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Intelligent transport systems

Handbook on Land Mobile (including Wireless Access)

Volume 4

2021 edition

INTELLIGENT
TRANSPORT
SYSTEMS

Handbook on
Land Mobile
(including Wireless Access)

Volume 4
(2021 edition)

Radiocommunication Bureau

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Foreword

Intelligent transport systems (ITS) are defined as systems utilizing the combination of computers, communications, positioning and automation technologies to improve the safety, management and efficiency of terrestrial transportation.

The 2021 Edition of the fourth volume of the ITU-R Handbook on Land Mobile (including Wireless Access) supersedes the Edition of 2006.

The development of this multi-volume Handbook was started in the late 1990s within the ITU-R to meet an increasing need by the developing countries for a handbook on state-of-the-art technologies covering the various aspects of the land mobile service; including technologies and systems.

The five volumes that have already been published to-date are:

– Volume 1: Fixed Wireless Access

– Volume 2: Principles and Approaches on Evolution to IMT-2000

– Volume 3: Dispatch and Advanced Messaging Systems

– Volume 4: Intelligent Transport Systems

– Volume 5: Deployment of Broadband Wireless Access Systems.

The purpose of the Handbook is to assist in the decision-making process involving planning, engineering and deployment of wireless-based land mobile systems, especially in the developing countries. It should also provide adequate information that will assist in training engineers and planners in regulating, planning, engineering, and deployment aspects of these systems.

This Volume of the Handbook provides a summary of the use of wireless communications in ITS, current and under development, around the globe, including architecture, systems, and applications. This is a rapidly developing sector, which is still partly in its infancy. This Volume is representative of the time that it was produced, and so provides a description of wireless communications used in ITS as of the year 2020.

Volume 4 (Edition of 2021) has been developed by a group of experts of Radiocommunication Working Party 5A. I wish to express my appreciation to Dr. Takahiko Yamazaki (Japan), Land Mobile Handbook Rapporteur, Dr. Hitoshi Yoshino (Japan), chairman of WG5A-5, Dr. Satoshi (Sam) Oyama (Japan), chairman of the SWG on ITS, and Dr. HyunSeo Oh (Republic of Korea) who kindly served as editor of this volume, as well as to all the experts who contributed to the development of the Handbook.

José M. Costa
Chairman, Radiocommunication Working Party 5A
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CHAPTER 1

INTRODUCTION

1.1 Purpose and scope of the Handbook on Land Mobile

The purpose and scope of Volume 4 of the Handbook on Land Mobile is to provide general and updated information on Intelligent transport system (ITS). ITS basically utilizes the combination of computers, communications, positioning and automation technologies to improve the safety, management and efficiency of terrestrial transportation systems. There are many current applications of ITS discussed in this Handbook, as well as new applications planned for the future. Most people rely on some form of transportation in their everyday lives, therefore a tremendous amount of users stand to benefit from ITS on a daily basis. This Volume of the Handbook provides a summary of the use of wireless communications in ITS, current and under development, around the globe. This is a rapidly developing sector. This version of Volume 4 is representative of the time that it was produced, and so provides a description of wireless communications used in ITS at the start of 2020.

1.2 Organization and use of Volume 4

Volume 4 is organized into a number of chapters providing key information to the reader, with detailed technical, operational and regulatory information provided in the Annexes.

The introduction to the Volume is provided in Chapter 1. Chapter 2 provides information on the ITS application. Chapter 3 covers ITS system and communication architecture. Chapter 4 covers radio technologies for ITS systems, and Chapter 5 discusses international and national standardization. Chapter 6 describes radio frequency usage for ITS systems. Annex A contains an acronym list. Annex B contains the usage of ITS in some countries, and Annex C includes publications on ITS.

CHAPTER 2

ITS APPLICATION

2.1 Introduction

There have been increases in motorization, urbanization and population all over the world for several decades. These trends cause traffic congestion, safety issues and air pollution. ITS supports a toolset to help mitigate and possibly reduce traffic congestion and incidents using wireless communications, sensors technologies computer and control technologies, and widespread information dissemination. ITS deployments leverage communication standards to facilitate interoperability and service accessibility.

FIGURE 1

ITS service concept

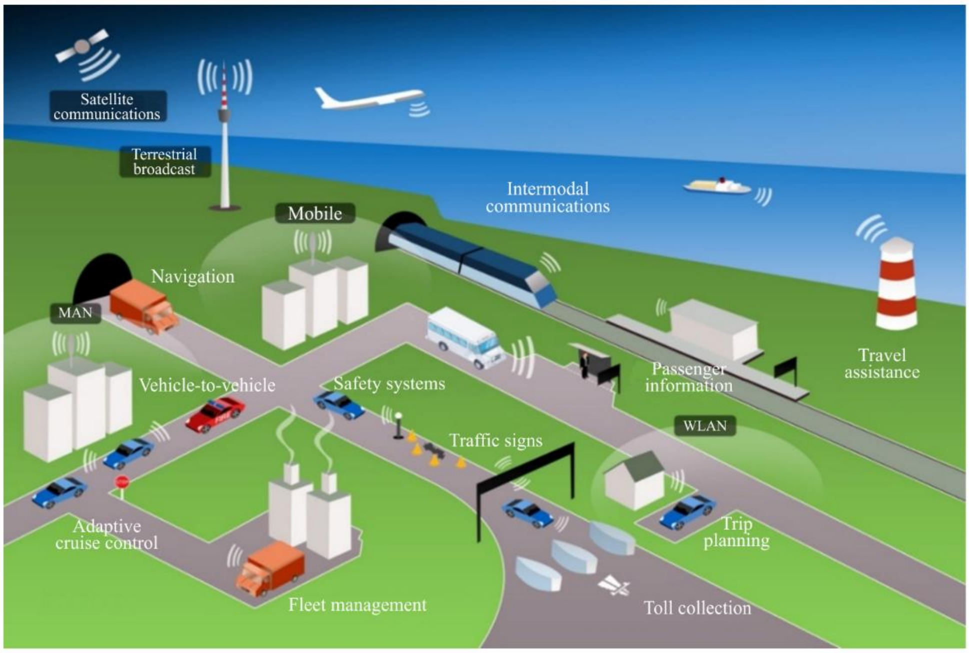

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Table 1 lists broad ITS service areas in order to illustrate the widespread potential societal impact of ITS. The ITS system provides specific examples of the user services as shown in Table 2, for the categories V2I Safety and V2V Safety, Agency Data, Environment, Road Weather, Mobility and Smart Roadside application.

There are three major user groups for ITS systems:

- The road operators who manage roads efficiently, monitors the road situation and provide information to road users;
- The vehicle drivers who go to their destination without accidents;
- Travelers or pedestrians who need traffic information or emergency assistance.

The ITS service can be explained from the point of view of ITS user groups. ITS users are ranged, largely, in three groups. The first user group is the road operator, the entity that manages roadways to meet local objectives, generally to maintain traffic flow and respond to safety incidents. The road operator monitors the road situation and provides information to road users. The road operator plays a significant role in most ITS services; only vehicle-to-vehicle safety applications leave out representatives of road or transit authorities. The second user group is composed of vehicle drivers to go the destination without accidents. This constituency is the end user for many ITS services, and indirectly the provider of much road performance data (either through remote sensing or actively gathered by the vehicle and provided to a third party). The third user group is travellers or pedestrians who use ITS to get traffic information, plan trips, use transit services or request emergency assistance.

Different regions naturally have different objectives when deploying ITS, but generally all can be categorized into five main areas: safety, mobility, environmental, regulatory and convenience. Within these broad areas, more focused objectives, sometimes blurred by the technology or architectural choice, provide more narrow groupings of deployable services. Often, these services satisfy multiple objectives. For instance, in the United States of America, the Border Management Systems service addresses mobility, regulatory and safety objectives. Thus, many services are ascribed multiple characteristics, depending on the objective(s) they help meet and the technology or architecture characteristics inherent to the service. Services can be summarized as fulfilling objectives in the service areas showed in Table 1.

TABLE 1

ITS service areas

Commercial Vehicle Operations	Data Management	Maintenance and Construction
Parking Management	Public Safety	Public Transportation
Support	Sustainable Travel	Traffic Management
Traveller Information	Vehicle Safety	Weather

Within these areas, well over one hundred services are defined. For a complete sortable listing of US-defined services, see https://local.iteris.com/arc-it/html/servicepackages/servicepackages-areaspsort.html.

In § 2.2, some of the more commercialized service types are explained in greater detail; these are Electronic Toll Collection, Vehicle and Road Safety, Emergency Call, Traffic Information Service and Automated Driving. The service functions and technical characteristics of radio communication technologies are described.

TABLE 2

Examples of user services of ITS system

Category	Example user services
V2I Safety	– Red Light Violation Warning – Curve Speed Warning – Stop Sign Gap Assist – Spot Weather Impact Warning – Reduced Speed/Work Zone Warning – Pedestrian in Signalized Crosswalk Warning (Transit)
V2V Safety	– Emergency Electronic Brake Lights (EEBL) – Forward Collision Warning (FCW) – Intersection Movement Assist (IMA) – Left Turn Assist (LTA) – Blind Spot/Lane Change Warning (BSW/LCW) – Do Not Pass Warning (DNPW) – Vehicle Turning Right in Front of Bus Warning (Transit)
Agency Data	– Probe-based Pavement Maintenance – Probe-enabled Traffic Monitoring – Vehicle Classification-based Traffic Studies – CV-enabled Turning Movement & Intersection Analysis – CV-enabled Origin-Destination Studies – Work Zone Traveller Information
Environment	– Eco-Approach and Departure at Signalized Intersections – Eco-Traffic Signal Timing – Eco-Traffic Signal Priority – Connected Eco-Driving – Wireless Inductive/Resonance Charging – Eco-Lanes Management – Eco-Speed Harmonization – Eco-Cooperative Adaptive Cruise Control – Eco-Traveller Information – Eco-Ramp Metering – Low Emissions Zone Management – AFV Charging / Fuelling Information – Eco-Smart Parking – Dynamic Eco-Routing (light vehicle, transit, freight) – Eco-ICM Decision Support System
Road Weather	– Motorist Advisories and Warnings (MAW) – Enhanced MDSS – Vehicle Data Translator (VDT) – Weather Response Traffic Information (WxTINFO)

TABLE 2 *(end)*

Category	Example user services
Mobility	– Advanced Traveller Information System – Intelligent Traffic Signal System (I-SIG) – Signal Priority (transit, freight) – Mobile Accessible Pedestrian Signal System (PED-SIG) – Emergency Vehicle Preemption (PREEMPT) – Dynamic Speed Harmonization (SPD-HARM) – Queue Warning (Q-WARN) – Cooperative Adaptive Cruise Control (CACC) – Incident Scene Pre-Arrival Staging Guidance for Emergency – Responders (RESP-STG) – Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE) – Emergency Communications and Evacuation (EVAC) – Connection Protection (T-CONNECT) – Dynamic Transit Operations (T-DISP) – Dynamic Ridesharing (D-RIDE) – Freight-Specific Dynamic Travel Planning and Performance – Drayage Optimization
Smart Roadside	– Wireless Inspection – Smart Truck Parking

2.2 ITS Service Types

The service functions and technical characteristics in radio communication technologies are described. ITS services may be grouped into Electronic Toll Collection (ETC), Vehicle and Road Safety, Emergency Call, Traffic Information Service and Automated Driving. These five services are the most commercialized or widely deployed ITS services.

These types of ITS services are provided by using direct available radiocommunication technologies such as Dedicated short range communication (DSRC) for ETC, 700 MHz band or 5.9 GHz band V2X communication for Vehicle and Road Safety; network based cellular communication for example, for Emergency Call; digital broadcasting for Traffic Information Service; and potentially V2X network based communication for automated driving. These five radio communication technologies are suitable for related service types and have the technical characteristics as shown in Table 3.

For example, DSRC for ETC can provide bi-directional packet data over short distances (~100 m). 5.9 GHz V2X for Vehicle and Road Safety can provide bi-directional packet data and data broadcasting over distances less than 1 km. Network based cellular for Emergency Call can provide bi-directional voice and data over a wide radio range (~10 km). Digital broadcasting for Traffic Information Service can provide unidirectional data over a wide radio range (< 10 km). For Vehicle and Road Safety or Automated Driving, low latency to transfer relevant vehicle kinematics and position information, along with control messages, is one of the most important communication requirements.

TABLE 3

Technical characteristics on radiocommunication technologies

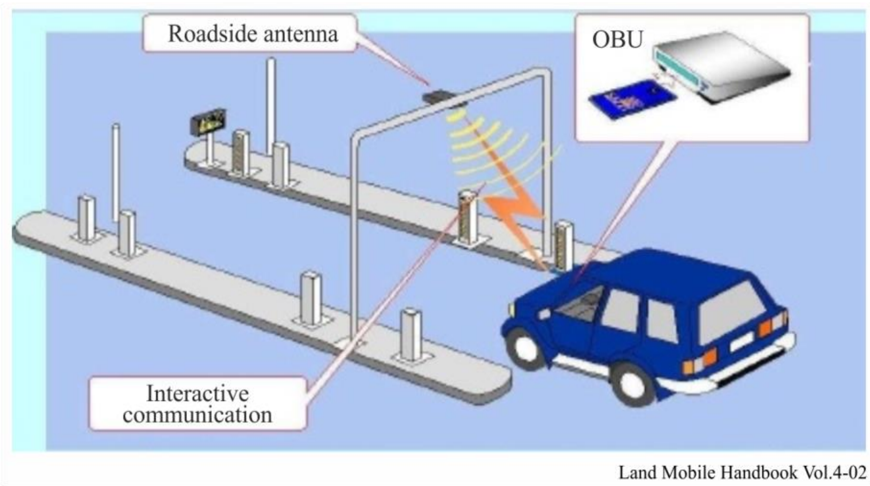
Service types	Radio communication technologies	Information	Radio Coverage	Message Latency
ETC	DSRC	Bi-directional data	Small (~100 m)	Low (<100 ms)
Vehicle and Road Safety	700 MHz or 5.9 GHz band V2X	Bi-directional data, Data Broadcasting	Medium (~1000 m)	Low (<100 ms)
Emergency Call	Cellular	Bi-directional voice and data	Wide (~10 km)	Large (~1 s)
Traffic Information Service	TPEG	Data Broadcasting	Wide (~100 km)	Medium (~1 s)
Autonomous Driving	V2X	Bi-directional data, Data Broadcasting	Medium (~1000 m)	Low (<5 ms)

2.2.1 Electronic Toll Collection

Electronic Toll Collection is road pricing service when vehicle passes through toll plaza. When the vehicle enters toll plaza, OBU initiates radio communication to RSU to execute billing transactions and possibly security function. If billing error occurs due to failure of radio communication, vehicle identification and enforcement for post billing is followed. Figure 2 shows the Electronic Toll Collection (ETC) service concept.

FIGURE 2

ETC service concept



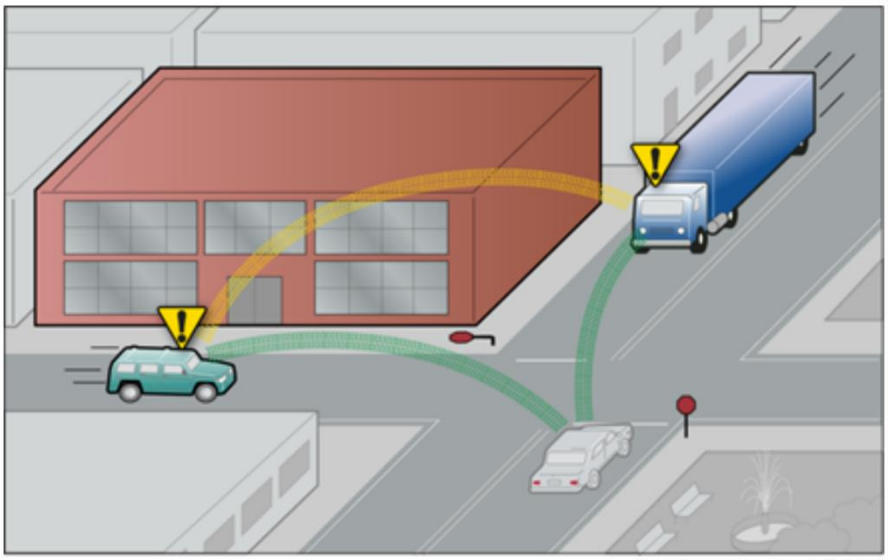
Electronic payment requires radiocommunication with low latency and high reliability to guarantee high reliability for safe billing. ETC may use DSRC, short-to-medium range communications technologies or network based cellular technology. DSRC communication is currently the most widely deployed communication scheme to support ETC systems.

2.2.2 Vehicle and Road Safety

The Vehicle Safety service provides warning information to prevent traffic accidents. When the vehicle enters an intersection, the vehicle does not know that other vehicles are approaching the intersection due to buildings blocking in non-line of sight. If vehicles transmit their location and status periodically, the vehicles recognize that the other vehicle(s) is approaching and take actions to prevent the collision. This can be executed by using Vehicle to Vehicle (V2V) communication. This service needs direct V2V communication with low-latency messaging, medium data rate and wider radio coverage compared with DSRC communication. For example, IEEE 802.11p V2X and ITS G5 will support a maximum of 27 Mbit/s with 100 ms in application layer (5 ms in radio access layer) and 1 km radio coverage. Vehicle to Infrastructure (V2I) communication can support road safety by sending information on accurate intersection geometries, traffic signal phase and timing, as well as unexpected situations to a vehicle. Most related use cases follow similar communications paradigms. For instance, in an intersection scenario with tall buildings, vehicles may be occluded by intervening buildings. Vehicle Safety service is to provide warning information to prevent traffic accidents. Where there are such occlusions, a vehicle will not be able to determine that other vehicles are approaching the intersection from another direction. Vehicle safety applications operate by leveraging a broadcast of vehicle kinematics and position; if the vehicle transmits the vehicle's location and status periodically, other vehicles recognize that the occluded vehicle is approaching and can take actions to prevent the collision. This type of safety application is commonly designed to use V2V communication.

FIGURE 3

Intersection safety warning



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Traffic efficiency is a major scenario of ITS service and an important component of smart transportation, for example, by using an LTE based V2X system. It has great significance for alleviating urban traffic congestion and promoting energy conservation and emissions reduction. Alleviating traffic congestion also enhances transportation safety.

Typical traffic efficiency scenarios include speed guidance. In the scenario of speed guidance, the roadside unit (RSU) collects the timing information on traffic lights and signal lights, and broadcasts information such as the present state of signal lights and the time remaining in this state to nearby vehicles. Based on the information received, combined with the current vehicle speed and location, the vehicle calculates the recommended driving speed and prompts the driver in order to increase the possibility of crossing the intersection without stopping. This scenario requires the RSU to be able to collect traffic signal information and broadcast V2X messages to vehicles and requires the nearby vehicles to be able to send and receive V2X messages.

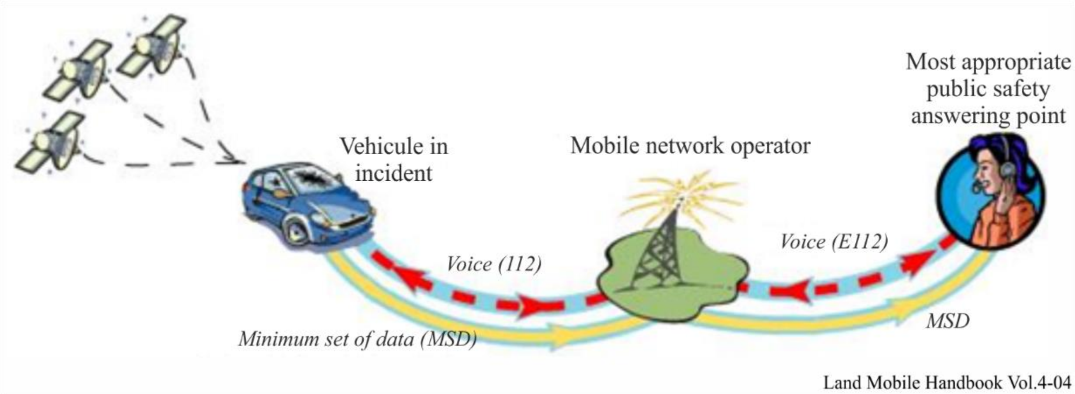
2.2.3 Emergency call

Emergency Call provides voice and data service for the vehicle driver's request. If a vehicle accident happens, the vehicle needs to request rescue operation by emergency calling or emergency data transfer. Emergency Call and Telematics[1] services represent the use of bi-directional voice and data using cellular networks. Figure 4 shows the emergency call service concept.

This service needs to support bi-directional voice and data with higher data latency and wide coverage. Cellular technology is the most suitable radiocommunication technology for this service.

FIGURE 4

Emergency call service



2.2.4 Traffic Information Service

Digital Broadcasting may provide traffic information to vehicle drivers. Transport Protocol Experts Group (TPEG) originally developed the global standards for Traffic and Travel Information (TTI) service. TTI (for example, traffic congestion, road construction, traffic accidents and so on) is converted into the TPEG standard and is broadcasted via a digital broadcasting channel. The vehicle driver can receive TTI as shown in Fig. 5.

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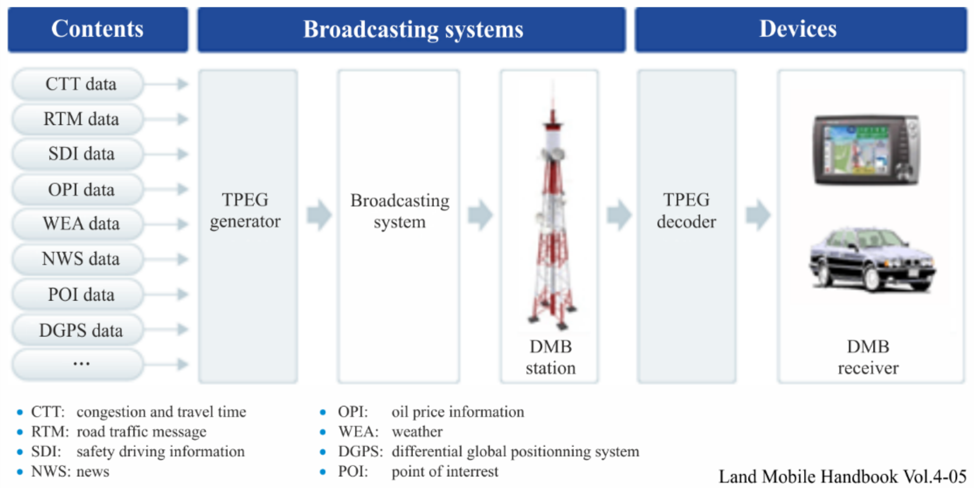
[1] Telematics is a very generic term that indicates the merger of telecommunications and informatics technologies, typically in an automotive context.

FIGURE 5

Traffic information service



This service supports one-way data broadcasting with wide radio coverage and medium latency.

2.2.5 Automated driving

Similar to existing video recognition on camera, millimetre wave radar, and laser radar, V2X offers another way of information interaction to obtain the motion states (speed, brake, and lane change) of other vehicles and pedestrians, However, V2X communications are not susceptible to the limitations of onboard sensors, by such factors as weather, obstacle, and range. As well, V2X provides ‘extra sensory’ perception capabilities for automated driving by being able to communicate driving intentions and to negotiate cooperative manoeuvres. At the same time, V2X helps to build a comprehensive service system of time-share rental favourable for the industrialization of Connected Automated Vehicles (CAVs) by integrating people, vehicles, road infrastructure, and the cloud platform. Currently, typical automated driving scenarios include vehicle platooning and remote driving. Vehicle platooning refers to the linking of vehicles through V2X communication. In a platoon, the lead vehicle may be manned or autonomous, and is followed by platoon member vehicles that maintain stable in-vehicle distance at a certain speed based on real-time information interaction. The application supports lane keeping and tracking, cooperative adaptive cruising, cooperative emergency braking, cooperative lane change reminder, and entry and exit platooning.

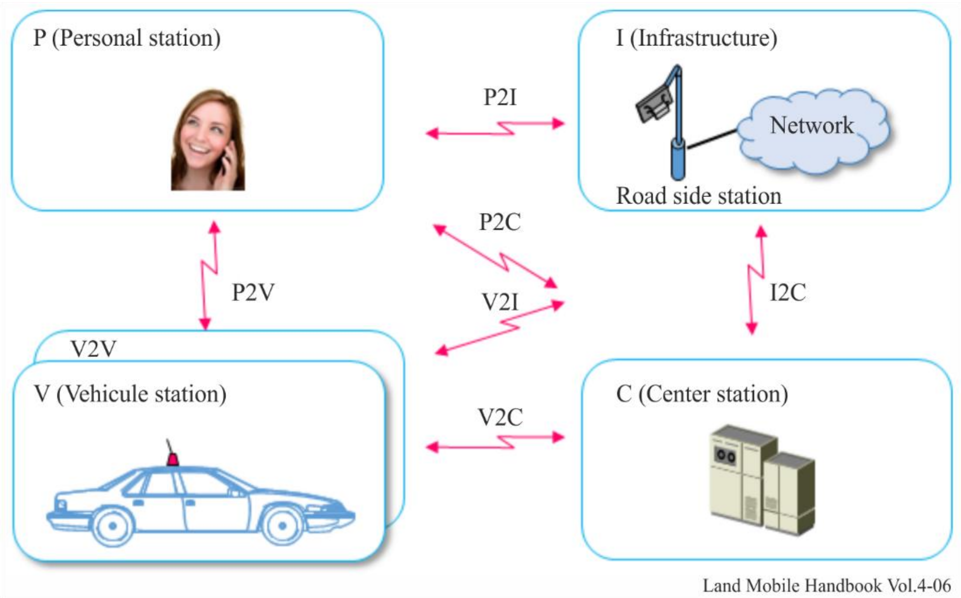
Remote driving enables the driver to remotely operate the vehicle through the driver console. The camera, radar, and other sensors mounted to the vehicle transmit in real time the multi-channel sensing information to the remote driver console. The communication for remote driving is envisioned to be provided through high-bandwidth 5G cellular network systems. The signals from the driver's remote console provide control instruction messages to steering wheel, throttle, and brake, which would also be transmitted in real time to the vehicle through low-latency and high-reliability 5G cellular network systems, which facilitates easy and accurate operations, such as driving, accelerating, braking, turning, and reversing.

2.3 Cooperative ITS service

Radiocommunication technologies enable provision of ITS applications and determine the service types and service quality of ITS applications. According to ISO standard, Cooperative ITS(C-ITS) consists of personal stations, vehicle stations, roadside stations, and a centre station, as shown in Fig. 6. By assuming peer-to-peer connectivity, ITS applications may be defined by Pedestrian to Anything connectivity (P2X) and Vehicle to Anything connectivity (V2X).

FIGURE 6

C-ITS system configuration



2.3.1 P2X based services

P2X communication technology may have Pedestrian to Vehicle connectivity (P2V), Pedestrian to Infrastructure connectivity (P2I), and Pedestrian to Centre connectivity (P2C) types.

- P2V communication enables connectivity between a personal station and a vehicular station. The communication will provide a pedestrian warning to a vehicle driver if the pedestrian approaches the vehicle. Also, it will provide a vehicle warning to a pedestrian if a vehicle approaches the pedestrian.

- P2I communication enables connectivity between a personal station and a roadside station. It provides personal navigation and vehicle warning at the intersection for disabled traffic users.

- P2C communication enables connectivity between a pedestrian and the centre. Traffic information-based navigation will be provided in the personal station if the centre station can provide the traffic information to the personal station.

A summary of P2X based services for the different connectivity types is given in Table 4.

TABLE 4

P2X based services

Connectivity	P2X Services
P2V	Pedestrian warning, Vehicle warning
P2I	Personal navigation, Vehicle warning
P2C	Traffic Information

2.3.2 V2X based services

V2X communication technology may have Vehicle to Infrastructure connectivity (V2I), Vehicle to Centre connectivity (V2C), Vehicle to Vehicle connectivity (V2V), and Vehicle to Anything connectivity (V2X) with sensors.

- V2I communication supports electronic toll collection to pay tolling fees when a vehicle passes through a toll plaza. Also, it may support vehicle data collection to periodically get vehicle status information, which is the vehicle’s dynamic speed, heading, emergency braking, identification, and location information. It may support the provision of road situation information such traffic signal information, road accidents, or road work.

- V2C communication supports a bus information service (BIS) to inform travellers of the arrival time and location. It also supports an emergency call to inform a vehicle emergency to the Public Safety and Assistance Party (PSAP). The Vehicle Information and Communication System (VICS) in Japan is a typical example of V2C.

- V2V communication, in conjunction with vehicle sensors, supports emergency brake warning, intersection collision warning, and cooperative adaptive cruise control (CACC).

- V2X with vehicle sensors or road sensors supports automated valet parking and automated driving.

A summary of V2X based services for the different connectivity types is given in Table 5.

