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Radio interface standards for C-V2X Communications

[C-V2X]

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1 HIGHLIGHTS

The ITU radio communication assembly provided a preliminary draft of the ITU-R M.2084-0 that includes the ITU recommendations on Cellular Vehicle-to-Everything (C-V2X) radio interface standards related to LTE V2X Release 14/Release 15. This Recommendation identifies specific radio interface standards of LTE V2X encompasses V2I (Vehicle-to-Infrastructure), V2N (Vehicle-to-Network), V2P (Vehicle-to-Pedestrian), and V2V (Vehicle-to-Vehicle) communications for Intelligent Transport Systems (ITS) applications. The technical and operational characteristics are based on the frequency bands already in use for ITS.

2 LIST OF STANDARDS DEVELOPMENT ORGANIZATIONS

The standards development organizations (SDOs) that are listed in this document are provided in Table 1.

Table 1: Standards Development Organizations

SDO	3GPP	ARIB	ATIS	CCSA	ETSI	IEEE	TTA
Region	Partnership among regions	Japan	North America	China	Europe	North America	Korea

3 STANDARDS DEVELOPMENT ORGANIZATIONS TECHNICAL CHARACTERISTICS FOR C-V2X COMMUNICATIONS

There are seven SDOs that we provide information about what specific radio interface standards and technical characteristics that are used within their region for C-V2X communications. Most regions use 5.9 GHz band (5.855 GHz – 5.925 GHz) or (5.850 MHz – 5.925 MHz) spectrum usage, with the exception of Japan which spectrum usage is part of the 700 MHz band (755.5 MHz – 764.5 MHz). In Table 2 and Table 3 we provide a summary of technical characteristics by region side-by-side for comparison.

Table 2: List of regions Technical Characteristics of PC5 Interface

Parameter	3GPP [1]	ARIB	ATIS	CCSA	ETSI	IEEE	TTA
Operating frequency range	5 855-5 925 MHz	755.5-764.5 MHz	5 855-5 925 MHz	5 855-5 925 MHz	5 855-5 925 MHz	5 850-5 925 MHz	5 855-5 925 MHz
RF Channel bandwidth	10 or 20 MHz per channel	Less than 9 MHz	10 or 20 MHz per channel	10 or 20 MHz per channel	10 or 20 MHz per channel (10+10MHz and 10+20MHz carrier aggregation are supported)	10 or 20 MHz per channel	Less than 10 MHz
RF Transmit Power/EIRP	Max 23 or 33 dBm		Max 23 or 33 dBm	Max 23 dBm	Max 23 or 33 dBm		20 dBm
RF transmit power density		10 dBm/MHz					
Modulation scheme	QPSK SC-FDMA, 16QAM SC-FDMA	BPSK OFDM, QPSK OFDM, 16QAM OFDM	QPSK SC-FDMA, 16QAM SC-FDMA	QPSK SC-FDMA, 16QAM SC-FDMA	QPSK SC-FDMA, 16QAM SC-FDMA	64-QAM-OFDM 16-QAM-OFDM QPSK-OFDM	BPSK OFDM, QPSK OFDM, 16QAM OFDM,

