5G-V2X Direct Communication Evaluation Approach: An Automotive Analysis

5GAA Automotive Association
White Paper

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Contents

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Abbreviations

5G	5th Generation	Technology Term
5G-V2X	5th Generation Vehicle-to-everything	Technology Term
BSM	Basic Safety Message	Higher Layers
BW	Bandwidth	Comm Layers
BWP	Bandwidth Part	Comm Layers
CAM	Cooperative Awareness Message	Higher Layers
CPM	Collective Perception Message	Higher Layers
CP-OFDM	Cyclic Prefix Orthogonal Frequency Division Multiplexing	Comm Layers
CSI	Channel State Information	Comm Layers
DENM	Decentral Environmental Message	Higher Layers
ETSI	European Telecommunication Standards	SDO
FR1/FR2	Frequency Range 1 & 2	Comm Layers
HARQ	Hybrid Automatic Repeat Request	Comm Layers
ITS	Intelligent Transport Systems	Technology Term
kHz	Kilohertz	Physical Term
KPI	Key Performance Indicator	Technology Term
L1	Layer 1	Comm Layers
L2	Layer 2	Comm Layers
LTE	Long-Term Evolution	Comm Layers
MAC	Medium Access (Layer)	Comm Layers
MCM	Manoeuvre Coordination Message	Higher Layers
MCS	Modulation Coding Scheme	Comm Layers
MHz	Megahertz	Physical Term
Ms	Millisecond	Physical Term
NACK	Negative Acknowledgement	Comm Layers
NR	New Radio	Comm Layers
OEM	Original Equipment Manufacturer	General Term
PC5	The Sidelink Interface in 3GPP System Architecture	Comm Layers
PDB	Packet Delay Budget	Comm Layers
PHY	Physical (Layer)	Comm Layers
PSCCH	Physical Sidelink Control Channel	Comm Layers
PSSCH	Physical Sidelink Shared Channel	Comm Layers
PSFCH	Physical Sidelink Feedback Channel	Comm Layers
PQI	PC5 Quality Indicator	Comm Layers
PRR	Packet Reception Rate	Comm Layers
QoS	Quality of Service	Comm Layers
RSRP	Reference Signal Received Power	Comm Layers
RSSI	Received Signal Strength Indicator	Comm Layers

SAE	Society of Automotive Engineers	SDO
SCI	Sidelink Control Information	Comm Layers
SDAP	Service Data Adaption Protocol	Comm Layers
SL	Sidelink	Comm Layers
SLR	Service Level Requirements	5GAA Term
V2X	Vehicle-to-Everything	Technology Term

1 Motivation for NR V2X Evaluation

Fifth-generation Vehicle-to-Everything (5G-V2X) technology, including the new direct communications radio technology (also called NR V2X), is moving toward deployment – starting in Europe with consensus among automotive OEMs, suppliers, and vendors [1]. To prepare for a massive deployment, an evaluation of NR V2X technology is needed. Such an evaluation needs to be realistic enough to cope with automotive requirements, use cases, and system limitations (considering, at least, the first environment for implementation). This White Paper is considering realistic evaluation assumptions based on a common understanding between both the automotive industry and 5G-V2X technology vendors.

2 Automotive-centric NR V2X Evaluation Methodology

Broadly, NR V2X technology provides more benefits for advanced use cases and Day-2 requirements compared to former generations of wireless communication; more capable of handling advanced and second-wave message types, e.g., release 2 messages specified in ETSI ITS (for EU deployment) [10, 11] and advanced messages specified in SAE (for US deployment) [12]. Enhancements to NR V2X mean greater flexibility and improvements related to the fulfilment of the use case requirements in the foreseen scenarios. However, this requires a high level of understanding of the performance of NR V2X and how it can cope with the use cases, services and scenario requirements. Further, the NR V2X evaluation should be harmonised to the profiling effort in the different regions, where the results of this study should help to identify service level requirements (SLR) according to the 5GAA Roadmap [9].

Beside the selection of the relevant NR V2X parameters, other decisive aspects such as channelisation and ITS bandwidth/fragmentation are also discussed in this analysis. It is envisaged that NR V2X technology will be allocated either a dedicated band or, in some regions, it may coexist with LTE V2X for some time. In this paper, we are only evaluating NR V2X on its dedicated band (foreseeably 10, 20 or 40 MHz) and according to regional regulations. A good case study for baseline evaluation is the discussion in Europe and the suggestion of wider band operation, i.e., bands bigger than 10 MHz [13]. Herewith, this evaluation considers 20 MHz as a first bandwidth to be evaluated. Additionally, 40 MHz bandwidth, which has been recommended by 5GAA in the spectrum needs study [7], is considered as an option for evaluating and demonstrating the advantages of wideband operation of NR V2X. It is worth mentioning that currently different regions have either 10 MHz or 20 MHz channelisation, at least, in ITS dedicated carriers [13].

In the following sections, two fundamental aspects for this work are introduced: an automotive-perspective-based approach to mapping ITS services to radio layer parameters and an evaluation methodology used to understand the NR V2X performance in selected relevant close-to-reality scenarios. These aspects improve the development of important simulation parameters and data traffic characteristics for the selected use cases, which are presented in Section 4.1.

2.1 NR V2X Evaluation Approach for Automotive Requirements

NR V2X evaluation should answer fundamental questions related to the required performance supporting automotive applications with NR V2X in real deployment scenarios. The target of this evaluation is to consider the following relevant criteria to conduct the analysis:

- Selection of relevant/reference evaluation “close-to-reality” scenarios

- Clarification of the relation between the ITS services and NR V2X technical aspects
- Definition of relevant requirements and evaluation metrics
- Analysis and evaluation of NR V2X performance related to the pre-defined requirements and metrics
- Selection of appropriate parameters to define the system profile for NR V2X deployment and related standardisation work

To achieve an evaluation that targets close-to-reality scenarios, the automotive ITS services have to be considered including:

- Use cases associated with these services
- Possible corresponding message types
- Possible implementation scenarios, e.g., the different user stories

In real automotive scenarios, multiple services can be multiplexed in a radio channel as per need. Hence, building the analysis limited to a single use case might not accurately reflect the performance of the NR V2X.

Examples of ITS services from an automotive perspective include, among others:

- Safety related services
- Road traffic steering services
- Convenience oriented services

Knowing the services, use cases and scenarios, the next step is the clarification and understanding of the interaction between the service and communication system aspects of NR V2X. Motivation behind this understanding is to ensure useful parameter sets can be defined, reflecting realistic system behaviour. Figure 2-1 offers a simplified overview of the relationship between the main aspects of the higher layer down to the PHY layer of the radio technology. The realisation of automotive ITS services and their associated applications, the ITS use cases, and their associated user stories, all impact the underlying ITS technologies based on strict profiles. These profiles consider the associated ITS SLRs impacting the underlying ITS radio technologies and inducing appropriate configurations/parameters for the radio access layers. As such, all the required message types and their parameters need to be configured according to the respective SLR of a certain ITS service/use case (e.g., message generation rate, message size, and the required service latency/reliability). Similarly, the considered V2X access technology will be impacted by the respective SLR of the said ITS services, e.g., affecting the NR V2X access layer parameters. Considering a certain ITS service/use case with a given SLR, the following should be considered:

- The impact the associated message types have based on the given SLR, e.g., messages are generated periodically with 50 ms (periodicity) and 99% reliability, etc.
- Allow the configuring of the NR access layer to the given SLR, e.g., considered periodic resource reservation, packet delay budget of 50 ms, and a PC5 QoS indicator (PQI) associated with the given service reliability/latency requirements

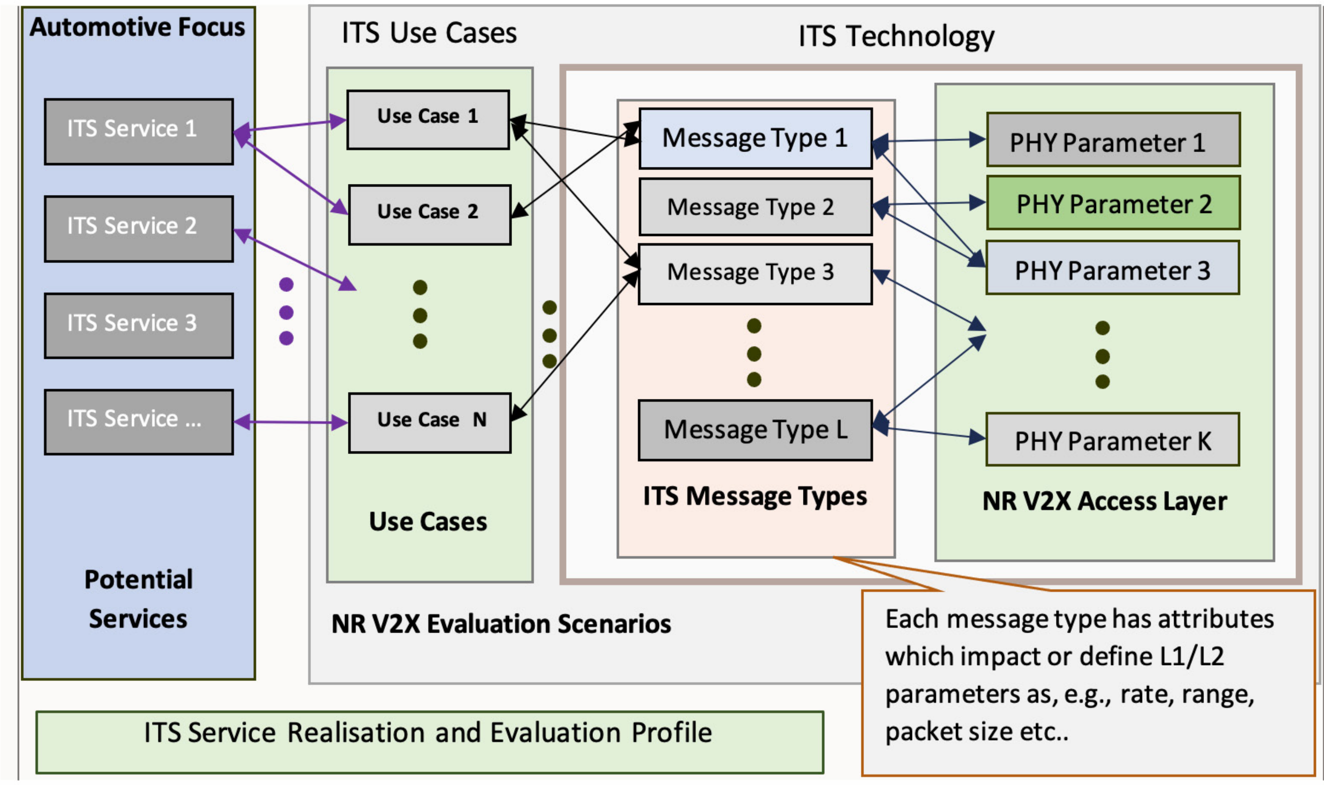

Figure 2-1: An overview of the analysis showing the interconnections from the automotive viewpoint down to the technology-specific parameters (note that the message type can be used in multiple use cases, and vice versa)

2.2 Evaluation Approach for NR V2X

This section presents a stepwise approach for NR V2X evaluation to consider the impact of the automotive services and associated use cases. The approach is divided into three main phases:

- First, initial analysis phase to set the goals of the evaluation framework including
  - evaluation environments,
  - the set of the prioritized ITS services, and
  - the associated use cases, etc.
- Second, middle evaluation analysis to evaluate the selected services (one-by-one) with one use case at a time.
- Third, a close-to-real evaluation with several use cases associated with multiplex scenarios; each one defined by a realistic story indicating the motivation, necessity and feasibility of the multiplexed services and their associated use cases.

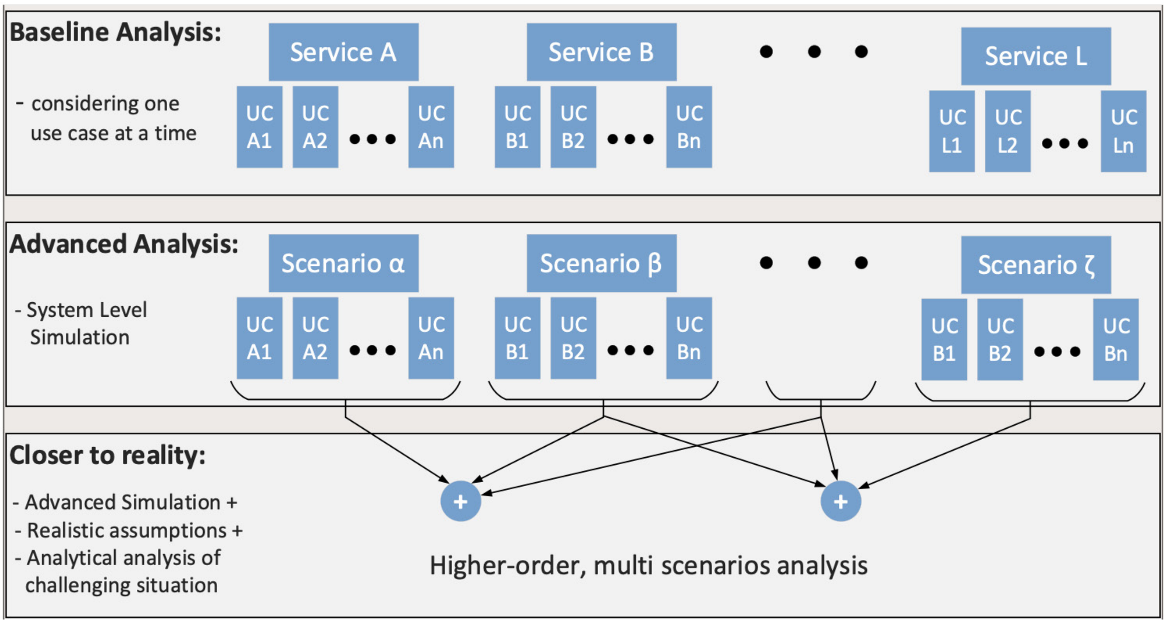

Figure 2-2: Service multiplexing and "close-to-real" evaluation scenario

As shown above, the evaluation sets or scenarios can be further defined according to:

- **Baseline Scenario:** perform an initial analysis by focusing on one use case at a time
- **Advanced Analysis:** perform evaluation for multiplexed advanced use cases considering a quasi-realistic data traffic model including a certain amount of baseline message traffic (e.g., CAM/BSM)
- **Closer to Reality:** perform advanced system-level simulations that emulate the micro-mobility conditions of advanced use cases, while considering realistic data-traffic assumptions and considerations.

Finally, additional analytical analysis needs to be performed to complement the system-level simulations in complex situations.

Note: Specific requirements, assumptions and possible multiplexing options are defined in Section 4.5.

3 NR V2X Specified Features in Release 16

3GPP started the specification of the NR Sidelink for V2X from Rel-16 onwards. Introducing the sidelink for NR involved changes to the physical and higher layers, which include new features compared to the previous 3GPP C-V2X LTE technology. The NR Sidelink is therefore optimised to enable advanced V2X use cases. NR V2X considers new broadcast transmission schemes including unicast and groupcast., Further features were added to NR V2X including, for example, a flexible number of blind re-transmissions, HARQ feedback re-transmission, flexible resource allocation for periodic and aperiodic traffic, communication range, extended Quality-of-Service (QoS) framework, etc. [14-19].