TABLE 5

V2X based services

Connectivity	V2X Services
V2I	ETC, Vehicle data collection, Curve speed warning, Emergency vehicle preemption, Enhanced maintenance decision support system, Incident scene work zone alerts for driver and workers, In-vehicle signage, In-vehicle signage, Oversize vehicle warning, Pedestrian in signalized crosswalk warning, Railroad crossing violation warning, Red light violation warning, Reduced speed zone warning, Restricted lane warning, Roadside lightening, Stop sign gap assistant, Stop sign violation warning, Transit vehicle at station/stop warning, Vehicle turning right in front of transit vehicle, Emergency stop, Intelligent traffic signal system, Intermittent bus line, Pedestrian mobility, Performance monitoring and planning, Speed harmonization, Traffic flow optimization, Transit signal priority, Variable speed limit for weather-responsive traffic management
V2C	BIS, VICS, Vehicle data for traffic operation, Eco-approach and departure at Eco speed harmonization, Low emission zone management, Authentication, Location and time, Security and credential management, wireless advertising, Internet, Drive-through payment, Border management, EV charging management, Integrated multi-modal electronic payment, Road weather information
V2V	Emergency Brake Warning, Intersection Collision Warning, Blind spot warning, Control loss warning, Do not pass warning, Emergency vehicle alert, Forward collision warning, Intersection movement assistance, Motor cycle approaching indication, Situation awareness, Wrong way driving warning, Emergency stop, Vulnerable road user warning, Queue warning, CACC
V2X with sensors	Automated valet parking, Automated driving

CHAPTER 3

ITS SYSTEM AND COMMUNICATION ARCHITECTURE

ITS architecture provides the basic framework from which deployers can design, plan and implement ITS services. This framework provides the basis for multiple designs that can be specifically tailored to meet the individual needs of the user, while maintaining the benefits of a common architecture. The architecture defines the functions (e.g. gather traffic information or request a route) that must be performed to implement a given user service, the physical entities or subsystems where these functions reside (e.g. the roadside or the vehicle), the interfaces/information flows between the physical subsystems, and the communication requirements for the information flow (e.g. wireline or wireless). In addition, it identifies and specifies the requirements for the standards needed to support security, national and regional interoperability, as well as product standards needed to support economies of scale considerations in deployment.

3.1 ITS System Architecture

A generic, technology-neutral approach has been developed for the overall ITS architecture to provide a common framework for planning, defining, and integrating Intelligent Transportation Systems[2]. The Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT)[3] includes a set of interconnected components that are organized into four views that focus on four different architecture perspectives, as illustrated in the following diagram:

1) Enterprise View considers ITS from an organizational perspective. It identifies stakeholder organizations or enterprises –the people and organizations that plan, develop, operate, maintain, and use ITS. It defines stakeholder roles and the relationships between stakeholders. This is also the view where needs are defined since ARC-IT, and more broadly ITS, is driven by the needs of stakeholder organizations, their constituents, and customers.

2) Functional View looks at ITS from a functional perspective. Functional requirements are defined that support ITS user needs. Processes and data flows provide a structured presentation of functions and interactions that support the requirements.

3) Physical View defines the physical objects (the systems and devices) that provide ITS functionality. Information flows define the flow of information between physical objects. Functional Objects organize the functionality that is required to support ITS within each physical object.

4) Communications View defines how physical objects communicate. It defines communications standards and profiles that are combined into communications solutions that specify how information can be reliably and securely shared between physical objects.

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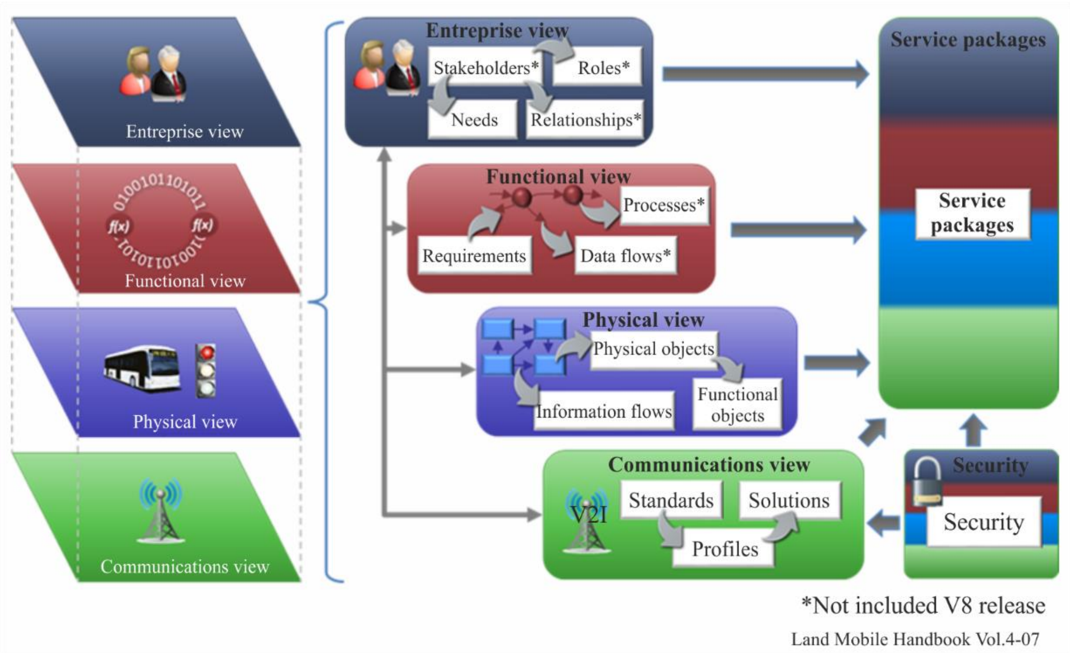
[2] http://local.iteris.com/arc-it/

[3] http://local.iteris.com/arc-it/html/architecture/architecture.html

FIGURE 7

Architecture reference for cooperative and intelligent transportation (ARC-IT)



Note that Security is paramount in 21st century Intelligent Transportation Systems, and ARC-IT addresses security holistically, addressing security concerns spanning all four views. As well, Service Packages are a service-oriented entry point that makes it easy to view a vertical slice of ARC-IT that spans all four views for a particular ITS service (e.g. traffic signal control).

3.1.1 Enterprise view[4]

The Enterprise view describes the relationships between organizations and the roles those organizations play within the cooperative ITS environment.

The building blocks of ARC-IT's Enterprise View are Enterprise Objects that interact to exchange information, manage and operate systems beyond the scope of one organization. The Enterprise View focuses on the relationships between those Enterprise Objects, but also defines how Enterprise Objects interact with Physical Objects, which appear in the Enterprise View as Resources.

The relationships between Enterprise Objects are organized as various types of Coordination: an agreement or contract intended to achieve the common purposes necessary to implement and deliver an ITS service. The relationship between an Enterprise Object and a Resource is a Role: owns, operates, develops, installs, maintains, etc.

3.1.2 Functional view[5]

This view describes system configuration and functional entities, and the relationships among functional entities. The Functional View addresses the analysis of abstract functional elements and their logical interactions. Here ARC-IT is depicted as a set of Processes organized hierarchically. These Processes (activities and functions) trace to a set of Requirements derived from source

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4 http://local.iteris.com/arc-it/html/viewpoints/enterprise.html

5 http://local.iteris.com/arc-it/html/viewpoints/functional.html

documents. The data flows that move between processes and the data stores where data may reside for longer periods are all defined in a Data Dictionary.

The behaviour of a Function (aka Process) is the set of actions performed by this element to achieve an objective. A Process performs actions to achieve an application objective or to support actions of another Process. This may involve data collection, data transformation, data generation, data generation, or processing in performing those actions. The Functional View defines Processes to control and manage system behaviour, such as monitoring, and other active control elements that are part of describing the functional behaviour of the system. It also describes data processing functions, data stores, and the logical flows of information among these elements.

3.1.3 Physical view

The Physical view[6] describes the transportation systems and the information exchanges that support ITS. In this view, the Architecture is depicted as a set of integrated Physical Objects (Subsystems and Terminators) that interact and exchange information to support the Architecture service packages. Physical Objects are defined to represent the major physical components of the ITS Architecture. Physical Objects include subsystems, and terminators that generally provide a set of capabilities more than would be implemented at any one place or time. Subsystems are Physical Objects that are part of the overall Intelligent Transportation System and provide the functionality that is 'inside-the-boundary' of ITS. Terminators are Physical Objects that lie at the boundary of ITS and supply information needed by ITS' functions or receive information from ITS. Functional Objects break up the subsystems into deployment-sized pieces and define more specifically the functionality and interfaces that are required to support a particular Service Package. Information Flows depict the exchange of information that occurs between Physical Objects (Subsystems and Terminators). The information exchanges in the Physical View are identified by Triples that include the source and destination Physical Objects and the Information Flow that is exchanged.

The Physical view is related to the other Architecture views. Each Functional Object is linked to the Functional view, which describes more precisely the functions that are performed and the details of the data that is exchanged by the object. Physical Objects and Functional Objects are also depicted as Resources in the Enterprise view, which describes the organizations that are involved and the roles they play in installing, operating, maintaining, and certifying all of the components of the Architecture.

In addition, the physical view includes a notional hierarchy. Considering the architecture from its most abstract (highest) level, the physical view describes interactions between support, centre, field, traveller, and vehicle systems as shown in Fig. 8.

Alternative terminology for Physical Objects has also been used, for example: personal station, vehicle station, Infrastructure (roadside station and network), and centre station.

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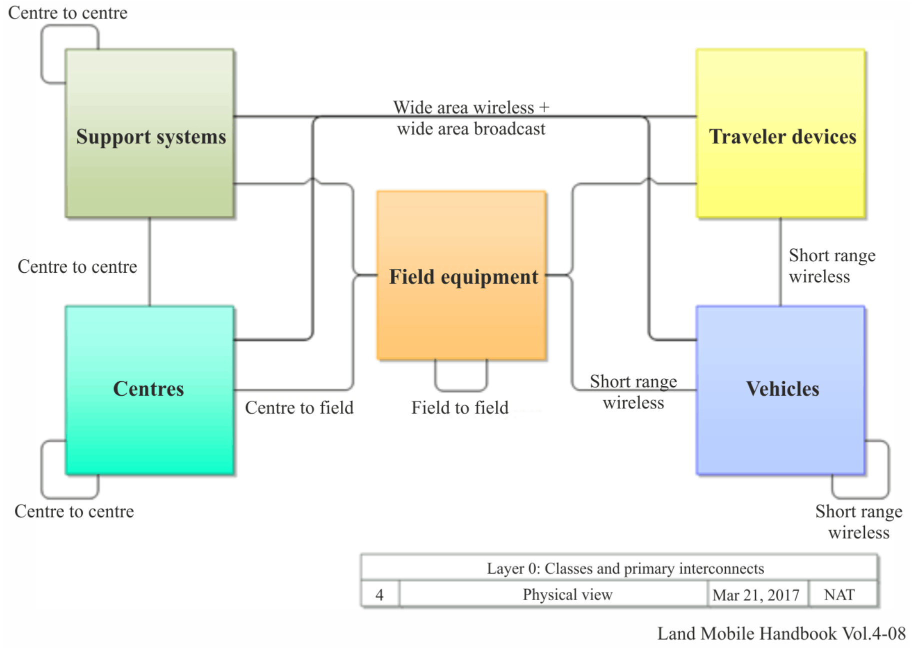
6 http://local.iteris.com/arc-it/html/viewpoints/physical.html

FIGURE 8

Physical view



3.1.4 Communications view

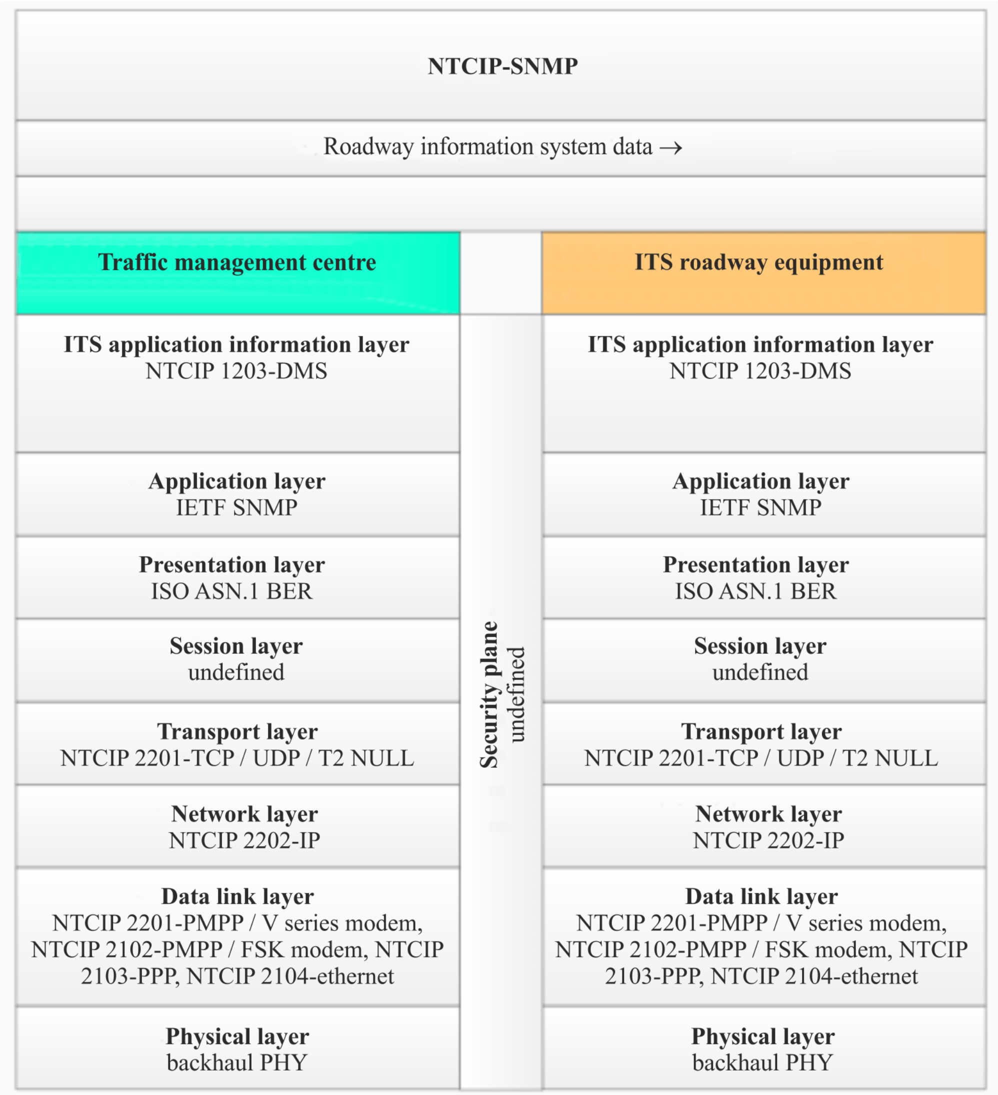
The Communications view[7] describes the protocols necessary to provide interoperability between Physical Objects in the Physical View. Each information flow triple from the Physical View can be mapped to a set of standards or published specifications that together can be used to build an interoperable implementation within an operational region. These standards are typically considered in hierarchical fashion, from those that include the data element, message, and dialog definitions at the top, to those providing access facilities, networking, transport and physical data exchange at the bottom. Owing to the necessary hierarchical nature of the relationships between most standards, these protocols are organized in a series of layers. Also considered are those standards providing device management and security, which are typically modelled across all communications–centric layers.

Figure 9 illustrates a sample such communications stack, in this case for control of a dynamic message sign by a traffic management centre. This communications solution uses any available media technology; while typically this would-be fixed-point wireline, wireless technologies could also be used.

7 http://local.iteris.com/arc-it/html/viewpoints/communications.html

FIGURE 9

Communication view



* Mechanism for transmitting raw bits over a physical link between the center and field, such as I.430/431, SONET/SDH, IEEE 802.3, IEEE 802.11 or any other viable physical layer specification or standard.

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The ITS architecture provides a common structure for the design of ITS. It is not a system design nor is it a design concept. What it does is define the framework around which multiple design approaches can be developed, each one specifically tailored to meet the individual needs of the user, while maintaining the benefits of a common architecture noted above. The architecture defines the functions (e.g. gather traffic information or request a route) that must be performed to implement a given user service, the physical entities or subsystems where these functions reside (e.g. the roadside or the vehicle), the interfaces/information flow between the physical subsystems, and the communication requirements for the information flow (e.g. wireline or wireless). In addition, it identifies and specifies the requirements for the standards needed to support national and regional interoperability, as well as product standards needed to support economies of scale considerations in deployment.

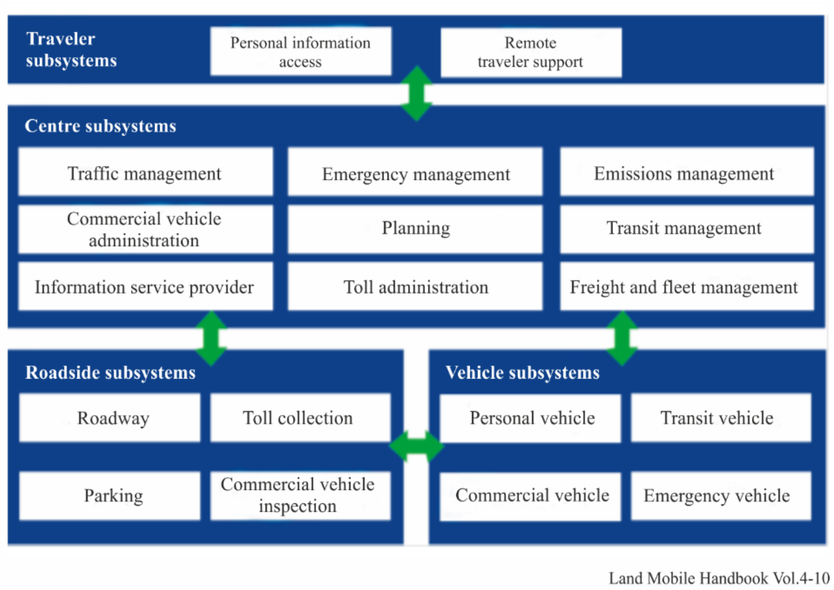
3.2 ITS communication architecture

3.2.1 ITS communication system

The ITS communication architecture provides the framework that ties the transportation and telecommunication worlds together to enable the development and effective implementation of the broad range of ITS user services. There are multiple communications options available to the system designer. The flexibility in choosing between various options allows each implementer the ability to select the specific technology that meets the local, regional, or national needs. The architecture identifies and assesses the capabilities of candidate communications technologies, but it does not select or recommend 'winning' systems and technologies. One of the fundamental guiding philosophies in the development of the ITS architecture has been to leverage the existing and emerging transportation and communication infrastructures in its design. This minimizes the risk and cost of deployment, and maximizes marketplace acceptance, penetration, and early deployment.

FIGURE 10

ITS communication architecture overview



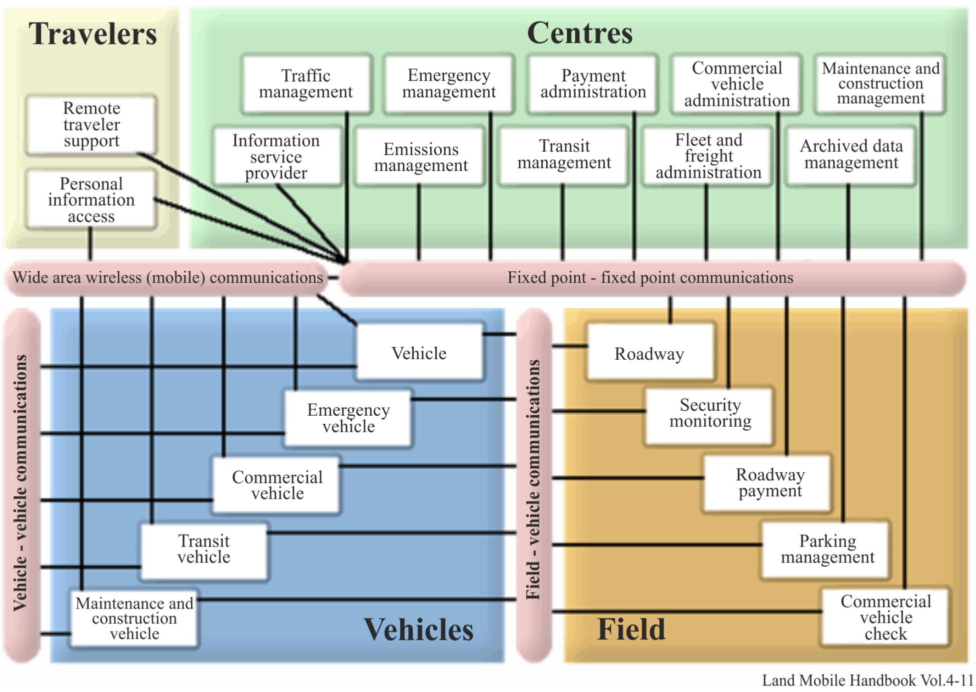
In Fig. 10, centre subsystems deal with those functions normally assigned to public/private administrative, management, or planning agencies. Roadside subsystems include functions that require convenient access to a roadside location for the deployment of sensors, signals, programmable signs, or other interfaces with travellers and vehicles of all types, and vehicle subsystems are installed in a vehicle. Traveller subsystems represent platforms for ITS functions of interest to travellers or carriers (e.g. commercial vehicle operators) in support of multimodal travelling. They may be fixed (e.g. kiosks or home/office computers) or portable (e.g. a palm-top computer), and may be accessed by the public (e.g. through kiosks) or by individuals (e.g. through cellular phones or personal computers). The architecture identifies four communication media types to support the communications requirements between the nineteen subsystems. They are wireline or wireless (fixed-to-fixed), wide area wireless (fixed-to-mobile), dedicated short range communications (fixed-to-mobile), and vehicle-to-vehicle (mobile-to-mobile). A top-level subsystem interconnect diagram that illustrates examples of the communications media interfaces between the architecture's multiple examples of possible subsystems is provided in Fig. 11.

There are numerous wireline technologies to choose from for fixed-to-fixed communications requirements. For example, the traffic management subsystem can use leased or owned twisted wire pairs, coaxial cable, or fibre optics to gather information and to monitor and control roadway subsystem equipment packages (e.g. traffic surveillance sensors, traffic signals, changeable message signs, etc.). As well, several wireless technologies are also available to support fixed to fixed wireless communications requirements.

The architecture identifies two distinct categories of wireless communications based on range and area of coverage. The first category, wide area wireless (fixed-to-mobile) communications, is suited for services and applications where information is disseminated to users who are not located near the source of transmission and who require seamless coverage. Wide area wireless communications are further differentiated based on whether they are one-way or two-way. Examples of a one-way, broadcast transmission are the traffic reports currently received over AM or FM radio. A mobile traveller who requests and receives current traffic information from an information service provider is an example of two-way communication. Each wireless technology has its own strengths and weaknesses relative to addressing ITS communication requirements.

FIGURE 11

C-ITS system interconnection



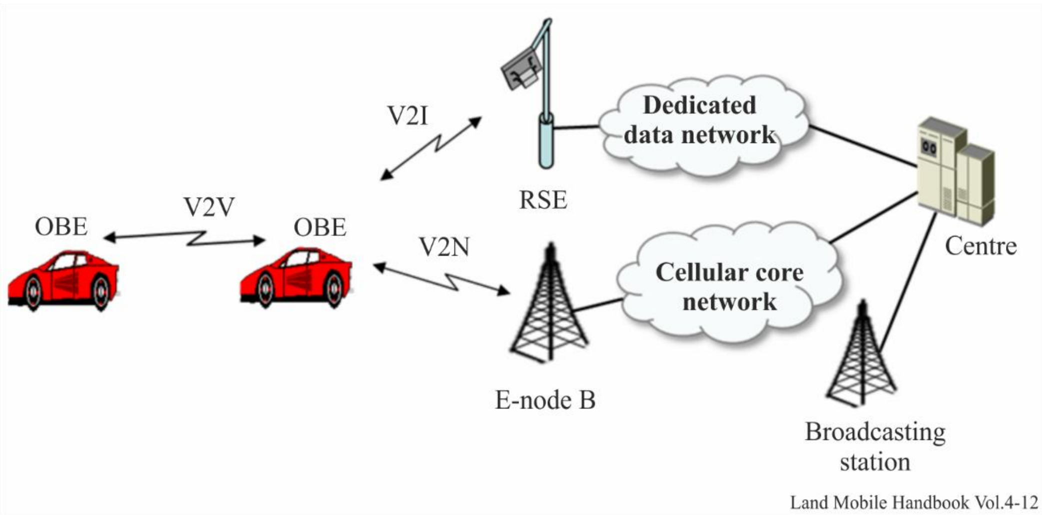
Short range wireless is applied to information transfer that is of a localized interest. Short range technologies are typically applied to emerging vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) information broadcasts and exchanges. Short range wireless communications are required to support the automated highway system (AHS), and most likely, intersection collision avoidance implementations. Examples of appropriate applications for short range communications include vehicle safety applications, localized payment, roadside safety inspections, credential checks, in-vehicle signing and related local traffic and mobility data dissemination such as queue alerts and traffic signal-related information.

3.2.2 ITS communication network

There are three types of wireless communication networks which are pertinent to ITS communication: direct, peer-to-peer communication, cellular network communication and Broadcasting transmissions. The generic ITS communication network shown in Fig. 12 illustrates the use of multiple communication types to support ITS. This communication network can be designed to meet the technical requirements of ITS applications. The ownership and operational responsibilities of the various portions of communication networks used for ITS vary according to the various needs of different administrations, and are therefore subject to the regulatory requirements of those respective administrations.

FIGURE 12

ITS communication network

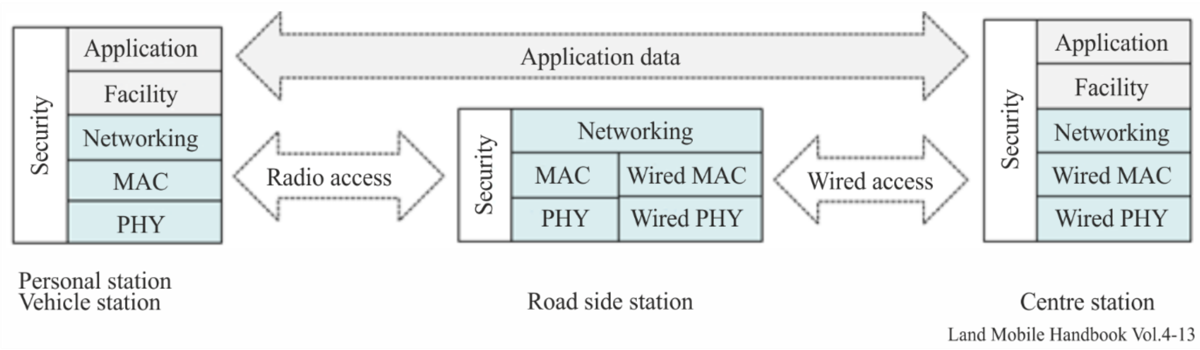


An example of a physical view of the ITS system consisting of a personal station, vehicle station, roadside station, and centre is shown in Fig. 13. These four stations are the physical entities to be able to communicate respectively. The personal station is hand-held device for pedestrian and travellers. The vehicle station is a vehicle mounted terminal for drivers. The two stations provide radio access function and application data processing for end users. The roadside station is installed at the road and provides both radio access and wired access to connect between the personal station (vehicle station) and the centre respectively. The centre is a data server to receive the service request and provide ITS service to the personal station or vehicle station.

According to the ISO 7 layer architecture, the personal station and vehicle station have physical layer, MAC, and networking layer for the radio access function. They also have a facility layer and application layer including a security layer. The centre also has a wired physical layer, MAC, and networking layer. It also has a facility layer and application layer including security layer like the communication architectural layers of the personal station and vehicle station. The roadside station has both radio access and wired access function like the gateway between the end user and server.

FIGURE 13

ITS communication system configuration



The transmitted message of the personal station or vehicle station is generated in the application and facility layer. The message is transformed into an IP or non-IP packet message and addressing information is added to the transmitted message. The IP or non-IP packet message is fragmented into short sized packets and is modulated and converted into an RF signal. The received RF signal is converted into a modulated signal, and the message is recovered in the application layer at the centre station. Table 6 shows the technical features of the example ITS communication architecture.

TABLE 6

Technical features of example ITS communication system

Communication architecture	Functions	Communication technologies
Physical layer	Digital modulation, FEC RF signal transmission and reception	ASK, BPSK, QPSK, OFDM
MAC layer	Radio channel access and assignment, packet data error detection	FDMA, TDMA, CSMA, OFDMA
Networking layer	Addressing and routing	TCP/IP, UDP/IP, WSMP, Geo Networking
Facility layer	Contents for application	Traffic signal, LDM
Security layer	Authentication and data privacy	Authentication, Encryption
Application layer	Application ID and source coding	ETC, BIS, Vehicle and Road Safety, e-call, T-PEG

CHAPTER 4

RADIO TECHNOLOGIES FOR ITS SYSTEMS

This chapter describes the technical requirements and characteristics of radio technologies for the ITS systems. Providing further details for the Communications View portion of the ITS architecture, this section describes the various possible radio technologies used for ITS services, including DSRC, V2X, ITS related cellular communication, broadcasting, millimetre-wave vehicle radar, and road radar.

