ITN-5VC

Integrated Telematics for Next Generation 5G Vehicular Communications

ITN-5VC D2.1

Report on the initial proposal for the new multi-band/link system simulation

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Executive summary

This deliverable describes an initial framework of the consistent multi-band/multi-link system simulation. The objective of these simulations is to evaluate the performance of cooperative data communication and sensing tasks among vehicles as well as infrastructure under dynamic systems settings. Since the ESRs involved in WP2 are working on the different OSI layers, their simulation parameters will be different from one another and thus they will use different simulation tools and software to simulate a multi-link road traffic scenario.

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List of acronyms and abbreviations

3GPP	3rd Generation Partnership Project
5G NR	Fifth Generation New Radio
B5G	Beyond 5G
C-V2X	Cellular Vehicle-to-Everything
Com-Rad	Communication & Radar
ESR	Early-Stage Researcher
I2N	Infrastructure-to-Network
KPI	Key Performance Indicator
LTE	Long Term Evolution
MAC	Medium Access Layer
MCS	Modulation Coding Scheme
OSI	Open System Interconnection
PDCP	Packet Data Convergence Protocol
PSCCH	Physical Sidelink Control Channel
PSSCH	Physical Sidelink Shared Channel
RLC	Radio Link Control
SCI	Sidelink Control Information
SDAP	Service Data Adaptation Protocol
TUIL	Technische Universität Ilmenau
UPV	Universidad Politécnica de Valencia
V2I	Vehicle-to-Infrastructure
V2N	Vehicle-to-Network
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
QoS	Quality of Service
WP2	Work Package 2

1 Introduction

Work Package 2 (WP2) of the ITN-5VC focuses on the enabling technologies for advanced data communication and cooperative sensing for autonomous vehicles by integrating 5G V2X technologies with the existing and future cellular mobile communication networks. To achieve this goal, the evaluation of cooperative communication and sensing tasks under dynamic vehicular communication channel settings must be required. Moreover, to realize this dynamic exchange of information in Cellular Vehicle-to-Everything (C-V2X) systems, a multi-band/multi-link system model is derived, analysed, and verified through simulations. To this end, WP2 aims to research and provide the enabling building blocks of evaluation methods at link and system level. So that a consistency between multiple bands, links, nodes, and events including interacting objects (as blocking vehicles) can be ensured.

WP2 consists of ESR 5, ESR 6 and ESR 8 from Technische Universität Ilmenau (TUIL), Universidad Politécnica de Valencia (UPV) and BOSCH respectively. The tasks assigned to each ESR are as follows:

- ESR 5 – 5G New Radio (NR) based cooperative communication and localization – needed to develop new sensors data management and fusion techniques for improved object detection.
- ESR 6 – 5G enabling technologies for hybrid and interoperable 5G V2X/cellular networks allowing range extension – dealing with the integration of legacy communication technologies. Basic feedback is location designed by ESR5.
- ESR 8 – Reliable communication for dense vehicular networks – Describing the Quality-of-Service (QoS) in terms of reliability and latency via simulations under different relevant scenarios utilizing AI/ML functions. System simulator will be harmonized between ESR 5, 6 and 8, whereas ESR 4 channel models will be used.

In this report, deliverable D2.1 of the ITN-5VC is discussed whose main objectives are as follows:

- Presenting OSI Model and standards of the future 5G-NR autonomous vehicular communication.
- Identification of the simulation tools and software to be used by ESRs involved in WP2:
- Providing an initial system simulation framework for the multi-band/multi-link V2X communication.
- Identification of the evaluation parameters and performance metrics in the simulation framework.

2 OSI Layers and Protocol stack of Autonomous Vehicular Communication

The automotive industry has developed several standards to support future ITS applications. These standards are well accepted and followed by the standardization organizations and the academic community. The 3rd Generation Partnership Project (3GPP) has developed the standards for C-V2X, the first C-V2X standards were based on the 4G Long Term Evolution (LTE) air interface and were developed in Release 14 and enhanced in Release 15. 3GPP has developed a new cellular V2X standard based on the 5G NR (New Radio) air interface in Release 16. Figure 1 shows the OSI layers and protocol stack used in autonomous vehicular communication for this standard. Layer 2 of the new radio protocol stack is divided into four sub-layers: Media Access

Control (MAC), Radio Link Control (RLC), Packet Data Convergence Protocol (PDCP), and Service Data Adaptation Protocol (SDAP).