The following table lists the features supported in the NR Sidelink as specified in Rel-16.

Table 3-1: NR Sidelink Rel-16 supported features

Supported Feature	NR V2X Rel-16
Cast Types	Unicast and groupcast (in addition to legacy broadcast)
Feedback Channel	Physical Sidelink Feedback channel (PSFCH): for HARQ ACK/NACK feedback (considering unicast and groupcast) See SL HARQ Section 6.1.2. Channel State Information (CSI): for unicast link adaptation
Power Control	For unicast only: considering an open loop power control (OLPC)
Optimised Traffic types	Periodic and aperiodic
Numerology, Sub-carrier Spacing (SCS)	FR1 (< 7 GHz) 15, 30, 60 kHz FR2 (> 7 GHz) 60, 120 kHz
Waveform	CP-OFDM (similar to downlink and uplink waveform of 5G)
PHY Channel Structure	NR slot-based, flexible slot structure (with PSCCH duration, sidelink symbols, demodulation reference symbols)
SCI Design	2-stage SCI; 1st stage with initial control about shared channel
Autonomous Resource Selection	NR V2X Mode 2 (UE controlled resource allocation)
BS-Scheduled Resource Allocation	NR V2X Mode 1 (network-controlled resource allocation)
Channel Operation (ITS)	single carrier, variable bandwidth part (BWP)
3GPP-Supported Channel BW (ITS)	10, 20, 30, 40 MHz (Note: Current ITS band foresees only 10 MHz and, possibly, 20 MHz carriers)
Shared Channel (PSSCH) Modulation	QPSK, 16/64/256-QAM
Layer Mapping (no. of layers)	1 or 2 layers

3.1 NR V2X Release 16 Lower Layer Enhancements Highlights

NR V2X enhancements have considered multiple advanced features; however, the most important features in the automotive context are the following:

- Flexible numerologies with multiple subcarrier spacing
- Two-stage sidelink control channel design
- Introduction of groupcast and unicast types with the associated HARQ-based feedback

Each of these important features and enhancements are elaborated in the following sections.

3.1.1 Flexible Numerologies

NR V2X adopted the 5G new radio enhancements including multiple frequency ranges, i.e., FR1 < 7 GHz and FR2 > 7 GHz. The first frequency range, FR1, allows multiple parametrization options for NR V2X subcarrier spacing, i.e., 15 kHz and additionally, 30 kHz and 60 kHz. While 30 kHz is recommended, e.g., in ETSI access layer profile, both 30 kHz and 60 kHz boost the performance and handling of the Doppler effect – changing wave frequency while in motion. Both 30 kHz and 60 kHz enable shorter transmission slots but at the expense of bandwidth. The 30 kHz SCS is recommended as a trade-off between slot duration (0.5 ms in this case) and bandwidth requirements. However, for optimal performance, 30 kHz SCS may require an operational bandwidth starting from 20 MHz. In 3GPP NR V2X evaluation, 20 and 40 MHz were considered [15], while in this evaluation, only 20 MHz bandwidth is considered for 30 kHz SCS.

For the second frequency range, FR2, both 60 kHz and 120 kHz are considered. Even though some regions allow for automotive bands in FR2, using these bands is not feasible in the near future. Additionally, the 3GPP NR specifications, at least Rel-16, 17 and 18, are not considered a fully capable FR2 design. Therefore, FR2 is not in the scope of this document.

3.1.2 Two-Stage SCI Channel Design

In Rel-16, the NR V2X introduced a two-stage control channel design, i.e., time and frequency division multiplexing. A first-stage SCI, also considered as a physical sidelink control channel (PSCCH) is introduced in the first two or three symbols. This allows all users to decode it without being involved in receiving all information in the transmission. The first-stage SCI includes important information such as the location of the second stage, data-resource frequency allocation, re-transmission slots, reservation periods, the priority of the associated data PSSCH, and the modulation coding scheme (MCS) of the data PSSCH.

While the second-stage SCI is carried alongside the data (PSSCH), it is mainly intended for the receivers involved in decoding the whole transmission. The second stage thus has different formats for different cast types and HARQ feedback requirements. It also carries further information for the target receivers including truncated source and destination Layer-2 IDs, HARQ process ID HARQ feedback enabled/disabled indicator, etc.

3.1.3 New Transmission Types and HARQ Feedback

3.1.3.1 Introduction of Unicast and Groupcast

NR V2X introduced two transmission/cast types in addition to legacy sidelink broadcast, namely unicast and groupcast. Unicast allows point-to-point communication with connection-oriented, total unicast link establishment. Also, the introduced sidelink groupcast features two different approaches:

- Connection-oriented groupcast with a specific group list (where there is definite group ID information and member ID of such group, i.e., UE can explicitly know the members of each group, as in platooning use cases).
- Connectionless groupcast, where the UE can dynamically establish the group based on the distance or Reference Signal Received Power (RSRP); intended receivers in this group lie within a newly defined communication range.

The connectionless groupcast uses the communication range as a metric to control the formation of the group and, more specifically, the link quality – where the communication range is defined as a part of QoS requirements [19]. To control the link quality of connection-less groupcast, the communication range is used as one of the HARQ criteria described later. Both supported groupcast types can be selected based on the use case. This selection can be easily done in the higher layers.

3.1.3.2 HARQ-based Feedback in NR V2X

For HARQ feedback enhancements, NR Sidelink has different mechanisms based on transmission/cast types, i.e., unicast and both groupcast mechanisms. These enhancements are as follows:

- **HARQ feedback for unicast:** ACK/NACK-based HARQ feedback is supported in unicast communication, where the receiver UE can transmit ACK- or NACK based on the data decoding result, either correct or not, respectively.
- **HARQ feedback for groupcast:** For the two types of the supported groupcast communication, two different HARQ-based feedback schemes are introduced. For connection-based groupcast, the UE can use different Physical Sidelink Feedback Channel (PSFCH) resources to transmit ACK/NACK information, which is similar to unicast. However, for the connectionless-based groupcast, all the RX-UEs responding to one PSSCH transmission share the same PSFCH resource and only feedback a NACK once failing to decode.

For this activity, the adopted cast types and corresponding HARQ feedback mechanisms have been selected to be common among all the considered use cases. Furthermore, the flexible utilisation of the NR waveform is supported considering multiple numerologies/SCS including a flexible slot structure.

3.2 NR V2X Enhanced User Plane: 5G QoS Handling

In NR V2X Rel-16, a new QoS mechanism has been introduced to ensure proper QoS handling for sidelink communications. QoS handling describes procedures and measures in order to ensure a certain service level for a specific data flow associated with that service (e.g., minimum guaranteed bit-rate, maximum packet delay etc.). The principal concept of NR Sidelink QoS handling is inherited from 5G Uu. Similar to 5G Uu, NR Sidelink uses a per-flow based QoS model. Compared to LTE V2X, in NR Sidelink a new layer, the so-called Service Data Adaption Protocol (SDAP) layer has been introduced on top of the user plane protocol stack. The SDAP layer guarantees the mapping between the QoS flow of an NR Sidelink user plane and an associated Sidelink Data Radio Bearer (SL-DRB) [19]. Each sidelink QoS flow has a specific PC5 QoS Identifier (PQI) similar to 5G QoS Indicator (5QI) for Uu. Note that several QoS flows (identified by a PFI-PC5 flow identifier) can be mapped to the same logical link or SL-DRB, as shown in Fig. 3-1. Additionally, each pair of sidelink UEs may also consider multiple logical links/SL-DRBs associated with different services, each with different PFI.

For NR Sidelink, 3GPP has standardised a set of pre-defined PQIs defined in [19, section 5.4]. In contrast to the 5QIs for Uu, PGIs in NR Sidelink can be associated with an additional parameter of the communication range, the distance between two devices communicating over PC5. For UEs beyond a configured range, the QoS parameters are not applicable.

Ten pre-defined V2X PQIs have been considered in the 3GPP specification as exemplary values for possible (pre-)configuration and/or system profiles. Using this as a starting point, the following steps have been considered:

- Mapping of the services (associated with the use cases) to the standardised PQIs in [19], while no new PQIs are currently foreseen
- Configuration of the PC5 radio parameters such that a given QoS rule (defined by PQI and the QoS flow) should be satisfied
- Analysis of the performance/KPIs of a given configuration to assess whether the selected PQI could be achieved and ensure that QoS requirements are fulfilled.

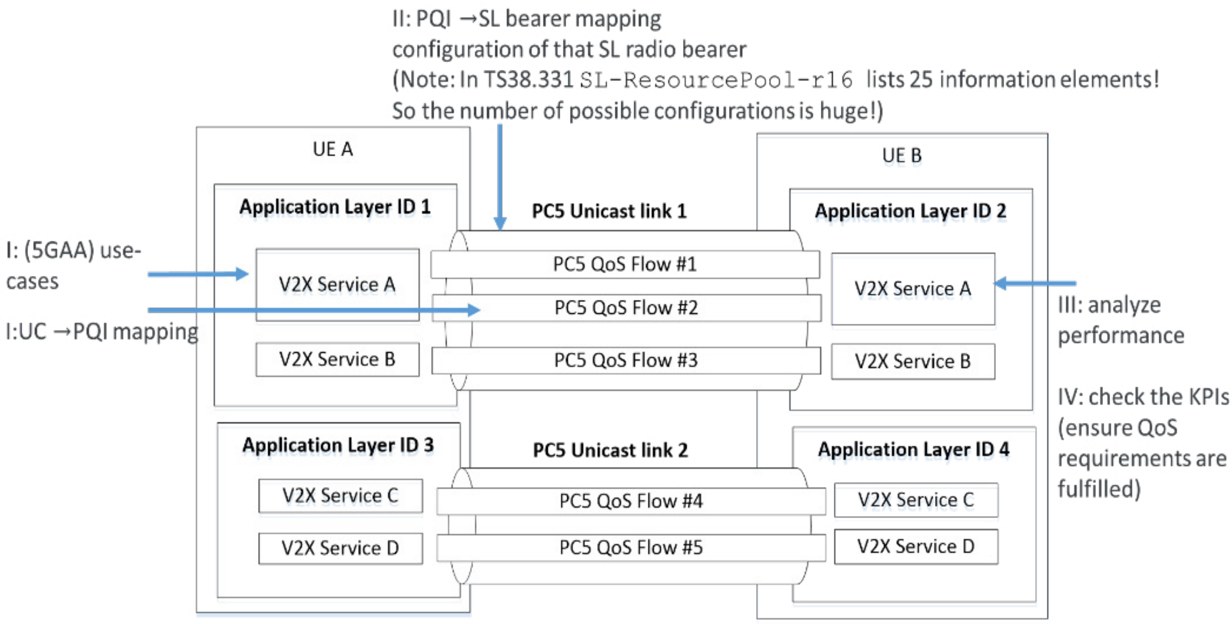

Figure 3-1: QoS handling and resource selection 3GPP Rel-16 NR V2X

With these NR V2X Sidelink enhancements, we can better understand the resulting data traffic characteristics. Importantly, this relationship and the resulting data traffic characteristics are only specific to V2V communication as they match the requirements for direct and short-range communication, such as V2V channel characteristics. As each message type has a specific packet size, periodicity characteristics and triggering condition, the resulting data traffic in our simulation is represented by a sum of the triggered/used messages required by the implemented services and use cases in the analysed scenarios.

4 Use Cases Selected for NR V2X Evaluation

An automotive-centric evaluation of NR V2X requires the understanding of relations between the ITS use cases and the wireless communication layers. This relationship is required to identify, design and model the data traffic/flows properly, and then to define a set of decisive parameters and aspects for the evaluation of NR V2X. Only few, and most relevant, use cases are used due to time constraints of this study. This section presents the method and analysis of the selected use cases, including identifying relevant parameters and associated user stories for the NR V2X evaluation methodology. Finally, based on these findings, a data traffic model for the NR V2X evaluation is developed.

In [5], multiple advanced use cases looked at specific features of NR V2X. In the study of spectrum needs [7], further use cases were evaluated representing both Day-1 and advanced use cases. Our analysis evaluates the advanced use cases with respect to the relevant Rel-16 NR V2X specification in a dedicated band as the ITS band n47 [TS 38.101]. It is also important to consider the need for advanced services using advanced message types, e.g., in ETSI, multiple messages are considered for Day-2 including, and not limited to, Manoeuvre Coordination Messages (MCM) and Collective Perception Messages (CPM). It is also important to consider the second release versions of the basic messages, as many of the advanced use cases are also relying on transmitting CAMs/BSMs. Herewith, we can accommodate these use cases within the identified spectrum together with the repeating broadcasts (CAM/BSM) or the event triggered messages, e.g., DENM, as part of the use cases or the evaluated environment.

The selected use cases have therefore considered the findings from NR V2X WI phase 2 [5] and the spectrum needs study [7]. The refinements executed in previous studies along with the prioritisation of use cases within [8, 9] lead to the following selection [2-4]:

1. UC1: Group Start
2. UC2: Coordinated Cooperative Driving Manoeuvre (i.e., Cooperative Lane Merge)
3. UC3: Vehicle Decision Assist
4. UC4: Sensor Data Sharing for AVs

These use cases have been defined in a high-level description, without considering the details or limitations, such as the environment. In this analysis, the user stories provide the level of detail needed for creating a realistic evaluation assumption. As an example, a lane merging manoeuvre on a highway must function under very different conditions/limitations compared to the same use case in a dense urban environment, even though their executed commands could be identical.

Each of the use cases has been defined with two user stories, each fitting to the selected road environment and with the corresponding limitation [14]. Depending on the user stories of each UC, the relevant parameters have been identified considering the required message generation frequency and the total message size. Additionally, use cases and their user story consider transmission and/or reception of basic continual/ repetitive broadcast messages, e.g., CAM/BSM or event triggered messages such as DENM.

Below, the ITS services and possible selected scenarios for evaluation are briefly described. Furthermore, detailed considerations covering the road environments and mobility models of the selected use cases are described. Finally, the data traffic models associated with the considered use cases for the respective mobility models/ road environments are presented.

4.1 Analysis of the Use Cases for NR V2X Evaluation

In this project, the mapping between the use cases, relevant parameters, and possible impact on the evaluation assumptions have been gathered. The user stories of the selected use cases have been reproduced (based on the studies in [2-4]) to consider two main road environments, namely an urban intersection and highway scenarios (see Section 4.4 for more details). The use cases are analysed as follows:

- Group Start (UC1): One user story has been identified for an urban intersection. The parameters of this user story covers the communication range scaled to the road type, service level reliability considering radio layer aspects, and the message latency/periodicity.
- Lane Merge (UC2): Similar to Group Start, it considers manoeuvring messages with specific transmission rate/latency, service level reliability, and message size for a highway. The communication range should consider the possible reliability given the speed, road width, etc.
- Vehicle Decision Assist (UC3): The use case has been developed into two user stories for the two road types , namely an urban user story and a highway user story.
- Sensor Sharing (UC4): Considered for the two road environments, it is assumed that sensor-generated data is based on pre-processed/analysed sensor information. The rate is limited to 64 Mbps as all vehicles are transmitting uniform transmissions.