4.1 Dedicated short range communication (DSRC)

4.1.1 Introduction

DSRC refers to a dedicated short range communication between a roadside infrastructure and vehicles for ITS applications. DSRC transfers packet data between a roadside and a vehicle radio unit at a short distance range. Generally, its radio coverage is less than 100 m. If the vehicle drives at 100 km/h, the allowable time for ITS service will be less than 3.6 seconds because the vehicle speed is 27.7 m/s and divided by 100 m. DSRC requires a fast link setup and termination including fast interactions between the roadside infrastructure and vehicles for ITS applications.

DSRC has two types of communication: active DSRC and passive DSRC. The active DSRC type has an oscillator source to generate the carrier frequency in the vehicle radio unit like the roadside radio unit. But passive DSRC type does not mount the oscillator to generate the carrier frequency in the vehicle radio unit. Instead, the roadside radio unit will provide the carrier frequency to the vehicle radio unit.

DSRC services include vehicle control systems, traffic management systems, traveller information systems, public transportation systems, fleet management systems, emergency management systems, and electronic payment services. DSRC is considered as an effective communication technology to provide ETC (electronic toll collection) and traffic information.

DSRC systems have the following features:

– Packet data communication between the vehicle and the infrastructure.

– Communications with fast link setup and link termination in a spot zone.

– Two types of DSRC: Active DSRC and Passive DSRC (called backscattering).

4.1.2 System configuration

DSRC communication system consists of on-board equipment (OBE) and roadside equipment (RSE), as shown in Fig. 14. OBE are the vehicle side radio units, and RSE is the roadside radio unit.

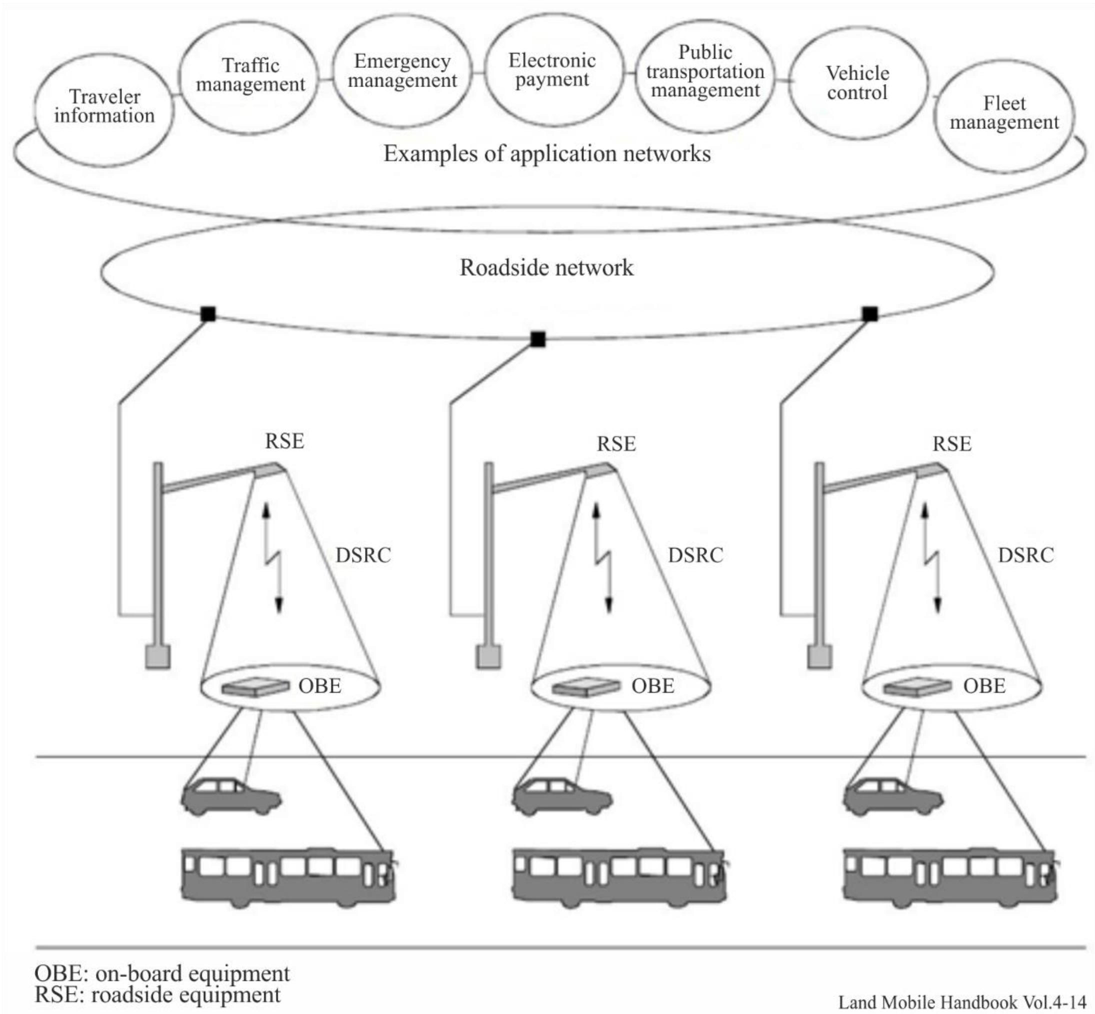
OBE is attached near the dashboard or on the windshield of the vehicle, and consists of radio communication circuits and an application processing circuit. It usually has a human-machine interface, including switches, displays, and a buzzer.

RSE is installed above or alongside the road and communicates with passing OBE by use of radio signals. RSE consists of radio communication circuits, an application processing circuit, and so on. It usually has a link to the roadside infrastructure to exchange data.

DSRC systems operate by transmitting radio signals for the exchange of data between vehicle mounted OBE and RSE. This exchange of data demands high reliability and user privacy as it may involve financial and other transactions.

FIGURE 14

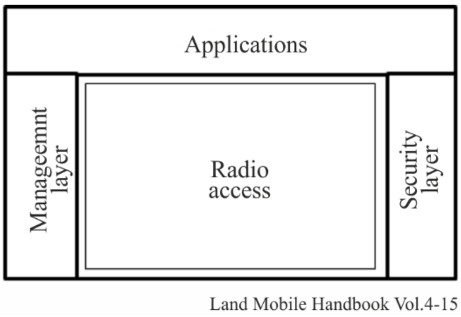
Typical configuration of a DSRC communication system



OBE and RSE have system reference model with radio access layer and application layer as shown in Fig. 15. ETC application will be implemented by the functions of radio access layer and application layer without networking function because ETC server is installed at toll plaza. And management and security layer will be connected to radio access layer and application layer for system initialization and management, privacy protection and data security.

FIGURE 15

DSRC communication reference model



4.1.3 Technical characteristics

4.1.3.1 European Passive DSRC

Background

In 1992, the CEPT (European Conference of Postal and Telecommunications Administrations) – ERC (European Radio communications Committee) agreed on ERC Decision (92)02 designating frequency bands for the development of a fully Integrated Road Transport system in order to improve all aspects of road transport. It was decided to designate the frequency band 5 795-5 805 MHz on a European basis, with an additional sub-band 5 805-5 815 MHz on a national basis, to meet the requirements of multilane road junctions. The frequency bands were foreseen for initial road-to-vehicle systems, in particular for road toll systems for which requirements had emerged in a number of European countries at that time. In 2002, the Electronic Communications Committee (ECC) withdrew ERC Decision (92)02 and replaced it by ECC Decision (02)01, entering in force on 15 March 2002. In 2012, the ECC withdrew ECC Decision (02)01 as EC Decision 2006/771/EC as amended by 2019/1345/EU and Annex 5 of ERC Recommendation 70-03 contain harmonization measure for RTTT (Road Transport and Traffic Telematics) DSRC within European Union and at CEPT level.

In addition, standards for DSRC for ITS applications have been developed by European Committee for Standardization (CEN) and European Telecommunications Standards Institute (ETSI). A standard for the physical layer using microwaves at 5.8 GHz (CEN EN 12253) describes radiocommunication and RF parameter values necessary for co-existence and interoperability of DSRC systems. This standard forms part of the DSRC family of standards consisting of four standards covering the protocol layers 1, 2, and 7 of the Open Systems Interconnection (OSI) protocol stacks and profiles for RTTT (Road Transport and Traffic Telematics) applications. All these CEN standards were approved and published in 2003 and 2004.

The harmonized ETSI standard EN 300 674-2: “Dedicated Short Range Communication (DSRC) transmission equipment (500 kbit/s / 250 kbit/s) operating in the 5.8 GHz Industrial, Scientific and Medical (ISM) band” was approved and published in 2004. This standard contains general and environmental test conditions, methods of measurements and parameter limits.

The use of this harmonized ETSI standard gives a presumption of conformity to article 3 of the Directive 1999/5/EC of the European Parliament and of the (R&TTE Directive).

Furthermore, ETSI developed standards EN 300 674-2-1 “Dedicated Short Range Communication (DSRC) transmission equipment (500 kbit/s, 250 kbit/s) operating in the 5 795 MHz to 5 815 MHz frequency band; Part 2: Harmonised Standard covering the essential requirements of article 3.2 of the

Directive 2014/53/EU; Sub-part 1: Road Side Units (RSU)” published in 2016 and EN 300 674-2-2 “Dedicated Short Range Communication (DSRC) transmission equipment (500 kbit/s / 250 kbit/s) operating in the 5 795 MHz to 5 815 MHz frequency band; Part 2: Harmonised Standard for access to radio spectrum; Sub-part 2: On-Board Units (OBU)” published in 2019 which give a presumption of conformity to article 3.2 of the Radio equipment Directive 2014/53/EU of the European Parliament.

Technical characteristics

European DSRC systems use the passive backscatter (transponder) method. This method does not have an internal oscillator for generating a 5.8 GHz band radio carrier signal in the on-board equipment (OBE), so it relies on the 5.8 GHz oscillator of the roadside unit with which it communicates. A detailed explanation is given in Fig. 16 with a typical functional block diagram.

As the passive transponder does not have a carrier signal oscillator, when transmitting from the OBE, the roadside unit has to emit an unmodulated carrier signal continuously. The OBE receives this signal, which is fed to the transmission circuit and makes it its own carrier signal (B). The transmission data from the main processing unit modulates the output of the sub-carrier signal oscillator C and mixes it with the carrier signal from the receiver. Resultant sideband signals carrying transmission data with different frequencies (carrier signal frequency plus/minus sub carrier frequency) from the carrier signal are transmitted with the carrier signal. The sub-carrier modulation method is utilized to extend the communication zone through reduction of the carrier phase noise and to reduce the re-use distance of RSE in the passive transponder system. The modulated signal from the RSE is detected in the detector and processed by the main processing unit as receiving data. The communication zone of the passive (transponder) system is very small, typically up to 10 or 20 meters in front of the RSE. To extend the communication zone to some degree, an additional radio frequency amplifier D may be inserted into the transmission circuit of the transponder.

One of the significant features of the passive backscatter method is a narrow communication zone, typically up to 10 or 20 metres in front of the RSE. This characteristic, i.e. communications can only take place at a precise point, is particularly important to correctly locate the vehicle. There are many applications utilizing this characteristic such as Electronic Toll Collection (ETC), Automatic Vehicle Identification (AVI), etc. Another feature of the passive backscatter method is that the structure of the OBE is simple and results in low manufacturing costs.

FIGURE 16

Typical configuration of OBE in passive backscatter method

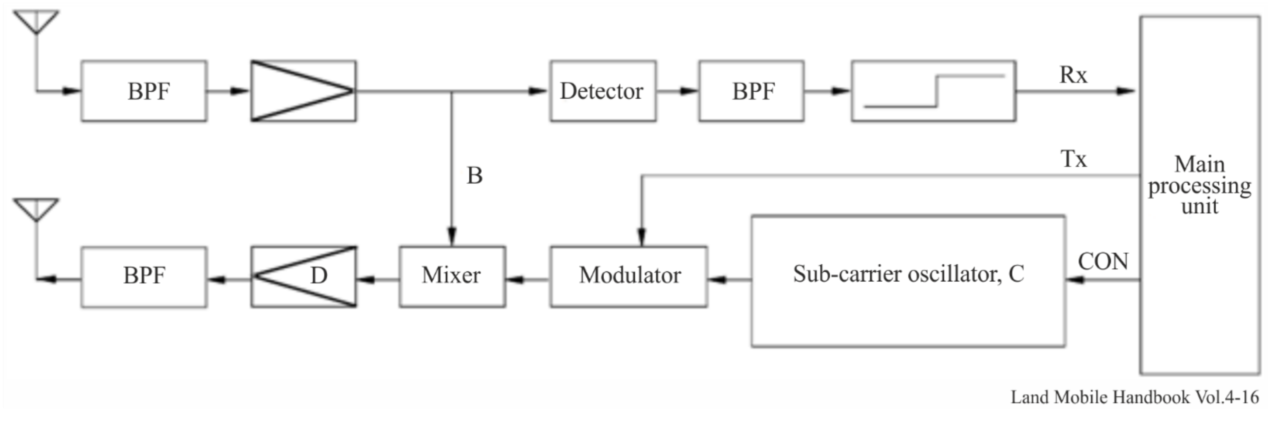


Figure 17 shows the RSE and OBE transmission timing chart, and Fig. 18 shows the RSE and OBE transmission spectrum in passive backscatter method.

FIGURE 17

Transmission timing chart in passive backscatter method

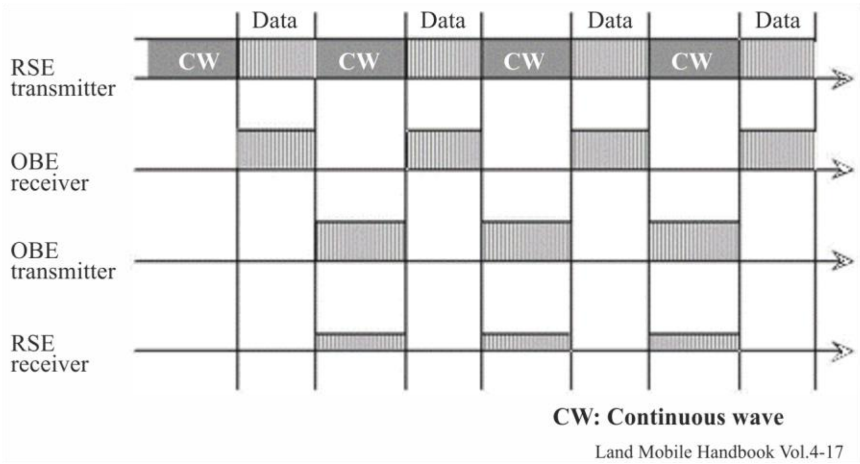
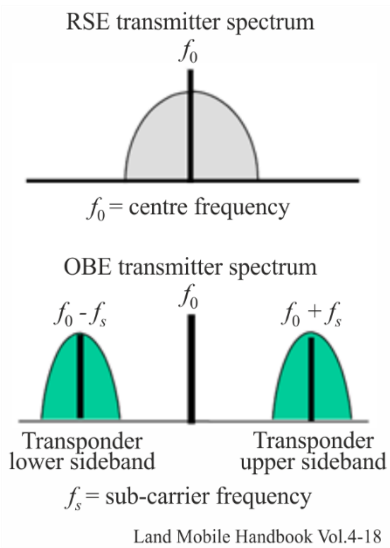


FIGURE 18

RSE and OBE transmission spectrum in passive backscatter method



Technical specification

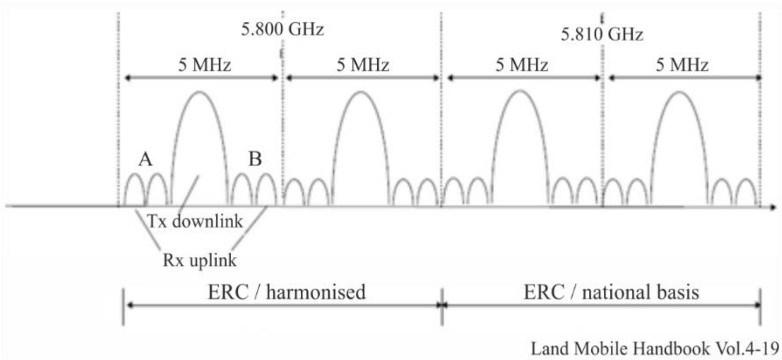
The technical characteristics of the European backscatter (transponder) method are shown in Table 7 which is an excerpt from Recommendation ITU-R M.1453-2. The Recommendation incorporates the "Medium data rate" European standard (CEN EN 12253) as well as the "High data rate" Italian standard into a single Recommendation.

In the European DSRC standard, the OBE supports two kinds of sub-carrier frequencies (1.5 MHz and 2.0 MHz). Selection of sub-carrier frequency depends on the profile indicated by the RSE. (1.5 MHz is recommended). The frequency spectrum of "Medium data rate" European standard is shown in Fig. 19.

In the case of "High data rate" Italian standard, the OBE uplink sub-carrier frequency is 10.7 MHz, resulting in a higher uplink data transmission speed. The frequency spectrum of the "High data rate" Italian standard is shown in Fig. 20.

FIGURE 19

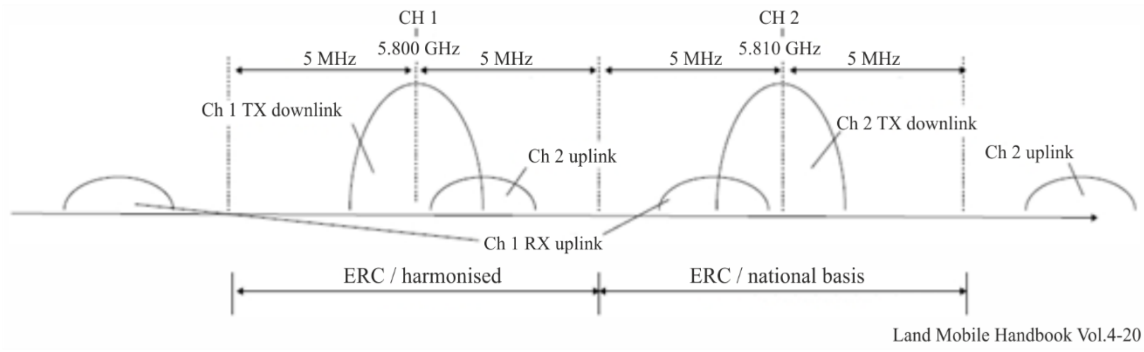
Frequency spectrum of "Medium data rate" European standard



(RAST6(98)29, "Intelligent Transportation System – An ETSI View")

FIGURE 20

Frequency spectrum of "High data rate" Italian standard



(RAST6(98)29, "Intelligent Transportation System – An ETSI View")

TABLE 7

Characteristics of backscatter (transponder) method

Item	Technical characteristics	
	Medium data rate	**High data rate**
Carrier frequencies	5.8 GHz band for downlink	5.8 GHz band for downlink
Sub-carrier frequencies	1.5 MHz/2 MHz (uplink)	10.7 MHz (uplink)
RF carrier spacing (channel separation)	5 MHz	10 MHz
Allowable occupied bandwidth	Less than 5 MHz/channel	Less than 10 MHz/channel
Modulation method	ASK (downlink carrier) PSK (uplink sub-carrier)	ASK (downlink carrier) PSK (uplink sub-carrier)
Data transmission speed (bit rate)	500 kbit/s (downlink) 250 kbit/s (uplink)	1 Mbit/s (downlink) 1 Mbit/s (uplink)
Data coding	FM0 (downlink) NRZI (uplink)	
Communication type	Transponder type	Transponder type
Maximum e.i.r.p. (NOTE 1)	≤ +33 dBm (downlink) ≤ −24 dBm (uplink: single sideband)	≤ +39 dBm (downlink) ≤ −14 dBm (uplink: single sideband)

NOTE 1 – ERC Recommendation 70-03 specifies values of 2 W e.i.r.p. for active and 8 W e.i.r.p. for passive systems.

4.1.3.2 America DSRC

In the United States of America, different proprietary roadside and vehicle technologies are presently in use for electronic toll collection in different areas within North America. These technologies are not directly interoperable, so multiple transceivers are required in order to enable electronic toll collection across these diverse areas, and data exchange agreements are used to provide limited interoperability within regional areas[8]. In the longer term, connected vehicle technologies are expected to allow convergence of electronic toll collection onto one or more technologies based upon voluntary industry standards.

4.1.3.3 Japanese Active DSRC

Background

In July 1996, a comprehensive plan for ITS in Japan was structured to promote ITS as a long-term vision. It illustrates the proposed functions of ITS and the basic concepts of development and deployment for Japan. This plan defines twenty ITS user services and establishes goals for research, development and deployment by public, academic and industrial sectors, categorized into nine development areas. Electronic toll collection system (ETC) is categorized as one of the nine development areas.

DSRC is a key technology for ETC and various other ITS application services. In 1994, development for DSRC started in the Telecommunications Technology Council, established by the Ministry of Posts and Telecommunications (now Ministry of Internal Affairs and Communications). In 1997, in accordance with the report from the Telecommunications Technology Council, the Ministry of Posts and Telecommunications published the regulation on DSRC (for ETC). In November 1997, the DSRC

8 https://www.ibtta.org/sites/default/files/Interoperabiity%20Background-1.pdf.

standard was established and published by ARIB (Association of Radio Industries and Businesses) in Japan.

In 1994, the Japanese Ministry of Construction (now Ministry of Land, Infrastructure and Transport), in cooperation with four major public toll operators and ten consortiums consisting of private companies, started a joint research project on electronic toll collection (ETC) systems which have nationwide interoperability in Japan. The research was completed by the test operation conducted on the Odawara – Atsugi highway in 1997.

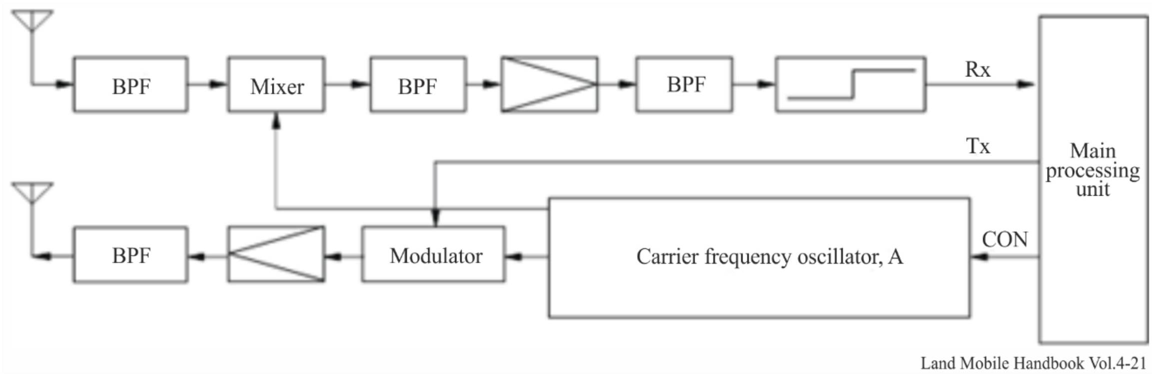
In 2001, ETC services started across the nation. As of 2017, the number of ETC subscribers reached 60 million. Increasing the number of subscribers will allow for various applications to be served by DSRC technology using the same OBE. In 2015, ETC2.0 services, e.g. traffic information service VICS (Vehicle Information Communication System) started across the nationwide highways.

Technical characteristics

The Japanese DSRC system adopts the active (transceiver) method. For the active (transceiver) method, the OBE is equipped with the same functions as the RSE which is equipped with devices necessary for radiocommunication. More specifically, both RSE and OBE incorporate a 5.8 GHz band carrier frequency oscillator and have the same functionality for radio transmission. Figure 21 shows a typical block diagram for the OBE’s radio circuitry. The upper half of Fig. 21 is the receiver, the lower half is the transmitter, and the processing unit is to the right. The transmission and reception antennas may be shared. The OBE in the active (transceiver) method receives radio signals from the RSE with the antenna on the upper left. Each signal received passes through each functional block and is processed by the main processing unit as reception data. The transmission signal from the OBE is the 5.8 GHz band carrier signal from oscillator A modulated with transmission data. The signal is sent from the antenna on the bottom left.

FIGURE 21

Typical configuration of OBE in active method



The active (transceiver) method can easily realize small or large communication zones by controlling the directivity of the transmission antenna. The footprint (communication zone) of an ETC antenna is very small (typically 3 m × 4 m). On the other hand, a large footprint of up to 30 m in length can be realized by approach antenna for information dissemination. The bit error ratio (BER) within the footprints is very low (less than 10^{-6}). The main feature of the active (transceiver) method is flexible zone forming, in addition to large volumes of information to be communicated with high reliability. These characteristics are indispensable for various ITS application services using DSRC.

Technical Specification

Technical characteristics of the Japanese active (transceiver) method are shown in Table 8, which is also an excerpt from Recommendation ITU-R M.1453-2. In this Table there are two specifications in the RF carrier spacing column. Wide spacing (10 MHz channel separation) is mainly for current ETC applications with the ASK (amplitude shift keying) modulation method. Narrow spacing (5 MHz channel separation) is for multiple DSRC application services with the ASK and/or QPSK modulation method. Specifications for the narrow spacing were added in October 2000 when the Japanese Ministry of Posts and Telecommunications (now MIC) revised the radio law according to the proposal of the Telecommunications Technology Council on general purpose DSRC system applications. The revision was proposed to and adopted by the ITU-R as the modified DSRC Recommendation ITU-R M.1453-1 in August 2002.

The maximum communication zone of DSRC is recommended to be within 30 m to promote effective use of frequencies by reducing the re-use distance of the RSE. FDD systems are also adopted to promote effective use of radio frequencies.

TABLE 8

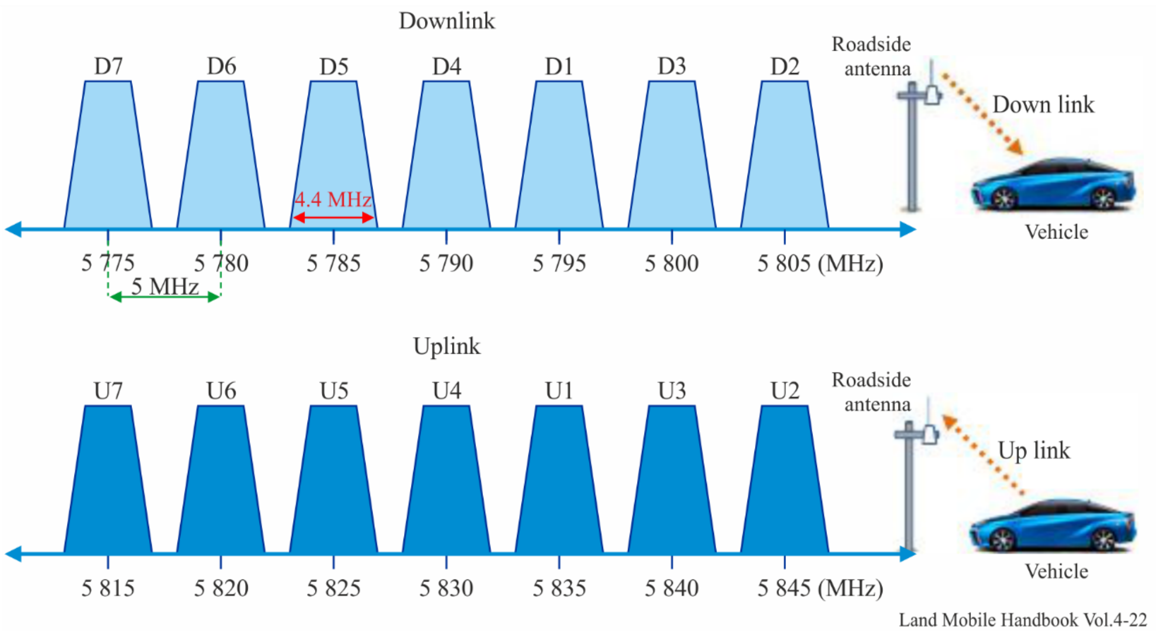
Characteristics of active (transceiver) method

Item	Technical characteristics
Carrier frequencies	5.8 GHz band for downlink and uplink
RF carrier spacing (channel separation)	5 MHz
Allowable occupied bandwidth	Less than 4.4 MHz
Modulation method	ASK, QPSK
Data transmission speed (bit rate)	1024 kbit/s/ASK, 4 096 kbit/s/QPSK
Data coding	Manchester coding/ASK, NRZ/QPSK
Duplex separation	40 MHz in case of FDD
Communication type	Transceiver type
Maximum e.i.r.p.	≤ +30 dBm (downlink) (For a transmission distance of 10 m or less. Power supplied to antenna ≤ 10 dBm)
	≤ +44.7 dBm (downlink) (For a transmission distance of more than 10 m. Power supplied to antenna ≤ 24.77 dBm)
	≤ +20 dBm (uplink) (Power supplied to antenna ≤ 10 dBm)

Figure 22 shows the channel arrangement of ITS applications using DSRC in the 5.8 GHz band in Japan.

FIGURE 22

Channel arrangement of DSRC for ITS applications in Japan in the 5.8 GHz band



4.1.3.4 China DSRC

The Chinese ETC System adopts the active (transceiver) method. Both RSE and OBE work in the 5.8 GHz band. There are two classes specified in the physical layer. Class A with ASK modulation should meet the basic requirement of ETC application. Class B with FSK modulation should meet the requirement of high-speed data transmission. Technical characteristics of downlink and uplink are shown in Tables 9 and 10 respectively.

