fully benefits from the fact that no connection between the stations is necessary. Measures implemented for security and privacy are based on downloaded certificates and encryption.

Unicast mode is generally not used in safety critical scenarios with the rare exception of geo-location-based addressing.

ITS-G5 introduces geo-networking, where the destination position is an inherent part of the communication's addressing.

Existing ITS-G5 system and radio chips are optimized for mobile applications to allow for robust communication.

5.3.2 ITS-G5 communications architecture and protocol stack

The baseline for a European ITS communications architecture for cooperative road traffic systems is described in [AD-7]. The ITS station (ITS-S) reference architecture (Figure 5-1) explains the functionality contained in ITS communication stations which are part of all ITS sub-systems in a particular deployment. Beyond the standard access and network layers functionality, the facilities layer represents the main feature set of the vehicular communications architecture and support for common message and data management for data exchange between ITS-S applications.

Applications making use of the ITS-S services to connect to one or more other ITS-S applications are on the top of the vertex.

A particular implementation of the above set of layered functionalities is called ITS-S protocol stack.

Access and link level protocols follow the respective Access layer standard and comply with applicable regional frequency regulations.

Networking and Transport protocols, beyond standard internet protocols, include GeoNetworking.

Perhaps most importantly, Facilities protocols support basic common functionalities of the vehicle communications system that are defined in order to ensure the correct system functioning and to satisfy interoperability. Facilities layer entities manage the ways how information is stored and used at ITS station level, perform data fusion, positioning and database handling, and are key to fully autonomous operation.

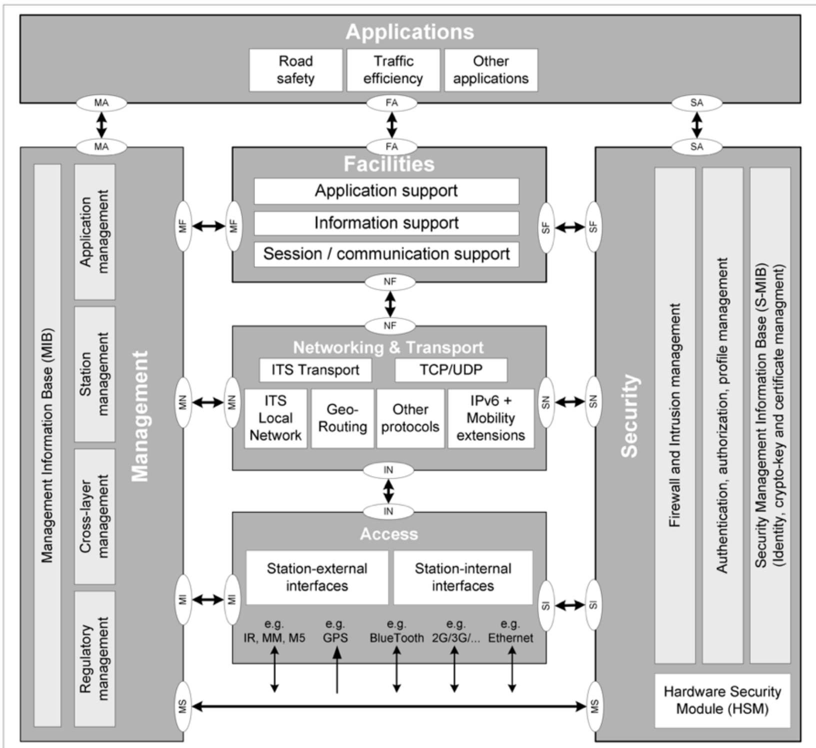

Figure 5-1: Road ITS station reference architecture in acc. with [AD-7]

Cooperative Awareness Basic Service (CABS), which provides a cooperative awareness service to neighbouring nodes by means of periodic sending of status data is a mandatory functionality. This generates and distributes Cooperative Awareness Messages (CAMs) in the ITS-G5 network in a deterministic timely basis (with 1 to 10 Hz frequency, depending on the ITS-S context). This provides information of presence, positions as well as basic movement status of communicating ITS stations to neighbouring ITS stations that are located within a single hop distance.

In contrast to CABS, Decentralized Environmental Notification (DEN) service handles messages (DENM) in an event driven manner and provides the key messaging functionality for hazard warning. For high resolution dynamic hazard warning and hazard information sharing the Cooperative Perception Message (CPM) service is under development in ETSI [AD-33]. The concept of sharing the perceived environment of an ITS-S based on perception sensors. In contrast to Cooperative Awareness (CA), an ITS-S broadcasts information about its current sensed environment rather than about itself. In fact, CPM services implement a very important link between C-ITS and UR systems that make the harmonized C-ITS/UR system capable for joint detection and annotation of safety hazards in the common road-rail space.

A local dynamic map (LDM) manages location and status information of communicating vehicles on a small geographical scale, dynamically, collecting digital map and sensory information in a single manageable data-base format. The system service position and time as provided by the PoTi facility layer entity is another part of the ITS system architecture [AD-32].

MAP is the road infrastructure description data structure and SPAT is the communication protocol between vehicles and active elements of the infrastructure, such as e.g., traffic lights and controllers.

5.3.3 Requirements and solutions for V2X safety and security

Certification and functional safety requirements are defined in the package of ISO standards [AD-22] for road vehicles. This provides requirements for validation and confirmation measures to ensure a sufficient and acceptable level of safety is achieved. Risk and hazard analysis determine the Automotive Safety Integrity Level (ASIL) grade by weighting the potential to threaten lives. Since ITS-G5 V2X have the capability controlling the vehicle in safety critical use-cases, like in many autonomous drive applications it is assumed that V2X requires the ASIL B grade next to other automotive electronics certifications as various stress test qualification [AD-23], EMC immunity [AD-24] and functional safety qualification [AD-22].

Cyber security and End-to-End (E2E) device security are two main requirements of V2X technology. To enforce E2E device security of a connected vehicle system, including user and vehicle protections such as ensuring secure and trusted information exchange among users to support secure communications one needs to ensure that

- messages originate from a trustworthy and legitimate device (authenticity),
- messages are unhurt and not modified between sender and receiver (integrity),
- misbehaving units and malicious actions are detected and removed from the system (fault tolerance).

Recent ITS-G5 V2X security solutions to ensure authenticity, confidentiality, message integrity with non-repudiation maintaining users’ privacy between V2X entities are certificate based. The format for the certificates is specified in [AD-12]. Certificate management is the service of Certificate Authority (CA) system which is implemented over the Public Key Infrastructure (PKI), see Figure 5-2.

The security credential system provides secure communication between parties which is practically unbreakable in reasonable time (minutes). Certificate is only valid for 5 min and discarded after use. It uses public key cryptography and digital signatures to provide authentication. Public key cryptography ensures that each entity has a private key (only known to the owner) and a public key that is distributed to all message receivers. A message sent to the receiver contains a digital signature (private key) of the message and a certificate that contains the public key of the sender. CAM, DENM and generic message types are affected as described in TS 103.097.

Cyber security solutions differ from E2E security as they involve interaction with Sensors, Actuators and Cloud entities and are based on trusting and credibility analysis.

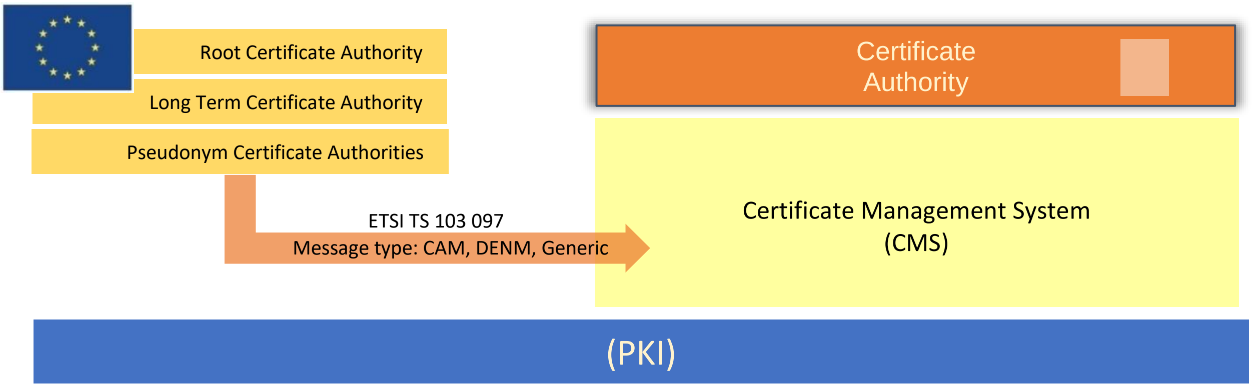

Figure 5-2: General overview of the European road ITS security credential system

5.3.4 Safety and security of CBTC communications

All ITS Stations are required to deploy infrastructure security certificate. Since the Urban Rail systems are operated in a more controlled environment, the distribution of certificates and the implementation of the certificate management system itself is expected simpler than in automotive environment. The extension of road PKI infrastructure to railway seems is straightforward.

Traditional CBTC systems (based on unicast technology as described in Option 1, above) apply mitigation techniques to reduce severity of communication malfunctions (communication blackouts and packet losses) as follows:

- Application of two OBUs per train, one in the front, another on the tail.
- Use of two radios per OBU (less frequent solution).
- Two antennas per radio.
- Alternating use of two or more frequencies in order to avoid interference with neighbouring waysides.
- Application of redundant TS-ITS-S coverage areas by construction.
- Application of redundant TS-ITS-Ss per location.
- Redundancy TS-ITS-S/trackside backbone networks.

In Section 5.3.5, we will summarize how the changeover from unicast to ITS broadcast mode can have the potential to comply with the safety requirements of CBTC.

5.3.5 Preliminary considerations to the use of broadcast mode

Mapping the concept of CBTC onto a broadcast-based operation means that both TS-ITS-S and T-ITS-S stations are used in broadcast-based GN operation.

In CBTC, the broadcast-based scenario can be used to enable direct communication between trains, without the extra overhead involved in the train-to-wayside communication. This might play an important role in reducing the end-to-end delay, thereby resulting in even shorter headways between trains.