The possible mapping between the proposed ITS (including conveying the services over lower layers using the ITS messages, as discussed above) to suitable data “traffic types” is considered for simulation and numerical analysis. This is necessary to enable an abstraction of the user story requirements to values transferable to simulation. The identified data traffic types are available in Annex A.

These user story-specific attributes/aspects have been carefully modelled with the following outcome: related to dynamics and regional attributes, the simulation environment can emulate a specific mobility traffic type in the modelled road environments to reproduce the mobility of the user story, i.e. merging highway lanes. The virtually created traffic should reproduce the required data traffic related to the selected user story. More details are available in Annex C.

4.2 ITS Services and Possible Evaluation Scenarios

One of the fundamental requirements for the NR V2X evaluation is the understanding of the relationship between a specific evaluation scenario (with a single use case or multiple use cases, as detailed below) and the resulting data traffic at or on the NR layers. The ITS data traffic is made up from the standardised message types generated based on the profiling information, e.g., transmission rate, triggering condition etc.

In this section, we identify possible/relevant ITS message types for the selected use cases. While other use cases and ITS services may coexist using different message types in the same ITS channel, they were out of the scope of this study. The selected ITS message types in this White Paper are limited to V2V only. Table 4-1 illustrates the relationship between selected message types and use cases.

Table 4-1: Relation between selected message type, attributes and use cases which use V2V communications alone

Use case	Possible message types needed for the (setup, initialising, execution ...) of the use case
UC1	MCM, CAM
UC2	MCM, DENM, CAM
UC3	MCM
UC4	CPM, CAM

The SLRs of the use cases dictate the required reliability and traffic model of each use case. Additionally, the user stories shape the deployment constraints and can be considered in defining some evaluation profile aspects, e.g., which transmission and cast type is used (i.e., unicast, groupcast, broadcast), whether retransmissions is enabled or not, etc.

They also define the traffic models that should be considered for evaluation. In all of the cases in Table 4-1, background base-line communication messages (e.g., CAMs) should be multiplexed in the same channel with other messages associated with the use cases. This baseline traffic model should consider parameters that follow realistic values in terms of latency, periodicity, and message sizes. For the traffic associated with use cases, MCMs could be an example of messages considered. In most examples, the traffic associated with the use cases can be considered as periodic – adopting the characteristic of the traffic from the use case definitions [2-4]. However, some phases of specific use case, e.g., UC1 and UC2, may start as event-triggered transmission but continue for some time as periodic traffic. Such event-triggered messages can thus be evaluated as “event-triggered periodic traffic”. Some use cases, such as UC3, may only involve “aperiodic traffic transmission”, which makes them challenging to evaluate together with periodic traffic using the same channel. Proposals to evaluate multiplexed scenarios for periodic and aperiodic traffic will be discussed in the next sections.

Including NR V2X Sidelink enhancements (listed above) such as groupcast, HARQ modes, Rel-16 enhancements for resource allocation etc., we are able to understand the resulting data traffic characteristics. Importantly, these relationships and the resulting data traffic characteristics are only specific to V2V (direct and short) communications, such as V2V channel characteristics. As each message type has a specific packet size, periodicity characteristics and triggering condition, the resulting data traffic in our simulation is represented by a sum of the triggered/used messages required by the implemented services and use cases in the analysed scenarios. The following table summarises the possible used traffic type and associated NR V2X enhancements.

Table 4-2: Relationship between selected use cases, associated transmission schemes, NR V2X attributes for NR V2X evaluation

Use case	Type of transmission	Possible relation to NR V2X (including message priority, generation rules, message sizes, etc.)
UC4	Continual repetitive messages (V2V)	– Periodic reservations – HARQ enabled/disabled – At least groupcast
UC3	Event triggered messages (V2V)	– Aperiodic/ periodic reservations – HARQ enabled – Pre-emption enabled for (optional for UC3) broadcast /unicast/group cast
UC1 UC2 UC3 UC4	Event-triggered messages and then Continual repetitive (V2V)(broadcast/ groupcast/unicast)	– periodic reservations – HARQ enabled – Pre-emption enabled – Unicast/groupcast

In Section 4.3, more details about evaluation traffic models and possible evaluation profile configuration for sidelink communication are introduced.

4.3 Data Traffic Model Analysis

The data traffic models from the 3GPP V2X evaluation [14] have been extended based on our analysis of the relevant ITS and mobility patterns, in addition to the different identified data traffic models. A laid out version from the 3GPP V2X evaluation is given in the following sub-section.

In addition to the 3GPP data traffic model, we propose to introduce a flexible version that can accommodate all previous assumptions in addition to considering the selected UC user stories and SLRs. To further adapt the messages to the simulation and obtain valid results, samples from the different message types (e.g., for CAM Release 2, DENM Release 2, CPM, etc.) were taken. It is very important to have approximate packet sizes, periodicity, PDB, etc. for the different data transmission models.

To simplify the proposed intensive evaluation, it was agreed to focus on semi-persistent traffic or periodic traffic models for all transmitted messages. The periodicity in these data traffic models has been selected to fulfil the latency requirements, as indicated in the associated SLRs. To further simplify and, additionally, unify the simulation of multiple services in a channel, all message types are considered to be groupcasted following NR V2X connectionless protocols. In contrast to radio technologies whose range is limited by predefined MCS requiring only minimum sensitivity, NR V2Xs also offer a unique distance-based communication feature. This feature ensures the required minimum coverage range independent of any channel scenario. Different communication ranges for the connectionless groupcast should be then selected based on the associated SLRs. In this evaluation, all vehicles are assumed to be able to transmit and receive baseline traffic-generated messages (e.g., CAMs). However, other use cases are either considered only for certain geographical positions in the evaluation scenario (e.g., Group Start traffic at intersections, Lane Merge highway ramps/exits, etc.) or with certain percentages (e.g., Sensor Sharing use case). Further details about the proposed data traffic models are presented in Annex A.1 and Annex A.2. In Annex A.1, possible identified parameters for baseline traffic, e.g., CAM/BSM, and other traffic type identifiers are listed. Additionally, the link between the proposed traffic types for evaluation and the selected use cases and/or possible message type implementation is considered. Finally, the proposed data traffic parameters for the suggested use cases are listed in Annex A.2 based on use case requirements, the simulation environment (urban, highway), required evaluation analysis, and target KPIs, etc.

It is also noted that, in evaluating 5GAA NR V2X selected scenarios, situations that consider a mixture of unicast/groupcast/broadcast and periodic/aperiodic traffic need further analysis in future NR V2X studies.

4.4 Road Environment and Mobility Model

For evaluating the selected use cases and associated scenarios/use stories, it is important to consider close to realistic evaluation scenarios and/or the system-level simulation environment. The 3GPP evaluation study [14] defines two types of environments (intersection and highway) which were reused and adapted to fit the purpose of the study. As the existing defined environments only represent plain topologies, the adaptations made for this evaluation only contain changes enabling the selected use cases to take place.

However, in realistic automotive scenarios, more dynamics and/or road interactions are envisaged. To cite one modification, an adaptation had to be made in the urban intersection model to enable the UC2 user story for coordinated intersection and manoeuvres around, for example, a road blockage. Furthermore, some modification to the evaluation scenario has to consider the dynamics of UC1 including the presence of stationary or moving vehicles (in groups) near the intersection. See Figure 2-2 for more details.

Other modifications are considered for highway scenarios including the introduction of multiple lane merges. Additionally, the lane merge vehicle traffic has to be adapted to the model to emulate lane-merging behaviour in highway situations. See Figure 2-2 for more details.

To represent the modifications needed in the evaluation scenario without changing the 3GPP simulation methodology, we propose to introduce stationary virtual vehicles/ user equipment (UE) into the equation. Such virtual UEs should be inserted carefully to emulate the different mobility models and data traffic requirements. Further description of virtual UE concept is considered in Section 5.4. Other mechanisms to evaluate realistic or representative road environments are not precluded.

4.4.1 Intersection in an Urban Scenario

Figure 4-1 represents an intersection with adaptations required to implement the use cases and mobility requirements. All urban user stories can therefore be evaluated in the same environment and under the same conditions.

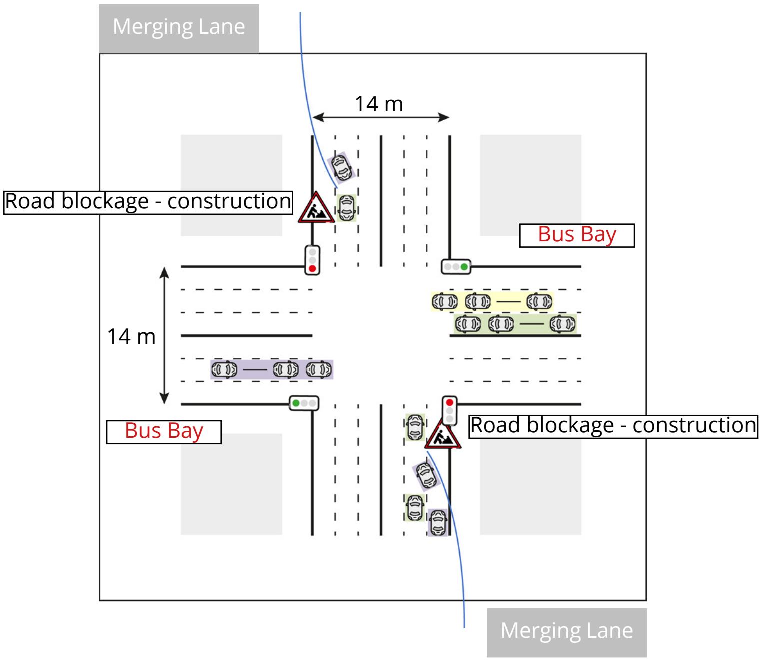

Figure 4-1: Representation of the intersection scenario with the required adaptations according to the evaluation methodology

4.4.2 Highway Scenario

Figure 4-2 illustrates the environment model applied to analyse and evaluate a highway scenario. As previously mentioned, the selected use cases were projected on this environment.

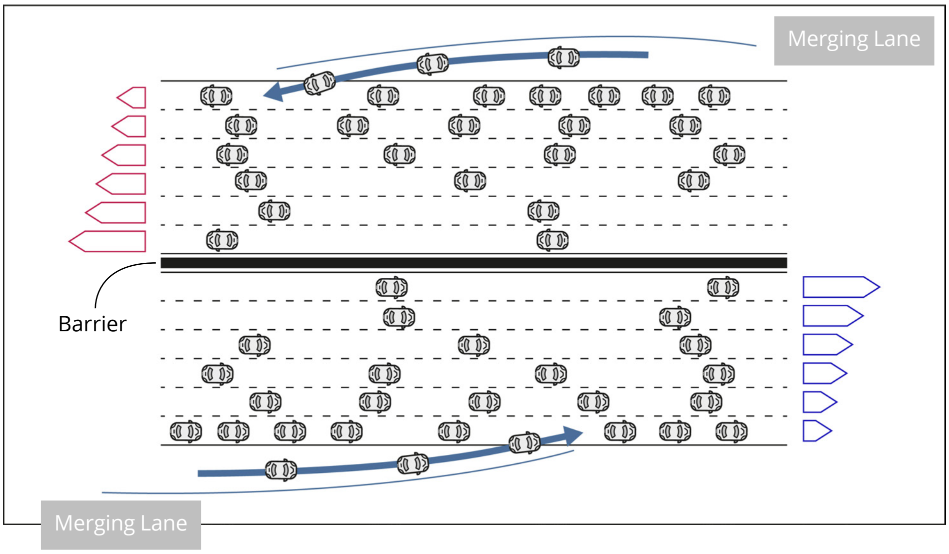

Figure 4-2: Representation of the highway scenario with the required adaptations according to the evaluation methodology

As can be seen here, a slight adaptation had to be made to the highway scenario of the 3GPP model to add a merging lane. However, again as with the intersection, all use cases can be evaluated in this improved environment.

4.5 Automotive NR V2X Evaluation Scenario and KPIs

4.5.1 Evaluation scenario considering Automotive Requirements

To evaluate NR V2X, it is required to have different evaluation scenarios considering the requirements of the different use case SLRs (i.e., for specific user stories) and considering the (close to) realistic automotive assumptions made in Section 1. The scenarios well consider the following aspects:

- Parameters, e.g., existing channels, QoS requirements, 3GPP specific parameters, application layer requirements including message generation rules
- Assumptions for evaluation, e.g., number of vehicles, evaluation environment, etc.
- Performance evaluation metrics (exact definition of metrics and KPI requirements for each metric discussed during drafting)

The evaluation scenarios should consider one of the two nominated road environments proposed in Section 3.3. Each evaluation scenario should also consider a certain criterion to multiplex the different use cases in the given evaluation channel. For example, the urban intersection may consider a) baseline traffic (e.g., periodic CAM) and b) other use case(s), e.g., UC1, UC3, and/or UC4. For the baseline traffic, it can be assumed that all vehicles are equipped with NR V2X, such that 100% of the vehicles are able to transmit and receive the baseline messages. Use cases 1, 2, or 3 may have different penetration rates according to the evaluated scenario. Additionally, each use case in this multiplexed environment can consider different transmission/cast types (e.g., unicast, groupcast, broadcast), different traffic types, different message periodicity, and other different QoS requirements. Similarly, a different multiplexed use cases should be considered for highway scenarios.

The following tables propose different automotive evaluation scenarios considering the aforementioned assumption of multiplexing services/use cases in a channel. To evaluate the following parameters, a modified system-level simulator (based on existing 3GPP simulations) needs to be considered. Additionally, the different traffic and mobility conditions induced from the selected use cases need to be adapted and fed into the evaluation scenario, e.g., introducing the group start mobility and data traffic models at road intersection. In our evaluation, we are considering that the multiplexed services are all existing in the same radio channel, e.g., 20 MHz in the ITS band.

