SECUR

Safety Enhancement through Connected Users on the Road

Deliverable 2.1

Technical document: ITS-G5 based on 802.11p

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EXECUTIVE SUMMARY

This document is the technical document of ITS-G5 based on 802.11p technology. It gathers general information, performances KPI (data rate, range & reliability, latency, congestion, mobility and positioning) and technology's characteristics.

All these performances and characteristics will be compared to the requirements of each use cases defined in SECUR D2.2.

ITS-G5 based on 802.11p 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
RCR	Reliable Connectivity Range
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
UCR	Unreliable Connectivity Range
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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1. General information

1.1 Technology's name

ITS-G5 with IEEE 802.11 in OCB mode (aka. IEEE 802.11p)
(C2C-CC BSP R1.6.0, C-Roads RSP R1.8.0)

1.2 Operating frequency band

5.9 GHz (Channel 180), only the safety channel is used for considered services.

1.3 Standard (access layer)

1.3.1 Standardization organization

- European Telecommunications Standards Institute ETSI EN 302 663 v1.3.1
- Institute of Electrical and Electronics Engineers IEEE
- International Organization for Standardization ISO

Projects and consortiums providing inputs to standardization bodies.

- Car-2-Car Communication Consortium C2C-CC
- C-Roads

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

Published and continuously improved (IEEE 802.11bd will be released soon).

1.3.3 Is the organization active?

Yes, there is a continuous improvement of existing standards and new messages. For example, C2C-CC update every 6 months.

1.4 Communication profile

C2C-CC BSP v1.8.0
C-Roads RSP v1.8.0

1.5 All supported communication types (broadcast…)

Topology-scoped Broadcast.
Unicast and multicast could be supported as well.
Multi-Hop through geo-routing is supported in ETSI and ISO standards.

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

Table 1 - Technology capability by V2X communication types

V2X Type	Supported or not?	Mandatory infrastructure(s)/hardware for the technology operability
V2V	Supported	On-Board Unit (OBU)
V2I	Supported	On-Board Unit (OBU) + Road Side Unit (RSU)
V2N	Not supported (indirectly yes)	Possible only using a RSU but not directly: V2I2N
V2VRU	Supported	OBU or P-ITS-S (Personal ITS Station) supporting ITS G5.

1.7 Technology's deployment maturity

Rate of deployment: >20.000 vehicles per month
Infrastructure deployment: Several countries deployed large test field, for example in C-Road 43 cities and 6000 km of road in various environment.

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

Table 2 - Companies using the same technology

Companies	OEM	Volkswagen (500 000 vehicles in 2021
	Tier 1	Aptiv, Bosch, Denso
	Software provider	Cohda Wireless, Commsignia, YoGoKo, Lacroix City
	Chipset provider	Autotalks, NXP

ITS-G5 has been deployed mainly in Europe and is also have small sections/cities deployed in Israel & Australia.

2. Performance

2.1 Range and reliability

2.1.1 Testing context

"Range tests verify the distance at which a V2V technology achieves communication in various scenarios. Range or reliability tests also verify the reliability of basic safety packet communication as a function of distance between the vehicles. Range test scenarios are categorized as follows:

- Line-of-Sight (LOS) tests
- Non-Line-of-Sight (NLOS) tests [1]"

A detailed plan of these tests is in [1] Section 8.5.1 and 8.5.2

2.1.2 Performances

PER < 10% is acceptable. Above that, it is assumed there is no communication between the objects.
The following test could be performed for various environment.
Evaluation of the range while PER < 10%:

Table 3- Range performances of ITS-G5

Type	Value
Maximum range during outdoor tests [m]	LOS : 1400 m NLOS : 1020 m
Average range during outdoor tests [m]	LOS :625-925 NLOS :250-350

The previous summary table is based on the following studies.

