ITN-5VC

Integrated Telematics for Next Generation 5G Vehicular Communications

ITN-5VC D2.2

Midterm report on concepts for joint communication & radar and RRM & Protocol design

Document properties:

Grant Number:	955629
Document Number:	D2.2
Document Title:	Midterm report on concepts for joint communication & radar and RRM & Protocol design
Partners involved:	TUIL, UPV, BOSCH
Authors:	Vishakha Shukla, Syed Najaf Haider Shah, Yanet Estrada González
Contractual Date of Delivery:	2023/02/28
Dissemination level:	PU[1]
Version:	1.2
File Name:	ITN-5VC D2.2-v1.2

[1] CO = Confidential, only members of the consortium (including the Commission Services)
PU = Public

Table of Contents

Executive summary

This deliverable illustrates the work progress made by the ESRs of WP2. This report highlights three concepts that can play a significant role in cellular-vehicle-to-everything (C-V2X) communication: 1) Integrated sensing and communication (ISAC) and its integration into 5G-V2X as an emerging and promising technology, 2) radio resource management (RRM) in ISAC based 5G-V2X sidelink communication for enhanced awareness, and 3) Congestion Control and protocol design in 5G-V2X. The ESRs deal with different aspects of ISAC such as radio resource management, interoperability between technologies, and congestion control frameworks which gives an understanding of how the technology works and is implemented in real-case scenarios.

List of Figures

List of Tables

List of acronyms and abbreviations

ESR	Early-Stage Researcher
WP2	Work Package 2
TUIL	Technische Universität Ilmenau
UPV	Universidad Politécnica de Valencia
5G NR	Fifth Generation New Radio
B5G	Beyond 5G
6G	Sixth Generation
Com-Rad	Communication & Radar
C-V2X	Cellular Vehicle-to-Everything
V2V	Vehicle-to-Vehicle
V2P	Vehicle-to-Pedestrian
V2N	Vehicle-to-Network
V2I	Vehicle-to-Infrastructure
I2N	Infrastructure-to-Network
QoS	Quality of Service
3GPP	3rd Generation Partnership Project
MAC	Medium Access Layer
KPI	Key Performance Indicator
ISAC	Integrated Sensing and Communication
PRR	Packet Reception Ratio

1 Introduction

Next-generation wireless networks (such as beyond 5G (B5G) and 6G) have been envisioned as key enablers for many emerging applications. These applications demand high-quality wireless connectivity as well as highly accurate and robust sensing capability. Among many visionary assumptions about B5G/6G networks, a common theme is that sensing will play a more significant role than ever before. While the speculative study for future wireless systems has just begun, the technological trends clearly show that we are ready to embrace the new sensing functionality in the forthcoming B5G and 6G eras [1]. Indeed, radio sensing and communication (S&C) systems are both evolving towards higher frequency bands, larger antenna arrays, and miniaturization, thereby becoming increasingly similar in terms of hardware architectures, channel characteristics, and signal processing. This offers an exciting opportunity of implementing sensing by utilizing wireless infrastructures, such that future networks will go beyond classical communication and provide ubiquitous sensing services to measure or even to image surrounding environments [2]. This sensing functionality and the corresponding ability of the network to collect sensory data from the environment are seen as enablers for learning and building intelligence in the future smart world and may find extensive usage in numerous location/environment-aware scenarios [3]. To name but a few, vehicle-to-everything, smart home, smart manufacturing, remote sensing, environmental monitoring, and human-computer interaction will have a key impact of ISAC on them. Towards that end, there is a strong need to jointly design the S&C operations in networks, which motivates the recent research theme of Integrated Sensing and Communications (ISAC).

The information processing for S&C shows a striking distinction. Sensing collects and extracts information from noisy observations, while communication focuses on transferring information via specifically tailored signals and then recovering it from a noisy environment [2]. The ultimate goal of ISAC is to unify these two operations and to pursue direct trade-offs between them as well as mutual performance gains. On the one hand, ISAC is expected to considerably improve spectral and energy efficiencies, while reducing both hardware and signalling costs, since it attempts to merge sensing and communication into a single system, which previously competed over various types of resources [1]. On the other hand, ISAC also pursues a deeper integration paradigm where the two functionalities are no longer viewed as separate end goals but are co-designed for mutual benefits, i.e., via communication-assisted sensing and sensing-assisted communication [3].

Although it has only recently gained growing attention from both the academia and wireless industry, ISAC has been investigated by various research communities under different names for decades, e.g., Radar-Communications (RadCom), Joint Communication and Radar (JCR), Joint Radar and Communication (JRC), and Dual-functional Radar-Communications (DFRC). While these terminologies may have varying connotations, the sensing functionality therein mainly refers to radar sensing, which has long been mainstream in ISAC. In this overview, we use ISAC as a unified term to refer to all the joint designs of radar sensing and communications.

The document is organized as follows:

- Section 2 focuses on ISAC-based 5G-V2X systems, different ISAC strategies for V2X, and the challenges faced by ISAC based V2X.
- Section 3 presents a detailed overview of radio resource management (RRM) in vehicular networks including DSRC and C-V2X, RRM for ISAC based 5G V2X, and challenges in ISAC RRM for NR sidelink.

- Section 4 describes the congestion control mechanisms and protocol design in 5G-V2X.
- Section 5 shows the initial simulation results obtained by each ESR of WP2.
- Lastly, the conclusions are given in Section 6.

2 ISAC – a promising 5G Technology

Wireless sensing has long been a separate technology developed in parallel with communication systems. Positioning is the only sensing service that communication systems could offer. General sensing rather than positioning will become a new function integrated into the 5G communication system. These services are currently provided by various dedicated sensing equipment, such as radar, light detection and ranging (LIDAR), and professional CT and MRI equipment [2].

The ISAC capability will thus enable many new services that communication system operators can offer. These include very high accuracy positioning, localization and tracking, imaging for biomedical and security applications, simultaneous localization and mapping to automatically construct maps of complex indoor or outdoor environments, pollution or natural disaster monitoring, gesture and activity recognition, flaw and material detection, and many other services. These services will in turn enable application scenarios in all kinds of business for future consumers and vertical industries [3]. The potential new services that could be supported by future ISAC systems are listed below:

- **High-accuracy localization and tracking:** Low-latency high-accuracy localization and tracking enable meaningful association between cyber information and the locations of physical entities in multiple scenarios from factories to warehouses, hospitals to retail shops, and agriculture to mining. Having high-accuracy relative localization is important when two or more entities exist and they are approaching one another, or the entities have coordinated moving direction and speed.
- **Simultaneous imaging, mapping, and localization:** In simultaneous imaging, mapping, and localization, the sensing capabilities from these three perspectives are mutually enhanced. ISAC will leverage advanced algorithms, edge computing, and AI to produce super-resolution and highly recognizable images and maps in which the vast network of objects, including vehicles and base stations, act as sensors to provide a remarkably extended imaging area. Moreover, performance will significantly improve due to the ease of fusing results that are shared with cloud-based services across the entire network.

