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TECHNICAL REPORT

Intelligent Transport Systems (ITS); Study on Spectrum Sharing between ITS-G5 and LTE-V2X technologies in the 5 855 MHz - 5 925 MHz band

Reference

DTR/ERM-TG37-274

Keywords

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Electromagnetic compatibility and Radio spectrum Matters (ERM).

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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1 Scope

The present document proposes an overall framework based on combinations of co-channel and/or non-co-channel operation, as presented to CEPT, to address spectrum sharing between ITS-G5 and LTE-V2X ITS technologies enabling both technologies to use the same spectrum in the same geographical area. The overall framework may consist of several options for such combined operation.

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] ETSI TR 103 766: "Intelligent Transport Systems (ITS); Pre-standardization study on co-channel co-existence between IEEE- and 3GPP-based ITS technologies in the 5 855 MHz-5 925 MHz frequency band".

[i.2] ECC Decision (08)01: "The harmonised use of Safety-Related Intelligent Transport Systems (ITS) in the 5875-5935 MHz frequency band", latest amendment on 06 March 2020.

[i.3] Commission Implementing Decision (EU) 2020/1426 of 7 October 2020 on the harmonised use of radio spectrum in the 5 875-5 935 MHz frequency band for safety-related applications of intelligent transport systems (ITS) and repealing Decision 2008/671/EC.

[i.4] ETSI EN 302 665 (V1.1.1) (09-2010): "Intelligent Transport Systems (ITS); Communications Architecture".

[i.5] ETSI EN 302 663 (V1.3.1) (01-2020): "Intelligent Transport Systems (ITS); ITS-G5 Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band".

[i.6] IEEE Std 802.11™-2020: "IEEE Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks-Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications".

[i.7] IEEE/ISO/IEC 8802-2™ -1998: "Information technology -- Telecommunications and information exchange between systems -- Local and metropolitan area networks -- Specific requirements -- Part 2: Logical Link Control".

[i.8] IEEE 802.11e™ -2005: "IEEE Standard for Information technology - Local and metropolitan area networks - Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications - Amendment: Medium Access Method (MAC) Quality of Service Enhancements".

[i.9] ANSI/IEEE Std 802.1D™ 1998: "IEEE Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Common specifications - Part 3: Media Access Control (MAC) Bridges".

[i.10] ETSI EN 303 613 (V1.1.1) (01-2020): "Intelligent Transport Systems (ITS); LTE-V2X Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band".

[i.11] ETSI TS 136 213: "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures (3GPP TS 36.213 version 15.9.0 Release 15)".

[i.12] ETSI TS 136 211: "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation (3GPP TS 36.211 version 14.3.0 Release 14)".

[i.13] 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 version 14.3.0 Release 14)".

[i.14] ETSI TS 136 321: "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification (3GPP TS 36.321 version 14.2.1 Release 14)".

[i.15] ETSI TS 136 101: "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception (3GPP TS 36.101 version 14.4.0 Release 14)".

[i.16] ETSI TS 103 723 (V1.2.1) (2020-11): "Intelligent Transport Systems (ITS); Profile for LTE-V2X Direct Communication".

[i.17] ETSI TR 103 319 (V1.1.1): "Broadband Radio Access Networks (BRAN); 5 GHz high performance RLAN; Mitigation techniques to enable sharing between RLANs and Road Tolling and Intelligent Transport Systems in the 5 725 MHz to 5 925 MHz band".

3 Definition of terms, symbols and abbreviations

3.1 Terms

Void.

3.2 Symbols

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3.3 Abbreviations

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

AC	Access Category
AIFS	Arbitration Interframe Space
AIFSN	AIFS number
AP	Access Point
ARQ	Automatic ReQuest
BE	Best Effort
BK	BacKground
BPSK	Binary Phase Shift Keying
BSS	Basic Service Set
BSSID	BSS IDentifier
CW	Contention Window
DCF	Distributed Coordination Function
DFS	Dynamic Frequency Selection
DIFS	Distributed Interframe Space
DL	Data Link layer
EDCA	Enhanced Distributed Coordination Access
EE	Excellent Effort
HARQ	Hybrid ARQ
IBSS	Independent BSS

ITS	Intelligent Transport Systems
LLC	Logical Link Control
MAC	Medium Access Control
MCS	Modulation and Coding Scheme
MIB	Management Information Base
MPDU	MAC Protocol Data Unit
NC	Network Control
OFDM	Orthogonal Frequency Division Multiplexing
OSI	Open System Interconnect
PHY	Physical Layer
PLCP	Physical Layer Convergence Procedure
PPDU	PLCP Protocol Data Unit
PSCCH	Physical Sidelink Control Channels
PSDU	PLCP Service Data Unit
PSSCH	Physical Sidelink Shared Channels
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RB	Resource Block
RLAN	Radio Local Area Network
RSRP	Reference Signal Received Power
RSSI	Received Signal Strength Indicator
SCI	Side Control Information
SPS	Semi-Persistent Scheduling
TTI	Transmission Time Interval
UP	User Priority
VI	VIdeo
VO	VOice

4 Spectrum Sharing Options for ITS Technologies

4.1 Introduction

Currently, there are two technologies for short-range wireless communications for cooperative ITS that can be used in the 5,9 GHz band [i.3]: ITS-G5 [i.5] based on IEEE 802.11p [i.6] and LTE-V2X [i.10] developed by 3GPP. Spectrum sharing options are therefore necessary to make sure both technologies can co-exist in a seamless way. The spectrum sharing options need to be defined in the context of the new CEPT band plan for 5,9 GHz, which is depicted in **Figure 1**. It designates a total of 40 MHz in the frequency range 5 875 MHz - 5 915 MHz for safety related ITS prioritized for road ITS. Therefore, the spectrum sharing options which will be proposed are based on the availability of 10 MHz radio channels for road ITS. In addition, the frequency range 5 915 MHz - 5 925 MHz, which is prioritized for urban rail ITS, could be used by road ITS after ETSI has developed polite protocols and/or proper co-channel sharing mechanisms between road ITS and urban rail ITS. According to the ECC decision (08)01 [i.2], the frequency range 5 915 MHz - 5 925 MHz could be used for road ITS I2V applications on a national basis before the development of the above mentioned polite protocols and/or proper co-channel sharing mechanisms, which is out of the scope of the present document. Therefore, the sharing of the frequency range 5 915 - 5 925 MHz between road ITS technologies discussed in clause 4.3.4 assumes that road ITS technologies could access this frequency range by applying the polite protocols and/or proper co-channel sharing mechanisms between road ITS and urban rail ITS specified by ETSI.

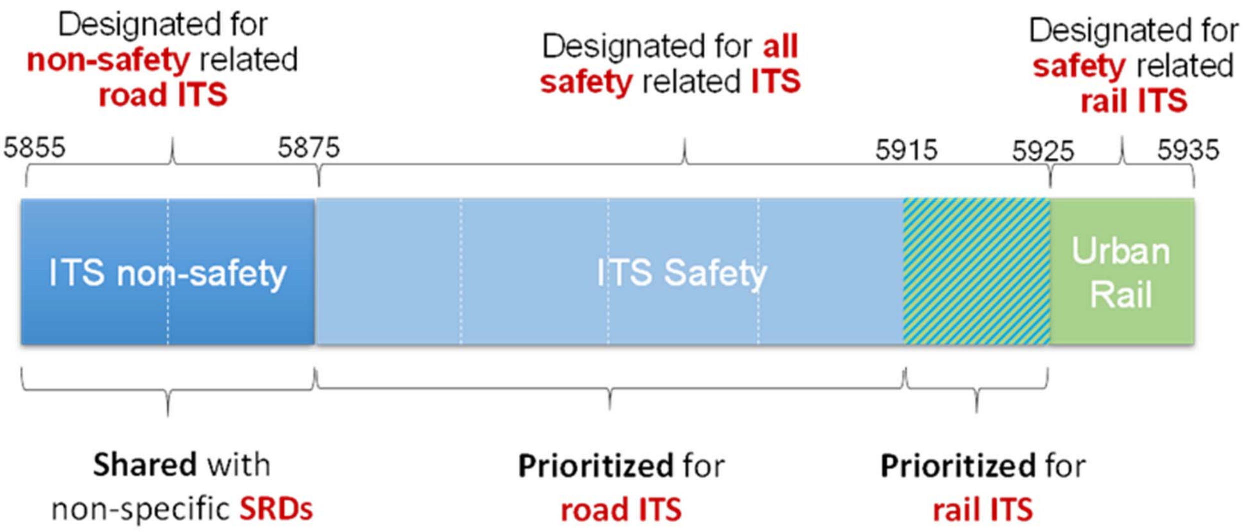


Figure 1: New CEPT band plan for ITS technologies

Table 1 shows the frequency range for each of the four radio channels in 5 875 MHz - 5 915 MHz prioritized for road ITS and a proposed mapping of these radio channels to the channel numbers used in the present document. In addition, the same nomenclature is used in the present document for the frequency range 5 915 MHz - 5 925 MHz prioritized for urban rail ITS under the assumption that road ITS technologies can access this frequency range by applying the polite protocols and/or proper co-channel sharing mechanisms between road ITS and urban rail ITS specified by ETSI (not covered by the present document, as above clarified).