TABLE 9

Technical characteristics of downlink for Chinese ETC system

Item		**Class A**	**Class B**
Carrier frequencies	Channel 1	5 830 MHz	5 830 MHz
	Channel 2	5 840 MHz	5 840 MHz
Allowable occupied bandwidth		≤ 5 MHz	≤ 5 MHz
Modulation method		ASK	FSK
Data transmission speed (bit rate)		256 kbit/s	1 Mbit/s
Data coding		FM0	Manchester
e.i.r.p.		≤ +33 dBm	≤ +33 dBm

TABLE 10

Technical characteristics of uplink for Chinese ETC system

Item		**Class A**	**Class B**
Carrier frequencies	Channel 1	5 790 MHz	5 790 MHz
	Channel 2	5 800 MHz	5 800 MHz
Allowable occupied bandwidth		≤ 5 MHz	≤ 5 MHz
Modulation method		ASK	FSK
Data transmission speed (bit rate)		512 kbit/s	1 Mbit/s
Data coding		FM0	Manchester
e.i.r.p.		≤ +10 dBm	≤ +10 dBm

4.1.3.5 Active DSRC in Korea

Background

In Korea, there was an increasing demand on transportation facilities and services because of rapid growth in the population and employment in the urban city. The Korean Ministry of Land, Infrastructure and Transport (MOLIT) announced the Advanced Transportation Systems deployment project, and it made a significant milestone to initiate ITS in Korea. In the fall of 2000, MOLIT chose Daejeon, Jeju Island, and Jeonju city as model city to deploy ITS systems. This project motivated public and private sector partners to develop ITS technology.

The Korean DSRC technology has been developed by the national project by the Ministry of Science and ICT (MSIT) from 1998 to 2000. In 2001, 5.8 GHz radio frequency band was assigned for ITS applications. It has two frequency bands: one band has 20 MHz (5.795~5.815 GHz) for public ITS and the other 20 MHz (5.835~5.855 GHz) for ITS operators.

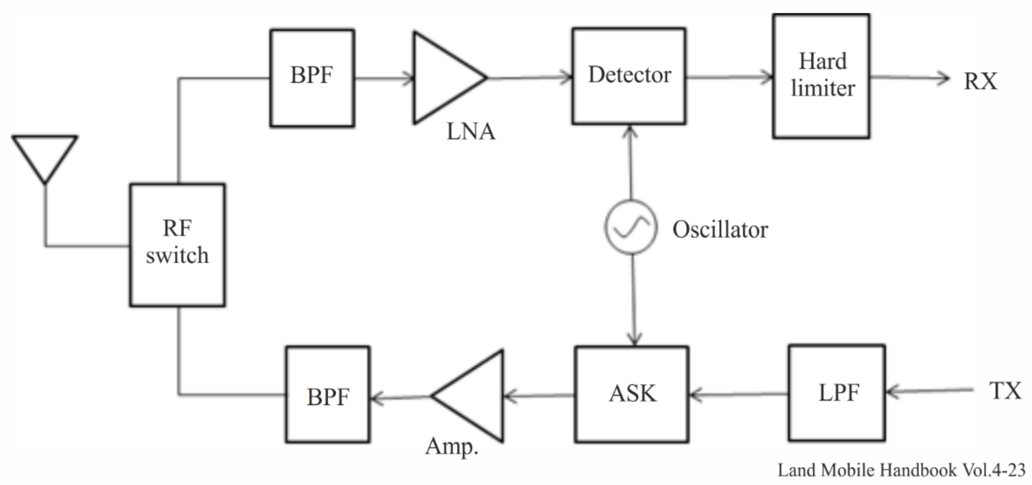
Korean DSRC technology has been applied for Electronic Toll Collection (ETC) and the Bus Information System (BIS). ETC is called as "Hi-Pass" service in Korea. Hi-Pass provides the automatic tolling service at highway toll plazas. Korean DSRC technology has been applied for BIS in urban cities. When the public bus arrives at a stop station, it is connected to the ITS centre via RSE and the wired network. The ITS centre will be able to detect the bus number and its location and send arrival and departure time to the stop station. The passenger will get the location and its status on bus driving. In 2004, Hi-Pass is commercialized, and its subscriber number was increased to over 10 million.

Technical characteristics

The Korean DSRC frequency band has 10 MHz channel bandwidth and 10 mW radiated power excluding antenna gain. It adopts a TDD scheme to use a single RF carrier in downlink and uplink access, which is more efficient in frequency use rather than an FDD scheme. TDD has an RF switch to select the transmitted signal or received signal. In the transmission part, the transmitted digital data is transformed into a modulated signal through Low Pass Filter (LPF) and Amplitude Shift Keying (ASK) modulation. In the reception part, the received RF signal is recovered by using an envelope detector and Hard Limiter as shown in Fig. 23.

FIGURE 23

OBU configuration of TDD DSRC scheme



Technical specification

The Korean DSRC has short radio coverage less than 100 m, and the allowable communication time is limited in the order of several hundred milliseconds. Thus, it must have a fast link setup and bi-directional communication in a vehicular driving condition. The transmitted data rate is 1.024 Mbit/s, and its data rate is doubled by Manchester coding, which is the encoding to transit either low then high, or high to low, for the bit time. Manchester coding helps clock recovery at the receiver. The RF power is 10 dBm (10mW).

TABLE 11

Korea DSRC communication technical specification

Item		**Radio characteristics**
Carrier frequencies	Channel 1	5.80 GHz
	Channel 2	5.810 GHz
RF Carrier spacing		10 MHz
Modulation method		ASK (Amplitude Shift Keying)
Data transmission speed		1.024 Mbit/s
Data coding rate		Manchester
The maximum RF power		10 dBm
Duplexing		TDD

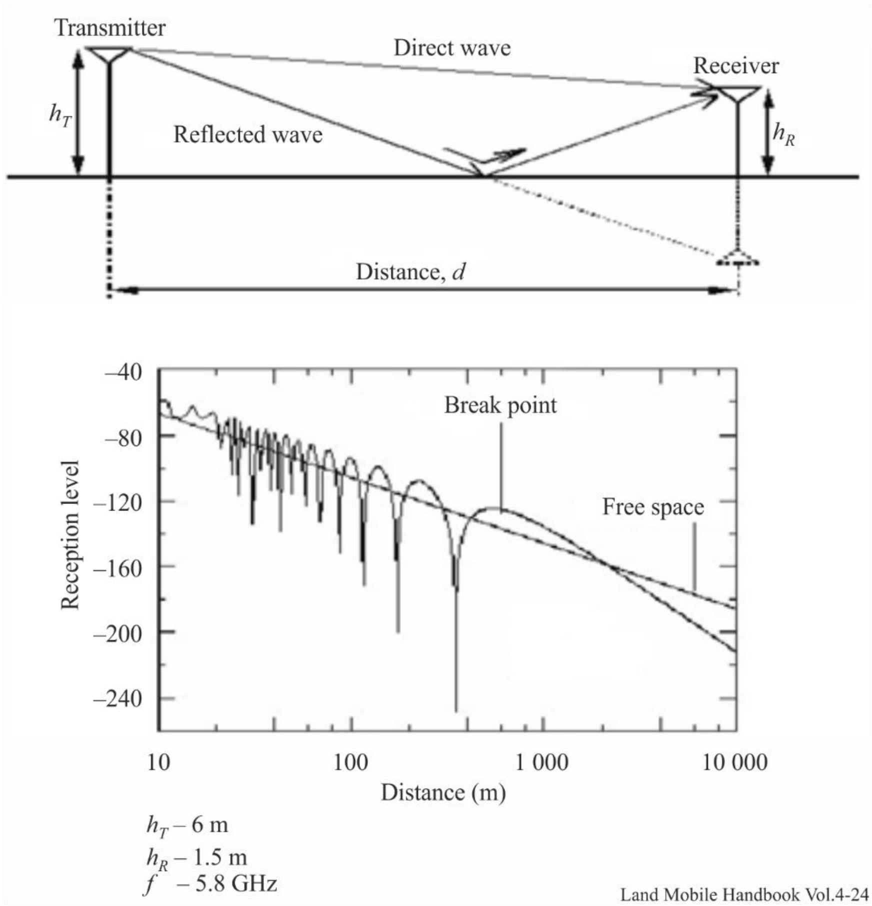
4.1.4 DSRC Radio propagation characteristics

Radio propagation

In DSRC radio propagation, ground reflection is the most important element to determine the reception characteristics at the receiver. Figure 24 shows the relationship between the direct and reflected paths and an example of the reception level at the receiver at a distance. The direct and ground-reflected waves may increase or decrease the reception level, depending on the difference ($\Delta_r = 2h_T h_R/d$) between the lengths of the direct and reflected paths. Since the direct and ground-reflected waves interfere constructively or destructively depending on the phase relation between the reflected and direct wave, the reception level at the receiver changes remarkably up to the break point ($d_{BP} = (4h_T h_R)/\lambda$, where λ is the wavelength) from where the reflected wave begins to cancel the direct wave permanently and the reception level decays more rapidly ($1/d^4$) than the free space level ($1/d^2$).

FIGURE 24

Two-ray propagation model



Three areas, characterized by the distance between the transmitter and receiver, are recognized:

- Area 1: Up to several tens of meters (typically up to 30 m)

  Though the theoretical reception level at the receiver changes with distance by the ground reflection, it can be mostly neglected, thanks to the directivity of the transmitter and receiver antenna. This area is most suited for DSRC applications.

- Area 2: From several tens of meters up to the break point

  The reception level at the receiver changes remarkably with distance, and the vehicles moving along the roadway experience rapid fading.

- Area 3: Beyond the break point

  The reception level decays rapidly ($1/d^4$). Vehicles moving along the roadway are subject to the most severe interference.

Reception level decays rapidly (*1 radio frequency assignment for ITS system* radio frequency assignment for ITS system $1/d^4$). Vehicles moving along the roadway are subject to most severe interference.

Radio propagation characteristics

Besides the characteristics of the two-ray propagation model described above, the following interference factors must be considered in an actual DSRC environment:

- Multipath fading: Multipath propagation due to scattering and reflection from the ground, buildings, and other vehicles leads to rapid fading in high-speed vehicles, see Fig. 25.

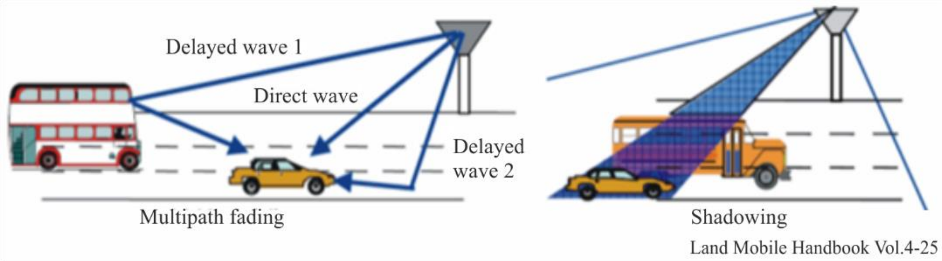
- Delay spread: When digital information to be sent is at a high data rate, the delay spread effects (distortion caused by time dispersion introduced by multipath channels) must be considered.

- Shadowing: Diffraction loss due to shadowing by large obstacles such as a bus causes a significant field-strength attenuation, see Fig. 25.

- Doppler effects: Particularly at high frequencies and at high vehicle speeds, the Doppler effects (distortion caused by frequency dispersion due to Doppler effects) may be considered.

FIGURE 25

Multipath fading and shadowing



4.2 Advanced ITS radio communication

4.2.1 Introduction

Advanced ITS radiocommunication is also dedicated short range communication to provide vehicle to vehicle communication (V2V) and vehicle to infrastructure communication (V2I) in a vehicular environment for safety applications. A V2V connection means peer-to-peer direct communication without connecting infrastructure and may be applied for vehicle safety application.

The existing DSRC is also dedicated short range communication to provide V2I connectivity in an ISM frequency band. However, Advanced ITS radiocommunication provides both V2I and V2V connectivity in a dedicated frequency band for safety applications. A comparison of the technical characteristics of DSRC (Korea) and Advanced ITS radiocommunication (WAVE) is given in Table 12.

V2V communication uses a distributed control access method because every OBU will be able to try to access the radio channel when the OBU has data to send. V2V communication uses distributed control access method to ensure every OBU will be able try to access the radio channel when the OBU has data to send.

North America Wireless Access in vehicular environment (WAVE) is the typical example of V2X communication. According to the WAVE specification, it meets a 100 ms packet latency and a 10% packet error ratio in a 300m radio range at a 200 km/h vehicle speed requirement for safety related systems Also, it meets data authentication and security, which are necessary because the safety message includes the vehicle location information. Other ITS use cases are supported by WAVE communications for ranges up to 1km. Table 12 provides a high-level comparison of DSRC and Advanced ITS radio communication.

TABLE 12

Technical characteristics comparison of DSRC and Advanced ITS radio communication

Item	DSRC	Advanced ITS radio communication
Frequency Band	ISM	Dedicated frequency band
Connectivity	V2I	V2I and V2V
Duplexing	FDD, TDD	TDD
Modulation	ASK	OFDM[9]
Data transmission speed	1.024 Mbit/s	Maximum 27 Mbit/s[10], 6 Mbit/s typical for safety-related communications in deployed systems
Maximum RF Power	10 dBm	Maximum 44 dBm (40 Watt), 20 mW typical for safety-related deployed systems
Data Latency	Low	Less than 100 ms
Radio coverage	Less than 100 m	Maximum 1000 m, 300 m omnidirectional coverage at 10% maximum packet error ratio typical requirement for safety-related deployed systems

Advanced ITS radiocommunication technology also has a fast link setup and termination for vehicle safety and C-ITS applications. Advanced ITS radiocommunication provides improved performance over the existing DSRC communication in terms of packet latency, data rate, and radio coverage. Advanced ITS radio communication has the following features:

– Packet data communication by using V2I or V2V connection

– Fast link setup and link termination in a spot zone

– Reliable communication in a vehicular environment

– Data authentication and security.

4.2.2 System configuration

The advanced ITS radio communication system consists of on-board equipment (OBE) and roadside equipment (RSE) as shown in Fig. 26. OBEs are the vehicle side radio units, and RSEs are the roadside radio units which is the same terminology used for DSRC communication. The RSE is connected to the ITS centre through an IP network which may use wired or wireless infrastructure.

Advanced ITS radio communication uses a distributed channel access scheme because every OBE will be able to try to access the radio channel at any time that it needs to send a message.

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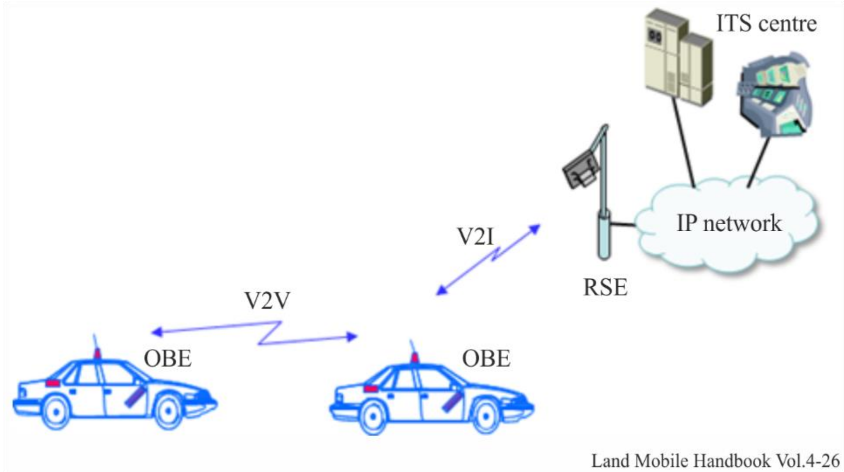
9 IEEE Std. 802.11™-2016, p 2303, Chapter 17.

10 IEEE Std. 802.11™-2016, p 2303, Table 17-16 for a 10 MHz channel.

FIGURE 26

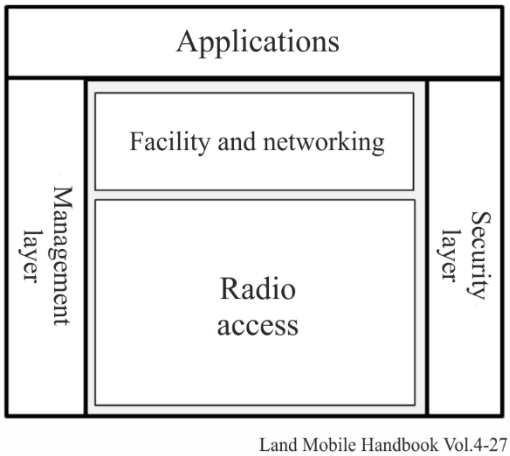
Advanced ITS radiocommunication system



The OBE and RSE have system reference models with a radio access layer, facility and networking and application layer, as shown Fig. 27. The radio access layer will support V2X radio connections among vehicles and RSEs. Facility and networking provides contextual information on vehicle and road status in real time (for example, Local Dynamic Map). It supports IP networking or non-IP networking. The management and security layers are connected to the radio access layer, facility and networking, application layer for system initialization and management, ID authentication and data security.

FIGURE 27

V2X communication reference model for advanced ITS



4.2.3 Technical characteristics

4.2.3.1 European ITS G5

Background

Cooperative ITS communication (C-ITS) is based on standardized and interoperable wireless ad-hoc communication systems. The interoperability must be guaranteed at least in the different worldwide regions. This interoperability requirement does not imply the use of exactly the same system in all regions, e.g. C-ITS in Europe in 5.9 GHz is mainly based on IEEE 802.11p and ETSI ITS-G5, whereas the US implementation in 5.9 GHz is based on the slightly different IEEE 802.11p and WAVE system as described above. For these technologies, the standards are finished, intensive testing and validation has taken place, first implementations are done, and deployment is underway. Most of the actual discussed systems are based on a well-established access layer (PHY-layer and MAC-layer) standardized by IEEE802 as IEEE802.11p, which is now integrated as part of the IEEE802.11TM-2016 set of standards.

In certain countries, a frequency band in the range between 5 850-5 925 MHz (up to 75 MHz bandwidth), consistent with Recommendation ITU-R M.2121-0 (01/2019) – Harmonization of frequency bands for Intelligent Transport Systems in the mobile service, has been chosen as the main band of operation for the upcoming traffic-safety related C-ITS deployments. In addition, the frequency band 63.72-65.88 GHz has been designated for traffic safety related applications under the Mobile Service in CEPT.

Worldwide a broad range of standardization organizations are involved in the standardization of C-ITS. The main actors with a strong support from the automotive industry are the US activities around IEEE/WAVE/SAE and the European activities around ETSI TC ITS. These activities are backed by industry consortia CAMP (Crash Avoidance Metric Partnership) in the US and the C2C-CC (CAR-to-CAR Communication Consortium) in Europe.

The C2C-CC as an industry driven, non-profit association of 16 European vehicle manufacturers, 37 suppliers and 28 research organisations, dedicated to realizing cooperative road traffic and herewith increase traffic safety, efficiency, and driving comfort. The C2C-CC plays an important role in the development of European standards for C-ITS and cooperates closely on C-ITS with the CAMP consortium in the US. To align and harmonize the C-ITS roll-out in vehicles and traffic infrastructure in Europe by 2019, the consortium engaged with the Amsterdam Group. This is a strategic alliance of the CAR 2 CAR Communication Consortium, the ASECAP (Association of operators of toll road infrastructures), CEDR (Conference of European Directors of Roads), and POLIS (European Cities and Regions Networking for Innovative Transport Solutions). Furthermore, the consortium actively contributes to the work of the C-ITS Deployment Platform organized by the European Commission.

The C2C-CC participated in the initial design of vehicle-to-vehicle communications technologies through the publication of a manifesto. It also helped to validate C-ITS by getting involved in FOT (Field operational tests) and ongoing cross-border C-ITS corridor projects, and focusing on interoperability testing.

In 2007, the CAR 2 CAR Communication Consortium published the Manifesto on its website[11]. The document built the basis for the first interoperability demonstration shown in 2008 at the Opel test site in Dudenhofen.

The document describes the C-ITS scenarios for improving safety and traffic efficiency as well as using the communication system for infotainment and other purposes. From the scenarios, the system

[11] https://www.car-2-car.org/documents/basic-system-profile/

prerequisites and constraints are derived, and the system architecture developed. The architecture describes the communication principles, the individual components, the layers' architecture and related protocols. The further chapters describe the applications, the radio and communication system as well as data security and privacy.

The document specifies the standard profile that enables interoperability of C-ITS units. The first Basic System Profile (BSP) version was released for C2C-CC internal usage by end of the end of 2014. The latest revised BSP version was shared with the members of the consortium and public in 2020 and is kept updated[11]. It contains a system specification complemented by a selection of standards and parameters. It allows to test the aspects that are going to be used by "day one" applications.

Technical characteristics

ETSI ITS-G5 has been specified in the ETSI Technical Committee ITS (Intelligent Transport Systems). The basic system is fully harmonized with the US V2X (WAVE) system as described in earlier sections.

ETSI ITS-G5 has been developed as a full ad-hoc system not relying on any fixed network components like access points, base station, or other infrastructure components. Nevertheless, the deployment of infrastructure based on the ETSI ITS-G5 standards as part of the ad-hoc network can enhance the operational capabilities by introducing infrastructure-based information.

ITS applications depend upon high reliability and low latency communication, as well as and Distributed Congestion Control (DCC), which maintains network stability, throughput efficiency, and fair resource allocation by using Transmit Power Control (TPC) and adjustment in data rate and packet rate.

The frequency band 5 855-5 925 MHz for ITS applications is split into channels with a bandwidth of 10 MHz. The maximum spectral power density for ITS stations should be limited to 23 dBm/MHz e.i.r.p. but the total power should not exceed 33 dBm e.i.r.p. with a Transmit Power Control (TPC) range of 30 dB. The CEPT has designated the lower 20 MHz of the frequency band for non-traffic safety related ITS applications such as enhancing traffic-efficiency, while the upper 50 MHz of the frequency band is designated for traffic-safety related ITS applications such as time critical status information exchange whose aim is to reduce the number of traffic fatalities or accidents using communications between ITS stations. The frequency channel assignment of the ITS system is summarized in Table 13 containing the V2V and V2I communication for road ITS. In CEPT and EU is an additional 10 MHz from 5 925-5 935 MHz designated for urban rail ITS which is not in the scope of this Report.

TABLE 13

Frequency channel assignment of ITS

Application	Regulation	Frequency range (MHz)	Deployment or plan year
V2V and V2I communication	CEPT: ECC/REC/(08)01 EU: (EU) 2019/1345	5 855 to 5 865	
		5 865 to 5 875	
Traffic-safety related ITS, V2V and V2I communication	CEPT: ECC/DEC/(08)01 EU: (EU) 2020/1426	5 875 to 5 885	Deployment of infrastructure in some member states since 2016[12], deployment of vehicles in 2019[13]
		5 885 to 5 895	
		5 895 to 5 905	
		5 905 to 5 915	
		5 915 to 5 925	
Traffic-safety-related ITS, V2V and V2I communication	CEPT: ECC DEC (09)01 EU: (EU) 2019/1345	63.72-65.88 GHz	

Technical specification

The ETSI ITS-G5 systems specify a protection mechanism for the protection of ETC systems based on CEN-DSRC operating in the band 5 795 MHz to 5 815 MHz. These mechanisms and restrictions optimize the smooth coexistence of the two systems operating in a close vicinity.

Furthermore, ETSI ITS-G5 systems must implement a congestion control mechanism in order to guarantee a smooth operation under high channel load conditions. This mechanism has been defined in ETSI TS 103 175.

The main transmitter characteristics of ETSI ITS-G5 are shown in Table 14. The transmitter spectrum mask for 10 MHz channel bandwidth for ETSI ITS-G5 is shown in Table 15.

TABLE 14

Main transmitter characteristics

Parameter	Value	
Emission 3 dB bandwidth (MHz)	10 MHz	
Power (Peak) (dBm) e.i.r.p.	33 dBm	
Power spectral density dBm/MHz e.i.r.p.	23 dBm/MHz	
Data rate	3, 4.5, 6, 9, 12, 18, 24 and 27 Mb/s	
Modulation parameters	Modulation: BPSK, QPSK, 16-QAM, 64-QAM	Coding Rate: 1/2, 3/4, 2/3
Azimuth off-axis antenna pattern	Vehicles – omnidirectional (360^0); sectorized antennas sometimes used with Infrastructure ETSI-ITS-G5 transmitter antennas	

12 https://www.c-roads.eu/platform.html

13 https://www.volkswagenag.com/en/news/2017/06/pwlan.html

TABLE 15

Transmitter spectrum mask for 10 MHz channel bandwidth according to ETSI EN 302-571 v2.1.1

Carrier frequency f_c (dBc)	±4.5 MHz offset (dBc)	±5.0 MHz offset (dBc)	±5.5 MHz offset (dBc)	±10 MHz offset (dBc)	±15 MHz offset (dBc)
0	0	−26	−32	−40	−50

4.2.3.2 North America WAVE

Background

WAVE is a dedicated mobile radio communication system for providing non-voice communications among vehicles that travel on roads, rails, or other dedicated facilities; as well as between those vehicles and the transportation infrastructure. WAVE is therefore a fundamental technology for ITS communications, helping link roads, traffic and vehicles covered by ITS deployment with coordinated, interoperable information technology. This particular wireless technology could be transformational to the evolution of transportation systems, since it provides very localized and low latency communications capabilities on a peer-to-peer basis. These capabilities are intended to support the planned, as well as the still unforeseen, data needs of the evolving, more automated and future transportation system. WAVE systems specifically utilize the broadcast mode of operations as the primary means to support public benefits; and also communicate using two-way communications between vehicles and infrastructure, including the ability to provide lower priority messages related to the specific units involved in a variety of public and private transportation environments.

WAVE is being pursued in the United States "to improve traveller safety, decrease traffic congestion, facilitate the reduction of air pollution, and help to conserve vital fossil fuels"[12], and as a particular focus in the United States, to reduce highway fatalities[7]. Although not yet widely deployed, the United States has developed multiple applications, a number of which have been tested in large-scale field tests or operated in model deployments[13] This progress has provided the United States with extensive knowledge of these applications that contribute to transportation safety, mobility, and environmental stewardship in the context of advanced ITS. The WAVE ITS applications are designed to perform operations related to the improvement of traffic safety and traffic flow, as well as other intelligent transport service applications, including enhancing transportation systems efficiencies and operations (for example, facilitating roadway freight movements or transportation management during emergency responses). The main points of focus for the US deployment of advanced ITS applications

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[12] Federal Register, Volume 64, Issues 225-227, page 66405.

[13] "Collaborative Connected Vehicle Research Update" (https://www.its.dot.gov/presentations/CV_PublicMeeting2013/PDF/Day1_LukucInteroperability.pdf) at 10-12; "Safety Pilot Model Deployment: Lessons Learned and Recommendations for Future Connected Vehicle Activities" (https://rosap.ntl.bts.gov/view/dot/4361) at 11-12; "CV Applications Already Deployed by Responding Agencies (http://transops.s3.amazonaws.com/uploaded_files/V2I%20DC%20TWG%201%20-%20January%2028%2C%202016%20Webinar%20Slides%20V3.pptx) at 30; "Maricopa County Department of Transportation (MCDOT) SMARTDriveSM Program" (https://www.maricopa.gov/640/Connected-Vehicles-Program); "Connected Vehicle Pilot Deployment Program Phase 1: Concept of Operations (ConOps) – New York City" (https://rosap.ntl.bts.gov/view/dot/30881) at 36; "Connected Vehicle Pilot Deployment Program: ICF/Wyoming Concept of Operations" (http://www.its.dot.gov/pilots/pdf/ICF_ConOpsWebinar_02042016.pdf) at 34.

using WAVE communications include: transportation safety, nationwide interoperability; long-term technical stability; voluntary industry standards; and support for public benefits.

Technical characteristics

On-board equipment (WAVE OBE): The OBE consists of communications and processing equipment installed in vehicles to enable WAVE communications with other vehicles and infrastructure, and support WAVE-enabled applications. OBEs may be most effective when integrated into the vehicle and able to interface with other on-board equipment such as the vehicle's sensor suite, anti-lock braking system, and other subsystems, allowing it to complement these existing systems.