					64QAM SC-FDMA	BPSK-OFDM 52 subcarriers	64QAM
Forward error correction	Convolutional coding and turbo coding	Convolutional coding, rate = 1/2, 3/4	Convolutional coding and turbo coding	For control channel: Tail biting convolutional coding, rate=1/8. For data channel: Turbo coding with rate up to 0.86. Rate can be controlled with a fine granularity	Convolutional coding and turbo coding	Convolutional coding, rate = 1/2, 3/4¾	Convolutional coding, rate = 1/2, 3/4
Data transmission rate	From 1.3 Mbit/s to 15.8 Mbit/s for 10 MHz channel	3 Mbit/s, 4.5 Mbit/s, 6 Mbit/s, 9 Mbit/s, 12 Mbit/s, 18 Mbit/s	From 1.3 Mbit/s to 15.8 Mbit/s for 10 MHz channel	Up to 15.8 Mbit/s for 10 MHz channel bandwidth. Up to 31.7 Mbit/s for 20 MHz channel bandwidth. Rate can be controlled with a fine granularity	From 1.3 Mbit/s to 24.5 Mbit/s for 10 MHz channel	3, 4.5, 6, 9, 12, 18, 24 and 27 Mbit/s for 10 MHz channel spacing 6, 9, 12, 18, 24, 36, 48 and 54 Mbit/s for 20 MHz channel spacing	3, 4.5, 6, 9, 12, 18, 24, 27 Mbit/s
Media access control	Centralized scheduling or distributed scheduling	CSMA/CA	Centralized scheduling or distributed scheduling	For Mode 4: Sensing with SPS, random selection. For Mode 3: eNB scheduling.	Centralized scheduling or distributed scheduling	CSMA/CA, Option: Time Slot based CSMA/CA	CSMA/CA
Duplex mode	TDD	TDD	TDD	TDD	TDD	TDD	TDD

Note [1]: Provide information about many different regions.

Table 3: List of regions Technical Characteristics of Uu Interface

Parameter	3GPP [1]	ARIB	ATIS	CCSA	ETSI	IEEE	TTA
Operating frequency range	For Rel-14 Band 3: UL: 1 710-1 785 MHz DL: 1 805-1 880 MHz Band 5: UL: 824 MHz–849 MHz DL: 869 MHz–894 MHz Band 5: UL: 824 MHz–849 MHz DL: 869 MHz–894 MHz Band 7: UL: 2 500-2 570 MHz DL: 2 620-2 690 MHz Band 8: UL: 880-915 MHz DL: 925-960 MHz Band 20: UL: 832 MHz–862 MHz DL: 791 MHz–821 MHz Band 28: UL: 703 MHz–748 MHz DL: 758 MHz–803 MHz Band 34: UL: 2010 MHz–2025 MHz DL: 2010 MHz–2025 MHz	N/A	For Rel-14 Band 5: UL: 824-849 MHz DL: 869-894 MHz Band 7: UL:2 500-2 570 MHz DL: 2 620-2 690 MHz Band 41: 2 496-2 690 MHz Band 71: UL: 663-698 MHz DL: 617-652 MHz	For Rel-14 For FDD UL: 1 710-1 785 MHz; DL: 1 805-1 880 MHz UL: 880-915 MHz DL: 925-960 MHz For TDD 1 880-1 920 MHz 2 496-2 690 MHz	For Rel-14 Band 3: UL: 1 710-1 785 MHz DL: 1 805-1 880 MHz Band 7: UL: 2 500-2 570 MHz DL: 2 620-2 690 MHz Band 8: UL: 880-915 MHz DL: 925-960 MHz Band 39: 1 880-1 920 MHz Band 4 1:2 496-2 690 MHz	N/A	N/A