Table 4-3: Automotive evaluation scenario for urban intersection environment with multiplexed services/use cases

Use case	**Road environment urban intersection parameters**							
	Percentage of vehicles*	**Cast type**	**Traffic category**	**Part of the proposed service level KPI (QoS flows/PQI)**				
				PDB (Periodicity)	Comm. Range [m]	Radio** Reliability	Suggested PQI (Priority)	NACK Feedback
CAM-baseline	100% (all vehicles Equipped)	Groupcast connection-less	v2vTType-10	200 ms	80	95%	59 (6)	Yes
UC1: Group Start	vehicles at, e.g., 9 intersections	Groupcast connection-less	v2vTType-21	50 ms	50	95%	22 (4)	Yes
UC4: Sensor Sharing for Avs	50% of vehicles	Groupcast connection-less	v2vTType-26	100 ms	80	95%	58 (4)	Yes
UC3‡: Vehicle Decision Assist	10% of vehicles†	Groupcast connection-less	v2vTType-24	100 ms‡	80	95%	23 (3)	Yes

Table 4-4: Automotive evaluation scenario for highway environment with multiplexed services/use cases

Use case	**Road environment urban intersection parameters**							
	Percentage of vehicles*	**Cast type**	**Traffic category**	**Part of the proposed service level KPI (QoS flows/PQI)**				
				PDB (Periodicity)	Comm. Range [m]	Radio** Reliability	Suggested PQI (Priority)	NACK Feedback
CAM-baseline	100% (all vehicles Equipped)	Groupcast connection-less	v2vTType-11	100 ms	300	95%	59 (6)	Yes
UC2: Cooperative lane Merge	8 lanes in 2 km road segment	Groupcast connection-less	v2vTType-33	50 ms	150	95%	55 (3)	Yes

UC4: Sensor Sharing for AVs	50% of vehicles	Groupcast connection-less	v2vTType-34	100 ms	300	95%	58 (4)	Yes
UC3[‡]: Vehicle Decision Assist	10% of vehicles	Groupcast connection-less	v2vTType-32	10 ms[‡]	300	95%	90 (3)	Yes

***** *Proposed multiplexing use cases scenario for evaluation.*

****** *Possible achievable reliability within the configured communication range with only one possible retransmission. Reliability is measured in terms of the Packet Reception Ration (PRR). The value of PRR outside the defined communication range may vary from the value in the table. The PRR of 95% is considered as a feasible value for the selected radio layer parameters and the configured number of retransmissions. Furthermore, a gap has been identified to directly link the radio layer reliability to SLRs.*

‡ *UC3 (Vehicle Decision Assist) is an aperiodic data traffic use case (e.g., v2vTType-24 and v2vTType-32 in Annex A). Herewith, the PDB should be considered for resource (re-)selection without periodic reservation. The evaluation of aperiodic traffic (together with periodic traffic in the same channel) is very difficult and requires further analysis, e.g., considering analytical evaluation for the possible aperiodic traffic fitting into the remaining resources. For this reason, UC3 was only evaluated for basic traffic categorisation in this White Paper.*

4.5.2 KPIs for Evaluation Scenario

If multiple services in a channel are considered for evaluation, multiple options are considered to identify the suitable KPIs or evaluation methodologies. The following consideration is adopted when evaluating multiple services in a channel: each of the different individual services multiplexed in the channel must have a specific traffic model, user density and allocated transmission.

Therefore, the suitable KPIs for such a service can be evaluated separately per traffic model-based service, i.e., evaluation different KPI(s) for each individual service separately. Alternatively, it is also important to note that an overall KPI can be considered for all running services in the channel.

4.5.2.1 KPIs for Evaluating Reliability

At least for reliability, the Packet Reception Ratio (PRR) can be considered in different situations, i.e., including being used as an overall KPI for the multiplexed services. For one transmitted packet, the PRR is calculated by S/Z, where Z is the number of UEs in the intended set of receivers, and S is the number of UEs with successful reception among Z. Further information about PRR is given in [14].

With a sufficient number of simulation iterations or there are large enough UEs in a group of groupcast-based sidelink transmission, it can be assumed that the PRR for groupcast is equivalent to 1-PER (Packet Error Rate, i.e., high layer PER after retransmissions) of the transmitted packets from the transmitting UE perspective. Therefore, the evaluation of PRR can be directly linked to the QoS requirements in [19]. Further KPIs are discussed but have been deprioritised in this analysis including, e.g., Packet Inter-Reception (PIR) [14].

4.5.2.2 KPIs for Evaluating Latency

In Tables 4-3/4-4 and Annex A, latency is presented as a “fixed value” in milliseconds.

However, in real deployment and when observed the overall latency is a time variant with a statistical distribution. This is especially true when considering highly congested systems or several consecutive failures (with multiple re-transmissions as NR V2X is allowing multiple retransmissions). In this case, the overall latency, when evaluated, will have the statistical distribution of all in-time and correctly received packets, e.g., 95% of packets are received correctly within 100 ms. The choice of the percental value for latency requirements also relates to the required system reliability, i.e., when delayed packets are dropped. In real systems, the “late” packets (exceeding an assigned Packet Delay Budget (PDB) will be dropped by the transmitter’s scheduler, which impacts the PRR and the system reliability.

In this NR V2X evaluation, the PDB values (assigned based on the services) consider the maximum allowed latency for each packet and retransmissions. In other words, the system-level simulation assumption is to guarantee transmission and retransmissions of the packet within the PDB. This ensures that the simulation does not have late packets to be dropped, i.e., no effect on the PRR analysis (in Section 5) due to latency.

5 Simulation Details and Analysis

5.1 Simulated Scenarios and Parameters

In this work, further details about the urban and highway scenarios/simulations are considered for the selected use cases. The following are general assumptions about the simulation setup considering UE dropping and vehicle dynamics, where:

- Vehicle dynamics:
  - Vehicles move at constant speed
  - Vehicles don't stop
  - No acceleration/deceleration/lane change
- UE drop and mobility modelling:
  - From TR 37.885 [14], the 3GPP Type 2 (passenger vehicle with higher antenna position) is consider, which describes a vehicle with: length 5 m, width 2.0 m, height 1.6 m, antenna height 1.6 m

5.2 Simulation of Baseline Traffic Services

It is assumed that baseline traffic is composed of basic safety messages, e.g., CAM and sensor-sharing traffic and similar to traffic for Cooperative Perception Messages (CPM). The basic safety message (e.g., CAM) is assumed to be available from 100% of the vehicles, i.e., all vehicles are equipped with V2X modules capable of generating such a basic message. The CAM traffic is identified in Annex A.2.

Additionally, in the sensor sharing case,, it is assumed that only 50% of the vehicles are transmitting such a service, while all vehicles are able to receive the, i.e., in either highway settings or urban intersections. Wherein the number of vehicles in the system that can share their sensor information are considered to be 50% of the total devices in the field. The background sensor-sharing periodicity, traffic types and message sizes are given in Annex A.2. Evaluation assumptions, simulation details, and the data traffic models of both CAM and sensor sharing are given in Table 5-1.

On the top of this assumed background traffic type, further advanced use cases are also considered in the next sections.

Table 5-1: Simulation parameters for baseline traffic (CAM and sensor-sharing traffic)

	Urban grid	Highway
Cast types	Distance based on groupcast	
Bandwidth	20 MHz	
Subcarrier spacing	30 KHz	
Carrier frequency	5.9 GHz	
Simulation area	1399 m x 750 m Urban Grid (9 intersections)	2km 3GPP highway
Number of vehicles	708+ 36 (VUEs)	123 + 8 (VUEs)
Speed of vehicles	50 km/h	140 km/h
CAM periodicity	Periodic with 200ms (or 5 Hz) (see v2vTType-11, Rate 1 in Annex A2)	Periodic with 200ms (or 5 Hz) (see v2vTType-11, Rate 1 in Annex A2)
CAM packet size	Variable as given in Annex A2 (i.e., v2vTType-10, MessageSize1)	Variable as given in Annex A2 (i.e., v2vTType-11, MessageSize1)
Sensor-sharing periodicity	100 ms	100 ms
Sensor-sharing packet size	600 byte	600 byte
NACK distance	80 m (sensor sharing)	300 m (sensor sharing)

5.3 Simulation of Advanced Use Cases Using Virtual UE Concept

The following are the selected advanced use cases to be simulated for the respective scenarios:

- Group start/cooperative intersection with baseline traffic (urban intersection)
- Cooperative lane merge with baseline traffic (highway)

In order to model the data traffic generated by the above advanced use cases, without implementing the protocols, we introduce the concept of virtual UEs. These are stationary UEs at specific locations transmitting the appropriate messages with a certain periodicity to simulate specific use cases with special mobility requirements, e.g., lane merge or intersection coordination or group start.

It is important to emulate the traffic generated by the event-based use cases above, i.e., group start for the urban intersection and lane merge for the highway, and then multiplex it with the generated baseline traffic discussed in Section 4.2. Given the sophisticated requirements of such even-triggered scenarios (e.g., being geographically related to a certain location in the simulation like intersection/lane merge, and due to their specific mobility requirements), it was difficult to factor in with the given 3GPP stochastic System-Level Simulations (SLS). Therefore, we needed to simplify the implementation of a new simulation concept to emulate such events and overlay them on a 3GPP-like SLS together with other assumed traffic situations. See more details and discussions on this concept in the next section.

5.4 Virtual UEs for Emulating Advanced Use Cases

Here we define the concept of the virtual UE which emulates the total data traffic that would be generated because of a given use case. A virtual UE helps the simulation effort as it is simpler to implement, without going into the nuances of the actual protocols associated with the given use cases. We choose a packet size and a periodicity to emulate the continuous triggering of such a use case, although the use cases in question (i.e., group start or lane merge for urban intersection or highway) happen sporadically. It is assumed that the receiving UEs are located with the configured communication range around the virtual UEs (i.e., those UEs approaching the intersection from each side of the cross-section in our simulation).

It is assumed that every virtual UE is continuously transmitting the configured traffic for the identified use case – e.g., group start, lane merge – during the whole simulation timeframe. This way we are able to load the system and analyse the worst-case scenario of traffic coming from these advanced use cases.

The table below shows the simulation details associated with the manoeuvre-related messages associated with the advanced use cases.

Table 5-2: Simulation details for group start (urban intersection)/lane-merge (highway)

	Urban grid	Highway
Cast types	Distance based on groupcast	
Bandwidth Carrier frequency Subcarrier spacing	20 MHz 5.9 GHz 30 KHz	
Use case deployment	Group start based on virtual UEs	Lane merge based on virtual UEs
Area	1399 m x 750 m urban grid (9 intersections)	2 km 3GPP highway
Number of vehicles	708+36	120+8 (Source 1) or 123+8 (Source 2)
Speed of vehicles	60 km/h (Source 1) or 50 km/h (Source 2)	140 km/h
Periodicity	Periodic with 50 ms (see v2vTType-21, Annex A.2)	Periodic with 100ms (see v2vTType-33, Annex A.2)
packet size	300 bytes (see v2vTType-21, Annex A.2)	300 bytes (see v2vTType-33, Annex A.2)
NACK distance	50 m (group start)	150m (lane merge)
Virtual UEs	4 VUEs x 9 Intersections = 36 VUEs	8 lane merge ramps = 8 UEs. We are considering higher number of merge lanes

For the urban intersection, we consider the 3GPP urban map with nine intersections. Where each intersection has four virtual UEs as indicated by the blue UE in the figure below.

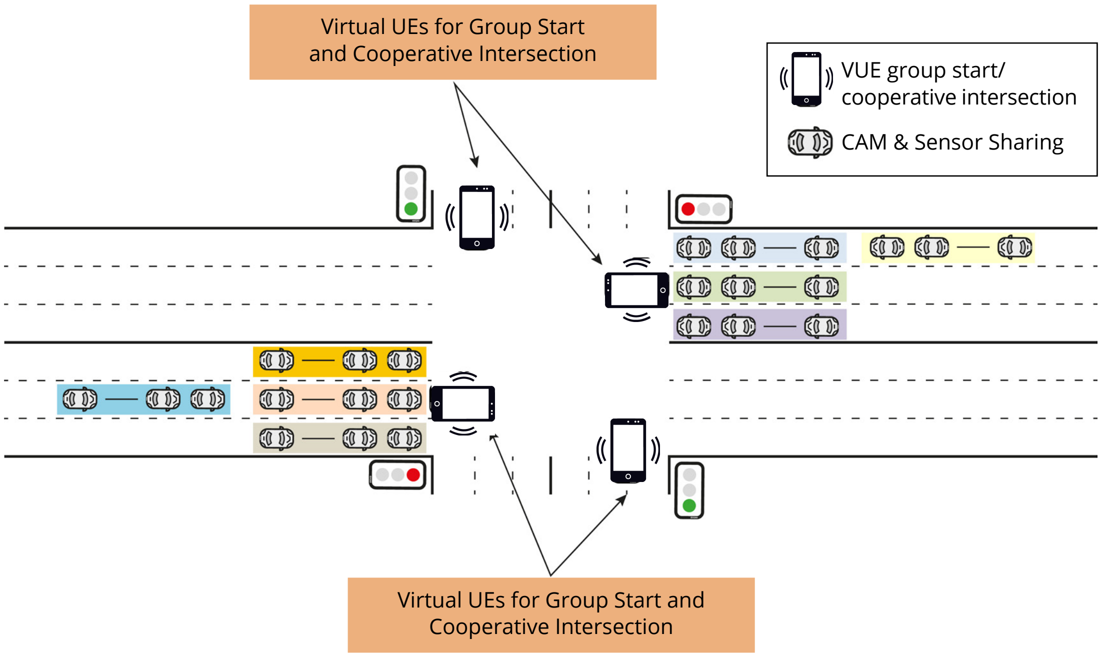

Figure 5-1: Virtual UE concept emulating group start overlaid on baseline traffic

For the highway scenario the length of the highway is 2 km, with four lane merge UE places at a distance of 250 m on each side of the highway, as indicated by the blue UEs in the figure below.

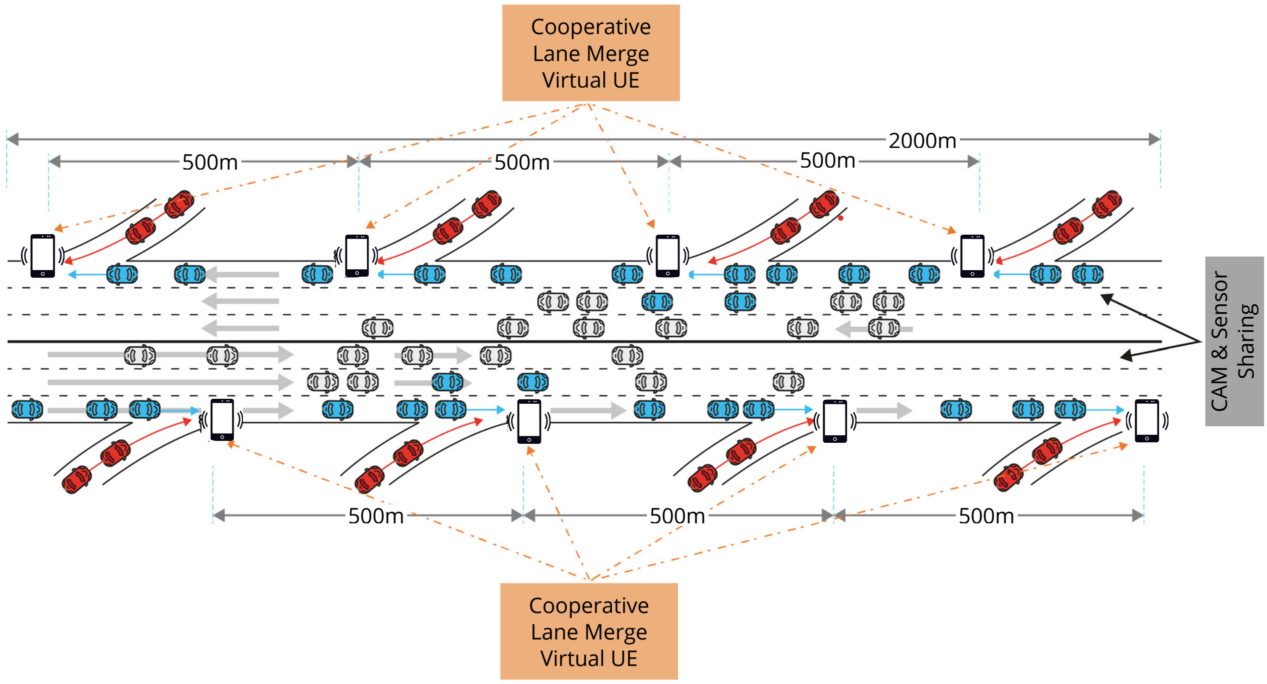

Figure 5-2: Virtual UE concept emulating dense lane-merge scenario (four lanes each side in 2 km highway segment) overlaid on baseline traffic (CAM and sensor sharing)

5.5 Simulation Results and Analysis

The simulation has been generated by two sources after extensive parameter selection and calibration. In addition to the baseline evaluation methodology of NR V2X in [14], updated evaluation assumptions, needed for multiplexing services in channel, have been considered. The results of the two sources are deemed to be consistent and matched to each other. By analysing the results, we conclude the following general aspects:

- The simulation results of urban and highway scenarios clearly show that NR V2X is able to support mixed data traffic from basic and advanced use cases simultaneously.
- The performance of the highway scenarios is mostly LOS communication on the highway; the PRR at the required distance range is above 97%.
- The urban intersection scenario is a mixture of LOS and NLOS communications and hence the PRR performance is lower than the highway scenario for the required distances (i.e., PRR is above 90% for the required distance range).