2.1 ISAC aided 5G V2X

ISAC can play a significant role in the 5G NR V2X communication system. The basic idea behind ISAC-aided 5G NR V2X is to combine sensing into V2X communication technologies to enhance the performance and reliability of V2X systems. In other words, instead of installing separate radar sensors alongside the V2X communication module, ISAC enables them to work together synergistically.

ISAC achieves this by utilizing advanced signal processing algorithms and machine learning techniques to extract useful information from the signals received by the V2X system. For example, a V2X system equipped with ISAC can use the radar signals received from nearby vehicles to determine their position and velocity and then use this information to optimize its transmission parameters for better communication. Similarly, it can use the information from its communication signals to refine its sensing capabilities and improve its understanding of the surrounding environment.

ISAC-aided V2X has several advantages over traditional V2X systems. First, it can significantly improve the reliability and accuracy of V2X communication by reducing interference and optimizing the transmission parameters based on the environment and traffic conditions. Second, it can provide more detailed and accurate information about the surrounding environment, including the presence of other vehicles, road conditions, and potential hazards. This information can be used to enhance the safety and efficiency of the driving experience. Finally, ISAC-aided V2X can enable new applications and services that were not possible with traditional V2X systems, such as autonomous driving and smart traffic management.

2.2 ISAC Challenges

While the ISAC-aided 5G V2X system offers significant benefits, there are also several challenges that must be addressed. One challenge is related to the complexity of the system. ISAC requires sophisticated signal processing algorithms and machine learning techniques, which can be computationally intensive and require significant processing power. This can lead to higher system costs, increased energy consumption, and longer processing times.

Another challenge is related to the implementation of an ISAC-aided V2X system either as a Monostatic/Full-duplex or Bi-static/half-duplex system. In the former case, the primary challenge is achieving In-Band Full Duplex operation. The transceiver must be capable of receiving the echoes from targets while simultaneously transmitting, and effective self-interference cancellation techniques are necessary. Although In-Band Full Duplex may be easier to achieve for sensing than for communication, as the transmitted wave can be treated as a nearby target with zero doppler shift, the quality of self-interference cancellation is still critical. For Bi-Static/Multi-Static/half-duplex systems, the challenges are primarily related to achieving proper time-synchronization between the sensing transmitter and receiver and effectively fusing information from multiple sensors to obtain comprehensive knowledge about the environment.

Moreover, there is a challenge in developing a standard protocol for ISAC-aided V2X systems. As these systems are still in the development stage, there is a need to create a standardized protocol that is compatible with different sensors and communication systems. This can be a complex process, requiring collaboration among different companies and organizations.

Additionally, privacy and security are major concerns in ISAC systems. These systems collect a vast amount of data, including location and other sensitive information. Therefore, there is a need to ensure that this data is protected from unauthorized access and use.

3 Radio Resource Management in Vehicular Networks

Radio resource management (RRM) in vehicular networks refers to the set of techniques and algorithms used to efficiently allocate and manage the available radio resources, such as frequency spectrum, time slots, and transmit power, in a way that maximizes the performance and reliability of communication between vehicles and the infrastructure. Vehicular networks can be classified into two main standards; 1) Dedicated Short Range Communication (DSRC) or ITS-G5 and 2) C-V2X. However, with the upcoming technologies in B5G and 6G, a third group can be introduced in which radar sensing can be integrated into C-V2X to form ISAC-V2X. Based on these groups, RRM can be modified accordingly. The hierarchical model of vehicular networks is shown in Figure 1.

3.1 RRM in DSRC

DSRC is a Wi-Fi-based vehicular communication technology to support ITS applications. As the name suggests, this technology is designed for short-range vehicular communications. The current standard of DSRC is IEEE 802.11p which has several shortcomings in terms of low data rate at higher vehicular density, and packet loss due to the hidden terminal problem [4]. To overcome these shortcomings, IEEE 802.11bd standard is being developed [5]. Resource allocation in DSRC-based vehicular networks can be performed by optimizing different PHY and MAC layers parameters such as MCS and contention time or window respectively, to achieve the required QoS (data rate, throughput, PPR, etc.).

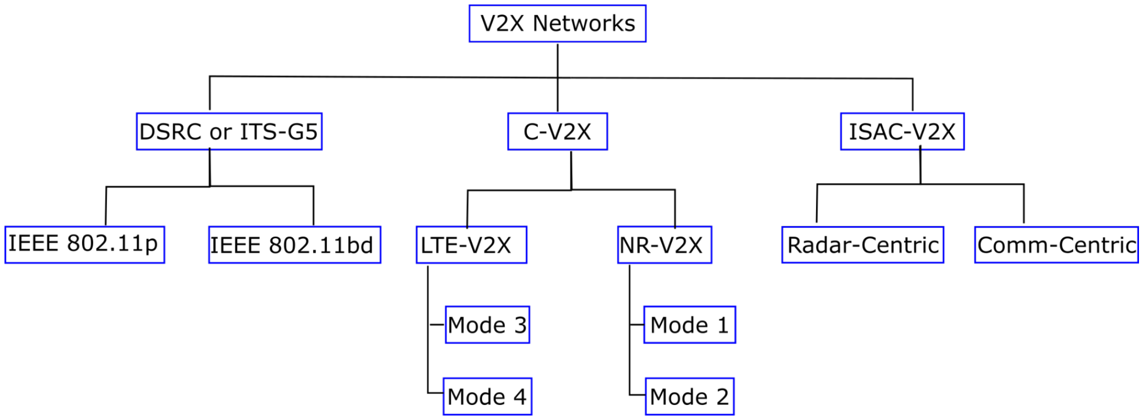

Figure 1: V2X Technologies

3.2 RRM in C-V2X

C-V2X is another vehicular communication protocol defined by 3GPP. C-V2X utilizes a cellular radio network for vehicular communication. Although DSRC is considered the ad-hoc vehicular communication standard, it lacks many advantages such as long-distance coverage, high capacity, high quality of service, ubiquitous deployment of infrastructure, etc. These requirements can be fulfilled by exploiting cellular network facilities. Cellular communications emerged as a potential vehicular communication technology with 3GPP releases 12 and 13 that support Device to Device (D2D) communications [6]. Initially, it was considered that the V2X safety application requirements of high reliability and low latency cannot be achieved by cellular network support because the data has to first go through the infrastructure. However, with the development of the D2D communication mode, it is believed that the aforementioned V2X requirements can be fulfilled. In D2D communication, vehicles can directly communicate with neighbouring vehicles without heavily relying on the infrastructure. This concept was further explored and polished in 3GPP releases 14 and 15 in the form of LTE-V2X. LTE-V2X is the first cellular V2X (CV2X) standard based on the 4G Long Term Evolution (LTE) air interface. However, to meet the requirements of ultra-reliable and ultra-low latency of future autonomous driving, 3GPP in release 16 has developed a new C-V2X standard based on a 5G new radio air interface called NR-V2X. Further improvements in 5G NR-V2X are under progress in 3GPP releases 17 and 18. In the following sections, these two C-V2X standards have been explained along with respective resource allocation mechanisms.

