ETSI EN 302 663 V1.3.1 (2020-01)

Intelligent Transport Systems (ITS);
ITS-G5 Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band

Reference

REN/ITS-0040191

Keywords

ITS, layer 1, layer 2, MAC, profile, radio

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Foreword

This European Standard (EN) has been produced by ETSI Technical Committee Intelligent Transport Systems (ITS).

National transposition dates	
Date of adoption of this EN:	23 December 2019
Date of latest announcement of this EN (doa):	31 March 2020
Date of latest publication of new National Standard or endorsement of this EN (dop/e):	30 September 2020
Date of withdrawal of any conflicting National Standard (dow):	30 September 2020

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Introduction

The present document outlines the two lowest layers - physical layer and data link layer - in the protocol stack for supporting vehicle-to-vehicle communications in an *ad hoc* network to be used at the 5,9 GHz frequency band allocated in Europe in compliance with Commission Decision 2008/671/EC [i.1], ECC/DEC/(08)01 [i.2] and ECC/REC/(08)01 [i.3]. The two lowest layers are termed access layer according to ETSI EN 302 665 [i.4] in the present document and the technology specified for the access layer is collectively called ITS-G5. The ITS-G5 access layer technology is using already existing standards for communications. The data link layer is divided into two sublayers; medium access control and logical link control. The physical layer and the medium access control layer are covered in IEEE 802.11-2016 [1]. The logical link control is based on the IEEE/ISO/IEC 8802-2-1998 [2]. The ITS-G5 standard also adds features for Decentralized Congestion Control (DCC) methods ETSI TS 102 687 [3] to control the network load.

By setting the Management Information Base (MIB) parameter `dot11OCBActivated` to true in IEEE 802.11-2016 [1] a new capability is introduced namely the possibility to communicate outside the context of a Basic Service Set (BSS), which is the smallest building block of an 802.11 network. Communication outside the BSS implies that neither authentication/association procedures nor security mechanisms are supported. Further, no access point functionality is present. The disable of these features also affects other built-in features of IEEE 802.11-2016 [1]. The requirement that nodes should share a common clock is no longer valid while `dot11OCBActivated` is true. Further, scanning of available frequency channels for joining a BSS is also disabled implying that communication outside the context of the BSS requires that a node is configured for a predetermined frequency channel where more information about other available frequency channels can be obtained.

1 Scope

The present document defines the two lowest layers, physical layer and the data link layer, grouped into the access layer of the ITS station reference architecture ETSI EN 302 665 [i.4].

2 References

2.1 Normative 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.

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The following referenced documents are necessary for the application of the present document.

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

[2] 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".

[3] ETSI TS 102 687 (V1.2.1): "Intelligent Transport Systems (ITS); Decentralized Congestion Control Mechanisms for Intelligent Transport Systems operating in the 5 GHz range; Access layer part".

[4] IEEE 802™-2014: "IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture".

[5] ETSI EN 302 571 (V2.1.1): "Intelligent Transport Systems (ITS); Radiocommunications equipment operating in the 5 855 MHz to 5 925 MHz frequency band; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU".

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

2.2 Informative references

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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] Commission Decision 2008/671/EC of 5 August 2008 on the harmonised use of radio spectrum in the 5 875-5 905 MHz frequency band for safety-related applications of Intelligent Transport Systems (ITS).

[i.2] ECC/DEC/(08)01: "ECC Decision (08)01 on the harmonised use of the band 5875-5925 MHz for Intelligent Transport Systems (ITS)".

[i.3] ECC/REC/(08)01: "ECC Recommendation (08)01 on the use of the band 5855-5875 MHz for Intelligent Transport Systems (ITS)".

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

[i.5] IEEE 802.11p™-2010: "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 6: Wireless Access in Vehicular Environments".

[i.6] IEEE 802.11™-2012: "IEEE Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks-Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications".

[i.7] IEEE 802.11a™-1999: "IEEE Standard for Telecommunications and Information Exchange Between Systems - LAN/MAN Specific Requirements - Part 11: Wireless Medium Access Control (MAC) and physical layer (PHY) specifications: High Speed Physical Layer in the 5 GHz band".

[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 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] IEEE Registration Authority.

NOTE: Available at https://standards.ieee.org/content/ieee-standards/en/products-services/regauth/index.html.

[i.11] List of assigned EtherTypes at the IEEE Registration Authority.

NOTE: Available at http://standards-oui.ieee.org/ethertype/eth.txt.

[i.12] ETSI EN 302 636-4-1 (V1.3.1): "Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; Part 4: Geographical addressing and forwarding for point-to-point and point-to-multipoint communications; Sub-part 1: Media-Independent Functionality".