The main functions and tasks of each OSI layer in autonomous driving systems are briefly described below:

Application Layer: The application layer includes various types of messages that are used by vehicles to enable different ITS applications. It includes message formats, message coverage range and message arrival times. An example of such messages is Cooperative Awareness Messages (CAMs) or Basic Safety Messages (BSMs).

Facility Layer: The facilities layer provides data structures for vehicle sensor data maintenance, filtering, and aggregation of received traffic information messages and communication session management.

Transport Layer: The transport layer provides services such as end-to-end delivery, reliable data transfer and congestion mitigation.

Network Layer: The network layer handles routing of data from the source vehicle to the destination vehicle, multi-hop broadcast communications for Decentralized Environmental Notification Messages (DENMs) and data dissemination to a particular geographical area.

MAC Layer: The MAC layer is a sublayer of the data link layer. The MAC protocols specify the ways in which different nodes share the vehicular communication channel. It allocates use of shared channels among vehicles, networks, and road infrastructure. The other functions include frame delimiting and recognition, addressing, transfer of data from upper layers, error protection (generally using frame check sequences) etc.

PHY Layer: The physical layer is responsible for the most significant tasks in vehicular communication such as modulation design, waveform design, resource allocation, vehicular channel characterization and modelling, channel parameter estimation etc.

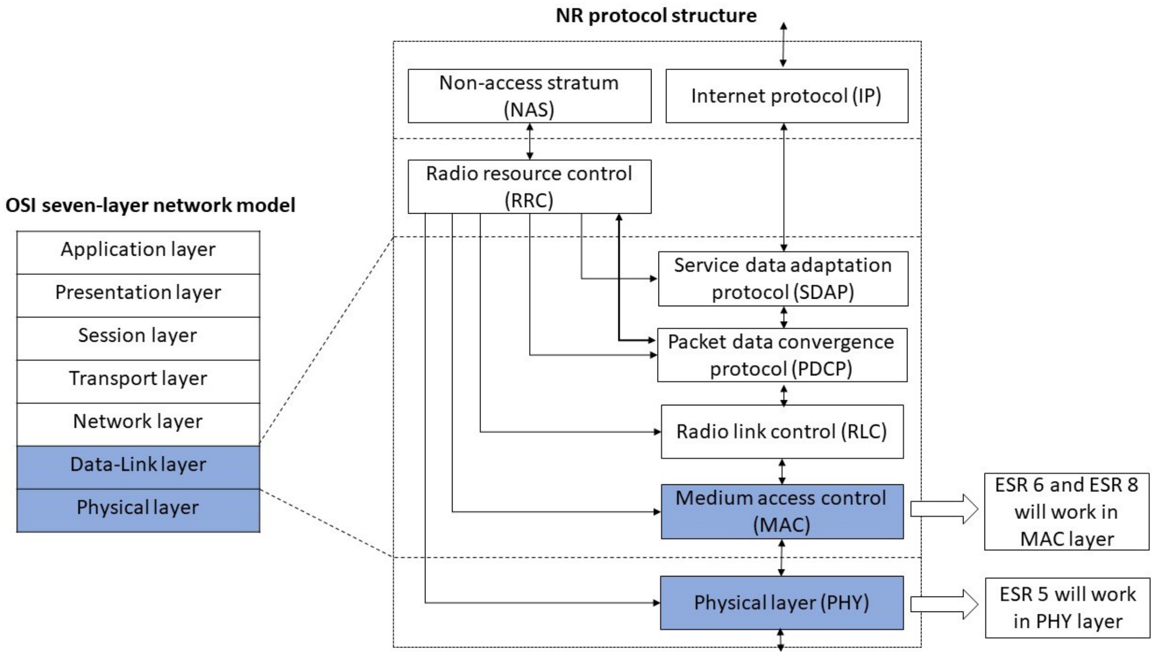
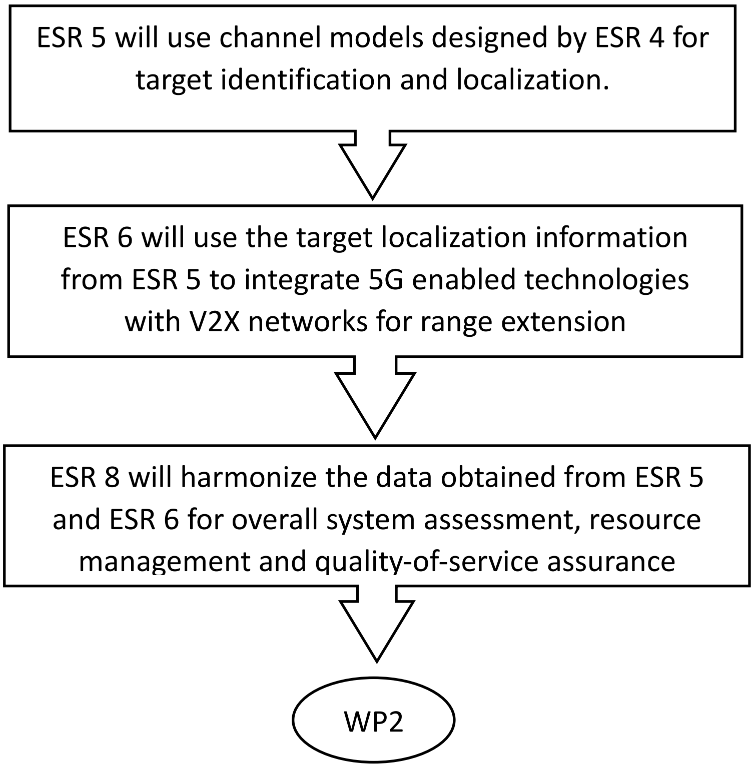


