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TECHNICAL REPORT

**Intelligent Transport Systems (ITS);
Pre-standardization study on ITS architecture;
Part 2: Interoperability among heterogeneous
ITS systems and backward compatibility**

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Foreword

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

The present document is part 2 of a multi-part deliverable covering the Intelligent Transport Systems (ITS); Pre-standardization study on ITS architecture, as identified below:

Part 1:   "Architecture for communications among ITS stations with multiple access layer technologies";

Part 2:   "Interoperability among heterogeneous ITS systems and backward compatibility".

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Introduction

There are a number of candidate wireless communications technologies to address ITS requirements, including ITS-G5, IEEE 802.11bd[TM] [i.24], LTE-V2X PC5, NR-V2X, mmWave, mobile cellular systems (Uu-Interface), etc. The available band, such as the 5,9 GHz ITS band, could be occupied by several distinct ITS technologies, and those technologies are likely to operate simultaneous at the same time and location. It is thus needed to clarify the inherent challenges in this situation and discover possible solutions to overcome the challenges.

1   Scope

The present document presents the results of the investigation for achieving interoperability and backward compatibility, two principles of ITS Directive [i.2], when implementing the ITS architecture with multiple communication interfaces according to the existing ETSI ITS specifications. The present document elaborates the definitions of interoperability and backward compatibility.

The requirements for functional safety according to ISO 26262 [i.12] and IEC 61508 [i.13], as well as privacy and security requirements are not addressed in detail in the present document.

2   References

2.1   Normative references

Normative references are not applicable in the present document.

2.2   Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

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

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

[i.1]   M/453 (6th October 2009) Standardication Mandate addressed to CEN, CENELEC and ETSI in the field of information and communication technologies to support the interoperability of co-operative systems for intelligent transport in the European Community.

[i.2]   Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport.

[i.3]   Commission Decision 2008/671/EC of 5 August 2008 on the harmonised use of radio spectrum in the 5875 - 5905 MHz frequency band for safety-related applications of Intelligent Transport Systems (ITS) (notified under document number C(2008) 4145).

[i.4]   CEPT/ECC Decision (08)01: "The harmonised use of the 5875-5925 MHz frequency band for Intelligent Transport Systems (ITS)", approved 14 March 2008, Amended 3 July 2015.

[i.5]   ETSI TS 136 300: "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2 (3GPP TS 36.300)".

[i.6]   ETSI EN 302 663: "Intelligent Transport Systems (ITS); ITS-G5 Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band".

[i.7]   ETSI TR 102 962: "Intelligent Transport Systems (ITS); Framework for Public Mobile Networks in Cooperative ITS (C-ITS)".

[i.8]   ETSI TS 103 613: "Intelligent Transport Systems (ITS); Access layer specification for Intelligent Transport Systems using LTE Vehicle to everything communication in the 5,9 GHz frequency band".

[i.9]   ETSI TS 123 401 (V10.5.0): "LTE; General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access (3GPP TS 23.401 version 10.5.0 Release 10)".

[i.10]   ETSI TS 125 300: "Universal Mobile Telecommunications System (UMTS); Universal Terrestrial Radio Access Network (UTRAN); General description; Stage 2 (3GPP TS 25.300)".

[i.11]   ETSI TS 138 300: "5G; NR; Overall description; Stage-2 (3GPP TS 38.300)".

[i.12]   ISO 26262: "Road vehicles -- Functional safety".

[i.13]   IEC 61508: "Functional safety of electrical/electronic/programmable electronic safety-related systems".

[i.14]   ETSI EN 302 665: "Intelligent Transport Systems (ITS); Communications Architecture".

[i.15]   EC COM(2016) 766 final (30th November 2016): "Communication from the Commission to the European Parliament, the Council, the European economic and social committee and the committee of the regions -- A European strategy on Cooperative Intelligent Transport Systems, a milestone towards cooperative, connected and automated mobility".

[i.16]   European Commission C-ITS Platform reports I, January 2016.

NOTE: Available at https://ec.europa.eu/transport/sites/transport/files/themes/its/doc/c-its-platform-final-report-january-2016.pdf.

[i.17]   European Commission C-ITS Platform reports II, September 2017.

NOTE: Available at https://ec.europa.eu/transport/sites/transport/files/2017-09-c-its-platform-final-report.pdf.

[i.18]   ETSI TS 101 539-1 (V1.1.1): "Intelligent Transport Systems (ITS); V2X Applications; Part 1: Road Hazard Signalling (RHS) application requirements specification".

[i.19]   ETSI TS 101 539-2 (V1.1.1): "Intelligent Transport Systems (ITS); V2X Applications; Part 2: Intersection Collision Risk Warning (ICRW) application requirements specification".

[i.20]   ETSI TS 101 539-3 (V1.1.1): "Intelligent Transport Systems (ITS); V2X Applications; Part 3: Longitudinal Collision Risk Warning (LCRW) application requirements specification".

[i.21]   Bijlsma, Tjerk & Hendriks, T & Vissers, J & Elshof, L & Jansen, T & Krosse, B. (2016): "In-Vehicle Architectures for Truck Platooning: The Challenges to reach SAE Automation Level 3".

[i.22]   Directive 2014/53/EU of the European Parliament and of the Council of 16 April 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of radio equipment and repealing Directive 1999/5/EC.

[i.23]   Directive (EU) 2018/1972 of the European Parliament and of the Council of 11 December 2018 establishing the European Electronic Communications Code.

[i.24]   Description of IEEE 802.11bd[TM], C2C Journal page 21ff.

NOTE: Available at https://www.car-2-car.org/fileadmin/downloads/PDFs/car-2-car-journal/Journal_23_C2C-CC_Oct_2019_web.pdf.

[i.25]   IEEE 802.11[TM]-2016: "IEEE Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks-Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications".

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the terms given in ETSI EN 302 665 [i.14], ETSI EN 302 663 [i.6] and ETSI TS 103 613 [i.8] apply.

3.2 Symbols

Void.

3.3 Abbreviations

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

3GPP	3rd Generation Partnership Project
5G	5th generation of cellular mobile communications
CEN	Comité Européen de Normalisation (European Committee for Standardization)
CENELEC	Comité Européen de Normalisation Électrotechnique (European Committee for Electrotechnical Standardization)
DTC	Duplicated transmission via cellular interface
GW	GateWay
IBC	Infrastructure Based Conversion
ITS	Intelligent Transportation System
ITS-G5	Access layer technology

NOTE: As defined in ETSI EN 302 663 [i.6].

ITS-S	ITS Station
LTE	Long Term Evolution
LTE-V2X	Long Term Evolution based Vehicle-to-Everything

NOTE: As defined in ETSI TS 103 613 [i.8].

MAC	Media Access Control
MEC	Multi-access Edge Computing
MTA	Multiple technologies for all ITS-Ss
MTL	Multiple technologies for later deployed ITS-Ss
MTL-DT	Multiple technologies and duplicated transmission for later deployed ITS-Ss
NGV	Next Generation V2X
NR	New Radio
PC5	Proximity-based Communication (Interface) 5
V2N	Vehicle-to-Network
V2X	Vehicle-to-Everything

4 Challenges in a heterogeneous ITS environment

There are a number of candidate wireless communications technologies to address ITS requirements, including in particular 3GPP LTE-V2X (Releases 14 and 15) specified in ETSI TS 103 613 [i.8], ITS-G5 specified in ETSI EN 302 663 [i.6], and 3GPP cellular technologies specified in ETSI TS 125 300 [i.10], ETSI TS 136 300 [i.5], ETSI TS 138 300 [i.11] and ETSI TR 102 962 [i.7] for short and long-range communications. Furthermore, it is expected that communication standards evolve; for example, 3GPP has a work item on an evolution of the existing LTE-V2X solution towards 5G New Radio (NR) technology, which aims to comprise a new system design, including a new access layer and aims to support interoperability and backward compatibility on system level with the existing LTE-V2X systems. Also, IEEE is developing IEEE 802.11bd [i.24] which aims to provide a next generation V2X access layer that aims to be interoperable and backward compatible with the existing ITS-G5 (IEEE 802.11p [i.25] - based access layer) on system level and radio access technology level.