	Band 39: 1 880-1 920 MHz Band 41: 2 496-2 690 MHz Band 71: UL: 663 MHz – 698 MHz DL: 617 MHz – 652 MHz						
RF Channel bandwidth	1.4, 3, 5, 10, 15, or 20 MHz per channel	N/A	1.4, 3, 5, 10, 15, or 20 MHz per channel	1.4, 3, 5, 10, 15, or 20 MHz per channel	1.4, 3, 5, 10, 15, or 20 MHz per channel	N/A	N/A
RF Transmit Power/EIRP	Max 43 dBm for eNB Max 23 or 33 dBm for UE	N/A	Max 43 dBm for eNB Max 23 or 33 dBm for UE	Max 23 dBm for UE	Max 43 dBm for eNB Max 23 or 33 dBm for UE	N/A	N/A
RF transmit power density		N/A				N/A	N/A
Modulation scheme	Uplink: QPSK SC-FDMA, 16QAM SC-FDMA, 64QAM SC-FDMA; Downlink: QPSK OFDMA, 16QAM OFDMA, 64QAM OFDMA	N/A	Uplink: QPSK SC-FDMA, 16QAM SC-FDMA, 64QAM SC-FDMA; Downlink: QPSK OFDMA, 16QAM OFDMA, 64QAM OFDMA	Uplink: QPSK SC-FDMA, 16QAM SC-FDMA, 64QAM SC-FDMA, 256QAM SC-FDMA;	Uplink: QPSK SC-FDMA, 16QAM SC-FDMA, 64QAM SC-FDMA; Downlink: QPSK OFDMA, 16QAM OFDMA, 64QAM OFDMA	N/A	N/A
Forward error correction	Convolutional coding and turbo coding	N/A	Convolutional coding and turbo coding	PUCCH / (Physical Uplink Control channel): Tail biting convolutional coding / Block code PUSCH / (Physical Uplink Shared channel): Turbo coding	Convolutional coding and turbo coding	N/A	N/A
Data transmission rate	Uplink: From 1.4 Mbit/s to 36.7 Mbit/s for 10 MHz channel Downlink: From 1.4 Mbit/s to 75.4 Mbit/s for 10 MHz channel	N/A	Uplink: From 1.4 Mbit/s to 36.7 Mbit/s for 10 MHz channel Downlink: From 1.4 Mbit/s to 75.4 Mbit/s for 10 MHz channel	Max 105.5 Mbps	Uplink: From 1.4 Mbit/s to 36.7 Mbit/s for 10 MHz channel Downlink: From 1.4 Mbit/s to 75.4 Mbit/s for 10 MHz channel	N/A	N/A
Media access control	Centralized scheduling by eNB	N/A	Centralized scheduling by eNB	eNB scheduling	Centralized scheduling by eNB	N/A	N/A
Duplex mode	FDD or TDD	N/A	FDD or TDD	FDD or TDD	FDD or TDD	N/A	N/A

Note [1]: Provide information about many different regions.

3.1 3GPP STANDARDS

The 3rd Generation Partnership Project (3GPP) have created their standards on C-V2X that is provided in Table 4.

Table 4: 3GPP standards for C-V2X

	3GPP C-V2X Standards	3GPP Standards Definition
	<Core network and UE protocol>	
1	Service requirements for V2X service	3GPP TS 22.185
	<Core network and UE protocol>	
2	Numbering, addressing and identification	3GPP TS 23.003
3	Restoration procedures.	3GPP TS 23.007
4	Organization of subscriber data	3GPP TS 23.008
5	Non-Access-Stratum (NAS) functions related to Mobile Station (MS) in idle mode	3GPP TS 23.122
6	Policy and charging control architecture	3GPP TS 23.203
7	Architecture enhancements for V2X service	3GPP TS 23.285
8	Proximity-based services (ProSe); Stage 2	3GPP TS 23.303

9	Non-Access-Stratum (NAS) protocol for Evolved Packet System (EPS); Stage 3	3GPP TS 24.301
10	Proximity-services (ProSe) User Equipment (UE) to Proximity-services (ProSe) Function Protocol aspects; Stage 3	3GPP TS 24.334
11	V2X services Management Object (MO)	3GPP TS 24.385
12	User Equipment (UE) to V2X control function; protocol aspects; Stage 3	3GPP TS 24.386
13	Representational state transfer over xMB reference point between content provider and BM-SC	3GPP TS 29.116
14	Policy and Charging Control (PCC); Reference points	3GPP TS 29.212
15	Evolved Packet System (EPS); Mobility Management Entity (MME) and Serving GPRS Support Node (SGSN) related interfaces based on Diameter protocol	3GPP TS 29.272
16	V2X Control Function to Home Subscriber Server (HSS) aspects (V4); Stage 3	3GPP TS 29.388
17	Inter-V2X Control Function Signalling aspects (V6); Stage 3	3GPP TS 29.389
18	Group Communication System Enablers for LTE (GCSE_LTE); MB2 reference point; Stage 3	3GPP TS 29.468
19	Characteristics of the Universal Subscriber Identity Module (USIM) application	3GPP TS 31.102
	<Security>	
20	Security aspect for LTE support of V2X services	3GPP TS 33.185
	<Device performance requirements>	
21	Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception	3GPP TS 36.101
22	Evolved Universal Terrestrial Radio Access (E-UTRA); Requirements for support of radio resource management	3GPP TS 36.133
	<Physical layer aspects>	
23	Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation	3GPP TS 36.211
24	Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and channel coding	3GPP TS 36.212
25	Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures	3GPP TS 36.213
26	Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer; Measurements	3GPP TS 36.214
	<Medium access and radio resource management protocols>	
27	Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2	3GPP TS 36.300
28	Evolved Universal Terrestrial Radio Access (E-UTRA); Services provided by the physical layer	3GPP TS 36.302
29	Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) procedures in idle mode	3GPP TS 36.304