Table 1: The frequency range of road ITS radio channels and the numbers assigned to them

Channel 1	Channel 2	Channel 3	Channel 4	Channel 5
5 875 MHz - 5 885 MHz	5 885 MHz - 5 895 MHz	5 895 MHz - 5 905 MHz	5 905 MHz - 5 915 MHz	5 915 MHz - 5 925 MHz

4.2 Framework for non-prioritized use of road ITS channels

This framework means that all road ITS radio channels can be accessed on equal footing by all road ITS technologies through a co-channel co-existence method. The decision to use a specific channel is not based on technology but rather on other criteria, which could for example be based on use cases, where different channels would be used for different clusters of use cases, such as basic CAM/DENM safety messages, platooning messages, collective perception messages, etc. Addressing the requirements for such scenarios is out of the scope of the present document.

This framework means that all road ITS radio channels can be accessed on equal footing by all ITS technologies, and the decision to use a specific channel is not based on technology but on other criteria. One example scenario is "use case" as a criterion, where different channels would be used for different clusters of use cases, such as basic CAM/DENM safety messages, Platooning messages, cooperative perception messages, etc. Addressing the requirements for such scenarios is out of the scope of the present document.

There are several proposed methods for co-channel coexistence between the road ITS technologies ITS-G5 and LTE-V2X in ETSI TR 103 766 [i.1].

4.3 Priority-based framework for using road ITS channels

4.3.1 Overview

Unlike the non-prioritized framework of the previous clause 4.2, the priority-based framework assigns technology-dependent priorities to individual road ITS channels. The goal is to develop a framework for spectrum sharing because co-channel sharing is not yet defined, and it is not still assessed if such sharing would be feasible with acceptable performance degradation. The purpose is the assignment of priorities to different ITS technologies in the different ITS radio channels shown in Table 1. For this purpose, the following driving criteria are considered:

1) The basic essential safety messages need to be delivered with the reliability and latency requirements defined for such messages.

2) Other safety and non-safety messages can be delivered with a different level of reliability and latency.

The ultimate objective of criterion 1 is to make sure that essential safety messages will be reliably transmitted over a 10 MHz radio channel. In this context, the reliability of the safety messages is a key factor for the selection of a proposed spectrum sharing option. Because such option aims at coexistence between the two road ITS technologies with different radio air interfaces, its selection in a manner to avoid impacts on the structure of the radio air interface of the involved technologies might be challenging, especially for the latency requirement in the case of short timescale interaction (in the order of μs) with high reliability. Also, the impact on existing specifications depends on the detection capability and the envisaged target reliability. A high-level pictorial representation of different trade-offs involved in developing a coexistence solution is shown in the example of Figure 2.

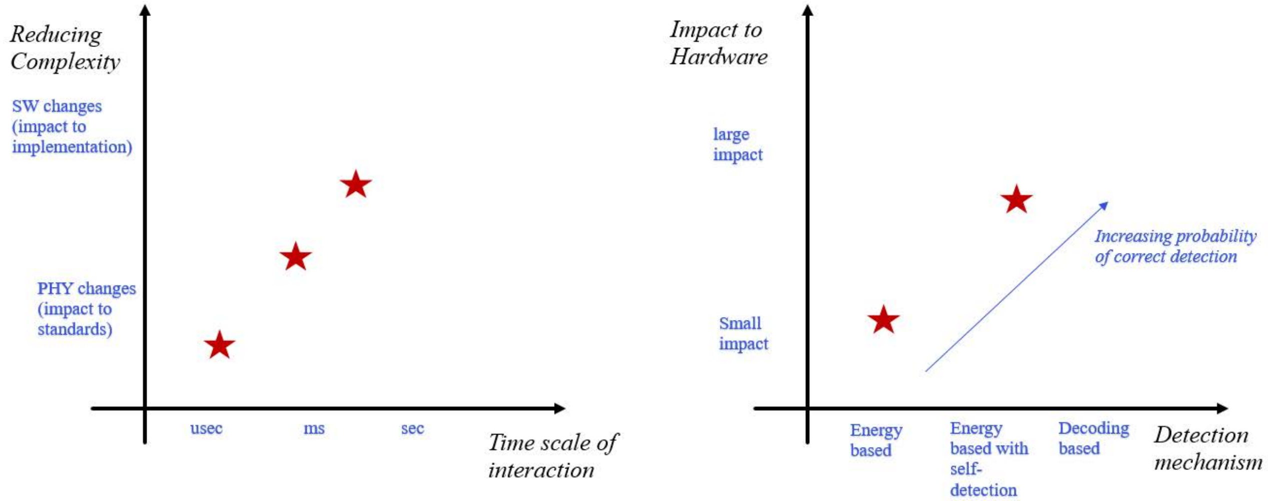


Figure 2: An example of trade-offs in designing/developing a coexistence solution

4.3.2 Description of the basic idea of priority-based framework

Based on the above observations, a hybrid approach is proposed where different technologies need to fulfil different coexistence requirements on different radio channels. The coexistence requirements depend on priorities assigned to specific technologies in specific channels. A set of radio channels is meant to be used for essential safety messages of a certain technology. To guarantee high reliability in such channels, a priority level is assigned to each technology in each of the channels. Depending on way the priority levels are assigned to different technologies, different options will result.

A pictorial presentation of the basic idea is depicted in Figure 3, assuming two different technologies, Tech A and Tech B, operating in the band prioritized for road ITS. The example can be summarized as follows:

- Tech A and Tech B share the available 40 MHz spectrum (4 radio channels each 10 MHz).

- Two 10 MHz radio channels are assigned for essential safety with different priority levels for Tech A and Tech B:
  - In the channel with the highest priority level assigned to Tech A (Tech B), Tech A (Tech B) does not need to perform any detection of the presence of Tech B (Tech A).
- The other two 10 MHz channels are shared in time between the two technologies, for example based on one of the methods described in ETSI TR 103 766 [i.1].

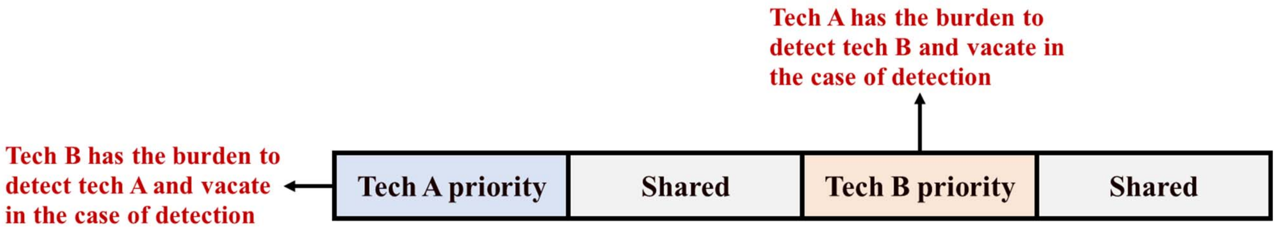


Figure 3: Proposed hybrid approach for road ITS coexistence

On the priority channels the burden of detection will be on the technology which has the least priority. On the other hand, in the shared channels, the burden of detection is shared between the two technologies. Based on this principle, two coexistence mechanisms can be defined:

- A mechanism for the channels assigned with high priority level to a specific technology. In this case, the burden of detection will be on the technology which does not have priority. In particular, the technology that intends to use the channel, that is prioritized for the other technology, would need to meet additional coexistence criteria which requires the detection of the channel use by the other technology. These criteria, e.g. detect and vacate, are not yet defined and are out of the scope of the present document. Existing detect and vacate schemes, e.g. DFS in RLAN to protect radars where an access point monitors the frequency for some time and coordinates channel switching cannot be applied to ITS, since ITS stations are highly mobile and communicate via broadcast without connection establishment. The technology with lower priority cannot assign a service solely to this channel without risking service interruption. Therefore, additional mechanisms for service continuity are required in this case.
- A different mechanism will be used for the channels which are shared. For such channels, both technologies need to detect the presence of each other based on the equal sharing principle. The solution is defined in ETSI TR 103 766 [i.1].

The detect and vacate method is not studied in detail in the present document and needs to be investigated in the future. Similar studies on detection with other technologies have been done in other ETSI deliverables such as ETSI TR 103 319 [i.17]. Detect and vacate needs to be implemented to achieve a good trade-off between protection of prioritized technologies and efficient use of spectrum.

So, in summary for channels which are shared, the coexistence solution will be based on the co-channel coexistence study in ETSI TR 103 766, while requirements associated to the imbalance priority case will be defined in a future ETSI specification.

The priority channels identified for safety are some sort of "anchor" channels: one technology can always use the 10 MHz assigned with high priority for basic safety applications but can only get access to the other channels if the coexistence requirements defined for those channels are met. This approach represents a trade-off between optimizing spectrum utilization and providing reliable access to the "anchor" channels. The benefit of the proposed approach is that from day 1 both technologies can operate on such "anchor" channels, where they have the highest priority, without requiring any change to their radio air interface specifications. The potential disadvantage is that initially deployed technologies without sharing capability may stay on their priority channels for the future and could impact other technologies using those channels for safety applications in the case that priorities for using those channels are changed. At the same time, the shared channels could be used by all technologies provided additional requirements for the co-channel coexistence are met.

4.3.3 Formalization and extension of the priority-based framework

The proposed approach can be formalized as follows:

- For each radio channel a priority level is assigned to each technology, called mapping between a radio channel and the priority level assigned to a specific technology in that channel.
- Based on the assigned priority level in a specific channel, a decision is made by a technology in that channel in case of detection of the other technology (if detection required).

