SECUR

Safety Enhancement through Connected Users on the Road

Deliverable 2.1

Technical document: PC5 based on 3GPP Release 14 (mode 4)

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EXECUTIVE SUMMARY

This document is the technical document of PC5 based on Release 14 technology, and especially on the mode 4 for resource allocation since this mode has been specifically designed for V2X communication and can operate out of the coverage of a base station. It gathers general information, performances KPI (data rate, range & reliability, latency, congestion, mobility and positioning) and technology's characteristics.

PC5 Release 14 present sufficient performances to address all SECUR use-cases from a range, latency & congestion point of view based on the different sections of the document. Thus it could both address low-latencies critical safety use cases & informative use cases.

ABBREVIATIONS

3GPP	3rd Generation Partnership Project
4G	4G is the fourth generation of broadband cellular network technology, succeeding 3G and preceding 5G
5G	In telecommunications, 5G is the fifth-generation technology standard for broadband cellular networks
5GAA	5G Automotive Association
ASIL	Automotive Safety Integrity Level
BC	Bicyclist
BLE	Bluetooth Low Energy
C2C-CC	Car 2 Car Communication Consortium
CAM	Cooperative Awareness Message
CBR	Channel Busy Ratio
C-ITS	Cooperative Intelligent Transport Systems
CPM	Cooperative Perception Message These messages broadcast information on detected object to its surrounding.
D2VO	Datex-II Vehicle Obstruction
D2WRRC	Datex-II Weather Related Road Conditions
DENM	Decentralized Environmental Notification Message
ECTL	European Certificate Trust List
ETSI	European Telecommunications Standards Institute
EU	European Union
GDPR	General Data Protection Regulation
IP	Internet Protocol
ITS-G5	Direct communication technology based on Wi-Fi. European name for WAVE or DSRC.
IVS	In-Vehicle Signage
KPH	Kilometers per hour
KPI	Key Performance Indicator
LOS	Line-of-sight
LTE	Long Term Evolution
MAPEM	MAP Extended Message
NLOS	Non-line-of-sight
OBU	On-Board Unit
PC	Passenger Car
PC5	Direct communication technology based on mobile network (3GPP). PC5 is one part of C-V2X/LTE-V2X that enable direct communication between objects.
PD	Pedestrian
PDR	Packet Delivery Ratio
PER	Packet Error Rate
PKI	Public Key Infrastructure
PTW	Powered Two-wheeler
REL	Release
RSU	Road Side Unit
RTK	Reel Time Kinematic
SB	Steering Board
SPATEM	Signal Phase And Timing Extended Message

TTC	Time To Collision
UC	Use case
UK	United Kingdom
Uu	Radio interface in cellular communication between a user equipment (UE) and the cellular network base station.
V2I	Vehicle-To-Infrastructure
V2N	Vehicle-To-Network (Uu communication)
V2P	Vehicle-To-Pedestrian
V2V	Vehicle-To-Vehicle
V2VRU	Vehicle-To-Vulnerable Road User
V2X	Vehicle-To-Everything (i.e. vehicle to any type of other station)
VAM	VRU Awareness Message
VRU	Vulnerable Road User (motorcyclist, bicyclist and pedestrian)
WG	Working Group
WP	Work Package
WP1	SECUR Work Package n°1: Accidentology study
WP2	SECUR Work Package n°2: V2X technologies study
WP3	SECUR Work Package n°3: Potential of V2X to improve ADAS performances and final use cases selection
WP4	SECUR Work Package n°4: Development of testing connected targets
WP5	SECUR Work Package n°5: Test and assessment procedures

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Introduction

This document focus on PC5 R14 mode 4 which operate independently of the LTE infrastructure (i.e., the base station). The mode 3 relies on a base station operated by a telecom operator to manage radio resource and for synchronization. In the mode 4 the radio resource management is distributed using the SPS (Semi Persistent Scheduling) algorithm and relies on GPS signal for synchronization.

"V2V communications are based on D2D communications defined as part of ProSe services in Release 12 and Release 13 of the specification. As part of ProSe services, a new D2D interface (designated as PC5, also known as sidelink at the physical layer) was introduced and now as part of the V2V WI it has been enhanced for vehicular use cases, specifically addressing high speed (up to 250Kph) and high density (thousands of nodes). To that end, a few fundamental modifications to PC5 have been introduced. Firstly, additional DMRS symbols have been added to handle the high Doppler associated with relative speeds of up to 500kph and at high frequency (5.9GHz ITS band being the main target). […]. As illustrated the V2V sub-frame for PC5 interface has 4 DMRS symbols, in addition to the Tx-Rx turnaround symbol at the end, allowing for better tracking of the channel at high speed."

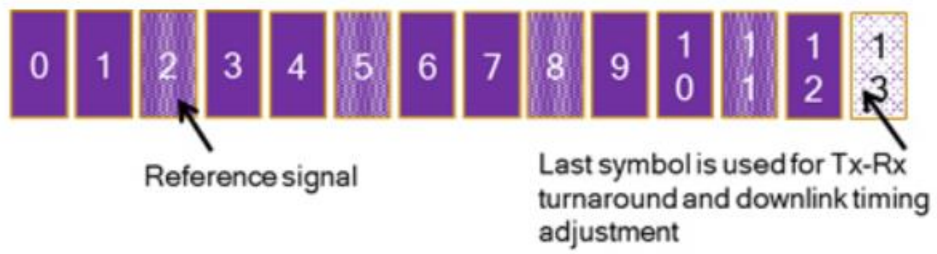

Figure 1: V2V Subframe structure illustrated by 3GPP

1. General information

1.1 Technology's name

LTE-V2X based on ETSI ITS 103 723 V1.1.1 and 3GPP Release 14 mode 4 (PC5).