5.5.1.1 Simulation Setup and UE Dropping for Source 1 and Source 2

The UE dropping of both evaluation sources considered the following methodology:

- The baseline vehicle creation and mobility modelling (vehicle dropping, movement/velocity, turning probability at intersection etc. from [14]) is used.
- UE dropping options for the urban grid/group start scenario (using [14]):
  - Vehicle type distribution: 100% vehicle Type 2, with a vehicle speed of 50 or 60 km/h (depending on the source) in all lanes and intersections
  - It is also assumed that the UE goes straight in the wrap-around setup (as in [14])
  - Vehicles are moving with constant velocity
- UE dropping options for the highway scenario:
  - Vehicle type distribution: 100% vehicle type 2/ Vehicle speed is 140 km/h in all the lanes
  - Also vehicles are moving with constant velocity

5.5.2 Simulation Results from Source 1

Source 1 considers all given parameters in Table 5-1 and Table 5-2 for two possible antenna configurations (V2X implementations): the 2 Transmit/4 Receive Antenna (2TX/4RX) and 1 Transmit/2 receive antenna (1TX/2RX). The 2TX/4RX was considered to illustrate the performance enhancements when multiple antennas are considered on both sides, TX and RX.

Figure 5-3 depicts the PRR performance of CAM, group start, and sensor sharing in the urban grid discussed in Section 4.4. Figure 5-4 depicts the PRR performance of CAM, lane merge scenarios, and sensor sharing in the updated highway grid described with four lane merges on the highway from each side (also described in Section

4.4). The results shows the PRR (y-axis) vs the distance between vehicles in metres (in x-axis), where the performance up to the required communication range, i.e., for NACK only based re-transmission, is sufficiently higher than the required performance according to the SLRs (as shown in Table 4-3, Table 4-4). The results also show a slight performance drop (in measured PRR) once the communication range span or distance is bigger than the configured communication range, as there will be no further NACK-based retransmissions.

The following is the observation from Source 1.

Observation on Source 1 results:

1. With the implemented 3GPP Rel-16 V2X features, the system can provide performance (in terms of PRR) that fulfils the requirements of the target services in this study, namely Group Start and Cooperative Lane Merging.
2. CAM and sensor-sharing services are included as the background data traffic and their performance requirements are also fulfilled.
3. According to their QoS parameters, the priority for the CAM service is set as higher than that of CPM service during the NR V2X resource (re)selection procedure (as described in Table 4-3, Table 4-4), which leads to better performance for CAM services than that for CPM services, as expected.
4. In general, service performance in the urban environment is worse than that in the highway environment, due to NLOS blockage effects in the former.
5. In addition to the baseline antenna parameters, 1TX/2RX, another antenna configuration is considered, 2TX/4X. For the studied environment types, the higher order antenna configuration observed with 2TX/4RX can bring 2.5% PRR gains for CPM, 1% for CAM and 0% for MCM services at their respective typical NACK distance in the urban environment; and 0.2% PRR gain for CPM, 0.1% for CAM and 0.1% for MCM services at their respective typical NACK distance in the highway environment. A general observation could be that such antenna configurations benefit services in "worse" environments (i.e., poor channel quality and/or services with less allocated transmission resources).

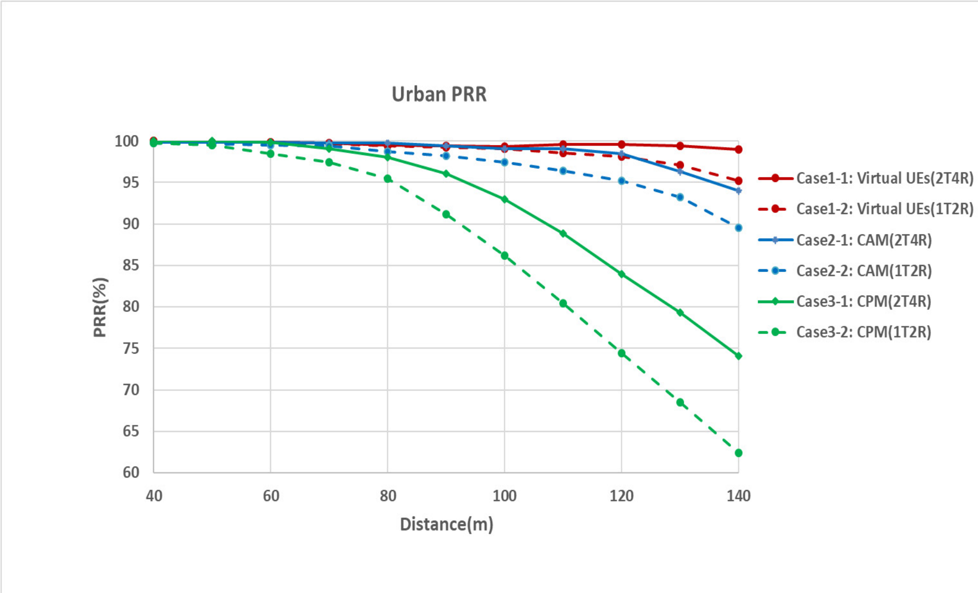

Figure 5-3: Simulation results for CAM, group start (with virtual UEs), and sensor sharing service in urban scenario multiplexed in the same channel according to Table 4-3

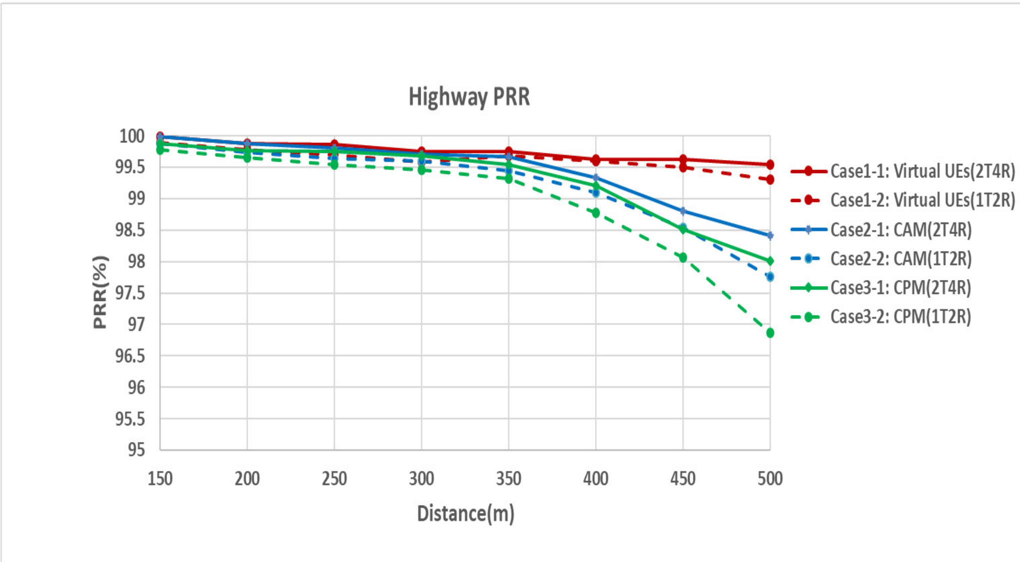

Figure 5-4: Simulation results for CAM, lane-merge (with virtual UEs), and sensor sharing service in highway scenario multiplexed in the same channel according to Table 4-4

5.5.3 Simulation Results from Source 2

This source considers only one antenna configuration for V2X, namely 1TX/2RX, where all results have been computed accordingly. Also in contrast to Source 1, the three possible transmissions (i.e. for CAM and advanced use cases) are considered to be with equal priority, to illustrate equal resource sharing for the resource reselection procedure.

In order to analyse the performance of CAMs, two approaches have been considered in Figure 5-5. First, an overall performance of a CAM with the configured mixed packet sizes and given percentages in the urban scenario (as in Table 4-3). Second, the performance of each packet size individually, i.e., three curves for 190, 350, and 450 bytes. The performance of the overall curve stands as the weighted average of the three individual packet sizes. Figure 5-6 then shows the same analysis and performance trend for the highway scenario (as in Table 4-4).

Figure 5-7 and Figure 5-8 show the overlapping of CAM and other use cases, i.e., group star, lane merge and sensor sharing. Similar to Source 1, the results of Source 2 show that NR V2X performance, up to the required communication range (i.e., for NACK only re-transmission) is sufficiently higher than the required performance according to the SLRs (as shown in Table 4-3, Table 4-4).

For urban scenario, the performance of the different CAM sizes is as follows:

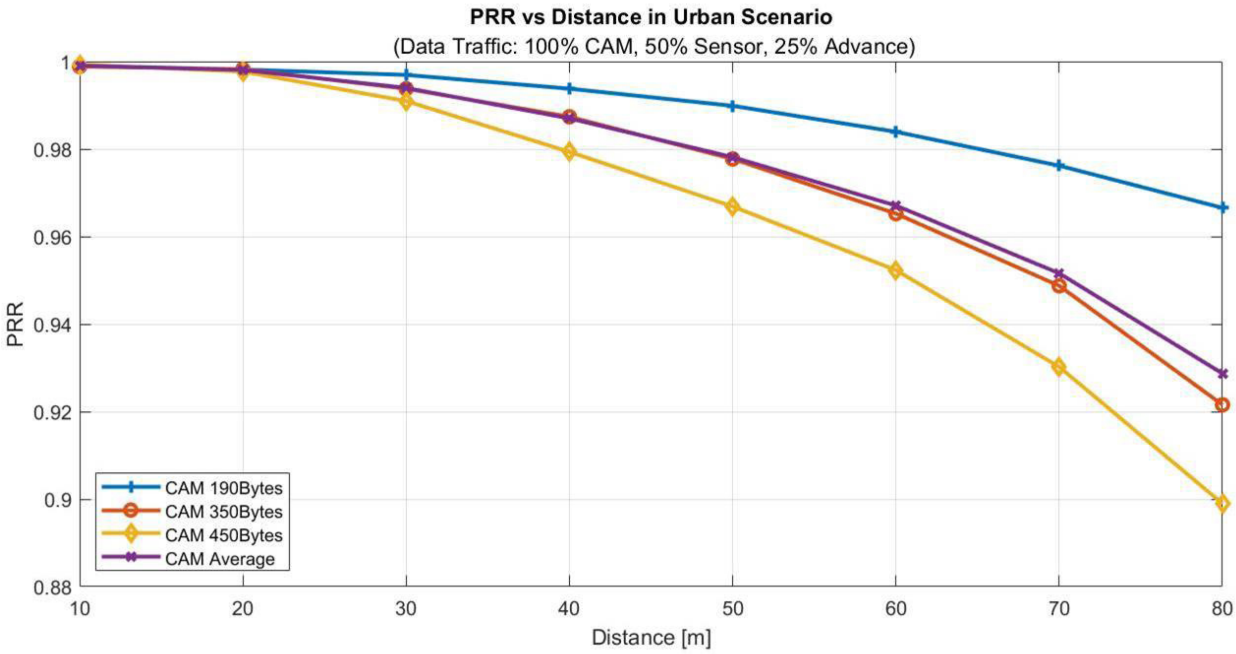

Figure 5-5: Simulation results for CAM in urban scenario consider the different generated packet sizes of the CAM assuming multiplexed messages in the same channel with sensor sharing and advanced use case, as configured in Table 4-3

For highway, the performance of the different CAM sizes is as follows:

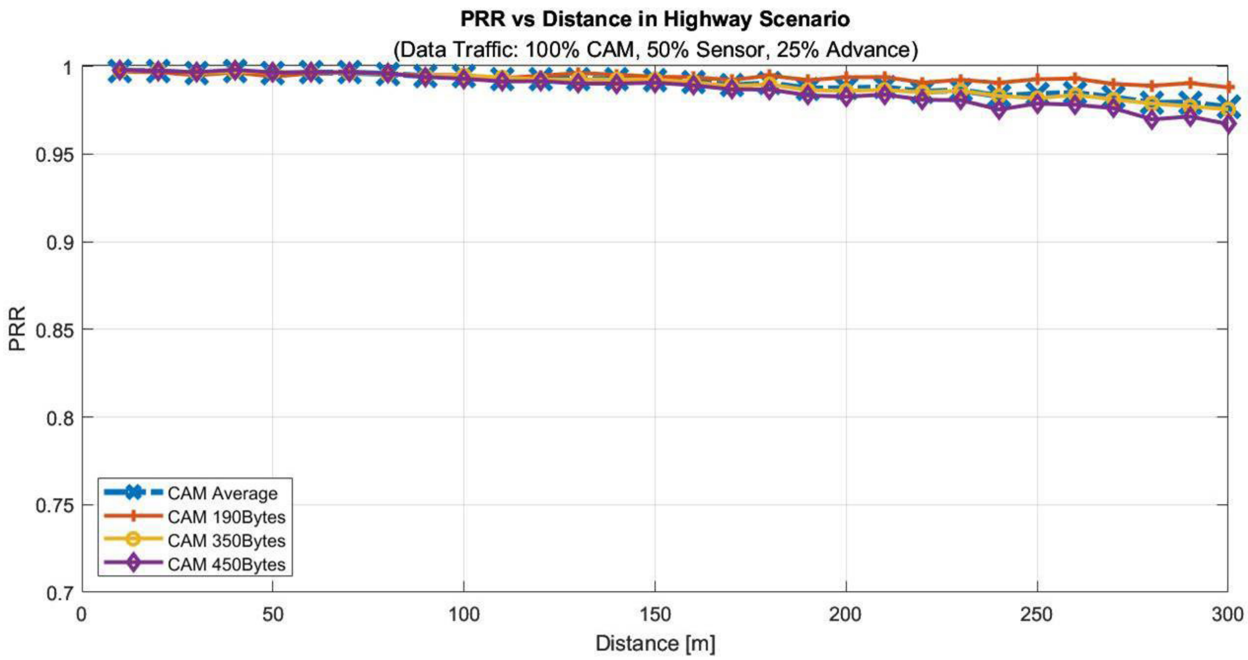

Figure 5-6: Simulation results for CAM in highway scenario consider the different generated packet sizes of the CAM assuming multiplexed messages in the same channel with sensor sharing and advanced use case, as configured in Table 4-4

