



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

<https://standards.iteh.ai/catalog/standards/sist/48ad56a8-26a1-49e2-888d-53db1c6b2239/etsi-tr-103-766-v1-1-1-2021-09>

Reference

DTR/ERM-TG37-273

Keywords

coexistence, ITS, radio

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Association à but non lucratif enregistrée à la
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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.

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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.

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3 Definition of terms, symbols and abbreviations

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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 Assessment |
| 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 Repeat 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 |

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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.

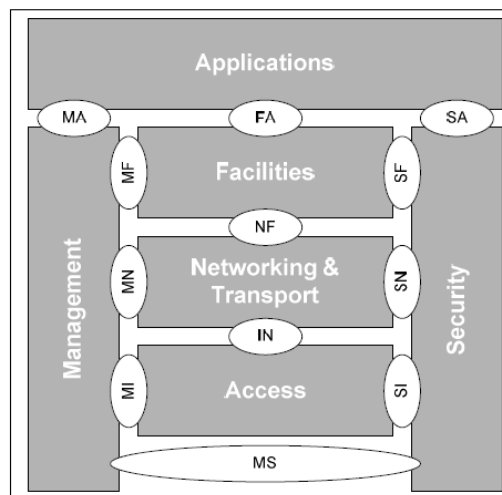


Figure 4.1: The ITS stations reference architecture [i.1]

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 μ s, 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]).

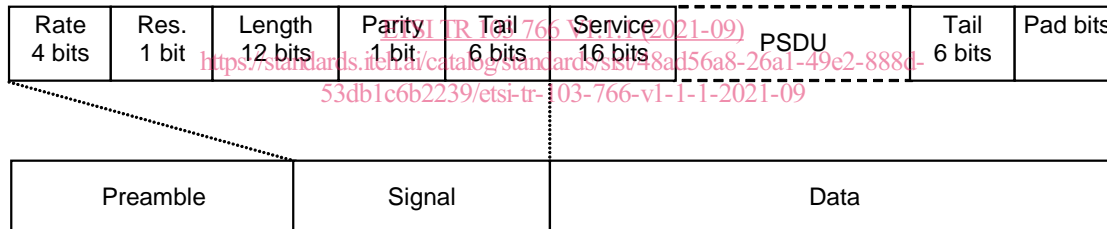


Figure 4.2: ITS-G5 packet format, i.e. PPDU, ready for transmission

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 μ s |
| Signal | Rate | Transfer rate at which the data field in the PPDU will be transmitted. | 8 μ s |
| | 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 μ s);
- 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 μ s 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).

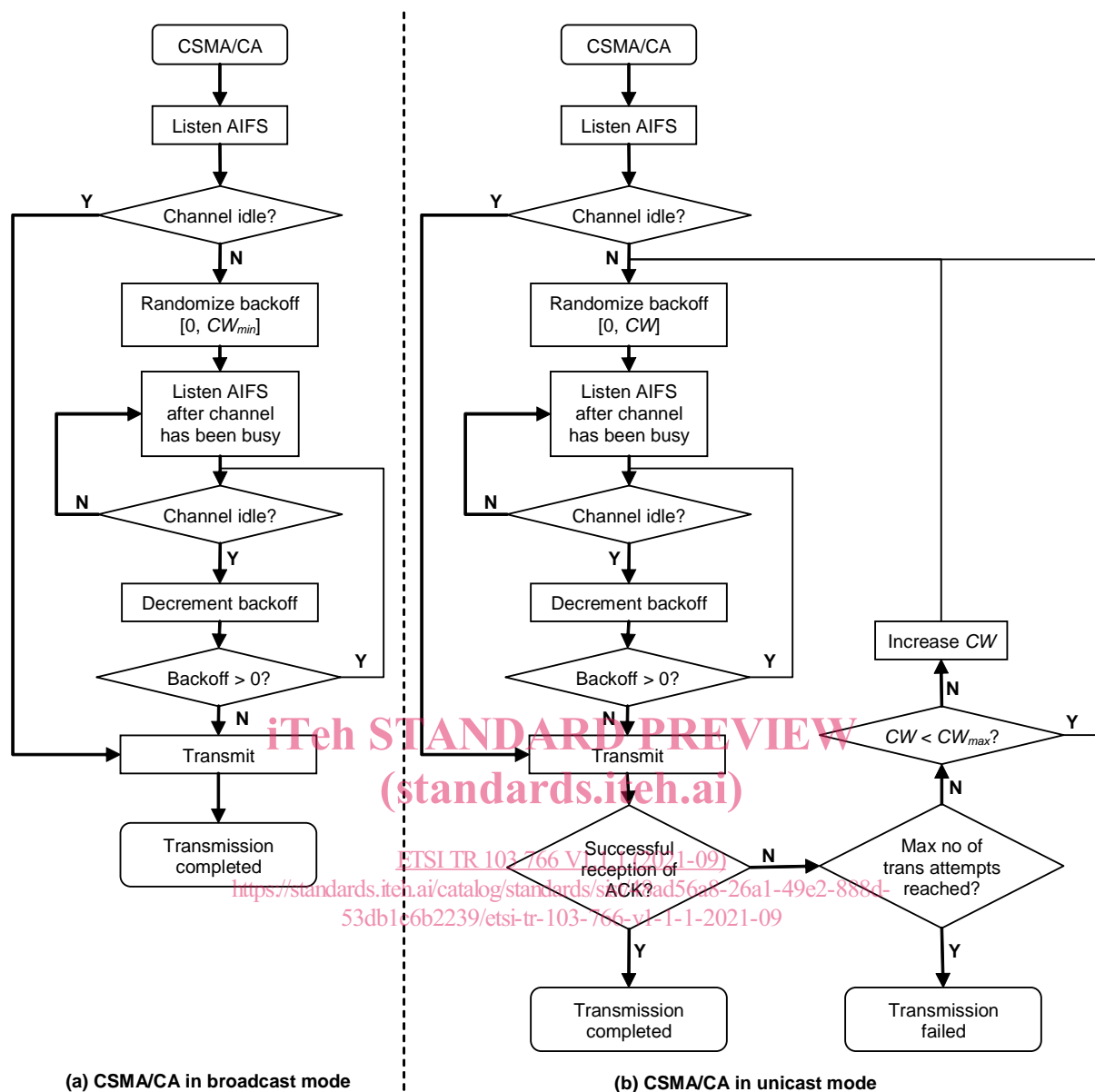


Figure 4.3: A simplified drawing of the channel access procedure in IEEE 802.11-2020 [i.3] in (a) broadcast and (b) unicast mode

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.