1.2 Operating frequency band

5.9 GHz

1.3 Standard (access layer)

1.3.1 Standardization organization

European Telecommunications Standards Institute ETSI (EN 303 613)
3rd Generation Partnership Project (3GPP)

1.3.2 Standard level of maturity [draft/in work/released/rework]

RELEASED: Last version of the PC5 rel 14 in June 2017.

1.3.3 Is the organization active?

3GPP is active and it is not the only body working on the technology, nevertheless the standardization of R14 has been completed and should not be modified.
ETSI is still active on the adaptation it's ITS architecture to the use of 3GPP R14 [ETSI-103723, ETSI-303613, ETSI103794, ETSI-102636-4-3, ETSI-102636-7-1, ETSI-102636-7-2].

1.4 Communication profile

The communication profile is described in ETSI-103723 (3GPP Release 14, based on C2C-CC BSP v1.5.0 and C-Roads Profile 1.6.0)

1.5 All supported communication types (broadcast…)

3GPP R14 PC5 only support broadcast communications.

1.6 V2X SYSTEMS CAPABILITY (V2V, V2I, V2N, V2VRU)

Table 1 - Type of Communication supported

V2X Type	Supported or not?	Mandatory infrastructure(s)/hardware for the technology operability
V2V	Supported (PC5 mode 4)	On-Board Unit (OBU)
V2I	Supported (PC5 mode 4)	On-Board Unit (OBU) + Roadside Unit (RSU)
V2N	Not Supported (PC5 mode 4)	Indirectly possible with a V2I2N communication but limited to very few use cases (PKI) due to spectrum scarcity
V2VRU	Supported (PC5 mode 4)	OBU or P-ITS-S (Personal ITS Station) supporting PC5 R14.

1.7 TECHNOLOGY'S DEPLOYMENT MATURITY

There is no deployment in Europe of the technology and quite few performances evaluations with real equipment.
There is still a lack of interoperability testing and almost no multi-vendor tests. During the April 2022 ETSI Plug tests on C-V2X two chipsets have been tested (Qualcomm & Autotalks) with a test plan proposed by Qualcomm.

1.8 WHERE IS THE TECHNOLOGY USED? (ONLY WITH THE SAME COMMUNICATION PROFILE)

This table gathers information on companies that test and propose project pilots. Today, we have no information on usage of the technology. It is not and exhaustive list.

Table 2 – Mains V2X companies and regions

Companies	OEM	No inputs
	Tier 1	Lacroix City, Fareco, Valeo
	Software provider	YoGoKo, Commsignia,
	Chipset provider	Qualcomm, China Unicom, Goscuncn, Huawei, Autotalks
Regions	China, USA, Europe	

Situation in USA.
In November 2020, US FCC issue the decision [FCC-20201118] to free the 4 lower ITS bands for unlicensed users and to keep the 3 upper bands for ITS arguing that it will be enough for current ITS services and that other communications means (cellular/Wi-Fi) is used to deliver supplementary ITS services. FCC also decided to move from DSRC (IEEE 802.11 OCB) to 3GPP-based V2X (LTE-V2X). They also open the possibility to obtain a waiver to use LTE-V2X in upper bands if there is no DSRC users in the same area.
This decision has been confirmed in summer 2021 and let one year to current licensed user to leave the lower ITS bands. DSRC users have 2 years to stop operation in the upper ITS bands.
It is worth to note that the LTE-V2X user can use a 10Mhz or a 20Mhz channel in the ITS bands.
The FCC decision is still under debate in US and ITS stakeholders are still fitting to have and adequate spectrum for ITS services [https://www.itsinternational.com/feature/its-america-v2x-needs-adequate-spectrum].
There is deployment in China, but we've got very few trustable information on the performance of the technologies. Most of the Chinese publication are still based on simulation study. And in

[1] authors explained in 2021 that the "domestic standards related to LTE-V2X are still in the early stage”. And they use an SDR-based implementation of LTE-V2X. In [2] a real experiment is conducted in 2020 with devices far from truly industrialized devices.

2. Performance

This report focusses only on PC5 release 14 mode 4.

This report is based on a literature review, and it is worth to note that if the PC5 rel 14 mode 4 has been extensively studied, most of the performance assessment has been done through system level or radio level simulations. Various simulations are difficult to compare since they are based on ad-hoc software developments. Very few real experiments are reported especially if we compare with ITS-G5.
Two test field results are documented: one from the German "Convex project" [3] and the other one from the 5GAA in the "C-V2X performance assessment project" [4]. In both cases C-V2X stakeholders are strongly involved in the experiments.

The results obtained in the 5GAA evaluation only show results for 20Mhz channel and with HARQ activated (which is mandatory in ETSI-103723 profile). They show that the use of a congestion control mechanism allows to reach performance good enough for most of the use case. But they also show that results are impacted by the congestion. Without congestion control the PER increase above 10% at short range (100m in few scenario). The congestion control improves the performances but has an impact in terms of Information Age (up to 1s) and inter-message time (above 200ms).

LTE-V2X mode 4 include a Semi-Persistent Scheduling (SPS) that work well to allocate resources for CAM messages but lead to delay for Event-based (DENM) messages. The performance even in simulation depend strongly on the way SPS is configured.