Packet acknowledgement mechanism needs to be handled in this mode. For example, geo-addressing can be used to address the trains located in the area covered by the APs, with the addition of the ITS Station Id defined at Facilities Layer to identify a specific train.

APs (TS-ITS-Ss) operation can rely a special type of beacon to advertise itself. A node can connect to the AP simply by receiving this beacon advertisement. This further reduces the overhead associated to a normal IEEE 802.11 handover and makes the handover significantly safer in the rare unicast situations.

The concept of zones defined in CBTC needs to be mapped onto the LDM concept. This will allow for the backward compatibility to existing installations, while future extension to new concepts is possible. Broadcast mode is also very well suited for multi ZC communications.

TS-ITS-S on trackside integrate the C-ITS protocol stack as well. They are entities having the same type of functionality as T-ITS-S and S-ITS-S can be seen as a distributed sensing network. There is no need to address a TS-ITS-S individually for message transfer, as all TS-ITS-S within the communication range receive the message via broadcast. However, a ZC can be individually addressed using its location information by the application of the GeoNetworking concept (via unicast).

Uplink communication

Vehicle ITS stations (or OBUs) are installed in trains and become T-ITS-S. They broadcast CAM-like messages at a fixed rate. These messages, hereafter named Urban Rail CAM (UR-CAM), are expected to be simpler than automotive CAM in the sense that a smaller set of parameters is needed. They include the train position (location report) and kinematics, and if necessary, some functional status information. Their duty cycle is around 5 messages per second with a length between 300 bytes and 1500 bytes (depends on content and security). They may address only relevant APs using the GeoNetworking capability.

For the broadcast on demand messages, it can be performed either by adding a field to UR-CAM or by defining a DENM-like message (UR-DENM).

The track-side ITS stations receive the information from the trains and transfer it to the relevant ZC based on positioning information. They use GeoNetworking capabilities to address the correct ZC, together with an additional functional block in the facilities layer.

Downlink Communication

Based on the position information received from the train, the ZC transmits movement authorisation using SPAT (Signal Phase and Timing) like messages (UR-SPAT).

Line information from the ZC to the train can be communicated using MAP like messages (UR-MAP) that include positions of TS-ITS-S (or track-side ITS-S) and other trains (if required).

5.4 Positioning and timing

Location and time management is an important functionality in both road ITS and UR systems.

ITS-G5 applications require the exchange of position and time information as part of the information exchange among ITS-Ss. The position and time information at a given instant may be represented by the ITS-S geolocation and time reference function. Similarly, the position and time of a specific road traffic event when detected may be represented by the ITS-S geolocation and time reference. For the implementation of ITS applications the accuracy, validity, availability, integrity, quality and reliability of the geolocation and time reference information are key requirements to ensure a correct behaviour of these applications. Even if ITS-G5 communication is asynchronous, for road safety applications requiring short latency, the time synchronization of ITS-Ss with regards to the International Atomic Time (TAI) [AD-3] is required.

As defined earlier, position and time services are part of the facilities layer PoTi entity. ITS-Ss may be equipped with a Global Navigation Satellite System (GNSS) providing the geolocation and time ITS system references. As such the GNSS signals are used to synchronize all ITS-Ss in the ITS system and PoTi include various methods to ensure the accuracy, validity, availability, integrity, quality and reliability of the geolocation and time references.

Three main PoTi functionalities which play key role in road-rail harmonization are as follows.

- Position information management: it manages the quality of the ITS-S geolocation information, handles updates of the data and provision of the geolocation information to application and Facilities layer entities.
- Time information management: it manages the quality of the current local time, handles updates of the ITS-S time information and provision of the time information to application and Facilities layer entities.
- Position augmentation service: it implements the position augmentation technologies

The position and time information (including confidence values) are provided by the PoTi module of ITS-S upon request, or automatically when the system receives an update.

Road vehicle ITS-S may require that PoTi provides the position and time update with a specific rate. This rate is specified as 1 - 10 Hz. Recently, the most accepted update frequency is 10 Hz, to comply with the requirements of the basic awareness protocols (CA basic service triggers the transmission of CAM at 10 Hz frequency).

The basic ITS-S geolocation reference is based on GNSS technology providing absolute location reference of horizontal and vertical position, speed and heading information. ITS-Ss are, therefore, normally equipped with GNSS receivers of varying accuracy. As road ITS safety use-cases ultimately rely on the accuracy and robust availability of location reference information, augmentation technologies are used to enhance the service quality of positioning. Augmentation methods combine absolute and relative positioning techniques and estimation corrections. While the field of augmentation technologies are wide and varied advanced multibrand GNSS augmentation with RTCM correction can provide sub decimetre accuracy routinely, by now.

For any train positioning system, however, IEC 61508 SIL 4 must be achieved because position measurements are used for speed control. This represents a unique requirement for safety and system integrity, different from road ITS and other civil positioning applications.

For the application of the moving block concept on UR systems, the trains have to have precise location information. There have been significant efforts to adopt GNSS-based positioning to rail systems. This uses an onboard GNSS-based positioning system to detect when a train passes well-defined locations stored in a database onboard (also called virtual balises), enabling the odometer calibration to be performed.

Because of the presence of sporadic electromagnetic disturbance in railway environment (due to the high voltage power lines and other electrical equipment and actuators), however, the GNSS-based position determination can be problematic. The application of specific navigation data signal types may improve satellite reception in rail applications. One signal type can be more robust than others (Galileo E5AltBOC showed the best performance according to PRoPaRT project) but further research and experimentation will be needed to select the optimum GNSS configuration for railway use.

GNSS presents limitations in signal-denied areas, such as tunnels, urban environments, and foliage. In such areas, no GNSS solution is safely available. Consequently, the safety integrity of the positioning system is jeopardized. Therefore, the need for measurement compensation for the lost satellite reception in covered areas is a more serious issue for railways than for road systems. GNSS is also vulnerable to spoofing threats and solutions must be identified to mitigate this.

There is a general consensus that GNSS must be integrated with other sensors and sources of information in order to meet the SIL 4 safety requirements of train control applications.

Typical railway sensors available to use for position enhancement include Doppler radar, the wheel sensor (tachometer or odometer) and the Balise transponders that should be included as aided navigation sensors.

Recent safety train positioning technology ultimately relies on the robust and proven beaconing solution according to which passive position transponders (i.e., balises) are mounted along the railway lines which provide the pre-programmed location data in response to radio frequency energy broadcast by a Balise Transmission Module (27 MHz) mounted under the passing trains.

For obvious safety reasons this balise-based technology is expected to remain the basic train positioning technology in UR systems in the future. Recently, railway balises have received renewed attention, however. Techniques considering state-of-the-art solutions rather than the old, currently used passive transponders are being researched. Balises can be designed to operate from the side of the track (rather than on the track), which provide more convenient equipment location from many reasons (maintenance) that uses the ultra-wideband impulse radio (UWB-IR) technique. This technique possesses the intrinsic qualities of providing precise relative location capability and high signal security which is on favour for SIL 4 certification.

With the harmonization of the road and rail communication systems, however, these new techniques may provide an additional augmentation method which is to be included in the forthcoming releases of the PoTi standard [AD-32].

5.5 Message set proposal

Based on the above discussion one has to define new / updated message set for introducing Urban Rail and Rail as part of ITS-G5 system:

- UR-CAM (Urban Rail CAM)
- UR-DENM (Urban Rail DENM)
- other messages required (UR-SPAT, UR-MAP)

Furthermore,

- Update LDM (Local Dynamic Map) to mimic Zone Concept including moving Zone Concept
- Update MAP to describe the structure of railway line infrastructure as well as the layout of rail/road level crossings.
- Define Facilities Layer CBTC functional block to interface with backbone operation and to abstract ITS-G5 functionality

These messages would be handled by a new component of the Facilities layer dedicated to UR-ITS services as illustrated in Figure 5-3.

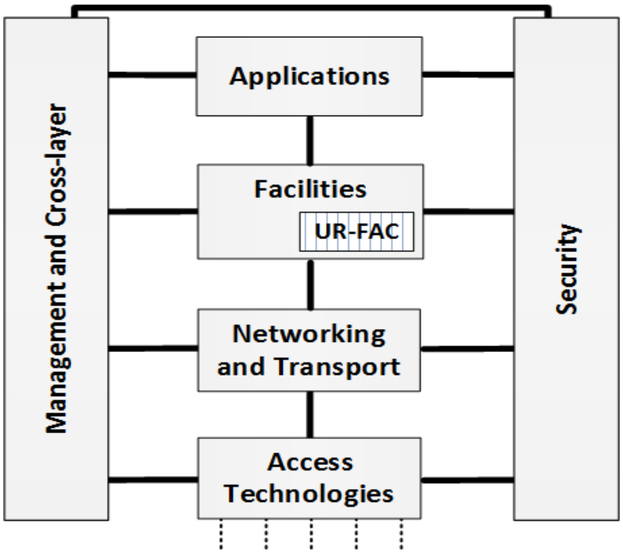

Figure 5-3: ITS Station model showing UR-ITS specific component in Facilities layer

5.5.1 UR-CAM

The ITS-G5 CAM [AD-2] informs neighbouring stations of the presence and of dynamic parameters of the transmitting station. The CAM is broadcasted in a periodic way (1 to 10 Hz when functioning normally) in the geographic area surrounding the transmitting station at a single hop distance.

The CAM content varies depending on the transmitting ITS-S and is split over several “containers”. For example, for a V-ITS-S, the basic container provides the type of ITS-S and its geographical position. The HF (High Frequency) container provides information that varies very rapidly: direction, speed, dimensions, steering angle. The LF (Low Frequency) container holds information on more static characteristics of the ITS-S: the vehicle’s role, the state of the lights, the opening of doors, etc. Some vehicles may also indicate their role: public transport, emergency priority vehicle or transport of hazardous substances. A R-ITS-S only distributes its characteristics: type, position, etc. in the HF container.