Figure 1. ESRs' respected OSI Layers and Protocol stack

3 Simulation Tools and Software Used

The nature of work of the ESRs of WP2 is different from one another. However, their tasks are not completely independent; rather they will jointly work to achieve the goals of WP2 as shown in the following workflow diagram.



Based on their work requirements and framework, all ESRs will perform different simulations at the corresponding OSI-layers. The further details on the ESRs' work description and the simulation tools to be used by them are discussed below.

3.1 ESR 5 Simulation Tools (TUIL)

ESR 5 aims to develop a joint communication and radar (Com-Rad) architecture that can be incorporated into a distributed 5G/B5G network to extend road traffic situation and awareness. In view of this, ESR 5 will have to use the radio and network resources in such a way that an optimized performance for both the radar and communication systems can be achieved. In particular, the focus will be on cooperative bi/multi-static high resolution target parameters estimation based on 5G and beyond 5G waveforms. Apart from that, ESR 5 will also work on sensor data management and fusion techniques for improved objection detection.

To validate the performance of the joint communication and sensing (JCAS) framework, different performance metrics and parameters of both communication and radar will be evaluated. The performance metrics for JCAS include, but not limited to, bit error rate (BER), multiuser interference (MUI), CRLB for waveform optimization, probability of detection etc. The evaluation of these metrics will ensure a better trade-off between communication and radar sensing. Similarly, the key parameters to be estimated include propagation delay, Doppler-shift, Angle of Arrival, Angle of Departure, and amplitude target reflections. Since these parameters belong to the PHY layer of the OSI model, ESR 5 will perform different simulations at the physical layer. He will be using software such as Python and MATLAB for modelling and simulating the JCAS framework.

As a proof of concept, a simple V2V JCAS framework is modelled and simulated in Python, in which a moving vehicle, in the presence of some static scatterers, communicates with another moving vehicle while simultaneously sensing the range and velocity of the second vehicle as shown in Figure 2. In this framework, both radar and communication parameters have been estimated: delay and doppler shift for radar target while data decoding at communication receiver. This can be shown in Figure 3a and 3b. For the sake of simplicity, no interference from other communication-only transmitters has been considered to validate the performance of the JCAS framework.