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

[i.14] IEEE 802.11™-2007: "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 following terms apply:

ethertype: identifier to the network protocol above the data link layer

ITS-G5 access layer: access layer technology to be used in frequency bands dedicated for European Intelligent Transport Systems (ITS)

3.2 Symbols

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

aCWmax	Maximum value of Contention Window
aCWmin	Minimum value of Contention Window
AIFS	Arbitration InterFrame Space
AIFSN	Arbitration InterFrame Space Number
aSIFSTime	Short InterFrame Space defined by the physical layer
aSlotTime	A slot time defined by the physical layer
CW	Contention Window
CW_{max}	Maximum value of Contention Window
CW_{min}	Minimum value of Contention Window
T_{busy}	period of time the channel is busy
T_{CBR}	period of time

3.3 Abbreviations

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

AC	Access Category
AC_BE	Access Category Best Effort
AC_BK	Access Category Background
AC_VI	Access Category Video
AC_VO	Access Category Voice
ACK	Acknowledgment
AIFS	Arbitration InterFrame Space
AIFSN	Arbitration InterFrame Space Number
AP	Access Point
BE	Best Effort
BK	Background
BPSK	Binary Phase Shift Keying
BSS	Basic Service Set
BSSID	Basic Service Set Identification
CBR	Channel Busy Ratio
CEN	European Committee for Standardization
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
CW	Contention Window
DCC	Decentralized Congestion Control
DCF	Distributed Coordination Function
DIFS	Distributed InterFrame Space
DSRC	Dedicated Short-Range Communication
DUT	Device Under Test
ECC	Electronic Communication Committee
EDCA	Enhanced Distribution Coordination Access
EE	Excellent Effort
EN	European Norm
EPD	EtherType Protocol Discrimination
GPS	Global Positioning System
HalfBT	Half Bathtub
HDR	High Data Rate
IBSS	Independent Basic Service Set
IEEE	Institute of Electrical and Electronics Engineers
ITS	Intelligent Transport Systems
LLC	Logical Link Control
LOS	Line-Of-Sight

MAC	Medium Access Control
MCS	Modulation and Coding Scheme
MIB	Management Information Base
MPDU	MAC Protocol Data Unit
NC	Network Control
NLOS	Non Line-Of-Sight
OFDM	Orthogonal Frequency Division Multiplexing
PDU	Protocol Data Unit
PER	Packet Error Rate
PHY	Physical layer
PLCP	Physical Layer Convergence Protocol
PPDU	PLCP Protocol Data Unit
PSDU	PLCP Service Data Unit
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
SNAP	SubNetwork Access Protocol
TDL	Tapped Delay Line
TS	Technical Specification
TX	Transmitter
UP	User Priority
VI	Video
VO	Voice
WLAN	Wireless Local Area Network

4 Access layer requirements

4.1 Introduction

The access layer bundles the data link layer and the physical layer and it is situated at the bottom of the ITS protocol stack, see Figure 1. The ITS station reference architecture and the definition of an ITS station are outlined in ETSI EN 302 665 [i.4].

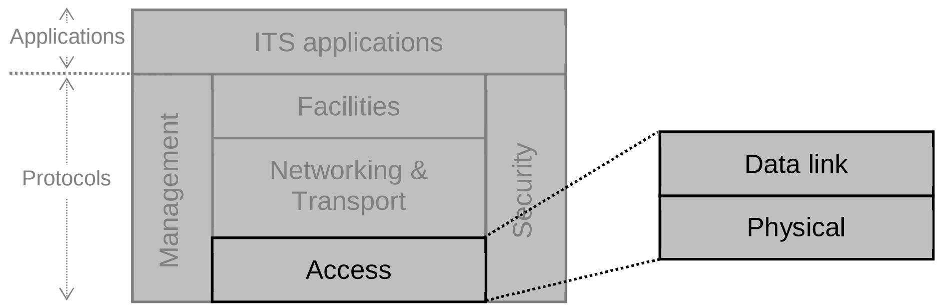


Figure 1: ITS station reference architecture

The access layer technology consists of IEEE 802.11-2016 [1], IEEE/ISO/IEC 8802-2-1998 [2], IEEE 802-2014 [4] and ETSI TS 102 687 [3], see Figure 2. An introduction to IEEE 802.11-2016 [1] with the MIB parameter `dot11OCBActivated` set to true is provided in informative Annex C. Interfaces between access layer and management entity and access layer and networking & transport layer are found in Annex B.