2.1 Range and reliability

2.1.1 Testing context

Several experiments aim at evaluating the distance at which an LTE-V2X could achieve a good enough communication (PER < 10%). The effective range depend on the scenario (relative speed, communication parameters, obstacles, ...). Results usually present the PER as a function of the distance for each scenario:
- Line-of-Sight (LOS) tests (Highway scenarios)
- Non-Line-of-Sight (NLOS) tests (Urban scenarios) [4]. The results for NLOS communication strongly depend on the nature of the obstacle (another vehicle, a building, trees, ...)

The reference [4] details plan of such tests in its Section 8.5.1 and 8.5.2. But the result reported in this document are challenged by NXP [5]. Anyway, experiments conducted by 5GAA are detailed in [4]. The description of the implementation of the equipment on the vehicles from various car manufacturers show that two antennas are necessary on the roof and that the results in terms of range depend on the vehicle even with the same communication devices and antennas.
If 5GAA detail testing methodology including 10Mhz and 20Mhz spectrum, they only give result for 20Mhz with HARQ activated.
As far as we know there is no test to experiment to verify if the technology work without GPS synchronisation (parking lot, tunnel, GPS spoofing) and if there are performance issues in this case.

2.1.2 PERFORMANCES

PER < 10% is acceptable. Above that, it is assumed there is no communication between the objects.
The following test has been performed for various environment and are reported in [4].
Evaluation of the range while PER < 10%:

Table 3 - Range performances

Type	Value
Maximum range during outdoor tests [m]	LOS: more than 1400m for V2I (can reach more) LOS: more than 1100 for V2V LOS High Speed: 900m NLOS: more than 800m for V2I, more than 250m for V2V
Average range during outdoor tests [m]	LOS: around 1000m NLOS: <300m (from 200 to 800 depending on the obstacle, here vehicles are used) But with strong uncertainties on how C-V2X deals with congestion.

The previous summary table is based on the following studies: [4]

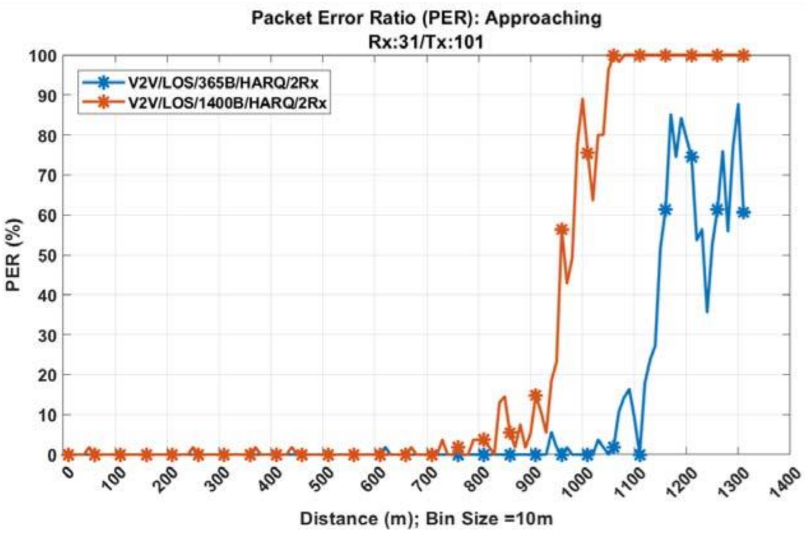

Figure 2: LOS Communication between one stationary vehicle and one approaching vehicle for two sizes of packet [2]

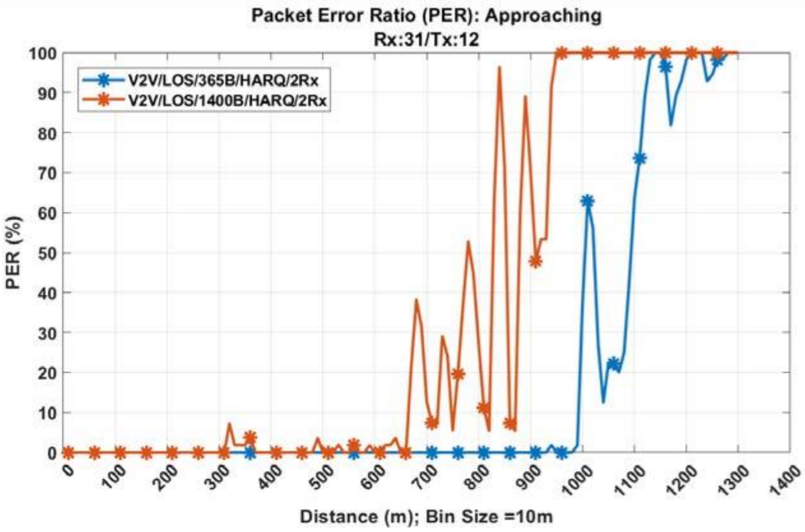

Figure 3: The same with another stationary vehicle [2]

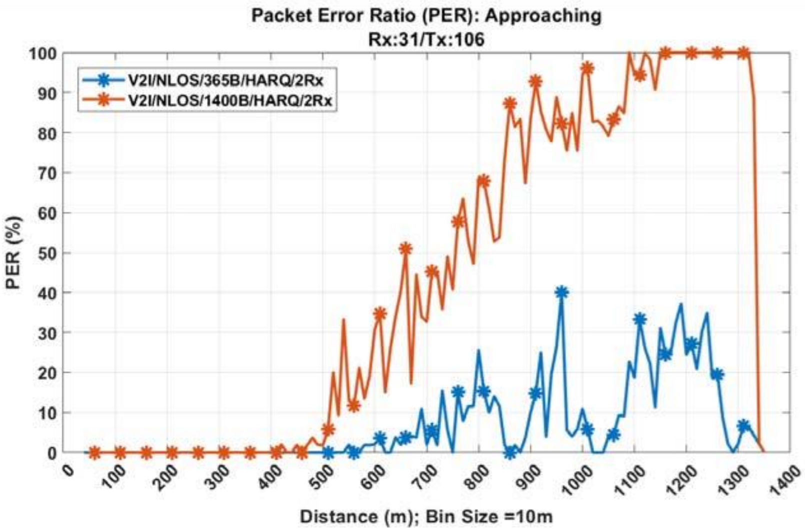

Figure 4: V2I NLOS communication with approaching vehicle behind a truck, vehicle receiving [2]