The CAM could be adapted to fit the needs of several CBTC services:

- Location Report to one ZC
- Periodic Train Functional Status message
- On demand specific status message
- Platform Screen Door monitoring and control approaching, in station and leaving station

The containers would include the following information (more study is needed here).

- Basic container: the type of ITS-S and its geographical position
- HF container: direction, speed, dimensions
- LF container: functional status, monitoring of doors

5.5.2 UR-DENM

The ITS-G5 DENM [AD-8] is used to broadcast a dated and geo-localised alert when an event is detected: dangerous weather conditions, road work, animal on the road or brutal speed decrease.

The DENM content is split over several containers as well.

- The Management Container provides general information: action ID (originating Station ID, sequence number), detection time, reference time, event position, relevance distance, relevance traffic direction, originating station type.
- The Situation Container gives more specific information: information Quality, event Type.

A new message set, with a structure similar to that of DENM, could be defined to fit the needs of several CBTC services:

- Information about Line from ZC
- Request for Health train status

The content and structure of this new message would be identical to that of the DENM message as currently defined, only new values for the field equivalent to the "event Type" field would have to be created to suit the needs of Urban Rail.

5.5.3 UR-SPAT

The ITS-G5 SPAT message [AD-25] [AD-26] is mainly used to inform road ITS-S in real-time about the operational states of a signal system, e.g. a traffic light, its current signal state, the residual time before changing to the next signal state and to provide assistance for crossing, including lane information.

The SPAT Message contains the following parameters

- status of the traffic controller: e.g., active, manual control, stopped, failure, off, etc…
- timestamp
- enabled lanes (optional)
- movement state for each lane or group of lanes: signal phase state, time change, advisory speed)
- manoeuvre assistance (optional): traffic queue length, available storage length, wait on Stop, pedestrian or bicycle detected
- priority state (optional)
- pre-empt state (optional).

The SPAT message could be adapted to fit the needs of the following CBTC service:

- Movement of authority from ZC

Most of the existing parameters in the SPAT message could be applicable to Urban Rail. The UR SPAT message would only need to be simplified by ignoring some of the optional fields in the existing SPAT message.

5.5.4 UR-MAP

The ITS-G5 MAP message [AD-25] [AD-26] is used to broadcast the topology/geometry of a set of lanes. E.g. considering an intersection, the MAP message defines the topology of the lanes or parts of the topology of the lanes identified by the intersection reference identifier. It includes the lane topology for e.g. vehicles, bicycles, parking, public transportation and the paths for pedestrian crossings and the allowed manoeuvres within an intersection area or a road segment. It should be noted that the MAP message is quite stable over time.

The MAP message contains the following parameters

- Geographic layer type (optional): intersection, curve, roadway, parking, …
- Definition of intersections / road segments. For each component:
  - Reference point (latitude, longitude, elevation)
  - Lane width (optional)
  - Speed limit (optional)
  - Lanes set: for each lane
    - Identifier
    - Ingress approach / egress approach (optional)
    - Attributes: type (vehicle, crosswalk, bicycle, sidewalk, parking), direction of use, sharing (e.g. with bus, taxis, pedestrians ...)
    - Allowed manoeuvres (optional)
    - Lane geography, defined by a set of points and/or computed segments
    - Connecting lanes, overlay lanes.

The MAP message could be adapted to fit the needs of the following CBTC service:

- Track data base update

Most of the existing parameters in the MAP message could be applicable to Urban Rail tracks. The new UR-MAP message would only need to be simplified to take into account the constrained geography of tracks. It would also require the definition of a new lane type for rail tracks.

5.6 Overall architecture and protocol extensions required

Based on the study in the previous paragraphs, the following modifications of the existing standard set would be needed to support the integration of UR-ITS in the ITS-G5 system:

- Networking and Transport Layer
  - If the service is based on broadcast mode, the existing GeoNetworking standard [AD-31] can be used without modification
  - If the service is based on Geographically-Scoped Multicast (see description in Appendix B), the GeoNetworking standard needs to be updated accordingly. This proposal has been submitted at ETSI to be included in TR 103 563 " Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; Pre-standardization study Release 2"
- Facilities Layer
  - The UR-CAM message should be implemented as a new container / update of the existing CAM message. Accordingly, this would require the update of ETSI EN 302 637-2 [AD-2] and ETSI TS 102 894-2 [AD-3].
  - A **new standard** would be needed to specify the UR-ITS basic service, the details of the new message set presented in section 5.3 and the protocol behaviour. This standard would reference ETSI EN 302 637-2 for the UR-CAM message specification. It would reference ETSI TS 103 301 for the UR-SPAT and UR-MAP messages
  - The specification of PoTi (TS 102 890-2) is under progress at ETSI. It would need further checking to ensure that it fits the needs of UR-ITS.

6 IEEE 802.11 for ITS and CBTC use - Roaming frequency and latency

A critical aspect of roaming in mobile environments is how a radio communication system smoothly switches from one access point (vehicle or roadside unit) to another (i.e., handover), without causing interruptions and delays in the communication.

A large handover latency, for instance, might result in a delayed reception of the CBTC control information and the train might have to apply emergency brakes. Moreover, studies show that the number of packet losses due to handover in CBTC systems is much larger than from any other disturbance reasons.

Regarding handover, it is important to note that IEEE 802.11 is used differently in CBTS and road ITS applications.

The IEEE 802.11-2012 standard contains two basic network topologies. The infrastructure BSS that contains an access point (AP) and the independent BSS (IBSS), which does not. BSS mode contains the complete functionality for scanning, authentication and association. The IBSS is a set of nodes communicating directly without authentication and is used to create an ad hoc or peer-to-peer network. With the introduction of the 802.11p mode, a new capability of the 802.11 is introduced, namely communication outside the context of a BSS (OCB). Note that IBSS is different from OCB. In OCB mode the scanning on frequency channels for the node in order to join an existing network is no longer enabled, moreover, authentication, association and security between nodes are disabled at the MAC sublayer. Therefore, the implementation of 802.11 OCB mode in the vehicular environment required predetermined frequency channels to be set in the management.

- CBTC traditionally relies on 802.11 BSS (Basic Service Set) mode. BSS is a group of IEEE 802.11 stations anchored by an Access Point (AP) and configured to communicate with each other over the air-link. Communicating stations belong to the BSS and communicate via an access point.
- Road ITS communications (ETSI ITS-G5) relies on IEEE 802.11 OCB (Communicating Outside the Context of a BSS) mode (traditionally this was called the 802.11p). Communicating stations are not member of the BSS and communicate directly with each other in an ad-hoc mode.

This property has far reaching consequences regarding performance of road ITS and CBTC handover operation.

To minimize adjacent-channel interference, adjacent APs in CBTC systems are deployed on alternating frequency channels. This means that CBTC radios need to change not only over APs, but frequencies as well. As IEEE 802.11 does not specify how this complex handover mechanism is achieved CBTC systems typically develop their own roaming/handover algorithm and radio solutions. Normally a smooth transition is achieved by equipping a train with at least two radios, one at each end of the train, such that at least one of these radios is always connected to an AP. A similar multi-radio based roaming method for CBTC aims for a transport layer solution rather than the data link layer to further minimize the handover latency. The application of proprietary handover support solutions further enhances the variety and diversity of CBTS deployments.

Handover in IEEE 802.11 BSS consists of three phases: (1) scanning for APs, (2) authentication, and (3) association.

- The latency of the scanning phase accounts for approximately 90% of the total handover latency.
- Utilizing a centralized security architecture that involves communicating with an authentication server authentication may last up to one second. In CBTC scenarios, where seamless handover is critical, one approach is to skip the authentication phase altogether. However, the drawback is that authentication then must be performed by a higher layer security protocol, such as IP security.
- Association is a deterministic low value proportional with the packet transfer delay, which is not a decisive factor.

Handover time in CBTC is typically in the range of 70-120 milliseconds, with an upper limit of 1 sec, see [RD-2].

In contrast with 802.11 in BSS mode, the OCB mode avoid the latency associated with establishing a BSS and does not utilize the standard 802.11 authentication, association, or data confidentiality services. Authentication is subject to the communication station management function or performed by facilities and applications outside the MAC layer. Perhaps most importantly, safety use-cases of ITS-G5 communication are implemented in broadcast mode, meaning that handover latency is completely eliminated from the scenarios.

7 Conclusions and further steps

In order to guarantee the efficient use of the available spectrum resources, a shared use of the 5.9 GHz band between road ITS systems and Rail systems including Urban Rail would be beneficial. The most efficient sharing between the applications could be reached by deploying the same communication system for both applications.

This report presents relevant elements for the deployment of an ETSI ITS based system for Urban Rail and Rail systems to imitate further developments and standardisation work.

In this paper two different approaches have been proposed:

- Connection-based solution and
- Broadcast-based solution

For an initial deployment the connection-based approach seems to be the solution of choice since no significant changes to the overall rail communication architecture would be needed. The level of integration into the overall system would be limited to the access layer and thus no further reuse of the enhanced features (e.g., positioning, security, geo-networking) in the ETSI ITS protocol stack is envisaged here.

The broadcast-based solution using the OCB feature of the IEEE 802.11 standard and the ETSI ITS protocol structure would allow a much deeper integration and the reuse of already existing features beneficial for the operation of a rail communication system. Since this approach will include some significant changes in the architecture it can been seen as a mid to long-term solution for an integrated ITS communication system. This approach could lead to significant cost saving due to the reuse of broadly existing equipment.

In both solutions, it is essential to integrate all available positioning systems including the rail specific methods into the system. The positioning of a rail vehicle can not only rely on a GNSS approach but need to integrate the systems used in rail environments. The ETSI ITS architecture can support this integration and this will significantly increase the positing reliability.

In further steps the ETSI ITS-G5 performance needs to be evaluated in more detailed measurement campaigns. In recent time some initial work has been performed by the DLR and some universities. In a next step the test setup needs to be adapted towards the use cases presented in this document.

The given requirements in this report should also be used in the new IEEE802.11bd group developing an evolution of the vehicular IEEE802.11 system, also known as Next Generation Vehicular (NGV). Some enhanced features could improve the usability of the system in rail environments in general without breaking the backwards compatibility and interoperability required for a smooth integration of the systems.