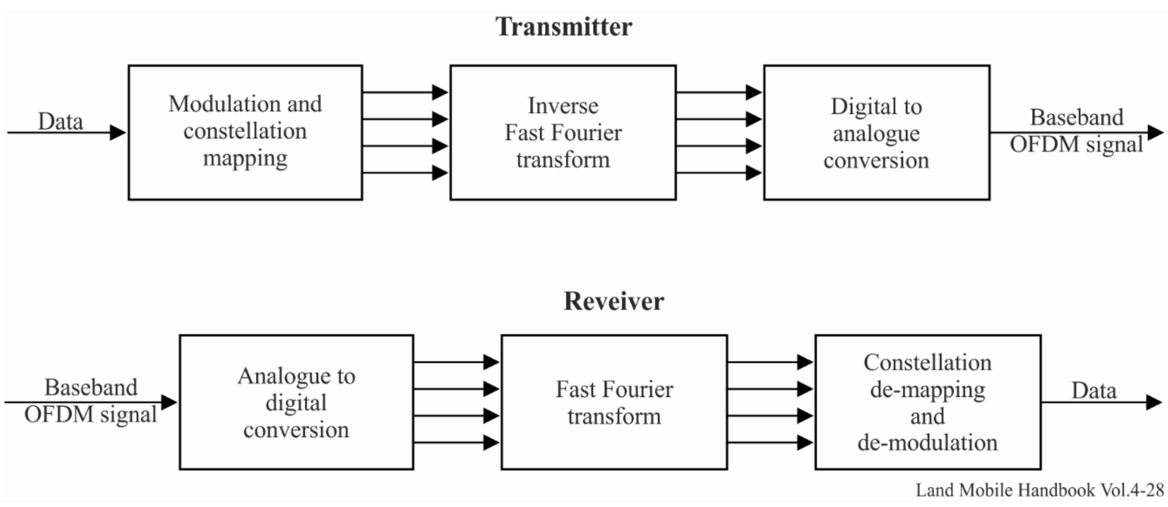
Roadside unit (WAVE RSU): A WAVE RSU is installed above or alongside the road or other infrastructure and communicates with passing OBEs by the use of radio signals. An RSU consists of radio communication circuits, an application processing circuit, and related equipment. It may have data linkages to traffic management centres (TMCs) and to other roadside equipment (such as traffic signal controllers), as well as to the Internet to exchange data and to maintain security credential information.

The WAVE systems operate by transmitting radio signals for the exchange of data among vehicle-mounted OBEs, and between OBEs and infrastructure-based RSUs. By adhering to requirements set by industry standards, these systems accomplish a data exchange that ensures that data is interoperable across a wide range of device and application manufacturers. Interoperability is key to support the rapid, standardized adoption of applications that deliver critical safety related, system and operational efficiencies, and other public benefits.

Much of the information to complete the following tables comes from standard 802.11-2016. The modulation used for WAVE is 'half-clocked' OFDM on 10 MHz channels. Figure 28 is basic OFDM transmitter and receiver block diagram.

FIGURE 28

WAVE transmitter and receiver



WAVE applications may have access to each of the seven 10 MHz channels on a dynamic assignment basis under the direction of the control channel as shown in Table 16, but do not use the 20 MHz combined channels, designated as Channels 175 and 181 in the Table. This band plan provides dedicated channels for crash-imminent safety-related (Channel 172) and high-powered public safety-related (Channel 184) applications, as well as flexible assignment of other service channels through the control channel mechanism to support the wide range of advanced ITS WAVE applications. Many applications will only partially use a particular assignable channel at a particular time and location, permitting sharing among WAVE applications on individual assignable service channels.

Safety-related applications which are not pre-assigned to the dedicated channels typically use the control channel to transmit very short, infrequent messages, or else use WAVE Service Announcements (WSA) on the control channel to indicate a service channel upon which to communicate, if those messages are less dependent upon having very low latency. Lower priority messages typically use WSAs on the control channel to be assigned to a service channel which is not fully occupied by safety-related communications at that location at that time. This flexible designation of application messages to different service channels in various locations facilitates spectral efficiency and reduces interference among WAVE applications.

TABLE 16

Band plan for WAVE in the United States

5.850 GHz							5.925 GHz
		CH175			CH181		
5 850-5 855 Reserve 5 MHz	CH172 service 10 MHz	CH174 service 10 MHz	CH176 service 10 MHz	CH178 control 10 MHz	CH180 service 10 MHz	CH182 service 10 MHz	CH184 service 10 MHz

Note – This band plan may need to be revised if regulatory changes occur as a result of ongoing regulatory proceedings in the United States.

Technical specification

TABLE 17

Transmitter characteristics

Parameter	Value	
Emission 3 dB bandwidth (MHz)	10 MHz	
Power (peak) (dBm)	23 to 44.8 dBm e.i.r.p. (depending on channel used, RSU or OBE and government or private); also, transmissions shall use only the power necessary to support the particular application	
Emission spectrum (relative attenuation (dB) as a function of frequency offset from centre frequency (ΔF) (MHz))	Attenuation	ΔF
	See Fig. 29	See Fig. 29
Data rate	6 Mb/s	

TABLE 17 *(end)*

Parameter	Value	
Modulation parameters	Modulation QPSK	Coding Rate 1/2
Azimuth off-axis antenna pattern	Vehicles – omnidirectional (360^0); sectorized antennas sometimes used with Infrastructure WAVE transmitter antennas	
Elevation off-axis antenna pattern	−6 to +10 degrees – vehicles infrastructure – implementation dependent	
Antenna height (meters)	1.5-15 m	
Antenna polarization	Primarily vertical (some right-hand circular)	

TABLE 18

Maximum STA transmit power classification for the 5 850-5 925 MHz band in the United States

STA transmit power classification	Maximum STA transmit power (mW)	Maximum permitted e.i.r.p. (dBm)
A	1	23
B	10	33
C	100	33
D	760 Note that for this class higher power is permitted as long as the power level is reduced to this level at the antenna input and the emission mask specifications are met.	33 for non-government 44.8 for government

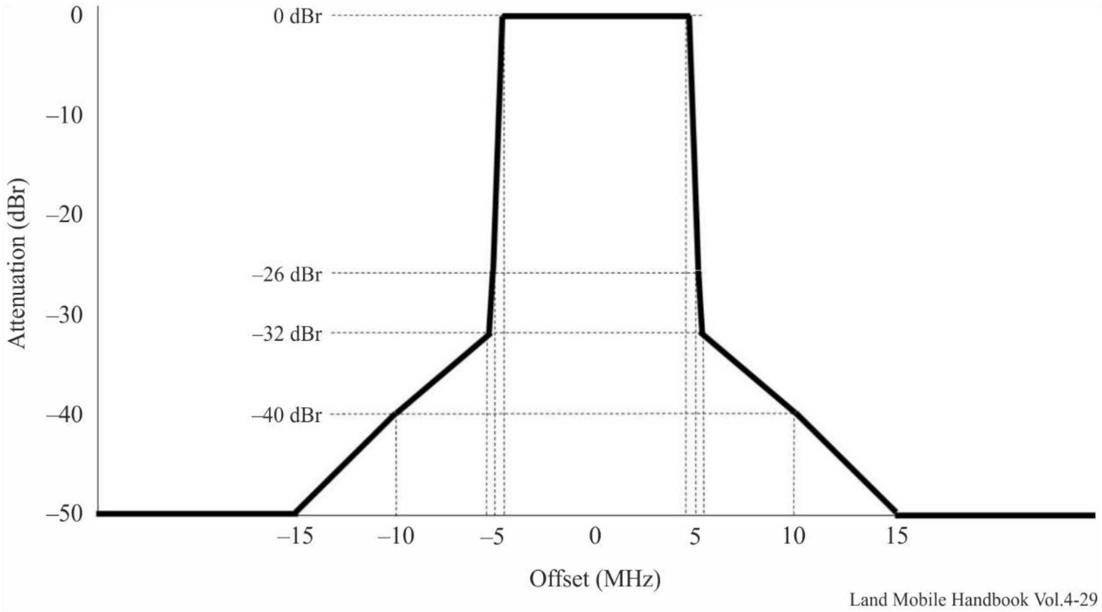
TABLE 19

Spectrum mask data for 10 MHz channel spacing

STA transmit power class	Permitted power spectral density (dBr)				
	±4.5 MHz offset (±*f*1)	±5.0 MHz offset (±*f*2)	±5.5 MHz offset (±*f*3)	±10 MHz offset (±*f*4)	±15 MHz offset (±*f*5)
Class A	0	−10	−20	−28	−40
Class B	0	−16	−20	−28	−40
Class C	0	−26	−32	−40	−50
Class D	0	−35	−45	−55	−65

FIGURE 29

Transmit spectrum mask for 10 MHz OBE transmission (Class C typical)



4.2.3.3 Japan ITS connect

Background

In Japan, ITS Connect uses 755.5-764.5 MHz. The centre frequency is 760 MHz. If ITS Connect would be used in another country, and, for example, when a band lower than 1 GHz band will be assigned, performance of communication distance on NLOS/LOS is similar with 760 MHz, the system may be able to provide similar road safety and environmental effects.

Technical characteristics

ITS Connect is configured using roadside units (RSUs) and On-board equipment (OBE). Basic functions of ITS Connect are the following:

– Conveyance and exchange of information that contributes to reducing the number of traffic accidents.

– Conveyance and exchange of information that contributes to assisting safe driving.

– Conveyance and exchange of information that contributes to smoothing traffic flow.

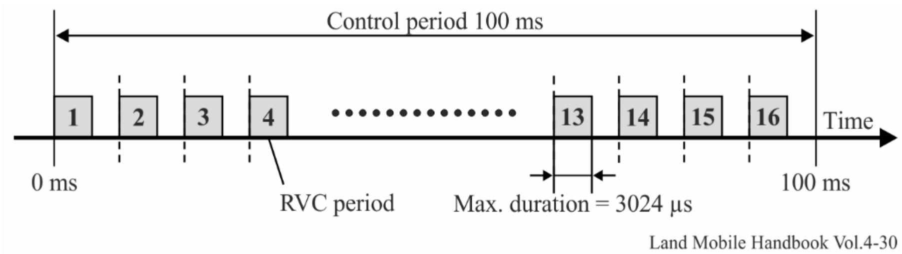
The OBE is installed inside the vehicle. The OBE performs radio communication with the RSUs or other OBEs. The radio equipment of the OBE is composed of a transmitter, receiver, controller, antenna, etc. The OBE sends vehicle information (such as position, speed, direction, and so on). The OBE receives signals from other OBE and RSUs. Then the vehicle can know the position and situation of other vehicles, and can provide adequate information or behaviour to the driver for assisting safe driving.

The RSU performs radio communication with OBEs or the other RSUs. The radio equipment of the RSU is composed of a transmitter, receiver, controller, antenna, etc. The RSU is installed at roadside (mainly at junctions). One of the use cases of Infrastructure to Vehicle (I2V) is to broadcast traffic signal information. For this use case, the RSU connects to the traffic signal control centre. Another use case of I2V is to broadcast information about vehicles and pedestrians when there is a pedestrian crossing around a junction where the RSU is installed. A sensor detects the vehicle and pedestrian, and the sensor transfers the information to the RSU.

All RSU and OBE share one RF channel. A time slot is divided into V2V communication periods and I2V communication periods, then the RSU and OBE can share the frequency without mutual interference. Figure 30 shows the sharing mechanism. The RSUs and OBEs carry out communications normally in a cycle of 100 ms. In Fig. 30, the RSU can use the grey period. If the RSU does not use all 3024 microseconds, the OBE can use the time for V2V communication.

FIGURE 30

RSU transmitting periods



In order to avoid collisions between OBE to OBE transmissions, a CSMA/CA protocol is used.

Technical specification

ITS Connect uses one RF channel OFDM modulated signal. The occupied bandwidth is 9 MHz or less. Most OFDM parameters are the same as in IEEE 802.11p. The modulation and coding method is described in Table 20. The transmission data rate is 5 Mbit/s or more.

TABLE 20

Specification of the modulation and coding method

Item	Parameter
Frequency band	755.5-764.5 MHz (single channel)
Channel selection	Not required (fixed)
Error correction	Convolution FEC R=1/2, 3/4
Modulation	BPSK/OFDM, QPSK/OFDM, 16QAM/OFDM

These regulations are defined for co-existence between ITS Connect that uses 755.5-764.5 MHz and adjacent channel systems (LTE, Digital TV, radio microphone, and so on).

The reception sensitivity is the same as in IEEE 802.11p. In this system, BPSK, QPSK and 16QAM of 10 MHz channel spacing are selected. Transmitting power for the operating frequency band is 10 mW or less per 1 MHz bandwidth on average.

4.2.3.4 V2X communication technology in Korea

Background

The national Vehicle Multi-hop Communication (VMC) project on Korea V2X communication technology was started in the year 2007, and V2X communication technology development primarily aims to meet the American WAVE standard.

In 2009, the Smart Highway project has been launched to develop OBE and RSE and has been tested on the highway from Seoul Toll Gate to Suwon IC. In 2014, C-ITS pilot test was started, and 3,000 OBE and 79 RSE have been installed to verify 15 applications in highway, suburban, and urban roads.

In 2016, the Ministry of Science and ICT assigned the 5.855-5.925 GHz frequency band for the C-ITS applications and technical specification. In 2018, the Ministry of Land, Infrastructure, and Transportation decided to deploy the C-ITS system on the highway, in Seoul city, and in Jeju Island.

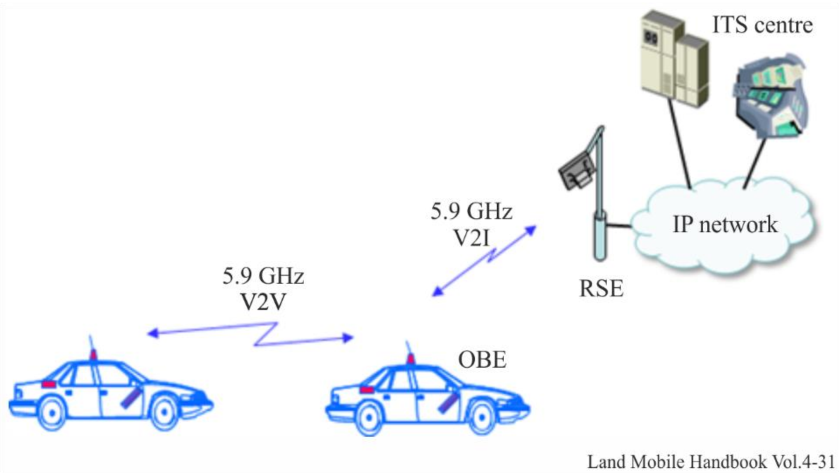
Technical characteristics

The Korean V2X communication system uses a 5.9 GHz dedicated frequency band for C-ITS and vehicle safety applications. It shall support 1 km radio coverage and 100 ms latency in V2V and V2I communication.

The Korean V2X communication system can use 1 control channel and SIX service channels. The control channel is used to make an initial link connection or transmit safety related messages. It must support multi-channel operation to do physical channel switching between the control channel and service channel.

FIGURE 31

V2X communication system configuration



Technical specification

TABLE 21

V2X communication specification

Items	Specification
Frequency band	5.855~5.925 GHz (7 channels)
Channel bandwidth	10 MHz
Latency	Less than 100 ms
Modulation	OFDM (BPSK, QPSK, 16QAM, 64QAM)
Data rate	3, 4.5, 6, 9, 12, 24, 27 Mbit/s
MAC	CSMA/CA

4.2.3.5 ITS in Brazil

Brazil considers important the emergence of vehicle connectivity solutions to mobile communications networks in urban, rural and highway environments, for sending and receiving data and information to aid in driving traffic, traffic conditions and preventive maintenance of the vehicle.

The requirements for ITS communications in Brazil are included in the regulation governing the technical requirements for conformity assessment of restricted radiation radiocommunication equipment, which includes systems for data communication between vehicles and between vehicles and road infrastructure. The characteristics for use of ITS in Brazil are based on the standard ETSI EN 302 571, covering the use of radiocommunications equipment operating in the 5 855-5 925 MHz frequency band, divided in blocks of 10 MHz.

TABLE 22

Band plan for ITS in Brazil

Channel number	Frequency range (MHz)
1	5 855-5 865
2	5 865-5 875
3	5 875-5 885
4	5 885-5 895
5	5 895-5 905
6	5 905-5 915
7	5 915-5 925

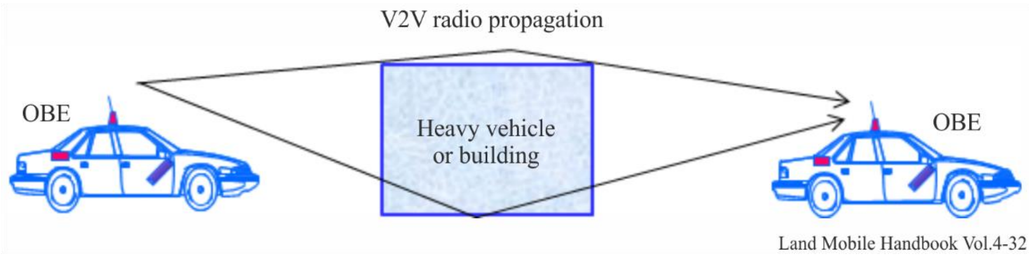
For V2V and V2I communications using the 5.9 GHz frequency band, the maximum EIRP power is 23 dBm (200 mW). For high power communications of vehicle-to-infrastructure, a maximum EIRP of 26 dBm (400 mW) is permitted. Channels 5 to 7 are limited to traffic and vehicle safety applications.

4.2.4 Radio propagation characteristics

Advanced ITS radio communication has both V2V and V2I radio channels. The V2V and V2I radio channels must consider the different environments, for example, urban, rural, and highway roads. V2V radio channel may have LOS or NLOS fading characteristics because there are radio blockings such as heavy busses or buildings in an urban area. Practically, a V2V radio channel has NLOS multipath fading channel with delay spread and Doppler shift.

FIGURE 32

NLOS V2V radio channel



Delay spread means time delay statistics of the arrived radio signal in the time domain, and Doppler shift is frequency shift statistics of the arrived radio signal in the frequency domain. Delay spread is determined by the radio range, and Doppler shift depends on the relative speed of two vehicles communicating with each other.

There has been a V2V radio channel study on 5.9 GHz V2X communication which tested the delay spread and Doppler shift under the conditions of 1 km radio coverage and 108 km/h vehicle speed.

The delay spread is less than 1.5 μs, and the maximum Doppler spread is approximately 1.53 kHz. Table 23 shows the delay spread and Doppler shift in urban, rural, and highway environments.

TABLE 23

V2V radio channel characteristics

Radio channel parameter	Urban	Rural	Highway
Maximum delay spread (μs)	0.6	1.5	1.4
Doppler shift (kHz)	0.583	1.11	1.53

4.3 Cellular V2X communication

4.3.1 Introduction

Cellular communication is bi-directional communication to provide user applications in a wide area. It has multi-cell architecture and may support human voice, data, and video. Cellular communication is continually evolving towards performance improvement in terms of data rate and latency.

The 1st generation (1G) cellular technology only provides human voice calling by means of FDMA, and the 2nd generation (2G) cellular technology may provide both digital voice and data by using a digital radio access scheme, such as TDMA and CDMA. The 3rd generation (3G) cellular technology may provide digital voice, data, and video communication by using CDMA. The 4th generation (4G) cellular technology may provide All-IP based multimedia by using OFDMA. Also, the state-of-the-art 5G generation (5G) cellular technology may provide 3D multimedia by using New Radio (NR) access technologies.

In the 4th generation cellular communication standards, LTE V2X and LTE eV2X were developed to provide V2X connectivity for ITS applications such as vehicle safety and automated driving. They may be used to set up dedicated communication networks for ITS applications. They have the following technical characteristics:

– Packet data communication by using V2I, V2V and V2P connection

– Reliable communication in 500 km/h high mobility

– Distributed access and centralized access.

TABLE 24

Technical characteristics on cellular communication technologies

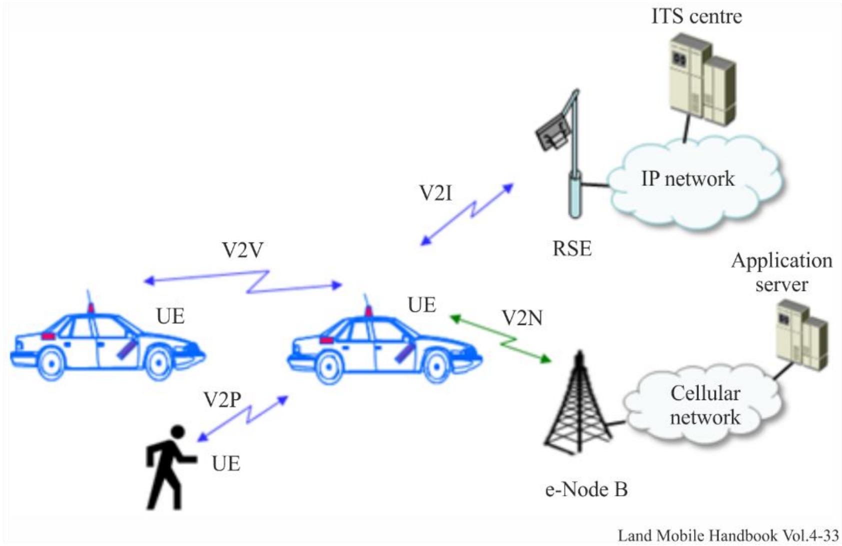
Item	**1G**	**2G**	**3G**	**4G**	**5G**
Radio access standard	Analogue AMPS	Digital (GSM, CDMA)	IMT-2000 (WCDMA)	IMT Advanced	IMT-2020
Radio access method	FDMA	TDMA, CDMA	CDMA	OFDMA	Scalable OFDM-based numerology
Maximum data rate	–	64 kbit/s	2 Mbit/s	100 Mbit/s	10 Gbit/s
Frame size	20 ms	20 ms	10 ms	5 ms	1 ms
Applications	Analogue voice	Digital voice, data	Digital voice, data, video	IP-based Multimedia	Broadband, Massive IoT, ULCC

4.3.2 System configuration

LTE V2X and eV2X cellular communication networks consist of User Equipment (UE), base station e-Node B, and Road Side Equipment (RSE). A UE may provide V2V, V2P, V2I, and V2N. V2I provides connectivity to ITS dedicated network via RSE. V2N provides connectivity to the application server via e-Node B.

FIGURE 33

Cellular V2X communication system



In the case of V2V, V2I and V2P applications, the User Equipment (UE) may be connected in a dedicated, distributed V2X peer-to-peer communication arrangement. If so, the frequency band used will be harmonized with the 5.9 GHz frequency band recommended for ITS applications.

V2N connectivity is provided by a cellular operator, and its frequency band will be managed by the cellular operator. The radio frequencies from 1st generation to 4th generation cellular technology are 450 MHz, 800 MHz, 10.8 GHz, and 2.1 GHz, while the 5th generation cellular technologies may use the 3.5 GHz and 28 GHz millimetre frequency bands, for example.

Therefore, LTE based V2X supports working scenarios with or without relying on cellular network coverage or deployment. In terms of specific communication technologies, LTE based V2X encompasses two interfaces (as shown in Fig. 34) which are called the Uu interface (cellular communication interface) and the PC5 interface (direct communication interface) respectively. The Uu interface can be used under a cellular network when a terminal device (such as an on-board terminal, smart phone, or RSU) supporting LTE based V2X services is covered by the cellular network. Whether there is cellular network coverage or not, the PC5 interface can be used for V2X communication. This combination of mutually supportive interfaces for V2X services provides communication choices, depending upon the communication requirements of the specific V2X applications, including, for example, latency, range and reliability requirements.

PC5 interface

The PC5 interface mechanism design, based on LTE-D2D technology, has been enhanced in many aspects, in order to support the broadcast of V2X messages (especially V2V messages), the exchanges of fast-changing dynamics (such as location, speed, and driving direction), and potentially autonomous driving applications in the future, including vehicle platooning and sensor sharing.

The physical layer is augmented to support the relative moving speed of up to 500 km/h in the high frequency band and solve the problem of high Doppler frequency spread and fast time-varying channels.

To ensure communication performance, LTE based V2X receivers and transmitters need to be synchronized with each other during communication. C-V2X enables the synchronization from different sources including GNSS, base stations, and vehicles. The terminal can obtain optimal synchronization sources through network control or retrieval of pre-configured information to achieve the possible network-wide synchronization. Moreover, LTE based V2X supports the dynamic maintenance of optimal synchronization sources, which allows the terminal to select the most prioritized source in a timely manner for clock synchronization.

As the core key technology of LTE based V2X, the PC5 interface supports the modes of scheduled resource allocation (Mode-3) and autonomous resource allocation (Mode-4). In addition, LTE based V2X adopts a centralized-distributed combined congestion control mechanism, which can markedly increase the number of users accessing the system in high-density scenarios, but with less frequent access distributed per user.

Uu interface

In order to better match the characteristics of V2X services, the uplink, downlink and multi-access edge computing (MEC) enhancements have been made to the Uu interface.

The uplink transmission supports multi-way semi-static scheduling based on service characteristics, which significantly reduces the uplink scheduling delay under the premise of high service transmission reliability. The downlink transmission has the features of small-range broadcast, low-latency single-cell point-to-multipoint (SC-PTM) transmission, and multicast / broadcast single-frequency network (MBSFN) for local communication of V2X services. In addition, LTE based V2X supports the localized deployment of core network elements and defines the quality of service (QoS) parameters for V2X services to ensure service transmission performance.

MEC has been integrated into LTE based V2X to support the Internet of Vehicles (IOV) services (such as autonomous driving, and real-time high-resolution map downloading) that demand ultra-low latency and ultra-reliable transmission. At present, the European Telecommunications Standards Institute (ETSI) and 3GPP have jointly launched a key project that studies MEC's overall framework, user plane selection, service offload, mobility, service continuity, and network capability openness.

4.3.3 Technical characteristics

Background

LTE based V2V device-to-device direct link communications, as specified in Release 14, are based on D2D communications defined as part of ProSe (proximity service) services in 3GPP Release 12 and Release 13. As part of ProSe services, a new D2D interface was introduced in Release 14, and it has been enhanced for vehicular use cases, specifically addressing high speed (relative speeds up to 500 km/h) and high-density connection scenarios[14]. A few fundamental modifications to LTE-V2V PC5 have been introduced.

– Additional DMRS symbols have been added to handle the high Doppler associated with relative speeds of up to 500 km/h and at high frequency (5.9 GHz ITS band being the main target)

– The arrangement of scheduling assignment and data resources are designed to enhance the system level performance under high density scenarios while meeting the low-latency requirements of V2V.

Distributed scheduling (Mode 4), which is a sensing mechanism with semi-persistent transmission, was introduced.

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[14] See 3GPP Specification #: 36.785 – Vehicle to Vehicle (V2V) services based on LTE sidelink; User Equipment (UE) radio transmission and reception.

Technical characteristics

The 3GPP "Study on LTE-based V2X services" [15] specifies enhancements required to enable V2X services with LTE uplink and downlink, to enable LTE PC5 interface to support additional V2X services such as vehicle to pedestrian (V2P), and to support more operational scenarios for V2V services using LTE PC5. Specifically, the following are the main features considered in this study:

– Uplink and PC5 enhancement to enable eNB to quickly change semi-persistent scheduling (SPS) in adapting to a change in the V2X message generation pattern

– Introduction of shorter scheduling periods in downlink and PC5 for broadcasting V2X messages within latency requirements

– Introduction of an additional resource allocation procedure in PC5 mode 4 for power saving in pedestrian UEs

– Introduction of PC5 congestion control for operation in high traffic load

– Enhancement to PC5 synchronization for operation outside GNSS or eNB coverage

– Support of simultaneous V2X operations over multiple carriers.

The PC5 interface for V2X supports QPSK and 16QAM in a 10 MHz or 20 MHz channel, leading to a peak rate of 41.472 Mbit/s. The Uu interface for V2X reuses the existing LTE Uu interface, so the modulation scheme and the peak rate are the same. The technical characteristics are shown in Table 25.