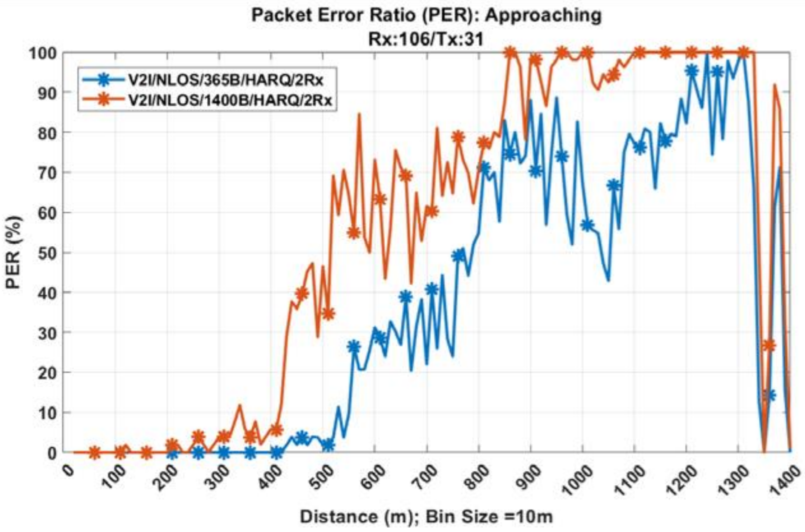

Figure 5: V2I NLOS communication with approaching vehicle behind a truck, RSU receiving [2]

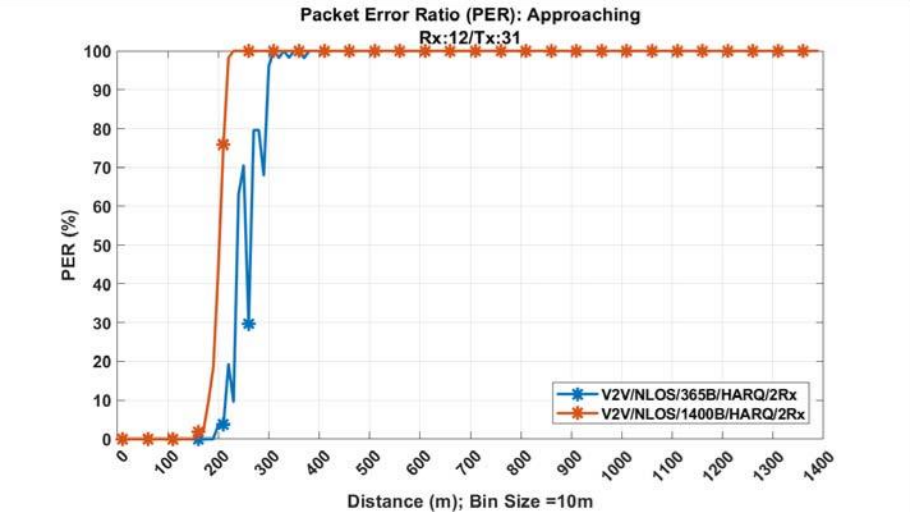

Figure 6: V2V NLOS same lane blocking with vehicle approaching, stationary vehicle receiving [2]

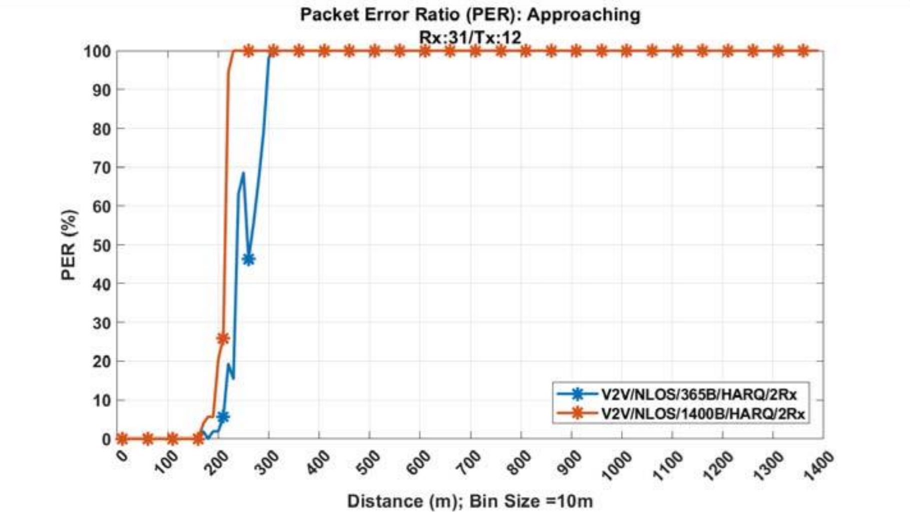

Figure 7: V2V NLOS same lane blocking with vehicle approaching, moving vehicle receiving [2]

Some experiments [4] (p49) have been made in mixed traffic conditions. Several vehicle traveling together and the lead vehicle send messages each 100ms. The result show very few packet losses.