Depending on the number of priority levels used and the mapping between the radio channels and the priority levels assigned to different technologies, several options are possible as presented below. For this purpose, the following priority levels are defined:

- "0": the radio channel cannot be used, since it is either reserved for future services or no sharing between technologies with different access schemes is allowed, unless the technology with a lower priority applies a channel access scheme compatible with that of the technology with the higher priority.
- "1": the radio channel could be accessed by Tech A (Tech B), which has lower priority, provided it is not occupied by Tech B (Tech A), which has higher priority.
- "2": the radio channel is shared in time between Tech A and Tech B on a non-prioritized basis.
- "3": the radio channel is prioritized for Tech A (Tech B) but could be used by Tech B (Tech A), provided it is not occupied by the technology, which the radio channel is prioritized for.

Depending on the mapping between a radio channel and the assigned priority to a specific technology in that channel, one of the following actions will be taken by this technology if it detects another technology in the considered radio channel.

- VOID/ COMPATIBLE ACCESS: corresponds to the priority level "0" assigned to a technology in a radio channel and means that a device implementing this technology cannot use the radio channel.
- VACATE: corresponds to the priority level "1" assigned to a technology in a radio channel and means that a device implementing this technology should vacate the radio channel if it detects there a device implementing a technology with a higher assigned priority for that radio channel.
- SHARE: corresponds to the priority level "2" assigned to a technology in a radio channel and means that the radio channel is shared between the technologies operating in this channel by using one of the coexistence methods defined in ETSI TR 103 766 [i.1].
- STAY: corresponds to the priority level "3" assigned to a technology in a radio channel and means that a device implementing this technology may access the channel without any need for modifications in its channel access mechanism. Such device does not need to perform any assessment about the presence of another technology in such radio channel and even if does so and detects in the radio channel a device implementing a technology with a lower assigned priority for that radio channel, it should stay in the radio channel. In other words, the technology with a lower priority, which can use the channel, carries the full burden of assessing whether the technology with a higher priority is operating in the channel and needs to vacate the channel if it detects a device implementing the technology with the higher priority.

Based on the framework above, different priority options can be set in different situations. What matters is that for the supported priority the device fulfils the minimum requirement associated to that priority.

Option 1: Two prioritized channels and 3 priority levels

It is the option in Figure 3 and the mapping between the radio channels and the priority levels assigned to different technologies is shown in Table 2. In this option, the anchor channels will consist of 10 MHz.

Table 2: Example of assigned priorities

	Priorities			
	Channel 1	Channel 2	Channel 3	Channel 4
Tech A	3	2	1	2
Tech B	1	2	3	2

Depending on the mapping between the radio channels and the priority level assigned to a specific technology in Table 2, the actions shown in Table 3 need to be taken in the case that one technology detects another technology.

Table 3: Decisions to be taken by each technology in case of detection

	Decision in case of detection			
	Channel 1	Channel 2	Channel 3	Channel 4
Tech A	STAY	SHARE	VACATE	SHARE
Tech B	VACATE	SHARE	STAY	SHARE

The abovementioned actions put specific requirements on PHY mechanisms which would allow to facilitate channel access depending on the priority level. Depending on the prioritization, each technology will then choose to multiplex its traffic across different channels in the most appropriate way as outlined below.

- Tech A:
  - It can use channel 1 with very relaxed/no PHY additional requirement.
  - It can use channel 2 and channel 4 with a specific PHY additional requirement not covered in the present document. This requirement is one of the possible co-channel coexistence requirements defined in ETSI TR 103 766 [i.1].
  - It can use channel 3 with a specific PHY additional requirement not covered in the present document. This requirement can be defined in an ETSI specification and should be a very stringent requirement since it needs to allow the other technology to use the same channel with a high priority level. The goal is that the channel is not used if the other technology is present.
- Tech B:
  - It can use channel 3 with very relaxed/no PHY additional requirement.
  - It can use channel 2 and channel 4 with a specific PHY additional requirement not covered in the present document. This requirement is one of the possible co-channel coexistence requirements defined in ETSI TR 103 766 [i.1].
  - It can use channel 1 with a specific PHY additional requirement not covered in the present document. This requirement can be defined in an ETSI specification and should be a very stringent requirement since it needs to allow the other technology to use the same channel with high priority. The goal is that the channel is not used if the other technology is present.

Option 2: Four prioritized channels and 2 priority levels

In the option presented in Figure 4, one of the shared channels in Option 1 is assigned to Tech A with the priority level "3" whereas the other shared channel is assigned to Tech B with the priority level "3". In this option, the anchor channels will consist of 20 MHz (two 10 MHz radio channels). The corresponding priorities and decisions to be taken in case of detecting the other technology are shown in Table 4 and Table 5, respectively.

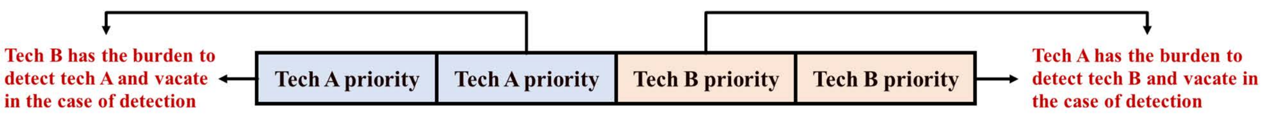


Figure 4: An approach for road ITS coexistence with four prioritized channels

Table 4: Example of assigned priorities

	Priorities			
	Channel 1	Channel 2	Channel 3	Channel 4
Tech A	3	3	1	1
Tech B	1	1	3	3

Depending on the mapping between the radio channels and the priority level assigned to a specific technology in Table 4, the actions shown in Table 5 need to be taken in the case that one technology detects another technology.

Table 5: Decisions to be taken by each technology in case of detection

	Decision in case of detection			
	Channel 1	Channel 2	Channel 3	Channel 4
Tech A	STAY	STAY	VACATE	VACATE
Tech B	VACATE	VACATE	STAY	STAY

The abovementioned actions put specific requirements on PHY mechanisms which would allow to facilitate channel access depending on the priority level. Depending on the prioritization, each technology will then choose to multiplex its traffic across different channels in the most appropriate way as outlined below.

- Tech A:
  - It can use channel 1 and channel 2 with very relaxed/no PHY additional requirement.
  - It can use channel 3 and channel 4 with a specific PHY additional requirement not covered in the present document. This requirement can be defined in an ETSI specification and should be a very stringent requirement since it needs to allow the other technology to use the same channel with a high priority level. The goal is that the channel is not used if the other technology is present.
- Tech B:
  - It can use channel 3 and channel 4 with very relaxed/no PHY additional requirement.
  - It can use channel 1 and channel 2 with a specific PHY additional requirement not covered in the present document. This requirement can be defined in an ETSI specification and should be a very stringent requirement since it needs to allow the other technology to use the same channel with high priority. The goal is that the channel is not used if the other technology is present.

Option 3: Two prioritized channels and 3 priority levels

In this option, the radio channel assigned to Tech A as anchor channel is not accessible for Tech B stations and vice versa. As in Option 1, the other two radio channels are shared in time between the two technologies, for example based on one of the methods described in ETSI TR 103 766 [i.1].

Table 6: Example of assigned priorities

	Priorities			
	Channel 1	Channel 2	Channel 3	Channel 4
Tech A	3	2	0	2
Tech B	0	2	3	2

Depending on the mapping between the radio channels and the priority level assigned to a specific technology in Table 6, the actions shown in Table 7 need to be taken in the case that one technology detects another technology.

Table 7: Decisions to be taken by each technology in case of detection

	Decision in case of detection			
	Channel 1	Channel 2	Channel 3	Channel 4
Tech A	STAY	SHARE	VOID/ COMPATIBLE ACCESS	SHARE
Tech B	VOID/ COMPATIBLE ACCESS	SHARE	STAY	SHARE

This option differs from Option 1 as the "VOID/ COMPATIBLE ACCESS" setting are used. The rationale is:

- The "STAY" setting in this option refers to plain Tech A (Tech B) without any modifications of this technology.
- "VOID/ COMPATIBLE ACCESS" setting introduces an even more constraining situation than the "VACATE". This might be especially useful for the situations where one technology is already started to be deployed in a specific channel without any concept of coexistence. Thus, to ensure maximal safety and no performance compromise, access to this channel, characterized as "COMPATIBLE ACCESS", strictly requires applying the channel access scheme of the technology that has "STAY' setting for this channel.

The abovementioned actions put specific requirements on PHY mechanisms which would allow to facilitate channel access depending on the priority level. Depending on the prioritization, each technology will then choose to multiplex its traffic across different channels in the most appropriate way as outlined below:

- Tech A:
  - It can use channel 1 without any PHY additional requirement.
  - It can use channel 2 and channel 4 with a specific PHY additional requirement not covered in the present document. This requirement is one of the possible co-channel coexistence requirements defined in ETSI TR 103 766 [i.1].
  - It cannot use channel 3, unless it uses the channel access scheme of Tech B.
- Tech B:
  - It can use channel 3 without any PHY additional requirement.
  - It can use channel 2 and channel 4 with a specific PHY additional requirement not covered in the present document. This requirement is one of the possible co-channel coexistence requirements defined in ETSI TR 103 766 [i.1].
  - It cannot use channel 1, unless it uses the channel access scheme of Tech A.

Option 4: Four prioritized channels and 3 priority levels

In this option, the channel assigned to Tech A (Tech B) as anchor channel is not accessible for Tech B (Tech A) stations and vice versa. Amongst the other two channels, one is prioritized for Tech A and one for Tech B, as in Option 2.

