



Cellular V2X

Conclusions based on Evaluation of Available Architectural Options

White Paper

Version:	1.0
Date of publication:	20 February 2019
Document type:	White Paper
External publication:	Yes
Date of approval by 5GAA Board:	03 December 2018

5GAA

Postal address

5GAA address

5GAA c/o MCI Munich
Neumarkter Str. 21
81673 München – Germany

Internet

<http://www.5gaa.org>

Copyright Notification

No part may be reproduced except as authorized by written permission. The copyright and the foregoing restriction extend to reproduction in all media.

Contents

1.0	Introduction	5
2.0	V2V Architectural Proposals Analysis	5
2.1	V2V Architectural Proposals	5
2.2	V2V Simulation analysis.....	7
2.3	V2V Analytical Evaluations	8
3.0	V2N2V and V2N Architectural Proposals Analysis	9
3.1	V2N2V and V2N Architectural Proposals.....	9
3.2	V2N2V Simulation analysis	12
3.2.1	Uu Based Solutions Evaluations.....	12
3.2.2	Cloud Assisted Solutions Evaluations	13
3.3	V2N2V Analytical evaluations	14
4.0	Multi Operator Aspects	16
4.1	Usage Scenario 1: RAN Sharing	16
4.2	Usage Scenario 2: Regional Roaming	16
4.3	Usage Scenario 3: Multiple PLMN offering V2X Service	16
4.3.1	Exclusive carriers allocation for different PLMNs for V2X services over PC5.....	17
4.3.2	Carrier sharing among different PLMNs for V2X services over PC5.....	17
5.0	Conclusions	17
	References.....	19
	Annex A: Evaluation Assumptions for the Numerical Evaluations.....	20
A.1	Evaluations for Radio Access Supporting PC5 Communications	20
A.2	Evaluations for Radio Access Supporting Uu Communications	21
A.3	Simulation assumptions and scenario description	22
	Annex B: Evaluation Assumptions for the Analytical Evaluations.....	24
B.1.1	Assumptions	24
B.1.2	PC5	24
B.1.2.1	Mode 4.....	24
B.1.2.2	Mode 3.....	25
B.1.3	Latency analysis of Uu-based V2X communication	27
B.1.3.1	UL SPS.....	28
B.1.3.2	DL unicast.....	28

B.1.3.3 DL broadcast (MBSFN and SCPTM) 29

1.0 Introduction

During the last decade, a set of connected transportation services has been identified utilizing mobile network communication. One question that has to be answered is whether these transportation services can be handled by the current cellular networks or particular enhancements are needed in order to provide a commercially viable solution.

This document tries to analyze the cellular V2X architectural solutions and to evaluate them against two particular use cases of interest: the Intersection Movement Assist (IMA) and the Vulnerable User (VRU) Discovery. The cellular V2X communication considered in this report are solutions based on PC5 interface and solutions relying on Uu.

Regarding deployment aspect, the multi operator scenario, which is relevant for real-world environment, are analyzed in this document as well.

2.0 V2V Architectural Proposals Analysis

2.1 V2V Architectural Proposals

Based on the understanding in 5GAA, V2V communication relates to communication where both endpoints (application layer) are vehicles in close proximity. V2V is direct communication between vehicles. The communicating vehicles for exchanging information use short range communication, for Release 14, LTE PC5. In the current analysis V2V architectural proposals relate to the two modes of PC5 communications of V2V, namely PC5 mode 3 (network scheduled operation mode) and mode 4 (UE autonomous selection mode).

PC5 Mode 3

In PC5 mode 3, scheduling and interference management of V2V traffic are assisted by eNBs via control signaling over the Uu interface. The eNodeB will assign the resources being used for V2V signaling in a dynamic manner.

According to [3GPP TS36.331] for mode 3, when a UE in-coverage of an eNB receives SystemInformationBlock21, it checks whether `v2x-CommTxPoolNormalCommon` is included in the `sl-V2X-ConfigCommon` carried in SystemInformationBlock21[3GPP TS 36.331]. If `v2x-CommTxPoolNormalCommon` is not included, an RRC connection establishment is initiated by the UE [3GPP TS 36.331].

An RRC_CONNECTED UE requests assignment of dedicated sidelink resources based on its Buffer Status Reports (Sidelink BSR)

RRC controls BSR reporting for sidelink by configuring the relevant timers [3GPP TS 36.331]. Each sidelink logical channel belongs to a ProSe Destination and is allocated to a Logical Channel Group (LCG) depending on its priority and the mapping between LCG ID and priority provided by upper layers.

For transmitting in the sidelink a UE proceeds in V2X sidelink resource request. The respective resource allocation may be based on Dynamic Scheduling, where the serving eNB allocates the respective resources to the UE or Semi-Persistent Scheduling, where a set of resources is allocated and certain transmission opportunities.

PC5 Mode 4

In PC5 mode 4 scheduling and interference management of V2V traffic are based on distributed algorithms implemented between the vehicles and they rely on sensing with semi-persistent transmission. Additionally, geographical restrictions may be used for handling near far effect arising due to in-band emissions and hidden terminal problem.

According to [3GPP TS36.331], PC5 mode 4 is used in any of the following situations:

- If the UE is in RRC_CONNECTED, the UE transmits V2X sidelink data based on sensing using one of the resource pools indicated by the respective fields for the CONNECTED state.
- If the UE is in RRC_IDLE, the UE transmits V2X sidelink data based on sensing using one of the resource pools indicated by the respective fields for the IDLE state.
- When UE is out of coverage, the UE transmits V2X sidelink data based on sensing using one of the resource pools indicated by fields for the out of coverage case.

The UE may also reselect a resource at any time if the data available for transmission does not fit in the selected resource.

PC5 mode 4, since as it is described above, is able to operate without the network coordination, certain parameters need to be configured in advance. Figure 1 provides the C-V2X reference architecture supporting PC5 pre-configuration. The Common Cloud Entity (CCE) Function is in charge of common PC5 parameters setting/storage, whereas the Proprietary Cloud Entity (PCE) Function and V2X Control Function (VCF) are in charge of common PC5 parameters provisioning/conveying to the UE. In particular:

- CCE undertakes to provide the up-to-date common PC5 parameters to PCE/VCF via A1 interface.
- PCE (which could be integrated to existing cloud server functionalities) undertakes to:
 - Ensure that the pre-installed configuration in the factory is in accordance with the up-to-date common PC5 parameters given by CCE
 - give the up-to-date common PC5 parameters to UEs in charge via A2 interface
- VCF undertakes to:
 - ensure the pre-installed configuration in the factory synchronized with the up-to-date common PC5 parameters given by CCE
 - give the up-to-date common PC5 parameters to UEs in charge via V2 interface which is defined in [3GPP TS 23.285]

Interactions among the entities takes place via the following interfaces:

- A1 interface
 - the content and format of PC5 parameters should reuse [3GPP TS 24.385] as much as possible
 - standardization of outer encapsulation (e.g., IP address, port, security scheme, etc.) in A1 interface is needed
- A2 interface
 - the content and format of PC5 parameters should reuse [3GPP TS 24.385] as much as possible
 - the outer encapsulation could be left proprietary

Note: a certain UE may obtain PC5 pre-configurations parameters from both V3 interface and A2 (V1) interface, in this case the detailed prioritization of those parameters could be investigated further.

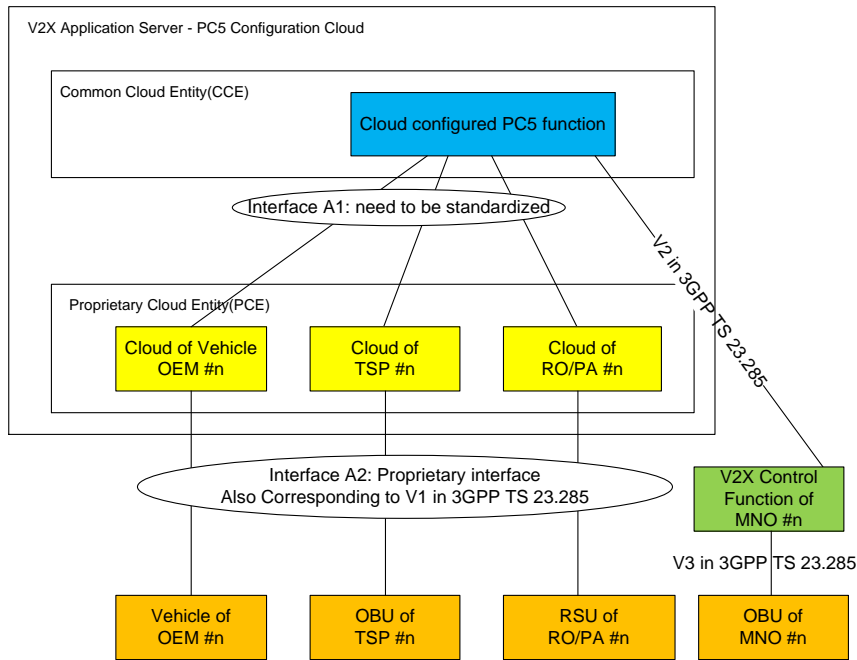


Figure 1: C-V2X reference architecture supporting PC5 pre-configuration

2.2 V2V Simulation analysis

The Intersection Movement Assist use case has been considered for the evaluation of the available V2V architectural proposals. In brief, this use case relates to vehicles entering an area of interest (e.g., an intersection) requiring to inform and be informed about the movement of other vehicles in the intersection. The detailed use case description as well as the assumptions used for the evaluation are being provided in the Annex A.1.

The considered deployment model is urban whereas for the notification of the neighboring vehicles both dedicated signaling and CAM messages can be used. For the evaluations in this document CAM messages have been used with 10Hz CAM generation rate and 190B packet size.