3.2.1 LTE-V2X

LTE-V2X was designed to support basic traffic safety applications such as traffic management and telematics applications. In LTE-V2X, vehicles use the PC5 interface for sidelink communication (V2V or LTE-PC5), whereas, for network communication (V2N or LTE-Uu), the Uu interface (between UE and eNB) is utilized by the vehicles. To utilize the radio resources for sidelink communications, LTE-V2X performs radio resource allocation in two ways or modes: Mode 3 and Mode 4. These two modes have been discussed in the following sections.

3.2.1.1 Mode 3

In LTE-V2X sidelink mode 3, radio resources are managed by the network (eNB). The eNB schedules and allocates resources (subchannels or a group of a variable number of PRBs [7] to vehicles. A subchannel is the smallest resource element that can be allocated to a vehicle to transmit its packet (CAM or BSM). Furthermore, a subchannel comprises two elements: 1) a transport block (TB) that carries the packet and 2) sidelink control information (SCI) that contains the necessary information to decode the TB packet at the receiver. The physical sidelink shared channel (PSSCH) carries TB, and SCI is carried by the physical sidelink control channel (PSCCH). 3GPP has not standardized any specific algorithms for RRA in mode 3. However, It has defined two scheduling approaches [8] namely, a) Dynamic Scheduling and b) Semi-Persistent Scheduling (SPS).

3.2.1.1.1 Dynamic Scheduling

In dynamic scheduling, the vehicle first requests resources or subchannels from the eNB in the UL. The eNB then schedules the subchannels and informs the vehicle about the available subchannel through DL. Finally, the vehicle sends its packet on the scheduled subchannel. This type of allocation is employed in the case of aperiodic traffic. The main disadvantage of dynamic allocation is that it increases signaling overhead in the UL and DL, which in turn increases the latency.

3.2.1.1.2 Semi-Persistent Scheduling

In the SPS approach, the eNB reserves subchannels for the vehicles involved in some periodic transmission of packets. The vehicle sends assistance information (i.e. packet size, packet priority, packet periodicity) to the eNB. The eNB uses this information to semi-persistently allocates subchannels to the vehicle. The periodicity of the reserved subchannels can also be configured by the eNB using DCI sent over the PDCCH. The advantage of the SPS approach is that it reduces the signalling overhead over the channel and improves the latency.

3.2.1.2 Mode 4

In LTE-V2X, to ensure the basic safety services in the case when the vehicles are out-of-the-cellular coverage, the 3GPP has standardized a second mode known as mode 4. In mode 4, vehicles autonomously select and allocate their resources without the support of cellular infrastructure. 3GPP has defined a standard algorithm for RRM in mode 4, called Sesning-based Semi-Persistent Scheduling (SB-SPS). In mode 4, vehicles select their radio resources autonomously using SB-SPS.

3.2.1.2.1 Sensing-based Semi-Persistent Scheduling

In Sensing based SPS scheme, sensing is performed within a pool of candidate resources before selecting a resource or subchannel on which the data transmission is carried out. When a vehicle selects a subchannel, it reserves it for the next n_{RC} number of transmissions with some resource reservation interval (RRI), where n_{RC} is the reselection counter value. The purpose of this resource reservation is to inform other vehicles that the selected subchannel will be reused by the same vehicle for the transmission of the next TBs at defined RRIs. A reselection counter is a random number of consecutive TBs and it is selected based on the RRI chosen from the RRI list (0ms, 20ms, 50ms, 100ms, 300ms, ... 1000ms). The n_{RC} will be selected between 5 and 15 for

RRI ≥ 100ms, between 10 and 30 for RRI = 50ms, and between 25 and 75 for RRI = 20ms. The n_{RC} value is decremented by one each time when a TB is transmitted after an RRI. When n_{RC} reaches 0, the vehicle has two options: either 1) it keeps the same subchannel for the next transmissions with probability p or 2) it selects a new subchannel with probability 1-p using a sensing-based SPS scheme as shown in Figure 2. Any fixed value of p has not been specified by the standard. However, it can be chosen from interval [0,0.8].

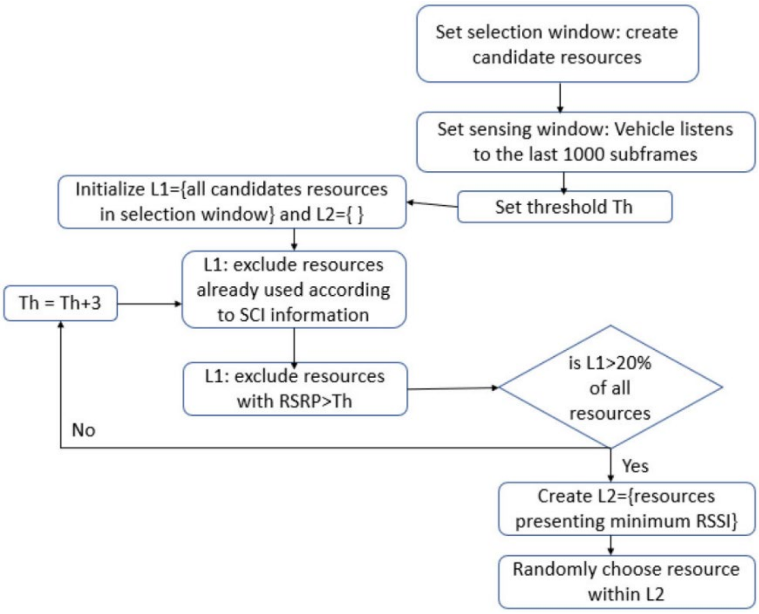

Figure 2: Flowchart of SB-SPS

3.2.2 5G NR-V2X

3GPP has designed 5G NR-V2X standard to complement LTE-V2X. NR-V2X supports advanced V2X use cases such as Vehicle platooning, extended sensors, and advanced and remote driving [9]. These four use cases were not supported by LTE-V2X because of stringent requirements of ultra-high reliability and ultra-low latency. Further requirements of these 3GPP use cases are summarized in Table 1 [10]. Apart from these advanced use cases, NR-V2X also supports basic safety and traffic management use cases already supported by LTE-V2X. For instance, a vehicle is equipped with both C-V2X technologies: LTE-V2X and NR-V2X, It will use LTE-V2X for basic safety use cases, and NR-V2X for aforementioned advanced use cases. Thus, NR-V2X is backward compatible with LTE-V2X. Akin to LTE-V2X, NR-V2X also supports two communication interfaces: 1) PC5 interface to support sidelink communication and 2) Uu interface to support uplink (UL) and downlink (DL) communication. NR-V2X PHY layer design includes but is not limited to some key modifications: 1) flexible numerology, i.e., NR-V2X supports multiple SCS (15kHz, 30kHz, 60kHz, 120kHz) unlike LTE-V2X which only supports 15kHz), 2) a new physical sidelink feedback channel (PSFCH) to ensure successful data reception in unicast and group-cast communication, 3) two sidelink resource allocation modes: Mode 1 and Mode 2, 4) time domain multiplexing in physical sidelink control channel (PSCCH) and physical sidelink shared channel (PSSCH) to avoid long delays faced in LTE-V2X.

3.2.2.1 Mode 1

Akin to LTE-V2X Mode 3, sidelink resources are scheduled and allocated by the infrastructure (i.e. gNB) in NR-V2X mode 1. 3GPP has defined two types of RRM approaches in Mode 1: a) dynamic grant (DG) scheduling (as LTE-V2X mode 3) and b) configured grant (CG) scheduling (instead of SPS in mode 3).