2.1.3 Consequences

The range & reliability could be a limitation depending on the use case and the environment. The average range with a good reliability is a few hundred meters in NLOS scenario and is probably enough for most of the envisioned services.

2.2 Latency

2.2.1 Performances

Table 4 - Latency performances of PC5 R14

Type	Value
Outdoor tests - Nominal	Channel load dependant (~30 ms for low congestion)
Outdoor tests - Min	4 ms
Outdoor tests - Max	200 ms

The previous summary table is based on the following studies [4]

2.2.2 Consequences

In the experiments reported in [4] it is stated that 95% of the packet latency is around 30ms.

Long latencies could theoretically create data-age problems for some apps. With high congestion, latency, as well as the interval between subsequent messages, increases significantly. Message reception reliability thus becomes unsuitable for safety applications. ITS-G5 presents better performance on latency, however, the main source of latency would be the data processing from the vehicle to collect the information, process it, make an action depending of the information the messages brought to it. In that case, the end-to-end latency impact would be very low on the global latency during a safety use case.

2.3 Congestion

To quantify the behaviour of the technology in congested environment, the KPI used is the expected communication range and latency in presence of 200 users in area of 1 km². This information is typically obtained using simulation and it is difficult to compare different studies. Here we focus more on the results provided in [4] which seems to be the only quite large test with actual PC5 R14 devices.

2.3.1 Testing context

Most of the evaluation of the LTE-V2X in congested scenario has been made through simulation, such as the one in [6]: “The performance of both communication systems has been evaluated by simulating their respective MAC layers, […]. The performance of the physical layer is integrated by considering the level of interference resulting from the scheduling generated by the MAC layer. For the simulations, we considered a static dis-shaped network with a given number of vehicles depending on the network load. […]. Hence, for each level of user density in the network and each distance between two vehicles, we draw randomly 5000 network topologies (location of the users) that we simulated for a duration of 5 seconds. [3]”

The 5GAA experiment uses 50 congestion generation pods [4] p. 55 to emulate up to 260 moving and stationary units. Three level of congestion has been used in several scenarios: platoon at different speeds (20MPH and 80MPH) and critical events notification. The congestion control mechanism is activated or not. Here we report the results obtained in the Critical Event Test (p.

110 in [4] where to vehicles are moving in a lane at 55 mph and the first one perform a hard brake in the congested area.

2.3.2 PERFORMANCES

Assessment of reliability while there is congestion (medium-high channel load ~200 users/km²):

Table 5 - Congestion performances of PC5 R14

Type	Value
Theoretical	Range: 270 m Latency: 60 ms

The previous summary table is based on the following studies [4] [6].

From the simulation study provided in [6] for LTE-V2X we can see that the range where PER is good enough (>10^{-2}) decrease linearly from 400 to 100 with the congestion level (Fig. 8). For a medium load (100 users/km2) the latency is stable until 350 m, but it depends on the configuration of the SPS algorithm (Selection window) (Fig. 9).

Figure 8 draws the range at PER=10^{-2} as a function of the congestion level (users/km²). The loss in terms of range on the ITS-G5 technology has a logarithmic shape. On the study performed in [6] between 0 and 100 users, the range is divided approximately by 2.

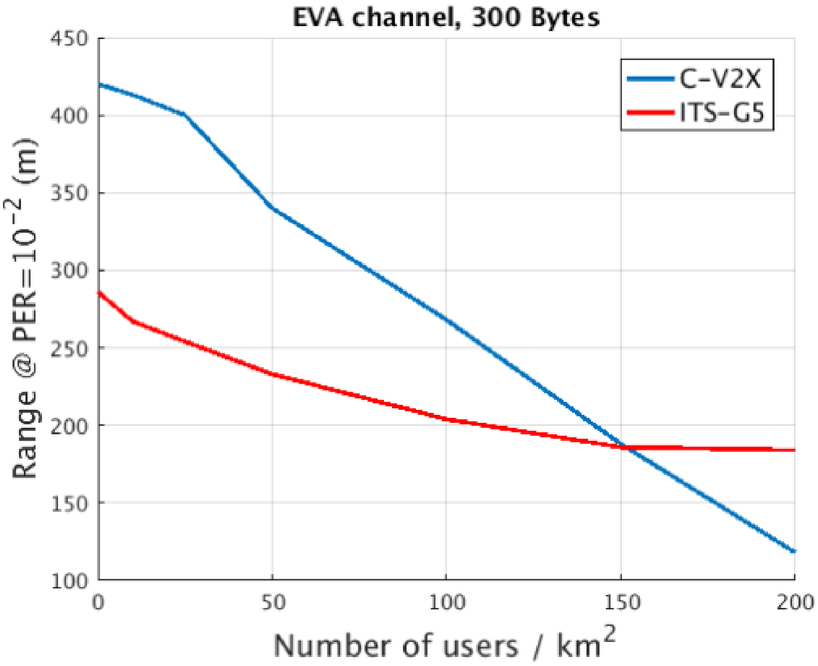

Figure 8: Performance synthesis of C-V2X and ITS-G5: range evolution as a function of the network load [4]

The latency describe here is the average time to receive one packet correctly for a density of 100 users/km² for 300 Byte packets. The Packet Error Probability is taken in account in this performance measurement. Moreover, this PEP is dominated by additive noise and collisions when the range is increased.