The area of interest is captured by the intersection area as illustrated in Figure 2; in particular the intersection area is considered as 50 meter radius from the center of the intersection whereas the transmitter vehicles considered are those located at most 150 meters from the center of the intersection.

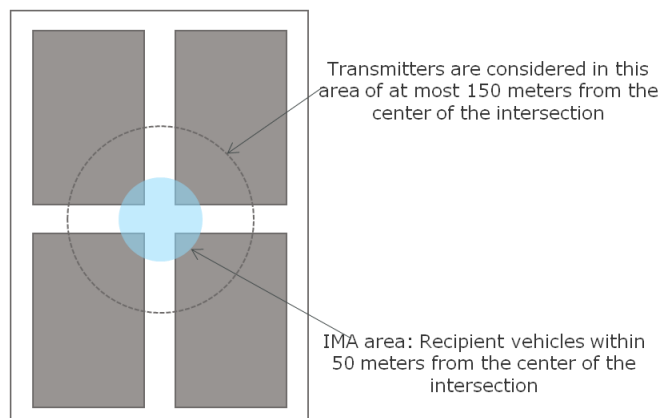


Figure 2: IMA use case for this evaluation

Three cases are evaluated in this analysis:

- PC5 mode 4 without zones
- PC5 mode 4 with static zones: the resources are uniformly split to all the zones. The repetitive zone pattern is deployed.
- PC5 mode 4 with dynamic configuration of zones: the zone configuration (e.g., power, resource pools, etc.) is updated according to the topology/traffic

Figure 3 shows the PDR vs transmission distance from the intersection area. The PDR is provided for two cases, one with traffic jam conditions (280 vehicles in the deployment area following the 3GPP assumptions [3GPP TR 36.885]) in the intersection area and one with limited number (i.e., 60 vehicles) of vehicles in the overall deployment.

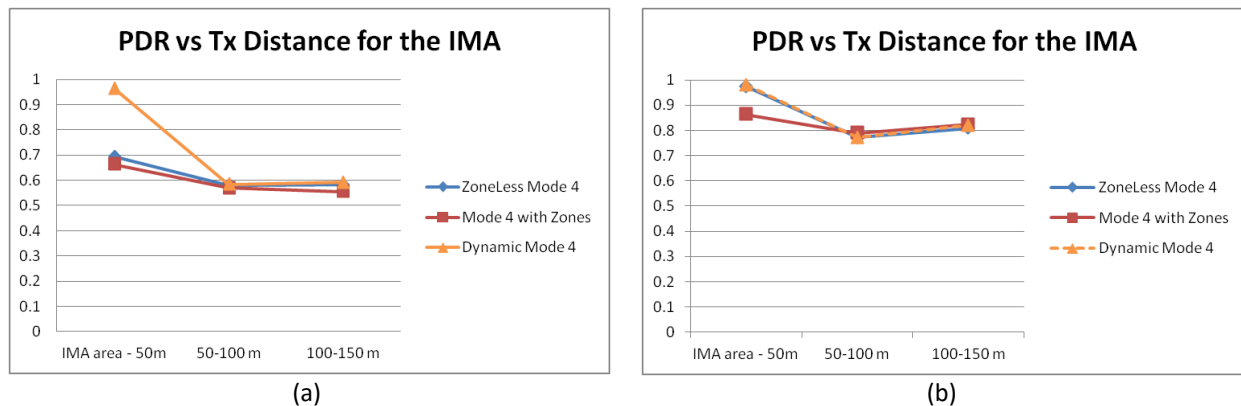


Figure 3: PDR vs Distance for the IMA use case for high (a) congestion conditions (3GPP vehicle deployment) and (b) low congestion deployments (60 vehicles in the area under consideration)

From Figure 3 it can be concluded that, in the IMA use case, PC5 mode 4 with dynamic configuration may perform better in high congestion conditions since it enables proper resource pool allocation and transmission power setting. In low density deployments, PDR performance is not significantly affected by the different configurations. These two observations show that the dynamic configurations of the zones, depending on the traffic conditions, can significantly improve packet delivery ratio for particular scenarios.

2.3 V2V Analytical Evaluations

In C-V2X architecture for V2V, two resource allocation schemes/transmission modes (i.e., mode 3 and mode 4) as specified in 3GPP R14 V2X are reused for 5GAA PC5-based V2X communication.

Assuming L-SL is the latency of SL transport between two UEs (i.e., the time duration from the time UE has a V2V message to send over sidelink to the end time destination UE successfully receives the V2V message). For RRC_CONNECTED UE configured with mode 3 or mode 4 resource selection, the latency calculation should consider the time from UE sending sidelinkUEInformation for resource configuration request to receiving RRC reconfiguration from eNB (i.e., L-SL_config). In some cases RRC_IDLE UE may need to enter RRC_CONNECTED to receive sidelink resource configuration from eNB. In this case, the latency calculation should consider the UE state transition time from RRC_IDLE to RRC_CONNECTED as well (i.e., L-RRC). Therefore, the end-to-end latency of PC5-based V2X communication can be calculated as (L-RRC + L-SL_config) + L-SL. However the L-RRC and L-SL_config control plane delays only happens at the beginning of RRC connection establishment or resource request which can be seen as start-up cost. Thus, these delays are optional part (with parentheses) in latency evaluation and we can only focus on the mandatory part (without parentheses), i.e., the latency of SL transport between two UEs.

For Mode 4, Mode 3 dynamic scheduling and mode 3 SPS, the overall latency results are provided in Table 1 (The assumptions are provided in Annex B). As presented mode 3 and mode 4 typically can achieve (depending on the resource selection window, and the considered traffic) latency below 100ms without considering the control plane

latency of UE's state transition and sidelink resource configuration; only when T2 is set to 100ms the latency may exceed 100 ms.

Table 1 Latency results for PC5-based V2V communication

scenario \ latency	(L-RRC + L-SL_config) + L-SL (ms) (mandatory + optional) ^{Note 1}			L-SL (ms) (only mandatory)		
	Min	Mean	Max	Min	Mean	Max
L-SL_mode 4	86.1	134.6	185.1	7 ^{Note2}	55.5	106 ^{Note3}
L-SL_mode3_sps ^{Note4}	86.1	135.1	185.1	7	56	106
L-SL_mode3_dynamic_bsr ^{Note5}	105.6	105.6	110.6	26.5	26.5	31.5

Note 1: the component with parentheses is optional-present while component without parentheses is mandatory-present. The control plane delays (L-RRC and L-SL_config) only happen at the beginning of RRC connection establishment or resource request which can be seen as start-up cost. They are optional parts in the latency evaluation. According to TR 36.885, L-RRC is 50ms, L-SL_config is 29.1ms.

Note 2: refer to Table 7 (Annex B.1.2.1), T1 is set to 1ms, the min is T1+6=7ms.

Note 3: refer to Table 7 (Annex B.1.2.1), T2 is set to 100ms, the Max is T2+6=106ms.

Note 4: refer to Table 9 (Annex B.1.2.2), SL SPS period of 100ms is selected for calculation. Note that in most cases the configured SPS resources can be aligned with packet transmission period and packet arrival time or only a minor offset to the actual packet arrival time by using UE assistance information reporting mechanism, as stated previously.

Note 5: refer to Table 8 (Annex B.1.2.2), SR period is set to 10ms.

3.0 V2N2V and V2N Architectural Proposals Analysis

3.1 V2N2V and V2N Architectural Proposals

Contrary to the solutions described up to this point, mainly dealing with direct vehicle communication, the approach handled in this section builds upon vehicle communication involving the network. The communication may relate to communication only among vehicles, or communication between vehicles and network itself. The former solutions are captured by the term V2N2V, which is indirect communication between vehicles via cellular network and ICT infrastructure, whereas the latter solutions are captured by the term V2N where one endpoint of the communication is a vehicle and the other endpoint is located in ICT infrastructure. For both V2N2V and V2N cellular communication is used.

V2N2V Architectural Proposals

V2N2V solutions consider typical Uu communications as basis. In the cases where the P-GW can be located close to the eNB, the backhaul delay can be significantly reduced; local breakout thus seems beneficial in order to better fulfil the stringent latency requirements of V2X services. This enables a more local termination of V2X traffic instead of traversing the EPC. A SIPTO solution [3GPP TR 23.859] could be used for this type of V2X deployment, which is based on the existence of Local Gateway (L-GW) [3GPP TR 36.885]. Different alternatives have been identified in [3GPP TR 36.885] for the position of the L-GW and the interaction with a V2X server i.e., V2X Server behind a L-GW (stand-alone or co-located with the eNB), or in the eNB itself.

Given that V2X functionality provides road safety services to moving vehicle UEs, the connection of the V2X server via SIPTO with a stand-alone L-GW seems to be more appropriate with respect to the other options, since it is the only one that maintains the data connection through handovers.

V2N Architectural Proposals

Similarly to V2N2V, V2N solutions use Uu communication. The key difference as mentioned above is that the one communication endpoint is in the ICT infrastructure. The network should facilitate the deployment of the ICT application both centralized and in the edge cloud. The major functions to achieve this in an efficient way are CUPS and SIPTO.

Control and User Plane Separation (CUPS), introduced in 3GPP release 14, see [3GPP TS 23.214] enables the further distribution of the user plane of EPC in a cost efficient way.

Selected IP Traffic Offload (SIPTO) is a function that enables the network to offload traffic close to the UE/vehicle. SIPTO is based on the local break-out architecture of EPC. Meaning that the MME function to select the SGW and PGW make use of the UE location information.