Use Case	Data Rate (Mbps)	Range (m)	Reliability (%)	Latency (ms)
Platooning	Up to 60	80-350	Up to 99.99	10-25
Extended Sensors	Up to 1000	50-1000	Up to 99.999	3-10
Advanced Driving	10-50 (SL) 50 (DL) 0.25-10 (UL)	360-700	Up to 99.999	10-100
Remote Driving	1 (DL) 25 (UL)	1000+	Up to 99.999	5

Table 1: 3GPP Use Cases Requirements [10]

3.2.2.1.1 Dynamic Grant

In DG scheduling, a UE sends a request for resources to gNB for the transmission of TB using PUCCH. This request is called a scheduling request (SR). In response to SR, the gNB informs the UE about the available resources (e.g., slot and subchannel) using DCI over PDCCH. With this information, the UE then informs other UEs about its allocated resources using SCI. In this way, the UEs operating in mode 2 will be able to know about the resources utilized by mode 1 UEs. Since the UE needs to send SR to gNB every time it wants to transmit TB, two problems arise in DG: 1) signaling overhead and 2) increased delay.

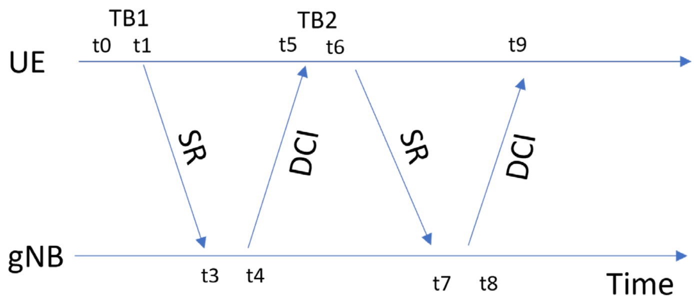

Figure 3: Dynamic Grant Scheme

3.2.2.1.2 Configured Grant

To address the limitations of DG scheduling, mode 1 introduces a concept of configured grants (CG) which means pre-allocated resources. In CG scheduling, the gNB assigns a set of resources for the UE to transmit its TB at specific intervals. In this regard, the UE first sends the packet's assistance information to the gNB. This assistance information includes information about the packet size, packet periodicity, and the required packet QoS (i.e. latency and reliability). Based on this assistance information, the gNB configures resources that satisfy the TB requirements.

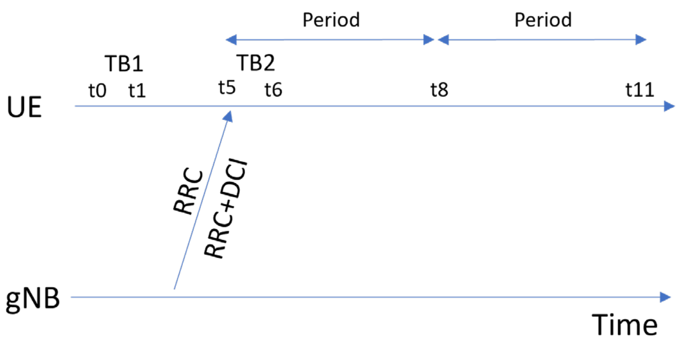

Figure 4. Configured Grant Scheme

3.2.2.2 Mode 2

In Mode 2, the vehicles schedule their resources on their own in out-of-network coverage This mode is also called distributed out-of-network coverage mode. For mode 2, in addition to SB-SPS, 3GPP has defined a dynamic allocation scheme to select and allocate resources in aperiodic traffic in contrast to mode 4, in which periodic traffic is considered.

3.2.2.2.1 Dynamic Resource Allocation

In a dynamic scheme, the resources are selected for a TB transmission and can be reserved for the retransmission of that TB only. The selected resources are not reserved with a reselection counter. For the transmission of each TB, a new resource is selected every time using a short-term resource sensing and selection method, in contrast to LTE-V2X mode 4 where the long-term sensing method is used. Dynamic resource scheduling is used in the case of aperiodic traffic, where the arrival of future packets cannot be predicted by sensing previous transmissions from the surrounding UEs.

3.2.2.2.2 Semi-Persistent Scheduling

In case of periodic traffic, mode 2 uses an SB-SPS scheme similar to LTE-V2X mode 4 with two modifications: 1) the averaging operation of the RSRP measurements over the sensing window is removed (only the value corresponding to the TB directly associated with the SCI is used), and 2) The L2 list is not created. The reason for the former modification is that, in highly dynamic traffic, taking the average of RSRP measurements is not advisable instead, a more recent measurement is considered rather than the less recent ones. One drawback of this modification is that it is also possible that the last reservation can be lost, due to which the UE will not be able to detect the busy status of the resource, and hence collision might occur. On the other hand, the removal of the L2 list makes the algorithms less complex at the cost of the inclusion of interfered resources. It is important to note here that SB-SPS is not recommended in the case of aperiodic traffic because it might increase the probability of packet collision when packets are generated aperiodically. The following procedure explains the sidelink resource sensing and selection scheme in mode 2.

As discussed in [11] random resource selection is also supported by NR-V2X. In this case, the UE does not go through the sensing procedure rather, it considers all the resources within the selection window as candidate resources and selects from them randomly for its sidelink transmissions.

Mode 1 and Mode 3 are less challenging because the scheduling of transmissions is centralized at the eNB/gNB. As a result, these centralized modes 1 and 3 can outperform decentralized modes 2 and 4. However, the limitations of modes 1 and 3 include: 1) for operation, the modes require network coverage (out-of-network coverage is not supported), and 2) the modes cause cellular uplink (UL) and downlink (DL) signaling overhead. On the other hand, Mode 2 and Mode 4 do not need any cellular network support for radio resource allocation. However, modes 2 and 4 impose more challenges in terms of collision, congestion, and interference due to their decentralized or distributed nature.

3.3 RRM in ISAC-based 5G-V2X

In general, ISAC-based vehicular networks can be categorized into two groups. 1) communication-centric ISAC, and 2) radar-centric ISAC. In communication-centric ISAC-V2X, the onboard vehicular communication modules are used to sense the surrounding environment. In such systems, the communication signals (e.g., OFDM) are exploited for radar sensing purposes to increase the vehicle's awareness of the environment. On the other hand, in a radar-centric ISAC-V2X system, the conventional radar waveforms (e.g., LFM), embedded with communication symbols, are used to convey information from one vehicle to another vehicle while simultaneously performing localization. This work focuses on the communication-centric ISAC-V2X system in which C-V2X technology has been employed with integrated radar sensing functionality. In particular, standard 5G NR sidelink communication signals have been used for sensing purposes. Moreover, the performance of mode 2 resource allocation with integrated radar sensing capability has been evaluated. Further details have been discussed in the following sections.