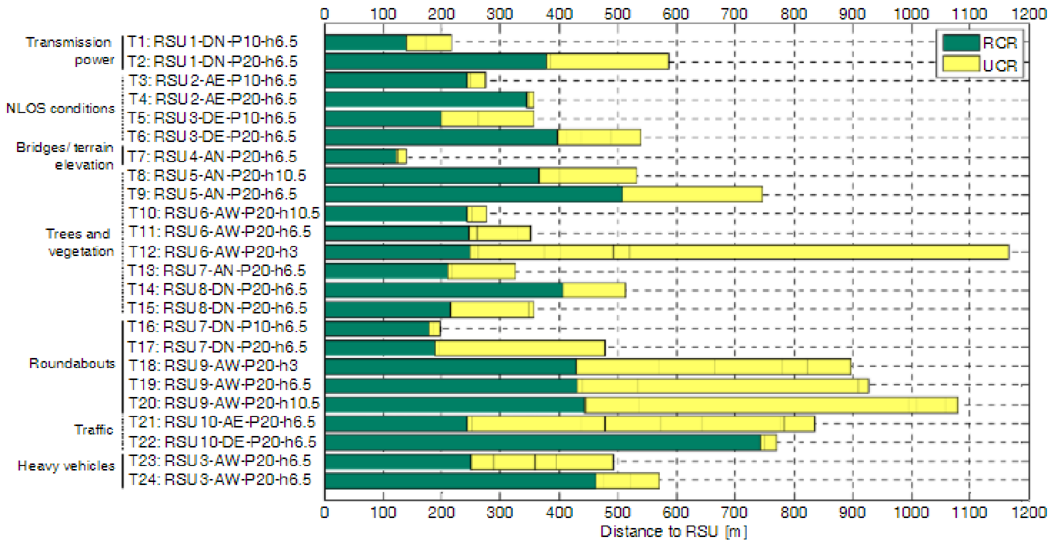

Figure 4. RCR and UCR parameters for the most significant tests (Tx). Notation RSU[a]-[b][c]-P[d]-h[e]: RSU[a] is the ID of the RSU, [b] denotes if the OBU approaches (A) or drives away (D) from the RSU, [c] represents the cardinal point (N, S, E, W) from which the OBU approaches the RSU or to which the OBU drives away from the RSU, P[d] is the transmission power (dBm), and h[e] the RSU antenna height (meters).

Figure 1: RCR and UCR parameters for the most significant tests (Tx) [2]

V2V delivery ration (PDR) related to distance and considering various cases. The dotted lines represent the 20% and 80% quantiles. The environment has an important impact on the range.

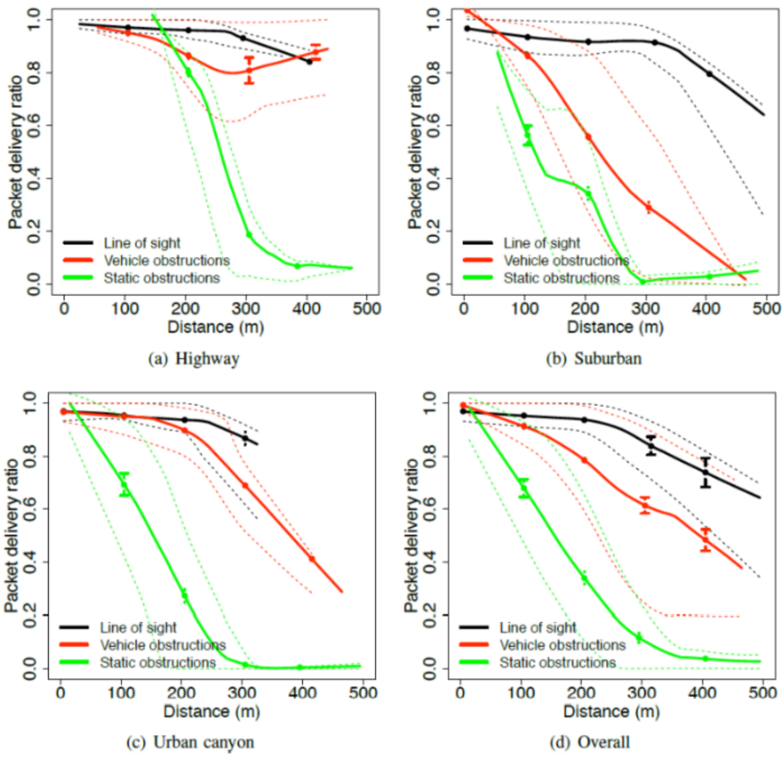

Figure 2: V2V PDR according to distance. Dotted lines represent 20% & 80% quantiles [4]