8 Appendix A - Proposal for Urban Rail Protected Zones

This proposal has been initially presented at ETSI as [AD-14].

8.1 Overview

The prioritisation of Urban Rail and Rail applications in the band 5905MHz to 5925MHz (5935MHz) can be performed using various methods and techniques such as:

- Duty cycle limitations
- Power reduction
- Exclusion of Urban Rail and Rail applications from the DCC algorithm and decrease of the DCC load limits in Road ITS (e.g. increase load headroom from 10% to 40% channel load)
- Other methods

In order to be able to limit the effect of this prioritisation to the area where it is really required (i.e., within the operational area of an Urban Rail and Rail system where the protection is required) and to the time frame where a prioritisation is needed it is important to provide Road ITS system with the dynamic information about the sharing needs of Road and Urban Rail and Rail, based on the actual traffic situation. This information can be transmitted by means of a **dynamic beacon** solution which is only active where and when the spectrum sharing is effectively required. The beacon solution itself is not the sharing mechanism but provides the required information to perform an efficient sharing operation on the Road ITS side with a limited impact (with respect of time and area) on the operation of the Road ITS system.

This section presents a beacon solution based on the CAM message announcement of the zone to be protected, as an extension of the solution that is already specified to protect the CEN DSRC tolling zones.

8.2 Requirements

For the definition of the characteristics of a beacon for the facilitation of the Urban Rail protection different requirements have to be fulfilled.

- **Time requirements:** Any kind of beacon should only be operational when an Urban Rail communication takes place. It should be envisaged that, only when an Urban Rail train enters a critical area where interference with road ITS communication could occur, a warning beacon should be transmitted. The beacon should be active as long as the train is in the potential interfered area. For a straight 1 km track line with a train speed of 80 km/h (22 m/s) the beacon would be active for around 45 sec. In case the train stops from any reason, the beacon duration might be increased.
- **Range/Area requirements:** Due to the construction of an Urban Rail system most of the areas of operation will not be impacted by interference from a Road ITS system (rail lines are well separated and isolated from road systems by distance and/or other architectural solutions). The operation in tunnels or areas where no relevant road traffic will occur, for instance, will not need any specific treatment. The communication critical areas need to be identified during the network planning process of an Urban Rail line and only at these positions a beacon needs to be installed. The range of the beacon needs to be sufficiently large to reduce the potential impact onto the rail systems. The range could be increased by using a higher TX power than typically is being deployed in a Road ITS systems

(23 dBm). This asymmetry could help to overcome the effects of the narrow beam antennas used in Urban Rail systems.

- **Repetition requirements:** A beacon should be received by all participant of the Road ITS system in the critical area. Since new car might enter the area and other will leave the area, the beacon needs to be repeated with a reasonable frequency. The highest repetition rate would be 10 Hz, but the lowest CAM generation rate of 1Hz (i.e. one beacon per second) might be quite sufficient considering that a vehicle in Urban scenario, driving at 50km/h takes 7.2 s to travel 100 m. Here further evaluations are required. The repetition will also increase the reliability of the reception of the message by the road ITS users.
- **Physical layer requirements:** Since the beacon has to be received by all Road ITS systems, the PHY layer deployed needs to be adapted to the technology used in the relevant area. In the worst case all used Road ITS technologies need to be supported.
- **Frequency band requirement:** The protection should only cover the operational band of the Urban Rail system in order to reduce the impact on any kind of road ITS communication.

8.3 Beacon based on Cooperative Awareness Messages (CAM)

8.3.1 Introduction

This section presents an adaptation of the CEN DSRC protection mechanisms to be used for Urban Rail. The main goal is to limit the adaptation mechanism to the use of a minimal set of modified features. This solution provides technology neutrality because it relies on the Facilities layer, which is a higher layer in the Road ITS protocol stack that will be common to and mandatory for all Road-ITS access layer.

8.3.2 Summary of the CEN DSRC zones protection

Typical CEN DSRC stations operate in the band 5 795 MHz to 5 815 MHz. CEN DSRC RSUs are generally installed in tolling stations and CEN DSRC OBUs in the subscribing vehicles. OBUs are active only when they are located in the close vicinity of an RSU.

Studies [AD-27] have shown that there is a potential for harmful interference from ITS Stations. ITS Stations can cause blocking at the receiver in a CEN DSRC RSU and / or interference at the receiver in a CEN DSRC RSU or OBU.

Therefore, a protection mechanism has been set-up in ITS Stations in such a way which minimize the effect of interference, originated in road ITS communication, to CEN DSRC RSU and OBU tolling stations by maintaining the performance of ITS communications.

The procedure defined in the standard introduces two operational modes in the ITS Stations:

- ***normal mode*** where transmit duty cycle is not limited; output power level is limited to the legal values specified in ETSI EN 302 571; unwanted emissions in the band 5 795 MHz to 5 815 MHz are limited to -30 dBm/MHz.
- ***coexistence mode*** where transmit duty cycle is limited; and/or output power level and unwanted TX emissions are reduced.

Both modes are fully specified in ETSI TS 102 792 [AD-1].

An ITS Station determines that it should apply coexistence mode restrictions when it localises itself as inside a CEN DSRC protected zone. One of the methods used for this localisation of protected zones uses CAM messages containing the required information broadcasted from an ITS station with a station type "roadSideUnit".

Figure 8-1 below shows the basic structure of a CAM message. The details can be found in the ETSI EN 302 637-2 [AD-2].

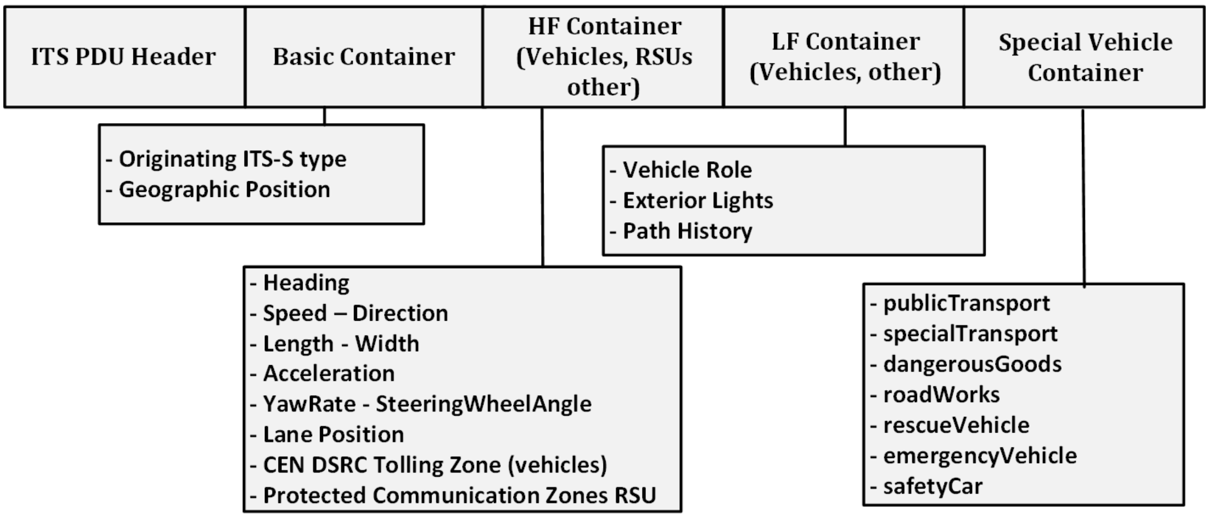

Figure 8-1: Basic structure of a CAM message

The Protected Communication Zones RSU field, appearing in the High Frequency Container of an RSU CAM is constructed as follows and specified in the CAM specification EN 302 637-2 [AD2]. The numbers of in the table resemble the elements as defined in the Common Data Dictionary (CDD) for Road ITS in the ETSI TS 102 894-2 [AD-3].

Date element / data frame	Data type (No. in CDD [i.6])
CAM	
header	ItsPduHeader (114)
cam	CoopAwareness
generationDeltaTime	GenerationDeltaTime
camParameters	CamParameters
basicContainer	BasicContainer
highFrequencyContainer	HighFrequencyContainer
rsuContainerHighFrequency	RSUContainerHighFrequency
protectedCommunicationZonesRSU	ProtectedCommunicationZonesRSU (122)
ProtectedCommunicationZone	ProtectedCommunicationZone (121)
protectedZoneType	ProtectedZoneType (58)
expiryTime	TimestampIts (82)
protectedZoneLatitude	Latitude (41)
protectedZoneLongitude	Longitude (44)
protectedZoneRadius	ProtectedZoneRadius (57)
protectedZoneID	ProtectedZoneID (56)

Table 8-1: Structure of the CAM with Protected Zone elements

```
ProtectedCommunicationZonesRSU ::= SEQUENCE (SIZE(1..16)) OF ProtectedCommunicationZone
```

In this field up to 16 different zones can be defined and transmitted to the ITS station. This information is saved in a vehicle-internal dynamic data store of protected locations, similar to the Local Dynamic Map [AD-28] [AD-29]. Once it has been received and stored, the data is kept until new data is received or the vehicle is turned off. The data store is not preserved when the vehicle is turned off. It needs to be reloaded after the vehicle is turned on and the CAM message is received. The message repetition, even with the same content increases the capacity of receiving ITS stations reaching the protected zone to update their data store.

The following definitions apply for the parameters listed above. The Latitude and Longitude parameters define the centre of the zone to protect, e.g. the DSRC RSU location. These parameters can be found in the common data dictionary ETSI TS 102 894-2 V1.3.1 [AD-3]. The actual definitions are given in Section 8.5 of this document.

