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TECHNICAL REPORT

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

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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

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1 Scope

The present document carries out studies on the feasibility of co-channel co-existence between ITS-G5 and LTE-V2X technologies based on solutions presented to CEPT. It defines methodologies and metrics required for performing the studies and evaluating the performance of the solutions studied. To find co-channel co-existence methods, which enable both technologies to use the same frequency channel in the same geographical area, while meeting the metrics defined.

The present document classifies co-channel co-existence methods depending on the observed metrics.

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

[i.2] 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.3] 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.4] 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.5] 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.6] 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.7] 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.8] ETSI TS 136 213 (V15.9.0): "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures (3GPP TS 36.213 version 15.9.0 Release 15)".

[i.9] ETSI TS 136 211 (V14.3.0): "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation (3GPP TS 36.211 version 14.3.0 Release 14)".

[i.10] ETSI TS 136 300 (V14.3.0): "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.11] ETSI TS 136 321 (V14.3.0): "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification (3GPP TS 36.321 version 14.3.0 Release 14)".

[i.12] ETSI TS 136 101 (V14.4.0): "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.13] 3GPP TR 36.885: "Study on LTE-based V2X services" (V14.0.0, Release 14)", June 2016.

[i.14] F. Berens, V. Martinez, and K. Moerman: "Survey on CAM statistics," presented at ETSI ITS workshop 2019.

NOTE: Available online: https://docbox.etsi.org/Workshop/2019/201903_ITSWS/SESSION03/NXP_Moerman.pdf.

[i.15] CAR2CAR Communication Consortium: "Survey on ITS-G5 CAM statistics," 2018.

NOTE: Available online: https://www.car-2-car.org/fileadmin/documents/General_Documents/C2CCC_TR_2052_Survey_on_CAM_statistics.pdf.

[i.16] ETSI EN 302 637-3 (V1.3.1) (04-2019): "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service".

[i.17] ETSI EN 302 637-2 (V1.4.1) (04-2019): "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service".

[i.18] 3GPP TR 36.843: "Study on LTE Device to Device Proximity Services; Radio Aspects (V12.0.1, Release 12)" March 2014.

[i.19] Report Recommendation ITU-R M.2135-1 (2009): "Guidelines for evaluation of radio interface technologies for IMT-Advanced".

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[i.24] ECC Report 250: "Compatibility studies between TTT/DSRC in the band 5805-5815 MHz and other systems," April 2016.

[i.25] ETSI TS 103 574 (V1.1.1) (11-2018): "Intelligent Transport Systems (ITS); Congestion Control Mechanisms for C-V2X PC5 interface; Access layer part".

[i.26] ETSI TS 102 687 (V1.2.1) (04-2018): "Intelligent Transport Systems (ITS); Decentralized Congestion Control Mechanisms for Intelligent Transport Systems operating in the 5 GHz range; Access layer part".

[i.27] IEEE Std 1609.4™-2016: "IEEE Standard for Wireless Access in Vehicular Environments (WAVE) - Multi-Channel Operation".

[i.28] ETSI TS 103 723 (V1.2.1) (11-2020): "Intelligent Transport Systems (ITS); Profile for LTE-V2X Direct Communication".

[i.29] 3GPP TS 36.101: "Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception (V16.4.0, Release 16)", December 2019.

[i.30] TGbd: "Project Authorization Request (PAR)", IEEE 802.11-18/0861r9.

NOTE: Available at https://mentor.ieee.org/802.11/dcn/18/11-18-0861-09-0ngv-ieee-802-11-ngv-sg-proposed-par.docx.

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[i.33] ETSI TS 136 133 (V14.17.0): "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Requirements for support of radio resource management (3GPP TS 36.133 version 14.7.0 Release 14)".

[i.34] 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".

[i.35] ETSI TS 103 613: "Intelligent Transport Systems (ITS); Access layer specification for Intelligent Transport Systems using LTE Vehicle to everything communication in the 5,9 GHz frequency band".