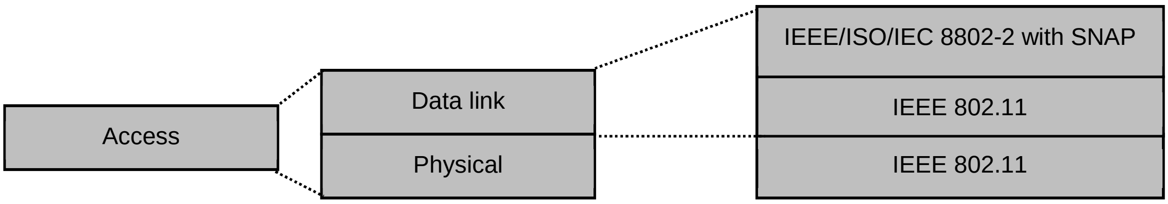


Figure 2: Protocols comprising the access layer

4.2 Physical layer

The physical layer of ITS-G5 shall be the orthogonal frequency division multiplexing (OFDM) "half-clocked" operation using 10 MHz frequency channels as outlined in IEEE 802.11-2016 [1], clause 17. Mandatory transfer rates are 3 Mbit/s, 6 Mbit/sand 12 Mbit/s.

The limits for static receiver sensitivity shall be as outlined in Table 1.

Table 1: Static receiver sensitivity

Transfer rate (Mbit/s)	Modulation	Coding rate	Minimum sensitivity for 10 MHz channel spacing (dBm)
3	BPSK	1/2	-91
4,5	BPSK	3/4	-90
6	QPSK	1/2	-88
9	QPSK	3/4	-86
12	16-QAM	1/2	-83
18	16-QAM	3/4	-79
24	64-QAM	2/3	-75
27	64-QAM	3/4	-74

The limits for dynamic receiver sensitivity (i.e. the receiver sensitivity in the presence of interference) shall be as outlined in Table 2.

Table 2: Dynamic receiver sensitivity

Transfer rate (Mbit/s)	Modulation	Coding rate	Minimum sensitivity for 10 MHz channel spacing (dBm)
6	QPSK	1/2	-85

The limits for receiver adjacent channel rejection and alternate adjacent channel rejection shall be as outlined in Table 3.

Table 3: Limits for receiver adjacent channel rejection and alternate adjacent channel rejection

Transfer rate (Mbit/s)	Modulation	Coding rate	Adjacent channel rejection (dB)	Alternate adjacent channel rejection (dB)
3	BPSK	1/2	28	42
4,5	BPSK	3/4	27	41
6	QPSK	1/2	25	39
9	QPSK	3/4	23	37
12	16-QAM	1/2	20	34
18	16-QAM	3/4	16	30
24	64-QAM	2/3	12	26
27	64-QAM	3/4	11	25

4.3 Data link layer

4.3.1 Introduction

The data link layer consists of two sublayers - logical link control (LLC) and medium access control (MAC) - where the former provides means for distinguishing between different network layer protocols and the latter is responsible for scheduling transmissions to minimize interference between ITS stations. Decentralized Congestion Control (DCC) is a management entity controlling the network load by for example regulating the number of transmission opportunities the ITS station has based on the current load. Thus DCC is not a protocol to achieve interoperability but merely an algorithm controlling that a single ITS station does not consume all resources on the channel. Figure 3 illustrates the different sublayers and protocols.

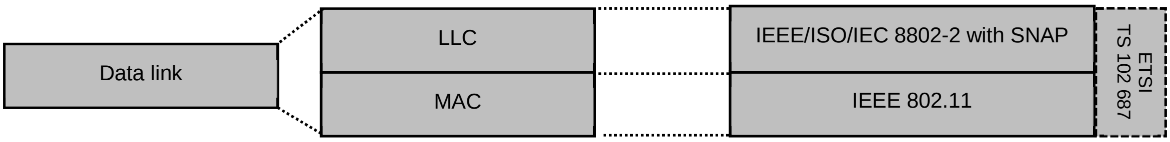


Figure 3: Protocols and DCC management entity comprising the data link layer

4.3.2 Decentralized congestion control

ETSI TS 102 687 [3] shall be fulfilled and the selected DCC algorithm shall respect the limits provided below.

The Channel Busy Ratio (CBR) is used for determining the transmission behaviour. CBR is an estimate of how much a single channel is used based on listening on surrounding radio transmitters. The determination of CBR for the equipment shall be as performed according to Equation 1. Any other equivalent mechanism may be used providing a CBR with a deviation of ±3 %.

$$\mathrm{CBR} = \frac{T_{busy}}{T_{CBR}}, \quad (1)$$

T_{busy} is the period of time in milliseconds when the strength of received ITS-G5 signals over a period of T_{CBR} exceeds -85 dBm. T_{CBR} is equal to 100 milliseconds. T_{on} is the duration of a transmission by the equipment and T_{off} is the time interval between two consecutive transmissions by the equipment.

Duty cycle is defined as the ratio, expressed as a percentage of the transmitter total "on" time on one carrier frequency, relative to 1 second period.