30	Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio access capabilities	3GPP TS 36.306
31	Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification	3GPP TS 36.321
32	Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Link Control (RLC) protocol specification	3GPP TS 36.322
33	Evolved Universal Terrestrial Radio Access (E-UTRA); Packet Data Convergence Protocol (PDCP) specification	3GPP TS 36.323
34	Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification	3GPP TS 36.331
	<Radio access network aspects>	
35	Evolved Universal Terrestrial Radio Access Network (E-UTRAN); M2 Application Protocol (M2AP)	3GPP TS 36.443
36	Evolved Universal Terrestrial Radio Access Network (E-UTRAN); S1 Application Protocol (S1AP)	3GPP TS 36.413
37	Evolved Universal Terrestrial Radio Access Network (E-UTRAN); X2 application protocol (X2AP)	3GPP TS 36.423

The 3GPP standards are developed for Long Term Evolution (LTE) Release 14 /Release 15. These standards include many aspects of the LTE V2X communications system, such as the physical layer signals/channels, medium access (MAC) and radio resource management (RRM) protocols, radio access network (RAN), core network (CN) and user equipment (UE) protocol, and security.

The C-V2X standards have two different interfaces for V2X communications. The first one uses the Uu interface which provides communication between the cellular network, road infrastructure, pedestrians and vehicles using uplink and downlink via eNB. The second one uses the PC5 interface which provides point-to-point communication among vehicles and road infrastructure. The Uu interface typically uses centralized scheduling which means that the eNB controls the medium access and radio resource management. However, the PC5 interface supports two scheduling options which consists of the centralized scheduling (Mode 3) similar to that used for Uu interface and the distributed scheduling (Mode 4) in which each vehicle itself determines the suitable time and frequency resources to use for its transmissions. Moreover, the PC5 interface with distributed scheduling can operate both inside and outside cellular coverage and does not require cellular operator support. Furthermore, the PC5 interface only support broadcast transmissions, whereas the Uu interface supports unicast, groupcast, and broadcast transmissions.

3.2 ARIB STANDARDS

In the region of the Japan the SDO, Association of Radio Industries and Businesses (ARIB) have created their standards on C-V2X that is provided in Table 5.

Table 5: ARIB standards for C-V2X

	ARIB C-V2X Standards	ARIB Standards Definition
1	700 MHz band intelligent transport systems	ARIB STD-T109

The ARIB standard is based on the 700 MHz band Intelligent Transport Systems (ITS). A 9 MHz channel width in the 700 MHz radio frequency band will be used for the safe driving support systems.

Data transmission rate is variable based on the selection of modulation scheme and coding rate as shown in Table 5-1:

Table 5-1: Data Transmission Rates

	Data rate	Modulation	Code Rate
1	3 Mbit/s	BPSK OFDM	1/2
2	4.5 Mbit/s	BPSK OFDM	3/4
3	6 Mbit/s	QPSK OFDM	1/2
4	9 Mbit/s	QPSK OFDM	3/4
5	12 Mbit/s	16QAM OFDM	1/2
6	18 Mbit/s	16QAM OFDM	3/4

The single channel accommodates both V2V and V2I communications based on Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) media access control.

3.3 ATIS STANDARDS

In the region of the United States the SDO, Alliance for Telecommunications Industry Solutions (ATIS) have created their standards on C-V2X that is provided in Table 6.