3.3.1 5G NR Sidelink Resource Structure

5G NR defines the radio resource structure in both the time and frequency domains. When it comes to sidelink communication, the structure for radio frames, sub-frames, and slots is identical to NR's uplink and downlink. Additionally, different numerologies are supported for sidelink communication, resulting in shorter slot times. This feature enables use cases that require low latency. There are three main concepts in the NR-V2X radio resource allocation which are 1) physical sidelink channels and signals, 2) bandwidth part (BWP) 3) radio resource pool. The relation among these parameters has been shown in Figure 5.

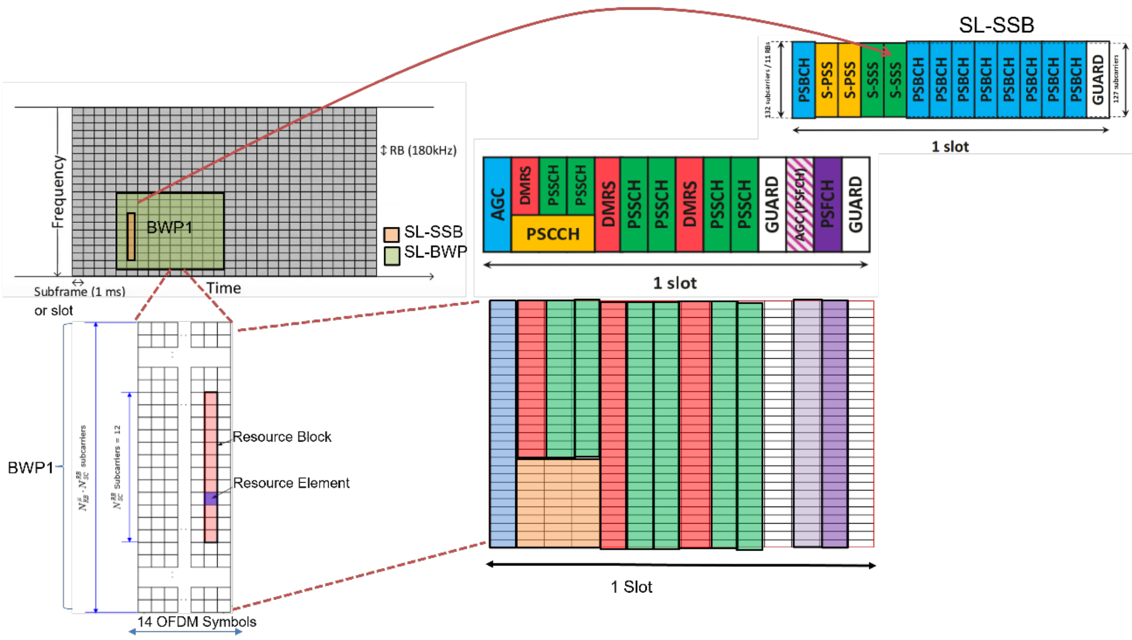

Figure 5: 5G NR Resource Structure

3.3.2 Radar Sensing Performance with different NR Sidelink Signals

To evaluate the performance of radar sensing, range resolution, and velocity resolution have been considered because range and velocity resolutions depend on sensing bandwidth and integration time respectively.

$$\Delta r = \frac{c}{2 * BW} = \frac{c}{2 * SCS * N_{subcarriers}}$$

$$\Delta v = \frac{c}{2 f_c T_{observation}} = \frac{c}{2 f_c T_0 M_{symbols}}$$

Where, $c, BW, SCS, N_{subcarriers}, f_c, T_{observation}, M_{symbol}$ represent the speed of light, bandwidth, subcarrier spacing, number of subcarriers, carrier frequency, observation time, and number of OFDM symbols respectively.

NR sidelink physical signals are classified into reference signals and synchronization signals, which are given below:

- The Demodulation Reference Signals (DM-RS) serve as reference signals for message demodulation in a receiver for PSCCH, PSSCH, and PSBCH.
- The Channel State Information Reference Signal (CSI-RS) is a reference signal that facilitates channel state estimation/sounding and reporting between a transmitter and a receiver UE.
- The Phase Tracking Reference Signal (PT-RS) is employed as a reference signal for compensating phase noise.
- The Sidelink Primary/Secondary Synchronization Signal (SPSS/S-SSS), along with PSBCH, is a component of the Sidelink Synchronization Signal Block (S-SSB) that is utilized for Sidelink synchronization.

Since these reference and synchronization signals are assigned different time and frequency resources, they provide different range and velocity resolutions as shown in Table 2.

Two cases are considered – Case 1 uses 50 MHz and Case 2 uses 100 MHz bandwidth, SCS of 30 kHz, and 5.9 GHz band.

Type of Signal	**Range Resolution (m)**	**Velocity Resolution (m/s)**
DMRS (one symbol)		
• DMRS_50	3	762.71
• DMRS_100	1.5	762.71
SSB (#subcarriers=132, and #symbols = 4)	37.87	190.68
PSSCH with 50 MHz		
• PSSCH_50_1slot	3	127.12
• PSSCH_50_2slots	3	63.56

• PSSCH_50_frame	3	6.35
PSSCH with 100 MHz		
• PSSCH_100_1slot	1.5	127.12
• PSSCH_100_2slots	1.5	63.56
• PSSCH_100_frame	1.5	6.35

Table 2: Range and Velocity Resolutions with different Sidelink Signals

3.3.3 Limitations of NR Sidelink Signals

In the context of 5G V2X sidelink communication, there are different packet sizes that are utilized for different types of data transmission. Specifically, there are 190-byte and 350-byte packets, which are used for Cooperative Awareness Messages (CAMs), as well as 1000-byte packets, which are used for Cooperative Perception Messages (CPMs). While these packet sizes are suitable for their intended purposes, they may not be sufficient for meeting the demanding requirements associated with radar sensing for road traffic monitoring shown in Table 3.

Parameters	**Values**
Range Resolution	1 – 3 m
Velocity Resolution	10 km/h
Maximum Unambiguous Distance	100 – 150 m
Maximum velocity	+150 km/h
Minimum Velocity	-150 km/h

Table 3: Radar Sensing requirements for road traffic monitoring

In particular, if we were to use the data payload associated with one of these packet sizes for radar sensing, likely, we would not be able to achieve the necessary precision and accuracy required for effective road traffic monitoring. This is due to the fact that radar sensing requires a much higher level of data resolution and processing than is typically provided by the 5G V2X sidelink communication system.

Therefore, in order to meet the stringent sensing requirements associated with road traffic monitoring, it may be necessary to explore other options beyond the packet sizes currently used for 5G V2X communication. This could involve the incorporation of additional resources both in the time and frequency domain that can provide the necessary level of radar resolution. By doing so, it may be possible to improve the overall effectiveness of road traffic monitoring systems and enhance the safety and efficiency of our transportation networks.

4 Congestion Control Mechanism and Protocol Design in V2X

Congestion control in safety-oriented vehicle-to-vehicle (V2V) communication has been oblivious to varying application-level requirements. Existing recommendations and regulations, in particular, impose the same response on all vehicular user equipment (VUEs) to reduce the spatial/temporal footprint of their broadcast safety traffic regardless of what their specific applications need in terms of quality of service (QoS). Which component of QoS is jeopardized by a specific congestion management strategy is entirely dependent on the mechanisms used by the scheme. Yet, even in the face of congestion, applications may prefer that certain QoS criteria be sacrificed last [12].