The following limits apply:

$$0 < T_{on} \leq 4 \text{ ms} \quad (2)$$

$$\textit{duty cycle} \leq 3\ \% \quad (3)$$

If *CBR* is < 0,62, **then** $T_{off} \geq 25$ ms (4)

If *CBR* is ≥ 0,62, **then** $T_{off} \geq 25$ ms

and $T_{off} \geq \min\{1\,000 \text{ ms}, T_{on} \times \left(4\,000 \times \frac{CBR - 0{,}62}{CBR} - 1\right)\}$ (5)

NOTE: The rationale behind Equation 5 is outlined in ETSI TS 103 175 [i.13], Equation 1 in clause 7.2.

4.3.3 Logical link control

The LLC functionality shall be according to IEEE/ISO/IEC 8802-2-1998 [2] and the mode of operation is set to Type 1 - unacknowledged connectionless mode.

The subnetwork access protocol (SNAP) shall be according to IEEE 802-2014 [4].

EtherType protocol discrimination (EPD) as defined in IEEE 802.11-2016 [1], Annex E.2.4 shall not be used.

NOTE: The SNAP provides the possibility to distinguish between different network protocols through EtherTypes. Ethertypes are assigned by the IEEE Registration Authority [i.10] and a full list of all Ethertypes are found in [i.11]. The GeoNetworking protocol ETSI EN 302 636-4-1 [i.12] has been assigned EtherType 0x8947.

4.3.4 Medium access control

The MAC sublayer functionality shall be enabled by setting the MIB parameter `dot11OCBActivated` to true in IEEE 802.11-2016 [1].

4.4 CEN DSRC and HDR DSRC protection

The ITS station shall be conformant to ETSI TS 102 792 [6].

5 ITS-G5 radio tests

5.1 Radio tests defined in ETSI EN 302 571

ITS-G5 radio tests shall be done according to ETSI EN 302 571 [5] with the following modifications:

a) for receiver selectivity, the limits shall be as specified in Table 3;

b) for receiver sensitivity, the limits shall be as specified in Table 1.

5.2 Additional radio tests

5.2.1 Dynamic receiver sensitivity

The dynamic sensitivity limit shall be as specified in Table 2.

The testing of dynamic receiver sensitivity shall be performed with the channel models outlined in Table A.2 and the test procedure shall be as follows:

Step 1:

- Connect the DUT receiver to the output of the test system.

Step 2:

- Activate a test transmission from the test system at the carrier frequency of the DUT, at a level adjusted to reference sensitivity +5 dB at the receiver input.

Step 3:

- Reduce the power level until the packet error rate PER is 10^{-1}.

Step 4:

- Compare the power level value to the limit specified in Table 2.

The transmitter shall use a frame size of 1 000 octets. The PER is calculated from the number of sent packets Pkt_{Tx} and the number of correctly received packets Pkt_{Rx} as shown in Equation (6). At least 1 000 frames shall be used for evaluating the PER.

$$PER = \frac{Pkt_{Tx} - Pkt_{Rx}}{Pkt_{Tx}} \times 100\,\% \qquad (6)$$

Annex A (normative): Channel models for testing dynamic sensitivity values

The present annex outlines channel models representing different vehicular scenarios with accompanied specific channel conditions. The type of channel model selected for capturing more dynamic behaviour such as fading and multipath is a Tapped Delay Line (TDL) model. The TDL models provided herein shall be used when testing the dynamic receiver selectivity outlined in clause 4.2. Five different vehicular scenarios have been selected, where three are under Line-Of-Sight (LOS) conditions and two are under Non-LOS (NLOS) conditions, see Table A.1.

Table A.1: Description of scenarios

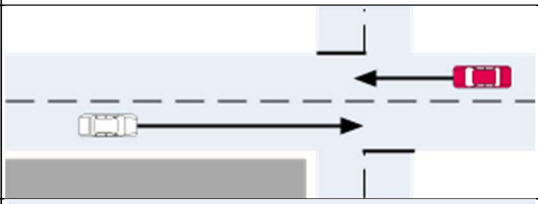
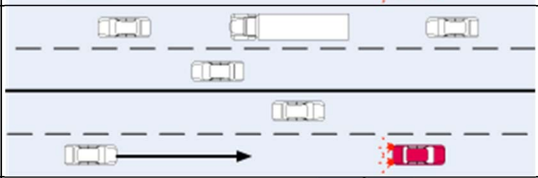
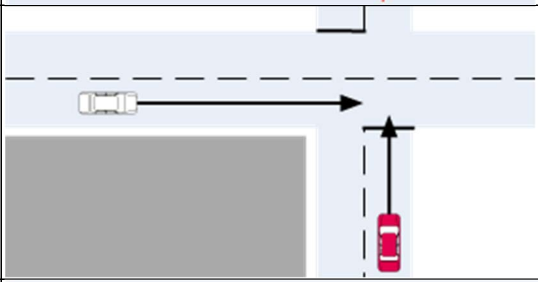
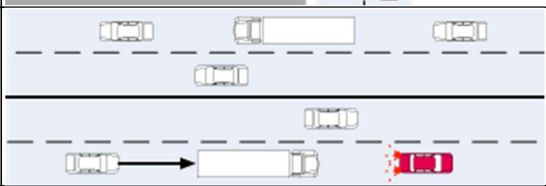
Scenario	Picture	Description
Urban approaching LOS		Two vehicles approaching each other in an urban setting with buildings.
Rural LOS		This setting reflects an open environment where other vehicles, buildings and fences are absent.
Highway LOS		Two vehicles communicating in a multilane scenario where other vehicles as well as road infrastructure such as traffic signs are present.
Urban crossing NLOS		Two vehicles approaching an intersection where the LOS component is blocked by a building.
Highway NLOS		Highway scenario where the LOS component is blocked by other vehicles.