To allow for mobility with SIPTO, the MME may check if the PGW for a UE needs to be changed. If so, the MME initiates Detach with reattach required or PDN disconnection with reactivation required procedure after the completion of a TAU procedure (hence this mobility only happens in ECM_IDLE state). Using CUPS and SIPTO S/PGW-U may be deployed in a distributed fashion to connect to the distributed clouds instances.

Furthermore, traffic flows in the core can be logically separated and be subjected to special treatment by using a number of functionalities of the EPC:

- The connection to the central cloud and edge cloud instances can be separated using multiple PDN connections, (also a single PDN connection can be used, both options are supported by 3GPP specifications), see [3GPP TS 23.401].
- The traffic on the EPS default bearers of the different PDN connections may be treated using different QCI and ARP values per default EPS bearer, see [3GPP TS23.401].
- Within one PDN connection, traffic may be separated using dedicated EPS bearers, which may have different QCI values. This option however calls for an interface between the cloud applications and the EPC to convey address information for the flows that are to be separated out, see [3GPP TS23.401].

Dedicated network based on DECOR (see [3GPP TR23.707]) that may use eDECOR (see [3GPP TR 23.711]) introduced enhancements can be used to create a logical automotive core instances as presented in the figure below (Figure 4).

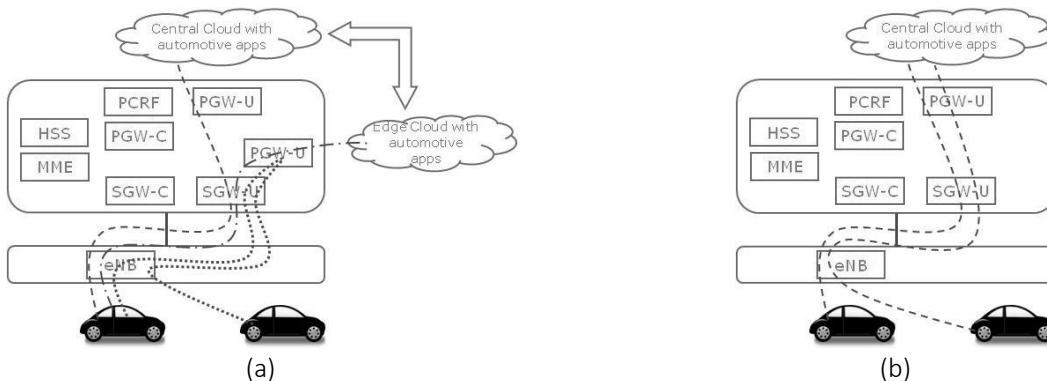


Figure 4: Dedicated Automotive Cores for (a) Wave 1 use cases and (b) eMBB/Infotainment services

Cloud Architecture Options

Cloud architecture options are split in two, centralized cloud and edge cloud.

With the term centralized cloud, we here mean that:

- the infrastructure performing cloud computing and storage are logically located outside of the access network domain and that are reached by IP routing,
- the cloud computing/storage service offering is commercially separated from the access service and are able to serve vehicles over multiple access services provided by different access service providers.

Centralized cloud solutions may use public available infrastructure or private cloud infrastructure. The trend for the infrastructure provider role is to move from private cloud infrastructures to public available infrastructures.

The cloud stack is layered as presented in the figure below (Figure 5). To simplify the matters, two distinct roles can be defined. The application provider that provide the application that give service to the user of the vehicle and a cloud infrastructure provider that provides (some of) the resources needed to run the application.

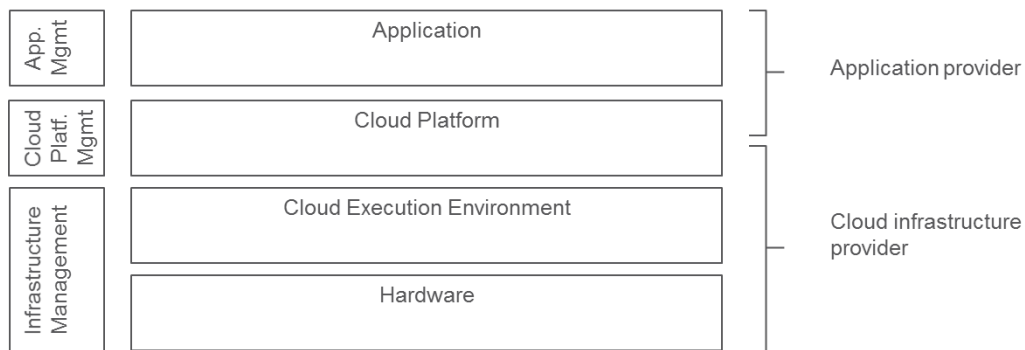


Figure 5: A cloud stack and two possible roles

The distribution of the cloud infrastructure is in general one or a few clusters per continent (plus what is needed to provide geographical redundancy per region). The reasons for this distribution for instance are; regulatory requirement that hinders data produced by the vehicles to leave a country or region, latency, service offerings and operations set-up per regional market.

Edge computing is about hosting applications at the network edge, closer to the consumers or clients, or closer to the source of information required by the application. Such deployment can result in measurable benefits in latency and bandwidth usage as well as in deployment flexibility. The edge computing solution of ETSI MEC includes the framework and well-defined APIs for exposing the information and capabilities available at the edge to the hosted applications. The mobile access network in particular possesses valuable information and capabilities related to e.g., UE mobility, UE location and radio link conditions. The ability of the MEC platform to expose such information and capability to the MEC applications via standards defined APIs allows the applications to gain near real time context awareness, adding further value to their deployment at the edge. In this environment an application can also be deployed for the sole purpose of collecting and/or generating information of value to other applications or to MEC platform, and exposing that information via a well-defined service API.

Edge computing is widely recognized as a key technology for 5G [5GIA 2015]. 3GPP is adopting the Edge computing concept and putting measures in place accordingly [3GPP TS 23.501] [3GPP TS 23.502]. ETSI MEC is positioning itself as the preferred solution for Edge computing, as an enabler for several service scenarios [MEC-IEG 004], including automotive use cases.

Currently specified MEC system is based on use cases that are deriving technical requirements [MEC002] for the implementation of the ME platform.

3.2 V2N2V Simulation analysis

V2N2V simulation analysis aims at capturing two aspects of V2N2V communication. The former relates to the evaluation of the Uu based solutions and in particular how these can handle the IMA use case (evaluated also in for the PC5 case) and the latter relates to the evaluation of the cloud based schemes using the vulnerable road user (VRU) discovery.

3.2.1 Uu Based Solutions Evaluations

For the evaluation of the Uu based solutions in IMA use case an urban deployment model is considered. The CAM generation rate is in average 5Hz or 10Hz and the packet size is 300B/packet (details on the evaluation assumptions are available in the Annex A.2). The cloud reflects each CAM packet to all UEs within 300m or 150m from the transmitter UE, with multicast delivery. Statistics are logged only for UEs deployed at intersections, while traffic is generated by all UEs in the system. Two network architectures have been evaluated:

- “Local breakout” with no additional “core” delay
- “Public internet” with an average 70ms additional delay penalty due to inter-PLMN packet transition. This assumption is based on field measurements and is justified in the Appendix.

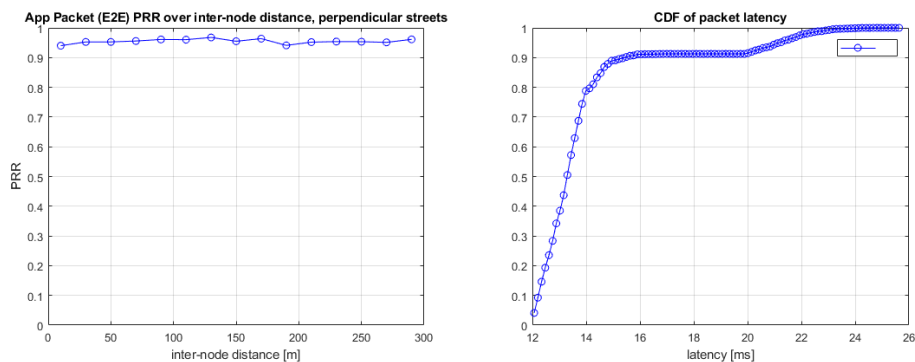


Figure 6: “Local breakout” scenario. Left: Average packet reliability vs tx-rx distance (PRR). Right: E2E Packet delivery latency distribution (CDF) for successful deliveries.

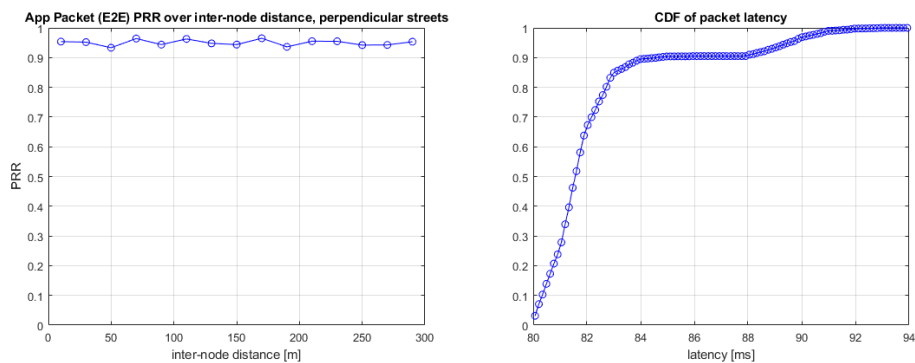


Figure 7: “Public internet” scenario. Left: Average packet reliability vs tx-rx distance (PRR). Right: E2E Packet delivery latency distribution (CDF) for successful deliveries.