The European Telecommunications Standards Institute (ETSI) defined the Decentralized Congestion Control (DCC) specification, which permits transmission power, rate, modulation, and channel coding (MCS) controls to be utilized independently or in conjunction. According to the per-packet priority field stated in the Sidelink Control Information, the 3GPP TS 38.214 standard specifies how much the channel occupancy ratio (CR) of individual VUEs should be limited under high channel busy ratio (CBR) levels (SCI). It also specifies when and how to compute CR and CBR and recommends control techniques such as modulation and channel coding (MCS) control, Tx power management, and packet drops (a type of rate control). It does not, however, provide a specific congestion control mechanism. QoS degradation is inevitable under channel congestion as every VUE needs to scale down its resource footprint in time, frequency, or space, by means of MCS, rate, or power control, among others [13].

Machine learning (ML) has seen a significant surge and uptake across many diverse applications. The high flexibility, adaptability, and computing capabilities it provides extend traditional approaches used in multiple fields, including network operation and management. Numerous surveys have explored ML in the context of networking, such as traffic engineering, performance optimization, and network security. Many ML approaches focus on clustering, classification, regression, and reinforcement learning (RL). As a fundamental component of computer networks, CC plays a significant role in improving network resource utilization to achieve better performance. With the emergence of a large number of new technologies and new networks, e.g., data centers (DCs), WiFi, 5G, and satellite communications, the complexity and diversity of network transmission scenarios and protocols have increased dramatically. This has brought significant challenges to transmission protocol design. A rich variety of CC algorithms have been designed for specific scenarios [14]. However, the variety of network scenarios and more importantly the intrinsic dynamics of the network, make it extremely difficult to design efficient generic CC algorithms. Therefore, CC algorithms based on ML have been proposed to provide a generic CC mechanism that could potentially underpin different network scenarios.

Before the implementation of any ML-based congestion control mechanism, it is important to understand; how the different KPIs used to study congestion control are related to each other. In order to initiate this study, we used linear regression; a type of supervised learning method to analyze the correlation between received power and distance. Figure 6 shows the relation as well as linear regression on the received power versus distance for a highway scenario.

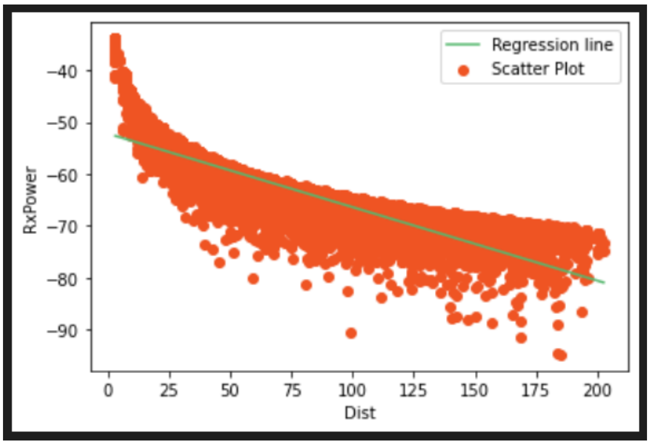

Figure 6: Received power versus Distance

It is clearly understood from the graph that there exists a relationship and the signal fades with the increase in the distance. It is shown as an example of how ML can be used to perform regression on congestion control KPIs to understand their correlation. We can also infer that solely distance can't be used as a parameter to estimate the successful packet reception as there are other parameters such as interference which also contribute to the loss of packets in case of congestion. Distance together with received power can be used as an input feature to design a congestion control mechanism. We need to identify and develop more correlations contributing to congestion in V2V scenarios in order to design an efficient congestion control technique which will be the further step n this study.

C-V2X was initially proposed by 3GPP in Rel-14 [15] as a 4G upgrade based on the Long-Term Evolution (LTE) network. V2X is implemented in 3GPP standards to support various types of vehicular communication networks, including vehicle-to-vehicle communication (V2V), vehicle-to-infrastructure communication (V2I), vehicle-to-pedestrian communication (V2P), vehicle-to-network communication (V2N), and vehicle-to-roadside unit communication (V2R). Rel-14 focused on leveraging Evolved Packet System (EPS) to provide V2V networks as the first step in implementing the V2X idea in the cellular network. Automotive use case verticals were proposed with System Architecture Evolution (SAE) [16]. 3GPP later standardized it with an NR 5G network in Rel-15 [16]. Its initial version defined the architecture and capabilities of the 5G System (5GS). Rel-15 specified the service-based approach for the 5G Core Network (5GC), data connectivity across NR and LTE access technologies, mobility, quality of service (QoS), traffic steering, and network slicing characteristics in terms of architecture. It expanded numerous forms of eV2X services with these definitions, including platooning, advanced driving, extended sensors, and remote driving. Rel-16, a step ahead in 3GPP, gave specification enhancements in further completing 5G architecture and providing additional services with more particular use cases, which were critical for network topology. It defined the 5G network's position in the advanced V2X use case as well as the NR and LTE sidelink coexistence scenario. The sidelink will be controlled by the Next Generation Node B (gNB) via the Uu interface (which links user equipment (UE) to the gNB) and the PC5 interface (the connection between UEs). Rel-16 additionally supported V2X services based on 5GS; broadcast, groupcast, and unicast modes in the NR PC5 interface; improved QoS management for the NR Uu interface; and simultaneous LTE PC5 and NR PC5. Recently, in Rel-17, 3GPP added some new and improved sidelink features. More specifically, it brought power management and savings, optimized resource allocation, and started to support new frequency bands. The standards also extended the use cases to the Internet of Things (IoT) and public security issues via the utilization of relay in sidelink [17]

5 Simulation Results

5.1 ESR 5

ESR 5 aims to propose an optimal radio resource allocation mechanism in 5G NR sidelink communication by investigating the radar sensing capability of the standard NR sidelink communication signals. To validate the performance of proposed RRA schemes, an ISAC framework has been developed in which radar sensing and communication among vehicles have been performed simultaneously. ESR 5 is working on an open-source simulator called WiLabV2Xsim [18]. This simulator is an event-based purely 5G-V2V resource allocation simulator that is developed in MATLAB. ESR 5 integrated his developed ISAC-V2X framework with WiLabV2Xsim, to evaluate the radar sensing and communication performance metrics. The sensing performance metrics include, but are not limited to, range and velocity resolution, and (Cramér–Rao Lower Bounds) CRLBs of both range and velocity estimator. However, the communication performance metrics include packet reception ratio (PPR), inter-packet delay, throughput, etc. Out of these parameters, only range and velocity resolution, and packet reception ratio have been simulated.

As a proof of concept, a 3GPP highway scenario has been simulated with simulation settings shown in Table 4.