Since it is possible that distinct short-range access layer technologies may be operated in the 5,9 GHz ITS band at the same time and location, interoperability and backward compatibility are addressed in the present document.

Other challenges, e.g. coexistence of different short-range communication technologies and potential architecture enhancement for ITS-Ss with multiple access layer technologies, are addressed by other work within ETSI.

5   Regulatory environment

To guide the investigation of interoperability and backward compatibility on utilizing multiple access layer technologies for Cooperative ITS, the related regulatory environments are summarized in this clause. The ITS Directive 2010/40/EU [i.2] is the umbrella legislation for ITS services. M/453 [i.1] was subsequently adopted to ensure that the addressed standardization bodies are taking their role in developing the standards. Those standards provide a basis for the effective provision of Cooperative ITS priority services.

The interoperability and backward compatibility aspects for heterogeneous communication systems are considered based on the definitions of interoperability and backward compatibility in the ITS Directive 2010/40/EU [i.2]. With regards to the regulatory framework, at least the following additional regulations and reports exist:

- COM(2016) 766 [i.15].

- European Commission C-ITS Platform reports I [i.16] and II [i.17].

- European spectrum regulation, EC Decision 2008/671/EC [i.3], Directive 2014/53/EU [i.22] and Directive (EU) 2018/1972 [i.23].

6   Interoperability

6.1   Context

Multiple ITS access layer technologies have been developed independently of each other or are currently in development, e.g. ITS-G5 specified in ETSI EN 302 663 [i.6], LTE-V2X specified in ETSI TS 103 613 [i.8], and cellular technologies specified in ETSI TS 125 300 [i.10] for 3G, ETSI TS 136 300 [i.5] for 4G and ETSI TS 138 300 [i.11] for 5G. Some access layer technologies for ITS services are fundamentally different and thus not interoperable at the physical and MAC layers. For example, an LTE-V2X PC5 radio is not able to process ITS-G5 signals nor vice versa. However, interoperability of C-ITS services between devices using different access layer technologies might be supported via other means such as those described in subsequent clauses of the present document.

NOTE: Some other access layer technologies in development aim to be interoperable and backward compatible with each other, for example IEEE 802.11p [i.25] access technology and its evolvement IEEE 802.11bd [i.24].

6.2   Definition

The Article 4 in the Directive 2010/40/EU [i.2] defines interoperability as follows:

- **interoperability:** capacity of systems and the underlying business processes to exchange data and to share information and knowledge.

The Annex II in the Directive 2010/40/EU [i.2] provides a related principle and definition as follows:

- **deliver interoperability:** ensure that systems and the underlying business processes have the capacity to exchange data and to share information and knowledge to enable effective ITS service delivery.

7   Backward Compatibility

7.1   Context

As various short-range ITS access technologies designed to operate in the 5,9 GHz ITS band as well as long-range cellular technologies supporting ITS applications have been developed and are continuing to evolve, it is important to consider how a new iteration of a technology can operate with previous iterations of that technology. In practice, this often leads to the following approach that earlier generation features are maintained by later generation equipment; however, later generation equipment include additional innovations, services and features.

>   NOTE: Where updates of existing equipment are needed to obtain backward compatibility it should be noted that updates in the field, when possible, might imply recalls for ITS equipment where a 100 % update rate would be unrealistic to guarantee.

7.2   Definition

The article 4 in the Directive 2010/40/EU [i.2] defines compatibility as follows:

- **compatibility:** general ability of a device or system to work with another device or system without modification.

The Annex II in the Directive 2010/40/EU [i.2] defines the support of backward compatibility as follows:

- **support backward compatibility:** ensure, where appropriate, the capability for ITS systems to work with existing systems that share a common purpose, without hindering the development of new technologies.

>   NOTE: Incumbent technologies are not considered here and are treated according to frequency regulation.

8   Implementation options

8.1   Context

The context and terminology explanation for the interoperability and backward compatibility have been introduced in previous clauses. The objective of clause 8 is to introduce candidate solutions, which allow vehicular wireless communications equipment of distinct short-range communication technologies interact with each other.

The background of 5,9 GHz ITS band is described in clause 8.2, the evaluation criteria used to evaluate implementation options are listed in clause 8.3, and the baseline implementation options which do not take into account the interoperability and backward compatibility are described in clause 8.4 for the purpose of comparison. The implementation options supporting interoperability are described in clause 8.5, and those supporting interoperability and backward compatibility are described in clause 8.6.

>   NOTE 1: For technologies which support interoperability and backward compatibility via their access layer design, the implementation options providing interoperability and backward compatibility via higher layer design described in clauses 8.5 and 8.6 are not needed.

Coexistence of access layer technologies is out of scope of the present document. Co-channel and adjacent channel coexistence between the two existing C-ITS technologies are covered by other work in ETSI. For the scope of the present document, it is assumed that different technologies use separate channels, but coexistence studies may overcome this assumption.

>   NOTE 2: It is essential to know how long products equipped with ITS-Ss will be supported. For vehicles it is typical for 10 years after end of production. For a typical vehicle model, typical development time is 3-5 years, production time is 5-8 years and lifetime is more than 10 years with guaranteed support. In contrast, the typical lifetime of consumer communication equipment is 2-3 years.
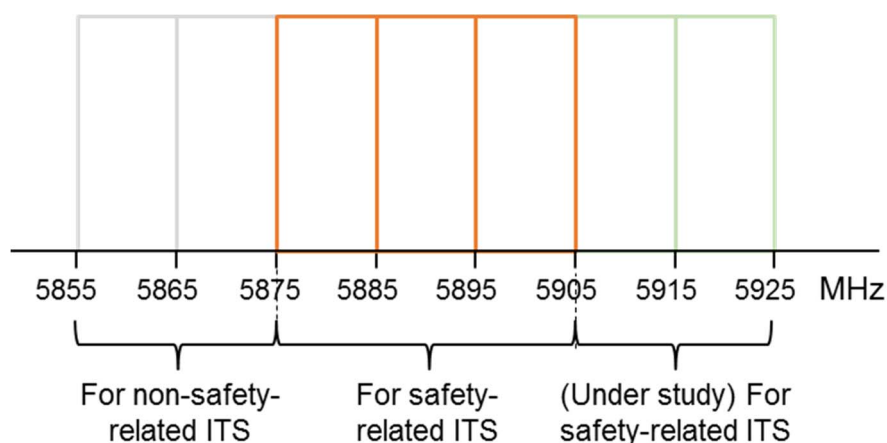
8.2   Background of 5,9 GHz ITS band

Figure 1: European 5,9 GHz channel layout

According to Commission Decision 2008/671/EC [i.3] and ECC Decision (08)01 [i.4], the 5,9 GHz ITS band in Europe consists of three 10 MHz frequency channels for safety-related ITS applications, as shown in Figure 1.

8.3   Evaluation criteria

The following criteria are considered in the present document to support applications for the road safety and traffic efficiency, and are used to evaluate the implementation options described in clauses 8.4 to 8.6.

1) **Interoperability:** as defined in clause 6.2.

2) **Backward compatibility:** as defined in clause 7.2.

3) **Latency:** time it takes to transfer a given piece of information from a transmitting ITS-S to a receiving ITS-S at the facilities layer, more specifically time from the moment that a given piece of information is passed to the facilities layer at the transmitting ITS-S to the moment that the given piece of information is passed from the facilities layer to its upper layer of the receiving ITS-S.

NOTE 1: Implementation options with higher latencies above C-ITS safety services requirements are not suitable. Latency requirements for several C-ITS services are found in ETSI TS 101 539-1 [i.18], ETSI TS 101 539-2 [i.19], ETSI TS 101 539-3 [i.20] and [i.21].

4) **Efficiency of spectrum usage:** the efficiency of spectrum usage is defined in the present document as the effective and efficient spectrum usage. The efficiency of spectrum usage is considered as high when duplicated message transmission is not needed regardless of the radio technology, and as low when duplicated message transmission is needed to transmit a same ITS message.

5) **Radio access impartiality:** the radio access impartiality is defined in the present document that the system design neither imposes nor discriminates in favour of the use of a particular type of radio access technology.