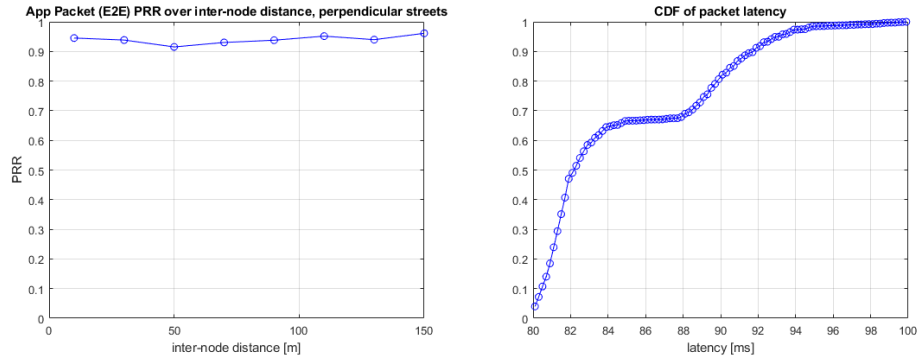


Figure 8: “Public internet” scenario. Left: Average packet reliability vs tx-rx distance (PRR). Right: E2E Packet delivery latency distribution (CDF) for successful deliveries. 10 Hz CAM generation rate, all UEs within 150m from the transmitter

It can be concluded from Figure 6, Figure 7 and Figure 8 that mobile networks can fulfil both reliability and latency requirements, with and without local breakout. Awareness messages are reliably (~95%) exchanged among vehicles that are at least 150m from each other, within a maximum e2e 100ms latency. Latency can be further improved to less than 30ms with local breakout (edge cloud).

3.2.2 Cloud Assisted Solutions Evaluations

This section targets the evaluation of the cloud aspects incorporating Multi-access Edge Computing (MEC). The latency evaluation in this document is based on 3GPP R14 V2X traffic model defined in TR 36.885 [3GPP TR 36.885] and the data is assumed to be fully transmitted in one time. Retransmission is not considered. A single operator/single OEM is assumed.

The focus of the present evaluations is on VRU discovery use case, and with emphasis on latency considering also cloud aspects. The key idea of the considered UC is captured in Figure 9; additional assumptions are described in the Annex A.3.

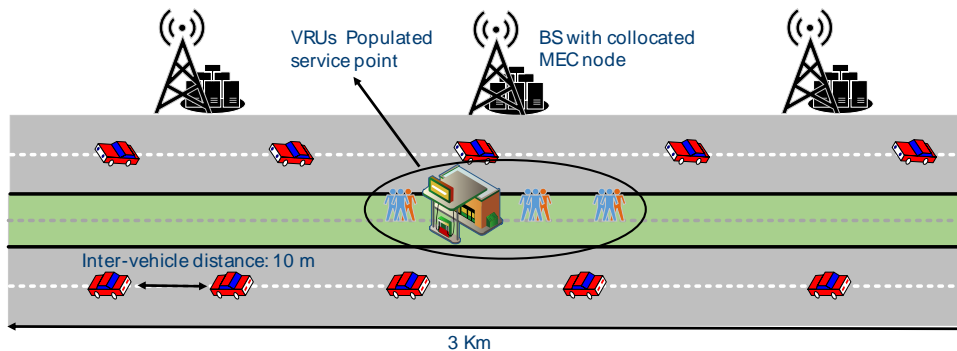


Figure 9: Reference scenario (VRU exemplary use case)

In the VRU discovery case the usage of edge cloud to shorten the E2E latency is a reasonable option, as the consequent gain can be qualitatively understood and foreseen (since the E2E traffic path through the application server does not need to include CN, transport and backhauling segments, avoiding the so-called “tromboning effect” due to non-useful data transfer across the network to reach a remote server).

In this case a UE app (running on a pedestrian user) periodically sends short notifications to the network, while, the latter, in its turn, sends awareness messages to a cluster of neighboring cars, to warn about the presence of VRUs in the system.

Performance comparisons with and without MEC deployments have been conducted also with increasing # VRUs in the system. The following figure shows average and standard deviation of the E2E latency, together with a breakdown of all delay components involved.

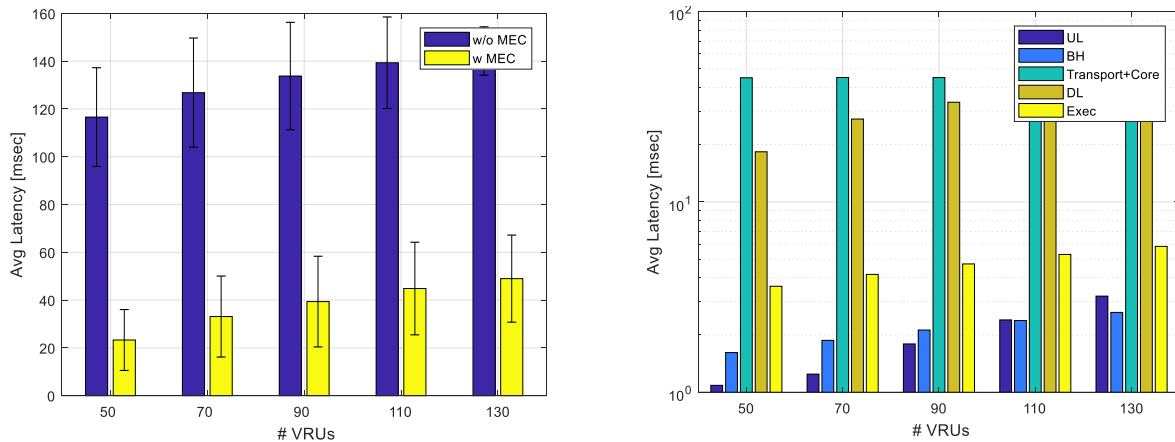


Figure 10: Average E2E latency for MEC and non-MEC cases (left), and latency breakdown (in logarithmic scale) of all delay components (right), as a function of the number of VRUs considered.

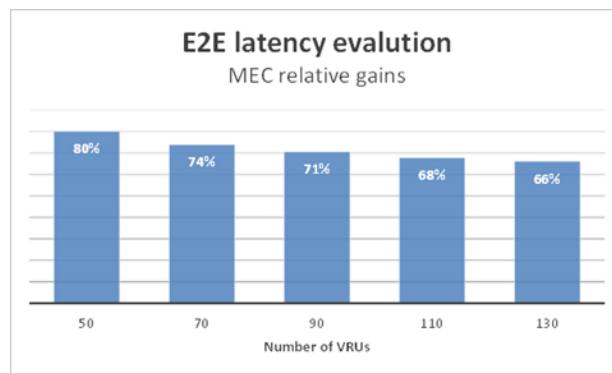


Figure 11: MEC relative gains vs number of VRUs

Results show evident MEC-related gains due to closer proximity utilization of edge servers, i.e., in the range of 66-80%. This trend is converging with the increase of VRUs to gains around 66%, as the end-to-end VRU latency in the absence of MEC hosts is mainly dominated by the transport and core latency components (Figure 10). In other words, the relative impact of radio transmission-related delay components on the end-to-end latency performance is rather low, therefore, MEC-enabled network deployments successfully relieve the system from the main delay bottleneck.

3.3 V2N2V Analytical evaluations

For the LTE-Uu based V2X communication, uplink V2X transmission is usually based on unicast whereas downlink V2X transmission can be based on unicast or MBMS (MBSFN or SCPTM). With different transmission mode (unicast, MBSFN, SCPTM) in downlink, the end-to-end latencies of Uu-based V2X communication for different cases are calculated as below. Similar to latency evaluation of PC5-based V2X communication, we only focus on the mandatory part that the components without parentheses for Uu-based V2X communication latency

evaluation. We will discuss components which are different from the evaluation in TR 36.885 in the following subsections and present the overall latency results for each case.

- Case 1: UL unicast and DL unicast (L-RRC) + L-UL + L-NW_uc + (L-paging + L-RRC) + L-DL_uc, in which L-UL represents the latency of UL transport between UE and eNB, L-NW_uc is the backhaul delay of unicast, L-DL_uc is the latency of unicast DL transport between eNB and UE and L-paging is the latency required for reception of paging message.
- Case 2: UL unicast and DL MBSFN (L-RRC) + L-UL + L-NW_mbsfn + L-DL_mbsfn, in which L-NW_mbsfn is the latency of network processing in case of MBMS transport for DL and L-DL_mbsfn is the latency of MBMS transport between eNB and UE.
- Case 3: UL unicast and DL SCPTM (L-RRC) + L-UL + L-NW_scptm + L-DL_scptm, in which L-NW_scptm is the latency of network processing in case of SC-PTM transport for DL and L-DL_scptm is the latency of SC-PTM transport between eNB and UE.

Based on latency analysis provided in the Annex B for Uu-based V2X communication, the overall latency results of each scenario are listed in Table 2 as below.

Table 2 Overall latency results for Uu-based V2X communication

Scenario	Mandatory + optional (ms) ^{Note1}			only mandatory (ms)		
	Min	Mean	Max	Min	Mean	Max
Case 1: (L-RRC ^{Note2}) + L-UL ^{Note3} + L-NW_uc ^{Note4} + (L-paging ^{Note2} + L-RRC ^{Note2}) + L-DL_uc ^{Note2}	287.8	341.8	546.8	25.3	79.3	124.3
Case 2: (L-RRC ^{Note2}) + L-UL ^{Note3} + L-NW_mbsfn ^{Note5} + L-DL_mbsfn ^{Note6}	72	130	180	22	80	130
Case 3: (L-RRC ^{Note2}) + L-UL ^{Note3} + L-NW_scptm ^{Note5} + L-DL_scptm ^{Note6}	72	126	171	22	76	121

Note 1: In each case, the component with parentheses is optional-present while component without parentheses is mandatory-present. The control plane delays (L-RRC and L-paging) only happen at the beginning of RRC connection establishment which can be seen as start-up cost. They are optional parts in the latency evaluation.