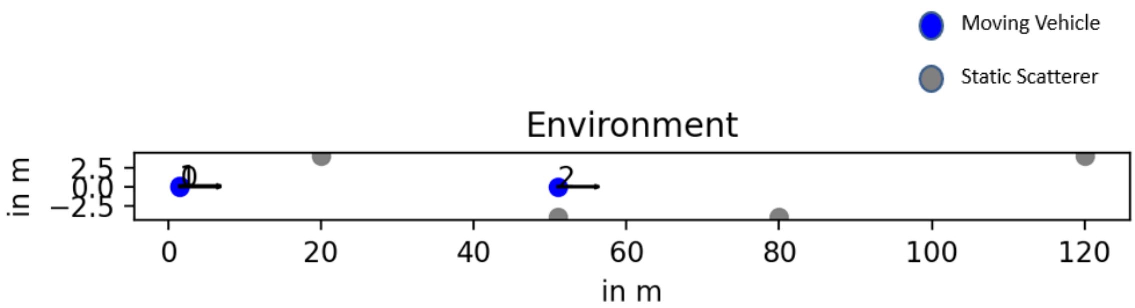


Figure 2: JCAS Simulation Environment

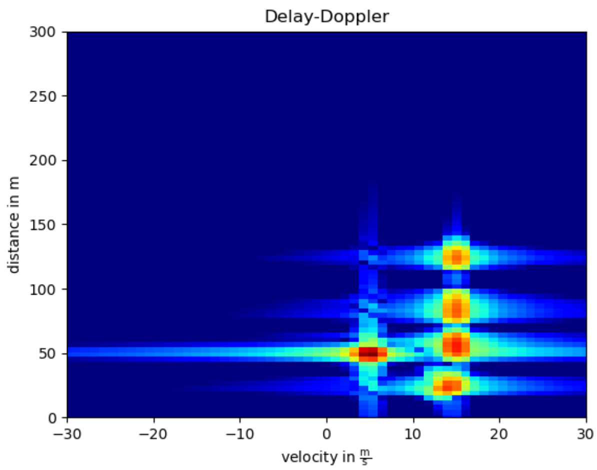


Figure 3: Delay Doppler Map

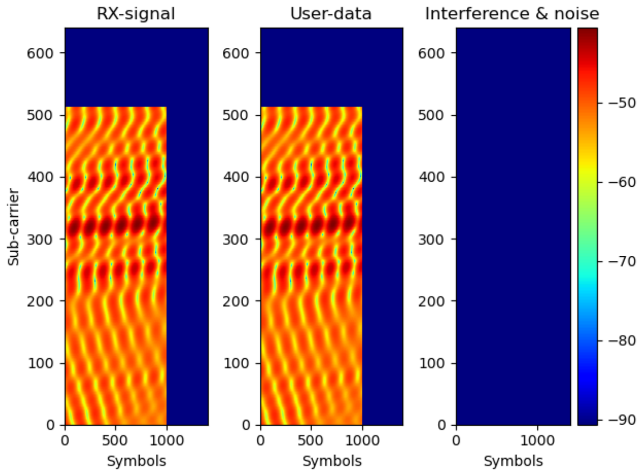


Figure 4: User Data Encoding

3.2 ESR 6 Simulation Tools (UPV)

In the case of ESR 6, she aims to extend 5G V2X enabling technologies to extend the reach of such networks and complement them with additional capacity even in challenging environments. In particular, ESR 6 will seek to optimize the reliability and robustness of hybrid V2X/cellular networks by aligning already standardized interfaces to achieve network interoperability, and ESR 6 will also work on the design of range extension solutions that are suitable for increasing the robustness of cellular V2X.

In order to design new enabling technologies that can cope with the expected requirements for future vehicular services, specific simulation tools are needed to evaluate system performance from an end-to-end perspective. Therefore, ESR 6 will use ns3 for most of the system simulations, as ns-3 is one of the most popular open-source simulation tools. It is the natural evolution of ns-2 and has a large community supporting its development. In addition, in recent years, ns3 has included the 5G-LENA simulator, which is a New Radio (NR) network simulator designed as a pluggable module to ns-3 for 5G (1).

ESR 6 will use this simulator in most of its simulations since 5G-Lena offers an extension to the NR module: the NR V2X extension, intended for vehicular communications. The NR V2X extension includes support for NR frame structure, the Physical Sidelink Control Channel (PSCCH) and the Physical Sidelink Shared Channel (PSSCH) multiplexing, resource allocation for NR V2X using mode 2 (autonomous resource selection), the Sidelink Control Information (SCI) update, scenario compliance and channel models based on TR 38.885 (2).