Table 6: ATIS standards for C-V2X

	ATIS C-V2X Standards	ATIS Standards Definition
	<Core network and UE protocol>	
1	Service requirements for V2X service	ATIS.3GPP TS 22.185
	<Core network and UE protocol>	
2	Numbering, addressing and identification	ATIS.3GPP TS 23.003
3	Restoration procedures.	ATIS.3GPP TS 23.007
4	Organization of subscriber data	ATIS.3GPP TS 23.008
5	Non-Access-Stratum (NAS) functions related to Mobile Station (MS) in idle mode	ATIS.3GPP TS 23.122
6	Policy and charging control architecture	ATIS.3GPP TS 23.203
7	Architecture enhancements for V2X service	ATIS.3GPP TS 23.285
8	Proximity-based services (ProSe); Stage 2	ATIS.3GPP TS 23.303
9	Non-Access-Stratum (NAS) protocol for Evolved Packet System (EPS); Stage 3	ATIS.3GPP TS 24.301
10	Proximity-services (ProSe) User Equipment (UE) to Proximity-services (ProSe) Function Protocol aspects; Stage 3	ATIS.3GPP TS 24.334
11	V2X services Management Object (MO)	ATIS.3GPP TS 24.385
12	User Equipment (UE) to V2X control function; protocol aspects; Stage 3	ATIS.3GPP TS 24.386
13	Representational state transfer over xMB reference point between content provider and BM-SC	ATIS.3GPP TS 29.116
14	Policy and Charging Control (PCC); Reference points	ATIS.3GPP TS 29.212
15	Evolved Packet System (EPS); Mobility Management Entity (MME) and Serving GPRS Support Node (SGSN) related interfaces based on Diameter protocol	ATIS.3GPP TS 29.272

16	V2X Control Function to Home Subscriber Server (HSS) aspects (V4); Stage 3	ATIS.3GPP TS 29.388
17	Inter-V2X Control Function Signalling aspects (V6); Stage 3	ATIS.3GPP TS 29.389
18	Group Communication System Enablers for LTE (GCSE_LTE); MB2 reference point; Stage 3	ATIS.3GPP TS 29.468
19	Characteristics of the Universal Subscriber Identity Module (USIM) application	ATIS.3GPP TS 31.102
	<Security>	
20	Security aspect for LTE support of V2X services	ATIS.3GPP TS 33.185
	<Device performance requirements>	
21	Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception	ATIS.3GPP TS 36.101
22	Evolved Universal Terrestrial Radio Access (E-UTRA); Requirements for support of radio resource management	ATIS.3GPP TS 36.133
	<Physical layer aspects>	
23	Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation	ATIS.3GPP TS 36.211
24	Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and channel coding	ATIS.3GPP TS 36.212
25	Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures	ATIS.3GPP TS 36.213
26	Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer; Measurements	ATIS.3GPP TS 36.214
	<Medium access and radio resource management protocols>	
27	Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2	ATIS.3GPP TS 36.300
28	Evolved Universal Terrestrial Radio Access (E-UTRA); Services provided by the physical layer	ATIS.3GPP TS 36.302
29	Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) procedures in idle mode	ATIS.3GPP TS 36.304
30	Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio access capabilities	ATIS.3GPP TS 36.306
31	Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification	ATIS.3GPP TS 36.321
32	Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Link Control (RLC) protocol specification	ATIS.3GPP TS 36.322
33	Evolved Universal Terrestrial Radio Access (E-UTRA); Packet Data Convergence Protocol (PDCP) specification	ATIS.3GPP TS 36.323
33	Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification	ATIS.3GPP TS 36.331
	<Radio access network aspects>	
35	Evolved Universal Terrestrial Radio Access Network (E-UTRAN); M2 Application Protocol (M2AP)	ATIS.3GPP TS 36.443
36	Evolved Universal Terrestrial Radio Access Network (E-UTRAN); S1 Application Protocol (S1AP)	ATIS.3GPP TS 36.413
37	Evolved Universal Terrestrial Radio Access Network (E-UTRAN); X2 application protocol (X2AP)	ATIS.3GPP TS 36.423

The ATIS standards are based on 3GPP Long Term Evolution (LTE) Release 14. These standards include many aspects of the LTE V2X communications system, such as the physical layer signals/channels, medium access (MAC) and radio resource management (RRM) protocols, radio access network (RAN), core network (CN) and user equipment (UE) protocol, and security.