Table 8: Example of assigned priorities

	Priorities			
	Channel 1	Channel 2	Channel 3	Channel 4
Tech A	3	3	0	1
Tech B	0	1	3	3

Depending on the mapping between the radio channels and the priority level assigned to a specific technology in Table 8, the actions shown in Table 9 need to be taken in the case that one technology detects another technology.

Table 9: Decisions to be taken by each technology in case of detection

	Decision in case of detection			
	Channel 1	**Channel 2**	**Channel 3**	**Channel 4**
Tech A	STAY	STAY	VOID/COMPATIBLE ACCESS	VACATE
Tech B	VOID/COMPATIBLE ACCESS	VACATE	STAY	STAY

This option differs from Option 2 as the "VOID/ COMPATIBLE ACCESS" setting are used in two of prioritized channels. The rationale is:

- The "STAY" setting in this option refers to plain Tech A (Tech B) without any modifications of this technology.
- "VOID/ COMPATIBLE ACCESS" setting introduces an even more constraining situation than the "VACATE". This might be especially useful for the situations where one technology is already started to be deployed in a specific channel, without any concept of coexistence. Thus, to ensure maximal safety and no performance compromise, access to this channel, characterized as "COMPATIBLE ACCESS", strictly requires applying the channel access scheme of the technology that has "STAY' setting for this channel.

The abovementioned actions put specific requirements on PHY mechanisms which would allow to facilitate channel access depending on the priority level. Depending on the prioritization, each technology will then choose to multiplex its traffic across different channels in the most appropriate way as outlined below.

- Tech A:
  - It can use channel 1 without any PHY additional requirement.
  - It can use channel 2 with very relaxed/no PHY additional requirement.
  - It cannot use channel 3, unless it uses the channel access scheme of Tech B.
  - It can use channel 4 with a specific PHY additional requirement not covered in the present document. This requirement can be defined in an ETSI specification and should be a very stringent requirement since it needs to allow the other technology to use the same channel with a high priority level. The goal is that the channel is not used if the other technology is present.
- Tech B:
  - It can use channel 3 without any PHY additional requirement.
  - It can use channel 4 with very relaxed/no PHY additional requirement.
  - It cannot use channel 1, unless it uses the channel access scheme of Tech A.
  - It can use channel 2 with a specific PHY additional requirement not covered in the present document. This requirement can be defined in an ETSI specification and should be a very stringent requirement since it needs to allow the other technology to use the same channel with a high priority level. The goal is that the channel is not used if the other technology is present.

Option 5: Two prioritized channels and two channels reserved for other services

This option is outlined as follows:

1) Address the allocation strategies for channels 3 - 4 (5 895 MHz - 5 915 MHz) according to Table 10 and Table 11 which may be used for day-1 basic safety.
2) Address the remaining channels 1 - 2 (5 875 MHz - 5 895 MHz) according to Table 10 and Table 11, which could be used for other services in the future.

This option will thus provide sufficient capacity for the deployment of day-1 basic safety services for Tech A and Tech B, while addressing the use of the two other radio channels in the future for other services.

Table 10: Example of assigned priorities

	Priorities			
	Channel 1	Channel 2	Channel 3	Channel 4
Tech A	0	0	1	3
Tech B	0	0	3	1

Table 11: Decisions to be taken by each technology in case of detection

	Priorities			
	Channel 1	Channel 2	Channel 3	Channel 4
Tech A	VOID	VOID	VACATE	STAY
Tech B	VOID	VOID	STAY	VACATE

The abovementioned actions put specific requirements on PHY mechanisms which would allow to facilitate channel access depending on the priority level. Depending on the prioritization, each technology will then choose to multiplex its traffic across different channels in the most appropriate way as outlined below.

- Tech A:
  - It can use channel 4 with very relaxed/no PHY additional requirement.
  - It cannot use channel 1 and channel 2.
  - It can use channel 3 with a specific PHY additional requirement not covered in the present document. This requirement can be defined in an ETSI specification and should be a very stringent requirement since it needs to allow the other technology to use the same channel with a high priority level. The goal is that the channel is not used if the other technology is present.
- Tech B:
  - It can use channel 3 with very relaxed/no PHY additional requirement.
  - It cannot use channel 1 and channel 2.
  - It can use channel 4 with a specific PHY additional requirement not covered in the present document. This requirement can be defined in an ETSI specification and should be a very stringent requirement since it needs to allow the other technology to use the same channel with a high priority level. The goal is that the channel is not used if the other technology is present.

Option 6: Two prioritized channels and two channels reserved for other services

This option is outlined as follows:

1) Address the allocation strategies for channels 3 - 4 (5 895 MHz - 5 915 MHz) according to Table 12 and Table 13 which may be used for day-1 basic safety.

2) Address the remaining channels 1 - 2 (5 875 MHz - 5 895 MHz) according to Table 12 and Table 13, which could be used for other services in the future.

This option differs from Option 5 as the "VOID/ COMPATIBLE ACCESS" setting is used in the two radio channels instead of "VACATE". Thus, this will provide sufficient capacity for the deployment of day-1 basic safety services for Tech A and Tech B, while addressing the use of the two other radio channels in the future for other services. The "VOID/ COMPATIBLE ACCESS" setting introduces an even more constraining situation than the "VACATE" in Option 5. This might be especially useful for the situations where one technology is already started to be deployed in a specific channel, without any concept of coexistence. Thus, to ensure maximal safety and no performance compromise, access to this channel, characterized as "COMPATIBLE ACCESS", strictly requires applying the channel access scheme of the technology that has "STAY" setting for this channel.

Table 12: Example of assigned priorities

	Priorities			
	Channel 1	**Channel 2**	**Channel 3**	**Channel 4**
Tech A	0	0	0	3
Tech B	0	0	3	0

Table 13: Decisions to be taken by each technology in case of detection.

	Priorities			
	Channel 1	**Channel 2**	**Channel 3**	**Channel 4**
Tech A	VOID	VOID	VOID/COMPATIBLE ACCESS	STAY
Tech B	VOID	VOID	STAY	VOID/COMPATIBLE ACCESS

The abovementioned actions put specific requirements on PHY mechanisms which would allow to facilitate channel access depending on the priority level. Depending on the prioritization, each technology will then choose to multiplex its traffic across different channels in the most appropriate way as outlined below.

- Tech A:
  - It can use channel 4 without any PHY additional requirement.
  - It cannot use channel 1 and channel 2.
  - It cannot use channel 3, unless it uses the channel access scheme of Tech B.
- Tech B:
  - It can use channel 3 without any PHY additional requirement.
  - It cannot use channel 1 and channel 2.
  - It cannot use channel 4, unless it uses the channel access scheme of Tech A.

4.3.4 Inclusion of the frequency range 5 915 - 5 925 MHz in the framework

The framework is extended in the present clause to the frequency range 5 915 MHz - 5 925 MHz (Channel 5) which is prioritized for urban rail ITS. As pointed out in clause 4.1, this frequency range could be used by road ITS after the development of polite protocols and/or proper co-channel sharing mechanisms between road ITS and urban rail ITS by ETSI. The development of such protocols and/or co-channel sharing mechanisms is out of the scope of the present document. According to the ECC Decision (08)01 [i.2], the use of this frequency range is allowed only for road ITS I2V applications on a national basis even before the development of such protocols and/or co-channel sharing mechanisms. Therefore, an expedient would be to extend the framework to the use of this frequency range for I2V applications on a national basis.

Given that this frequency range is prioritized for urban rail ITS and could be used by road ITS only on an opportunistic basis, the most reasonable option is the non-prioritized use of this radio channel by the road ITS technologies, i.e. it is shared in time between Tech A and Tech B, for example based on one of the methods described in ETSI TR 103 766 [i.1]. Such non-prioritized sharing of 5 915 MHz - 5 925 MHz would be appropriate even for other road ITS use cases, such as V2V, V2I etc., after the development of polite protocols and/or proper co-channel sharing mechanisms between road ITS and urban rail ITS.

Table 14: Example of assigned priorities

	Priorities
	Channel 5
Tech A	2
Tech B	2

Table 15: Decisions to be taken by each technology in case of detection

	Priorities
	Channel 5
Tech A	SHARE
Tech B	SHARE

4.4 Summary of options for priority-based framework

This clause summarizes the options for the assignment of priority levels to the different channels, as described in clause 4.3.3.

Table 14 lists 6 examples for priority configurations: Option Ids 1, 2, 3, 4, 5 and 6 correspond to the options described in Table 2, Table 4, Table 6, Table 8, Table 10, Table 12, respectively.

The presented priority options can be summarized as follows:

- In Option 1, half of the channels are equally shared and half of them have asymmetric priority. This configuration could be suitable in a situation in which some channels require higher reliability, while others can compromise performance. If no modifications are introduced to existing standards/products, at least one channel with high priority (the one with priority 3) is accessible by each technology for the transmission of essential safety messages.

- In Option 2, the available channels are equally distributed between different technologies, no channel is equally shared. This configuration could be suitable in a situation in which two high reliable channels are required by each technology. If no modifications are introduced to existing standards/products, then two channels with high priority (the ones with priority 3) are accessible by each technology for the transmission of essential safety messages .