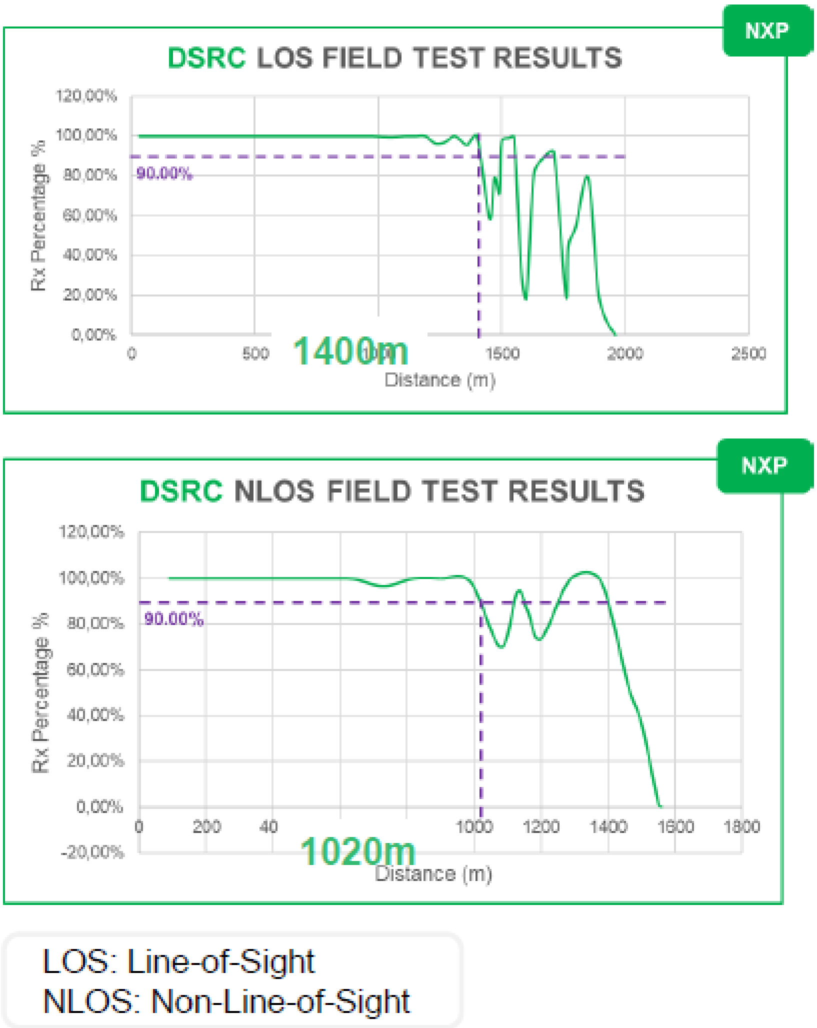

Figure 3: Range performances tests performed by NXP on their chipset

2.1.3 Consequences

The average range with a good reliability (PER< 10%) is at least a few hundred meters. On the typical safety use cases the performances of ITS G5 are sufficient.

2.2 Latency

2.2.1 Performances

Table 4- Latency performances of ITS-G5

Type	Value
Theoretical	1.24 ms (cf. Figure 6)
Outdoor tests - Nominal	Channel load dependant (<10 ms)
Outdoor tests - Min	< 1 ms
Outdoor tests - Max	100 ms

The previous summary table is based on the following studies.