The C-V2X standards have two different interfaces for V2X communications. The first one uses the Uu interface which provides communication between the cellular network, road infrastructure, pedestrians and vehicles using uplink and downlink via eNB. The second one uses the PC5 interface which provides point-to-point communication among vehicles and road infrastructure. The Uu interface typically uses centralized scheduling which means that the eNB controls the medium access and radio resource management. However, the PC5 interface supports two scheduling options which consists of the centralized scheduling

(Mode 3) similar to that used for Uu interface and the distributed scheduling (Mode 4) in which each vehicle itself determines the suitable time and frequency resources to use for its transmissions. Moreover, the PC5 interface with distributed scheduling can operate both inside and outside cellular coverage and does not require cellular operator support. Furthermore, the PC5 interface only support broadcast transmissions, whereas the Uu interface supports unicast, groupcast, and broadcast transmissions.

3.4 CCSA STANDARDS

In the region of the Republic of China the SDO, China Communications Standards Association (CCSA) have created their standards on C-V2X that is provided in Table 7.

Table 7: CCSA standards for C-V2X

	CCSA C-V2X Standards	CCSA Standards Definition
1	General technical requirements of LTE-based vehicular communication	2015-1616T-YD
2	Technical requirements of air interface of LTE-based vehicular communication	2016-1853T-YD

The CCSA standards are based on 3GPP Long Term Evolution (LTE) Release 14\Release 15. These standards include many aspects of the LTE V2X communications system, such as the physical layer signals/channels, medium access (MAC) and radio resource management (RRM) protocols, radio access network (RAN), core network (CN) and user equipment (UE) protocol, and security.

The C-V2X standards have two different interfaces for V2X communications. The first one uses the Uu interface which provides communication between the cellular network and user equipment (UE) in uplink/downlink, where V2N is supported and V2I, V2P, and V2V are supported via cellular network relay. It also provides features such as shorter repetition/modification period for multimedia broadcast multicast service (MBMS) in downlink and multiple semi-persistent scheduling (SPS) configuration in uplink. The second one uses the PC5 interface which provides point-to-point communication among vehicles and road infrastructure. In this mode between UEs in sidelink it supports V2I, V2P, and V2V operations. The Uu interface typically uses centralized scheduling which means that the eNB controls the medium access and radio resource management. However, the PC5 interface supports two scheduling options which consists of the centralized scheduling (Mode 3) similar to that used for Uu interface and the distributed scheduling (Mode 4) in which each vehicle itself determines the suitable time and frequency resources to use for its transmissions.

3.5 ETSI STANDARDS

In the region of Europe, the SDO, European Telecommunications Standards Institute (ETSI) have created their standards on C-V2X that is provided in Table 8.

Table 8: ETSI standards for C-V2X

	ETSI C-V2X Standards	ETSI Standards Definition
	<Core network and UE protocol>	
1	Service requirements for V2X service	ETSI TS 122 185
	<Core network and UE protocol>	
2	Numbering, addressing and identification	ETSI TS 123 003
3	Restoration procedures.	ETSI TS 123 007
4	Organization of subscriber data	ETSI TS 123 008
5	Non-Access-Stratum (NAS) functions related to Mobile Station (MS) in idle mode	ETSI TS 123 122