- In Option 3, half of the channels are equally shared and half of them have asymmetric priority. The difference between this option and option 1 is that the radio channel assigned to a specific technology with higher priority (the one with priority 3) for the transmission of essential safety messages is not accessible by the stations of the other technology unless it uses the channel access scheme of the technology with higher priority. However, the other two radio channels (the ones with priority 2) can compromise performance.

- In Option 4, the available channels are equally distributed to different technologies, no channel is equally shared. The difference between this option and option 2 is that one of the radio channels assigned to a specific technology with higher priority (one of the two channels with priority 3) for the transmission of essential safety messages is not accessible by the stations of the other technology unless it uses the channel access scheme of the technology with higher priority. In this manner, one radio channel is exclusively accessible by each technology. This option could be suitable in a situation in which two high reliable channels are required for each technology. If no modifications are introduced to existing standards/products, then a second radio channel is exclusively accessible by each technology.

- In Option 5, half of the channels have asymmetric priority and half of them is not used. This option could be suitable in a situation in which two high reliable channels are required and no modifications should be introduced to existing standards/products. In addition, some channels (in this case 2) should be reserved for other services in the future.

- In Option 6, half of the channels have asymmetric priority and half of them is not used, where the radio channel prioritized for a specific technology is not accessible by the other technology. This option could be suitable in a situation in which two high reliable channels are required and no modifications should be introduced to existing standards/products. In addition, some channels (in this case 2) should be reserved for other services in the future.

- All options are symmetric in terms of priority, i.e. Tech A and Tech B have the same overall priority within the four available channels.

- In all options, the priority levels are mapped to different PHY layer requirements and each technology needs to meet the minimum requirements associated to the priority level assigned to a channel for being able to use that channel. Using priority 3 for essential safety messages is just a possible example since the most sensitive data are sent through the most reliable/protected channel.

Table 16: List of priority-based options

Option	Option description	Tech Id	Priorities			
			Channel 1	Channel 2	Channel 3	Channel 4
1 (corresponds to Table 2)	Two channels are equally shared	Tech A	3	2	1	2
		Tech B	1	2	3	2
2 (corresponds to Table 4)	No channels are equally shared	Tech A	3	3	1	1
		Tech B	1	1	3	3
3 (corresponds to Table 6)	Two channels are equally shared and the channel prioritized for a specific technology is not accessible by the other technology	Tech A	3	2	0	2
		Tech B	0	2	3	2
4 (corresponds to Table 8)	No channels are equally shared and the channel prioritized for a specific technology is not accessible by the other technology	Tech A	3	1	0	3
		Tech B	0	3	3	1
5 (corresponds to Table 10)	No channels are equally shared and two channels are not used and reserved for other services in the future	Tech A	0	0	1	3
		Tech B	0	0	3	1
6 (corresponds to Table 12)	The radio channel prioritized for a specific technology not accessible by the other technology and two channels are not used and reserved for other services in the future	Tech A	0	0	0	3
		Tech B	0	0	3	0

5 Conclusions

The present document focuses on the definition of a framework to address spectrum sharing between ITS-G5 and LTE-V2X ITS technologies, enabling both technologies to use the same spectrum in the same geographical area. The framework implements an approach where for different radio channels distinct requirements in terms of coexistence apply. Those requirements for the operation of a specific technology in a specific channel depends on the priority level associated to the technology in the channel. In summary, the following distinct classes of access strategy are envisioned:

- Channels in which access is provided based on equal sharing. In this case, the technology will implement a co-channel coexistence mechanism according to one of the solutions provided in ETSI TR 103 766 [i.1].

- Channels in which a specific technology has a higher priority compared to the other technology. In this case, depending on the specific implementations, the technology with the higher priority should be able to operate with no modifications to existing standards and be protected against the co-channel interference from the other technology. Depending on the priority implementation, the technology with a low priority can still access the channel if protection to the high priority class is provided.

The detect and vacate method is not studied in detail in the present document and needs to be investigated in the future.

A list of different options for priority-based framework is summarized in clause 4.4.

Channels assigned based on equal priority might be subject to performance degradation depending on the specific co-channel coexistence mechanism defined in ETSI TR 103 766 [i.1]. Consequently, for initial road ITS deployments, it might be an option to assign at least one "anchor" channel with a high priority level to each technology (one channel per technology). Those high priority channels might be used to deliver basic safety services with equipment compliant to existing standards avoiding the risk of mutual interference across road ITS technologies. Other channels might be later assigned with equal priority based on the outcome of the studies carried out in ETSI TR 103 766 [i.1].

There is the need for further studies in the relevant groups to identify which option(s) would be suitable for initial road ITS deployments, considering that some options might be applicable for day-1 while the other ones might be used for day-2 applications.

Annex A: Technical description of road ITS technologies

A.1 Introduction

The two studied road ITS technologies herein are ITS-G5 and LTE-V2X (see [i.10], [i.11], [i.12], [i.13] and [i.14]). The technologies represent the access layer of the ITS communications architecture, see Figure A.1, outlined in ETSI EN 302 665 [i.4]. The access layer consists of the physical layer (PHY) and the Data Link layer (DL) of the OSI model.

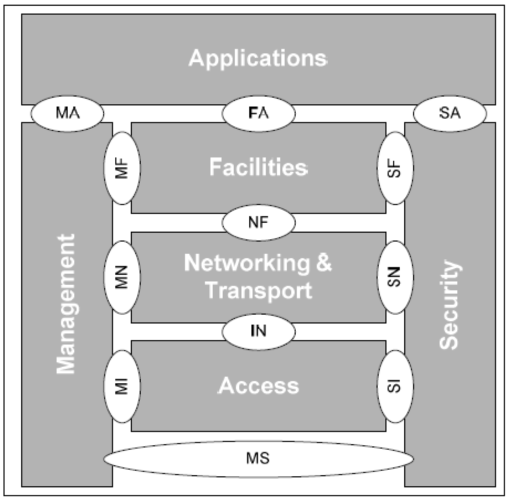


Figure A.1: The ITS station reference architecture [i.4]

A.2 ITS-G5

A.2.1 Introduction

ITS-G5 is outlined in ETSI EN 302 663 [i.5] describing the access layer of the ITS station reference architecture. The ITS-G5 access layer consists of:

- IEEE 802.11-2020 [i.6] operating outside the context of a basic service set (enabled by setting the MIB parameter `dot11OCBEnabled` to true)
- IEEE 802.2 Logical Link Control (LLC) [i.7]

IEEE 802.11-2020 [i.6] outlines the PHY and the Medium Access Control (MAC) protocol used for vehicular ad hoc networking in ITS-G5. The PHY is based on Orthogonal Frequency Division Multiplexing (OFDM) and the MAC is using the Enhanced Distributed Channel Access (EDCA) functionality, see clause 4.2.2 and clause 4.2.3 in ETSI TR 103 766 [i.1] for more technical details.

The IEEE 802.11-2020 [i.6] standard contains two basic network topologies: the infrastructure BSS and the Independent BSS (IBSS). The former contains an Access Point (AP) and data traffic usually takes a detour through the AP even though two nodes are closely co-located. The IBSS is a set of nodes communicating directly with each other and this is also called *ad hoc* or peer-to-peer network. Both these topologies are aimed for nomadic devices and synchronization is required between nodes performed via beacons. Further, they are identified with a unique BSSID. Association and authentication are required in infrastructure BSS whereas in IBSS association is not used and communication can take place in an unauthenticated mode. With the introduction of 802.11p a new capability of the 802.11 is introduced, namely communication outside the context of a BSS, see clause 4.3.17 of IEEE 802.11-2020 [i.6].

The communication outside of a BSS is enabled by setting the MIB variable `dot11OCBActivated` to true. In this mode authentication, association and security between nodes are disabled at the MAC sublayer. This implies that active and passive scanning of BSS and IBSS are disabled. The scanning on frequency channels for the node to join an existing network is no longer enabled. Therefore, the implementation when the MIB variable is set to `dot11OCBActivated` true in the vehicular environment requires predetermined frequency channels to be set in the management.

NOTE: The possibility to communicate outside the context of a BSS for vehicular communication was introduced in the IEEE 802.11p amendment. IEEE 802.11p was published in 2010 and it was enrolled into 802.11 in 2012, at which time the 802.11p amendment was classified as superseded. However, for the purpose of the present document, the notion "802.11p" will be used when referring to the vehicular components of IEEE 802.11-2020.

A.2.2 Physical layer

The OFDM PHY parameters of ITS-G5 are detailed in clause 17 of IEEE 802.11-2020 [i.6]. ITS-G5 uses 52 orthogonal subcarriers in a channel bandwidth of 10 MHz, where 48 subcarriers are used for data and 4 are pilot carriers. The OFDM PHY layer of ITS-G5 can support eight different transfer rates by using different modulation schemes and coding rates. The support of 3 Mbit/s, 6 Mbit/s, and 12 Mbit/s is mandatory. The duration of an OFDM symbol is fixed to 8 µs, and consequently for different transfer rates the number of data bits per OFDM symbol varies. Table A.1 outlines the different transfer rates together with coding and modulation schemes and data bits per OFDM symbol.