- `ProtectedZoneType::= ENUMERATED { permanentCenDsrcTolling (0), ..., temporaryCenDsrcTolling (1) }`
- `TimestampIts ::= INTEGER {utcStartOf2004(0), oneMillisecAfterUTCStartOf2004(1)} (0..4398046511103)`
- `Latitude ::= INTEGER {oneMicrodegreeNorth (10), oneMicrodegreeSouth (-10), unavailable(900000001) } (-900000000..900000001)`
- `Longitude ::= INTEGER {oneMicrodegreeEast (10), oneMicrodegreeWest (-10), unavailable(1800000001) } (-1800000000..1800000001)`
- `ProtectedZoneRadius ::= INTEGER {oneMeter(1)} (1..255,...)`
- `ProtectedZoneID ::= INTEGER (0..134217727)`

The processing of these field is mandatory in the standard. So far, only two types of protected zones are defined for the protection of stationary and mobile tolling stations (see Section 8.5).

8.3.3 Proposal of potential updates to address the protection of UR-Access Points

In the case of Urban Rail or Rail, the same mechanism can be adopted and standardised at ETSI TC ITS. Only a few changes in the definition of the Data Elements in the common data dictionary [AD-3] and a corresponding update of ETSI TS 102 792 [AD-1] will be required to fulfil the needs of an Urban Rail prioritisation:

- Creation of a new Protected Zone Type (e.g., type 2) to identify the zone to be protected as an Urban Rail zone around an Access Point or reference point.
- Adaptation of the geometry to the Urban Rail geometry. The protected zone could be defined as (see [AD-4])
    - an ellipse defined by the length of the long semi-axis; the length of the short semi-axis; the azimuth angle of the long semi-axis, or
    - a rectangle along the track, defined by the distance between the centre point and the short side of the rectangle; the distance between the centre point and the long side of the rectangle; the azimuth angle of the short side of the rectangle.

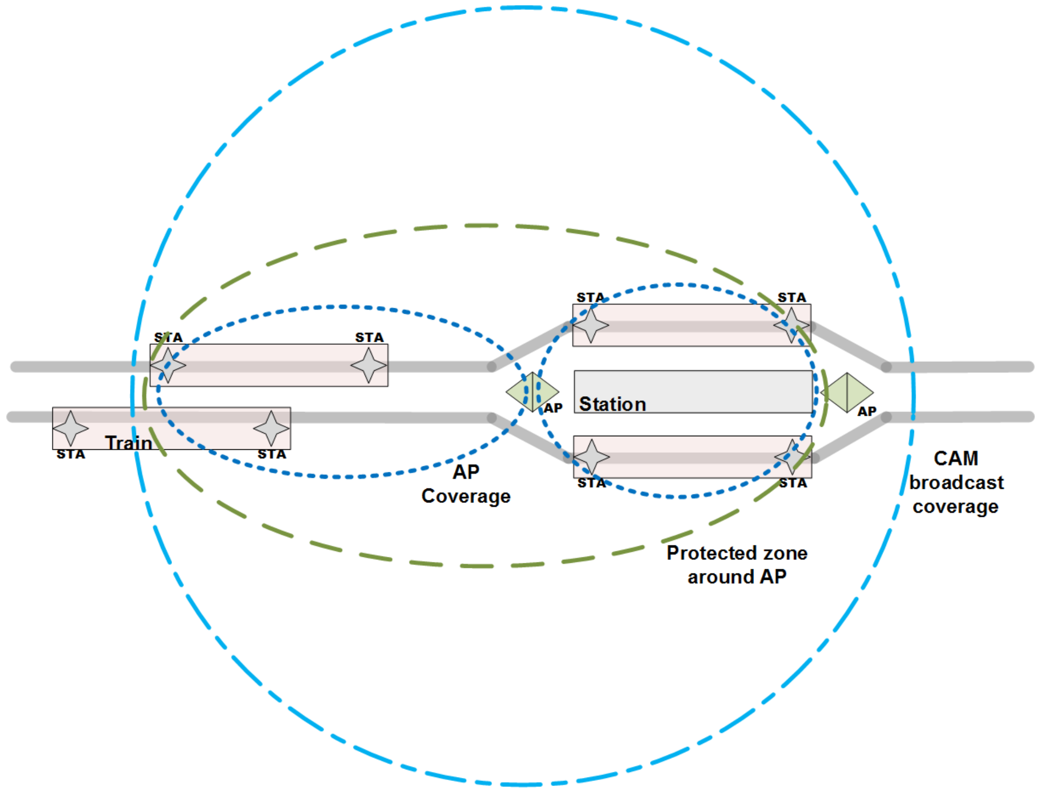

Figure 8-2: Example CAM Protected Zone represented as an ellipse

8.4 Conclusions

In this section, the details of the CAM message-based beacon announcement of the zone to be protected has been presented. The concept of a protected zone is already included in the ETSI ITS protocol set and the reception of the message is mandatory for all devices. The required extensions of the specification are very limited. Based on that information any ITS station can perform the required sharing techniques (Duty Cycle restrictions, power reduction, etc.) to reduce the risk of harmful interference towards an Urban Rail communication system to a minimum. The required protection areas need to be defined based on the actual network planning of the Urban Rail system.

8.5 Additional information: Data elements for protected zone definition [AD-3]

Descriptive Name	ProtectedZoneID
Identifier	DataType_ 56
ASN.1 representation	`ProtectedZoneID ::= INTEGER (0..134217727)`
Definition	ID of a protected communication zone. This DE is used in *CenDsrcTollingZoneID* DE as defined in clause A.11 and in *ProtectedCommunicationZone* DF as defined in clause A.121.
Unit	N/A
Category	Infrastructure information, Communication information

Descriptive Name	ProtectedZoneRadius
Identifier	DataType_ 57
ASN.1 representation	`ProtectedZoneRadius ::= INTEGER {oneMeter(1)} (1..255,...)`
Definition	Radius of a protected communication zone. This DE is used in *ProtectedCommunicationZone* DF as defined in clause A.121.
Unit	Metre
Category	Infrastructure information, Communication information

Descriptive Name	ProtectedZoneType
Identifier	DataType_ 58
ASN.1 representation	`ProtectedZoneType::= ENUMERATED { permanentCenDsrcTolling (0), ..., temporaryCenDsrcTolling (1) }`
Definition	DE that defines the type of a protected communication zone, so that an ITS-S is aware of the actions to do while passing by such zone (e.g. reduce the transmit power in case of a DSRC tolling station). The protected zone type is defined in ETSI TS 102 792 [i.16]. The DE is used in ProtectedCommunicationZone DF as defined in clause A.121.
Unit	N/A
Category	Communication information

Descriptive Name	ProtectedCommunicationZone
Identifier	DataType_ 121

ASN.1 representation	`ProtectedCommunicationZone ::= SEQUENCE {`
	`    protectedZoneType       ProtectedZoneType,`
	`    expiryTime TimestampIts OPTIONAL,`
	`    protectedZoneLatitude   Latitude,`
	`    protectedZoneLongitude  Longitude,`
	`    protectedZoneRadius ProtectedZoneRadius OPTIONAL,`
	`    protectedZoneID ProtectedZoneID OPTIONAL,`
	`...`
	`}`

Definition	DF that describes a zone of protection inside which the ITSG5 communication should be restricted. It shall include the following information: • protectedZoneType: type of the protected zone. It shall be presented as defined in clause A.58 *ProtectedZoneType*, • expiryTime: time at which the validity of the protected communication zone will expire. It shall be presented as defined in clause A.82 *TimestampIts.* This information is optional and shall be present when the protectedZone is temporarily valid, • protectedZoneLatitude: latitude of the centre point of the protected communication zone. It shall be presented as defined in clause A.41 *Latitude*, • protectedZoneLongitude: longitude of the centre point of the protected communication zone. It shall be represented as defined in clause A.44 *Longitude*, • protectedZoneRadius: radius of the protected communication zone in metres. It shall be presented as defined in clause A.57 *ProtectedZoneRadius*. This DE is optional, it shall be present if the data is available, • protectedZoneID: the ID of the protected communication zone. It shall be presented as defined in clause A.56 *ProtectedZoneID*. This DE is optional, it shall be present if the data is available. EXAMPLE: A protected communication zone may be defined around a CEN DSRC road side equipment.
Unit	N/A
Category	Infrastructure information, Communication information

Descriptive Name	ProtectedCommunicationZonesRSU
Identifier	DataType_ 122
ASN.1 representation	`ProtectedCommunicationZonesRSU ::= SEQUENCE (SIZE(1..16)) OF ProtectedCommunicationZone`
Definition	DF that describes a list of protected communication zones by a road side ITS-S (Road Side Unit RSU). It may provide up to 16 protected communication zones information. Each protected communication zone shall be presented as defined in clause A.121 *ProtectedCommunicationZone.*
Unit	N/A
Category	Infrastructure information, Communication information

Descriptive Name	DE_ Longitude
Identifier	DataType_ 44
ASN.1 representation	`Longitude ::= INTEGER {oneMicrodegreeEast (10), oneMicrodegreeWest (-10), unavailable(1800000001) } (-1800000000..1800000001)`
Definition	Absolute geographical longitude in a WGS84 co-ordinate system, providing a range of 180 degrees to the east or to the west of the prime meridian. Negative values are used for longitudes to the west, positive values are used for longitudes to the east. When the information is unavailable, the value shall be set to 1 800 000 001. The DE is used in *CenDsrcTollingZone* DF as defined in clause A.105, *ProtectedCommunicationZone* DF as defined in clause A.121 and *ReferencePosition* DF as defined in clause A.124.
Unit	0,1 microdegree
Category	GeoReference information

Descriptive Name	Latitude
Identifier	DataType_ 41
ASN.1 representation	`Latitude ::= INTEGER {oneMicrodegreeNorth (10), oneMicrodegreeSouth (-10), unavailable(900000001) } (-900000000..900000001)`
Definition	Absolute geographical latitude in a WGS84 coordinate system, providing a range of 90 degrees in north or in south hemisphere. Positive values are used for latitude in north of the Equator, negative values are used for latitude in south of the Equator. When the information is unavailable, the value shall be set to 900 000 001. The DE is used in *CenDsrcTollingZone* DF as defined in clause A.105, *ProtectedCommunicationZone* DF as defined in clause A.121 and *ReferencePosition* DF as defined in clause A.124.
Unit	0,1 microdegree
Category	GeoReference information

9 Appendix B - Geographically-Scoped Multicast

This text has been submitted as contribution ITSWG3(18)044006 to ETSI TC ITS WG3.