The following figure represent the End-To-End delay of ITS-G5 & PC5 R14 [mode 3] as a function of number of vehicles simulated (between 30 and 90 vehicles following by Krauss model at 30 km/h)

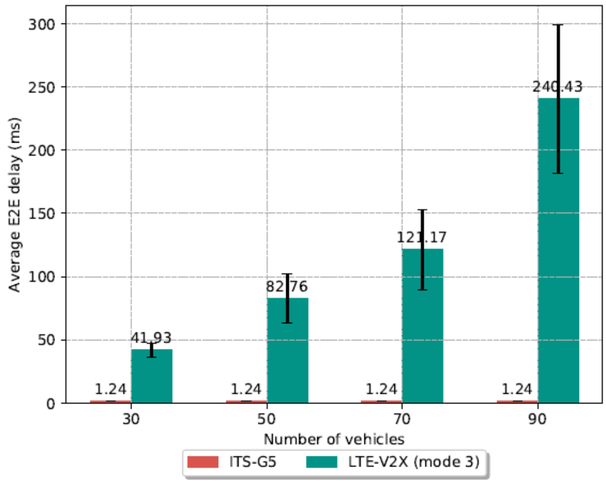

Figure 4: Average E2E delay according to simulation performed in [7]

In [7], average ITS-G5 end to end latency has been 1.24ms.

	Security	One use (Id 1) Latency (mean, std)/ms	Two Users (Id 1 and 2) Latency (mean, std)/ms	Three users (Id 1, 2, 3) Latency (mean, std)/ms
ITS-G5	Without security	(11.2, 3.5)	(10.9, 3)	(25, 12.5)
	Only Signing	(23.1, 5)	(21.5, 3.5)	(37.5, 13)
	Signing and Encryption	(24.7, 4)	(23.7, 4)	(41.2, 13)

Figure 5: Latency measurements for each technology (1 user, office) in CONCORDA project [6]

Technology - 3	Latency in application layer [ms]					
	Number of messages	Mean	Max	std	Mode	95% prctile
ITS-G5	149930	43.716	154	14.069	38.011	71.821

Figure 6: Latency in application Layer measured on highway for each technology in CONCORDA project [6]

Short range Technologies	Geo-Network OTT Latency (t8 –t1) [ms]					
	messages	mean	std	max	mode	95th prctile
ITS-G5	400864	3.3	0.65	28.6	2.9	4.5

Figure 7: Latency in Geo-Network measured on highway for each technology in CONCORDA project [6]

2.2.2 CONSEQUENCES

ITS-G5 presents good performances on latency. There are still uncertainties concerning the end-to-end latency with a high-congested use case. However, congestion control mechanism designed for ITS-G5 mitigate the effect of the congestion.
The contribution of the ITS-G5 transmission to the end-to-end delay depend on the level of congestion of the channel and the distance between the sender and the receiver.

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 100 users in area of 1 km². This information is typically obtained using simulation.

2.3.1 TESTING CONTEXT

Evaluating the effect of the congestion in real testbed is very complex this is why most of the results come from simulation-based studies.

"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. [9]"

2.3.2 PERFORMANCES

Assessment of reliability while there is congestion (high channel load ~ 100 users/km²):

Table 5- Congestion behaviour performances of ITS-G5

Type	Value
Theoretical	Range: 200 m Latency: 2 ms

The previous summary table is based on the following studies.

Figure 12 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 [9] between 0 and 100 users, the range is divided approximately by 2.