Note 2: according to TR 36.885 [3GPP TR 36.885], L-RRC is 50ms, L-paging is (min162.5ms, mean162.5ms, max322.5ms) when paging cycle is set to 320ms, latency of DL unicast transmission L-DL_uc is 7.8ms.

Note 3: L-UL_sps is on behalf of L-UL and UL SPS period is set to 100ms. Other values of these parameters can be used for calculating overall latency if needed. The numerical evaluations in chapter 3.2.1 do not use SPS and assume “dynamic uplink scheduling”. This explains the higher latency compared to the results in Section 5

Note 4: according to section B.1.3.2, 12ms is assumed for L-NW_uc,

Note 5: according to section B.1.3.3, 9ms is assumed for L-NW_mbsfn and L-NW_scptm.

Note 6: MCH scheduling period is set to 10ms. SCPTM scheduling period is set to 1ms, corresponding to the case SCPTM DRX is not configured.

4.0 Multi Operator Aspects

One aspect of V2X communication requiring particular analysis relates to which operator offers the V2X service; special considerations need to take place in case multiple operators offer it simultaneously. In principle the V2X communication will be multi operator environment since it is not possible to ensure that only one operator will offer the V2X service. Additionally, cross border communication cases require multi operator support since different operators will offer the V2X services in the two sides of the border.

According to [R2-168142] the following scenarios need to be supported for V2X:

- Usage Scenario 1: Only one operator (Operator A) has eNBs in a specific area. In this case the eNBs of Operator A are shared with the other operators in a specific area for all services including V2X. In this case Operator A's eNBs, indicate the support for other operators' PLMN ID in the transmitted SIB.
- Usage Scenario 2: Only one operator (Operator A) uses the dedicated V2X spectrum ([3GPP TS 36.101]) in a specific area. Operator A's eNBs are shared with other operators for V2X service.
- Usage Scenario 3: All operators have eNBs in a specific area and offer V2X services.

The term V2X includes V2V, V2N2V, V2N2P, V2N2I, V2N. The following subsections analyse the three usage scenarios for the V2X service and the respective implications.

4.1 Usage Scenario 1: RAN Sharing

In this case, only one operator (Operator A) serves a particular area delivering all services, including V2X, by sharing his eNBs with the other operators (Operator B) –Operator B is indicated in the respective fields in the transmitted SIB. In this particular case the V2V communication is directly controlled by Operator A, whereas the V2N2V, V2N2P, V2N2I, and V2N are handled by both operators.

It is the typical RAN sharing solution. Operator A offers the eNB infrastructure and each operator (Operator A and B) has its own core network. In this case Operator B uses the eNBs of Operator A, but its own core network is used for the edge computing applications and the corresponding multicast services. This solution for the V2N2V, V2N2P, V2N2I, and V2N requires extensions in the MBMS servers and edge computing interface among the operators.

This solution requires additionally RAN sharing agreement and implementation in the entire region where the V2X service is offered.

4.2 Usage Scenario 2: Regional Roaming

In this case only one operator (Operator A) manages the dedicated V2X spectrum in a specific area. Operators' A eNBs are shared with Operator B only for the V2X service.

In case of moving from an area where Operator A offers V2X service to an area where Operator B offers V2X service the transition requires additional delays and service interruptions. Also extensions are required for the MBMS servers and edge cloud for enabling this transition. Pre-registration of UEs to the operators that serve a particular area offers reduced delay in the transmission area.

4.3 Usage Scenario 3: Multiple PLMN offering V2X Service

In the third usage scenario multiple PLMNs cover one area and offer V2X services. The multiple operators may coordinate or not for offering V2X services. If they do not coordinate, the UEs belonging to a single operator may be served by it using V2V, V2N2V, V2N2P, V2N2I, and V2N, whereas for communicating with UEs of other operators they have to communicate using V2N2V solutions, requiring duplication (if multicast is used and two operators serve a specific area) of the messages to be transmitted for ensuring that both operators' vehicles will receive the respective messages. V2N2V, V2N2P, V2N2I, and V2N solutions for some services require extensions in the current network deployments if they are edge cloud based, or relate to multicast services. V2N2V, V2N2P, V2N2I, and V2N solutions for services without demanding requirements (e.g., slippery road warnings), current network deployments may be used with unicast and global cloud.

In order to reduce latency for V2N2V, V2N2P and V2N2I with edge cloud solutions, new peering points between different operators' networks and Internet is needed.

If the operators coordinate, the duplication of the messages may be avoided in some cases (for V2V communication); in multicast communication the messages have to be transmitted in all operators spectrum. The coordination of the operators relates to the spectrum resources to be used for delivering the V2V services and the respective configurations. The UE may acquire the V2V configurations:

- By reading the SIBs of the non-serving PLMNs,
- Via pre-configuration,
- Serving eNB signaling (i.e., SIB from serving PLMN),
- From V2X server.

Regarding the spectrum resources to be used for the V2V two options may be considered:

- Separate carriers are allocated for different PLMNs for V2V services over PC5
- The same carrier is shared among different PLMNs for V2V services over PC5

4.3.1 Exclusive carriers allocation for different PLMNs for V2X services over PC5

If dedicated carriers are allocated to PLMNs, a UE belonging to one PLMN transmits V2V data on the allocated carrier while receiving V2V data on the other carriers. Since separate carriers are allocated to different PLMNs, there is no resource collision between different PLMNs [R1-1611139].

On the other hand the UE has to listen to multiple channels requiring carrier switching with interruption and delay or multiple reception chains. Finally, some channels may be less interfered than others in case of coexistence with ITS-G5 or CEN DSRC, thus having unfair serving of the UEs.

Timing difference between eNBs of the two operators may arise; GNSS timing may be used to handle this aspect.

4.3.2 Carrier sharing among different PLMNs for V2X services over PC5

If the same spectrum resources are being used by the two operators, a single reception chain is required in the UE side [R1-166956]. For mode 4 V2V sensing based resource selection is used, requiring coordination among PLMNs only when reconfiguration of the UEs is needed. For mode 3 operation, the eNB needs to know the resource pool configuration of other operators. Furthermore, the resource which will be used by Operator A with Mode 3 should not overlap with the resource of another Operator B for both modes 3 and 4. Using TDM between different PLMNs can solve this aspect with the trade-off of higher latency for V2X services and resource waste in case of imperfect synchronization.

Timing difference between eNBs of the two operators may arise; GNSS timing may be used to handle this aspect.

Variations of this approach may apply use of static common channels shared among all PLMNs for road safety only messages with serving of other services with other channels.

5.0 Conclusions

This document summarizes the effort performed in 5GAA WG2 for Network Architecture focusing on the evaluation and the proposal of enhancements related to Cellular V2X Architecture. The analysis moved towards two directions, namely solutions that relate to PC5 interface and solutions that relate to Uu interface; the latter ones include the cloud enhancements. Based on the performed analysis we may conclude the following:

- For system architecture for V2V using mode 3, according to the analytical evaluations (No numerical evaluation was carried over for mode 3) latency requirements up to 100 ms can be met.
- For system architecture for V2V using mode 4,
 - According to the analytical evaluations latency requirements up to 100 ms can be met.

- According to the numerical evaluations, PC5 mode 4 with dynamic configuration (regarding power and resource pools allocation) covers the IMA reliability requirements (~95% delivery ratio) in both high and low traffic conditions. It is concluded that, in the IMA use case, PC5 mode 4 with dynamic configuration may perform better compared to zoneless PC5 mode 4 or statically configured PC5 mode 4 zones in high congestion conditions. In low density deployments, PDR performance is not significantly affected by the different configurations. These two observations show that the dynamic configurations of the zones, depending on the traffic conditions, can significantly improve packet delivery ratio for particular scenarios.
- For system architecture for V2N2V and V2N
 - According to both analytical and numerical evaluations, latency requirements up to 100 ms can be met with Radio Access for supporting Uu.
 - According to the numerical evaluations it can be concluded that Uu-based transport based on today's LTE mobile networks can support the predefined subset of UCs identified by 5GAA WG1 in terms of latency, reliability and capacity. Specifically, inter-vehicle/VRU ranges of 300-2000m have been achieved, with reliability consistently between 95-100% over the whole range. Even when including latency penalties to model the delays due to public internet, per-packet e2e latency below 100ms was achieved.
 - Regarding the cloud based solutions, according to numerical evaluations, Edge cloud solutions are shown to be capable of reducing e2e latency for V2N2P scenarios

Regarding the interoperability between operators conclusions relate to

- For PC5 Radio Access:
 - Coordination between Operators for V2X services using PC5 mode 4 may be needed if the operator dynamically deploys the PC5 mode 4 communication in his own licensed spectrum.
 - Coordination between Operators for V2X services using PC5 mode 4 in ITS spectrum is not needed as the use of ITS spectrum may be governed by regional regulation.
 - Coordination between Operators for V2X services using PC5 mode 3 may require agreements among the operators or separate spectrum resources for each operator.
 - PC5 communication, for mode 3, in multi operator environments may be achieved as in single operator scenarios (e.g., RAN sharing) and regional roaming schemes.
- For V2N2V and V2N, if inter-MNO interoperability is a requirement, V2N2V, V2N2P, V2N2I, and V2N use cases can be supported with Uu-based radio access using one of the following approaches:
 - Existing inter-MNO Peering point in the public internet (feasibility was not investigated, requires vetting by WG 5)
 - Adding new peering points among the MNOs
 - Using RAN sharing between MNOs
 - Using roaming agreements between MNOs