3 Definition of terms, symbols and abbreviations

3.1 Terms

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

subframe: time interval equal to 1 ms

NOTE: This equals the "subframe duration" as defined in ETSI TS 136 211 [i.9].

superframe: consists of two time slots

time slot: integer multiple of consecutive subframes

3.2 Symbols

Void.

3.3 Abbreviations

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

AC	Access Category
ACK	ACKnowledgement
AGC	Automatic Gain Control
AIFS	Arbitration InterFrame Space
AIFSN	AIFS Number
AP	Access Point
ARQ	Automatic Repeat reQuest
BE	Best Effort

BK	Background
BPSK	Binary Phase Shift Keying
BS	Base Station
BSS	Basic Service Set
BSSID	BSS identifier
C2C-CC	CAR2CAR Communication Consortium
CAM	Cooperative Awareness Message
CBR	Channel Busy Ratio
CCA	Clear Channel Assement
CDF	Cumulative Distribution Function
CEN	Comité Européen de Normalisation
CP	Cyclic Prefix
CRC	Cyclic Redundancy Check
CSI	Channel Sidelink Information
CSMA/CA	Carrier Sense Multiple Access/Collision Avoidance
CSR	Candidate Single-subframe Resources
CTS	Clear To Send
CW	Contention Window
DA	Data Age
DCC	Decentralized Congestion Control
DCF	Distributed Coordination Function
DENM	Decentralized Environmental Notification Message
DIFS	Distributed InterFrame Space
DL	Data Link Layer
DMRS	DeModulation Reference Signals
DSRC	Dedicated Short Range Communication
EDCA	Enhanced Distributed Channel Access
EE	Excellent Effort
EED	End-to-End Delay
ES	Energy Signals
EVM	Error Vector Magnitude
FCS	Frame Check Sequence
GNSS	Global Navigation Satellite System
HARQ	Hybrid Automatic ReQuest
IBSS	Independent BSS
IN	Interface
IPG	Inter-Packet Gap
IQ	In-phase Quadrature phase
ITS	Intelligent Transport Systems
ITS-S	ITS Station
KPI	Key Performance Indicator
LDPC	Low Density Parity Check
LLC	Logical Link Control
LOS	Line-Of-Sight
LTE	Long Term Evolution
LTF	Long Training Field
LUT	LookUp Table
MAC	Medium Access Control
MCS	Modulation and Coding Scheme
MIB	Management Information Base
MPDU	MAC Protocol Data Unit
MSPS	Mega Symbols Per Second
NAV	Network Allocation Vector
NC	Network Control
NLOS	Non-Line-Of-Sight
NR	New Radio
OBU	OnBoard Unit
OFDM	Orthogonal Frequency Division Multiplexing
OSI	Open System Interconnect
PDU	Protocol Data Unit
PER	Packet Error Rate
PHY	Physical Layer

PLCP	Physical Layer Convergence Procedure
PPDU	PLCP Protocol Data Unit
PPS	Parts Per Second
PRR	Packet Reception Ratio
PSCCH	Physical Sidelink Control Channels
PSDU	PLCP Service Data Unit
PSSCH	Physical Sidelink Shared Channels
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RA	Receive Address
RB	Resource Block
RSRP	Reference Signal Received Power
RSSI	Received Signal Strength Indicator
RSU	RoadSide Unit
RTS	Requestion To Send
RX	Receiver
SC-FDMA	Single-Carrier Frequency Division Multiple Access
SCI	Sidelink Control Information
SDR	Software Defined Radio
SIFS	Short InterFrame Space
SINR	Signal to Interference and Noise Ratio
SPS	Semi-Persistent Scheduling
STF	Short Training Field
SUMO	Simulation of Urban Mobility
TB	Transport Block
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TL	Time Length
TTI	Transmission Time Interval
TX	Transmitter
UP	User Priority
VI	Video
VO	Voice

4 Technical description of road ITS technologies

4.1 Introduction

The two studied road ITS technologies herein are ITS-G5 and LTE-V2X (3GPP Release 14) [i.2]. The technologies represent the access layer of the ITS communications architecture, see Figure 4.1, outlined in ETSI EN 302 665 [i.1]. The access layer consists of the physical layer (PHY) and the data link layer (DL) of the OSI model.