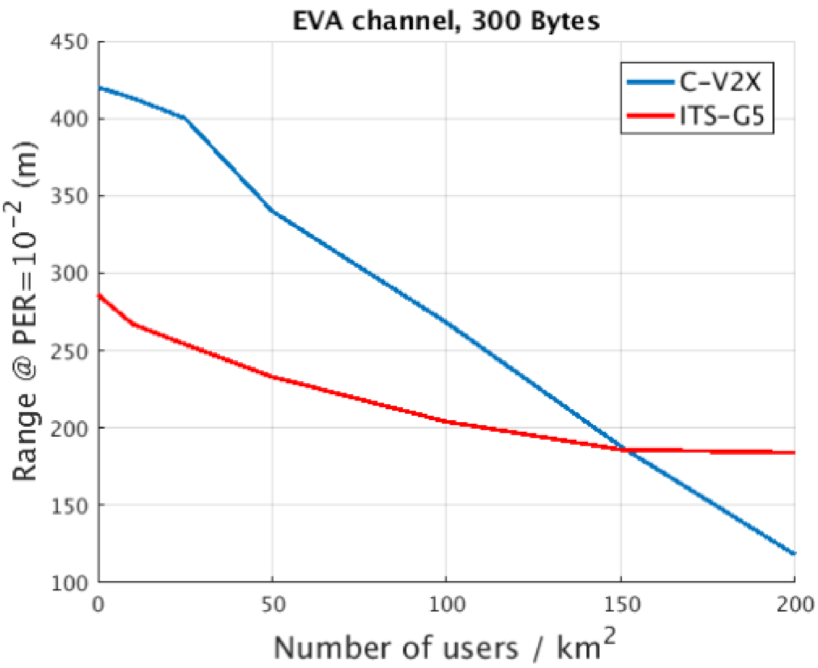

Figure 8: Performance synthesis of C-V2X and ITS-G5: range evolution as a function of the network load [9]

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.

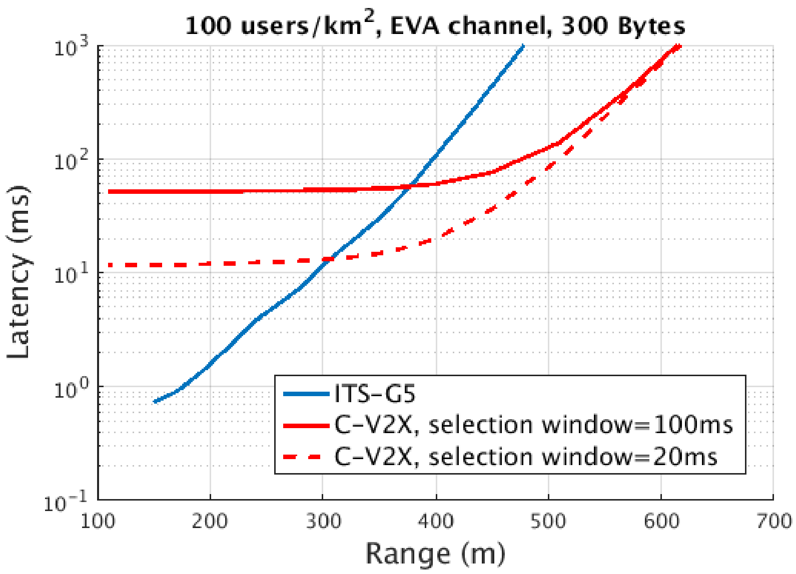

Figure 9: ITS-G5 and C-V2X latency as the function of the range for a density 100 users/km² [9]

Figure 14 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)