Motivation:

This addition to the GeoNetworking protocol proposes to distribute messages to a selected subset (group) of ITS Stations: emergency vehicles, agriculture equipment, Urban Rail ITS stations …

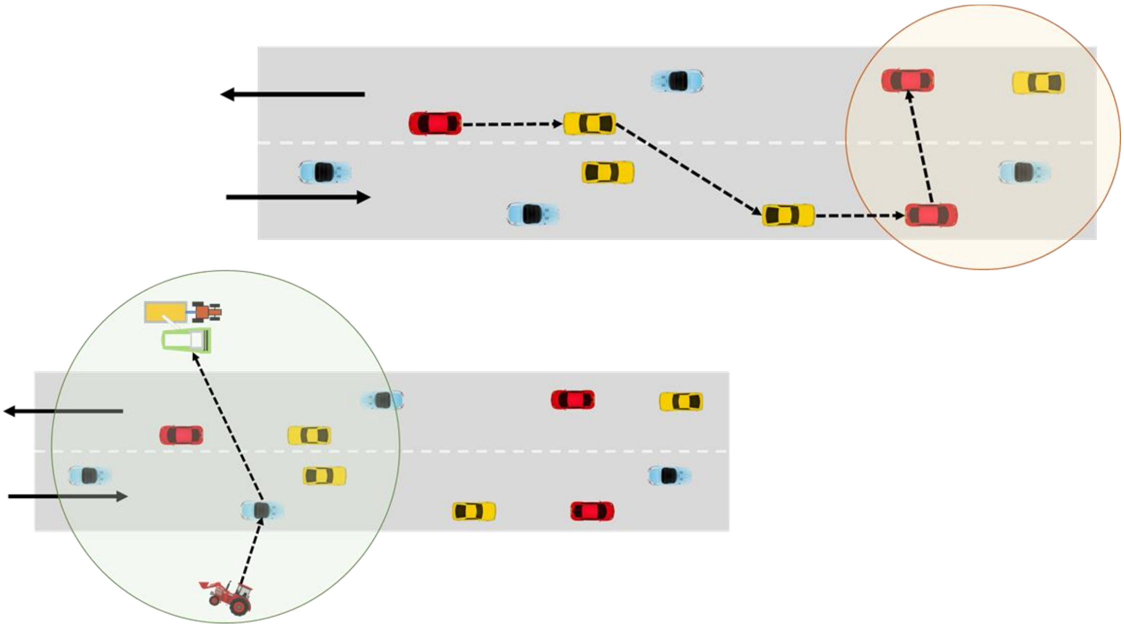

Figure 9-1: Examples of scenarios for Geographically-Scoped Multicast (GMC) messaging

Existing addressing methods

GeoNetworking supports the following communication scenarios [30] classified by connection multiplicity and addressing mode (address or location):

- Point-to-point: Communication starts at a single ITS station and ends at one ITS station.
- Point-to-multipoint: Communication starts at a single ITS station and ends at multiple ITS stations.
- GeoAnycast: Communication starts from a single ITS station and ends at an arbitrary vehicle ITS station within a geographical target area.
- GeoBroadcast: Communication starts from a single vehicle ITS station and ends at multiple vehicle ITS stations within a geographical target area.

Point-to-point and point-to-multipoint communication are legacy communication scenarios. GeoAnycast and GeoBroadcast are scenarios involving the concept of a geographical target area.

The GeoNetworking protocol [31] is defined for the following types of addressing:

- GeoUnicast
- Geographically-Scoped Anycast (GAC)
- Geographically-Scoped broadcast (GBC)
- Topologically-scoped broadcast (TSB)
- Single-hop broadcast (SHB)
- Geography can be defined as a circle, an ellipse or a rectangle.

Proposal:

This proposal applies to Geographically-Scoped messages which are relevant to a subset of the receiving ITS Stations only. It allows to exchange messages for internal communications only inside the subset of ITS stations in the target geographical area, for example

- Emergency vehicles
- Agriculture equipment
- Specific ITS-support of Urban Rail

In this case, the addressing types could be enhanced with a new destination addressing method called Geographically-Scoped Multicast (GMC).

Multicast allows to restrict the dissemination of messages to a certain group of receiving stations which have subscribed to the group messages. Membership in a group could be set up by pre-configuration (e.g. all urban rail ITS stations) or dynamically through a specific authorization right mechanism.

The GMC destination is defined by a double field (or criteria at the receiving station): the geographical target and the multicast group identifier.

Geographically-Scoped messages are well-suited for urban rail communications.

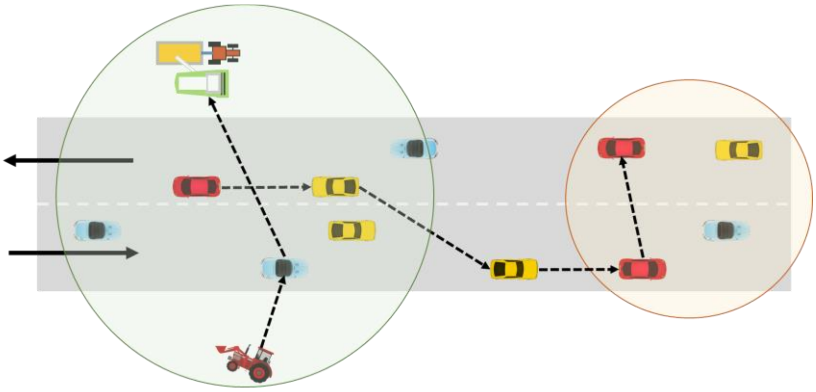

Figure 9-2: Geographically-Scoped Multicast (GMC) messaging

Benefits:

- GMC reduces processing requirements above networking layer at non-related ITS Stations
- The message is seen at the access layer and remains detectable for DCC evaluation, etc.

Security considerations

No specific mechanism is needed here. Information exchanged in the group is not forbidden to the other ITS stations (the group is not closed). However, an ITS station can transmit a message to a group only if it belongs to this group. Security related to the transmission and content of ITS messages, e.g. authorization, is handled using the existing mechanisms at Facilities layer.

10 Appendix C - CBTC 5.9 GHz projects list

The contribution RTJTFIR(18)019006_Position_of_Public_Transport_Operators_.rar [AD-9] provides a list of European CBTC projects and is copied in this appendix.

10.1 CBTC deployed or in construction

Already deployed or under construction lines:								
Country	**City**	**Situation**	**Opening to Public**	**Band**	**Trips per day**	**Full length (m)**	**Portion of the line outside (m)**	**% of outdoor part**
France	Paris L1	already in operation	2011	5915 – 5935 MHz	750 000	18 000	920m (in 2 places)	6%
France	Paris L3	already in operation	2010	5915 – 5935 MHz	350 000	13 000	0	0%
France	Paris L5	already in operation	2013	5915 – 5935 MHz	450 000	16 000	3200	20%
France	Paris L9	already in operation	2015	5915 – 5935 MHz	550 000	21 000	0	0%
Spain	Malaga L1	already in operation	-	5905 – 5925 MHz				
Spain	Malaga L2	already in operation	-	5905 – 5925 MHz				
France	Paris L4	contract awarded	Planned 2020	5915 – 5935 MHz	780 000	13 000	Only depot	
France	Rennes LB	Roll-out	Planned 2020	5872,5 – 5927,5 MHz		13 716	2330 + depot	17%
France	Lyon line B	Roll-out	Planned 2020	5905 – 5925 MHz				
France	Lille LM1 (refurbishment of existing lines)	Roll-out	Planned 2020	5915 – 5935 MHz				
Belgium	Brussels L1*	contract awarded	Planned 2021	5905 – 5925 MHz	220 000	42 000	4750	11%

Belgium	Brussels L5*	contract awarded	Planned 2021	5905 – 5925 MHz				
Belgium	Brussels L2**	contract awarded	Planned 2021	5905 – 5925 MHz	180 000	35 000	3900	11%
Belgium	Brussels L6**	contract awarded	Planned 2021	5905 – 5925 MHz				
France	Paris L11	contract awarded	Planned 2022	5915 – 5935 MHz	300 000	8 000	0	0%
Denmark	Copenhagen S-bane (6 phases)	first phase in operation – Roll out in several phases	Last phase planned 2022	5925 – 5975 MHz				
Austria	Vienna (resignalling project)	contract awarded	Opening planned 2022	Under discussion with regulator				
France	Marseilles L1	contract awarded	Planned 2023					
France	Marseilles L2	contract awarded	Planned 2023					
Germany	Frankfurt Airport	contract awarded	Planned 2023	Under discussion with regulator				
France	Paris L6	contract awarded	Planned 2023	5915 – 5935 MHz	600 000	15 000	6100	41%
France	Lyon line D	Roll-out	Planned 2023	5905 – 5925 MHz				
France	Paris L14 (orly-Pleyel)	contract awarded	Planned 2024	5915 – 5935 MHz	1 100 000			
France	Paris NExTEO EOLE	contract awarded	Planned between 2021 and 2023 (by areas)	5905 – 5925 MHz		27 600	9 000	33%
France	Grand Paris line 15	Tender in progress – To be awarded Q3 2018	Planned between 2024 to 2030	5905-5925 MHz		77 000	Only depot	0%

France	Grand Paris line 16	Tender in progress – To be awarded Q3 2018	Planned between 2024 to 2030	5905-5925 MHz		29 000	Only depot	0%

Table 10-1: CBTC lines already deployed or under construction

* L1 and L5 in Brussels have a common part

** L2 and L6 in Brussels have a common part

10.2 CBTC new projects

Projects waiting for regulator authorization for a frequency band and needing urgent decision:						
Country	**City**	**Situation**	**Opening to Public**	**Full length h(m)**	**Portion of the line outside (m)**	**% of outdoor part**
France	Paris line 10	to be awarded Q3 2018	Planned 2024	20 000	-	0%
France	Toulouse	project	Planned 2024			
France	Paris line 12	to be awarded Q1 2019	Planned 2026	17 000	-	0%
France	Paris NExTEO B	to be awarded	Planned between 2024 and 2029	80 000	44 000	55%
France	Paris NExTEO D	to be awarded	Planned between 2024 and 2029	24 500	17 000	69%
France	Paris line 17	Tender in progress – To be awared Q3 2018	Planned between 2024 to 2030	20 000	6 000	30%