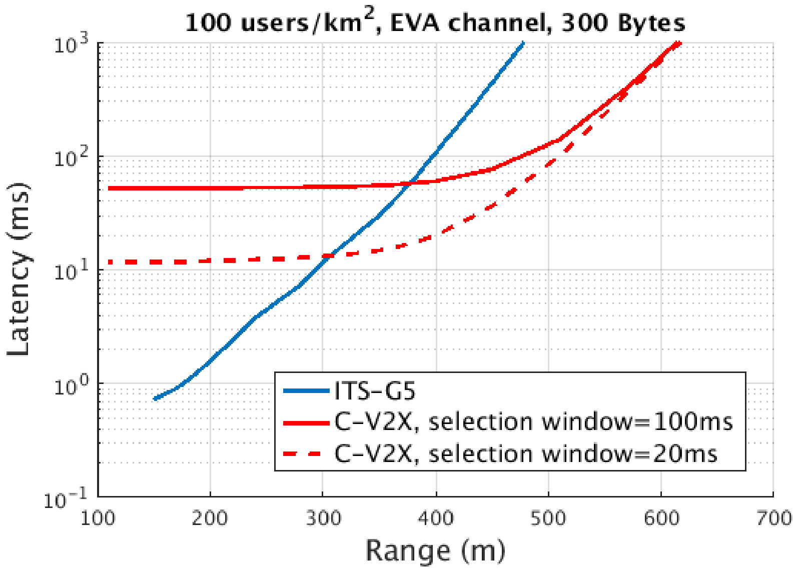

Figure 9: ITS-G5 and C-V2X latency as the function of the range for a density 100 users/km² [4]

Figure 10 gives performance derived out of 4 independent simulation configurations:

- 800 ITS-G5 vehicles (yellow curve)
- 1600 ITS-G5 vehicles (green curve)
- 800 PC5 mode 4 vehicles (blue curve)
- 1600 PC5 mode 4 vehicles (red curve)

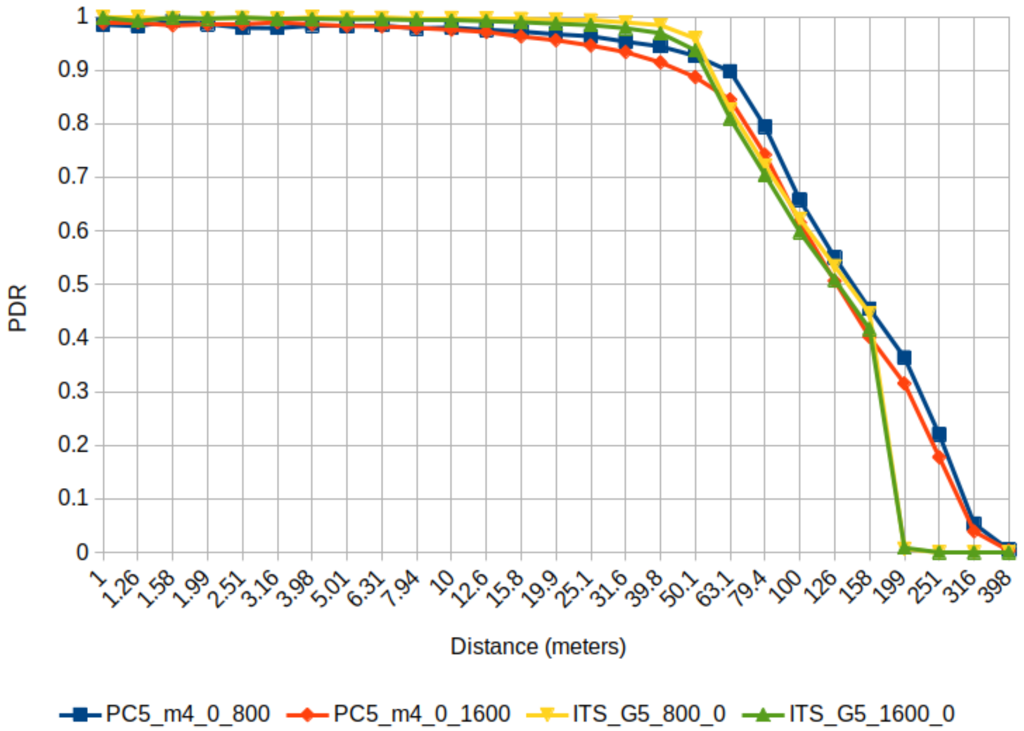

Figure 10: ITS-G5 and PC5 PDR as a function of the range for a density of 800 and 1600 users [5]

This figure shows that there is a difference between the red and blue lines that represent simulation with 800 and 1600 vehicles. So, there is a noticeable effect of the traffic density for PC5 R14.

From the [4] we can see that in the highly congested scenario (5x) even at 100m distance the level of error is too high. The situation is far better with Congestion Control mechanism activated and for lower congestion level.

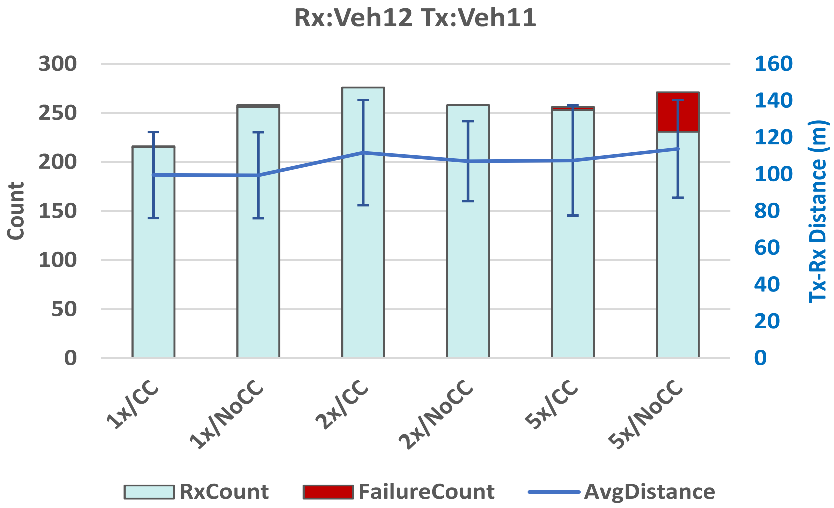

Figure 11: Vehicle 11 is braking and send a notification that is received by vehicle 12 [2] (p.115)