6	Policy and charging control architecture	ETSI TS 123 203
7	Architecture enhancements for V2X service	ETSI TS 123 285
8	Proximity-based services (ProSe); Stage 2	ETSI TS 123 303
9	Non-Access-Stratum (NAS) protocol for Evolved Packet System (EPS); Stage 3	ETSI TS 124 301
10	Proximity-services (ProSe) User Equipment (UE) to Proximity-services (ProSe) Function Protocol aspects; Stage 3	ETSI TS 124 334
11	V2X services Management Object (MO)	ETSI TS 124 385
12	User Equipment (UE) to V2X control function; protocol aspects; Stage 3	ETSI TS 124 386
13	Representational state transfer over xMB reference point between content provider and BM-SC	ETSI TS 129 116
14	Policy and Charging Control (PCC); Reference points	ETSI TS 129 212
15	Evolved Packet System (EPS); Mobility Management Entity (MME) and Serving GPRS Support Node (SGSN) related interfaces based on Diameter protocol	ETSI TS 129 272
16	V2X Control Function to Home Subscriber Server (HSS) aspects (V4); Stage 3	ETSI TS 129 388
17	Inter-V2X Control Function Signalling aspects (V6); Stage 3	ETSI TS 129 389
18	Group Communication System Enablers for LTE (GCSE_LTE); MB2 reference point; Stage 3	ETSI TS 129 468
19	Characteristics of the Universal Subscriber Identity Module (USIM) application	ETSI TS 131 102
	<Security>	
20	Security aspect for LTE support of V2X services	ETSI TS 133 185
	<Device performance requirements>	
21	Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception	ETSI TS 136 101
22	Evolved Universal Terrestrial Radio Access (E-UTRA); Requirements for support of radio resource management	ETSI TS 136 133
	<Physical layer aspects>	
23	Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation	ETSI TS 136 211
24	Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and channel coding	ETSI TS 136 212
25	Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures	ETSI TS 136 213
26	Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer; Measurements	ETSI TS 136 214
	<Medium access and radio resource management protocols>	
27	Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2	ETSI TS 136 300
28	Evolved Universal Terrestrial Radio Access (E-UTRA); Services provided by the physical layer	ETSI TS 136 302
29	Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) procedures in idle mode	ETSI TS 136 304
30	Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio access capabilities	ETSI TS 136 306
31	Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification	ETSI TS 136 321
32	Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Link Control (RLC) protocol specification	ETSI TS 136 322
33	Evolved Universal Terrestrial Radio Access (E-UTRA); Packet Data Convergence Protocol (PDCP) specification	ETSI TS 136 323
34	Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification	ETSI TS 136 331
	<Radio access network aspects>	
35	Evolved Universal Terrestrial Radio Access Network (E-UTRAN); M2 Application Protocol (M2AP)	ETSI TS 136 443
36	Evolved Universal Terrestrial Radio Access Network (E-UTRAN); S1 Application Protocol (S1AP)	ETSI TS 136 413

37	Evolved Universal Terrestrial Radio Access Network (E-UTRAN); X2 application protocol (X2AP)	ETSI TS 136 423
	<Base standards for the access and media layer>	
38	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	ETSI EN 302 571
39	Intelligent Transport Systems (ITS); Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band	ETSI EN 302 663
40	Intelligent Transport Systems (ITS); Decentralized Congestion Control Mechanisms for Intelligent Transport Systems operating in the 5 GHz range; Access layer part	ETSI TS 102 687
41	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	ETSI TS 102 792
42	Intelligent Transport Systems (ITS); Harmonized Channel Specifications for Intelligent Transport Systems (ITS) operating in the 5 GHz frequency band	ETSI TS 102 724
43	Intelligent Transport Systems (ITS); Cross Layer DCC Management Entity for operation in the ITS G5A and ITS G5B medium	ETSI TS 103 175
	<Base standards for security>	
44	Intelligent Transport Systems (ITS); Security; Security header and certificate formats	ETSI TS 103 097
45	Intelligent Transport Systems (ITS); Security; ITS communications security architecture and security management	ETSI TS 102 940
46	Intelligent Transport Systems (ITS); Security; Trust and Privacy Management	ETSI TS 102 941

The ETSI standards are based on 3GPP Long Term Evolution (LTE) Release 14 and ITS. These standards include many aspects of the LTE V2X communications system, such as the physical layer signals/channels, medium access (MAC) and radio resource management (RRM) protocols, radio access network (RAN), core network (CN) and user equipment (UE) protocol, and security.