France	Paris line 18	Tender to launch in 2019	Planned between 2025 to 2030	35 000	13 000	37%
France	Paris line 3	to be awarded 2025	Planned 2029	13 000	-	0%
France	Paris line 8	to be awarded 2025	Planned 2029	25 000	4 100	16%
Belgium	Brussels Line 3	Extension of awarded contract	Planned 2030	10 000	-	0%
France	Paris line 9	to be awarded 2027	Planned 2031	21 000	-	0%

Table 10-2: CBTC new projects

11 Appendix D - Spectrum requirements calculation

Environment	Parameter	Value	Comment
Urban_aver	Packet size (byte), $L_{message\_aver}$	200,0000	
	TX periodicity (Hz), 1/*P*	15,0000	Message to three Zone Controllers
	ITS stations in relevance area, N_{nodes}	1,0000	
	spectrum efficiency(bits/Hz), Eff_{access}	0,5500	pay load bit per Hz QPSK, R =1/2
	maximum channel load, $C_{channel}$	0,8000	LTE assumptions V2X
	Spectrum requirements (MHz), Req_{spec_aver}	**0,0545**	
Urban_Max	Packet size (byte), $L_{message\_max}$	800,0000	
	TX periodicity (Hz), 1/*P*	15,0000	Message to three Zone Controllers
	ITS stations in relevance area, N_{nodes}	1,0000	
	spectrum efficiency(bits/Hz), Eff_{access}	0,5500	pay load bit per Hz QPSK, R =1/2
	maximum channel load, $C_{channel}$	0,8000	
	Spectrum requirements (MHz), Req_{spec_max}	**0,2182**	

Table 11-1: Average and maximum spectrum requirements calculation for Location report three ZC

Environment	Parameter	Value	Comment
Urban_aver	Packet size (byte), $L_{message\_aver}$	500,0000	
	TX periodicity (Hz), 1/*P*	3,3300	Message to three Zone Controllers
	ITS stations in relevance area, N_{nodes}	1,0000	
	spectrum efficiency(bits/Hz), Eff_{access}	0,5500	pay load bit per Hz QPSK, R =1/2
	maximum channel load, $C_{channel}$	0,8000	LTE assumptions V2X
	Spectrum requirements (MHz), Req_{spec_aver}	**0,0303**	
Urban_Max	Packet size (byte), $L_{message\_max}$	1000,0000	
	TX periodicity (Hz), 1/*P*	3,3330	Message to three Zone Controllers

	ITS stations in relevance area, N_{nodes}	1,0000	
	spectrum efficiency(bits/Hz), Eff_{access}	0,5500	pay load bit per Hz QPSK, R =1/2
	maximum channel load, $C_{channel}$	0,8000	
	Spectrum requirements (MHz), Req_{spec_max}	**0,0606**	

Table 11-2: Average and maximum spectrum requirements calculation for Periodic Train Functional Status messages

Environment	Parameter	Value	Comment
Urban_aver	Packet size (byte), $L_{message\_aver}$	300,0000	
	TX periodicity (Hz), $1/P$	3,3300	Message to three Zone Controllers
	ITS stations in relevance area, N_{nodes}	1,0000	
	spectrum efficiency(bits/Hz), Eff_{access}	0,5500	pay load bit per Hz QPSK, R =1/2
	maximum channel load, $C_{channel}$	0,8000	LTE assumptions V2X
	Spectrum requirements (MHz), Req_{spec_aver}	**0,0182**	
Urban_Max	Packet size (byte), $L_{message\_max}$	1000,0000	
	TX periodicity (Hz), $1/P$	3,3300	Message to three Zone Controllers
	ITS stations in relevance area, N_{nodes}	1,0000	
	spectrum efficiency(bits/Hz), Eff_{access}	0,5500	pay load bit per Hz QPSK, R =1/2
	maximum channel load, $C_{channel}$	0,8000	
	Spectrum requirements (MHz), Req_{spec_max}	**0,0605**	

Table 11-3: Average and maximum spectrum requirements calculation for on demand specific status message

Environment	Parameter	Value	Comment
Urban_aver	Packet size (byte), $L_{message\_aver}$	200,0000	
	TX periodicity (Hz), $1/P$	1,6600	Message to three Zone Controllers
	ITS stations in relevance area, N_{nodes}	1,0000	

	spectrum efficiency(bits/Hz), Eff_{access}	0,5500	pay load bit per Hz QPSK, R =1/2
	maximum channel load, $C_{channel}$	0,8000	LTE assumptions V2X
	Spectrum requirements (MHz), Req_{spec_aver}	**0,0060**	
Urban_Max	Packet size (byte), $L_{message\_max}$	800,0000	
	TX periodicity (Hz), 1/*P*	1,6600	Message to three Zone Controllers
	ITS stations in relevance area, N_{nodes}	1,0000	
	spectrum efficiency(bits/Hz), Eff_{access}	0,5500	pay load bit per Hz QPSK, R =1/2
	maximum channel load, $C_{channel}$	0,8000	
	Spectrum requirements (MHz), Req_{spec_max}	**0,0241**	

Table 11-4: Average and maximum spectrum requirements calculation for Movement of authority DL 3 ZC

Environment	Parameter	Value	Comment
Urban_aver	Packet size (byte), $L_{message\_aver}$	500,0000	
	TX periodicity (Hz), 1/*P*	7,5000	Message to three Zone Controllers
	ITS stations in relevance area, N_{nodes}	1,0000	
	spectrum efficiency(bits/Hz), Eff_{access}	0,5500	pay load bit per Hz QPSK, R =1/2
	maximum channel load, $C_{channel}$	0,8000	LTE assumptions V2X
	Spectrum requirements (MHz), Req_{spec_aver}	**0,0682**	
Urban_Max	Packet size (byte), $L_{message\_max}$	1400,0000	
	TX periodicity (Hz), 1/*P*	7,5000	Message to three Zone Controllers
	ITS stations in relevance area, N_{nodes}	1,0000	
	spectrum efficiency(bits/Hz), Eff_{access}	0,5500	pay load bit per Hz QPSK, R =1/2
	maximum channel load, $C_{channel}$	0,8000	
	Spectrum requirements (MHz), Req_{spec_max}	**0,1909**	

Table 11-5: Average and maximum spectrum requirements calculation for Information about line from ZC

Environment	Parameter	Value	Comment
Urban_aver	Packet size (byte), $L_{message\_aver}$	50,0000	
	TX periodicity (Hz), 1/P	2,0000	Message to three Zone Controllers
	ITS stations in relevance area, N_{nodes}	1,0000	
	spectrum efficiency(bits/Hz), Eff_{access}	0,5500	pay load bit per Hz QPSK, R =1/2
	maximum channel load, $C_{channel}$	0,8000	LTE assumptions V2X
	Spectrum requirements (MHz), Req_{spec_aver}	**0,0018**	
Urban_Max	Packet size (byte), $L_{message\_max}$	10,0000	
	TX periodicity (Hz), 1/P	2,0000	Message to three Zone Controllers
	ITS stations in relevance area, N_{nodes}	1,0000	
	spectrum efficiency(bits/Hz), Eff_{access}	0,5500	pay load bit per Hz QPSK, R =1/2
	maximum channel load, $C_{channel}$	0,8000	
	Spectrum requirements (MHz), Req_{spec_max}	**0,0004**	

Table 11-6: Average and maximum spectrum requirements calculation for Request for health train status

Environment	Parameter	Value	Comment
Urban_aver	Packet size (byte), $L_{message\_aver}$	50,0000	
	TX periodicity (Hz), 1/P	10,0000	Message to three Zone Controllers
	ITS stations in relevance area, N_{nodes}	1,0000	
	spectrum efficiency(bits/Hz), Eff_{access}	0,5500	pay load bit per Hz QPSK, R =1/2
	maximum channel load, $C_{channel}$	0,8000	LTE assumptions V2X
	Spectrum requirements (MHz), Req_{spec_aver}	**0,0091**	
Urban_Max	Packet size (byte), $L_{message\_max}$	150,0000	
	TX periodicity (Hz), 1/P	10,0000	Message to three Zone Controllers
	ITS stations in relevance area, N_{nodes}	1,0000	
	spectrum efficiency(bits/Hz), Eff_{access}	0,5500	pay load bit per Hz QPSK, R =1/2

	maximum channel load, $C_{channel}$	0,8000	
	Spectrum requirements (MHz), *Req*$_{spec\_max}$	**0,0273**	

Table 11-7: Average and maximum spectrum requirements calculation for Burst traffic data base update

Environment	Parameter	Value	Comment
Urban_aver	Packet size (byte), $L_{message\_aver}$	50,0000	
	TX periodicity (Hz), 1/*P*	10,0000	Message to three Zone Controllers
	ITS stations in relevance area, N_{nodes}	1,0000	
	spectrum efficiency(bits/Hz), Eff_{access}	0,5500	pay load bit per Hz QPSK, R =1/2
	maximum channel load, $C_{channel}$	0,8000	LTE assumptions V2X
	Spectrum requirements (MHz), *Req*$_{spec\_aver}$	**0,0091**	
Urban_Max	Packet size (byte), $L_{message\_max}$	150,0000	
	TX periodicity (Hz), 1/*P*	10,0000	Message to three Zone Controllers
	ITS stations in relevance area, N_{nodes}	1,0000	
	spectrum efficiency(bits/Hz), Eff_{access}	0,5500	pay load bit per Hz QPSK, R =1/2
	maximum channel load, $C_{channel}$	0,8000	
	Spectrum requirements (MHz), *Req*$_{spec\_max}$	**0,0273**	

Table 11-8: Average and maximum spectrum requirements calculation for Request for health train status

12 Appendix E – Comments received from a national Frequency regulator on option 2

Changing the CBTC AP to include a C-ITS stack should be envisioned as a very long-term solution only. This is not considered as technology neutral and should take into account that safety certification for trains implies very long processes. As a consequence, UR vendors tend to maintain as much as possible certified solutions. For them, adopting TD-LTE (i.e. the Chinese version of LTE) enables them to upgrade only the radio system and keep the upper layers unchanged.