For multiplexing use cases in the channel, the following figures show the performance of the multiple traffic situations:

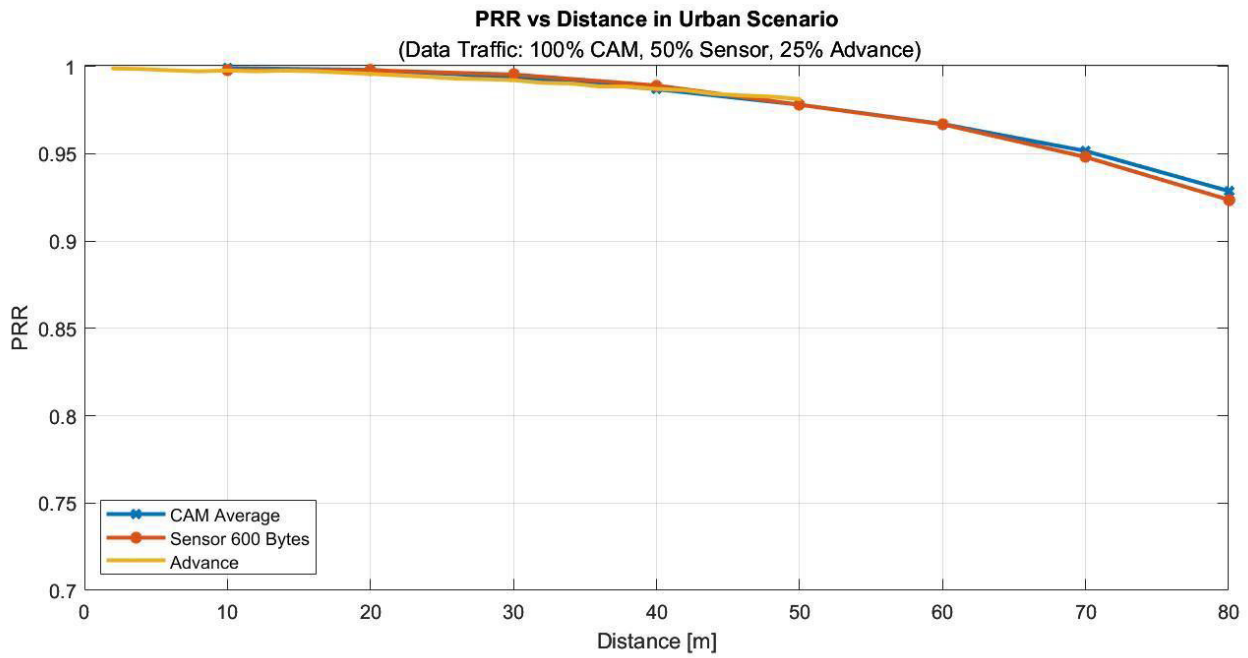

Figure 5-7: Simulation results for average CAM performance curve in addition to the PRR of other services, sensor sharing and group start in an urban scenario, as in Table 4-3

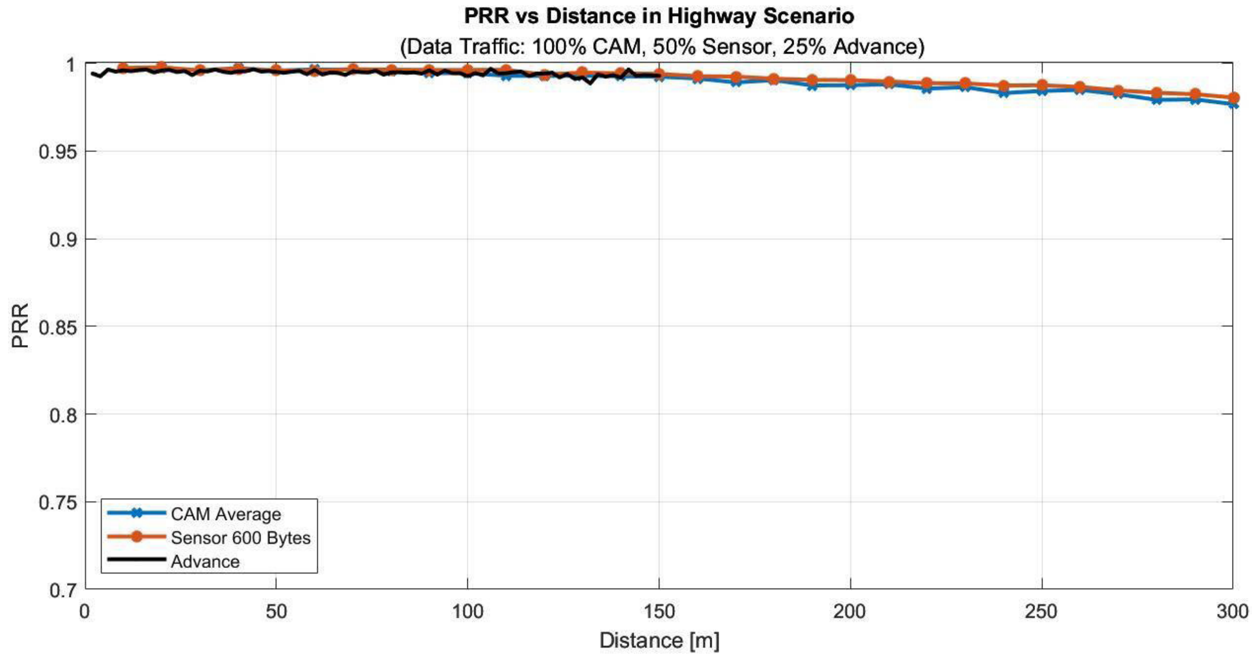

Figure 5-8: Simulation results for average CAM performance curve in addition to the PRR of other services, sensor sharing and lane merge in a highway scenario, as in Table 4-4

5.6 Summary on Evaluation of NR V2X for Automotive Aspects

This work mainly focuses on the performance of NR Sidelink for V2X based on the service layer aspects, therefore it is purely driven by the needs of automotive services and OEM perspective. Based on this fundamental expectation, a modified analysis and evaluation concept was developed which contains new and/or detailed aspects, such as usage of multiple services, perceived variability of message sizes (according to measurements of deployed V2V solutions), locality of use cases, service-to-access layer relations, etc. as well as some relevant use case/service implementation aspects. Those aspects decisively impact the performance of communication systems and, therefore, the quality of automotive services. Promising features, such as distance-based groupcast, were used to understand the benefits and performance of NR-SL for V2X. However, due to the complexity of this topic and missing information (especially implementation details), several gaps were identified for further analysis and evaluation, which are described in Section 5.2. The table below provides an overview of the results of the evaluation related to the relevant system and service aspects. Besides the description and status, a proposal for further analysis is provided.

Table 5-3: Analysis on topics considered for evaluation of NR V2X

Evaluation aspects	Topic	Priority	Status	Description	Issues	For further study
Variable message sizes	Access	**High**	Done	The size of CAMs varies approx. 200-800 bytes, due to the optional containers and the certification.	Current models consider these characteristics (based on CAM measurements and due to the multiple message types multiplexed data transmission of a single UE).	Additionally: As other message types have similar characteristics, it would be helpful to analyse these message types too.
Data traffic scenarios	Access	**High**	Done	Data traffic characteristics have to be understood for the most relevant scenarios. The focus should be on the challenging situations (some are already defined). However, there is no focus to over-challenge the technology in the limited time. The reason is that the definition of an "over-challenging" scenario is currently not available and out-of-scope of this paper.	This is one of the concrete results of this work, as it includes the fundamental aspects of the data traffic which were identified during the analysis of CAM measurements.	Additionally: Further work related to other message types would be required or helpful for the better preparation of future NR V2X SL deployments. Work on implementation of message types and related profiles for the different regions.
Number of vehicles	System	**High**	Done	Number of vehicles is to be defined in the relevant (challenging) "close-to-reality" scenarios.	See simulation assumptions. Based on the scenarios and road topologies (incl. expected velocities etc.), we calculated the number of vehicles based on 3GPP's assumptions/guidelines, illustrated in Section 5.	Additionally: Further analysis on new use case-specific scenarios could be done to refine the model for new aspects related to this.
Traffic scenarios	System	**High**	Done	Number of vehicles in specific scenarios related to the relevant use cases.	As for "Number of Vehicles", see simulation assumptions. Based on the scenarios and road topologies (incl. expected velocities etc.), we calculated the number of vehicles, as in Section 5.	
Use case req. CPM	System	**High**	Done		Analysis results were used in the design of the data traffic.	Additionally: further analysis of CPS combined to the implementation of use cases.
Use case req. CAM	System	**High**	Done		Analysis results were used in the design of the data traffic.	Additionally: further analysis on CAS combined to the implementation of use cases.

Use case req. MCM	System	**Medium**	Done		Analysis results were used in the design of the data traffic. Still some questions	
Message size	Facilities	**High**	Partly done	Number of bytes for all message types and scenarios needs to be understood.	Messages size calculation is not implemented. Size of CPM and MCM is currently only assumed.	Open
Group cast Type1	Access	**High**	Partly done	Connection-less and distance-based groupcast allows the usage of controlled HARQ retransmissions and combination to achieve greater efficiency.	The used solution is very simplified. Distance estimation is ideal. Therefor the performance of the Zone feature cannot be evaluated.	General analysis of the "zone concept" and simplified calculation of the zone ID and the effective communication range including GPS quality aspects.
Channel models	Access	**High**	Partly done	Understanding the channel characteristics belongs to the essential knowledge for understanding the performance of NR.	This task is time consuming and requires further resources than available	Literature or 3GPP channel modelling results research.
Communication range	Access	**High**	Partly done	Connection-less and distance-based groupcast uses the communication range QoS parameters to control distance-based re-transmissions. This leads to high efficiency and is unique for NR.	Currently the estimation communication range is not tested.	General analysis of the zone concept and simplified calculation of the zone ID and the effective communication range including GPS quality aspects.
Resource allocation	Access	**High**	Partly done	NR offers an improved RA scheme which might be very useful for challenging automotive direct communication scenarios/ situations (reselection/pre-emption).	Only basic description is considered in this white paper. However, this work does not include a detailed analysis of the resource allocation mechanism.	
Reliability	System	**High**	Partly done	Understanding the mechanism and reliability of services related to NR.	During the discussion and simulation we identified some open questions. It is obvious that the combination of several parameters, such as reliability, large communication range (+300 m) in very limited bandwidths and challenging channel conditions, the current reliability requirements and layer responsibility related to this have to be discussed.	
Latency	System	**High**	Partly done	Latency of a message related to the requirements.		

6 Conclusion, Analysis and Further Consideration

6.1 Conclusion

The central element for successful deployment of automotive services is based on wireless direct-communication technology, which not only supports the current requirements of those services but also is well prepared for future developments. In this work, NR V2X was studied from a service-centric perspective. With its unique set of features, such as distance-based groupcast, NR V2X supports automotive requirements for advanced Day-2 use cases and is well prepared to support future ITS needs. A fundamental aspect in this evaluation is our understanding of the relationship between the V2X services, including special functionalities, and the underlying wireless communication system. This relationship, including NR Sidelink capabilities for V2X, has been analysed and a set of parameters and models derived from selected regional standardisation efforts, ETSI ITS.

> The relationship between the services, messages, NR V2X lower layer parameters and data traffic models have been evaluated according to automotive requirements. Simulation results show that NR V2X technology serves the selected multiplex use cases well.

Ultimately, better understanding is required to configure, evaluate, and implement the access technology used for V2X connectivity solution. This knowledge strongly supports OEMs and other stakeholders in the automotive industry in making correct decisions for successful V2X deployments. Several aspects were also identified and analysed to fill potential gaps towards this deployment.

A novel mapping of services and associated technology aspects had to be developed for an effective NR V2X evaluation to satisfy automotive service requirements. This mapping accommodates the implementation needs of the V2X system and potential use cases better than previous models. The new model is thanks to a review of existing message traffic measurements and larger set of use cases, and more detailed analysis of various traffic scenarios. This helped to develop a deeper understanding of how the different actors in the V2X system chain interlink, such as the mapping between ITS services and message types, different message characteristics for services, and multiplexed data traffic. These aspects are critical to evaluate the capabilities of the radio technology, especially because the link between the service and radio has never been considered in this manner before. These gaps in the conventional evaluation process have addressed in the new model, therefore making the results of the evaluation more expedient.

New evaluation aspects have also been considered for multiplexing use cases and services in a channel. This starts with initial "realistic" automotive evaluation assumptions, then mapping them to the detailed simulation model. For each evaluation, a set of useful QoS parameters has been indicated together required evaluation KPIs. Furthermore, the analysis identified several data traffic models and their corresponding message flow characteristics, which fit the selected automotive services and use cases.

Finally, a novel simulation methodology has been considered emulating the different multiplexed services in the channel with their different data traffic models, mobility characteristics and environmental requirements. In addition to the different multiplexed services, basic and continuous data traffic (i.e., awareness messages) are considered. The indicated system-level simulations were conducted by two independent sources factoring in the identified methodology in this analysis. The results of the two sources were consistent and indicated that NR V2X is meeting the performance requirements of the V2X advanced use cases in complex scenarios. Furthermore, the results of the multiplexed scenarios showed that the selected bandwidth and traffic density achieved the requirements of the different scenarios and use cases.

Nevertheless, this study identified some gaps related to analysis and simulation capabilities, including limited time/budget for this work and the development status of the contributors' tools. These open issues, listed in the next section, need to be discussed in future steps towards the deployment of NR Sidelink for V2X services.

6.2 For Future Consideration

Due to the high complexity of the system and limited timescales for NR V2X Evaluation activities in 5GAA, there are some open questions/topics related to radio performance aspects that need further investigation and analysis, including:

- Evaluation of aperiodic and periodic messages multiplexed in a channel, where the evaluation of aperiodic traffic (together with periodic traffic in the same channel) is very difficult and requires further analysis, e.g., evaluating whether aperiodic traffic can be covered by the remaining resources (so-called "headroom").
- Missing implementation related SLRs such as communication range, reliability, etc.
    - For reliability, it is not clear how to link the achievable or required radio layer reliability values directly (e.g., in PRR or PER) to the required reliability (SLR) specs associated with certain use cases and user stories.
    - For communication range, parts of the decision process are either not defined (e.g., number of vehicles within the communication range that missed a packet) nor decisive lower-layer performance aspects such as e.g. zone ID based distance estimation quality which could not be modelled.
- Analysis of the performance of specific aspects, such as container dependency in message types with variable size (e.g., CAM), for instance:

How to report on MCS used in evaluation; and how to use the unique NR V2X Sidelink features, such as as distance-based groupcast, in contrast to typically broadcasted messages for radio technologies which do not have such capabilities.