2.3.3 Consequences

The latency depend on the type of traffic since the SPS algorithm is better with regular traffic than with unpredictable event notification. It also strongly depends on the congestion and this effect is well controlled using the same kind of congestion control than for DSRC. It is also shown that the information age (IA) in the 300m range could be higher than 1s even with congestion control activated in congested scenario and up 4s without it.

Lengthy transmission delays (e.g., one second) could lead to problems for some applications (e.g., Emergency Electronics Braking Lights). However, this would likely require extreme congestion conditions that are unlikely to be encountered in the near future. Indeed, in early stages of deployment, congestion will be difficult to encounter in real-world. In this very specific context LTE-V2X could fail to meet the required KPI for safety services.

The configuration of the SPS (Semi Persistent Scheduling) could be done for each message depending on the application requirements. This cross-layer interaction has not been studied and evaluated, especially the impact of the choice made by one ITS Station on the performances experienced by other ITS stations/services

2.4 Mobility

The ability of a technology to provide reliable communication (PER < 10%) at specific moving scenarios.

2.4.1 Testing Scenarios definition

Two vehicles are launched on different speeds and/or different directions. The speed used in the study is the relative speed. If vehicles are facing each other, the relative speed is the addition of the two speeds. This test is named V2V High Speed Opposite Direction (HSOD) in [4].

2.4.2 Testing context

The tests are performed on highway with line of sight.

2.4.3 Performances

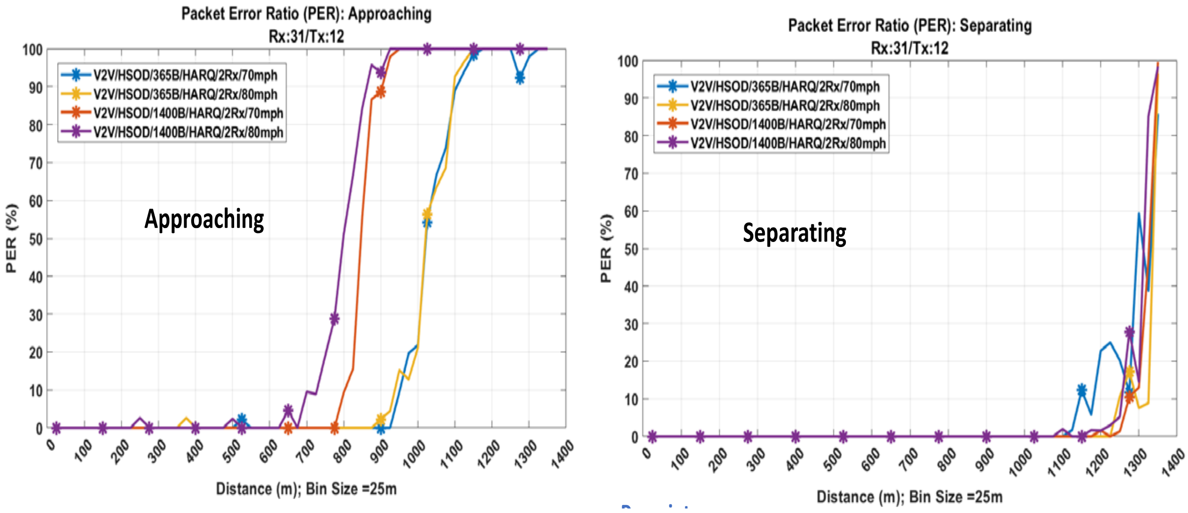

Figure 12: Test V2V HSOD (80-70 mph) with two vehicles approaching/separating [2]

The range is constantly higher when vehicles are separating that could be related to the implementation of the antennas on the roof top. Anyway, at such speed the impact of the speed on the performances seems limited.

The ability of a technology to provide reliable communication (PER < 10%) at specific moving scenarios:

Table 6 - Mobility performances of PC5 R14

Type	Value
Outdoor tests - Nominal	No difference to low speed
Outdoor tests - Min	No difference to low speed
Outdoor tests - Max	No difference to low speed

2.4.4 Consequences

The impact of the relative speed on the performance seems to be limited in LTE-V2X, but we have very few results from test field. We could note that simulation studies made for LTE V2X, constantly show a good resistance to high relative speeds.

2.5 Positioning

2.5.1 Can the technology provide a localization? What precision?

No, the LTE-V2X technology itself is not related with positioning so far.