This study should be brought to the Shift2Rail (S2R) initiative, under the IP2. This IP targets GoA4, which is for CBTC only. At least one of the stakeholders should be associated to define this option (Siemens, Alstom, RATP…).

The lifecycle is also very important in Urban Rail: a specific equipment may last more than 25 years.

Regarding the Option 0 (beacon), it will be important to clearly define the mitigation technique and make sure that the Day-1 deployed cars comply with the regulation. It is not clear how the update of the car system can be enforced with a pre-defined delay for already-deployed vehicles. For bands above 5905 MHz, this mitigation should include a reduction of TX power and/or duty cycle. Muting the ITS-S may not be necessary. [This notion of muting the ITS-S has been intensively discussed when agreeing to the LS for ECC]. It is good news to learn that the G5-CCH is the 5895-5905 MHz channel. Mitigation should be supported by analytical and simulation studies before being provided to CEPT.

The naming should clearly differentiate between ITS-G5 access technology and ITS-G5 as a protocol stack including all layers up to applications.

The temporal sharing of the CCH band between LTE-V2X and Its-G5 (e.g., 40% of time for one techno, 10 % silence, 40% the other techno, 10% silence) has been mentioned. The answer was that such a solution would be spectrally inefficient and trigger the risk of accidents, as ITS-S under one technology could transmit only 40% of the time and have to remain silent 60% of the time (not clear which period length this would apply). Geographical differentiation of the frequencies (e.g. by country) would trigger the issue of borders.

13 Appendix F – References

13.1List of abbreviations

AP	Access Point
APM	Automatic People Mover
ATC	Automatic Train Control
ATO	Automatic Train Operation
ATS	Automatic Train Stop
ATP	Automatic Train Protection
BSMD	Bounded Secured Managed Domain
BSS	Basic Service Set (IEEE 802.11)
CABS	Cooperative Awareness Basic Service
CAM	Cooperative Awareness Message
CBTC	Communications Based Train Control
CCH	Control Channel
CEN	Comité Européen de Normalisation
CEPT	Conférence Européenne des Postes et des Télécommunications
C-ITS	Cooperative Intelligent Transportation Systems
C-ITS-S	Central ITS Station
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
DCC	Decentralized Congestion Control
DENM	Decentralized Environmental Notification Message
DSRC	Dedicated Short-Range Communications
EC	European Commission
ECC	Electronic Communications Committee
EFC	Electronic Fee Collection
ERTMS	European Train Traffic Management System
ETCS	European Train Control System
ETSI	Dedicated Short-Range Communications
FRMCS	Future Railway Mobile Communication System
GAC	Geographically-Scoped Anycast
GBC	Geographically-Scoped broadcast
GMC	Geographically-Scoped Multicast
GN	GeoNetworking
GNSS	Global Navigation Satellite System
GSM	Global System for Mobile Communications
GSM-R	GSM for Railways
HF	High Frequency
HMI	Human Machine Interface

I2V	Infrastructure to Vehicle
ISO	International Standards Organisation
ISS	in the context of a service set
ITS	Intelligent Transport System
ITS-S	Communication Station for ITS
ITS-G5	ITS Communications in the 5 GHz range
JTFIR	TC ITS/TC RT Joint Task Force
LDM	Local Dynamic Map
LF	Low Frequency
LOS	Line-Of-Sight
MAC	Medium Access Control
OBU	Onboard Unit
OOCB	Outside the Context of the Basic service set (IEEE 802.11)
OEM	Original Equipment Manufacturer
OFDM	Orthogonal Frequency Division Multiplexing
PHY	Physical (layer)
R-ITS-S	Roadside ITS station
RSU	Road Side Unit
RT	Rail Telecommunications
RTCM	Radio Technical Commission for Maritime Services (for differential correction)
SAE	Society of Automotive Engineers
SCH	Service Channel
SHB	Single-hop broadcast
SPAT	Signal Phase and Timing
TC	Technical Committee
TDMA	Time Division Multiple Access
T2T	Train to Train (communication)
T2G	Train to Ground (communication)
TCS	Train Control System
T-ITS-S	Train ITS Communication Station
TS-ITS-S	Trackside ITS Communication Station
TSB	Topologically-scoped broadcast
UIC	International Union of Railways
UR	Urban Rail
UR-CAM	Urban Rail CAM
UR-DENM	Urban Rail DENM
UR-MAP	Urban Rail MAP (message)
UR-SPAT	Urban Rail SPAT (message)
V2I	Vehicle to Infrastructure

V2V	Vehicle to Vehicle
V2X	Vehicle to Anything
WLAN	Wireless Local Area Network
ZC	Zone Controller

13.2 Applicable documents

[AD-1]	ETSI TS 102 792 V1.2.1 (2015-06): " 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"
[AD-2]	ETSI EN 302 637-2: "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service"
[AD-3]	ETSI TS 102 894-2 (V0.0.5): "Intelligent Transport Systems (ITS); Users and applications requirements; Part 2: Applications and facilities layer common data dictionary"
[AD-4]	ETSI EN 302 931: "Intelligent Transport Systems (ITS); Vehicular Communications; Geographical Area Definition"
[AD-5]	ETSI EN 302 663: “Intelligent Transport Systems (ITS); Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band”.
[AD-6]	ETSI 103 097: Intelligent Transport Systems (ITS); Security; Security header and certificate formats.
[AD-7]	ETSI EN 302 665: Intelligent Transport Systems (ITS); Communications Architecture.
[AD-8]	ETSI EN 302 637-3: "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service"
[AD-9]	ETSI contribution RTJTFIR(18) 019006_Position_of_Public_Transport_Operators_.rar (July 2018)
[AD-10]	ITS Evolution towards Urban Rail, Caroline PAULET, ETSI Workshop “Developing the Future Radio for Rail Transport”, 05.07.2018
[AD-11]	ETSI RTJTFIR(17)002002: “Throughput requirements for generic CBTC system,” Sophia Antipolis Cedex, France, 2017
[AD-12]	ETSI TS 103 097: Intelligent Transport Systems (ITS); Security; Security header and certificate formats
[AD-13]	IEEE 1474.1-2004 - IEEE Standard for Communications-Based Train Control (CBTC) Performance and Functional Requirements
[AD-14]	RTJTFIR(18) 016006r1_CBTC_5_MHz_channel_occupancy
[AD-15]	RTJTFIR(17) 002002_Throughput_requirements_for_generic_CBTC_system
[AD-16]	RTJTFIR(18) 018004_Proposal_for_Urban_Rail_Protected_Zones
[AD-17]	IEEE 802.11-2016: 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
[AD-18]	European Commission Decision on the harmonized use of the ITS spectrum (2008/2671/EC)

[AD-19]	ECC/CEPT Recommendation (08)01: Use of the band 5855-5875 MHz for Intelligent Transport Systems (ITS)
[AD-20]	ECC/CEPT Decision (08)01: Decision of 14 March 2008 on the harmonised use of the 5875-5925 MHz frequency band for Intelligent Transport Systems (ITS), amended on 3 July 2015
[AD-21]	ISO 21217:2014. Intelligent transport systems -- Communications access for land mobiles (CALM) - Architecture
[AD-22]	ISO 26262 1-10 Road Vehicles Functional Safety Package
[AD-23]	AEC-Q100 Failure mechanism based stress test qualification for integrated circuits
[AD-24]	IEC 62132-1:2015 Integrated circuits - Measurement of electromagnetic immunity
[AD-25]	ETSI TS 103 301 Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Facilities layer protocols and communication requirements for infrastructure services
[AD-26]	SAE J2735 Dedicated Short Range Communications (DSRC) Message Set Dictionary
[AD-27]	ETSI TR 102 960 V1.1.1: “Intelligent Transport Systems (ITS); Mitigation techniques to avoid interference between European CEN Dedicated Short Range Communication (RTTT DSRC) equipment and Intelligent Transport Systems (ITS) operating in the 5 GHz frequency range; Evaluation of mitigation methods and techniques,” Sophia Antipolis Cedex, France, 2012.
[AD-28]	ETSI TR 102 863 V1.1.1: “Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Local Dynamic Map (LDM); Rationale for and guidance on standardization,” Sophia Antipolis Cedex, France, 2011.
[AD-29]	ETSI EN 302 895 V1.1.1: “Intellige nt Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Local Dynamic Map (LDM),” Sophia Antipolis Cedex, France, 2014.
[AD-30]	ETSI EN 302 636-2: "Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; Part 2: Scenarios".
[AD-31]	ETSI EN 302 636-4-1: "Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; Part 4: Geographical addressing and forwarding for point-to-point and point-to-multipoint communications; Sub-part 1: Media-Independent Functionality".
[AD-32]	ETSI EN 302 890-2 Intelligent Transport Systems (ITS); Facilities Layer function Part 2: Facility Position and Time management (PoTi) [Release 2]
[AD-33]	ETSI TR 103 562 V0.0.13 Intelligent Transport System (ITS); Vehicular Communications; Basic Set of Applications; Informative Report for the Collective Perception Service (2018)
[AD-34]	IEEE 802.11™-2012: "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”.

13.3 Related documents

[RD-1] Vincent Durepaire: Radio spectrum for present and future rail transport needs. Presentation on ETSI workshop on Developing the Future Radio for Rail Transport, Sophia-Antipolis, France, 2019, July 3-5.

[RD-2] Jahanzeb Farooq and José Soler, Radio Communication for Communications-Based Train Control (CBTC): A Tutorial and Survey. IEEE Communications Surveys & Tutorials, Vol. 19, No. 3, 3rd Quarter 2017.