Moreover, TR 37.885 (3) defines the system-level evaluation methodology for 5G V2X use cases, including the description and modelling of scenarios, deployment, mobility, antenna, traffic, and channel models. For channel modelling, TR 37.885 extends the geometry-based stochastic channel modelling framework introduced in TR 38.901 (4) for typical cellular communications, by adding the possibility to model wireless channel in vehicular environments and sidelink communications in which both the transmitter and the receiver are in motion. Two key scenarios are used for NR V2X evaluation (3):

- Urban grid, which targets urban environments with a grid of buildings and roads with four lanes (two in each direction) between the buildings, and
- Highway, which targets highway environments with a highway composed of a total six lanes, considering three lanes in each opposite direction.

For each scenario, TR 37.885 specifies new channel condition models, propagation models, and fast fading parameters capturing the characteristics of each environment. The developed ns-3 NR V2X module includes the channel and antenna models for both V2X Urban grid and Highway scenarios, as defined in (3).

ESR 6 will perform system-level simulations, where the Key Performance Indicators (KPIs) depend on the instantaneous network conditions, such as available infrastructure, radio resources, number of users or radio conditions. The KPIs taken as a basis for the assessment of requirements related to seamless interoperability between hybrid V2X/cellular networks will be latency, reliability, and throughput. Moreover, ESR 6 will use other simulation tools such as MATLAB and Python to process and plot the results obtained with ns 3.

3.2.1 Simulation example

To better understand the operation of this simulator, a simple example is described below. This example setups an NR Sidelink broadcast out-of-coverage simulation using the 3GPP V2V highway channel model from TR 37.885. It simulates a configurable highway topology consisting of vehicular UEs in each lane, which travels from west to east. In this example, 3 lanes are considered with vehicles moving in the same direction and with a distance of 4 m between lanes. Within each lane there are 5 vehicles with a distance of 20 m between them. The vehicles are of type 2 (i.e., passenger vehicles with an antenna height of 1.6 m) (1), and the speed of the vehicles is set at 140 km/h in all lanes. The deployment scenario considered is shown in Fig. 5.

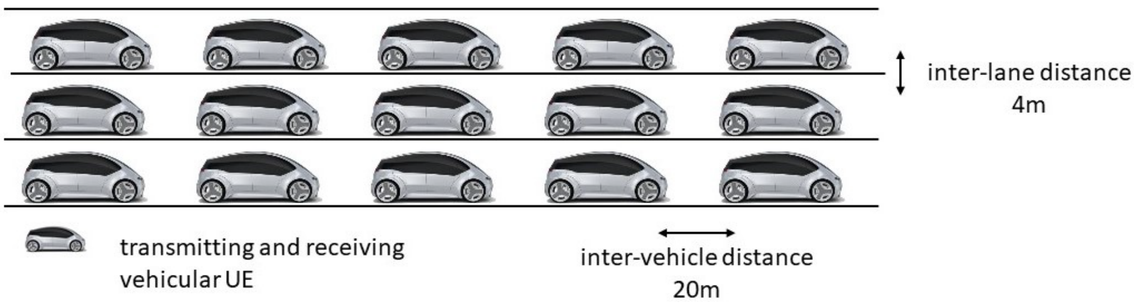


Figure 5: Highway Scenario

This example focuses on a use case that aims at broadcasting basic service messages and assumes that all vehicular UEs are half-duplex transceivers, having the same packet size, generated at the same rate, and using a fixed the Modulation Coding Scheme (MCS). The transmission is performed in the 5.9 GHz band, assuming a channel bandwidth of 40 MHz

For this example, we have analyzed as output statistics the Throughput, which is the total number of bytes successfully received during the simulation time for each transmit-receive UE pair. This example focuses on comparing ng sensing-based and random resource selection procedures for NR V2X.