Table A.2 provides the parameter settings for the TDL for the different scenarios in Table A.1.

Table A.2: Channel model parameters for the different scenarios

		Power (dB)	Delay (ns)	Doppler (Hz)	Profile
Urban approaching LOS	**Tap 1**	0	0	0	Static
	Tap 2	-8	117	236	HalfBT
	Tap 3	-10	183	-157	HalfBT
	Tap 4	-15	333	492	HalfBT
Rural LOS	**Tap 1**	0	0	0	Static
	Tap 2	-14	83	492	HalfBT
	Tap 3	-17	183	-295	HalfBT
Highway LOS	**Tap 1**	0	0	0	Static
	Tap 2	-10	100	689	HalfBT
	Tap 3	-15	167	-492	HalfBT
	Tap 4	-20	500	886	HalfBT
Urban crossing NLOS	**Tap 1**	0	0	0	Static
	Tap 2	-3	267	295	HalfBT
	Tap 3	-4	400	-98	HalfBT
	Tap 4	-10	533	591	HalfBT
Highway NLOS	**Tap 1**	0	0	0	Static
	Tap 2	-2	200	689	HalfBT
	Tap 3	-5	433	-492	HalfBT
	Tap 4	-7	700	886	HalfBT

Annex B (informative): Data and management service

B.1 Access layer data service

The present clause outlines the service exposed to the Networking & Transport layer (see Figure 1). The access layer provides connectionless transfer of Protocol Data Units (PDU) across the ITS-G5 radio interface. The service is specified by two primitives AL_DATA.request and AL_DATA.indicate, which extend the primitives of LLC based on the IEEE/ISO/IEC 8802-2-1998 [2] and are specific for proper operation of vehicular ad hoc communication.

The physical addresses (i.e. MAC addresses) are included as parameters in the service primitives since they are required by the GeoNetworking protocol ETSI EN 302 636-4-1 [i.12] - if present - in order to facilitate multihop functionality. Transmission-specific parameters, such as priority, transmit power and Modulation and Coding Scheme (MCS) enable setting TX parameters on a per-packet basis. Channel number and transceiver ID support multi-transceiver and multi-channel operation over ITS-G5 radio, whereas the transceiver ID specifies the ITS-G5 device if multiple devices are attached to one N&T layer protocol and logically appear as a single network interface.

```
AL_DATA.request (
    Source MAC address,
    Destination MAC address,
    Priority,
    Transmit power,
    MCS, -- Modulation and coding scheme
    Channel number,
    Transceiver ID, -- If several ITS-G5 devices are attached to one N&T layer protocol
                     -- and appear as a single network interface
    Data
)
AL_DATA.indicate (
    Source MAC address,
    Destination MAC address,
    CBR, -- Current local CBR
    Channel number,
    Transceiver ID,
    RSSI, -- Received signal strength
    Data
)
```

B.2 Access layer management service

The service offered to the management (the interface between access layer and the management plane) is outlined in clause 8.2 of ETSI TS 103 175 [i.13].

Annex C (informative): Introduction to IEEE 802.11-2016

C.1 Introduction

The aim with the present informative annex is to introduce the reader of the present document to the IEEE 802.11-2016 [1] when used in the vehicular environment.

NOTE 1: The annex is a brief introduction and the reader is referred to IEEE 802.11-2016 [1] for further details.