References

- [R1-1611139] 3GPP Meeting RAN1#87: R1-1611139 - Inter-PLMN operation on PC5
- [R1-166956] 3GPP Meeting RAN1#86: R1-166956 - Cross carrier and multi-operator scheduling for V2V over PC5
- [R2-168142] 3GPP Meeting RAN2#96: R2-168142: Discussion on the usage scenarios for inter-PLMN operation
- [S+ 2018] Sabella et al, 2018. "A hierarchical MEC architecture: experimenting the RAVEN use case", submitted for CLEEN2018 workshop (co-located with VTC2018-spring)
- [3GPP TR 36.885] 3GPP 2016, 3GPP TR 36.885, "Study on LTE-based V2X services", July 2016 (Release 14)
- [3GPP TS 23.214] 3GPP 2018, TS 23.214: "Architecture enhancements for control and user plane separation of EPC nodes; Stage 2"
- [3GPP TS 23.285] 3GPP 2018, TS23.285: "Architecture enhancements for V2X services"
- [3GPP TS 23.401] 3GPP 2018, 3GPP TS23.401: "General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access".
- [3GPP TS 23.501] 3GPP 2018, 3GPP TS 23.501 V0.4.0 (2017-04), "System Architecture for the 5G System; Stage 2 (Release 15)"
- [3GPP TS 23.502] 3GPP 2018, 3GPP TS 23.502 V0.3.0 (2017-03), "Procedures for the 5G System; Stage 2 (Release 15)"
- [3GPP TR 23.707] 3GPP 2014, 3GPP TR 23.707: "Architecture enhancements for dedicated core networks; Stage 2"
- [3GPP TR 23.711] 3GPP 2016, 3GPP TR 23.711: "Enhancements of Dedicated Core Networks selection mechanism; Stage 2"
- [3GPP TR 23.859] 3GPP 2013, 3GPP TR 23.859, "Local IP access (LIPA) mobility and Selected IP Traffic Offload (SIPTO) at the local network", April 2013 (Release 12)
- [3GPP TS 24.385] 3GPP 2018, 3GPP TR 24.385, "V2X services Management Object (MO)"
- [3GPP TS 36.101] 3GPP 2018, 3GPP TS 36.101 "Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception", January 2018, (Version 15.1)
- [3GPP TS 36.213] 3GPP 2018, 3GPP TS 36.213, "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures", January 2018, (Version 15)
- [3GPP TS 36.331] 3GPP 2018, 3GPP TS 36.331: "Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification".
- [5GIA 2015] 5G Infrastructure Association. (2015, Feb.). Vision white paper. [Online]. Available: <http://5g-ppp.eu/wp-content/uploads/2015/02/5GVision-Brochure-v1.pdf>
- [MEC002] ETSI GS MEC 002 V1.1.1 (2016-03) Mobile Edge Computing (MEC); Technical Requirements http://www.etsi.org/deliver/etsi_gs/MEC/001_099/002/01.01.01_60/gs_MEC002v010101p.pdf
- [MEC-IEG 004] ETSI GS MEC-IEG 004 V1.1.1 (2015-11) Mobile-Edge Computing (MEC); Service Scenarios http://www.etsi.org/deliver/etsi_gs/MEC-IEG/001_099/004/01.01.01_60/gs_MEC-IEG004v010101p.pdf

Annex A: Evaluation Assumptions for the Numerical Evaluations

A.1 Evaluations for Radio Access Supporting PC5 Communications

Table 3 Details of evaluation scenarios for the PC5

Simulation Parameters	
Speed Vehicle	50 kmph
CAM periodicity	100 ms
Message Size	190 bytes
Band	5.9 GHz
Bandwidth	10 MHz
MCS	18
No. Zones	9
Zone dimensions	100 x 100 meters
zoneldLongiMod	3
zoneldLatiMod	3

Note: MCS values may impact the PDR and the delivery delay of the messages; numerical comparison has not been included in this work.

In Urban case, a vehicle changes its direction at the intersection as follows:

- Go straight with probability 0.333
- Turn left with probability 0.333
- Turn right with probability 0.333

Table 4 Details of vehicle UE drop and mobility model

Parameter	Urban case
Number of lanes	2 in each direction (4 lanes in total in each street)
Lane width	3.5 m
Road grid size by the distance between intersections	433 m * 250 m. Note that 3 m is reserved for sidewalk per direction (i.e., no vehicle or building in this reserved space)
Simulation area size	866m*500m (interference conditions created for 1732m*1000m)

A.2 Evaluations for Radio Access Supporting Uu Communications

Two vehicle UE dropping cases are defined: Urban case and Freeway case.

Table 5 Details of evaluation scenarios for the Uu

Parameter		Assumption
Carrier frequency		- 2GHz
Bandwidth		- 10MHz for each of DL and UL in FDD;
Number of carriers		One.
Vehicle UE parameters	Antenna height	1.5 m for vehicle UE and pedestrian UE
	Antenna pattern	Omni 2D
	Antenna gain	3 dBi for vehicle UE and UE type RSU, 0 dBi for pedestrian UE
	Maximum transmit power	23 dBm
	Number of antennas	1 TX and 2 RX antennas. Baseline is that 2 RX antennas are separated by wavelength/2.
Noise figure		9 dB

In Urban case, a vehicle changes its direction at the intersection as follows:

- Go straight with probability 0.5
- Turn left with probability 0.25
- Turn right with probability 0.25

Details of vehicle UE drop and mobility model for each of Urban and Freeway cases are in Table 6.

Table 6 Details of vehicle UE drop and mobility model

Parameter	Urban case	Freeway case
Number of lanes	2 in each direction (4 lanes in total in each street)	3 in each direction (6 lanes in total in the freeway)
Lane width	3.5 m	4 m
Road grid size by the distance between intersections	433 m * 250 m. Note that 3 m is reserved for sidewalk per direction (i.e., no vehicle or building in this reserved space)	N/A
Simulation area size	Minimum [1299 m * 750 m]	Freeway length \geq 2000 m. Wrap around should be applied to the simulation area.
Vehicle density	Average inter-vehicle distance in the same lane is 2.5 sec * absolute vehicle speed. Baseline: The same density/speed in all the lanes in one simulation.	
Absolute vehicle speed	15 km/h	140 km/h

If macro eNBs are deployed for Urban case, ISD of macro eNB is 500 m is considered and wrap around model is used for proper results collections. Similarly, if macro eNBs are deployed for Freeway case, eNBs are located along the freeway 35m away with 1732m ISD, again considering wrap around model of equal size as the statistics collection area.

Finally, the e2e 2-way latency introduced by the core network and transition over public internet has been modelled as a fixed value of 70ms. Clearly this is a simplification, as the real latency is not deterministic. The justification is based on measurements performed by Ericsson, averaged for different MNOs respectively in US, China and France, taken as sample countries (similar results were obtained in many more regions).

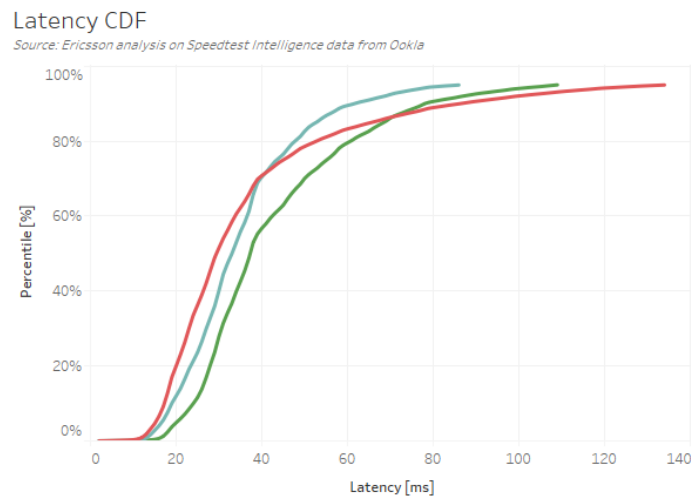


Figure 12: Live network 2-way “ping” latency measurements by Ericsson. Green = US, Red = China, Cyan = France, averaged over different MNOs.

We observe that the e2e 2-way latency, which includes radio, core, public internet and application processing, is <70ms with >90% probability. Obviously the number would be significantly lower if one could exclude the radio latency, which is explicitly modeled in the numerical evaluations. Therefore, we consider 70ms for core+ internet latency as a conservative assumption for numerical evaluation.

A.3 Simulation assumptions and scenario description

It is assumed that, focusing on a given VRU, a cluster composed of the k-th closest vehicles to this VRU is considered, as targeted receivers of the constructed VRUS messages. As a result, for every VRU in the system, a cluster of k vehicles is associated to it and transmission of this VRU’s messages is focused only on this associated cluster.

The simulated environment extracts relevant parameters taken from freeway scenarios (3GPP and NGMN evaluations), with the following simulation assumptions:

- Vehicle locations follow a Matern-hardcore Poisson point process over one dimension (for simplicity, vehicles are assumed to have a fixed y-coordinate dependent on the system’s number of lanes);
- A single lane per direction is considered (this scenario is extendable);
- Single-cell simulations are obtained, assuming absence of ICI, handover, etc.;
- Every 100 msec, all the VRUs send one message each (with random offsets within each 100ms time window);
- The locations of the vehicles is calculated online during at each of these messaging instances;
- 1000 network ‘snapshots’ of 100 ms each are simulated (Monte-Carlo runs, i.e., convergence area, are realized).

- The application messages to be transmitted via the wireless channel are modeled as randomly distributed between 8 and 12 kbits. For the sake of clarity, backhauling is considered transparent (compression-less, loss-less).
- Additional round trip time due to transport + core latency (in the case of non-MEC network deployments), is modeled as randomly distributed between the values of 30 ms and 150 ms (by considering real-world measurements in live networks [S+ 2018]). As a consequence, one-way delay is randomly distributed between 15 ms and 75 ms.