3. Technology Characteristics

3.1 Supported messages

Table 7 - V2X messages supported by PC5 R14

Type	Rate
Collective Awareness Message (CAM)	1-10 Hz
Decentralized Environmental Notification Message (DENM)	1-10 Hz
Infrastructure-to-Vehicle-Notification Message (IVIM)	/
Signal Phase and Timing Extended Message (SPATEM)	10 Hz
MAP Extended Message (MAPEM)	1 Hz
Collective Perception Message (CPM)	1-10 Hz
Signal Request Extended Message (SREM)	/
Signal Status Extended Message (SSEM)	/
Maneuverer Coordination Message (MCM)	/
Multimedia Content Dissemination Message (MCDM)	/
VRU Awareness Message (VAM)	1-10 Hz
Service Announcement Essentiel Message (SAEM)	/

3.2 Cohabitation and interferences

Table 8 - Interoperability matrix between technologies

Technology's name	Co-channel coexistence [OK] / Interferences [NOK]	Interoperability [OK / NOK]
ITS-G5 based on IEEE 802.11p	NOK	NOK
ITS-G5 based on IEEE 802.11bd	NOK	NOK
PC5 based on 3GPP rel 14	OK	OK
PC5 based on 3GPP rel 16	NOK	NOK
PC5 based on 3GPP rel 17	NOK	NOK
4G	NA	NA
5G	NA	NA
BLE	NA	NA
Wi-Fi	NA	NA

(1) The [4] study concludes that interferences between Wi-Fi devices operating in U-NII-4 unlicensed bands could impact the performances of LTE-V2X operating in the ITS upper bands. the U-NII-4 band corresponds to the ITS lower bands that has been free by FCC in USA [FCC-20201118].

3.3 Security

3.3.1 Consideration of GDPR

The technology meets the requirements of GDPR. By design, pseudonymization with sophisticated pseudonym and authorization ticket change strategy.

3.3.2 Does the technology meet the EU requirements in term of security?

This technology meets the requirements of EU in term of security. EU has published dedicated requirements as EU Certificate Policy and EU Security Policy. Moreover, PKI is used. However, the system is able to fulfil EU-Security regulation requirements for the European V2X-trust system (European Certificate Trust List “ECTL” Requirements) but is not considered yet.

CONCLUSION

Concerning the deployment of the technology, PC5 Release 14 is a technology that is already involved in several companies that test it in project pilots in Europe (cf. Table 2). However, today, there is no mass-market vehicles deployment in Europe for this technology. Concerning the situation in China, it cannot be taken in account in this count because the technology is different from Europe. Moreover, for all direct communication type of communications, there are both V2X profiles and V2X messages standards that permits OEM and infrastructure providers to communicate and be interoperable. However, the interoperability with other technologies that use the same frequency band (e.g., ITS-G5), there is a major issue in today’s ecosystem. Indeed, there is not yet standardization or guidelines to employ these technologies that are not designed to co-exist.

Concerning the pure performance of the technology, PC5 Release 14 present sufficient performances to address all SECUR use-cases from a range, latency & congestion point of view based on the different sections of the document. Thus it could both address low-latencies critical safety use cases & informative use cases. However, there is no study on the performances of the technology in situations where the GPS signal may not be available (e.g., in tunnel).

Finally, from the privacy point of view, the design itself of direct communication through ITS-G5 is proven private by design from ANSSI (Agence Nationale de la Sécurité des Systèmes d’Information) & BSI (Bundesamt für Sicherheit in der Informationstechnik) which are the French & German information system security agencies.

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Partners

Contributors

REFERENCES

[1] L. Meilu, Z. Lingfan, F. Yuanyuan, S. Zhaoyang et W. Kai, *Implementation and Verification of LTE-V2X Algorithm Based on Software Radio Platform.*

[2] W. Yunting, L. Xiaoyong, P. Xiao et D. Hao, *Research on LTE-V2X Outfield Expressway.*

[3] Bundesministerium für Verkehr und digitale Ifrastruktur, «Convex project - D7.1 Final report on Field Test and Evaluation results,» 2020.

[4] 5GAA (Automotive Association), «CAMP LLC C-V2X Performance Assessement Project,» 2019.

[5] NXP, «Analysis of CAMP Report on the C-V2X Performance Assessement Project,» 2020.

[6] Mouna Karoui, Antonio Freitas, Gerard Chalhoub, «Performance comparison between LTE-V2X and ITS-G5,» *IEEE VTC-Spring 2020,* May 2020.

[7] Valérian Mannoni, Vincent Berg, Stefania Sesia, Eric Perraud, «A Comparison of the V2X Communication Systems: ITS-G5 and C-V2X,» *IEEE Vehicular Technology Conference (VTC) Spring 2019,* 2019.

[8] Pierre Roux, Valerian Mannoni, «Performance evaluation for co-channel coexistence between ITS-G5 and LTE-V2X,» *VTC2020-Fall - The 2020 IEEE 92nd Vehicular Technology Conference,* 2020.

[9] Michael Menzel, Adwait Kale, Soheil Gherekhloo, Jens Wettach, Markus Schreiter, Wolfgang Scheidl, Geerd Kaakes, Bruno Cimoli, HaiTao Xing, Vassilis Psaltopoulos, Vasilis Sourlas, «CONCORDA Milestone no. 27: V2V High Density Truck Platooning evaluation completed,» 2021.

[10] Pierre Roux, Stefania Sesia, Valérian Mannoni, Eric Perraud., «System Level Analysis for ITS-G5 and LTE-V2X Performance Comparison,» chez *IEEE MASS 2019 - The 16th IEEE International Conference on Mobile Ad-Hoc and Smart Systems*, Monterey, United States, 2019.

[11] Mireles, Rui, Mate Boban, Peter Steenkiste, Ozan K. Tonguz, and Joao Barros., «Experimental study on the impact of vehicular obstructions in VANETs.,» *VNC,* pp. 338-345, 2010.

[12] Ministère de la transition écologique, «Rapport du groupe de travail : tecjnologies de communication pour les STI coopératifs,» 2019.

TABLE OF ILLUSTRATIONS