In March 2012, the amendment IEEE 802.11p-2010 [i.5] was classified as superseded and enrolled into the new version of IEEE 802.11-2012 [i.6]. Since 2012, a new version of IEEE 802.11-2016 [1] has been compiled and published and all amendments between 2012-2016 have been included. IEEE 802.11p-2010 [i.5] was developed to support new emerging applications utilizing wireless communication between vehicles in an effort to decrease road traffic accidents and improve road traffic efficiency. IEEE 802.11p-2010 [i.5] added a new Management Information Base (MIB) variable called `dot11OCBActivated` and by setting this to true a new capability in the IEEE 802.11-2012 [i.6] is introduced namely the possibility to communicate outside the context of a Basic Service Set (BSS), which is the smallest building block of an 802.11 network. The side effect of this are that the BSS authentication and association procedures are removed because this is a time consuming process and in a vehicular environment where nodes are highly mobile and transactions may not be completed until the nodes are out of each other's radio ranges. The communication outside of a BSS can be thought of as *ad hoc* communications and should not be confused with the independent BSS network topology supported in IEEE 802.11-2016 [1]. To distinguish between communication within a BSS and outside of a BSS the network identification (basic service set id, BSSID) is set to a wildcard in every frame transmitted in an 802.11p communications. The removal of authentication and association procedures implies further changes to IEEE 802.11-2016 [1], which will be outlined in the following clauses.

NOTE 2: An amendment is an improvement to an already existing work implying that IEEE 802.11p-2010 [i.5] was not standalone and knowledge about the core IEEE 802.11-2016 [1] was necessary to understand the functionality of IEEE 802.11p-2010 [i.5].

NOTE 3: All primitives ending with "`Enabled`" in the former published version of IEEE 802.11-2007 [i.14] have changed name to "`Activated`" in the 2012 version of IEEE 802.11-2012 [i.6].

NOTE 4: To facilitate the reading of the current annex the name 802.11p will be used throughout the text referring when the `dot11OCBActivated` is set to true enabling communication outside the context of a BSS in IEEE 802.11-2016 [1]. The references to specific clauses will be made to IEEE 802.11-2016 [1] and not the superseded IEEE 802.11p-2010 [i.5].

IEEE 802.11-2016 [1] offers several physical (PHY) layers and one common Medium Access Control (MAC) sublayer with Quality of Service (QoS) support. IEEE 802.11p-2010 [i.5] is using the Orthogonal Frequency Division Multiplexing (OFDM) PHY detailed in IEEE 802.11-2016 [1], clause 17, (a.k.a. IEEE 802.11a-1999 [i.7]), with minor additions, and it has support for QoS through the former amendment called IEEE 802.11e-2005 [i.8] (approved in 2004 and enrolled in the 2007 version of IEEE 802.11-2007 [i.14]).

C.2 Network topology

The IEEE 802.11-2016 [1] 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 4.3.16 of IEEE 802.11-2016 [1]. 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 in order to join an existing network is no longer enabled. Therefore, the implementation of 802.11p in the vehicular environment requires predetermined frequency channels to be set in the management.

C.3 Physical layer

The PHY in IEEE 802.11p-2010 [i.5] is OFDM detailed in IEEE 802.11-2016 [1], clause 17. The basic idea is to divide the available frequency spectrum into narrower subchannels (subcarriers). The high-rate data stream is split into a number of lower-rate data streams transmitted simultaneously over a number of subcarriers, where each subcarrier is narrow banded. There are 52 subcarriers, where 48 are used for data and 4 are pilot carriers. The OFDM PHY layer has support for eight different transfer rates, which are achieved by using different modulation schemes and coding rates. In Table C.1, the different transfer rates together with the coding schemes are tabulated for 10 MHz frequency channels. Support of three transfer rates are mandatory; 3 Mbit/s, 6 Mbit/s and 12 Mbit/s.

NOTE: The OFDM PHY supports 3 different frequency channel bandwidths, i.e. 5 MHz, 10 MHz and 20 MHz, where the latter is commonly used for WLAN at 5 GHz and 10 MHz is used for the vehicular environment at 5,9 GHz.

Table C.1: Transfer rates, modulation schemes and coding rates for 10 MHz channels

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

In Figure C.1, the resulting PHY packet is depicted, 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 and the signal field contains information about the packet length and at what data rate the data field is transmitted with. The signal field is always transmitted using BPSK with a coding rate of 1/2. The duration of one OFDM symbol is 8 µs and depending on the modulation scheme and coding rate different numbers of data bits can be carried in each OFDM symbol, see Table C.1. The signal field consists of 24 bits transmitted with the lowest transfer rates and therefore it takes 8 µs.