6) **Technology evolution acceptability:** the technology evolution acceptability is defined in the present document as not hindering the development of new technologies.

7) **Implementation complexity:** required hardware and software costs, package volume in vehicles.

8) **Infrastructure required:** whether or not an implementation option properly works only in an infrastructure coverage.

NOTE 2: The goal of the criteria 3) to 8) is to evaluate the qualitative cost that each implementation option needs for supporting the interoperability and backward compatibility compared to other options.

8.4   Baseline options

8.4.1   Single radio technology in 5,9 GHz ITS band (Base#1)

8.4.1.1   Description of the option

This option is defined with the following assumptions:

- Only a single iteration of a single radio technology is used in the 5,9 GHz ITS band.

- All ITS-Ss are equipped with the single iteration of that radio technology.

- All ITS-Ss transmit and receive ITS messages via the single radio technology.

Figure 2 illustrates an example of the solution described above.
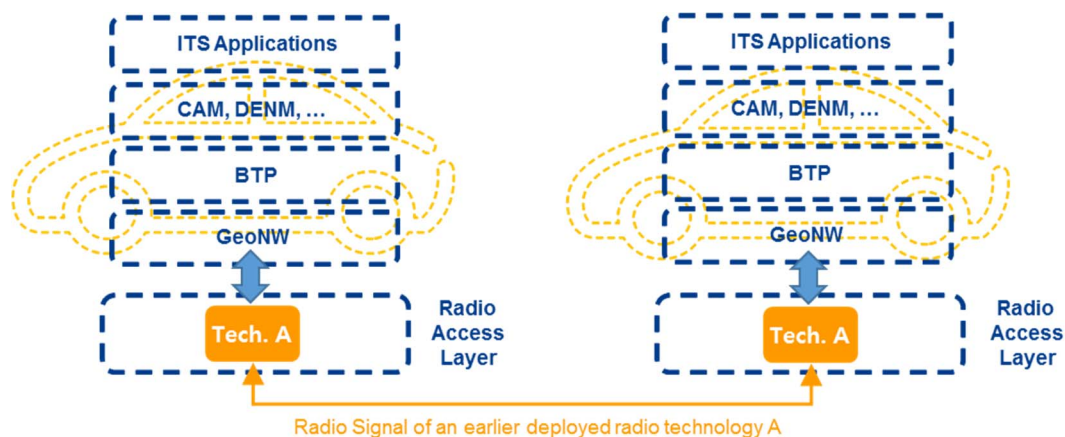
NOTE: ITS-Ss can be vehicle or roadside ITS-Ss.

Figure 2: Example architecture for Base#1

8.4.1.2   Observation and analysis of the option

- **Interoperability:** The interoperability between ITS-Ss equipped with distinct radio technologies is not addressed in this option because only a same iteration of one single radio technology is considered. The interoperability among all ITS-Ss in this option is supported the highest among all options, since all ITS-Ss are equipped with a same iteration of the same radio technology.

- **Backward compatibility:** Not applicable because only a single iteration of a single radio technology is considered.

- **Latency:** Lowest among all options.

NOTE 1:   The latency of this option is considered the lowest no matter which radio technology is used since this option does not need additional latency for supporting interoperability and/or backward compatibility. The latency of this option can be referred when evaluating the latency of other options.

- **Efficiency of spectrum usage:** Highest among all options.

NOTE 2:   The spectrum usage of this option is considered the highest no matter which radio technology is used since this option does not need additional spectrum usage for supporting interoperability and/or backward compatibility. The spectrum usage of this option can be referred when evaluating the spectrum usage of other options.

- **Radio access impartiality:** Not applicable by the definition of this option because only a single iteration of a single radio technology is considered.

- **Technology evolution acceptability:** Not applicable by the definition of this option because only a single iteration of a single radio technology is considered.

- **Implementation complexity:** Lowest among all options.

NOTE 3: The implementation complexity of this option is considered the lowest no matter which radio technology is used since this option does not need additional implementation complexity for supporting interoperability and/or backward compatibility. The implementation complexity of this option can be referred when evaluating the implementation complexity of other options.

- **Infrastructure required:** No.

8.4.2   Single radio technology with its future iterations in 5,9 GHz ITS band (Base#1b)

8.4.2.1   Description of the option

This option is defined with the following assumptions:

- Multiple iterations of a single radio technology, which are interoperable and backward compatible with each other at the physical and MAC layers, are used in the 5,9 GHz ITS band. No distinct channels are needed and all iterations can work in the same channel. All later iterations can receive and interpret messages from earlier iterations.

- All ITS-Ss are equipped only with one of the technology iterations.

- All ITS-Ss transmit and receive ITS messages via a single radio technology. Neither for transmission nor for reception multiple radios are necessary.

Figure 3 illustrates an example of the solution described above.
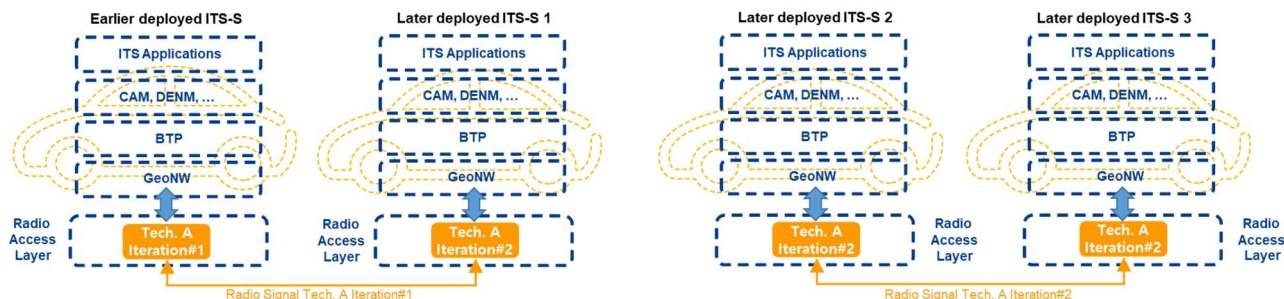
NOTE: ITS-Ss can be vehicle or roadside ITS-Ss.

Figure 3: Example architecture for Base#1b

8.4.2.2   Observation and analysis of the option

- **Interoperability:** The interoperability between ITS-Ss equipped with distinct radio technologies is not addressed in this option. However, the interoperability among all ITS-Ss in this option is supported because all ITS-Ss can communicate with others within the same or older iteration of the same radio technology.

- **Backward compatibility:** Supported.

- **Latency:** Same as that of Base#1, i.e. lowest among all options.

- **Efficiency of spectrum usage:** Same as that of Base#1, i.e. highest among all options.

- **Radio access impartiality:** Not applicable by the definition of this option because only iterations of a single radio technology are considered.

- **Technology evolution acceptability:** Limited as only one technology's backward compatible iterations are considered.

- **Implementation complexity:** On a system level similar to that of Base#1. For a given ITS Station the iterations of technology might increase complexity, but should be lower than multi-radio technology implementations.

- **Infrastructure required:** No.

8.4.3 Different radio technologies in distinct ITS-Ss (Base#2)

8.4.3.1 Description of the option

This option is defined with the following assumptions:

- Multiple different radio technologies are not interoperable with each other at the physical and MAC layers. It is assumed for simplicity of the present document that the different radio technologies use distinct 10 MHz channels of the 5,9 GHz ITS band. It is assumed that the number of distinct radio technologies is equal or less than the number of available 10 MHz channels.

  NOTE: Practical deployments may use different channels for different services using one radio technology.

- Each ITS-S is equipped with a single radio technology among the multiple radio technologies.

- Each ITS-S transmits and receives ITS messages via the equipped radio technology and does not communicate with the ITS-Ss equipped with the other radio technology.