The C-V2X standards have two different interfaces for V2X communications. The first one uses the Uu interface which provides communication between the cellular network, road infrastructure, pedestrians and vehicles using uplink and downlink via eNB. The second one uses the PC5 interface which provides point-to-point communication among vehicles and road infrastructure. The Uu interface typically uses centralized scheduling which means that the eNB controls the medium access and radio resource management. However, the PC5 interface supports two scheduling options which consists of the centralized scheduling (Mode 3) similar to that used for Uu interface and the distributed scheduling (Mode 4) in which each vehicle itself determines the suitable time and frequency resources to use for its transmissions. Moreover, the PC5 interface with distributed scheduling can operate both inside and outside cellular coverage and does not require cellular operator support. Furthermore, the PC5 interface only support broadcast transmissions, whereas the Uu interface supports unicast, groupcast, and broadcast transmissions.

The technical characteristics of V2V and V2I communications is for ETSI ITS-G5. The deployment of any radio interface technology based on standards listed in Table 8 has to follow the regional and national regulations.

3.6 IEEE STANDARDS

In the region of the United States the SDO, Institute of Electrical and Electronics Engineers (IEEE) have created their standards on C-V2X that is provided in Table 9.

Table 9: IEEE standards for C-V2X

	IEEE C-V2X Standards	IEEE Standards Definition
1	IEEE Guide for Wireless Access in Vehicular Environments (WAVE) – Architecture	IEEE 1609.0
2	IEEE Standard for Wireless Access in Vehicular Environments – Security Services for Applications and Management Messages	IEEE 1609.2
3	IEEE Standard for Wireless Access in Vehicular Environments (WAVE) – Networking Services	IEEE 1609.3
4	IEEE Standard for Wireless Access in Vehicular Environments (WAVE) – Multi-channel Operation	IEEE 1609.4
5	IEEE Standard for Wireless Access in Vehicular Environments (WAVE) – Over-the-Air Electronic Payment Data Exchange Protocol for Intelligent Transportation Systems (ITS)	IEEE 1609.11
6	IEEE Standard for Wireless Access in Vehicular Environments (WAVE) – Identifier Allocations	IEEE 1609.12

The IEEE standards are based on IEEE Std 802.11p. These standards include many aspects of the IEEE 802.11 communications system, such as the multi-channel wireless communications which is based on IEEE Std 802.11p, 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, which was originally developed as an amendment to IEEE 802.11 that was incorporated into the revision of IEEE 802.11; 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. The upper layer protocols and services requirements are described in the IEEE 1609 family of standards that use IEEE Std 802.11. Standardization of the upper layer protocols and services support the V2V and V2I communication requirements.

3.7 TTA STANDARDS

In the region of the Republic of Korea the SDO, Telecommunication Technology Association (TTA) have created their standards on C-V2X that is provided in Table 10.

Table 10: TTA standards for C-V2X

	TTA C-V2X Standards	TTA Standards Definition
1	Vehicle communication system Stage 1: Requirements	TTAK.KO-06.0175/R1
2	Vehicle communication system Stage 2: Architecture	TTAK.KO-06.0193/R1
3	Vehicle communication system Stage 3: PHY/MAC	TTAK.KO-06.0216/R1
4	Vehicle communication system State 3: Networking	TTAK.KO-06.0234/R1

The TTA standards are based on IEEE Std 802.11p. The wireless access in vehicular environments (WAVE) standards were selected for international harmonization. These standards include many aspects of the IEEE 802.11 communications system, such as the multi-channel wireless communications which is based on IEEE Std 802.11p, 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, which was originally developed as an amendment

to IEEE 802.11 that was incorporated into the revision of IEEE 802.11; 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. The upper layer protocols and services requirements are described in the IEEE 1609 family of standards that use IEEE Std 802.11. Standardization of the upper layer protocols and services support the V2V and V2I communication requirements.

For the V2V applications, it should consider using the low packet latency because the life-saving time of safety message is useful in the span of 100 ms. Also, it requires a highly activated radio channel when many vehicles are trying to activate radio channel simultaneously. Furthermore, for V2I applications, it should adopt the long packet transmission which includes a short message, map information and image information in the order of 2 Kbytes in a packet size in high mobility conditions.