- Possible field measurements, feedback from realistic experience or existing deployments were not available when this work was being carried out; all of which could have helped to better understand the limitations and functions of the system under real-time conditions.
- Use cases requiring aperiodic transmission: In V2X use cases, DENM traffic is considered to be very difficult to track and analyse. Therefore, it was important to apply analytical analyses to evaluate situations when DENM (or other aperiodic messages) need to be multiplexed in a channel. When the channel is not congested (e.g., there is headroom for more transmission), DENM can safely fit in the channel. Therefore, an analysis based on calculations of congestion control and remaining headroom of resources could be a way forward. This also requires additional analysis of potential DENM/aperiodic messages sizes, and priority (based on QoS) and triggering conditions. This needs to be considered for further evaluation.

Annex <A>Data Traffic Modelling

Different data traffic types are identified based on 5GAA documented use cases/ user stories and their service level requirements. For the sake of simplification, the different traffic models are enumerated and given the decisive evaluation parameters, as follows:

- 5GAA traffic model Type: v2vTType-X (where X will be listed in numbers from 1 to N)
  - Message traffic unique ID: **v2vTType-#**
  - Inter-packet Interval time in ms, or message rate in Hz: **Rate** in Hz or ms
  - Message size: **MessageSize** in Bytes
  - Latency budget requirement: **Latency** ms
  - Periodicity model: Periodic/Aperiodic

A.1 Urban and Highway Data Traffic Identifiers

Table A-1: Urban intersection traffic fragmentation according to use case(s), possible message types, or road scenarios

Traffic cat.	Possible use case(s)	Possible message type	Notes
v2vTType-10	100% of vehicles are able to send/receive baseline traffic	CAM	Adapt the realistic proposals in [23]
v2vTType-21	Group start	MCM	v2vTType-21 is used for all three phases of group start; where possible discovery and/or attachment procedures can be done using, e.g., baseline CAM
v2vTType-23	Group start or cooperative merging into intersection	MCM	Additional data traffic for group start with longer reservation period/low latency requirements; the traffic type can be used in cooperative merging into intersection
v2vTType-24	Vehicle decision assist	MCM, DENM	Aperiodic traffic (dynamic reservations)
v2vTType-25	Sensor sharing	CPM	Linked to sensor sharing, CPS services

Table A-2: Highway traffic fragmentation according to use case(s), possible message types, and/or road scenarios

Traffic cat.	Possible use case(s)	Possible message type	Notes
v2vTType-11	100% of vehicles are able to send/receive baseline traffic	CAM	Adapt the realistic proposals in [23]
v2vTType-32	Vehicle decision assist	MCM, DENM	Only aperiodic data traffic
v2vTType-33	Cooperative manoeuvres/ cooperative lane merge	MCM	Considering the autonomous vehicle manoeuvres in emergency situations [3]
v2vTType-34	Sensor sharing and CPS services	CPM	Linked to sensor sharing, CPS services

Note: CAM priority does not change based on the groupcast.

A.2 Urban and Highway Data Traffic Parameters

Table A-3: Traffic type fragmentation according to use case(s), possible message types, and/or road scenarios

Message traffic unique ID	Parameters	Comments
v2vTType-10 (Urban)	▸ **Speed 1:** 30 km/h and **Speed 2:** 50 km/h ▸ **Rate 1:** 200ms (or 5 Hz)and **Rate 2:** 500ms (or 2 Hz) ▸ **MessageSize 1:** 190 bytes with probability of 0.3, 350 bytes with probability of 0.4, 450 bytes with probability 0.3 ▸ **MessageSize 2:** 190 bytes with probability of 0.3, 300 bytes with probability of 0.3, 450 bytes with probability 0.3, 600 bytes with probability 0.1 ▸ **Latency 1:** 200 ms or **Latency 2:** 500 ms ▸ **Traffic type:** Periodic ▸ **Cast Type:** Broadcast	Urban intersection (with, at least, two scenarios for different speeds, 30 and 50 km/h)
v2vTType-11 (Highway)	▸ **Speed 1:** 70 km/h and **Speed 2:** 130 km/h ▸ **Rate 1:** 200 ms (or 5 Hz) and **Rate 2:** 100 ms (or 10 Hz) ▸ **MessageSize 1:** 190 bytes with probability of 0.3, 350 bytes with probability of 0.4, 450 bytes with probability 0.3 ▸ **MessageSize 2:** 190 bytes with probability of 0.3, 300 bytes with probability of 0.3, 450 bytes with probability 0.3, 600 bytes with probability 0.1 ▸ **Latency 1:** 200 ms or **Latency 2:** 100 ms ▸ **Traffic type:** Periodic ▸ **Cast Type:** broadcast	Highway (with, at least, two scenarios for different speeds, 70 and 130 km/h)

According to NR V2X WI in WG1, the following values have been conducted accordingly (i.e., considering manoeuvre requirements) and spectrum sharing study, Table 1.1 [7].

Table A-4: Urban intersection traffic models: related to manoeuvre, coordinated driving and sensor sharing

Message traffic unique ID	Parameters	Comments on possible use case(s)	Possible message type (ETSI)
v2vTType-21	▶ **Rate:** 50 ms (or 20 Hz) ▶ **MessageSize :** 300 bytes ▶ **Latency :** 50 ms and (optionally **Latency:** 10 ms) ▶ **Traffic type:** Periodic ▶ **Cast type:** Groupcast	Urban intersection (with, at least, two scenarios for different speeds, 30 and 50 km/h) Can be linked to group start (short period)	MCM
v2vTType-23	▶ **Rate:** 50 ms (or 20 Hz) ▶ **MessageSize:** 300 bytes ▶ **Latency:** 50 ms (10 ms is optional) ▶ **Traffic type:** Periodic ▶ **Cast type:** groupcast	1- Referring to group start, use case 13 in Table 1.1 [7], i.e., with a long periodicity 2- Can be linked cooperative merging into intersection	MCM
v2vTType-24	▶ **Rate:** Inter-packet arrival time; 100 ms and an exponential random variable with the mean of 100 ms ▶ **MessageSize:** between 800-1200 bytes (Bosch adapting the value in [4] to fit 3GPP V2X evaluation assumptions) ▶ **Latency:** 100ms ▶ **Traffic type:** Aperiodic [similar to [3]] ▶ **Cast type:** Unicast	[Referring to Vehicle Decision Assist (use case 43 in [7, Table 1.1] and user story #4 Slow Vehicle on Route "Urban" in [4], V2V) Can be linked to aperiodic Vehicle Decision Assist with aperiodic traffic	MCM, DENM
v2vTType-25	▶ **Rate:** 100 ms (or 10 Hz) ▶ **MessageSize:** 600 bytes ▶ **Latency:** 100 ms ▶ **Traffic type:** Periodic ([7] Table 1.1) ▶ **Cast type:** Broadcast	Adapted from use case 9a in [7], Table 1.1 Sensor Sharing for Autonomous Vehicles. Can be linked to sensor Sharing, CPS services, with very limited size of data: e.g., - with sufficient CAM/BSM transmission or limited channel bandwidth - pre-processed data and/or limited number of objects	CPM

Table A-5: Highway traffic models: related to manoeuvre and coordinated driving

Message traffic unique ID	Parameters	Comments on possible use case(s)	Possible message type (ETSI)
v2vTType-32	▸ **Rate:** Inter-packet arrival time; 50 ms and an exponential random variable with the mean of 50 ms ▸ **MessageSize:** between 800-1200 bytes (in [4] to fit 3GPP V2X evaluation assumptions) ▸ **Latency :** 50 ms ▸ **Traffic type:** Aperiodic [similar to [3]] ▸ **Cast type:** broadcast/ groupcast/unicast	Referring to Vehicle Decision Assist (use case 43 in [7] Table 1.1 and user story #4 Slow Vehicle on Route "Highway" in [4], V2V) Can be linked to Vehicle Decision Assist A periodic high latency	MCM DENM
v2vTType-33	▸ **Rate:** 100 ms (or 2010 Hz) ▸ **MessageSize:** 300 bytes ▸ **Latency:** 50ms (10ms100ms (50ms is optional) ▸ **Traffic type:** Periodic (relaxed from Aperiodic) ▸ **Cast type:** Groupcast	Referring to Vehicle Decision Assist (use case 18 in [7] Table 1.1 and user story #1 Cooperative Lane Merge on "Highway" in [4], V2V) Can be linked Cooperative Manoeuvres/ cooperative lane merge (when relaxed to periodic messages) of Autonomous Vehicles in Emergency Situations	MCM
v2vTType-34	▸ **Rate:** Inter-packet arrival time; 50 ms and an exponential random variable with the mean of 50 ms ▸ **MessageSize:** 600 bytes ▸ **Latency :** 100ms ▸ **Traffic type:** Aperiodic [similar to [3]]	Can be linked to sensor sharing, CPS services with limited sensor sharing for limited Bandwidth, e.g., 20 MHz, and assuming enough CAM transmission (100%, or all vehicles can send CAMs)	CPM

Annex <B>Communication Range Analysis

B.1 Communication Range Analysis

NR-SL groupcast using “communication range” offers another opportunity for reliable and efficient communication between vehicles in a very localised manner. V2X services and use cases need reliable communication within a predefined range related to the transmitting vehicle. Unfortunately, relying on a preconfigured MCS in broadcast mode has the drawback that in some channel state scenarios vehicles even within a required minimum range cannot be reached. In order to improve the reliability of the communication is such cases the usage of range combined with HARQ can be good solution.

This overview presents and discusses some of the range-related aspects, potential benefits of distance-based groupcast and the challenges.

To understand the need for a communication range SLR, a fundamental relationship between the services and NR performance has to be taken into account. V2X use cases and services require information shared between vehicles in the vicinity of the transmitter vehicle (see example in Figure B-1, below). From this figure, some basic characteristics can be identified which motivate distance-based groupcast:

a) Minimum communication range where vehicles need to be informed to ensure the proper operation of the used function.

b) Area outside the minimum communication range where vehicles can be informed but there is no reception rate requirement.

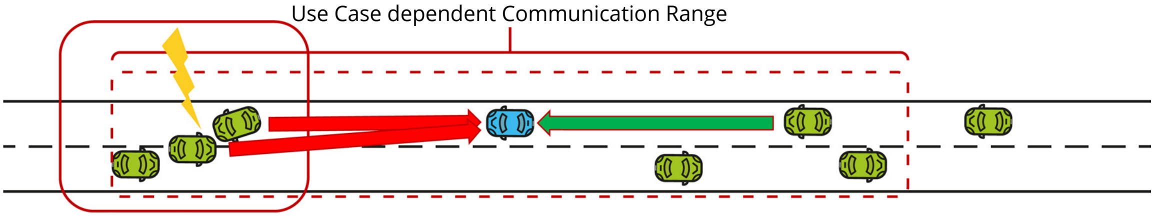

Figure B-1: Use case dependent communication range

Figure B-2 illustrates a potential approach (as shown in [2]) which helps to clarify and better define a formula for the communication range.

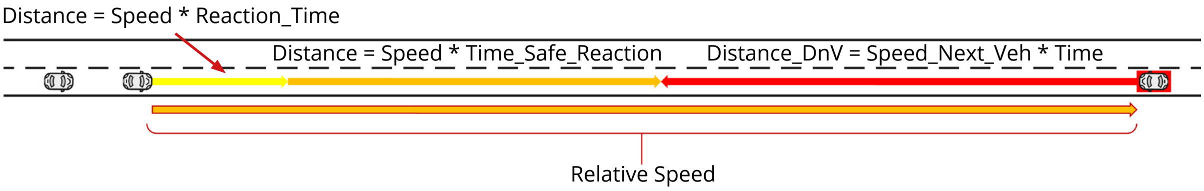

Figure B-2: Definition of range based on [2]

As in Table B-1 the range is calculated by adding two distances.

- Distance travelling during the reaction time of the driver.
- Distance travelling during the safe reaction of the driver

Table B-1: WG1 range definition [2]

SLR title	SLR Unit	SLR value	Explanations/reasoning/background
Range	[m]	220	Assuming oncoming traffic with maximum velocities of 100 km/h on highways (resulting in 200 km/h relative speed), reaction time (750 ms) + safe reaction distance (3 s): 55 m/s*4 s = 220 m

As different V2X direct communication-based services impact the use cases and traffic scenarios differently, the services also require different (communication) ranges. As also indicated in the figure below, several use case types can be (or are) performed in relatively short areas (e.g. below 100 m). Knowing that those use cases require data elements such as position, path history, velocity etc., it can be assumed that the range for a message type such as e.g. CAM needs to be available for all of these use cases.

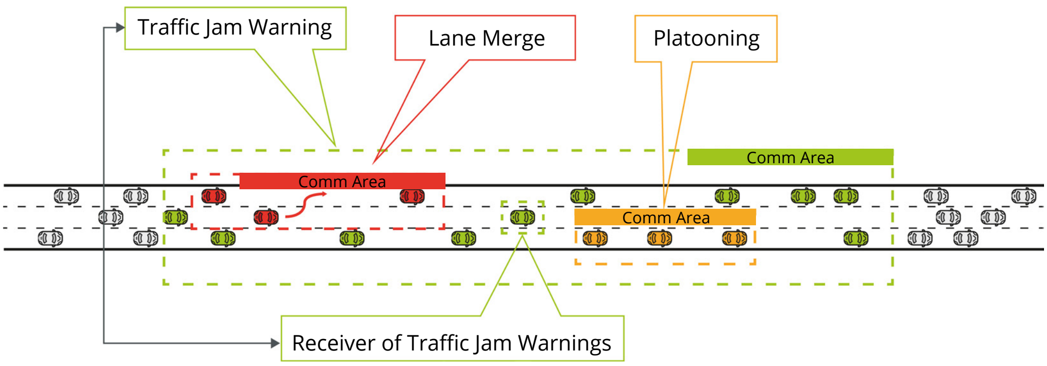

Figure B-3: Simplified illustration of the relations between required minimum communication range and use cases

With this assumption, a definition of a single communication range in a system profile has to be set by a profile, as indicated in Figure B-4.

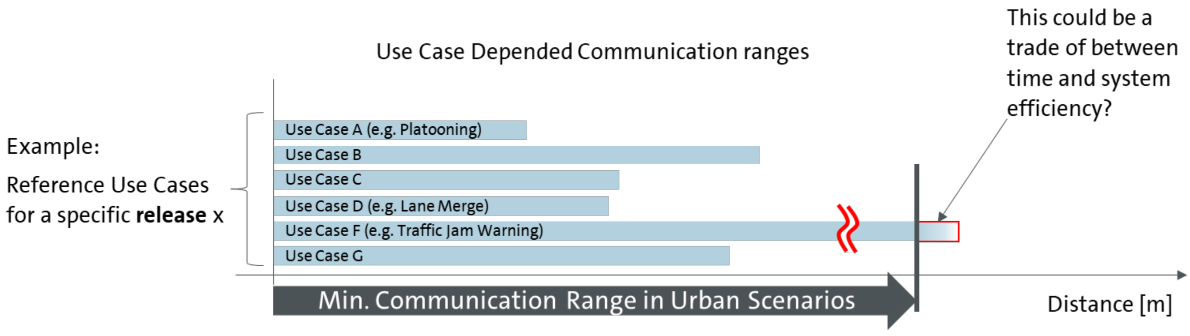

Figure B-4: Simplified illustration of a definition process for a communication range profiling parameter

The MCS should usually be adjusted to achieve the required range because of the relations between the MCS and the receivers minimum sensitivity. NR SL groupcast offers an additional feature to be used for this purpose. A simple overview of this is presented in the figure below. NR uses a so-called "zone structure" to localise the UEs related to each other. As the UEs know their GPS position also used in the communication layer, each UE is able to translate that position related to the structure of square zones (size of the squares is defined by ZoneSize). 3GPP defined a formula which assigns the position to a zone and to a related so-called "ZoneID" (see Table B-2 below).