Figure 4 illustrates an example of the solution described above.
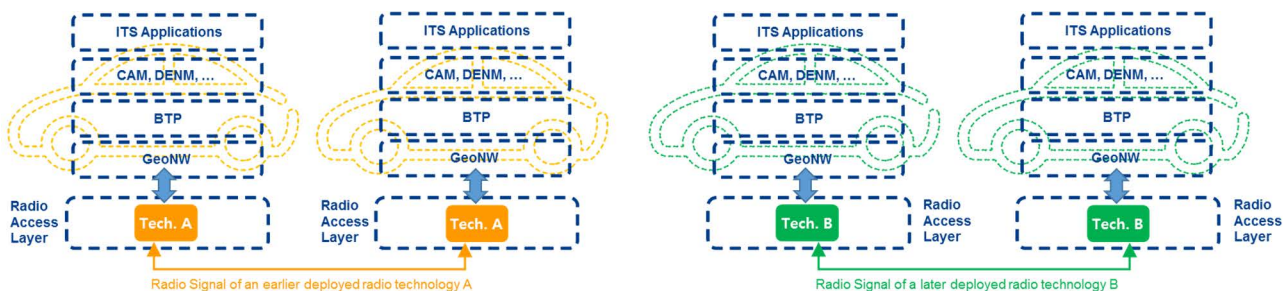
NOTE: ITS-Ss can be vehicle or roadside ITS-Ss. It is assumed that different radio resources are used by the different technologies.

Figure 4: Example architecture for Base#2

8.4.3.2 Observation and analysis of the option

- **Interoperability:** Not supported because ITS-Ss equipped with distinct radio technologies cannot communicate with each other.

- **Backward compatibility:** Not supported because ITS-Ss equipped with distinct radio technologies cannot communicate with each other.

- **Latency:** Same as that of Base#1, i.e. lowest among all options.

- **Efficiency of spectrum usage:** Same as that of Base#1, i.e. highest among all options because no message is duplicated compared to Base#1.

NOTE: Even though the spectrum usage of this option is same as that of Base#1, all options, including this option, assuming multiple radio technologies are used in distinct channels need additional channel assignment compared to the Base#1 and it reduces the number of channels available for other use cases. In case of high channel utilization and uneven distribution of technology deployment, it prevents load balancing over multiple channels: a channel is blocked even by a limited number of users of the minority technology.

- **Radio access impartiality:** Initially supported but limited by the number of available channels, since each technology is using a distinct channel. Later deployed technologies have a smaller number or no channel available.

- **Technology evolution acceptability:** Supported but limited by the number of available channels, since each technology uses a distinct channel. Later deployed technologies have a smaller number or no channel available.

- **Implementation complexity:** Same as that of Base#1, i.e. lowest among all options.

- **Infrastructure required:** No.

8.5   Interoperability options

8.5.1   Multiple technologies for all ITS-Ss (MTA)

### 8.5.1.1   Description of the option

An ITS message is transmitted via one of multiple radio technologies in the 5,9 GHz ITS band which cannot directly communicate with each other at the radio level. To ensure that ITS messages can be received and processed by ITS applications at the receiving ITS-Ss regardless of the radio technology used for the transmission, this option is defined with the following assumptions:

- Multiple different radio technologies are not interoperable with each other at the physical and MAC layers. It is assumed for simplicity of the present document that the different radio technologies use distinct 10 MHz channels of the 5,9 GHz ITS band. It is assumed that the number of distinct radio technologies is equal or less than the number of available 10 MHz channels.

NOTE: Practical deployments may use different channels for different services using one radio technology.

- Each ITS-S is equipped with all the multiple radio technologies and implements the identical and standardized ETSI ITS upper layer protocol stack. In this option, each ITS-S is assumed to be updatable so that each ITS-S will be equipped with all the multiple radio technologies including any new technologies.

- Each ITS-S transmits and receives ITS messages via any single radio technology of the equipped multiple radio technologies and can communicate with any other ITS-Ss. Multiple radio technologies are equally considered in this solution. ITS-Ss have the freedom to select the transmitting technology.

Figure 5 illustrates an example of the solution described above.
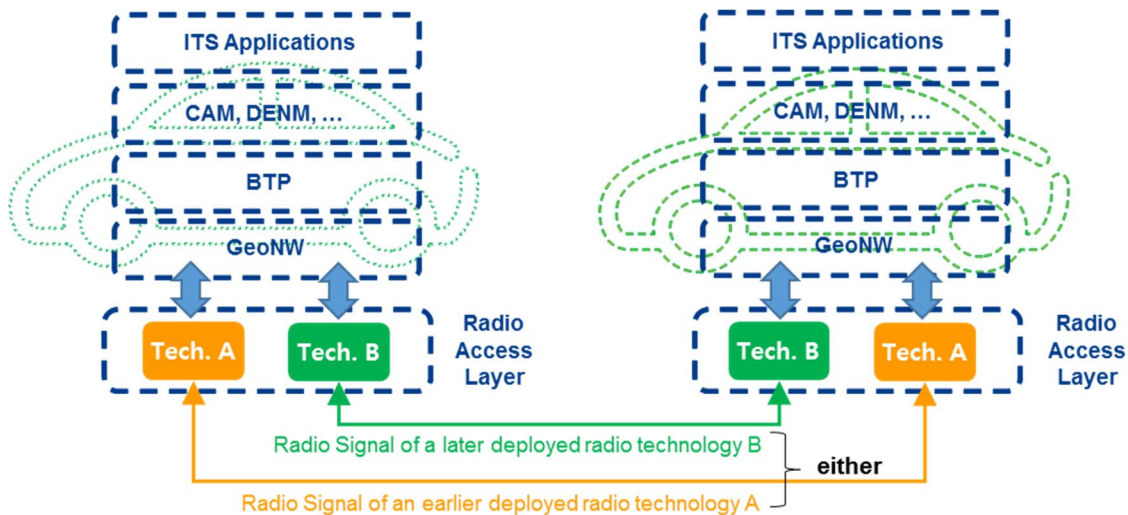
NOTE: ITS-Ss can be vehicle or roadside ITS-Ss.

Figure 5: Example architecture for MTA

8.5.1.2   Observation and analysis of the option

- **Interoperability:** Supported because each ITS-S can communicate with any other ITS-Ss.

- **Backward compatibility:** Not supported since an earlier deployed ITS-S needs a modification to be equipped with additional radio technology.

NOTE 1: Lack of backward compatibility might influence the interoperability, e.g. interoperability with earlier deployed equipment only supporting one technology is not supported.

- **Latency:** Same as that of Base#1, i.e. lowest among all options.

- **Efficiency of spectrum usage:** Same as that of Base#1, i.e. highest among all options.

- **Radio access impartiality:** Initially supported but limited by the number of available channels, since each technology is using a distinct channel. Later deployed technologies have a smaller number or no channel available.

NOTE 2: This option does not discriminate in favour of the use of a particular type of technology, but does impose requirements to be able to receive messages via all technologies.

- **Technology evolution acceptability:** Supported but limited by the number of available channels, since each technology uses a distinct channel. Later deployed technologies have a smaller number or no channel available.

- **Implementation complexity:** Higher than that of Base#1 to support more than one radio technology and might need update in the field.

- **Infrastructure required:** No.

8.5.2   Duplicated transmission via cellular interface (DTC)

8.5.2.1   Description of the option

Transmission of data packets on the cellular interface can be a way to enable the interoperability between the ITS-Ss which cannot directly communicate with each other at the radio level. This option is defined with the following assumptions:

- Multiple different radio technologies are not interoperable with each other at the physical and MAC layers. It is assumed for simplicity of the present document that the different radio technologies use distinct 10 MHz channels of the 5,9 GHz ITS band. It is assumed that the number of distinct radio technologies is equal or less than the number of available 10 MHz channels.

  NOTE: Practical deployments may use different channels for different services using one radio technology.

- Each ITS-S is equipped with a single short-range radio technology among the multiple radio technologies.

- All ITS-Ss are also equipped with a cellular radio technology, e.g. LTE-V2N Uu with a valid subscription to be able to participate in this scenario.

- Each ITS-S transmits and receives ITS message via the equipped single short-range radio technology and simultaneously via the cellular radio technology.

Cellular base stations or roadside ITS-Ss with a cellular communication technology re-transmit the received ITS messages to all ITS-Ss under their coverage via the cellular downlink. For reduced end-to-end latency, the edge computing technologies such as MEC can be employed.

The maximum retention periods of the data collected/processed by infrastructure, e.g. cellular LTE base stations, roadside ITS-Ss and the other related parties, are clearly and strictly constrained in order to avoid privacy risks.