Table A.1: Transfer rates, modulation schemes and coding rates used by ITS-G5

Transfer rate (Mbit/s)	Modulation scheme	Coding rate	Data bits per OFDM symbol	Coded bits per OFDM symbol
3	BPSK	1/2	24	48
4,5	BPSK	3/4	36	48
6	QPSK	1/2	48	96
9	QPSK	3/4	72	96
12	16-QAM	1/2	96	192
18	16-QAM	3/4	144	192
24	64-QAM	2/3	192	288
27	64-QAM	3/4	216	288

Figure A.2 shows the format of a transmitted ITS-G5 packet, i.e. the Physical Layer Convergence Procedure (PLCP) Protocol Data Unit (PPDU). The PLCP Service Data Unit (PSDU) contains the data from the MAC layer including MAC header and trailer (collectively named MAC Protocol Data Unit, MPDU). The preamble is used for synchronizing the receiver. The signal field contains information about packet length and data rate of the data field. It has a length of 24 bits and is always transmitted in one OFDM symbol using BPSK with a coding rate of 1/2 (3 Mbit/s). In Table A.2 details of the ITS-G5 PHY packet format are listed (see also clause 17 of IEEE 802.11-2020 [i.6]).

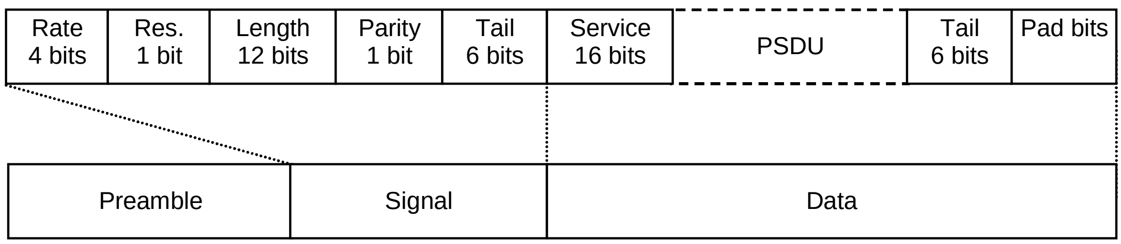


Figure A.2: ITS-G5 packet format, i.e. PPDU, ready for transmission

Table A.2: Explanation of the different fields of the PPDU

Field	Subfield	Description	Duration
Preamble	N/A	Consists of a short and a long training sequence.	32 µs
Signal	Rate	Transfer rate at which the data field in the PPDU will be transmitted.	8 µs
	Reserved	For future use.	
	Length	Length of the packet.	
	Parity	Parity bit.	
	Tail	Used to facilitate decoding and for calculation of rate and length subfields.	
Data	Service	Used for synchronizing the descrambler at receiver.	variable
	PSDU	The data from the MAC layer including header and trailer, i.e. MPDU.	
	Tail	Used for putting the convolutional encoder to zero state.	
	Pad bits	Bits added to fill up the last OFDM symbol of the packet.	

A.2.3 Medium Access Control (MAC)

A.2.3.1 Introduction

The MAC algorithm decides when in time a node is allowed to transmit based on the current channel status and the MAC schedules transmission with the goal to minimize the interference in the system to increase the packet reception probability. The MAC algorithm deployed is called Enhanced Distributed Coordination Access (EDCA). It is based on the basic Distributed Coordination Function (DCF) but adds QoS attributes. DCF is a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) algorithm.

NOTE: The EDCA was introduced with the IEEE 802.11e amendment and it added QoS to the DCF mechanism. IEEE 802.11e [i.8] was published in 2004 and it was enrolled into 802.11 in 2007, at which time the 802.11e document was classified as superseded.

In CSMA/CA a node starts to listen to the channel before transmission and if the channel is perceived as idle for a predetermined listening period the node can start to transmit directly. If the channel becomes occupied during the listening period the node will perform a backoff procedure, i.e. the node has to defer its access according to a randomized time period. In IEEE 802.11-2020 [i.6], the predetermined listening period is called either Arbitration Interframe Space (AIFS) or Distributed Interframe Space (DIFS) depending upon the mode of operation (EDCA or DCF). The former listening period is used when there is support for QoS.

A.2.3.2 Backoff procedure

The backoff procedure in 802.11 works as follows:

a) draw an integer from a uniform distribution [0, *CW*], where *CW* refers to the current maximum value of the contention window (the total number of integers to draw from is *CW*+1);

b) decrease the backoff value only when the channel is free, one decrement per slot time (for a 10 MHz channel the slot time is 13 µs);

c) upon reaching a backoff value of 0, transmit. In broadcast operation the node will only invoke the backoff procedure once during the initial listening period. When 802.11 is employed in unicast mode it acts as a stop-and-wait protocol and the transmitter will wait for an acknowledgment (ACK). If no ACK is received by the sender for some reason (the transmitted packet never reached the intended recipient, the packet was incorrect at reception, or the ACK never reached the sender), a backoff procedure will also be invoked.

For every attempt to send a specific packet (in broadcast mode there is only one attempt but in unicast mode it can be several attempts due to missing ACKs), the current size of the contention window, *CW*, will be increased from its initial value (CW_{min}) until it reaches a maximum value (CW_{max}). This feature of increasing the *CW* allows the network to recover from high utilization periods by spreading transmission attempts in time. After a successful transmission or when the packet had to be discarded because the maximum number of channel access attempts was reached, the *CW* will be set to its initial value again (CW_{min}).

If the channel becomes busy during the decrease of the backoff value once per 13 µs slot time the node has to suspend the countdown until the channel becomes free again. However, it should be noted that after every busy channel period the node will first wait an AIFS before the decrementation resumes.

NOTE: In broadcast mode the backoff procedure is only invoked once during the initial listening (AIFS) to the channel due to the lack of ACKs in broadcast transmissions. Therefore, the *CW* is always set to its minimum value, CW_{min}, and it will never be doubled.

More details about the backoff procedure are found in clauses 10.3.3 and 10.3.4.3 of IEEE 802.11-2020 [i.6].

A.2.3.3 Medium access control

In Figure A.3, simplified drawings of the channel access procedure as performed by 802.11 nodes is depicted for broadcast mode, Figure A.3(a), and unicast mode, Figure A.3(b).

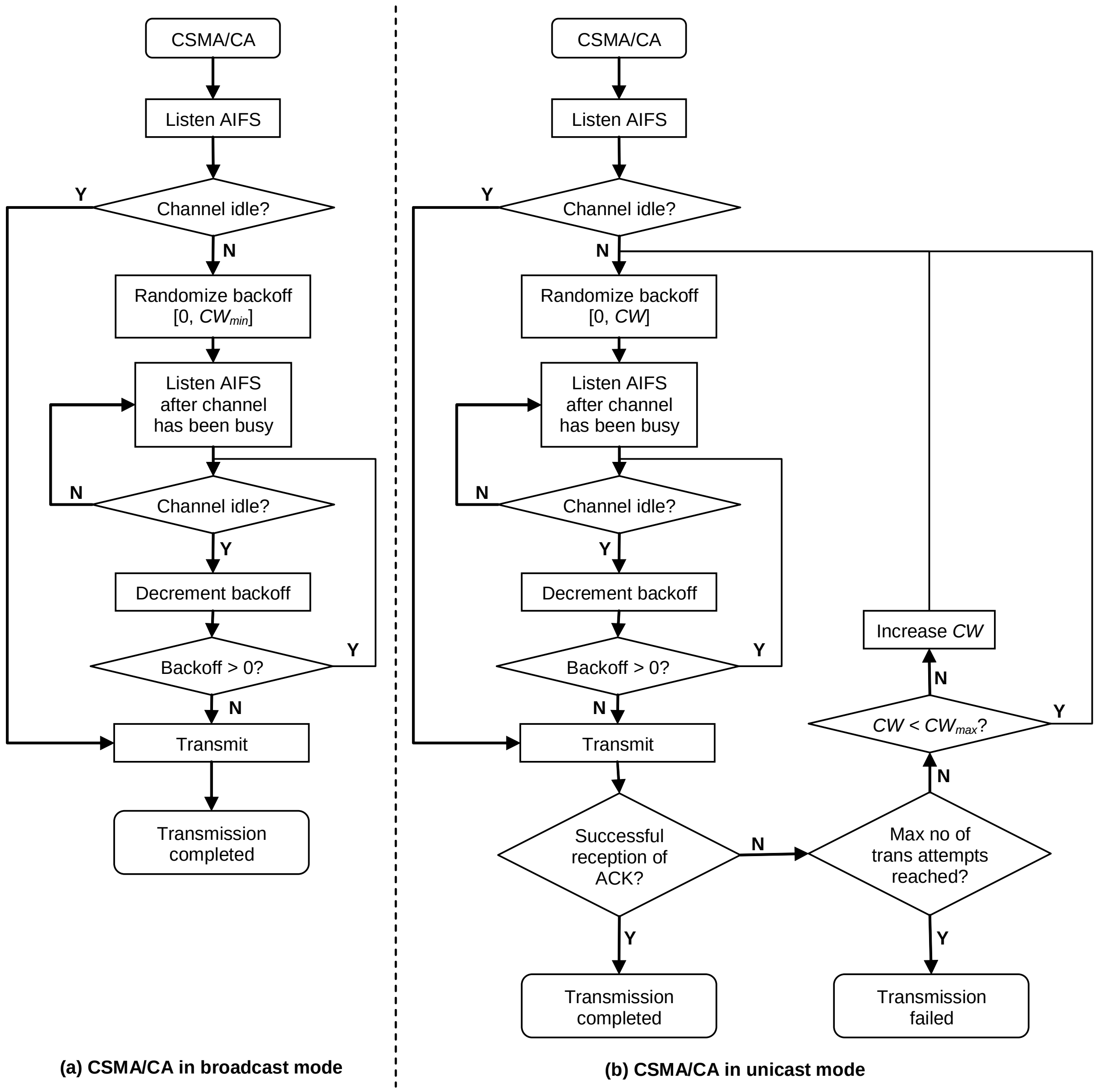


Figure A.3: A simplified drawing of the channel access procedure in IEEE 802.11-2020 [i.6] in (a) broadcast and (b) unicast mode

More details about the channel access procedure are found in clause 10 of IEEE 802.11-2020 [i.6].