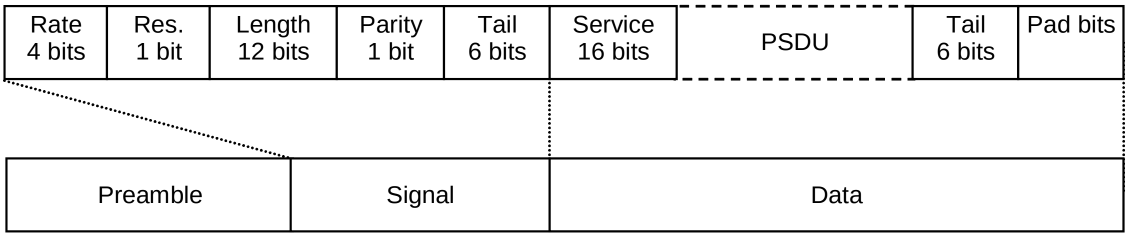


Figure C.1: The resulting PHY packet, i.e. PPDU, ready for transmission

In Table C.2, an explanation to all the different fields in the packet is given together with duration for 10 MHz frequency channels. The preamble and the signal field have fixed duration.

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

Field	Subfield	Description	Duration (μs)
Preamble	N/A	Synchronizing receiver. Consists of a short and a long training sequence.	32
Signal	Rate	Specifies the transfer rate at which the data field in the PPDU will be transmitted.	8
	Reserved	For future use.	
	Length	The length of the packet.	
	Parity	Parity bit.	
	Tail	Used for facilitate decoding and calculation of rate and length subfields.	
Data	Service	Used for synchronizing the descrambler at receiver.	Depending on selected transfer rate and packet length.
	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 reach a multiple of coded bits per OFDM symbol (i.e. 48, 96, 192, 288, see Table C.1).	

More details about the PHY are found in IEEE 802.11-2016 [1], clause 17.

C.4 Medium access control

C.4.1 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 by 802.11p is found in the IEEE 802.11-2016 [1] and it 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 2005 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 802.11-2016 [1], 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.

C.4.2 Backoff procedure

The backoff procedure in 802.11 works as follows:

i) 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);

ii) 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);

iii) 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 802.11-2016 [1].

C.4.3 Medium access control

In Figure C.2, simplified drawings of the channel access procedure as performed by 802.11 nodes is depicted for broadcast mode, Figure C.2(a), and unicast mode, Figure C.2(b).