Figure 6 illustrates an example of the solution described above.
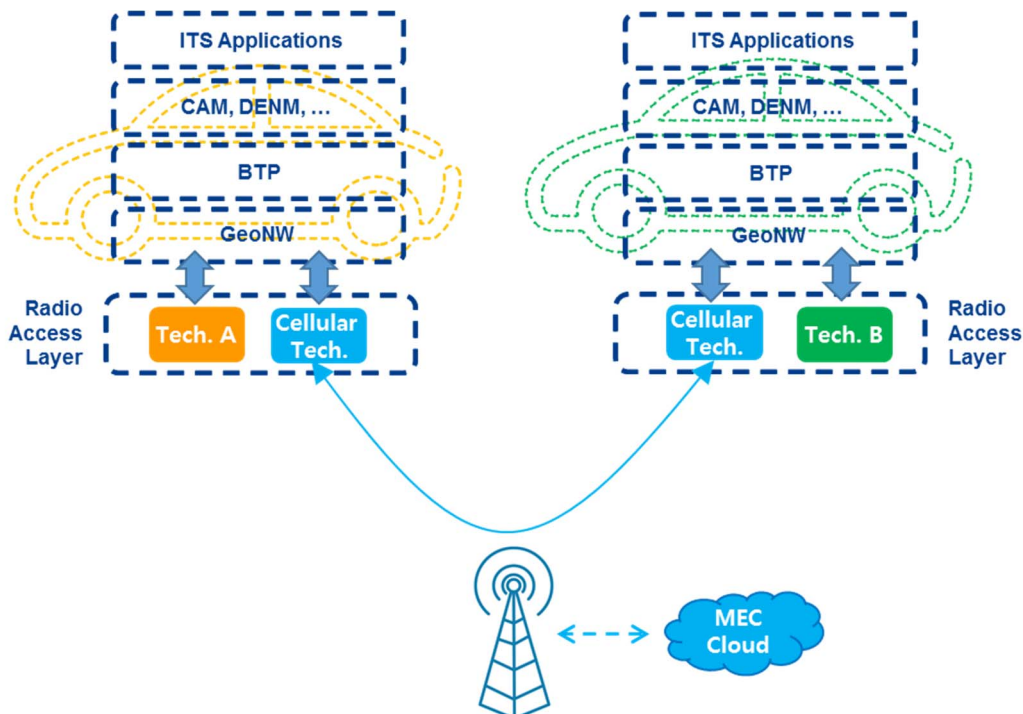
NOTE: ITS-Ss can be vehicle or roadside ITS-Ss.

Figure 6: Example architecture for DTC

8.5.2.2   Observation and analysis of the option

- **Interoperability:** Supported with cellular communication because each ITS-S can communicate with any other ITS-Ss via a cellular radio technology. Limited if communication uses MEC, which may require that ITS-S are connected to the same cellular network under the same service provider.

- **Backward compatibility:** Not supported since an earlier deployed ITS-S needs a modification to be equipped with an additional radio technology.

NOTE 1: It is assumed that the ITS-Ss follow the so-called 'hybrid communication' approach and include both short-range and long-range communication, e.g. cellular.

- **Latency:** Higher than that of Base#1 due to the retransmission via a cellular radio technology.

NOTE 2: Latency is the key issue for the transmission of safety related packets via LTE-V2N Uu, especially as cross-network communication among mobile operators would be required. This might be addressed by the deployment of edge computing, e.g. MEC, although more studies might be needed to further evaluate the performance of such deployment, especially under congestion.

   The MEC is localized/distributed close to the source of messages in order to reduce latency. Therefore the messages are transmitted/received at a local level avoiding any messages to be sent to a centralized data base or data centre, which helps to protect the privacy. Moreover, the retention periods of the data in infrastructure are strictly limited in this solution. Therefore, the privacy can be managed.

   The MEC depends on latency reduction solutions in network, a Local-GW deployed close to the RAN could be one solution to improve Network Latency as specified in ETSI TS 123 401 [i.9].

- **Efficiency of spectrum usage:** Lower than that of Base#1 due to the duplicated transmission of packets on the LTE-V2N Uu interface, in addition to an equipped direct short-range communication technology.

- **Radio access impartiality:** Not supported, since the use of a cellular access technology is imposed. However, it supports the radio access impartiality between the short-range access technologies.

NOTE 3: Communication via MEC may require that ITS-S are connected to the same cellular network under the same service provider.

- **Technology evolution acceptability:** Supported but limited by the number of available channels, since each technology uses a distinct channel. Later deployed technologies have a smaller number or no channel available.

- **Implementation complexity:** Higher than that of Base#1 to support a cellular radio technology.

- **Infrastructure required:** Yes. Cellular coverage is needed.

NOTE 4: In addition to the coverage limitation, interoperable MEC with different service providers needs to be investigated further for practical deployment.

8.6   Interoperability and Backward compatibility options

8.6.1   General

Backward compatibility will have to be achieved for any new release of a given technology and will be an issue in the future.

Backward compatibility of NR-V2X with LTE-V2Xfalls under the responsibility of 3GPP for lower layers and ETSI for higher layers. Similarly, backward compatibility of NGV with ITS-G5 is the responsibility of IEEE for lower layers and ETSI for higher layers.

Any new release of a given technology will have to be interoperable with older releases of another technology. For example, NR-V2X will have to be interoperable with ITS-G5. This could be achieved at higher layers or with system level mechanisms.

In the clauses below, interoperability and backward compatibility options are described with "earlier deployed" radio technologies and "later deployed" radio technologies. Examples of earlier deployed radio technologies are ITS-G5 and LTE-V2X. Later deployed radio technologies will be future iterations of ITS-G5 and LTE-V2X, e.g. NR-V2X and NGV, or completely new radio technologies.

8.6.2   Multiple technologies for later deployed ITS-Ss (MTL)

8.6.2.1   Description of the option

This option proposes two distinct types of ITS-Ss, i.e. a less complex type supporting only the earlier deployed radio technology and a more complex type supporting both the earlier deployed and the later deployed radio technologies. Regarding the road safety effect, this option allows all ITS-Ss to support basic safety features provided over the earlier deployed radio technology. New enhanced safety features are supported by ITS-Ss vehicles that also can use the later deployed radio technology. This option is defined with the following assumptions:

- Multiple radio technologies including earlier deployed and later deployed radio technologies, which are not interoperable with each other at the physical and MAC layers, are used in distinct 10 MHz channels of the 5,9 GHz ITS band. It is assumed that the number of distinct radio technologies is equal or less than the number of available 10 MHz channels.

  NOTE: Practical deployments may use different channels for different services using one radio technology.

- Each ITS-S is equipped with either an earlier deployed radio technology only, or both earlier deployed and later deployed technologies.

- All ITS-Ss transmit and receive ITS messages for basic safety features via the earlier deployed radio technology.

- ITS-Ss equipped with the later deployed radio technology transmits and receives ITS messages for enhanced safety features via later deployed radio technology.

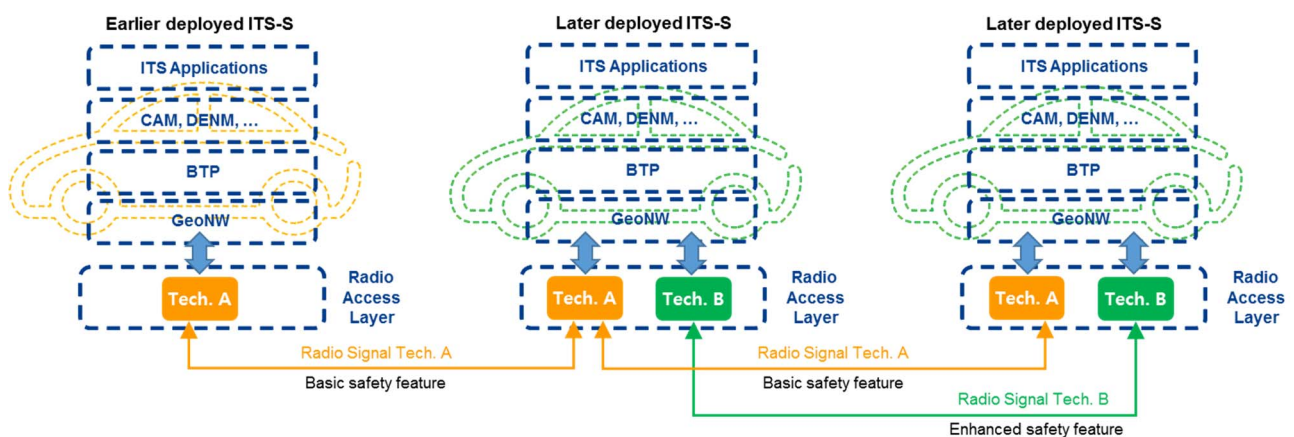Figure 7 illustrates an example of the solution described above.