TABLE 25

Characteristics of the transmission scheme

Item	Transmission characteristics	
	Uu interface	**PC5 interface**
Operating frequency range	All the bands specified in TS 36.101 support operation with the Uu interface, except Band 47 Bands for Uu interface when used in combination with PC5 Band 3: UL: 1 710-1 785 MHz DL: 1 805-1 880 MHz Band 5: UL: 824-849 MHz DL: 869-894 MHz Band 7: UL: 2 500-2 570 MHz DL: 2 620-2 690 MHz Band 8: UL: 880-915 MHz DL: 925-960 MHz Band 20: UL: 832-862 MHz DL: 791-821 MHz Band 28: UL: 703-748 MHz DL: 758-803 MHz Band 34: UL: 2-010-2-025 MHz DL: 2-010-2-025 MHz Band 39: 1 880-1 920 MHz Band 41: 2 496-2 690 MHz Band 71: UL: 663- 698 MHz DL: 617-652 MHz	For Release 14 Band 47: 5 855-5 925 MHz

[15] 3GPP Specification #: 36.885

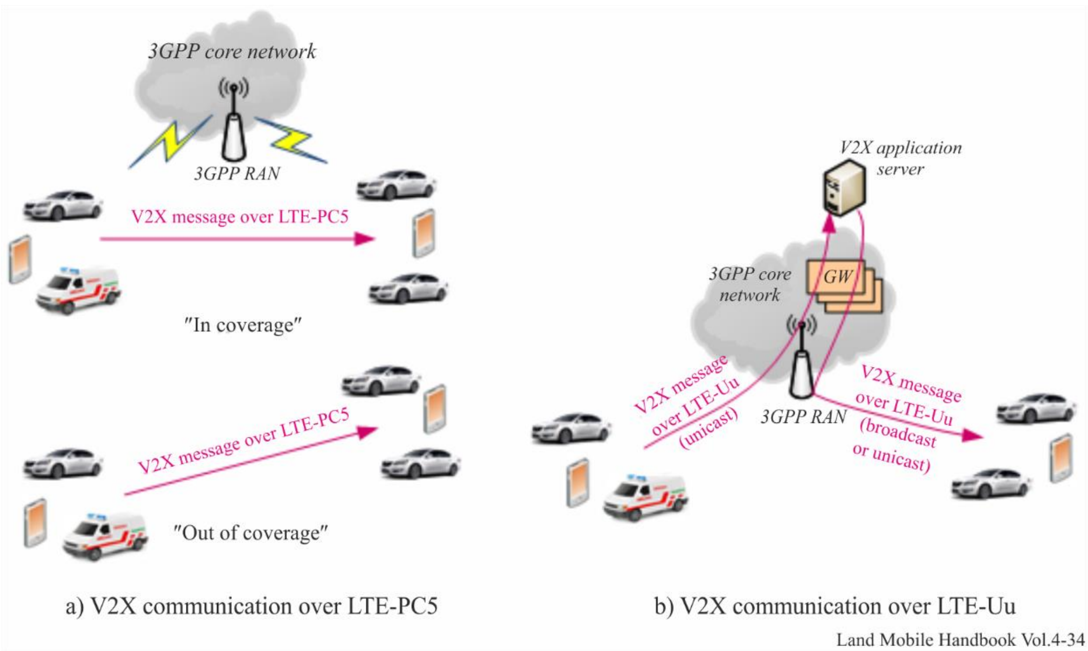
TABLE 25 *(end)*

Item	Transmission characteristics	
	Uu interface	**PC5 interface**
RF channel bandwidth	1.4, 3, 5, 10, 15, or 20 MHz per channel	10 or 20 MHz per channel
RF Transmit Power/EIRP	Max 43 dBm for eNB Max 23 or 33 dBm for UE	Max 23 or 33 dBm
Modulation scheme	Uplink: QPSK SC-FDMA, 16QAM SC-FDMA, 64QAM SC-FDMA; Downlink: QPSK OFDMA, 16QAM OFDMA, 64QAM OFDMA	QPSK SC-FDMA, 16QAM SC-FDMA
Forward error correction	Convolutional coding and turbo coding	Convolutional coding and turbo coding
Data transmission rate	Uplink: From 1.4 Mbit/s to 36.7 Mbit/s for 10 MHz channel Downlink: From 1.4 Mbit/s to 75.4 Mbit/s for 10 MHz channel	From 1.3 Mbit/s to 15.8 Mbit/s for 10 MHz channel
Media access control	Centralized scheduling by eNB	centralized scheduling or distributed scheduling
Duplex method	FDD or TDD	TDD

The LTE radio specification supports the two LTE based V2X communication methods, both PC5 and Uu interface, illustrated in Fig. 34 below. The interface communication supports direct link transmission when a cellular network provides coverage for vehicles (in coverage-Uu interface), or when vehicles are out of coverage of a cellular network (PC5 interface). LTE based V2X can support message transmission by both unicast and broadcast when using the Uu interface.

FIGURE 34

V2X communication over PC5 interface and Uu interface



4.3.3.1 LTE-based V2X

3GPP has completed the standardization of Release 14 LTE-based V2X, mainly including service requirements, system architecture, air interface technology and security.

In terms of service requirements, the specification defines 27 use cases of V2V, V2I, V2P, V2N and service requirements for LTE-based V2X services, and gives performance requirements for seven typical scenarios. In terms of system architecture, the specification identifies enhancements for support of V2X services based on the architecture of Proximity Services (ProSe) via the PC5 interface and LTE cellular communication via the Uu interface, and clearly stated that the enhancements support at least V2X services transmitted through the PC5 interface and the LTE-Uu interface. In terms of air interface technology, the specification clarifies the channel structure, synchronization process, and resource allocation on the PC5 interface, the PC5 and Uu interface's coexistence in the same carriers and adjacent carriers, radio resource control (RRC) signalling, and related radio frequency (RF) indicators and performance requirements, and explores Uu and PC5 transmission enhancements for support of LTE-based V2X services. Furthermore, the study on the security aspect of the LTE architecture enhancements for support of V2X services has been completed.

4.3.3.2 5G-V2X

5G V2X includes both evolution LTE-based V2X since Release 15, and NR-based technology. This 5G V2X has been designed to support more advanced a V2X service scenarios. 5G-V2X supports more advanced services and considers LTE-V2X enhancements by integrating LTE capabilities.

LTE-eV2X represents the phase (Release 15) of study on enhancement technologies that supports advanced V2X service scenarios, aiming to further improve the reliability, data rate and latency performance of the Device to Device (D2D) mode, and partially meet the needs of anticipated future V2X services.

The Technical Specification (TS) 22.886 has defined the service requirements for 25 use cases in five eV2X service categories, including basic requirements, vehicle platooning, semi-autonomous / autonomous driving, extended sensors, and remote driving. The ongoing study on 3GPP V2X specification Phase 2 mainly targets the feasibility and benefits of such enhancement technologies as carrier aggregation, transmit diversity, high-order modulation, resource pool sharing, and reduced delay, and shortened transmission time interval (TTI).

For NR-V2X, currently 3GPP has approved a study to develop TR 38.913 and TR 38.802 simulation methods according to the needs of TR 22.886, including simulation scenarios, performance indicators, and service models. The study covers the sidelink channel model above 6 GHz.

4.3.4 Radio propagation characteristics

Radio propagation in the 5.9 GHz frequency band is the same as the description in § 4.2.4.

4.4 Wide Area Broadcasting

4.4.1 Introduction

Although broadcasting techniques are used over short ranges, for example for V2V safety applications over the PC5 interface, wide area broadcasting technology is one-way communication from a base station to a user support user applications over a wide area. It may support human voice, data and video. Broadcasting technology has evolved towards the digitalization from analogue broadcasting to improve the radio performance.

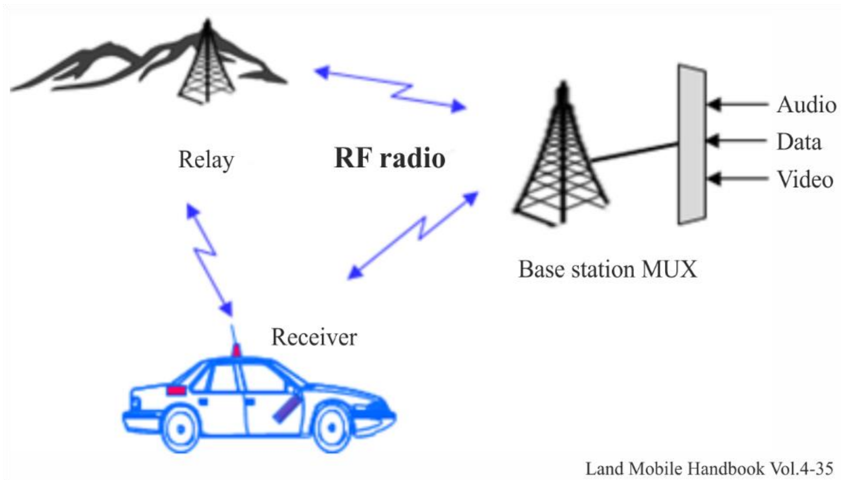
This broadcasting technology has been used for specific ITS applications because it can support one-way communication for ITS applications over a wide area. FM DARC and RDS are examples of data broadcasting technologies used for ITS applications. FM DARC and RDS use a 53-100 kHz subcarrier of the analogue FM frequency emissions.

DMB is a digital multimedia broadcasting technology to provide multimedia service for portable and vehicle users.

4.4.2 System configuration

FIGURE 35

Configuration of wide area broadcasting system



4.4.3 Technical characteristics

Frequency Modulation Data Radio Channel (FM DARC) is a FM multiplexing broadcasting system to send digital data in the existing FM broadcasting channel 60~94 kHz. FM DARC uses Level controlled Minimum Shift Keying (LMSK) modulation which is robust to multi-path interference in FM broadcasting channel. Its maximum data rate is 16 kbit/s and FM DARC can send traffic information, MAP download and differential GPS information for ITS applications. Its benefit is to provide digital packet data in wide radio coverage.

Digital Multimedia Broadcasting (DMB) is a digital TV broadcasting system used to send digital audio, video and packet data, which is adapted from Eureka-147 DAB system. Eureka-147 DAB is a digital audio system with packet data and streaming data mode. T-DMB is terrestrial DMB which uses MPEG-4 coding and Reed-Solomon forward error coding technology to provide digital audio and video signal.

4.4.4 Radio propagation characteristics

The FM broadcasting radio frequency is generally 87.5~108 kHz and has wide radio coverage up to 65 km. It takes advantage of the knife edge effect[16] to receive transmitted signals even though there is a NLOS radio environment.

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[16] https://www.its.bldrdoc.gov/fs-1037/dir-020/_2955.htm

4.5 Millimetre-wave communication

4.5.1 Introduction

The millimetre wave of electromagnetic spectrum corresponds to radio frequencies of 30-300 GHz, which have wavelengths ranging from 10 mm to 1 mm. One of the most important features of millimetre waves is that they may support wideband transmission, such as a large amount of computer data, multiplexed video, and voice channels for relay transmission of broadcasting applications. In addition, millimetre wave equipment will be compact sized with a small, high gain antenna.

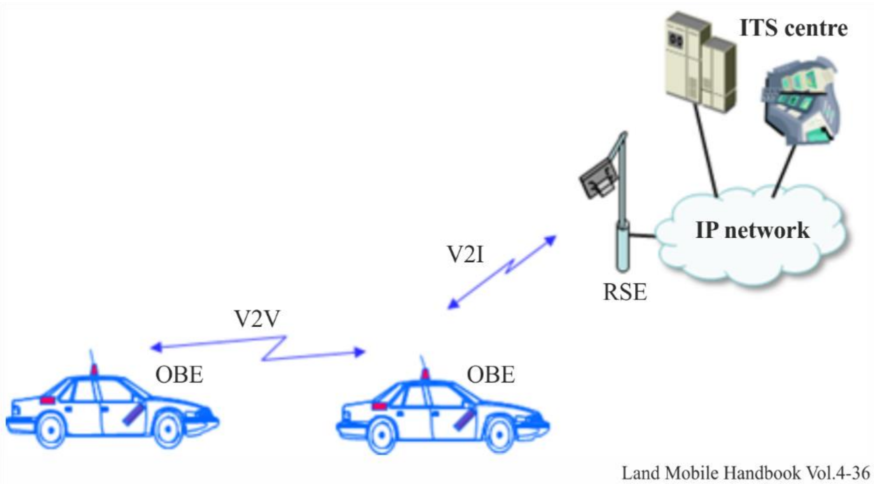
The millimetre wave frequencies can be used for V2X communication or vehicle radar for ITS applications. The millimetre wave V2X communication supports specific types of vehicle to vehicle or vehicle to infrastructure communication in the 63-66 GHz frequency band in some jurisdictions.

4.5.2 System configuration

Millimetre wave V2X communication systems consist of on-board equipment (OBE) and roadside equipment (RSE). OBE is the vehicle side radio unit, and RSE is the roadside radio unit, which is the same as DSRC communication.

FIGURE 36

Millimetre wave V2X communication system



4.5.3 Technical characteristics

Millimetre wave communication is basically considered to be a Line of Sight (LOS) radio channel because it has severe propagation loss in a NLOS environment. It has the potential to support wideband transmissions to provide broadband and secure communication for ITS and vehicle safety applications. Millimetre wave V2X communication has the following advantages:

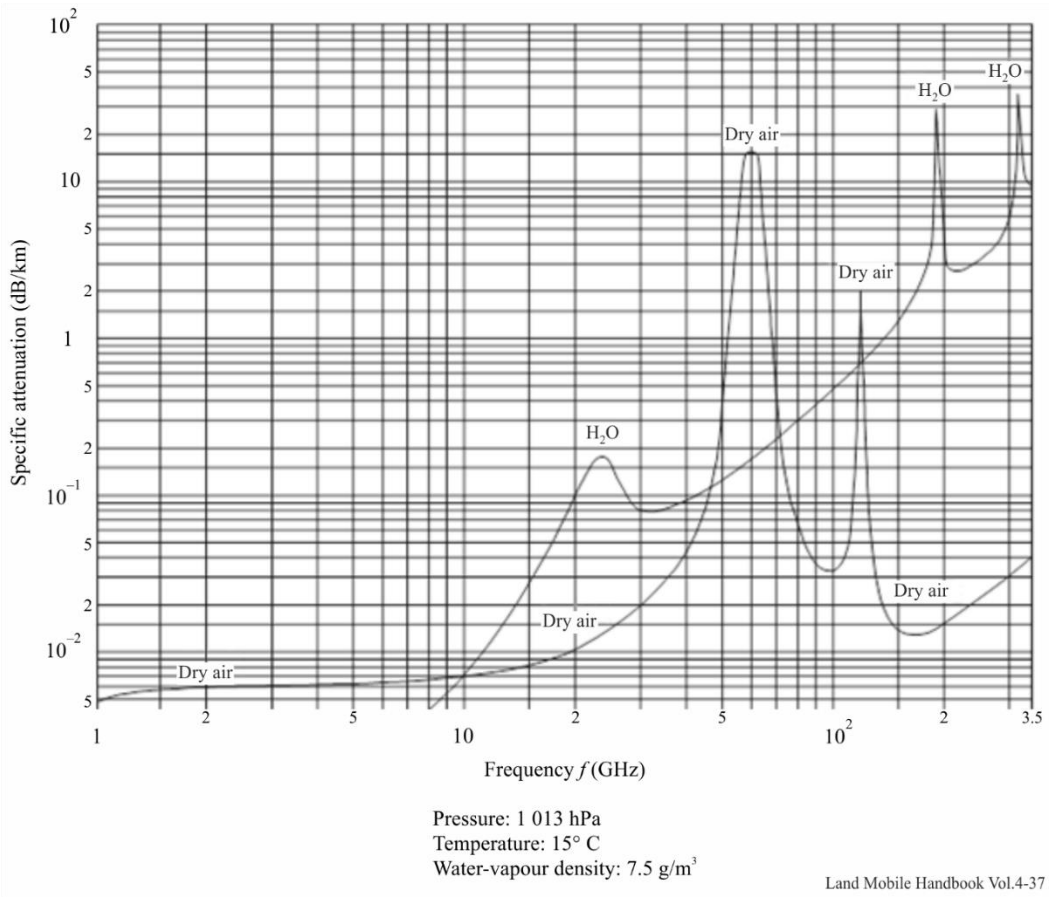
– Broad bandwidths for high data rate information transfer
– Low probability of interference due to high attenuation in the air
– Small multipath fading
– Low transmission power due to high antenna gain
– Small antenna and equipment size due to higher frequency
– High directivity and spatial resolution.

4.5.4 Radio propagation characteristics

The frequency band around 60 GHz is best suited for secure short-range communications, such as vehicle to vehicle communication and short range radar, because at 60 GHz, oxygen molecules in the air interact with electromagnetic radiation and absorb the transmitted energy, preventing the long reach of transmitted waves. It reduces interference among vehicle communications and significantly contributes to efficient use of radio frequency resources. Figure 37 shows the specific attenuation due to atmospheric gases. Transmission losses occur when millimetre waves travelling through the atmosphere are absorbed by molecules of oxygen, water vapour and other gaseous atmospheric constituents. These losses are greater at certain frequencies, coinciding with the mechanical resonant frequencies of the gas molecules. Around 60 GHz, absorption by molecules of oxygen shows a peak.

FIGURE 37

Specific attenuation due to atmospheric gases (Rec. ITU-R P.676-3)



Electromagnetic wave propagation at 60 GHz band experiences much higher path loss due to rain and oxygen molecules absorption in addition to diffraction, scattering due to vegetation, etc. The specific characteristic of the 60 GHz band made this band widely used for short range small power communications for unlicensed use.

60 GHz millimetre wave frequencies may be used for certain types of V2X communications. The 60 GHz radio frequency has radio propagation characteristics with fast decaying loss for the distance between transmitter and receiver. It is reported that the delay spread value is 20~50 ns in street, and 150 ns or more in the street square environment.

4.6 Millimetre-wave vehicle and road radar

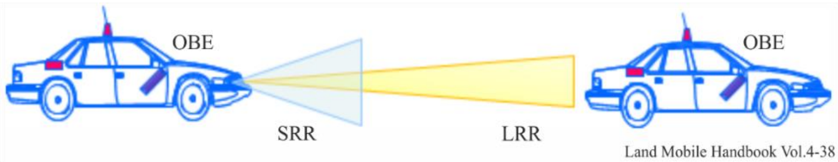
4.6.1 Introduction

The millimetre wave vehicle and road radar is sensor technology to monitor vehicle speed and distance for ITS applications. Even though there are ultrasonic sensors, image-processing sensors, infrared and Lidar, microwave radars, a millimetre-wave radar has the advantage to provide stable detection of targets under bad weather conditions such as rain or snow. The millimetre-wave radar may be applied for vehicle side or road infrastructure side, and is called a vehicle radar or road radar, respectively.

The vehicle radar has typically been mounted on a vehicle's front and rear side and is applied for Adaptive Cruise Control (ACC) and vehicular collision warning. The millimetre wave vehicle radar has two types: Long Range Radar (LRR) and Short-Range Radar (SRR). LRR has about 200 m radio range with a narrow antenna beam in the 76-77 GHz radio frequency band, and SRR has about 30m short range with wide antenna beam in the 22-29 GHz and 77-81 GHz frequency band.

FIGURE 38

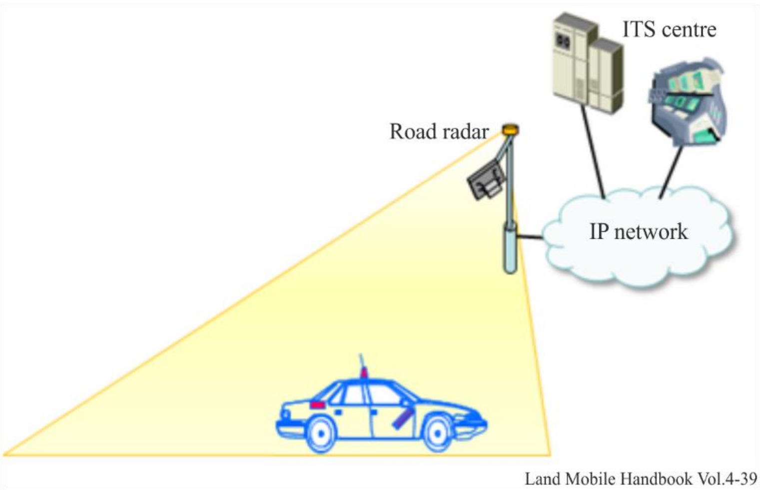
The millimetre wave vehicle radar



The road radar has been mounted on the road infrastructure side and is applied for hazard warning such as road work warning or intersection safety warning. The millimetre wave road radar should have 1 km long range to effectively monitor the road situation. The 34 GHz road radar has been tried to support the provision for unexpected road warnings.

FIGURE 39

The millimetre wave road radar



4.6.2 System configuration

The millimetre wave vehicle and road radar have three functional parts: Antenna and RF unit, Signal processing unit, and Recognition unit.

Antenna and RF unit: This part consists of a transmitting antenna, a receiving antenna, receiving equipment, and transmission equipment. Signal modulations, conversions to high frequencies, radio-wave transmission, and radio-wave reception are handled in this part. This part could be equipped with several antennas and could perform beam scanning.

Signal processing unit: This unit renders distance and speed by calculating signals handed over from the RF unit. Rendering of average distance and speed, and eradication of interference are sometimes handled here. When the antenna performs beam scanning, this unit calculates the direction of objects found.

Recognition unit: This unit can select and arrange the most wanted or necessary data depending on the needs of each system. For example, the unit will recognize the most dangerous obstacles, and can judge whether the vehicle in front is in lane. The unit occasionally averages figures gathered, filters interference, and enhances measuring accuracy and reliability of data from other sensors.

4.6.3 Technical characteristics

Low power automotive radar at 24 GHz

Today the frequency allocation for automotive radar application is in a rebuilding phase. Due to technological and commercial constraints, the frequency allocation for these safety related applications has been done in the beginning of the last decade in the range of 24 GHz. In Europe, e.g. an allocation for the 24 GHz UWB band (21.65-26.65 GHz) has been done as an intermediate solution due to the incompatibility with the Radio Astronomy Service, EESS, the Fixed Service and military applications. Therefore, the cut-off date of 1st July 2013 has been defined. In July 2011, the ECC extended the cut-off date (for sensors with reduced frequency range of 24.25-26.65 GHz) until 1st January 2018 by ECC decision 04(10) to allow the car manufacturers a seamless implementation of 79 GHz technology. The technological evolution during the last years led to the fact that with a similar effort a higher performance can be reached today.

It is to be noted, that the 24 GHz ISM band (24.05-24.25 GHz) plays an import role, especially for affordable vehicles. As this band is an ISM band and globally harmonized, 24.05-24.25 GHz ISM band automotive radars can be used worldwide without any time limitation.

High resolution short range automotive radar operating at 79 GHz (77-81 GHz)

The 77-81 GHz band has already been implemented for this kind of automotive radar applications in many countries. It is expected that further countries will implement the WRC-15 decision on 79 GHz automotive radars in the near future.

The 77-81 GHz band has been designated by CEPT in July 2004 (ECC/DEC/(04)03) for automotive radar applications. Also, the European Commission has adopted the decision 2004/545/EC on the harmonization of radio spectrum in the 79 GHz (77-81 GHz) range for the use of automotive radar. The harmonized standard EN 302 264 has been adopted by ETSI for short-range radar (SRR) operating in the 77-81 GHz band.

In March 2010, the Ministry of Internal Affairs and Communications (MIC) in Japan has started a study group in the Information and Communications Council for the introduction of high-resolution radar in the 77-81 GHz frequency band for national use. As a result of this activity the 78-81 GHz band was allocated to automotive radar in December 2012.

In October 2010, the Russian Federation identified the 77-81 GHz band for automotive radar.

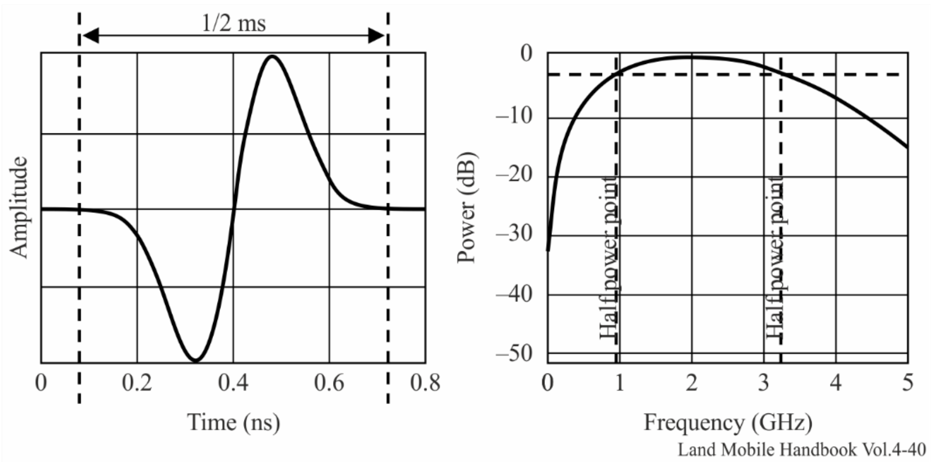
Ultra-wide band (UWB) radar

Generally, UWB is defined as the radio signal whose fractional bandwidth is greater than 20% of the centre frequency or the 10 dB bandwidth occupies 500 MHz or more of spectrum.

UWB technology originally employed very narrow or short duration pulses that result in very large or wideband transmission bandwidths (refer to Fig. 40). For automotive radar, the pulsed-UWB technique is replaced step-by-step by very wideband frequency chirps (Frequency-modulated continuous-wave = FMCW or pulse compression radar) without the need for short duration pulses. With appropriate technical standards, UWB devices can operate using spectrum occupied by existing radio services without causing interference, thereby permitting scarce spectrum resources to be used more efficiently.

FIGURE 40

UWB monocycle time and frequency domains
(UWB, "A possible area for standards", GSC 8 Presentation by FCC.)



Vehicle mounted radar

Regarding functional and safety requirements, the automotive radar systems operating in the 76-81 GHz band can be separated in two categories:

– **Category 1**: Adaptive Cruise Control (ACC) and Collision Avoidance (CA) radar, for measurement ranges up to 300 metres. For these applications, a maximum continuous bandwidth of 1 GHz is required. Such radars are considered to add additional comfort functions for the driver, giving support for more stress-free driving.

– **Category 2**: Sensors for high resolution applications such as Blind Spot Detection (BSD), Lane-Change Assist (LCA) and Rear-Traffic-Crossing-Alert (RTCA), detection of pedestrians and bicycles in close proximity to a vehicle, for measurement ranges up to 100 metres. For these high-resolution applications, a necessary bandwidth of 4 GHz is required. Such radars directly add to the passive and active safety of a vehicle and are therefore an essential benefit towards improved traffic safety.

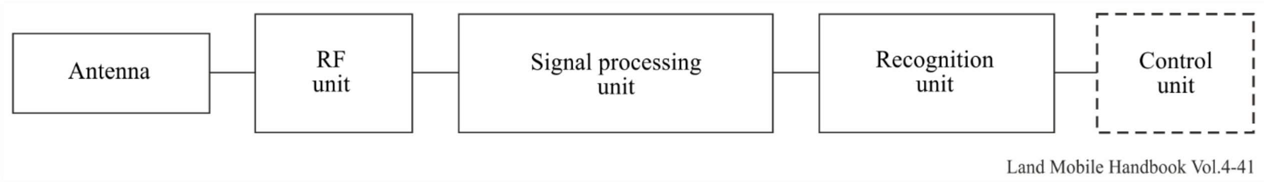
Depending on the number of radar sensors and their mounting position on the vehicle it is possible to detect objects in sectors or even the complete surrounding of a car. The sensor signals are the basis not only for driver assistance systems like ACC but also for a broad variety of automotive applications of active and passive safety.

Systems for monitoring the proximity to vehicles will play an important role in ensuring driving safety. High-resolution automotive radars will be a key sensor technology for autonomous driving vehicles. With its resistance to bad weather and dirt, automotive radar is suitable for vehicles driven in severe conditions.

Figure 41 shows the configuration of automotive radar.

FIGURE 41

Configuration of automotive radar



Subsystems are as follows:

- *Antenna/RF unit*

  This part consists of a transmitting antenna, a receiving antenna, receiving equipment and transmission equipment. Signal modulations, conversions to high frequencies, radio-wave transmission, and radio-wave reception are handled in this part. This part could be equipped with several antennas and could perform beam scanning.

- *Signal processing unit*

  This unit renders distance and speed by calculating signals handed over from the RF unit. Rendering of average distance and speed, and mitigation of interference are sometimes handled here. When the antenna performs beam scanning, this unit calculates the direction of detected objects.

- *Recognition unit*

  This unit can select and arrange the most wanted or necessary data depending on the needs of each system. For example, the unit will recognize the most relevant objects, and can judge whether the vehicle in front is in lane. The unit occasionally averages figures gathered, filters interference, and enhances measuring accuracy and reliability of data by tracking objects and by data fusion with data from other sensors.

Radar for road incident detection system[17]

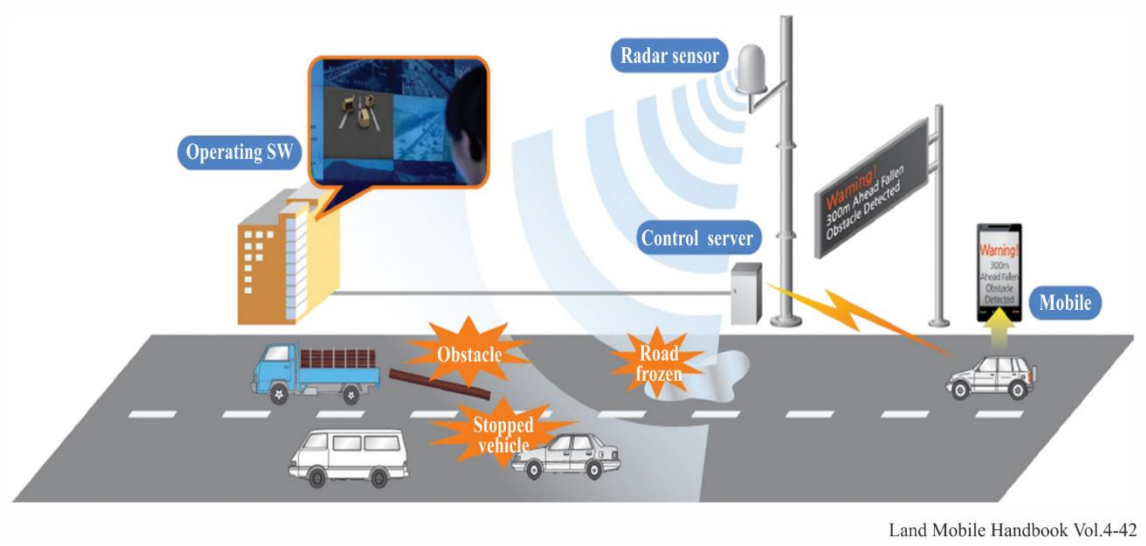
Incident detection service deployed in Korea enables drivers in vehicles to receive real-time information for unexpected road situation (obstacle, stopped and wrong way vehicle, frozen-road, etc.) through real-time and automatic detection system using radar sensors to prevent unexpected accidents. It also provides traffic information within 1 km from radar sensor. It supports driver in heavy rains and foggy weather to receive real–time information by incident detection system.

---

[17] Technical regulation on radio equipment without license: Ministry of Science and ICT, Republic Korea, Notice 2014-57, 2014.9.30; Article number 17 Radar for detection of road information.