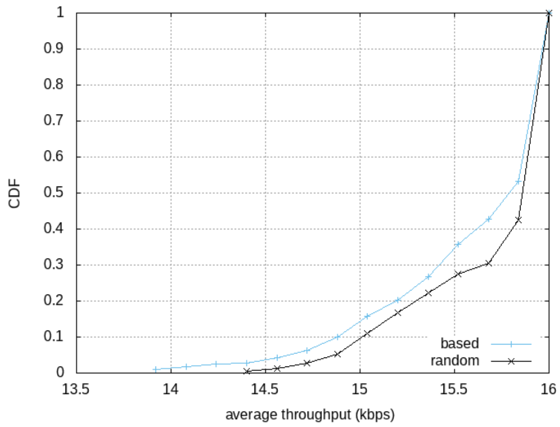


Figure 6: Impact of NR V2X resource selection procedure: sensing vs random

The expected results for this example would be a higher throughput for the sensing procedure. This is because sensing-based resource selection allows for a reduction in the number of simultaneous PSSCH transmissions and incorrect PSSCH receptions in the reception range, compared to the random resource selection procedure. Consequently, due to the efficiency of sensing, an improvement in sensing performance should be observed with respect to the random selection procedure. Since the obtained results do not show a higher performance for the sensing procedure (Fig. 6), ESR6 will continue testing to improve these results.

3.3 ESR 8 Simulation Tools (BOSCH)

ESR 8 will address the new challenges in vehicular systems arising from increasing data, varying traffic requirements, and varying mobility conditions in order to achieve ultra-reliable communication for safety-critical applications. For this purpose, different factors influencing the communication reliability and latency will be evaluated and mechanisms will be developed to describe the Quality of Service (QoS) in terms of reliability and latency. Methods based on machine learning will be developed to predict the QoS in dense vehicular networks. To this end, ESR 8 job roles include developing new approaches to predict QoS for safety-critical functions, research on methods to monitor and increase the reliability in V2X as kind of feed-back loop, building a simulation framework based on the newly developed NR-V2X technology, evaluate different proposed solutions for realistic vehicular environments (e.g., mobility, data traffic and channel models), and propose potential enhancements of the existing standards based on the performed studies.

Since ESR 8 tasks contain evaluation and validation of different V2X scenarios and parameters, she will perform several simulations to validate the system performance. In view of this, ESR 8 will perform system level simulations using OMNET++, SUMO and Veins. OMNET++ is an objective modular network testbed which provides an extensive GUI support and a simulation kernel that helps in embedding it to different applications. OMNET++ helps with network simulations whereas SUMO (simulation of urban mobility) does road traffic simulations and Veins (Vehicles in Network Simulation) combines both OMNET++ and SUMO to simulate vehicular networks. ESR 8 will also integrate machine learning algorithms designed using python with the simulated network to perform the prediction of QoS. The main KPIs involved but not limited to will be end-to-end latency, vehicle density, packet delivery ratio, channel busy ratio, throughput etc.

As a starting point an example of a network with a total of 6 nodes in OMNET++ is described below where one of the nodes generates a message, and the others keep tossing it around in random directions until it arrives at a predetermined destination node. Here we have created 6 modules as a module vector and connected them. The first node (tic [0]) will generate the message to be sent around. Every time forwardMessage () function is invoked whenever a message arrives at the node. It draws a random node number and sends out the message on that node. The delay of 100ms is given between the message transmission for the experiment purposes. The destination address is not hardcoded, and the code has been designed such that we draw a random destination every time and add the destination address to the message. This gives us an idea that even complex networks incorporating the MAC layer features can be visualized and analyzed using the described simulation software.

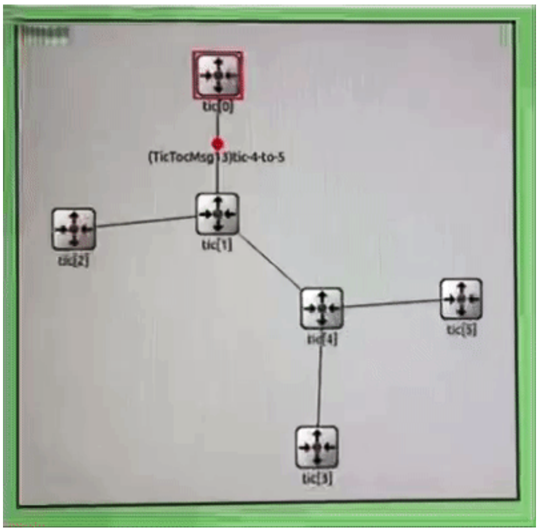


Figure 7: Basic Network Structure in OMNET

4 Simulation Framework

To elaborate the proposed framework for the multi-band/multi-link system simulation, a pictorial representation is shown in Figure 8. In this figure, 5G cellular assisted V2X communication system is presented, wherein vehicles equipped with user equipment (UE) communicate with the network directly as well as to the different entities on the road to make complete C-V2X network. Vehicle communicating with another vehicle is referred to as V2V. Communication between vehicle and pedestrian is termed as V2P. V2I is the communication between vehicle and road infrastructure (e.g., traffic lights), and communication of vehicles with the network is known as V2N. Moreover, to improve coverage and overall throughput, roadside units (RSUs) can be installed on the traffic lights along the road. These RSUs act like a small base station (BSs) that re-transmit the data to the network allowing a R2N communication. This framework provides low latency, high reliability V2X communication due to ubiquitous availability of radio resources.