NOTE: ITS-Ss can be vehicle or roadside ITS-Ss.

Figure 7: Example architecture for MTL

8.6.2.2   Observation and analysis of the option

- **Interoperability:** Supported because all ITS-Ss can communicate with each other via either the earlier deployed radio technology or the later deployed technology for basic safety features, but not for enhanced safety features.

- **Backward compatibility:** Supported because earlier deployed ITS-Ss can communicate with any other ITS-Ss without modification.

- **Latency:** Same as that of Base#1, i.e. lowest among all options.

- **Efficiency of spectrum usage:** Same as that of Base#1, i.e. highest among all options.

- **Radio access impartiality:** Limitedly supported because a later deployed radio technology is allowed but the additional implementation complexity is imposed only on the ITS-Ss equipped with the later deployed radio technology.

- **Technology evolution acceptability:** Limitedly supported because the additional implementation complexity is imposed only on the ITS-Ss equipped with a later deployed radio technology and it can hinder the development of new technologies.

- **Implementation complexity:** Same as that of Base#1 for earlier deployed ITS-Ss, but higher than that of Base#1 to support more than one radio technologies for later deployed ITS-Ss.

- **Infrastructure required:** No.

8.6.3   Multiple technologies and duplicated transmission for later deployed ITS-Ss (MTL-DT)

8.6.3.1   Description of the option

This option proposes two distinct types of ITS-Ss, i.e. a less complex type supporting only the earlier deployed radio technology and a more complex type supporting both the earlier deployed and the later deployed radio technologies like the implementation option MTL described in clause 8.6.2. Unlike the MTL option, however, this option proposes duplicated message transmission via all the equipped radio technologies without feature-based technology selection.

NOTE 1: The purpose of duplicated transmission is the support of interoperability. It could be accompanied with a sunset scheme for using the older technology to free up spectrum. Since the typical economical lifetime of vehicles is 15 years, this advantage may be slow to attain.

This option is defined with the following assumptions:

- Multiple radio technologies including earlier deployed and later deployed radio technologies, which are not interoperable with each other at the physical and MAC layers, are used in distinct 10 MHz channels of the 5,9 GHz ITS band. It is assumed that the number of distinct radio technologies is equal or less than the number of available 10 MHz channels.

NOTE 2: Practical deployments may use different channels for different services using one radio technology.

- Each ITS-S is equipped with either an earlier deployed radio technology only, or both earlier deployed and later deployed radio technologies.

- All ITS-Ss transmit and receive ITS messages via all the equipped radio technologies, i.e. either the earlier deployed radio technology only, or both earlier deployed and later deployed radio technologies.

Figure 8 illustrates an example of the solution described above.
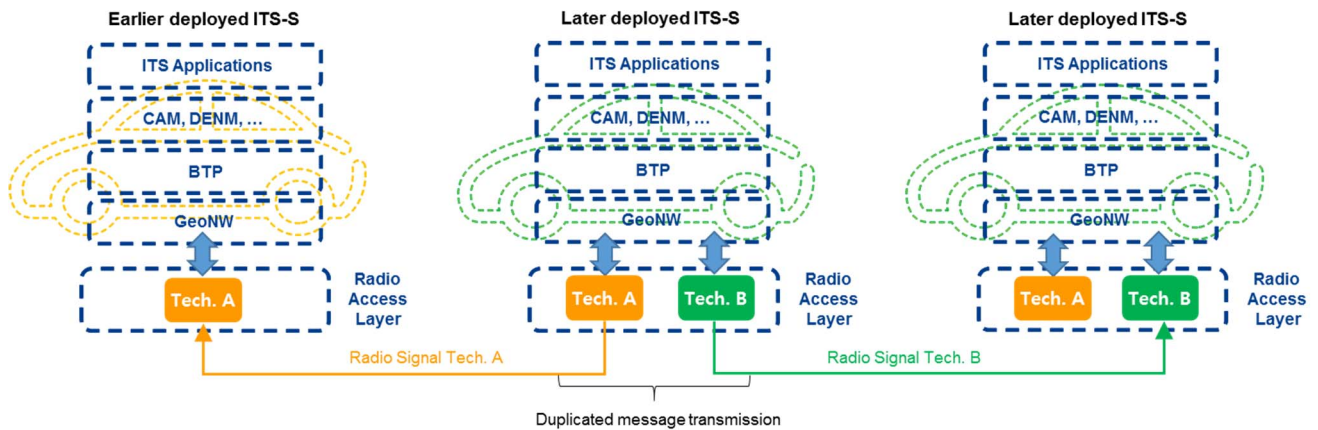
NOTE: ITS-Ss can be vehicle or roadside ITS-Ss.

Figure 8: Example architecture for MTL-DT

8.6.3.2 Observation and analysis of the option

- **Interoperability:** Supported because all ITS-Ss can communicate with each other via either the earlier deployed radio technology or the later deployed technology.

- **Backward compatibility:** Supported because earlier deployed ITS-Ss can communicate with any other ITS-Ss without modification.

- **Latency:** Same as that of Base#1, i.e. lowest among all options.

- **Efficiency of spectrum usage:** Same as that of Base#1 for message transmission of earlier deployed ITS-Ss, but lower than that of Base#1 due to the duplicated message transmission of later deployed ITS-Ss.

- **Radio access impartiality:** Limitedly supported because a later deployed radio technology is allowed but the additional implementation complexity is imposed only on the ITS-Ss equipped with the later deployed radio technology.

- **Technology evolution acceptability:** Limitedly supported because the additional implementation complexity is imposed only on the ITS-Ss equipped with a later deployed radio technology and it can hinder the development of new technologies.

- **Implementation complexity:** Same as that of Base#1 for earlier deployed ITS-Ss, but higher than that of Base#1 to support more than one radio technologies for later deployed ITS-Ss.

- **Infrastructure required:** No.

8.6.4 Infrastructure Based Conversion (IBC)

8.6.4.1 Description of the option

V2X data packets may be received and processed by infrastructure equipment deployed in the proximity of the transmission source, for example through deployment of roadside ITS-Ss or in cellular base stations as depicted in Figure 9. It is proposed to add a conversion feature to suitable infrastructure equipment in order to translate sidelink or short-range data packets of a first radio access technology, e.g. LTE-V2X PC5 to a second radio access technology, e.g. ITS-G5, and vice versa. This option is defined with the following assumptions:

- Multiple radio technologies including earlier deployed and later deployed radio technologies, which are not interoperable with each other at the physical and MAC layers, are used in distinct 10 MHz channels of the 5,9 GHz ITS band. It is assumed that the number of distinct radio technologies is equal or less than the number of available 10 MHz channels.

NOTE: Practical deployments may use different channels for different services using one radio technology.

- Each vehicle ITS-S is equipped with a single radio technology among the multiple radio technologies.

- Each vehicle ITS-S transmits and receives ITS messages via the equipped single radio technology.

- Roadside ITS-Ss or cellular base stations are equipped with all the multiple radio technologies and conversion functionality.

- The roadside ITS-Ss or cellular base stations receive data packets of a radio technology, convert them to the data packets for another radio technology, and transmit them for the ITS-Ss equipped with the latter radio technology.

The successful implementation of the proposed framework requires that the original transmission occurs in proximity to infrastructure equipment with conversion capability and the latency introduced by the conversion and retransmission meets overall latency budget requirements.