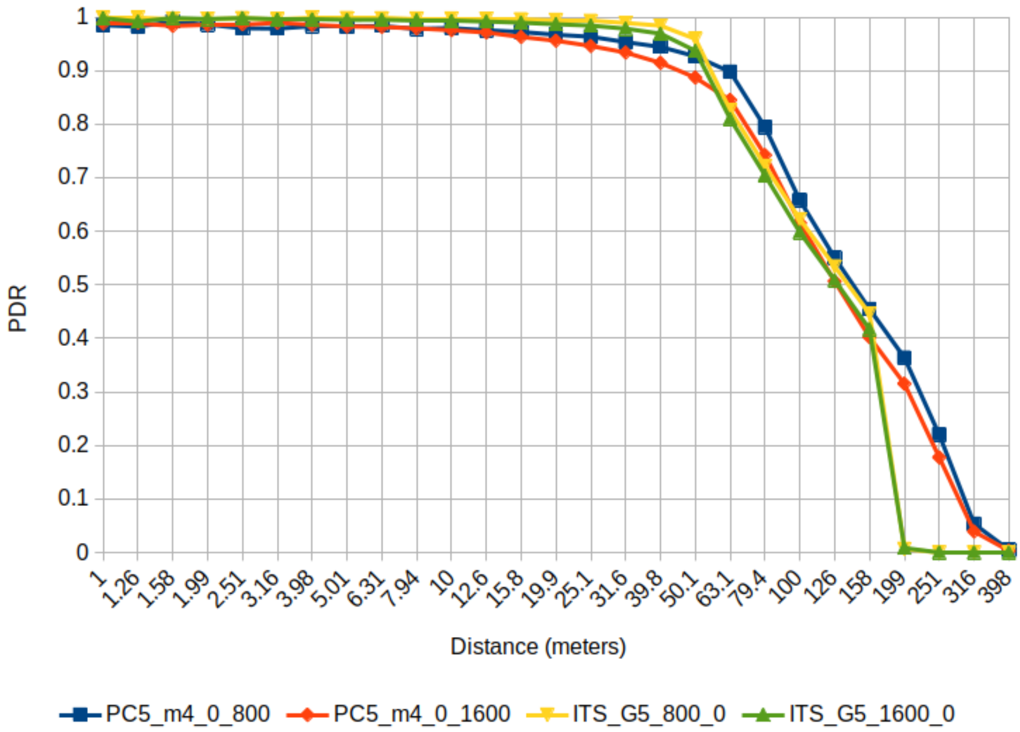

Figure 10: ITS-G5 and PC5 PDR as a function of the range for a density of 800 and 1600 users [8]

This figure shows that there is a small difference between the yellow and green lines that represent simulation with 800 and 1600 vehicles. So, there is a high resistance to traffic density for ITS-G5.

2.3.3 Consequences

Congestion and performance of ITS-G5 is sufficient for use cases according to the requirements defined in SECUR D2.2.

The loss in terms of range in ITS-G5 is limited in reasonable condition of congestion and acceptable in high user density. The variation in terms of delay is reasonable for few hundred-meter range even for high user density.

2.4 Mobility

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

2.4.1 Testing context

The tests are performed on highway with line of sight.

2.4.2 Performances

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

Table 6 - Mobility performances of ITS-G5

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

2.4.3 Consequences

These information on the technology's behaviour with differential speeds is based on multiple partner's experience. Mobility performance of ITS-G5 is sufficient for use cases according to the requirements defined in SECUR D2.2.

2.5 Positioning

2.5.1 Can the technology provide a localization? What precision?

ITS-G5 does not provide localization. The only localization information available is a given station is in the range of another one.

2.5.2 How does the technology can improve the precision of the GPS positioning?

It's realistically not possible. The ITS-G5 technology itself is not related with positing. ITS-G5 could be used as other communication technologies to transport GPS correction information.

3. Technology characteristics

3.1 Supported messages

Table 7 - Type of messages supported by ITS-G5

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	OK	OK
ITS-G5 based on IEEE 802.11bd	OK	OK
PC5 based on 3GPP rel 14	NOK	NOK
PC5 based on 3GPP rel 16	NOK	NOK
PC5 based on 3GPP rel 17	NOK	NOK
4G	NA	NA
5G	NA	NA
Bluetooth Low Energy (BLE)	NA	NA
Wi-Fi in ISM bands	OK (1)	NOK

(1) The [5GAA-2] 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]. There not known study of the potential impact on ITS-G5 but it is reasonable to consider it as possible.

3.3 SECURITY

3.3.1 CONSIDERATION OF GDPR

The technology with upper layers designed at ETSI 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. Finally, the system is able to fulfil EU-Security regulation requirements for the European V2X-trust system (European Certificate Trust List "ECTL" Requirements)

CONCLUSION

Concerning the deployment of the technology, ITS-G5 based on 802.11p is a technology that is already available and used by several companies in Europe (cf. Table 2). 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., PC5 Release 14 & 16), 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.
Besides, one of the challenges of this technology is the market penetration of both vehicles and infrastructure. There is today OEM that deployed the technology on mass-market vehicle (e.g., Volkswagen) and cities in their center (e.g., Hamburg).

Concerning the pure performance of the technology, ITS-G5 based on 802.11p 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.

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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Contributors

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