A.2.3.4 EDCA parameters, AC and UP

EDCA is the official name of one of the MAC algorithms in 802.11, which is used by 802.11p. It is the DCF with inclusion of QoS, i.e. the CSMA/CA algorithm with the possibility to prioritize data traffic. In EDCA every node maintain queues with different AIFS values and CW sizes with the purpose of giving data traffic with higher priority increased probability to access the channel before data traffic with lower priority.

The QoS facility in 802.11 defines eight different User Priorities (UPs) and these are inherited from the ANSI/IEEE Std 802.1D [i.9] defining MAC bridges. The UPs from 802.1D are shown in Table A.3 and they are mapped to four different Access Categories (ACs), i.e. queues, within the QoS facility. This mapping is shown in Table A.3, where the lowest priority is 0 and the highest 7.

Table A.3: Mapping of UPs in 802.1D to the ACs of QoS facility in 802.11

UP in 802.1D	Data traffic type in 802.1D	AC in 802.11	Data traffic type in 802.11
1	Background (BK)	AC_BK	Background
2	Spare (-)	AC_BK	Background
0	Best Effort (BE)	AC_BE	Best effort
3	Excellent Effort (EE)	AC_BE	Best effort
4	Controlled load	AC_VI	Video
5	Video (VI)	AC_VI	Video
6	Voice (VO)	AC_VO	Voice
7	Network Control (NC)	AC_VO	Voice

NOTE 1: In 802.1D best effort traffic has the lowest priority 0 but the traffic type background has the priority of 1 even if this traffic type in reality has lower priority than the best effort type. For historical reasons the priority of the best effort traffic in 802.1D is not changed because of interoperability problems with legacy network equipment. This priority conflict is however solved in the QoS facility in 802.11.

The resulting AIFS for the ACs is calculated using the following formula:

$$AIFS[AC] = AIFSN[N] \times aSlotTime + aSIFSTime \tag{A.1}$$

where the *AIFSN* stands for AIFS number, which is an integer, *aSlotTime* and the *aSIFSTime* (short interframe space) are fetched from the PHY in use and they are fixed. Consequently, the AIFSN is the parameter determining the listening period (AIFS) for each queue (AC). In Table A.4 the default values for AIFSN and CW is tabulated for the different ACs in 802.11p, found in Table 9-156 of IEEE 802.11-2020 [i.6].

Table A.4: The default values for the AIFSN and CW in 802.11p found in IEEE 802.11-2020 [i.6]

AC	CW_{min}	CW_{max}	*AIFSN*
AC_VO	$(aCW_{min} + 1) / 4 - 1$	$(aCW_{min} + 1) / 2 - 1$	2
AC_VI	$(aCW_{min} + 1) / 2 - 1$	aCW_{min}	3
AC_BE	aCW_{min}	aCW_{max}	6
AC_BK	aCW_{min}	aCW_{max}	9

NOTE 2: The default values may be changed through some other mean such as the advertisement, regulation or another controlling standard.

In Table A.5, the different parameter values needed to determine MAC specific functions for 10 MHz channels of the OFDM PHY layer are tabulated. These values are fetched from Table 17-21 in IEEE 802.11-2020 [i.6].

Table A.5: OFDM PHY specific parameters used in 802.11p found in IEEE 802.11-2020 [i.6]

Parameter	Value
aSlotTime	13 µs
aSIFSTime	32 µs
aCW_{min}	15
aCW_{max}	1 023

In Table A.6, the resulting default values for 802.11p's ACs are tabulated using Table A.4, Table A.5 and Equation (A.1).

Table A.6: The resulting AIFS and CW sizes for 802.11p's ACs

AC	CW_{min}	CW_{max}	AIFS
AC_VO	3	7	58 µs
AC_VI	7	15	71 µs
AC_BE	15	1 023	110 µs
AC_BK	15	1 023	149 µs

More details about the EDCA mechanism is found in clause 10 of IEEE 802.11-2020 [i.6].

A.3 LTE-V2X

A.3.1 Introduction

LTE-V2X is outlined in ETSI EN 303 613 [i.10] describing the access layer of the ITS station reference architecture.

A.3.2 Physical layer

LTE-V2X uses Single-Carrier Frequency-Division Multiple Access (SC-FDMA), and supports 10- and 20-MHz channels. Each channel is divided into subframes, Resource Blocks (RBs), and subchannels. Subframes are 1 ms long, as the LTE Transmission Time Interval (TTI). An RB is the smallest unit of frequency resource that can be allocated to a user. It is 180 kHz wide in the frequency domain and contains 12 subcarriers, which are 15 kHz each. LTE-V2X defines subchannels as a group of RBs in the same sub-frame, where the number of RBs per subchannel can vary. Subchannels are used to transmit data and control information. The data is transmitted in Transport Blocks (TBs) over Physical Sidelink Shared Channels (PSSCH), and the Sidelink Control Information (SCI) messages are transmitted over Physical Sidelink Control Channels (PSCCH) [i.11]. PSSCH and PSCCH are transmitted on the same subframe to reduce the impact of near-far issues and the issues related to the half-duplex operation. However, PSSCH and PSCCH may or may not be adjacent in the occupied RBs. Same power control parameters are used for both channels, however a 3 dB power spectral density boosting is applied for PSCCH to make sure that control information does not become the bottleneck.

A TB contains a full packet to be transmitted, e.g. a beacon or cooperative awareness message. A node intending to transmit a TB has to also transmit its associated SCI, also referred to as scheduling assignment. The SCI includes information such as the Modulation and Coding Scheme (MCS) used for transmitting the TB, the RBs it uses, and the resource reservation interval for Semi-Persistent Scheduling (SPS). The correct reception of SCI by other nodes is crucial for the decoding of the transmitted TB. LTE-V2X defines two sub-channelization schemes - adjacent and non-adjacent - see Figure A.4.

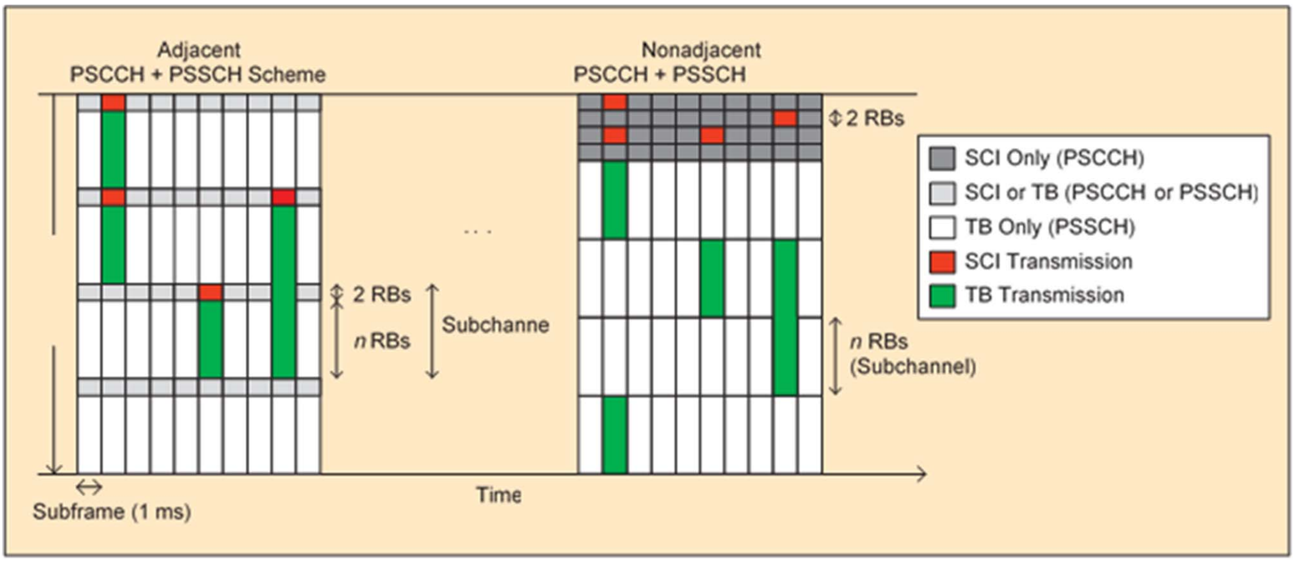


Figure A.4: LTE-V2X subchannelization

In the *adjacent PSCCH + PSSCH scheme*, the SCI and TB are transmitted in adjacent RBs. For each SCI + TB transmission, the SCI occupies the first two RBs of the first subchannel utilized for the transmission. The TB is transmitted in the RBs following the SCI, and depending on its size can occupy several subchannels. In this case, it will also occupy the first two RBs of the following subchannels.