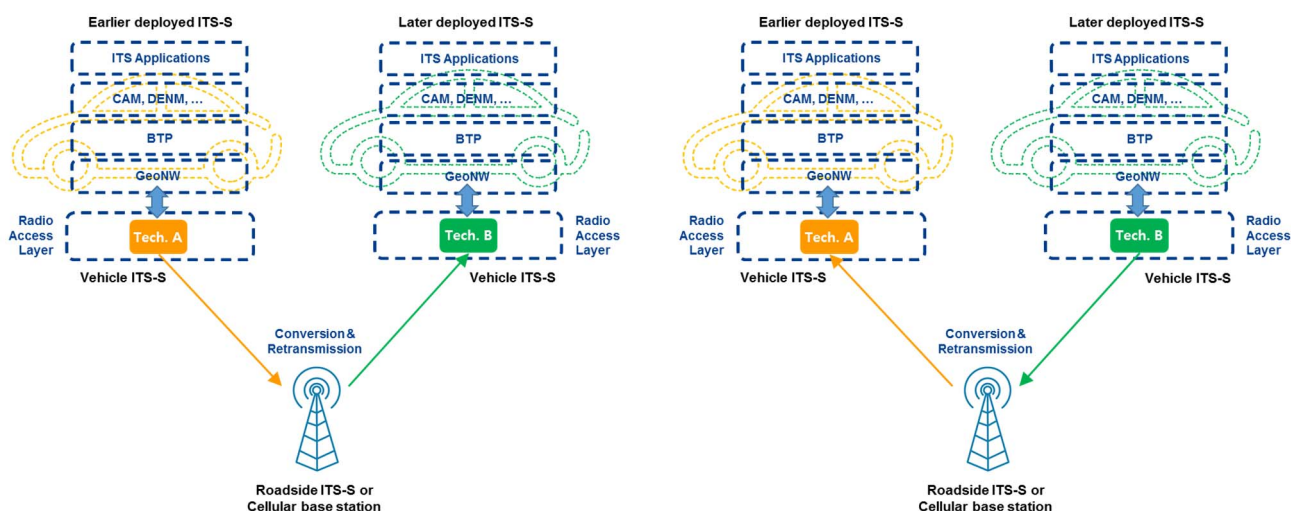Figure 9 illustrates an example of the solution described above.

Figure 9: Example architecture for IBC

The processing through the different protocol layers of the ITS-S architecture, which is included in the converter depends on different requirements for the conversion operations. One basic assumption is that ITS-Ss employ the same higher layer protocols, such as networking, transport, and facility layer, as well as their supporting security and management protocols. In Figure 10 the simplest conversion architecture is depicted with a radio access layer-only processing. In this case the complexity in the converter is minimal and the additional latency due to the conversion operation is expected to be low. Address conversion among different technologies need to be taken into account, especially if access layer addresses are used or referenced outside the protocol headers. Furthermore, protocols might rely on control messages that have no equivalent in the other technology.
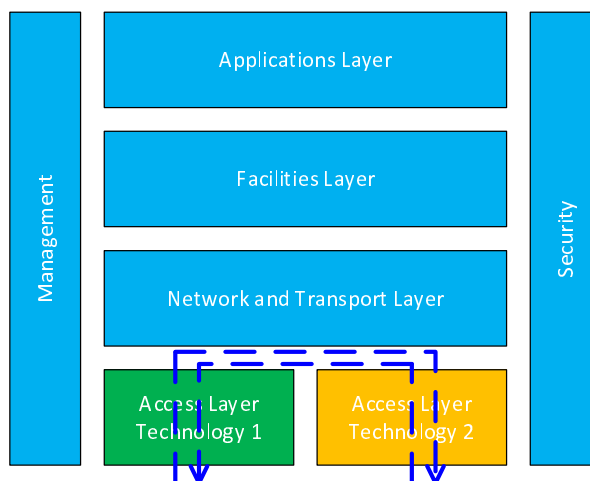
Figure 10: Converter reference architecture with radio access layer-only processing

In Figure 11 another converter architecture with radio access, network and transport layer processing is represented. Depending on an associated functionality that may be added to the converter, some intelligence can be included when processing the data packets in the network and transport layer. For example, GeoNetworking functionalities can be associated to the converter or the time-stamp of the packets can be verified to analyse if a message is still worth to be transcoded to the other technology or it has already become irrelevant. A slightly higher level of complexity has to be added to the converter compared to the radio access-only converter. Data elements which are electronically signed by the sender are an obstacle for transcoding on higher layers, since the original signature of the sender may get lost after transcoding, so that the receiver cannot assess the validity of the original message.
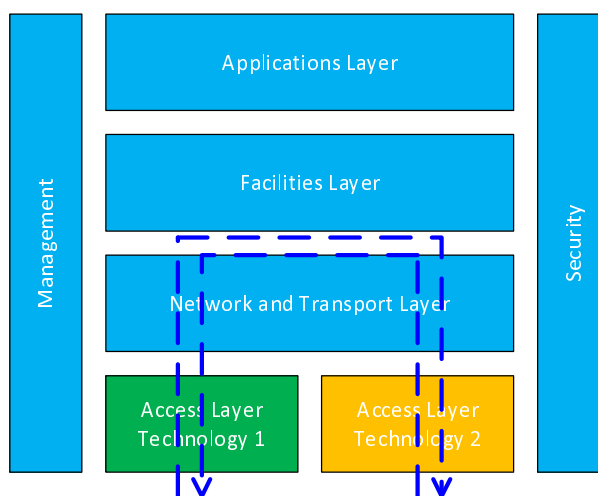
Figure 11: Conversion with radio access, network and transport layers processing

In Figure 12 a converter architecture with radio access, network, transport and facilities layer processing is shown. Here further functionalities associated to the facilities layers can be added to the converter. For example, the authenticity of the messages can be verified before the conversion is performed to avoid the multiplication of misbehaviour. A higher complexity as well as a higher latency are expected in this option. Data elements which are electronically signed by the sender are an obstacle for transcoding on higher layers, since the original signature of the sender may get lost after transcoding, so that the receiver cannot assess the validity of the original message.
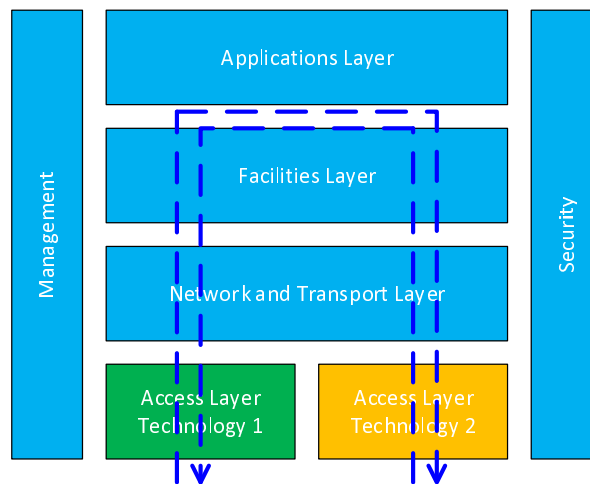
Figure 12: Conversion including radio access, networking, transport and facilities layers processing

The requirements of functional safety according to ISO 26262 [i.12] and IEC 61508 [i.13], as well as privacy and security requirements need to be addressed.

8.6.4.2   Observation and analysis of the option

- **Interoperability:** Supported because each ITS-S can communicate with any other ITS-Ss directly or via conversion.

- **Backward compatibility:** Supported for vehicle ITS-Ss. Not supported for roadside ITS-Ss since earlier deployed roadside ITS-Ss may communicate with one technology only.

- **Latency:** Higher than that of Base#1 due to the conversion and retransmission.

- **Efficiency of spectrum usage:** Lower than that of Base#1 due to the duplicated transmission.

- **Radio access impartiality:** Supported for vehicle ITS stations. For infrastructure, initially supported, but introduction of additional new technology will face a backward compatibility issue or require an infrastructure upgrade.

- **Technology evolution acceptability:** Supported.

NOTE 1: This approach will facilitate a transition from one technology to another and thus prepares for future evolutions of the respective technologies.