Simulation Settings	**Parameters**	**Values**
Scenario	Road Layout	3GPP Highway (3+3)
	Vehicle Density	10 vehicles/km
	Average Speed	70 km/h
Physical Layer	Frequency	5.9 GHz
	Bandwidth	10 MHz
	Transmission Power	23dBm
	Antenna Gain (Tx & Rx)	3dBi
	SCS	15 kHz
	Propagation Model	Winner+, Scenario B1
	MCS	11
MAC Layer	Resource Allocation	Mode 2
	Keep probability	0.4
	RSRP Sensing Threshold	-126 dBm
	Selection Window [T1, T2]	[1, 100] ms
	Sensing Window	1000 ms
	Subchannel Size	10 PRBs
	Number of Subchannels	5
Data Traffic	Packet generation	100 ms
	Packet size	350 bytes and 1000 bytes

Table 4: Simulation Settings

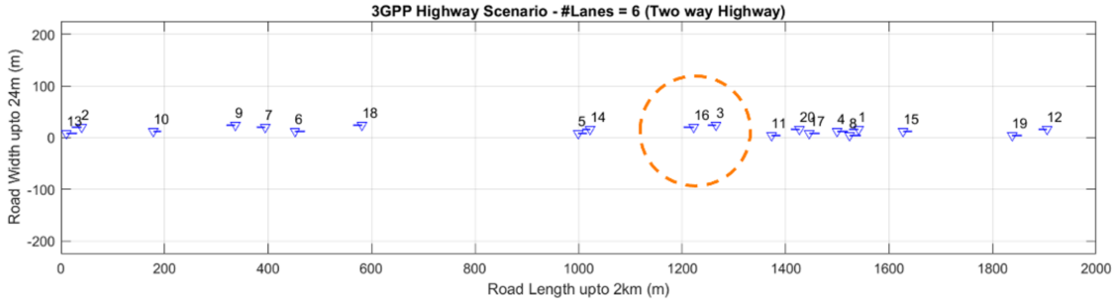

Figure 7: 3GPP Highway Scenario

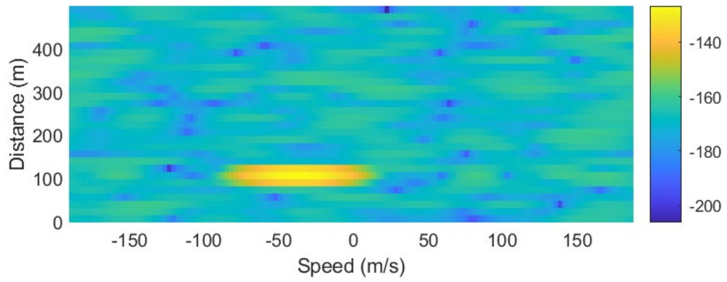

Figure 8: Range Doppler Map

The packet reception ratio (PRR) is computed as the average ratio between the number of vehicles correctly decoding a packet and the overall number of vehicles, given those receivers that are at a certain distance from the transmitter.

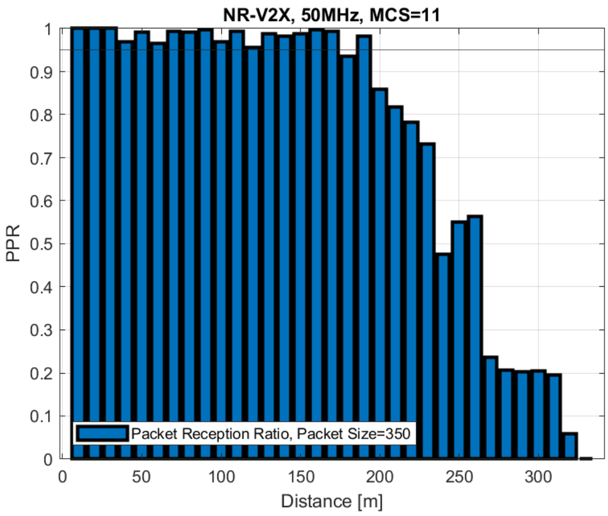

Figure 9: PRR vs Distance

5.2 ESR 6

Vehicle-to-Everything (V2X) technology is considered key in the automotive industry because it provides full awareness of the environment surrounding the vehicle by exchanging messages with other vehicles, road units, and pedestrians with low latency and high reliability. V2X builds on the capabilities of the 5G mobile network to ensure the desired capacity, throughput and low latency, high reliability, and security also in the delivery and reception of information between vehicles [19]. This is because 5G and beyond networks are being designed to efficiently support very different applications and services with diverse and stringent communication requirements, not only in terms of bandwidth and transmission rates but also reliability and latency [20]. In this context, ESR6 aims to achieve optimized 5G V2X/cellular interoperability and improved reliability for the autonomous driving use case, which is an advanced use case supported by 5G NR V2X.

For the case of autonomous driving, extremely high reliability is required, a reliability of 99.9999% or higher with a latency of 1ms is expected to decrease and prevent traffic accidents. With this in mind, ESR6 has performed simulations in the open-source simulator ns3 to assess reliability in 5G V2X systems.

For the simulations, a V2X Highway scenario has been modeled, as defined in 3GPP TR 37.885 [21], where the standard deployment consists of multiple motorway lanes with a lane spacing of 4 m and vehicular UEs in each lane, traveling from west to east. For the simulation results shown in this report, only 3 lanes with 30 vehicles per lane at a distance of 20 m between lanes have been considered. The vehicles are type 2 (i.e. passenger vehicles with an antenna height of 1.6 m) [21], and the speed of the vehicles is set to 140 km/h in all lanes.

This simulation focuses on a use case that aims at broadcasting basic service messages and assumes that all vehicular UEs are half-duplex transceivers, have the same packet size, are generated at the same speed, and use a fixed MCS. The transmission is performed in the 5.9 GHz band, assuming a channel bandwidth of 40 MHz. Table 5summarises the simulation parameters, for the end-to-end evaluations of NR V2X.

Parameter	Value
Channel Model	3GPP Highway
Deployment	3 lanes, 30 vehicles per lane
Carrier Frequency	5.89 GHz
Channel bandwidth	40 MHz
Noise power spectral	-174dBm/Hz
Maximum speed	140 km/h
Application packet size	300 Bytes
Inter-packet arrival time	100 ms

Table 5: Simulation Parameters

To assess the reliability of the 5G V2X system, the average packet reception ratio (PRR) has been measured. This metric is calculated as the average ratio between the number of neighbors that successfully decode a message and the total number of neighbors at a given target distance. For each UE, it should be calculated by considering only those UEs that are within a specific range at a certain distance from it, known as the ''awareness range''. For these simulations, an awareness range of 200 m has been considered, and all those vehicular UEs within this range from the originating UE are characterized as neighbors.

The results shown in Figure 9 provide a comparison of the PRR for different technologies, 5G V2X and LTE V2X. It has been decided to include another technology in the simulations to compare them and to get a more realistic picture of the technologies currently used in Europe for vehicle-to-vehicle communication. Overall, the simulation results have shown that 5G V2X systems offer better performance, as a higher number of decoded packets are obtained, that is to say, the PRR of more UE is higher.