FIGURE 42

Incident detection road radar



Characteristics of 34 GHz incident detection radar are given in Table 26.

TABLE 26

Road radar system

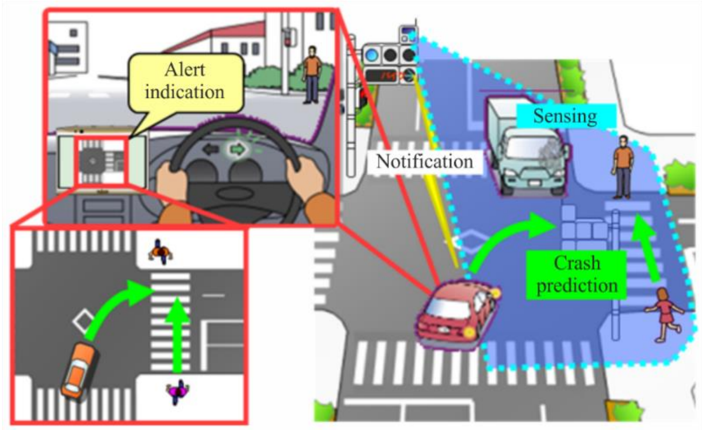
Characteristic (parameter)	Value
Operational characteristics	
Application/Service	Road Incident Detection System
Typical installation	Road Side Pole (or gantry)
Technical characteristics	
Max. range	1 000 m
Frequency range	34.275-34.875 GHz
Specified bandwidth (typical)	Up to 600 MHz
Peak power (e.i.r.p)	Up to +55 dBm
Mean power (e.i.r.p)	Up to +45 dBm

Radar for cooperative driving support

In Japan, a cooperative driving support system is developed and deployed for intersection safety. The system consists of the millimetre-wave radar as a roadside sensor to detect pedestrians, cyclists, and vehicles entering an intersection. The roadside sensor typically mounted at approximately the same height as traffic signals that have a wide field of view. The system also alerts motorists to potential hazards by using the ITS radio communication.

FIGURE 43

Cooperative driving support



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4.6.4 Radio propagation characteristics

The two-ray propagation model between direct wave and reflected wave from the surface of the road is used for estimation of propagation characteristics of millimetre-wave. Figure 45 is the schematic view of the two-ray propagation model. In this model, the received power P_r is expressed approximately as shown in the Figure, where P_t is the transmitted power, G_t and G_r are the antenna gains at the transmitter and the receiver, $L(r)$, is the absorption factor by oxygen, λ is the wave length, r is the distance between the antennas, d is the horizontal distance between the antennas, and h_t and h_r are heights of the transmitter and the receiver, respectively. In this model, the reflection coefficient of the pavement is assumed as −1 and the directivity of antenna is ignored. Absorption attenuation by oxygen molecules is assumed as 16 dB/km.

FIGURE 44

Two ray propagation model

$$\text{Received power } P_r = \frac{P_t G_t G_r}{L(r)} \left(\frac{\lambda}{4\pi r}\right)^2 \sin\left(\frac{2\pi h_t h_r}{\lambda d}\right)$$

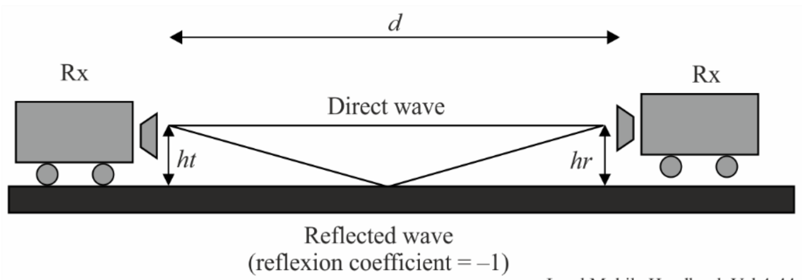

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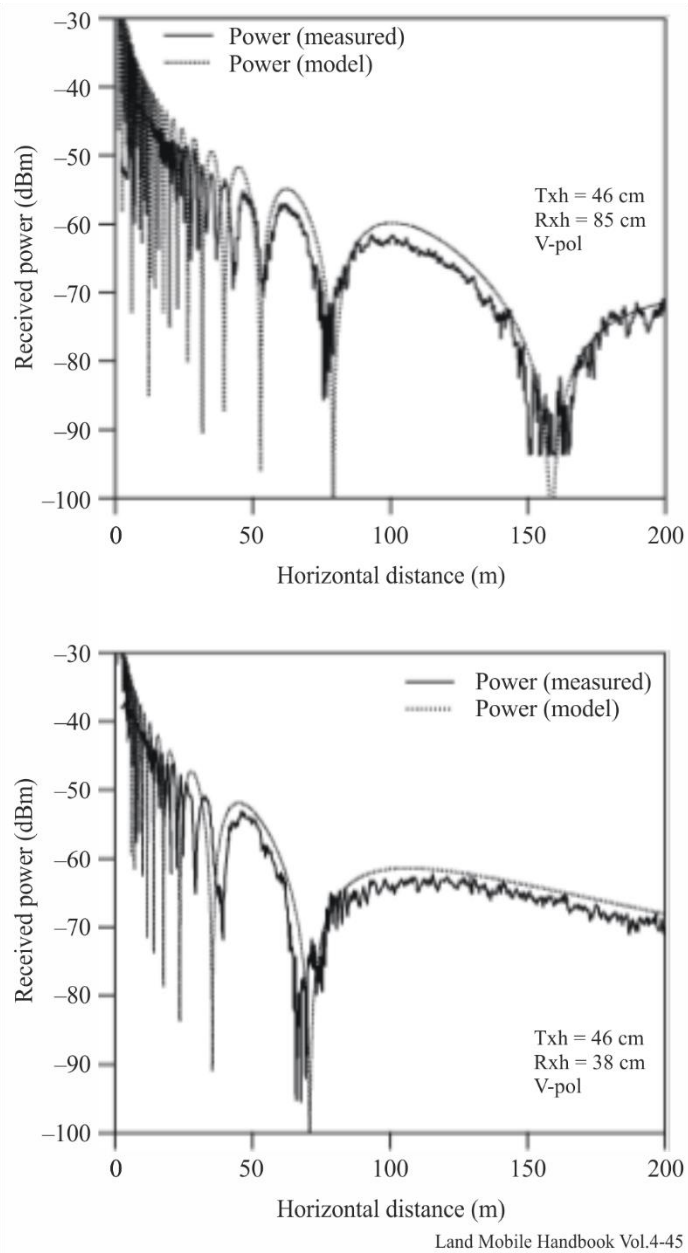
Figure 45 shows the measurement results of the received power. The horizontal axis represents the distance between the vehicles. The results of measured power are similar to those obtained by the two-ray propagation model.

FIGURE 45

Measurement results of received power between vehicles



CHAPTER 5

STANDARDS

This Chapter describes ITU-R and industrial standards in Regions 1, 2 and 3 to use the radio technologies for ITS applications.

5.1 DSRC standard

5.1.1 Global standard on DSRC

TABLE 27

Global standard on ETC

SDO	Standard No.	Standard title
ITU	ITU-R M.1453-2	Intelligent transport systems – dedicated short range communications at 5.8 GHz

5.1.2 DSRC Standard in Region 1

ETSI standards define OBE and RSE equipment and its test specification for electronic toll collection.

TABLE 28

Standard for ETC in Europe

SDO	Standard No.	Standard title
ETSI	EN 300 674	Road Transport and Traffic Telematics (RTTT); Dedicated Short Range Communication (DSRC) transmission equipment (500 kbit/s / 250 kbit/s) operating in the 5,8 GHz Industrial, Scientific and Medical (ISM) band
	ETSI EN 300 674-2-1	Transport and Traffic Telematics (TTT); Dedicated Short Range Communication (DSRC) transmission equipment (500 kbit/s / 250 kbit/s) operating in the 5.8 GHz Industrial, Scientific and Medical (ISM) band; Part 2: Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU; Sub-part 1: Road Side Units (RSU)
	ETSI EN 300 674-2-2	Transport and Traffic Telematics (TTT); Dedicated Short Range Communication (DSRC) transmission equipment (500 kbit/s / 250 kbit/s) operating in the 5.8 GHz Industrial, Scientific and Medical (ISM) band; Part 2: Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU; Sub-part 2: On-Board Units (OBU)
	TS 102 486	Test specifications for DSRC transmission equipment

5.1.3 DSRC Standard in Region 2

While there is a desire for a common standard and uniform interoperability throughout North America[18], different proprietary roadside and vehicle technologies are presently in use for electronic toll collection in different areas. These technologies are not directly interoperable, so multiple transceivers are required in order to enable electronic toll collection across these diverse areas, and data exchange agreements are used to provide limited interoperability within regional areas. In the longer term, connected vehicle technologies are expected to allow convergence of electronic toll collection onto one or more technologies based upon voluntary industry standards.

5.1.4 DSRC Standard in Region 3

DSRC standards defines radio access between OBE and RSE and its test specification for electronic toll collection.

TABLE 29

Standard for ETC in Asia-Pacific

SDO	Standard No.	Standard title
TTA	TTAS.KO-06.0025/R1	Standard of DSRC Radio Communication between Road-side Equipment and On-board Equipment in 5.8 GHz band
	TTAS.KO-06.0052/R1	Test specification for DSRC L2 at 5.8 GHz
	TTAS.KO-06.0053/R1	Test specification for DSRC L7 at 5.8 GHz
ARIB	STD-T75	Dedicated Short Range Communication (DSRC) System
SAC (Standardization Administration of China)	GB/T 20851.1-2007	Electrical toll collection – Dedicated short range communication – Part 1: Physical layer
	GB/T 20851.2-2007	Electrical toll collection – Dedicated short range communication – Part 2: Data link layer
	GB/T 20851.3-2007	Electrical toll collection – Dedicated short range communication – Part 3: Application layer
	GB/T 20851.4-2007	Electrical toll collection – Dedicated short range communication – Part 4: Equipment application
	GB/T 20851.5-2007	Electrical toll collection – Dedicated short range communication – Part 5: Test methods of the main parameters in physical layer
IMDA TSAC	IMDA TS DSRC	Technical Specification for Dedicated Short-Range Communications in Intelligent Transport Systems

[18] https://www.ibtta.org/sites/default/files/documents/Interoperability/IBTTA%20White%20Paper%20Toll%20Interoperability%20September%202016.pdf

5.2 Advanced ITS Radiocommunication Standard

TABLE 30

ITU Recommendations and Reports

SDO	Document number	Title
ITU	Rec. ITU-R M.1890	Operational radiocommunication objectives and requirements for advanced Intelligent Transport Systems
	Report ITU-R M.2228	Advanced intelligent transport systems (ITS) radiocommunications
	Rec. ITU-R M.2084	Radio interface standards of vehicle-to-vehicle and vehicle-to-infrastructure communication for intelligent transport systems applications

5.2.1 ITS G5 Standard in Region 1

The ITS G5 standard defines user requirement, system architecture, and layer specification for ITS V2X applications.

TABLE 31

Standard for advanced ITS radiocommunication in Europe

SDO	Standard No.	Standard title
ETSI	TS 102 637 series	Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications
	EN 302 637-2	ITS-Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service.
	EN 302 637-3	ITS-Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service.
	EN 302 665	Intelligent Transport Systems (ITS); Communications Architecture
	TS 102 636 series	Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking;
	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.
	TS 102 894-2	ITS-Users and applications requirements; Part 2: Applications and facilities layer common data dictionary. Dictionary of definitions used by other ETSI TC ITS standards.
	TS 102 890-3	ITS – Facilities layer function; facility position and time management.
	EN 302 895	Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Local Dynamic Map (LDM)

TABLE 31 *(end)*

SDO	Standard No.	Standard title
ETSI	TS 101 556-1	Intelligent Transport Systems (ITS); I2V Applications; Electric Vehicle Charging Spot Notification Specification
	TS 101 556-2	Intelligent Transport Systems (ITS); Infrastructure to Vehicle Communication; Part 2: Communication system specification to support application requirements for Tyre Information System (TIS) and Tyre Pressure Gauge (TPG) interoperability
	TS 101 539-1	ITS – V2X Applications; Part 1: Road Hazard Signalling (RHS) application requirements
	TS 101 539-3	ITS – V2X Applications; Part 3: Longitudinal Collision Risk Warning (LCRW) application requirement specification.
	TS 102 792	Intelligent Transport Systems (ITS); Mitigation techniques to avoid interference between European CEN Dedicated Short Range Communication (CEN DSRC) tolling equipment and Intelligent Transport Systems (ITS) operating in the 5 GHz frequency range.
	EN 302 571	Intelligent Transport Systems (ITS); Radiocommunications equipment operating in the 5 855-5 925 MHz frequency band; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU
	EN 302 686	Intelligent Transport Systems (ITS); Radiocommunications equipment operating in the 63 GHz to 64 GHz frequency band; Harmonised Standard covering the essential requirements of article 3.2 of the 3 R&TTE Directive This standard is under revision to take into account the updated frequency band 63.72-65.88 GHz and to cover the essential requirements of article 3.2 of Directive 2014/53/EU
	EN 302 663	Intelligent Transport Systems (ITS); European profile standard for the physical and medium access control layer of Intelligent Transport Systems operating in the 5 GHz frequency band

5.2.2 WAVE Standard in Region 2

The WAVE standards define user requirements, system architecture and layer specification for ITS V2X applications.

TABLE 32

Standards for advanced ITS radiocommunication in the United States of America

SDO	Standard No.	Standard title
ASTM	E2213-03	Standard Specification for Telecommunications and Information Exchange Between Roadside and Vehicle Systems – 5 GHz Band Dedicated Short Range Communications (DSRC) Medium Access Control (MAC) and Physical Layer (PHY) Specifications
IEEE	IEEE 802.11-2016	Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications
	IEEE 1609.0-2013	IEEE Guide for WAVE – Architecture
	IEEE 1609.2-2016	IEEE Standard for WAVE – Security Services for Applications and Management Messages
	IEEE 1609.3 -2016	IEEE Standard for WAVE – Networking Services
	IEEE 1609.4-2016	IEEE Standard for WAVE – Multi-Channel Operations
	IEEE 1609.11-2010	IEEE Standard for WAVE – Over-the-Air Electronic Payment Data Exchange Protocol for ITS
	IEEE 1609.12-2016	IEEE Standard for WAVE – Identifier Allocations
SAE	SAE J2735 March, 2016	Dedicated Short Range Communications (DSRC) Message Set Dictionary
	SAE J2945/1 March, 2016	On-board System Requirements for V2V Safety Communications

5.2.3 Advanced ITS Radiocommunication Standard in Region 3

There are V2X standards from ARIB, CCSA, ITS info-communication forum, ITS connect promotion forum, CCSA, IMDA TSAC, and TTA.

TABLE 33

Standards, technical specifications, guidelines on Advanced ITS Radiocommunication in Asia-Pacific

SDO	Standard No.	Standard title
TTA	TTAS.KO-06.0175/R2	Vehicle Communication System Stage1: Requirements
	TTAS.KO-06.0193/R2	Vehicle Communication SystemStage2: Architecture
	TTAS.KO-06.0216/R1	Vehicle Communication System Stage3: PHY/MAC
	TTAS.KO-06.0479	Vehicle Communication System Stage3: PHY/MAC (LTE-V2X)
	TTAS.KO-06.0234/R1	Vehicle Communication System State 3: Networking
	TTAK.KO-06.0242/R1	Vehicle Communication System Stage3: Application Protocol Interface
	TTAK KO-06.0344	In-Vehicle Signage System for Vehicle Safety Guidance Stage 1: Requirements
	TTAK KO-06.0344-Part 2	In-Vehicle Signage System for Vehicle Safety Guidance Stage 2: Data Exchange

TABLE 33 *(end)*

SDO	Standard No.	Standard title
ITS Info-communications Forum	ITS FORUM GUIDELINES	– ITS FORUM RC-008 Operation Management Guideline for Driver Assistance Communications System – ITS FORUM RC-009 Security Guideline for Driver Assistance Communications System – ITS FORUM RC-010 70 0MHz BAND INTELLIGENT TRANSPORT SYSTEMS – Extended Functions Guideline – ITS FORUM RC-013 700 MHz BAND INTELLIGENT TRANSPORT SYSTEMS – Experimental Guideline for Inter-vehicle Communication Messages
ITS Connect Promotion Consortium	ITS Connect TD-001	ITS Connect TD-001 Inter-vehicle Communication Message Specifications
ARIB	STD T109	700 MHz Band Intelligent Transport System
CCSA	YD/T 3400-2018	General technical requirements of LTE-based vehicular communication
	YD/T 3340-2018	Technical requirements of air interface of LTE-based vehicular communication
IMDA TSAC	IMDA TS DSRC	Technical Specification for Dedicated Short-Range Communications in Intelligent Transport Systems

5.3 Cellular V2X Standards

LTE V2X standards define V2X communication and applications.

TABLE 34

List of the 3GPP technical specifications related to V2X

Standard No.	Standard title
	<Core network and UE protocol>
3GPP TS 22.185	Service requirements for V2X service
	<Core network and UE protocol>
3GPP TS 23.003	Numbering, addressing and identification
3GPP TS 23.007	Restoration procedures.
3GPP TS 23.008	Organization of subscriber data
3GPP TS 23.122	Non-Access-Stratum (NAS) functions related to Mobile Station (MS) in idle mode
3GPP TS 23.203	Policy and charging control architecture
3GPP TS 23.285	Architecture enhancements for V2X service
3GPP TS 23.303	Proximity-based services (ProSe); Stage 2
3GPP TS 24.301	Non-Access-Stratum (NAS) protocol for Evolved Packet System (EPS); Stage 3

TABLE 34 *(cont.)*

Standard No.	Standard title
3GPP TS 24.334	Proximity-services (ProSe) User Equipment (UE) to Proximity-services (ProSe) Function Protocol aspects; Stage 3
3GPP TS 24.385	V2X services Management Object (MO)
3GPP TS 24.386	User Equipment (UE) to V2X control function; protocol aspects; Stage 3
3GPP TS 29.116	Representational state transfer over xMB reference point between content provider and BM-SC
3GPP TS 29.212	Policy and Charging Control (PCC); Reference points
3GPP TS 29.272	Evolved Packet System (EPS); Mobility Management Entity (MME) and Serving GPRS Support Node (SGSN) related interfaces based on Diameter protocol
3GPP TS 29.388	V2X Control Function to Home Subscriber Server (HSS) aspects (V4); Stage 3
3GPP TS 29.389	Inter-V2X Control Function Signalling aspects (V6); Stage 3
3GPP TS 29.468	Group Communication System Enablers for LTE (GCSE_LTE); MB2 reference point; Stage 3
3GPP TS 31.102	Characteristics of the Universal Subscriber Identity Module (USIM) application
	<Security>
3GPP TS 33.185	Security aspect for LTE support of V2X services
	<Device performance requirements>
3GPP TS 36.101	Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception
3GPP TS 36.133	Evolved Universal Terrestrial Radio Access (E-UTRA); Requirements for support of radio resource management
	<Physical layer aspects>
3GPP TS 36.211	Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation
3GPP TS 36.212	Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and channel coding
3GPP TS 36.213	Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures
3GPP TS 36.214	Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer; Measurements
	<Medium access and radio resource management protocols>
3GPP TS 36.300	Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2
3GPP TS 36.302	Evolved Universal Terrestrial Radio Access (E-UTRA); Services provided by the physical layer

TABLE 34 *(end)*

Standard No.	Standard title
3GPP TS 36.304	Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) procedures in idle mode
3GPP TS 36.306	Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio access capabilities
3GPP TS 36.321	Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification
3GPP TS 36.322	Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Link Control (RLC) protocol specification
3GPP TS 36.323	Evolved Universal Terrestrial Radio Access (E-UTRA); Packet Data Convergence Protocol (PDCP) specification
3GPP TS 36.331	Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification
	<Radio access network aspects>
3GPP TS 36.443	Evolved Universal Terrestrial Radio Access Network (E-UTRAN); M2 Application Protocol (M2AP)
3GPP TS 36.413	Evolved Universal Terrestrial Radio Access Network (E-UTRAN); S1 Application Protocol (S1AP)
3GPP TS 36.423	Evolved Universal Terrestrial Radio Access Network (E-UTRAN); X2 application protocol (X2AP)

5.4 Broadcasting Standards

TABLE 35

List of broadcasting standards

SDO	Standard No.	Standard title
TTA	TTAS.KO-07.0035	Terrestrial Digital Multimedia Broadcasting Systems; Specification of the traffic and travel information service transmission for VHF DMB to mobile, portable and fixed receivers
	TTAS.KO-07.0106/R1	Specification of TTI difference GPS service for DMB to mobile, portable and fixed receivers

5.5 Millimetre wave communication and radar

5.5.1 Millimetre wave automotive radar Standards in ITU

TABLE 36

Global standards for millimetre-wave automotive radar

SDO	Standard No.		Standard title
ITU	Recommendation	ITU-R M.1452	Millimetre wave radiocommunication systems for intelligent transport system applications
		ITU-R M.2057	Systems characteristics of automotive radars operating in the frequency band 76-81 GHz for intelligent transport systems applications
	Report	ITU-R M.2322	Systems Characteristics and Compatibility of Automotive Radars Operating in the 77.5-78 GHz Band for Sharing Studies
		ITU-R F.2394	Compatibility between point-to-point applications in the fixed service operating in the 71-76 GHz and 81-86 GHz bands and automotive radar applications in the radiolocation service operating in the 76-81 GHz bands

5.5.2 Millimetre wave automotive radar Standards in Region 1

TABLE 37

Standards for millimetre-wave automotive radar in Europe

SDO	Standard No.	Standard title
ETSI	TR 101 983	Radio equipment to be used in the 76 GHz to 77 GHz band; System Reference Document for Short-Range Radar to be fitted on road infrastructure
	EN 301 091 parts 1-2	Short Range Devices; Road Transport and Traffic Telematics (RTTT); Radar equipment operating in the 76 GHz to 77 GHz range;
	EN 302 258 parts 1-2	Short Range Devices; Road Transport and Traffic Telematics (RTTT) Radar equipment operating in the 24.05 GHz to 24.25 GHz or 24.05 GHz to 24.50 GHz range
	EN 302 288 parts 1-2	Short Range Devices; Road Transport and Traffic Telematics (RTTT); Short range radar equipment operating in the 24 GHz range
	EN 302 264 parts 1-2	Short Range Devices, Road Transport and Traffic Telematics (RTTT); Short Range Radar equipment operating in the 77 GHz to 81 GHz band

5.5.3 Millimetre wave automotive radar Standards in Region 2

TABLE 38

Standards on millimetre-wave vehicular radar in North and South America

SDO	Standard No.	Standard title
	ANSI C63.10-2013	
	FCC part 15.249	FCC Part 15 PART 15 – RADIO FREQUENCY DEVICES Operation within the bands 902-928, MHz, 2 400-2 483.5 MHz, 5 725-5 875 MHz, and 24.0-24.25 GHz.
	FCC part 15.252	FCC Part 15 PART 15 – RADIO FREQUENCY DEVICES 15.252 Operation of wideband vehicular radar systems within the bands 16.2-17.7 GHz and 23.12-29.0 GHz.
	FCC part 95M	FCC part 15 PART 15 – RADIO FREQUENCY DEVICES 15.253 Operation within the bands 46.7-46.9 GHz and 76.0-77.0 GHz.
	FCC part 15.515	FCC part 15 PART 15 – RADIO FREQUENCY DEVICES 15.515 Technical requirements for vehicular radar systems.

5.5.4 Millimetre wave automotive radar Standards in Region 3

TABLE 39

Standards on millimetre-wave automotive radar in Asia-Pacific

SDO	Standard No.	Standard title
ARIB	STD-T48	Millimeter-Wave Radar Equipment for Specified Low Power Radio Station
	STD-T111	79 GHz Band High-Resolution Radar
IMDA TSAC	IMDA TS SRD	
	IMDA TS UWB	

CHAPTER 6

FREQUENCY USAGE FOR ITS APPLICATIONS

This Chapter describes radio frequency assignment on the radio technologies for ITS applications. The Table below is a summary of the radio frequency assignments.

TABLE 40

Frequency usage of the radio technologies for ITS applications

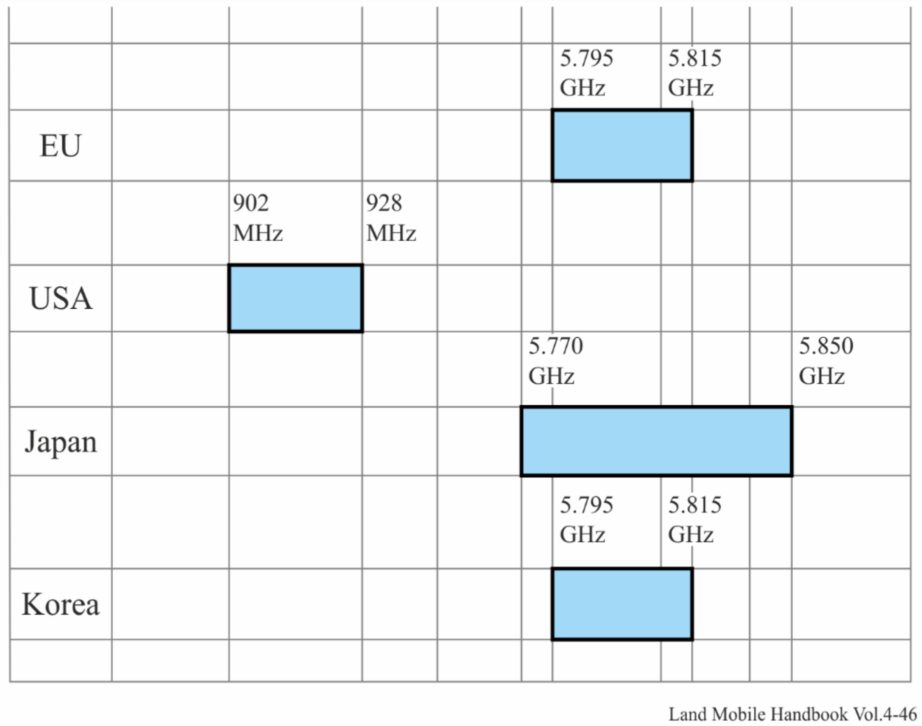
Radio technologies for ITS	Frequencies used
DSRC	900 MHz (only some countries in Region 2), 2.4 GHz, 5.8 GHz
Advanced ITS radio communication	760 MHz, 5.9 GHz, 63-66 GHz
FM broadcasting	74-90 MHz
Vehicle radar	5.8 GHz, 24 GHz, 60 GHz, 76 GHz, 79 GHz
Road radar	34 GHz

6.1 Frequency usage of DSRC

Figure 46 shows the frequency bands used for DSRC in Europe, North America, Japan and Korea. With the exception of North America’s 900 MHz band (902-928 MHz), the current use of frequency bands for each region is harmonized around the 5.8 GHz industrial, scientific and medical (ISM) band.

FIGURE 46

Frequency usage of DSRC communication



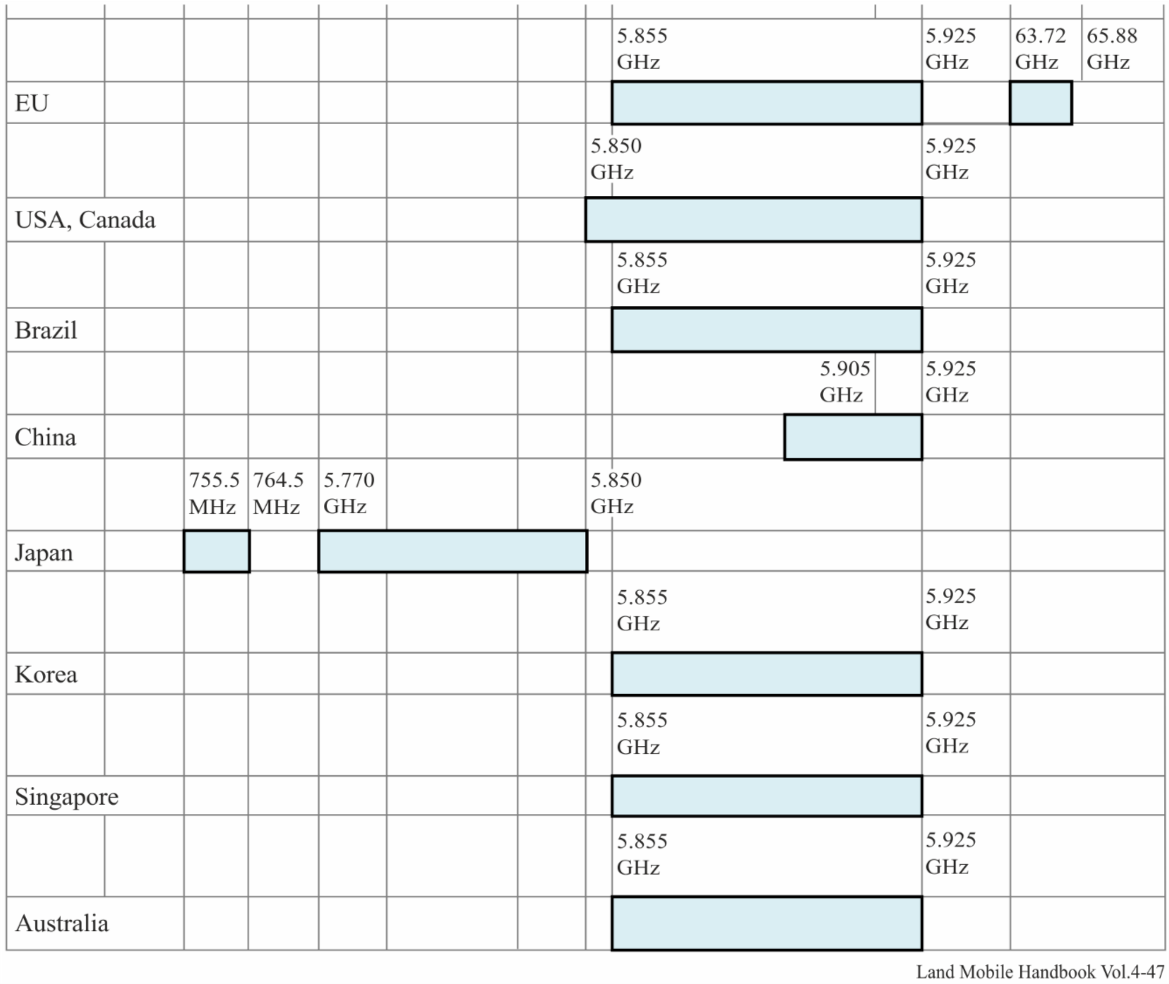
Section 4.1.3 describes the outline of technologies and characteristics for DSRC in the 5.8 GHz band, complementing the contents of Recommendation ITU-R M.1453-2 – Intelligent transport systems – Dedicated short range communications at 5.8 GHz.