Table B-2: Zone ID calculation – see Clause 5.8.11 in TS 38.331 [20]

Assumptions for zone configurations	Calculations of zone ID
▸ 2nd – stage SCI includes the required commination range and the TX UE's zone ID ▸ Zone ID is 12 bits long ▸ Area can be divided into 2^12 squared regions of equal size ▸ TX UE's zone ID indicates the zone in which the TX UE is located ▸ Required communication range is represented with 4 bits using a set of 16 (pre-) configured values that can be selected out of a defined set of possible values ▸ The sides of the zones are configurable per required communication range and resource pool and can be equal to 5, 10, 20, 30, 40 or 50 m	Formula: ▸ x1= Floor (x / L) Mod 64 ▸ y1= Floor (y / L) Mod 64 ▸ Zone_id = y1 * 64 + x1 Examples "Super Zone" size: a) 320 m for L = 5 b) 1280 m for L = 20 c) 1920 m for L=30

This zone ID is sent with each message. For instance, a CAM message packet also contains the *tx ZoneID*, which can be used to estimate the distance between the rx and tx.

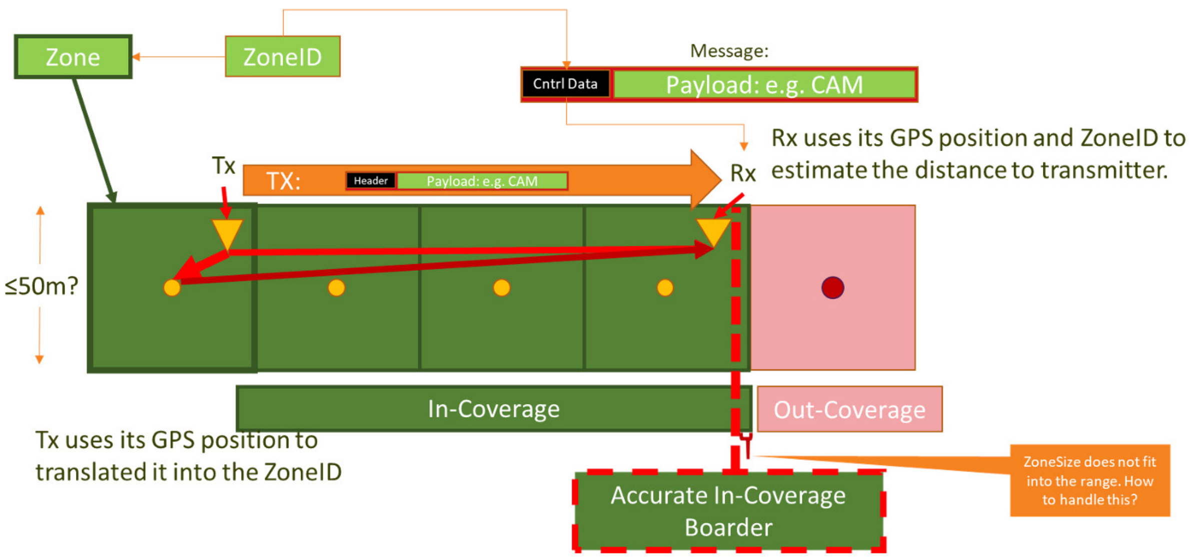

Figure B-5: Simplified zone concept for distance-based groupcast

As several factors in the range calculation are erroneous (GPS estimation and space quantification of the zone concept), the distance estimation experiences two error cases, as illustrated in Figure B-5 and B-6.

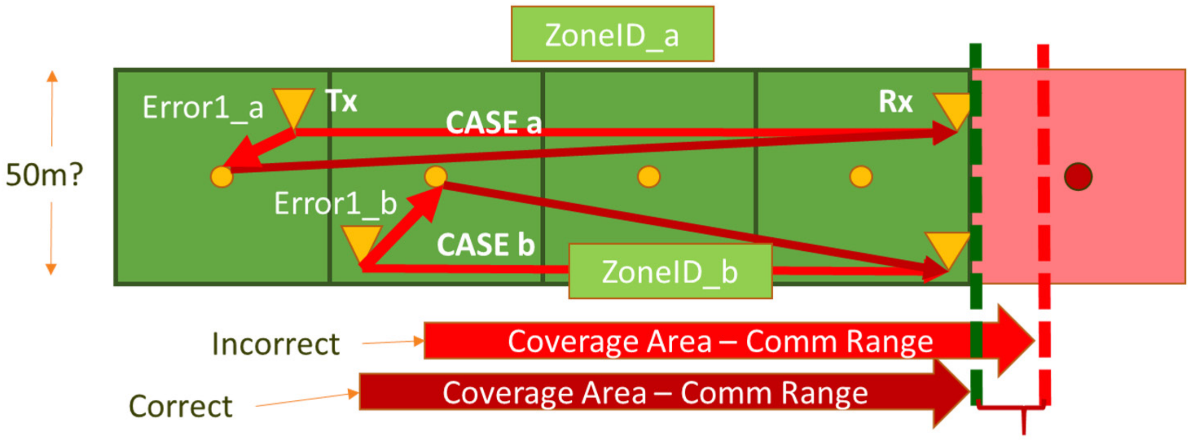

Figure B-6: Potential error cases of zone concept for distance-based groupcast

It is per definition that a zone size does not fit into a required range. In case A, we might lose a UE whereas in case B, we get “false-positive” decision. Unfortunately, in situation B we can expect more NACK feedback from vehicles out of the communication range. Additionally, it can be expected that this type of vehicles will transmit more NACKs than needed.

Also, as the zone concept is defined within the limited space of a “super zone” and repeats every 64 squares, another potential error can cause performance loss by missing vehicles. However, this can be avoided by properly adjusting the zone size, which also impacts the accuracy of the tx position.

B.1.1 Evaluation of the Distance-Based Groupcast Feature of NR Sidelink for V2V

In theory, this approach is promising to increase the reception rate (i.e., reduction of message loss) in a predefined distance, referring to the transmitting UE/vehicle. This should be much better than a “sensitivity-based coverage approach”. It requires a proper configuration and profiling related to the needs of the service (i.e., the zone size in particular).

Unfortunately, the required coverage area/distance is not sufficiently defined, e.g. it is not clear how many vehicles have to be reached within a set distance. This issue relates to the technology which cannot guarantee 100% “reachability” every time and everywhere.

The general evaluation status:

- Currently, we cannot assess the performance of this feature as there is no full implementation of all required sub-functions of this process in the simulation environments. We also don’t know the impact of GPS position and ZoneID estimation errors, for instance.
- Currently we don’t know the performance benefit of the distance-based groupcast approach compared to the sensitivity-based approach.
- Profiling seems to be more complex because of the additional degree of freedom.

A proposal would be to define a distance-based reachability probability requirement (e.g., in a distance of 300 m 90% of the vehicles can be reach with an reception rate of 95%). This parameter can be used to better evaluate the performance of this feature. Additionally, it would be required to understand the usefulness of this concept for V2V communication-based services.

Annex <C> User Story Simulation Abstraction

C.1 Use Case Messaging Traffic Description

To evaluate the use cases in a way that the simulation of abstracted traffic can be realised, some implementation aspects and the detailing of the user stories are necessary. The approach taken for all the use cases used for the evaluation is presented here based on the use case UC2 Coordinated Cooperative Driving Manoeuvre (CCDM) with the implementation of lane merge.

C.1.1 CCDM Description

The CCDM use case enables a multitude of manoeuvres, therefore requiring a deeper description and separation into a refined use case. CCDM enables the coordination of manoeuvres overall, but for the purpose of this evaluation, the implementation of a lane merge is considered.

An autonomous or semi-autonomous vehicle on a merging ramp detects the need to coordinate its lane merge (Figure C-1). To permit smooth integration of the host vehicle (HV) into the traffic stream, it coordinates its movement with the vehicles already in the lane. By indicating its intent, the remote vehicles (RV) can decide whether to participate and accept the proposed manoeuvre. The HV subsequently confirms the manoeuvre, and the vehicles execute their movements.

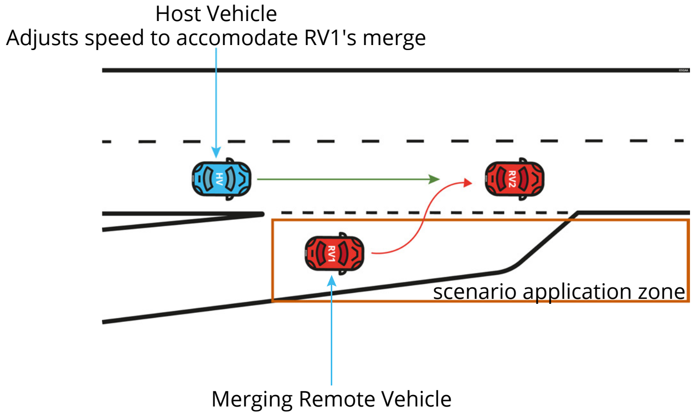

Figure C-1: Visualisation example of the lane merge process

Table C-1: CCDM overview of main attributes and requirements

Description	Requirement	Comments
Road environment	Intersection/urban/highway	Depending on the location of merging lane, the use case can take place in different environments
Vehicle roles	Acting in a group	Host vehicle and remote vehicle in groupcast, HV takes group lead role; the communication across these vehicles is necessary to achieve the use case; other actors are not explicitly needed but could be informed for general information purposes
Event flow selected	Decentralized Solution, use case driven by the HV (merging vehicle)	V2V use case phases: 1. Group formation and negotiation 2. Manoeuvre execution 3. Group release
Relevant service-level KPIs	Confidentiality Service level latency Service level reliability Group communication reliability	These SLRs are relevant for the evaluation in this use case

C.1.2 CCDM: Lane Merge User Story 1 (Urban Intersection)

In this user story the self-driving or semi-automated vehicle initiates the manoeuvre in or at an urban intersection. The behaviour of the vehicles is influenced by their intention to reach the right lane to either turn or go straight, but also the merging lane length is drastically shortened compared to other road environments. The type of traffic expected in such an intersection also differs; vehicle speeds are much slower than on highways, and different road users influence the vehicle behaviour. This user story is not evaluated in the study, however it is useful in evaluating a merge in an urban environment.

C.1.3 CCDM: Lane Merge User Story 2 (Highway)

In this user story the self-driving or semi-automated vehicle initiates the manoeuvre on a highway. The behaviour of the vehicles is mainly influenced by the traffic density and the vehicle speeds. A varying factor however is the length of the on ramp, which can require fast negotiation of the use case to avoid a stand-still of the merging vehicle. This use story is used in the evaluation with the multiple on-ramp simulations.

C.1.4 Implementation of CCDM

As considered in [5] CCDM Lane Merge can be broken down into three distinct phases:

Phase 1 (group forming and manoeuvre selection):

- Here the host vehicle communicates to a number of remote vehicles, announces its intention to perform a lane merge, shares relevant information, and seeks their cooperation.
- The remote vehicles signal their willingness (or not) to cooperate with the merging vehicle. Its positive response also contains RV requirements.
- The HV confirms the execution of the manoeuvre, and the RVs state their

reception and confirmation.

Phase 2 (manoeuvre execution):

- The manoeuvre start message is communicated from the HV to all surrounding road users, informing them of the manoeuvre.

When the merge location and time is reached, the vehicles provide the space for the merge as agreed.

- The vehicles execute the manoeuvre and survey the environment.

Phase 3 (group dissolution):

- After the vehicles have completed their movement the use case is finished, and the group is dissolved.

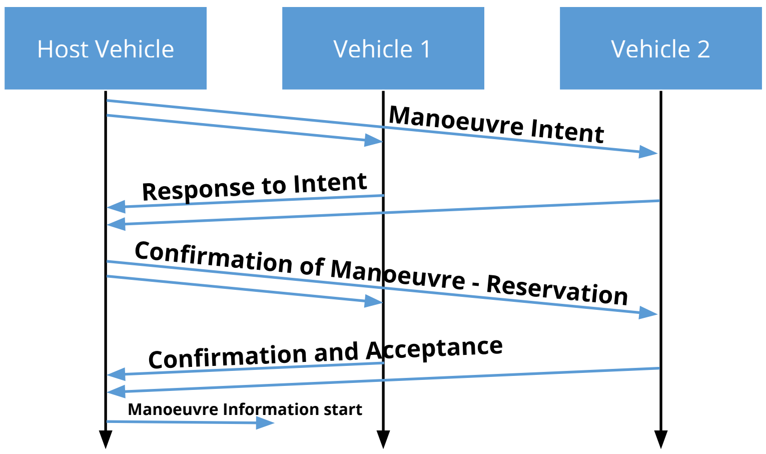

Figure C-2: CCDM messaging protocol overview.

1) A vehicle needs to merge from an on-ramp and identifies potential participating vehicles.
2) The vehicle communicates the merging intent (with use case conditions) to the potential participants.
3) The potential participants confirm/reject their participation in the use case (with proposed conditions).
4) The merging vehicle reconfirms to all the participants that the use case is taking place under the indicated conditions.
5) The participating vehicle reconfirms the correctness of the manoeuvre and their participation.
6) The vehicle broadcasts the manoeuvre to surrounding vehicles to inform them.
7) The further steps do not require use case-specific messaging, instead use existing messaging:
   a) The vehicles individually track the movements of the participating vehicles with beacon messages.

As presented above, Cooperative Lane Merging relies on V2V communication. Much of the information required with regards to the use case is communicated via dedicated messages. During the manoeuvre phase, however, the messaging is covered by cyclic communication such as CAM/BSM.

As shown in the message exchange, a minimum of three vehicles is required, further remote vehicles are supported, but optional. The message traffic load would therefore increase with every further vehicle. However, only the merging lane users should be involved. On a multilane-road, the further lanes can be ignored for the implementation.

Table C-2: CCDM message requirements per phase

Requirements	Message per link	Message type	Details (including message priority, generation rules, message sizes, etc.)
Phase 2	Continual repetitive V2V messages: broadcast/groupcast	CAM/BSM,	300 B messages at a repetition rate of <= 10 Hz using continual/periodic broadcast transmission and a latency budget of T=100ms
Phase 1	Event triggered V2V messages: broadcast/groupcast/unicast	DENM, MCM	300 B messages as a single burst or as a: 1st Message: 173 bytes 2nd message: 188 bytes 3rd message: 29 bytes 4th message: 29 bytes Using groupcast and a latency budget of T=20 ms

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