In the *nonadjacent PSCCH + PSSCH scheme*, the RBs are divided into pools. One pool is dedicated to transmit only SCIs, and the SCIs occupy two RBs. The second pool is reserved to transmit only TBs and is divided into subchannels. TBs can be transmitted using QPSK or 16-QAM, whereas the SCIs are always transmitted using QPSK. LTE-V2X uses turbo coding and normal cyclic prefix. LTE-V2X subcarriers have a total of 14 symbols per subframe, and four of these symbols are dedicated to the transmission of Demodulation Reference Signals (DMRSs) to combat the Doppler effect at high speeds. DMRSs are transmitted in the third, sixth, ninth, and 12th symbol of each subcarrier per subframe [i.12].

The adjacent PSCCH + PSSCH scheme has been selected for mode 4 operation in ETSI EN 303 613 [i.10].

A.3.3 Medium access control

A.3.3.1 Introduction

Vehicles using V2X communications mode 4, select their radio resources independently from the control of cellular network. In ETSI EN 303 613 [i.10], the number of subchannels has been selected to be 5, therefore each subchannel contains 10 RBs. When the vehicles are in the cellular network coverage, the network decides how to configure the V2X channel and informs the vehicles about V2X configurable parameters through the Uu interface [i.10]. The message includes the carrier frequency of the V2X channel, the V2X resource pool, synchronization references, the sub-channelization scheme, the number of subchannels per subframe, and the number of RBs per subchannel, among other things.

When the vehicles are not under the cellular network control, they autonomously select radio resources by using sensing with a semi-persistent transmission, which is a kind of "frequency domain listen before talk". Such transmission allows a node to take advantage of semi-periodic traffic arrival and uses past interference patterns to predict the future. The nodes utilize a preconfigured set of parameters to replace the sidelink V2X configurable parameters. The standard does not specify a concrete value for each parameter and the V2X resource pool indicates which subframes of a channel are utilized for V2X. The rest of the subframes can be utilized by other services, including cellular communications. The standard provides the option to divide the V2X resource pool based on geographical areas (referred to as zoning [i.10]). In this case, vehicles in an area can only utilize the resource pools which have been assigned to that areas.

A.3.3.2 Sensing based semi-persistent scheduling

Vehicles select in mode 4 their subchannels by using sensing-based Semi-Persistent Scheduling (SPS) scheme specified in Release 14 [i.13] and [i.14]. A vehicle reserves the selected subchannel(s) for a few consecutive reselection packet-counter transmissions. This counter is randomly set between five and 15, and the vehicle includes its value in the SCI. After each transmission, the reselection counter is decremented by one. When it is equal to zero, additional resources need to be selected and reserved with probability (1-P). Each vehicle can set-up P between zero and 0,8. Additional resources also need to be reserved if the packet to be transmitted does not fit in the subchannel(s) previously reserved. The reselection counter is randomly chosen every time additional resources are reserved. Packets can be transmitted every 100 subframes [i.e. ten packets per second (10 pps)] or in multiples of 100 subframes (up to a minimum of 1 pps). Each vehicle includes its packet transmission interval in the resource reservation field of its SCI. Thanks to the semipersistent reservation of resources and the inclusion of the reselection counter and packet transmission interval in the SCI, other vehicles can estimate which subchannels are free when making their own reservation, which reduces packet collisions. The process for reserving subchannels is organized in three steps as explained in Figure A.5.

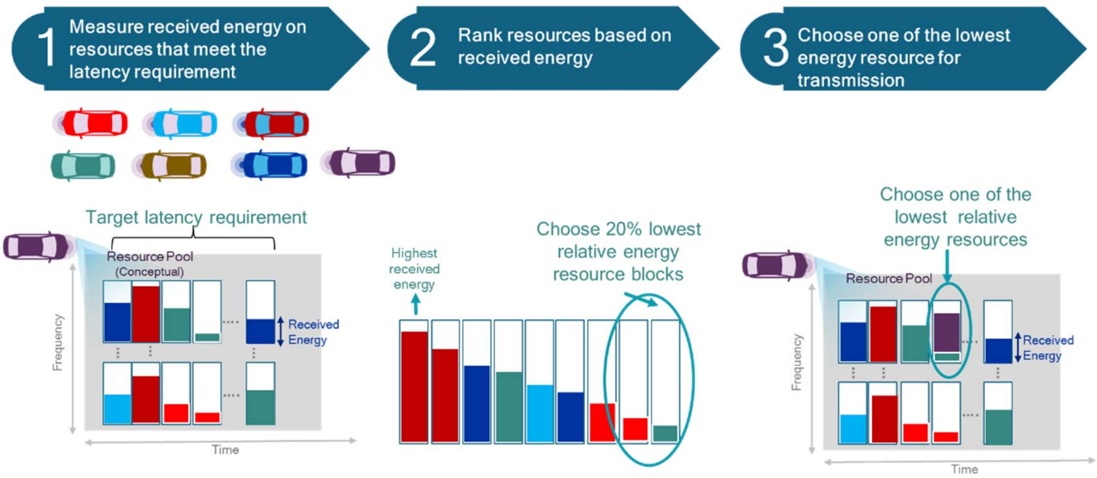


Figure A.5: Mode 4 resource selection

The resource selection is as follows:

Step 1: Suppose that a vehicle, *V*, needs to reserve new subchannels at time,*T*. It can reserve subchannels between *T* and the established maximum latency (≤ 100 ms [i.15]). Within this time period, called selection window, the vehicle identifies Candidate Single-subframe Resources (CSRs, also referred to as candidate resources) to be reserved by all groups of adjacent subchannels within the same subframe, where the SCI + TB to be transmitted will fit.

Step 2: Vehicle, *V*, analyses all the information it has received in the 1 000 subframes before *T* and creates a list, *L1*, of CSRs it could reserve. This list includes all the CSRs in the selection window except those that meet the following two conditions:

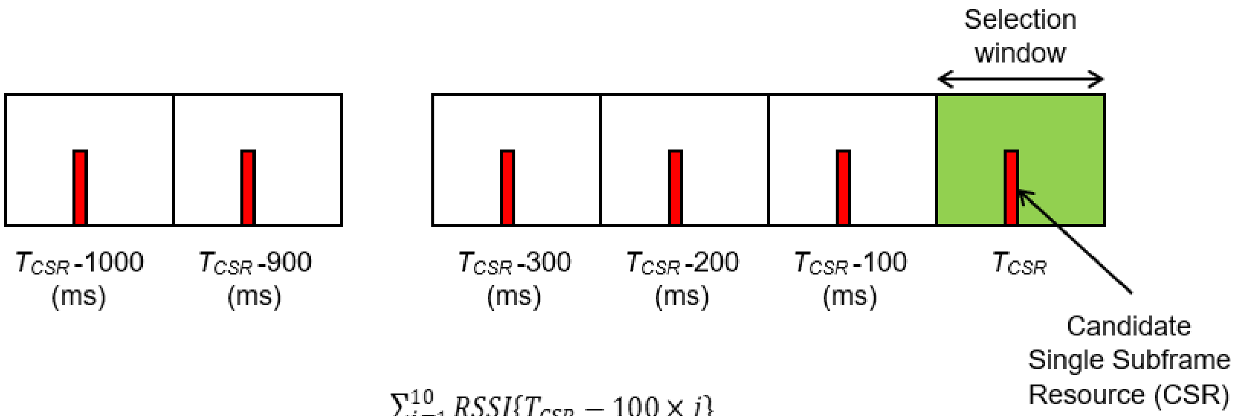
1) In the last 1 000 subframes, *V* has correctly received an SCI from another vehicle indicating that it will utilize this CSR at the same time *V* will need it to transmit any of its next reselection packet-counters.

2) *V* measures an average Reference Signal Received Power (RSRP) over the RBs utilized to transmit the TB associated to the SCI higher than a given threshold. The threshold depends on the priority of the packet. This priority is established by higher layers based on the relevance and urgency of the application. If V receives several SCIs from the same interfering vehicle reserving a given CSR, it will utilize the most recent one to estimate the average RSRP.

The above-mentioned conditions need to be simultaneously met for *V* to exclude a specific CSR. Vehicle *V* also excludes all CSRs of subframe *F* in the selection window, if *V* was transmitting during any previous subframe *F* - 100 × j (j ϵ N, 1 ≤ j ≤ 10). It should be noted that *V* is not able to receive the transmissions of other vehicles in the subframe it is transmitting due to half duplex transmissions.

After Step 2 is executed, *L1* has to include at least 20 % of all CSRs in the selection window. If not, Step 2 is iteratively executed until the 20 % target is met. The RSRP threshold is increased by 3 dB in each iteration.

Step 3: Vehicle *V* creates a second list *L2* of CSRs. The total number of CSRs in *L2* has to be equal to 20 % of all CSRs in the selection window. *L2* includes the CSRs from *L1* (after Step 2) that experienced the lowest average Received Signal Strength Indicator (RSSI) over all its RBs. This RSSI value is averaged over all the previous T_{CSR} - 100 × j subframes (j ϵ N, 1 ≤ j ≤ 10), see Figure A.6. Vehicle *V* randomly chooses one of the CSRs in *L2*, and reserves it for the next Reselection Counter packet transmissions.



$$RSSI = \frac{\sum_{j=1}^{10} RSSI\{T_{CSR} - 100 \times j\}}{10}$$

Figure A.6: The average RSSI of a candidate resource in Step 3

A.3.3.3 Hybrid automatic request

Hybrid Automatic Request (HARQ) is a mandatory feature in ETSI TS 103 723 [i.16]. It combines forward error correcting codes with ARQ error control and soft combining. The retransmission needs to be performed within 15 subframes of the original transmission.

History

Document history		
V1.1.1	September 2021	Publication