6.2 Frequency usage of Advanced ITS radiocommunication

The frequency band for dedicated V2X communication is shown in Fig. 47.

FIGURE 47

Frequency usage of Advanced ITS radiocommunication



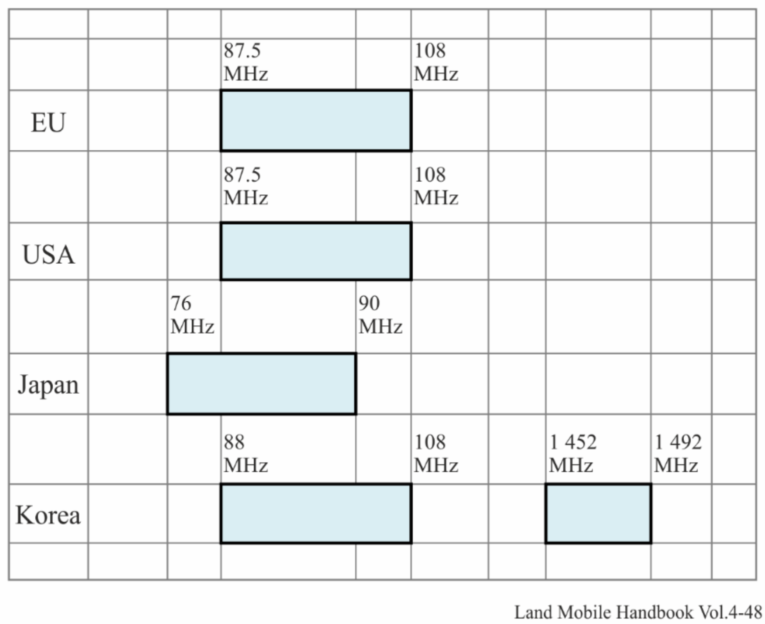
6.3 Frequency usage of cellular networks

Cellular networks operate on different frequency bands including the 450 MHz band, 700 MHz band, 800 MHz band, 900 MHz band, 1800 MHz band, 2100 MHz band, and 2 600 MHz band as the 1st generation Analog AMPS is evolving to 4th generation LTE. The recent 5G generation technologies are expected to be used in the 3.5 GHz and the 28 GHz frequency ranges. The frequency table is omitted because the frequency assignment and operation depend on the countries in ITU Regions 1, 2 and 3.

6.4 Frequency usage of broadcasting

FIGURE 48

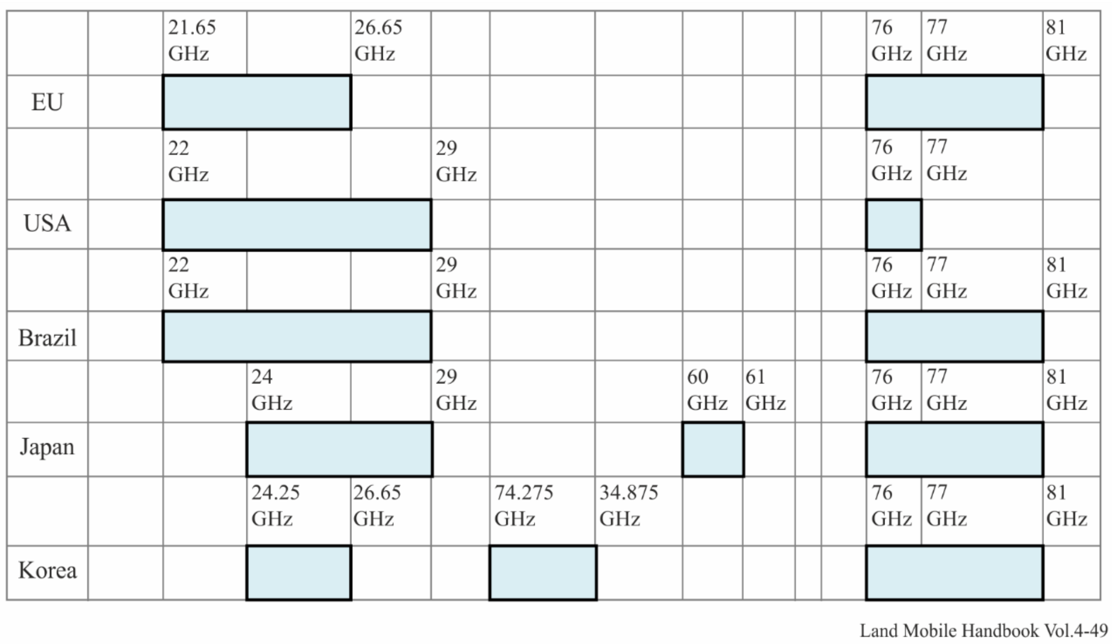
Frequency usage of broadcasting



6.5 Frequency usage of millimetre wave vehicle and road radar

FIGURE 49

Millimetre wave radar



Annex A

Acronym list

3GPP	3rd Generation partnership program
AACN	Automatic crash notification
ACC	Adaptive cruise control
ACR	Access control router
ADSL	Asymmetric digital subscriber loop
AGPS	Assisted GPS
AHS	Automated highway system
AoA	Angle of arrival
ARIB	Association of Radio Industries and Businesses
ASECAP	Association of operators of toll road infrastructures
ASK	Amplitude shift keying
ASL	Application sub-layer
ASTM	American Society for Testing and Materials, later ASTM International
ATIS	Advanced traffic information service
AVI	Automatic vehicle identification
AWG	APT Wireless Group
BCMCS	Broadcast-multicast service
BER	Bit error ratio
BIS	Bus information systems
BMS	Bus management system
BPSK	Binary phase shift keying
C2C-CC	CAR-to-CAR Communication Consortium
CACC	Cooperative adaptive cruise control
CAMP	Crash Avoidance Metric Partnership
CCSA	China Communications Standard Association
CCTV	Closed circuit television
CDMA	Code division multiple access
CEDR	Conference of European Directors of Roads
CEN	European Committee for Standardization
CEPT	European Conference of Postal and Telecommunications Administrations
C-ITS	Cooperative ITS communication
CLI	Caller line identification
CSMA	Carrier sensing multiple access
DARC	Data radio channel
DB	Data base

DCC	Distributed Congestion Control
DCU	Data communication unit
DELTA	DSRC electronics implementation for transportation and automotive applications
DGPS	Differential globe positioning system
DMB	Digital multimedia broadcasting
DQPSK	Differential QPSK
DSB	Digital sound broadcasting
DSRC	Dedicated short range communications
DTTB	Digital terrestrial television broadcasting
ECC	Electronic Communications Committee
EID	Entity identification
EIRP	Effective isotropic radiation power
ERC	European Radio Communications Committee
ERI	Electronic registration identification
ETC	Electronic toll collection
ETSI	European Telecommunications Standardization Institute
EU	European Union
EV	Electric vehicle
FA	Foreign agent
FCC	Federal Communications Committee
FDD	Frequency division duplexing
FDMA	Frequency division multiple access
FEC	Forward error control
FFT	Fast Fourier transform
FLO	Forward link only technology
FM0	Frequency modulation 0
FOT	Field operational tests
FWA	Fixed wireless access
GMLC	Gateway mobile location centre
GMSK	Gaussian filtered minimum shift keying
GNSS	Global navigation satellite system
GPR	Ground penetrating radars
GPS	Global positioning system
HDLC	High-level data link control
HSDPA	High speed downlink packet access
IAG	Interagency Group
ICT	Information and communication technologies
ID	IDentification
IEEE	Institute of Electrical and Electronics Engineers

IETF	Internet Engineering Task Force
IMDA	Infocomm Media Development Authority (Singapore)
IMS	IP multimedia subsystem
IMT-2000	International mobile telecommunication-2000
IP	Internet Protocol
ISM	Industrial, scientific and medical
ISO	International Organization for Standardization
ITI	Intelligent transportation infrastructure
ITS	Intelligent transport system
LAN	Local area network
LBS	Location based service
LCD	Liquid crystal display
LCP	Local control protocol
LDM	Local dynamic map
LED	Light emitting diode
LMS	Location and monitoring service
LMSK	Level controlled minimum shift keying
LOS	Line of sight
LRR	Long range vehicular radar
LTE	Long term evolution
LTE-V2X	LTE based V2X
MAC	Medium access control
MDSS	Maintenance decision support system
MIC	Ministry of Internal Affairs and Communications
MMD	Multi-media domain
MMI	Man machine interface
MMS	Multimedia messaging service
MNO	Mobile network operator
MOCT	Ministry of Construction and Transportation
MRPI	Medium range pre-information
MS	Mobile station
NLOS	Non-line of sight
NMS	Network monitoring system
NMS	Network monitoring system
NOMA	Non-orthogonal multiple access
NRZ	None return to zero
NRZI	None return to zero inverted
OBD	On-board diagnostics
OBE	On-board equipment

OBU	On board unit
OFDM	Orthogonal frequency division multiplexing
OFDMA	Orthogonal frequency division multiple access
OSI	Open system interconnection
OTDoA	Observed time difference of arrival
P2C	Pedestrian to centre
P2I	Pedestrian to infrastructure
P2V	Pedestrian to vehicle
P2X	Pedestrian to anything
PC5	Device-to-device direct link
PCS	Personal communication service
PDA	Personal digital assistance
PDE	Position determination entity
PHY	Physical layer
POI	Point of interest
POLIS	European cities and regions networking for innovative transport solutions
ProSE	Proximity server
PSAP	Public safety answering point
PSAP	Public Safety and Assistance Party
PSK	Phase shift keying
PSS	Portable subscriber station
PSTN	Public switched telephone network
PTIS	Public transportation information system
QAM	Quadrature amplitude modulation
QPSK	Quadrature phase shift keying
RADAR	Radio detecting and ranging
RDS	Radio Data System
RF	Radio frequency
RSE	Roadside equipment
RSU	Roadside unit
RTT	Radio transmission technology
RTTT	Road transport and traffic telematics
RVC	Road vehicle communication
SDM	Serving and diagnostic module
SIP	Session initiation protocol
SNP	Signalling network protocol
SRR	Short range vehicular radar
STA	Station
TCP/IP	Transmit control protocol/Internet protocol

TDD	Time division duplexing
TDMA	Time division multiple access
TDoA	Time difference of arrival
TIA	Telecommunications Industry Association
ToA	Time of arrival
TPC	Transmit power control
TPEG	Transport Protocol Experts Group
TRS	Trunked radio system
TSAC	Telecommunications Standards Advisory Committee (Singapore)
TTA	Telecommunication Technology Association
TTI	Traffic and travel information
UDP/IP	User datagram protocol/Internet protocol
UAE	United Arab Emirates
UE	User equipment
UMTS	Universal mobile telecommunications system
URA	UTRAN registration area
USD	Universal service directive
UTRAN	UMTS terrestrial radio access network
Uu	Link between a base station and a device
UWB	Ultra-wideband
V2I	Vehicle to infrastructure
V2N	Vehicle to network
V2V	Vehicle to vehicle communication
V2X	Vehicle to anything
VICS	Vehicle information and communication system
VIN	Vehicle identification number
VMC	Vehicle multi-hop communication
VMS	Variable message signs
VoIP	Voice over Internet protocol
WAVE	Wireless access for vehicle environment
WCDMA	Wide-band code division multiple access
WDN	Wireless packet data network
WiBro	Wireless broadband
WiMax	Worldwide interoperability for microwave access
WIPI	Wireless Internet platform for interoperability
WLAN	Wireless local area network
WNC	Wireless network controller
WNS	Wireless network switch
WSMP	WAVE short message protocol

Annex B

The usage of ITS in some countries

This Annex describes the summary on service overview, standards and frequency usage for ITS application listed in Tables 41 to 45.

TABLE 41

Summary of usage of ITS radiocommunication in ITU-R Member States

Country	Application	Standard	Frequency band	Deployment
EU countries	ETC	DSRC	5.795~5.815 GHz	Enacted in 2004
	C-ITS	ITS G5	5.855~5.925 GHz	Deployment of infrastructure in some member states since 2016
	ITS	ETSI EN 302 686	63.72~65.88 GHz	
	TIS	FM	87.5~108 MHz	
USA	ETC	DSRC	902~928 MHz	Enacted in 2004
	C-ITS	WAVE	5.850~5.925 GHz	Planned initiation of large-scale production vehicle deployment - 2021
	TIS	FM	87.5~108 MHz	
Canada	C-ITS	WAVE	5.850~5.925 GHz	
China	C-ITS	LTE V2X	5.905~5.925 GHz	Enacted in 2018
Japan	ETC	DSRC	5.795~5.805 GHz and 5.835~5.845 GHz	Enacted in 2001
	C-ITS	ITS Connect	755.5-764.5 MHz	Deployed in 2015
	VICS	FM Broadcasting	76~90 MHz	Enacted in 1996
		DSRC	5.770~5.850 GHz	Enacted in 2015
Korea	ETC	DSRC	5.795~5.815 GHz	Enacted in 2004
	C-ITS	WAVE, Cellular V2X	5.855-5.925 GHz	Enacted in 2016
	TIS	FM Broadcasting	88~108 MHz 1 452~1 492 MHz	
Singapore	C-ITS	WAVE	5.855~5.925 GHz	-
Australia	C-ITS	WAVE	5.855~5.925 GHz	-

TABLE 42

Frequency usage for millimetre-wave automotive radar in Region 1

	24.05 to 24.25 GHz ISM		76 to 77 GHz			77 to 81 GHz		
	Regulation	**Standard**	**Regulation**	**Standard**	**Report/Notes**	**Regulation**	**Standard**	**Report/Notes**
Europe - CEPT, EU	ERC/REC 70-03 Annex 5 COMMISSION IMPLEMENTING DECISION 2013/752/EU	ETSI EN 302 858 (2013-07)	-ERC/REC 70-03 Annex 5 -ECC/DEC/(02)01 COMMISSION IMPLEMENTING DECISION 2017/1483/EU	ETSI EN 301 091-1 (2006-11)	CEPT Reports 35, 36 and 37	- 2004/545/EC -ERC/REC 70-03 Annexes 5 and 13 ECC/DEC/(04)03	ETSI EN 302 264-1 (2009-04)	- ECC/REP 056 - Partly: CEPT Report 003 - CEPT Reports 46 and 37
- Russia	SFMC Decision No. 07-20-03-001 Annex 7		SFMC Decision No. 07-20-03-001 Annex 7		Appendix 1 Resolution of State Radio Frequency Committee No. 10-09-03 of 29 October 2010	SFMC Decision No. 07-20-03-001 Annex 7		Appendix 1 Resolution of State Radio Frequency Committee No. 10-09-03 of 29 October 2010
Arab States (e.g. Saudi Arabia, Oman, UAE)	UAE-TRA: Ultra-Wide band and Short Range Devices Regulations	CITC Technical Specification Doc. Number: RI054 (Rev 2)	UAE-TRA: Ultra-Wide band and Short Range Devices Regulations CITC	CITC Technical Specification Doc. Number: RI049 (Rev 2)		77-82 GHz -SRR Decision of TRA No 133/2008 of 28-Oct-08		

TABLE 43

Frequency usage for millimetre-wave vehicular radar in North and South America

	24.05 to 24.25 GHz ISM		76 to 77 GHz			77 to 81 GHz		
	Regulation	**Standard**	**Regulation**	**Standard**	**Report/Notes**	**Regulation**	**Standard**	**Report/Notes**
U.S.A.	FCC Part 15/15.249		FCC Part 15/15.253			Planned (NPRM FCC15-16)		
Canada		RSS-310	Spectrum Utilization Policies SP-47 GHz	RSS 251				
Brazil	ANATEL Resolution No. 506		ANATEL Resolution No. 506					

TABLE 44

Frequency usage on millimetre-wave automotive radar in Asia-Pacific

	24.05 to 24.25 GHz ISM		76 to 77 GHz			77 to 81 GHz		
	Regulation	**Standard**	**Regulation**	**Standard**	**Report/Notes**	**Regulation**	**Standard**	**Report/Notes**
Korea, Republic of	Technical regulations for unlicensed devices of MSIT (Notification 2020-58)		Technical regulations for unlicensed devices of MIST (Notification 2020-58)			Technical regulations for unlicensed devices of MIST (Notification 2020-58)		
China	Technical Specification for Micropower (Short Distance) Radio Equipment of Category G		Technical Specification for Micropower (Short Distance) Radio Equipment, part XIV					

TABLE 44 (*end*)

	24.05 to 24.25 GHz ISM		76 to 77 GHz			77 to 81 GHz		
	Regulation	**Standard**	**Regulation**	**Standard**	**Report/Notes**	**Regulation**	**Standard**	**Report/Notes**
Japan	Ministry of Internal Affairs and Communication Ordinance (46-2010)	ARIB STD-T73	Ordinance Regulating Radio Equipment Notification of MIC (643-1997)	ARIB STD-T48		Ordinance Regulating Radio Equipment, Notification of MIC (4432012)	ARIB STD-T111	
Singapore			IMDA Technical Specification Short Range Devices	IMDA TS SRD		IMDA Technical Specification Ultra-Wideband (UWB) Devices	IMDA TS UWB	
Thailand	Notification regarding licensing rules for vehicle radar radiocommunication equipment	NBTC TS 1011-2560 Section 2.1.1	Notification regarding licensing rules for vehicle radar radiocommunication equipment	NBTC TS 1011-2560 Section 2.1.2		Notification regarding licensing rules for vehicle radar radiocommunication equipment	NBTC TS 1011-2560 Section 2.1.3	
Viet Nam	Regulation on technical and operational requirements for short range devices (Circular No. 46/2016/TT-BTTTT)		Regulation on technical and operational requirements for short range devices (Circular No. 46/2016/TT-BTTTT)			Regulation on technical and operational requirements for short range devices (Circular No. 46/2016/TT-BTTTT)		

TABLE 45

Usage status on millimetre-wave automotive radar in Asia-Pacific

Country	Application	Technology/Standard	Frequency band	Deployment or plan year
Australia	Section 66 Ultra-wideband short-range vehicle radar systems transmitters	Radiocommunications (Low Interference Potential Devices) Class Licence 2015	22-26.5 GHz	-
	Section 66 Radiodetermination transmitters		24.0-24.25 GHz	
	Long-range vehicle radar (intelligent cruise control) Section 69 Radiodetermination transmitters		76-77 GHz	
	Section 70 Radiodetermination transmitters		77-81 GHz	
China	Vehicular range radar	Notice on Promulgation of the Technical Specification for Micropower (Short Distance) Radio Equipment	24.00-24.25 GHz	Enacted in 2005
			76-77 GHz	
	Vehicular range radar	Ministry of Industry and IT, Notice regarding 24 GHz frequency band short range automotive radar	24.25-26.65 GHz	Enacted in 2012
	Vehicular range radar	Radar	77-81 GHz	Field Experiment in 2017
	Vehicular radar systems	HKCA1075 Exemption from Licensing Order	76-77 GHz[19]	2005
			77-81 GHz[19]	2017

[19] This frequency usage is for Hong Kong, China.

TABLE 45 (*cont'*)

Country	**Application**	**Technology/Standard**	**Frequency band**	**Deployment or plan year**
Japan	Environmental recognition (Obstacle detection)	Quasi-millimetre wave system	24.0-24.25 GHz	Enacted in 2010
			24.25-29 GHz	
		Millimetre wave system	60-61 GHz	Enacted in 1995
			76-77 GHz	Enacted in 2011 (Occupied band width: 500 MHz) Revised in 2015 (Occupied band width: 1 GHz)
			77-81 GHz	Enacted in 2012 for 78-81 GHz. Revised in 2017 for inclusion above 77 GHz.
Republic of Korea	Vehicular collision avoidance radar	Radar	24.25-26.65 GHz	2012 (The device for "Automotive radar" can be installed until 31st Dec. 2021 and this can be used until lifetime of this device.)
			76-77 GHz	2008
			77-81 GHz	2016
	Road incident detection	Millimetre wave road radar	34.275-34.875 GHz	September 2014
Singapore	Short-range radar systems such as automatic cruise control and collision warning systems for vehicle	Radar IMDA TS SRD	76-77 GHz	2002
	Vehicular radar	Radar IMDA TS UWB	77-81 GHz	2008

TABLE 45 (*end*)

Country	Application	Technology/Standard	Frequency band	Deployment or plan year
Thailand	Vehicle radar application	NBTC Standard 1011-2560	22.00-24.05 GHz	Regulation adopted in 2018. Making and importing licenses for use within Thailand permitted until 31 December 2023. After that time, permitted for replacement parts only.
	Vehicle Radar application	NBTC Standard 1011-2560	24.05-24.25 GHz	Regulation adopted in 2007 and revised in 2018
	Vehicle Radar application	NBTC Standard 1011-2560	24.25-26.65 GHz	Regulation adopted in 2014 and revised in 2018. Making and importing licenses for use within Thailand permitted until 31 December 2023. After that time, permitted for replacement parts only.
	Vehicle Radar application	NBTC Standard 1011-2560	76-77 GHz	Regulation adopted in 2006
	Vehicle Radar application	NBTC Standard 1011-2560	77-81 GHz	Regulation adopted in 2018
Viet Nam	Non-specific short-range applications including short range vehicular radar	Low Interference Potential Devices	24.00-24.25 GHz	Regulation adopted in 2009
	Vehicular radar	Radar	76-77 GHz	2012
	Vehicular radar	Radar	77-81 GHz	2016

Annex C

Publications on ITS

1 Overview

The following sections provide a non-exhaustive list of relevant ITU publications on ITS. Summaries are provided for ease of reference.

2 ITU publications

2.1 WRC Recommendation

Recommendation 208 (WRC-19)

recommends

1 that administrations consider using globally or regionally harmonized frequency bands, or parts thereof, as described in the most recent versions of Recommendations (e.g. ITU-R M.2121), when planning and deploying evolving ITS applications, taking into account recognizing b) above;

2 that administrations take into account, if necessary, coexistence issues between ITS stations and stations of existing services (e.g. FSS earth stations), taking into account *considering f)*,

2.2 ITU-R Recommendations

ITU-R M.1452	Millimetre wave radiocommunication systems for Intelligent Transport Systems applications
ITU-R M.1453	Intelligent Transport Systems – dedicated short range communications at 5.8 GHz
ITU-R M.1890	Intelligent transport systems – Guidelines and objectives
ITU-R M.2057	Systems characteristics of automotive radars operating in the frequency band 76-81 GHz for intelligent transport systems applications
ITU-R M.2084	Radio interface standards of vehicle-to-vehicle and vehicle-to-infrastructure communication for intelligent transport systems applications
ITU-R M.2121	Harmonization of frequency bands for Intelligent Transport Systems in the mobile service

2.3 ITU-R Reports

ITU-R M.2228	Advanced intelligent transport systems (ITS) radiocommunication
ITU-R M.2322	Systems characteristics and compatibility of automotive radars operating in the frequency band 77.5-78 GHz for sharing studies
ITU-R F.2394	Compatibility between point-to-point applications in the fixed service operating in the 71-76 GHz and 81-86 GHz bands and automotive radar applications in the radiolocation service operating in the 76-81 GHz bands
ITU-R M.2444	Examples of arrangements for Intelligent Transport Systems deployments under the mobile service
ITU-R M.2445	Intelligent transport systems (ITS) usage

3 Other ITS references

ARC-IT

Amajor upgrade to the National Intelligent Transportation Systems (ITS) Reference Architecture that integrates content evolved from both the National ITS Architecture Version 7.1 and the CVRIA Version 2.2

ARIB STD-T48

Millimeter-Wave Radar Equipment for Specified Low Power Radio Station (https://www.arib.or.jp/english/std_tr/telecommunications/std-t48.html)

ARIB STD-T75

Dedicated Short-Range Communication System (https://www.arib.or.jp/english/std_tr/telecommunications/std-t75.html)

ARIB STD-T109

700 MHz Band Intelligent Transport Systems (https://www.arib.or.jp/english/std_tr/telecommunications/std-t109.html)

ARIB STD-T111

79 GHz Band High-Resolution Radar (https://www.arib.or.jp/english/std_tr/telecommunications/std-t111.html)

CEN EN 12253

Road transport and traffic telematics - Dedicated short-range communication - Physical layer using Microwave at 5.8 GHz

Commission Implementing Decision (EU) 2019/1345 of 2 August 2019 amending Decision 2006/771/EC updating harmonised technical conditions in the area of radio spectrum use for short-range devices

ERC Decision (92)02

The frequency bands were designated for the coordinated introduction of. Road Transport Telematics Systems

ECC Decision (08)01

The harmonised use of Safety-Related Intelligent Transport Systems (ITS) in the 5875-5935 MHz frequency band

ECC Decision (09)01

Harmonised use of the 63.72-65.88 GHz frequency band for Intelligent Transport Systems (ITS)

EC Decision 2006/771/EC as amended by 2019/1345/EU

ECC Decision (02)01

The frequency bands were designated for the coordinated introduction of. Road Transport Telematics Systems

ERC Recommendation 70-03

Relating to the use of Short-Range Devices (SRD)

ETSI EN 300 674-2

Transport and Traffic Telematics (TTT); Dedicated Short Range Communication (DSRC) transmission equipment (500 kbit/s / 250 kbit/s) operating in the 5,8 GHz Industrial, Scientific and Medical (ISM) band; Part 2: Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU;

ETSI EN 302 571

Intelligent Transport Systems (ITS); Radiocommunications equipment operating in the 5 855 MHz to 5 925 MHz frequency band; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU

ETSI EN 302 663

Intelligent Transport Systems (ITS); Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band

ETSI EN 302 665

Intelligent Transport Systems (ITS) communication architecture

ETSI EN 302 686

Intelligent Transport Systems (ITS); Radiocommunications equipment operating in the 63 GHz to 64 GHz frequency band; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive

ETSI TS 102 687

Intelligent Transport Systems (ITS); Decentralized Congestion Control Mechanisms for Intelligent Transport Systems operating in the 5 GHz range; Access layer part

ETSI TS 102 792

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

ETSI TS 102 724

Intelligent Transport Systems (ITS); Harmonized Channel Specifications for Intelligent Transport Systems (ITS) operating in the 5 GHz frequency band

ETSI TS 103 175

Intelligent Transport Systems (ITS); Cross Layer DCC Management Entity for operation in the ITS G5A and ITS G5B medium

IEEE 1609.0™-2013

IEEE Guide for Wireless Access in Vehicular Environments (WAVE) – Architecture

IEEE 1609.2™-2016

IEEE Standard for Wireless Access in Vehicular Environments – Security Services for Applications and Management Messages

IEEE 1609.3™-2016

IEEE Standard for Wireless Access in Vehicular Environments (WAVE) – Networking Services

IEEE 1609.4™-2016

IEEE Standard for Wireless Access in Vehicular Environments (WAVE) – Multi-channel Operation

IEEE 1609.11™-2010

IEEE Standard for Wireless Access in Vehicular Environments (WAVE) – Over-the-Air Electronic Payment Data Exchange Protocol for Intelligent Transportation Systems (ITS)

IEEE 1609.12™-2016

IEEE Standard for Wireless Access in Vehicular Environments (WAVE) – Identifier Allocations

SAE J2735 March, 2016

Dedicated Short Range Communications (DSRC) Message Set Dictionary

SAE J2945/1 March, 2016

On-board System Requirements for V2V Safety Communications

TTAK.KO-06.0175/R1

Vehicle communication system Stage 1: Requirements

TTAK.KO-06.0193/R1

Vehicle communication system Stage 2: Architecture

TTAK.KO-06.0216/R1

Vehicle communication system Stage 3: PHY/MAC

TTAK.KO-06.0234/R1

Vehicle communication system State 3: Networking

CCSA 2015-1616T-YD

General technical requirements of LTE-based vehicular communication

CCSA 2016-1853T-YD

Technical requirements of air interface of LTE-based vehicular communication

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