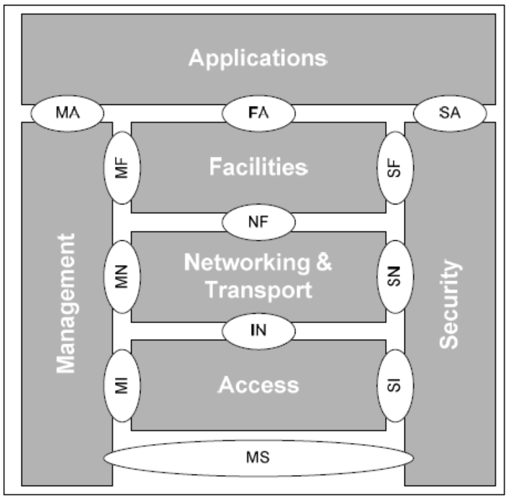

Figure 4.1: The ITS stations reference architecture [i.1]

4.2 ITS-G5

4.2.1 Introduction

ITS-G5 is outlined in ETSI EN 302 663 [i.2] describing the access layer of the ITS station reference architecture. The ITS-G5 access layer consists of:

- IEEE 802.11-2020 [i.3] 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.4].

IEEE 802.11-2020 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 for more technical details.

The IEEE 802.11-2020 [i.3] 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.3]. 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.

4.2.2 Physical layer

The OFDM PHY parameters of ITS-G5 are detailed in Clause 17 of IEEE 802.11-2020 [i.3]. 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 4.1 outlines the different transfer rates together with coding and modulation schemes and data bits per OFDM symbol.

Table 4.1: 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 4.2 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 4.2 details of the ITS-G5 PHY packet format are listed (see also Clause 17 of IEEE 802.11-2020 [i.3]).

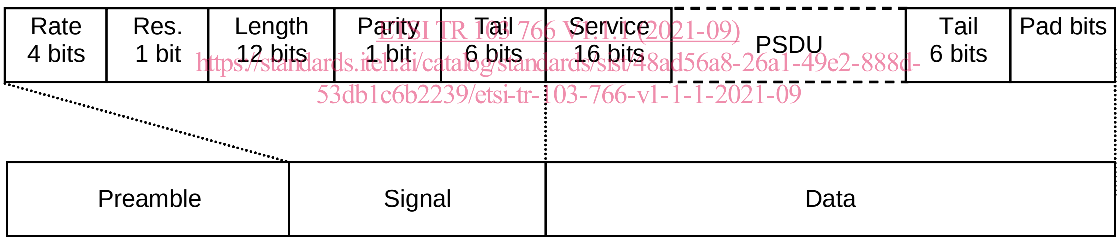

Figure 4.2: ITS-G5 packet format, i.e. PPDU, ready for transmission

Table 4.2: 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.	

4.2.3 Medium access control

4.2.3.1 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 [i.5] amendment and it added QoS to the DCF mechanism. IEEE 802.11e [i.5] 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.3], 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.

4.2.3.2 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 802.11-2020 [i.3].

4.2.3.3 Medium access control

In Figure 4.3, simplified drawings of the channel access procedure as performed by 802.11 nodes is depicted for broadcast mode, Figure 4.3(a), and unicast mode, Figure 4.3(b).