In cloud assisted V2N2P the links are managed by the cloud services. In fact, many 5GAA use cases can benefit from the usage of the cloud, as an application server may be involved to receive and distribute information to host vehicles. Other use cases relevant to cloud assisted V2N2V, V2N2P, V2N2I, V2N communications have been analyzed in other research groups and include Emergency Vehicle Priority, Traffic Light optimal speed advisory, Traffic Sign in car, Traffic Jam Warning, Software updates, etc.

Annex B: Evaluation Assumptions for the Analytical Evaluations

B.1.1 Assumptions

- The latency evaluation in this document is based on 3GPP R14 V2X traffic model defined in TR 36.885 ([3GPP TR 36.885]) and the data is assumed to be fully transmitted in one time.
- Retransmission is not considered.
- Single operator/single OEM is assumed.

B.1.2 PC5

B.1.2.1 Mode 4

Different from R12/R13 D2D resource design, the SCI and data are transmitted in the same subframe in 3GPP R14 V2X to reduce latency. Considering most V2X traffic are periodic CAM/BSM messages, UE using mode 4 resource selection can reserve a set of resources for V2X sidelink transmission as specified in TS 36.213 ([3GPP TS 36.213]). As depicted in Figure 13, m is the arrival time of the corresponding TB, $[m - a, m - b]$ is the sensing window, $[m + T1, m + T2]$ is the resource selection window, where $T1 \leq 4\text{ms}$ and $20\text{ms} \leq T2 \leq 100\text{ms}$. $T1$ is the processing time and $T2$ shall fulfill the latency requirement. If d in resource selection window is selected as the first transmission opportunity, a set of resources ($d + P * i$, P is the reservation period which is equal to the packet transmission period, $i = 1, 2, \dots$) are reserved for the periodic transmissions.

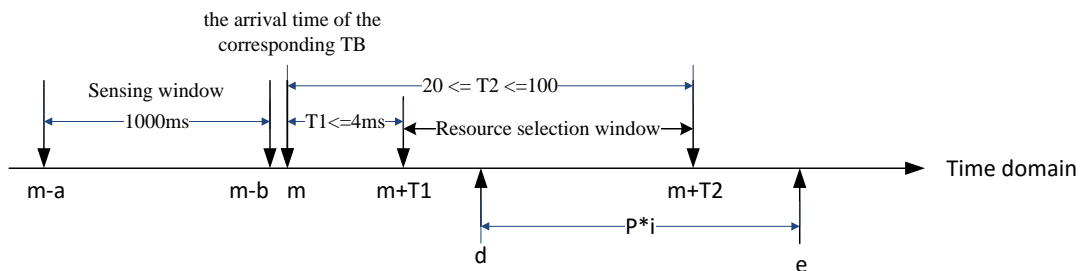


Figure 13: Timing of sensing and resource selection of mode 4

As we can see, the best case for minimum latency is when the selected resource located in the lower bound of the resource selection window and the minimum latency is $T1$. The worst case for maximum latency is when the selected resource located in the upper bound of the resource selection window and the maximum latency is $T2$. The Mean latency is $(T2 - T1)/2$. Therefore, latency of L-SL_mode4 is relevant to the lower/upper bound of the resource selection window. The overall latency of mode 4 L-SL is presented in Table 7.

Table 7 Overall latency of L-SL_mode 4

Sub-component	Time (ms)			Description
	Min	Mean	Max	
SCI + SL data transmission	T1	$(T2 - T1)/2$	T2	Min: resource of lower bound of resource selection window is selected, $T1 \leq 4$, according to TS 36.213. The best case is set T1 value to 1ms. Max: resource of upper bound of resource selection window is selected, $20 \leq T2 \leq 100$, according to TS 36.213. The worst case is set T2 to 100ms.
L1/L2 Tx UE processing	1.5	1.5	1.5	1.5ms for Tx UE L1/L2 processing is assumed.
L1/L2 RX UE processing	1.5	1.5	1.5	1.5ms for UE L1/L2 processing is assumed.
Upper layer RX UE processing	3	3	3	3ms for upper layer processing is assumed in TR 36.885.
Total	$T1 + 6$	$(T2 - T1)/2 + 6$	$T2 + 6$	

B.1.2.2 Mode 3

- PC5 Mode 3 with dynamic scheduling

UE in RRC_CONNECTED could request assignment of dedicated sidelink resources based on its sidelink BSR. The overall latency of L-SL_mode3_dynamic_bsr (latency of sidelink transport between two UEs with mode 3 based on dynamic scheduling) is presented in Table 8.

Table 8 Overall latency of L-SL_mode3_dynamic_bsr

Sub-component	Time (ms)			Description
	Min	Mean	Max	
SL scheduling	Mean	16 + SR period/2	16 + SR period	Referenced from step1-5 of Table A.1 in TR 36.881 with additional steps for BSR, as included in L-UL_dynamic_bsr: 1. Average delay to next SR opportunity SR periodicity/2 2. UE sends SR 1 TTI 3. eNB decodes SR and generates scheduling grant 3 TTI 4. Transmission of scheduling grant (assumed always error free) 1 TTI 5. UE processing delay (decoding scheduling grant + L1 encoding of data) 3 TTI 5.1. UE sends BSR 1TTI 5.2. eNB decodes SR and generates scheduling grant 3TTI 5.3. Transmission of scheduling grant (assumed always error free) 1TTI 5.4. UE processing delay (decoding scheduling grant + L1 encoding of data) 3 TTI
SCI + SL data transmission	1	1	1	SCI and SL data transmission at the same subframe 1 TTI
L1/L2 RX UE processing	1.5	1.5	1.5	1.5ms for UE L1/L2 processing is assumed.
Upper layer RX UE processing	3	3	3	3ms for upper layer processing is assumed in TR 36.885.
Total	$SR\ period/2 + 21.5$	$SR\ period/2 + 21.5$	$SR\ period + 21.5$	In TR 36.885, SR period of 1ms and 10ms are used for calculation.

- PC5 Mode 3 with SPS scheduling

Sidelink SPS is supported in 3GPP R14 V2X and maximum of 8 SPS configurations can be configured by eNB. In order to reduce transmission latency and assign SPS resources effectively, UE assistance information which includes V2X traffic characteristic parameters (e.g., expected SPS interval, timing offset, message size, etc.) can be reported to eNB. For the best case, SPS configuration is aligned with packet arrival time and transmission period. In this case the latency is 1ms for SCI and SL data transmission. For the worst case, UE misses the last transmission opportunity and needs to wait for one SPS period for the next transmission opportunity. On average, SPS latency can be reduced by using UE assistance information reporting mechanism compared to the case without UE assistance information reporting. The overall latency of L-SL_mode3_sps (latency of sidelink transport between two UEs with mode 3 based on SPS scheduling) is presented in Table 9.

Table 9 Overall latency of L-SL_mode3_sps

Sub-component	Time (ms)			Description
	Min	Mean	Max	
SCI + SL data transmission	1	SL SPS period/2	SL SPS period	<p>SL SPS period may be 20ms, 50ms, 100ms, 200ms, 300ms...1000ms which are specified in TS 36.331.</p> <p>Min: transmission of SCI and data 1 TTI. Configured SPS resources can be aligned with packet arrival time and packet transmission period by using UE assistance information report mechanism.</p> <p>Max: SL SPS period, that UE misses the last transmission opportunity and needs to wait for one SPS period for the next transmission opportunity.</p> <p>Generally, by using UE assistance information report mechanism, in most cases the configured SPS resources can be aligned with packet transmission period and packet arrival time or only a minor offset to the actual packet arrival time.</p>
L1/L2 Tx UE processing	1.5	1.5	1.5	1.5ms for Tx UE L1/L2 processing is assumed.
L1/L2 RX UE processing	1.5	1.5	1.5	1.5ms for UE L1/L2 processing is assumed.
Upper layer RX UE processing	3	3	3	3ms for upper layer processing is assumed in TR 36.885.
Total	7	SL SPS period/2+6	SL SPS period + 6	

B.1.3 Latency analysis of Uu-based V2X communication

For the LTE-Uu based V2X communication, uplink V2X transmission is usually based on unicast whereas downlink V2X transmission can be based on unicast or MBMS (MBSFN or SCPTM). With different transmission mode (unicast, MBSFN, SCPTM) in downlink, the end-to-end latencies of Uu-based V2X communication for different cases are calculated as below. Similar to latency evaluation of PC5-based V2X communication, we only focus on the mandatory part that the components without parentheses for Uu-based V2X communication latency evaluation. We will discuss components which are different from the evaluation in TR 36.885 in the following subsections and present the overall latency results for each case.

- **Case 1: UL unicast and DL unicast** (L-RRC) + L-UL + L-NW_uc + (L-paging + L-RRC) + L-DL_uc, in which L-UL represents the latency of UL transport between UE and eNB, L-NW_uc is the backhaul delay of unicast, L-DL_uc is the latency of unicast DL transport between eNB and UE and L-paging is the latency required for reception of paging message.

- **Case 2: UL unicast and DL MBSFN** (L-RRC) + L-UL + L-NW_mbsfn + L-DL_mbsfn, in which L-NW_mbsfn is the latency of network processing in case of MBMS transport for DL and L-DL_mbsfn is the latency of MBMS transport between eNB and UE.
- **Case 3: UL unicast and DL SCPTM** (L-RRC) + L-UL + L-NW_scptm + L-DL_scptm, in which L-NW_scptm is the latency of network processing in case of SC-PTM transport for DL and L-DL_scptm is the latency of SC-PTM transport between eNB and UE.