- **Implementation complexity:** Same as that of Base#1 for vehicle ITS-Ss which do not provide the conversion feature. Higher for roadside ITS-Ss to support more than one radio technology and provide the conversion feature.

- **Infrastructure required:** Yes.

NOTE 2: The service availability is limited to coverage areas of roadside ITS-Ss and/or base stations. In one example, a roadside ITS-S may have a coverage range of 300 meters. In such a case, the roadside ITS-Ss need to be deployed approximately every 600 meters. Additional installation of the infrastructure or update of the currently installed infrastructure will be needed. The feasibility of providing a reasonable coverage to bridge the incompatibility gap through this approach should be investigated in further study.

# 9		Analysis and Conclusion

## 9.1		Summary of analysis

The implementation options introduced in the present document are as follows:

- **Base#1:** Baseline option#1, "Single radio technology" described in clause 8.4.1.

- **Base#1b:** Baseline option#1b, "Single radio technology with its future iterations" described in clause 8.4.2.

- **Base#2:** Baseline option#2, "Multiple radio technologies" described in clause 8.4.3.

- **MTA:** Interoperability option#1, "Multiple technologies for all ITS-Ss" described in clause 8.5.1.

- **DTC:** Interoperability option#2, "Duplicated transmission via cellular interface" described in clause 8.5.2.

- **MTL:** Interoperability and backward compatibility option#1, "Multiple technologies for later deployed ITS-Ss" described in clause 8.6.2.

- **MTL-DT:** Interoperability and backward compatibility option#2, "Multiple technologies and duplicated transmission for later deployed ITS-Ss" described in clause 8.6.3.

- **IBC:** Interoperability and backward compatibility option#3, "Infrastructure based conversion" described in clause 8.6.4.

The observation and analysis of all the implementation options described in clause 8 are summarized in Table 1. "High", "Medium", and "Low" in Table 1 only indicate the relative level among the listed options.

Table 1: Summarized evaluation of the implementation options

Evaluation Criteria	Implementation Options							
	Baseline Options			Interoperability Options		Interoperability & Backward Compatibility Options		
	Base#1	Base#1b	Base#2	MTA	DTC	MTL	MTL-DT	IBC
Interoperability	Yes (note 1)	Yes (note 2)	No	Yes	Yes (note 7) (indirect)	Limited (note 12))	Yes	Yes (note 7) (indirect)
Backward compatibility	N/A	Yes	No	No	No (note 8)	Yes	Yes	Limited (note 18))
Latency	Low	Low	Low	Low	High	Low	Low	High
Efficiency of spectrum usage	High	High	High	High	Low	High	Medium (note 16)	Low
Radio access impartiality	N/A	N/A	Limited (note 5)	Limited (note 5)	Limited (note 9)	Limited (note 13))	Limited (note 13))	Limited (note 19)
Tech. evolution acceptability	N/A	Limited (note 3)	Limited (note 6)	Limited (note 6)	Limited (note 6)	Limited (note 14)	Limited (note 14)	Yes
Implementation complexity	Low	Low (note 4)	Low	High	Medium (note 10)	Medium (note 15)	Medium (note 17)	Medium (note 20)
Infrastructure required	No	No	No	No	Yes (note 11)	No	No	Yes (note 21)

Evaluation Criteria	Implementation Options							
	Baseline Options			Interoperability Options		Interoperability & Backward Compatibility Options		
	Base#1	Base#1b	Base#2	MTA	DTC	MTL	MTL-DT	IBC

NOTE 0:   For safety applications latency needs to be low enough to fulfil application requirements. For spectrum efficiency it is generally a goal to have a high spectrum efficiency.

NOTE 1:   The interoperability between ITS-Ss equipped with distinct radio technologies is not addressed in this option because only a same iteration of a same radio technology is considered. However, the interoperability among all ITS-Ss in this option is supported because all ITS-Ss are equipped with a same iteration of a same radio technology.

NOTE 2:   The interoperability between ITS-Ss equipped with distinct radio technologies is not addressed in this option. However, the interoperability among all ITS-Ss in this option is supported because all ITS-Ss can communicate with others with an iteration of a same radio technology.

NOTE 3:   Limited as only a single technology's backward compatible iterations are considered.

NOTE 4:   On a system level similar to Base#1. For a given ITS Station the iterations of technology might increase complexity but should be lower than multi-radio technology implementations.

NOTE 5:   Initially supported but limited by the number of available channels, since each technology is using a distinct channel. Later deployed technologies have a smaller number or no channel available.

NOTE 6:   Supported but limited by the number of available channels, since each technology uses a distinct channel. Later deployed technologies have a smaller number or no channel available.

NOTE 7:   Interoperability can be provided by direct communication between entities or indirect communication. This option provides the interoperability by indirect communication. Indirect interoperability is given, if an intermediary entity is needed to enable interoperability. Where such an entity provides a function so that dissimilar protocols can exchange information, the term interworking is used.

NOTE 8:   It is assumed that the ITS-Ss follow the so-called 'hybrid communication' approach and include both short-range and long-range communication, e.g. cellular. See clause 8.5.2.2.

NOTE 9:   Not supported, since the use of a cellular access technology is imposed. However it supports the radio access impartiality between the short-range access technologies.

NOTE 10: Additional implementation needed for all ITS-Ss and infrastructure, but already widely implemented. See clause 8.5.2.2.

NOTE 11: In addition to the coverage limitation, interoperable MEC with different service provider needs to be investigated further for practical deployment.

NOTE 12: Supported because all ITS-Ss can communicate with each other via either the earlier deployed radio technology or the later deployed technology for basic safety features, but not for enhanced safety features.

NOTE 13: A later deployed radio technology is allowed but the burden of interoperability is only on the later deployed technology side. See clauses 8.6.2.2 and 8.6.3.2.

NOTE 14: A later deployed radio technology is allowed but additional implementation complexity is imposed only on the ITS-Ss equipped with a later deployed radio technology. It can hinder the development of new technologies. See clauses 8.6.2.2 and 8.6.3.2.

NOTE 15: Additional implementation needed for later deployed ITS-Ss only. See clauses 8.6.2.2 and 8.6.3.2.

NOTE 16: Duplicated transmission is needed but it is needed for later deployed ITS-Ss, not for earlier deployed ITS-Ss. See clause 8.6.3.2.

NOTE 17: Same as that of Base#1 for earlier deployed ITS-Ss, but higher than that of Base#1 to support more than one radio technologies for later deployed ITS-Ss.

NOTE 18: Supported for vehicle ITS-Ss. Not supported for roadside ITS-Ss since earlier deployed roadside ITS-Ss may communicate with one technology only.

NOTE 19: Supported for vehicle ITS stations. For infrastructure, initially supported, but introduction of additional new technology will face a backward compatibility issue or require an infrastructure upgrade.

NOTE 20: Additional implementation needed for infrastructure only. See clause 8.6.4.2.

NOTE 21: The service availability is limited to coverage areas of roadside ITS-Ss and/or base stations. In one example, a roadside ITS-S may have a coverage range of 300 meters. In such a case, the roadside ITS-Ss need to be deployed approximately every 600 meters. Additional installation of the infrastructure or update of the currently installed infrastructure will be needed. The feasibility of providing a reasonable coverage to bridge the incompatibility gap through this approach should be investigated in further study.

9.2   Conclusion

The present document has compared system level design options that can be a way to resolve the current challenges in a heterogeneous ITS environment. Various implementation options supporting the interoperability and backward compatibility of C-ITS services between ITS-Ss using distinct access layer technologies which are not interoperable with each other at the physical and MAC layers, have been introduced and compared. The options studied offer interoperability with different kinds of limitations while incurring varying types of cost. They rely on appropriate higher and lower layer system design.

The present document has not analysed the aspects of security/privacy implications and the requirements of functional safety according to ISO 26262 [i.12] and IEC 61508 [i.13] which need to be fulfilled with respect to specific use cases/services have not been addressed.

Further study might be needed before realization of the proposed implementation options, such as architecture details with considerations of functional safety impacts. By its nature as a pre-standardization study, the present document does not claim to be consistent with EU transport policy, spectrum policy and respective regulatory deliverables.

History

Document history		
V1.1.1	February 2020	Publication