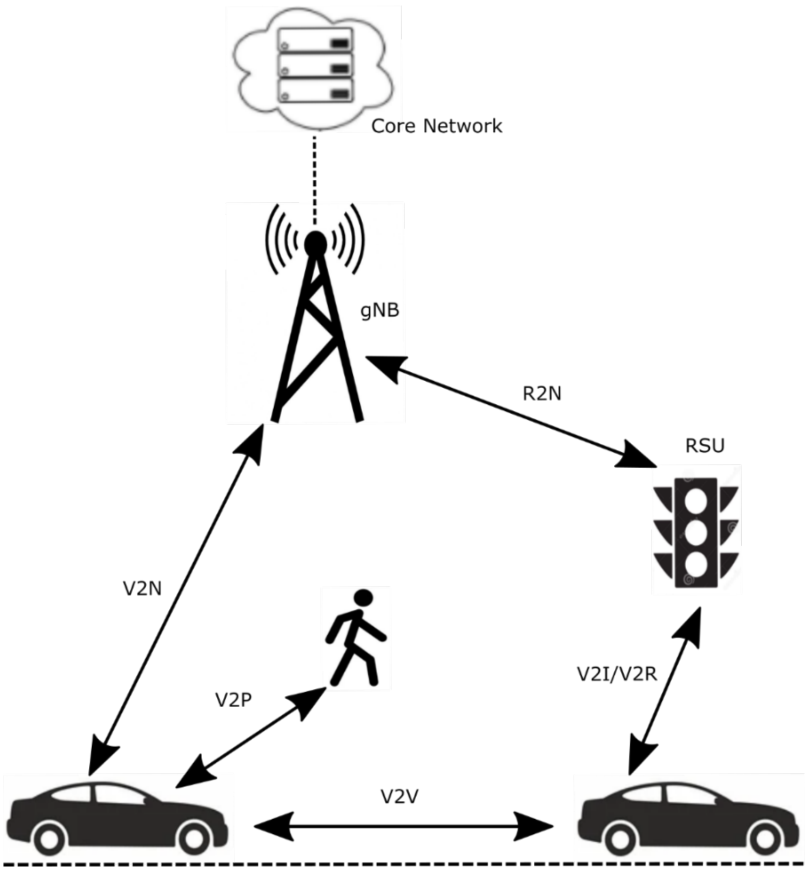


Figure 8: 5G NR based C-V2X Framework

5 Evaluation parameters or characteristics of the simulations

The key parameters to be simulated in this multi-band/multi-link simulation framework are, but not limited to, shown in Table 1.

Sr. No	Simulation Parameters	ESR
1	Propagation delay / Range	ESR 5
2	Doppler-Shift / Velocity	
3	Magnitudes of Reflections	
4	AOA & AOD	
6	Latency	ESR 6
7	Reliability	
8	Throughput	
9	QoS prediction	ESR 8
10	Reliability	
11	Data Rate & End-to-end latency	

Table 1: Simulation Parameters

Using different simulation tools explained in section 2, ESRs will be able to simulate above mentioned key parameters that validate and verify the operational assumptions of their system. Currently, no simulations results have been shown in this report as the ESRs are in their initial phase of work. In addition, as the project progresses, the ESRs will add other key parameters depending on what they need to verify and validate for the performance of the system.

6 Conclusions

In this report, deliverable 2.1 of the ITN-5VC project is presented, which describes an initial proposal of the consistent multi-band/multi-link system simulation. The objective of these simulations is to analyse the requirements of the realistic evaluation methods for cooperative and event triggered settings, and to derive multi-band/multi-link system modelling concept and its corresponding parameters. The software and framework/package used to simulate these scenarios include OMNET++, SUMO, Veins, NS-3, MATLAB and Python.

7 REFERENCES

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