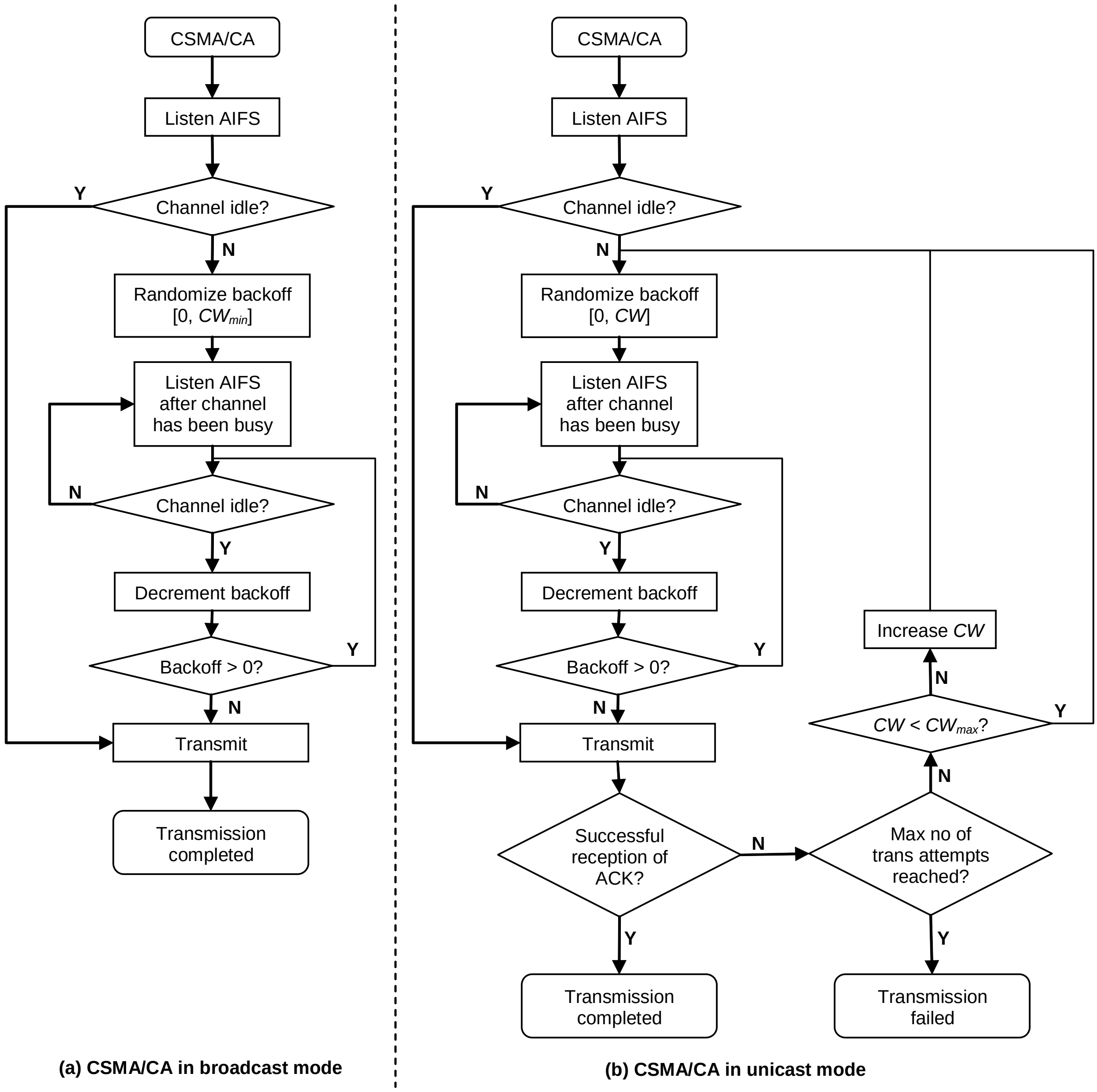


Figure C.2: A simplified drawing of the channel access procedure in IEEE 802.11-2016 [1] in broadcast and unicast mode

More details about the channel access procedure are found in clause 10 of IEEE 802.11-2016 [1].

C.4.4 EDCA parameters, AC and UP

EDCA is the official name of one of the MAC algorithms in IEEE 802.11-2016 [1], which is used by IEEE 802.11p-2010 [i.5]. 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 IEEE 802.11-2016 [1] defines eight different user priorities (UPs) and these are inherited from the ANSI/IEEE 802.1D-1998 [i.9] defining MAC bridges. The UPs from 802.1D are shown in Table C.3 and they are mapped to four different access categories (ACs), i.e. queues, within the QoS facility. This mapping is shown in Table C.3, where the lowest priority is 0 and the highest 7.

Table C.3: Mapping of UPs in ANSI/IEEE 802.1D-1998 [i.9] 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:

$$AIFS[AC] = AIFSN[N] \times aSlotTime + aSIFSTime \quad \text{(C.1)}$$

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 C.4 the default values for AIFSN and CW is tabulated for the different ACs in 802.11p, found in Table 9-138 of IEEE 802.11-2016 [1].

Table C.4: The default values for the AIFSN and CW in 802.11p found in IEEE 802.11-2016 [1]

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

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

In Table C.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 802.11-2016 [1].

Table C.5: OFDM PHY specific parameters used in 802.11p found in IEEE 802.11-2016 [1]

Parameter	Value
aSlotTime	13 µs
aSIFSTime	32 µs
aCWmin	15
aCWmax	1 023

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

Table C.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 802.11-2016 [1].

C.5 Implications of the dot11OCBActivated set to true

In 802.11p the new MIB variable `dot11OCBActivated` is introduced and when this is set to true certain features are disabled or given new default values in 802.11. The major change to the overall 802.11 standard is the possibility to exchange data frames without any prior network establishment, i.e. no authentication and association procedures are allowed at the MAC sublayer in 802.11p. The removal of these procedures affects many things because now there is no node that is responsible for determining network specific features such as power save mode, network id (basic service set identification, BSSID), security, synchronization, and negotiation about QoS. The following list is an excerpt of examples that is affected by the `dot11OCBActivated` is set true:

- MAC sublayer authentication and association procedures are disabled
- Power save is not allowed
- The BSSID is set to a wildcard containing only ones
- The traditional synchronization found in 802.11 is not possible because no beacons exist, however 802.11p also defines a new Timing Advertisement management frame type
- 802.11 Security needs association and authentication procedures and it is therefore not supported

NOTE: Security will be provided through other standards in the cooperative ITS domain and synchronization can be done using, e.g. GPS.

Annex D (informative): Change History

Date	Version	Information about changes
2010-01	1.1.0	First publication as ETSI ES 202 663.
2013-07	1.2.1	First version as European Norm of ETSI ES 202 663; updates to take into account 802.11p final changes and 802.11p transfer to 802.11, linkage to ETSI TS 102 792 clarified, other changes based on new information from G5 related projects.
2019-05	1.3.0	Update of the title and references; clarifications and minor error corrections.

History

Document history				
V1.1.0	January 2010	Publication as ETSI ES 202 663		
V1.2.1	July 2013	Publication		
V1.3.0	May 2019	EN Approval Procedure	AP 20190806:	2019-05-08 to 2019-08-06
V1.3.1	October 2019	Vote	V 20191222:	2019-10-23 to 2019-12-23
V1.3.1	January 2020	Publication		