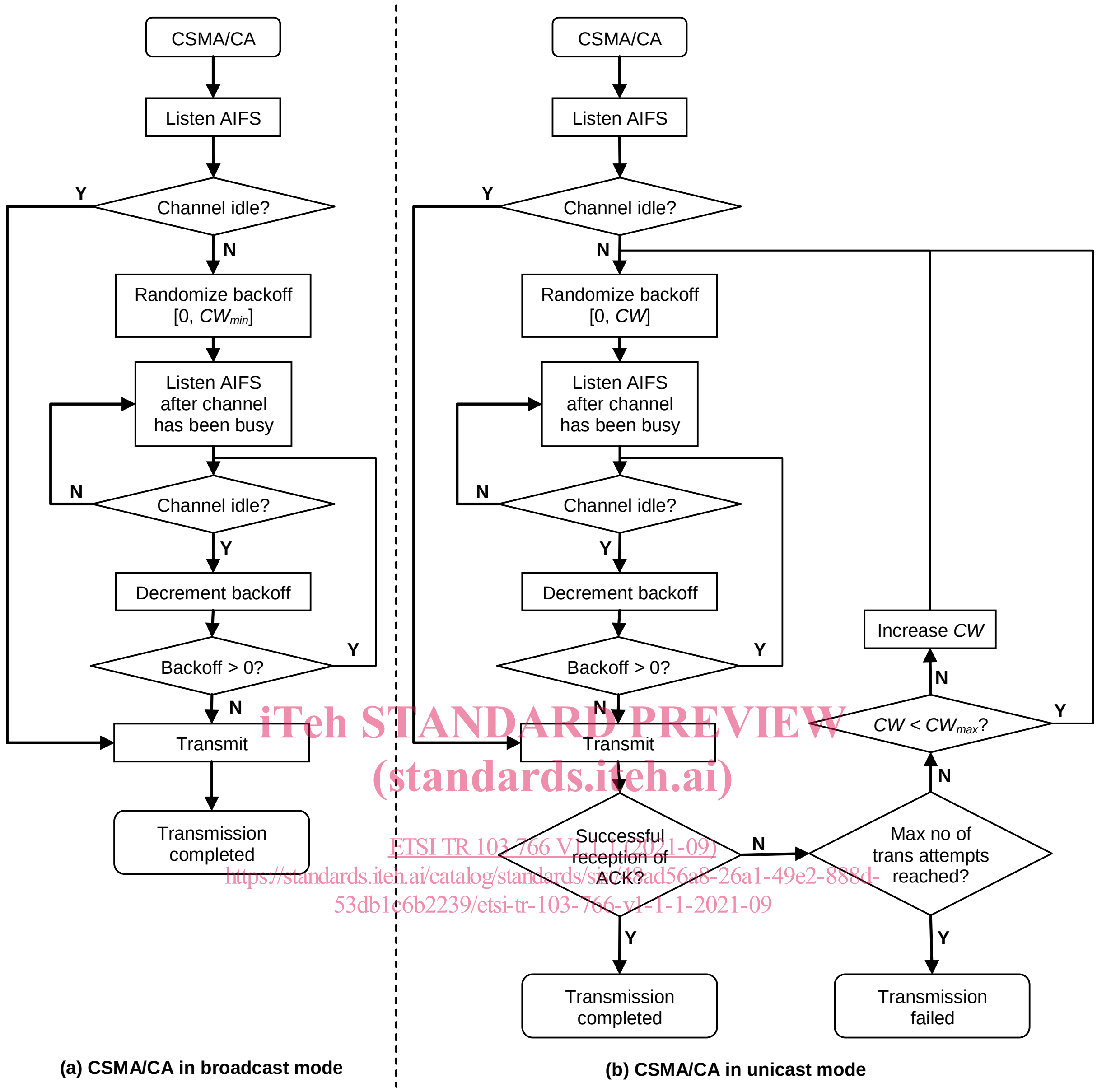

Figure 4.3: A simplified drawing of the channel access procedure in IEEE 802.11-2020 [i.3] in (a) broadcast and (b) unicast mode

More details about the channel access procedure are found in Clause 10 of IEEE 802.11-2020 [i.3].

4.2.3.4 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.6] defining MAC bridges. The UPs from 802.1D are shown in Table 4.3 and they are mapped to four different Access Categories (ACs), i.e. queues, within the QoS facility. This mapping is shown in Table 4.3, where the lowest priority is 0 and the highest 7.