B.1.3.1 UL SPS

Three options of L-UL are provided in TR 36.885 [3GPP TR 36.885], i.e., SPS, dynamic scheduling with a separate BSR and dynamic without a separate BSR. The latter two options are same as LTE, and the UL SPS is enhanced in 3GPP R14 V2X. Since most V2X traffic are periodic messages, we will use L-UL_sps representing L-UL for the overall latency evaluation.

Similar to SL SPS, maximum of 8 UL SPS configurations with different parameters can be configured by eNB for UL transmissions and UE assistance information related to UL SPS configuration can be reported to eNB. Latency of L-UL_sps (latency of UL transport between UE and eNB with UL SPS) is presented in Table 10.

Table 10 Latency of L-UL_sps

Sub-component	Time (ms)			Description
	Min	Mean	Max	
UL transmission	1	UL SPS period/2	UL SPS period	Max: UL SPS interval. UE misses the last transmission opportunity and needs to wait for one SPS period for the next transmission opportunity. UL SPS period of 50ms, 100ms, 200ms, ...1000ms are specified in TS 36.331 for V2X transmission. Min: UL transmission 1 TTI. Configured SPS resources can be aligned with packet arrival time and packet transmission period by using UE assistance information reporting mechanism.
L1/L2 UE processing	1.5	1.5	1.5	1.5ms for UE L1/L2 processing is assumed as in TR36.885.
eNB processing	3	3	3	3ms for eNB processing is assumed as in TR36.885.
Total	5.5	UL SPS period/2 + 4.5	UL SPS period + 4.5	

Considering transmission period of V2X messages are multiple of 100ms generally, UL SPS period of 100ms, 200ms, ...1000ms and 50ms which is half of the minimum transmission periodicity of V2X messages are specified in R14 V2X to be more easily aligned with V2X transmission period to reduce latency. With UE assistance information reporting mechanism, the minimum latency of L-UL_sps can be achieved in most cases.

B.1.3.2 DL unicast

For case 1, V2V messages transmitted over DL unicast, the data delivery path is shown in Figure 14, in which S-GW/P-GW and V2X server are located in core network. L-NW_uc is the backhaul delay of unicast that the latency of V2V message travelling from eNB, then passing through S-GW/P-GW, ITS server, and back to the eNB for unicast DL transmission. 20ms is assumed for L-NW_uc in TR 36.885 [3GPP TR 36.885].

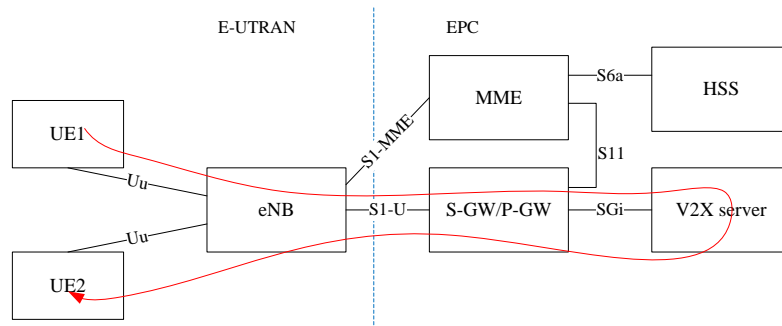


Figure 14. Delivery path of legacy Uu-based V2V messages

In case Local Gateway is used, the backhaul delay can be reduced. Multiple options for the location of L-GW and local V2X server can be considered. Considering the mobility of vehicle UEs, V2X server connected through SIPTO@LN with stand-alone GW seems to be more appropriate since it can maintain data connection through handover. In this case, the delivery path of V2V message is shown in Figure 15. Since stand alone GW and V2X server are closed to eNB, processing/backhaul delay for each interface may decrease. Assuming 3ms processing time for each interface is considered, the backhaul delay for unicast (L-NW_uc: eNB -> L-GW -> local V2X server -> L-GW -> eNB) is reduced to 12ms.

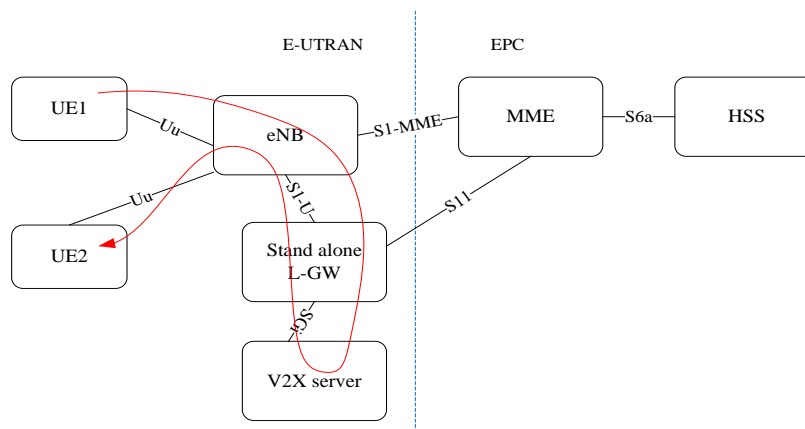


Figure 15. delivery path of Uu-based V2V messages with stand alone localized GW

B.1.3.3 DL broadcast (MBSFN and SCPTM)

MBSFN

For case 2, V2V messages are transmitted via MBSFN in downlink. In legacy LTE, the BM-SC, MBMS-GW and MME are located in the Core Network. The backhaul delay between the BM-SC and the eNB is non-negligible when calculating the end-to-end delay, when MBMS is used to delivery downlink V2X packets in the V2X system. In order to minimize V2X latency, local MBMS is considered in 3GPP R14 V2X and different deployment of BMSC and MBMS-GW are provided. Here we select the case the V2X Server, BM-SC, and MBMS GW are all co-located, but not in the eNB to analyze the end-to-end latency since this case has advantage in forwarding V2X traffic toward several eNBs. As shown in Figure 16, in uplink L-GW is used and in downlink local MBMS is used. Assuming 3ms processing time for each interface is considered, the backhaul delay for MBMS (i.e., L-NW_mbsfn: eNB -> L-GW -> local MBMS -> eNB) is 9ms.

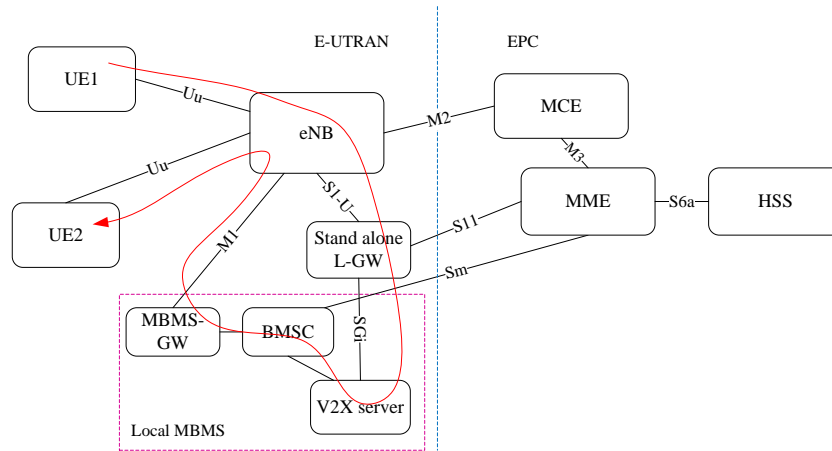


Figure 16. Localized MBMS and V2X server, not co-located with the eNB

In order to reduce MBSFN latency (when eNB has V2X messages to transmit to when UE successfully receives the V2V message over MBMS, i.e., L-DL_mbsfn), shorter MCCCH repetition period, modification period and MCH scheduling period for MBSFN are supported. The shorter MCH scheduling period of 10ms and 20ms are added as specified in TS 36.331 ([3GPP TS 36.331]). The latency of L-DL_mbsfn is presented in Table 11.

Table 11 Latency of L-DL_mbsfn

Sub-component	Time (ms)			Description
	Min	Mean	Max	
Wait for MTCH opportunity	2	MSP/2+1	MSP+1	Depending on packet arrival time at eNB and MCH Scheduling Period (MSP). Details refer to G.2.2.10 in TR 36.885. The shorter MCH scheduling period of 10ms and 20ms are added as specified in TS 36.331.
DL transmission	2.5	2.5	2.5	Assumed 1ms TTI and 1.5ms UE L1/L2 processing time
RX UE processing	3	3	3	3ms for upper layer processing is assumed in TR 36.885.
Total	7.5	MSP/2+6.5	MSP+6.5	

- SCPTM

For case 3, V2V messages are transmitted via SCPTM in downlink. When L-GW and local MBMS is used, the backhaul delay for SCPTM (i.e., L-NW_scptm) is the same as L-NW_mbsfn. For DL transmission via SCPTM, the latency of L-DL_scptm is the same as Table G.2.2.11 in TR 36.885 [3GPP TR 36.885].

Table 12 Latency of L-DL_sptm

Sub-component	Time (ms)			Description
	Min	Mean	Max	
Wait for SCPTM opportunity	2	$\max(\text{SSP}/2 + 1, 2)$	SSP+1	Depending on packet arrival time at eNB and SCPTM Scheduling Period (SSP). Details refer to G.2.2.11 in TR 36.885.
DL transmission	2.5	2.5	2.5	1ms TTI and 1.5ms UE L1/L2 processing time are assumed.
RX UE processing	3	3	3	3ms for upper layer processing is assumed in TR 36.885.
Total	7.5	$\max(\text{SSP}/2 + 1, 2) + 5.5$	SSP+6.5	

5GAA is a multi-industry association to develop, test and promote communications solutions, initiate their standardization and accelerate their commercial availability and global market penetration to address societal need. For more information such as a complete mission statement and a list of members please see <http://5gaa.org/>