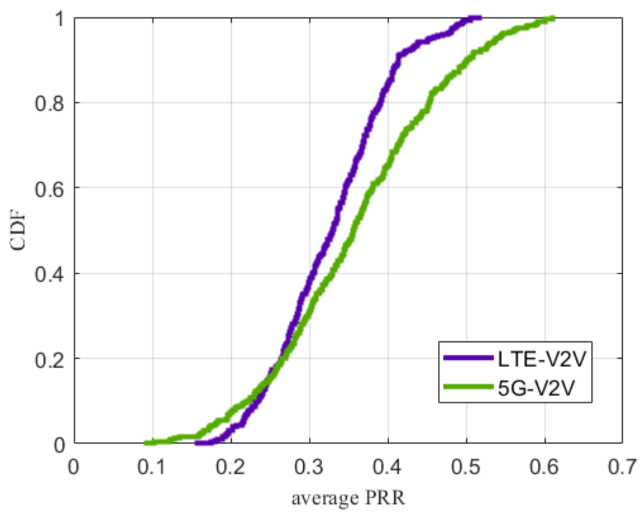

Figure 10: Comparison of PRR of 5G V2V and LTE-V2V

Considering the simulations performed, it can also be concluded that in order to optimize the reliability of the systems, packet forwarding can be duplicated using two different technologies. In this way, service failure can be avoided even in the case that packet transmission using one of the two technologies occasionally fails or exceeds the delay requirement. With this in mind, the next step would be to obtain and analyze results by applying this theory.

5.3 ESR 8

ESR's work addresses the new challenges in vehicular systems arising from increasing data, varying traffic requirements, and varying mobility conditions to achieve ultra-reliable communication for safety-critical applications. For this purpose, different factors influencing communication reliability and latency are being evaluated and mechanisms will be developed to predict the Quality of Service (QoS) in terms of reliability and latency. Methods based on machine learning are being studied to predict the QoS in dense vehicular networks. Since ESR 8 tasks contain evaluation and validation of different V2X scenarios and parameters, she has started to perform simulations to validate the system performance for a parking lot scenario to develop correlations between the key performance indicators (KPIs). The parking lot scenario is initially taken into consideration to remove the mobility restrictions to develop these correlations. As a result, ESR 8 has spent a significant amount of time learning about various system-level simulators to determine which one would be best suited to our research work. After much effort, we determined that OMNET++ would be the best network simulator for performing system-level simulations as it provides extensive GUI support and can be integrated with traffic simulator SUMO and Veins, a VANET simulation framework.

Network simulator OMNET++ is a discrete event network simulation library and framework equipped with many infrastructures and tools for simulations. OMNET++ has a generic component-based and C++ architecture that supports hierarchical and simple components to assemble compound components to form reusable components. OMNET++ supports different types of networks, routing protocols, and hardware architectures validating, evaluating performance…etc. The simulation can be run via different interfaces such as the graphical and animation interface and the CLI.

Traffic simulator SUMO stands for Simulation of Urban Mobility. SUMO accepts data from different sources like Open Street Map (OSM), it also allows the manual creation of roads via XML and GUI. Vehicles' traffic, road network, and vehicle type are generated via CML command and can be configured and easily customized. Along with that, files produced by SUMO, are portable and can be used as input for other simulators. SUMO is capable of handling huge networks, and multiple vehicles type. It can also deploy vehicle collision avoidance; support traffic at junctions; use either single or multiple-vehicle routes. SUMO provides a Traffic control Interface (TraCI) to support bidirectional communication with the network simulators.

VANET simulation framework Veins is an open-source framework and co-simulation of communication of networks and road traffic. Veins include a suite of models for running vehicular network simulations via the use of the OMNET++ network and SUMO traffic simulator. Both simulators are connected through the standardized Traffic Control Interface (TraCI). The nature of Veins, with their co-existing technologies and components, permits the simulation of complex heterogeneous scenarios with a high degree of realism. The key KPIs into consideration for evaluation of the simulated parking lot scenario are vehicle density, one-way-delay, and packet delivery ratio.

ESR8 has simulated the parking lot scenario with the following key parameters:

- Stationary vehicles
- V2V communication
- Data rate: 6 Mbps
- Technology: IEEE 802.11p
- Fixed transmission rate: 10 msg/s

ESR 8 aims at developing a relationship between these KPIs with the help of the data obtained from the simulated scenarios. After obtaining the preliminary results, it was possible to conclude that there is a relationship between the delay and the number of vehicles, and the preliminary conclusive plot is shown below:

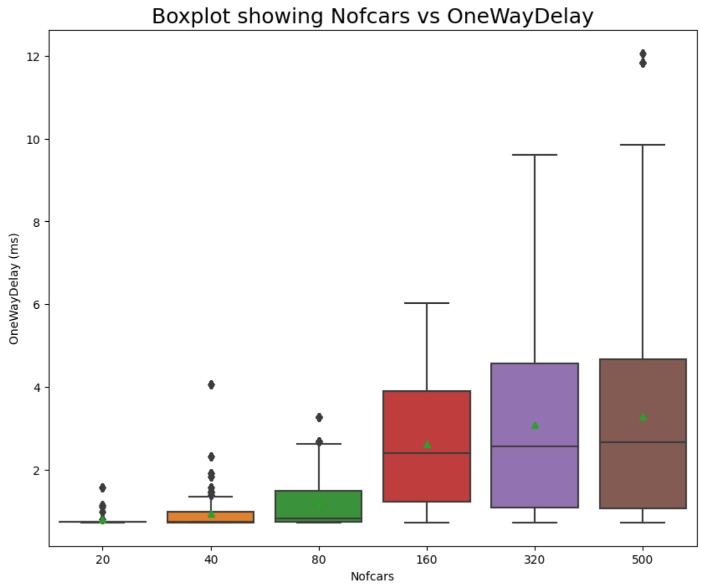

Figure 11: Packet delay vs Number of Vehicles

It can be well understood from the initial results that the mean value of delay varies significantly for the increasing number of cars, which shows a correlation between the delay and vehicle density. We expect that this data will help in delay prediction dependent on the number of cars.

The next step would be to establish a link between the packet delivery ratio and the number of cars. ESR also plans to expand the simulation to include mobility constraints, in which we will try to simulate a highway scenario with similar parameters and develop correlations between various considered KPIs. Furthermore, the ESR intends to implement well-known machine learning techniques for predicting latency, based on the number of vehicles, as well as to determine whether the KPIs under consideration are sufficient for QoS prediction or whether additional parameters will be required to perform the prediction, as well as to try to understand which of the existing machine learning algorithms are best suited for predictive analysis, or whether a new prediction algorithm with higher accuracy will be developed. In addition, the ESR intends to extend this simulated configuration to LTE and 5G communication technology to achieve even lower latencies and higher reliability.

6 Conclusion

As explained in this deliverable, integrating sensing and communication (ISAC) has immense scope in increasing spectrum efficiency and provides the feasibility of incorporating both sensing and communication capabilities under one telematics unit. This deliverable also explained in-depth strategies and the current challenges in the field of ISAC. The concept of radio resource management, specifically for the current V2X technologies, has also been described in detail, which gives an overview of how this can help attain efficient communication capabilities in ITS. Increasing traffic and varying data requirements have completely overloaded the network. Machine learning can play a vital role in designing strategies for congestion control which can learn from the behaviour of the networks and take appropriate measures to keep the network congestion free. The stepping stone on how that can be achieved is also explained in the deliverable. Lastly, all the involved ESRs of WP2 have illustrated their current work progress in the form of results.

7 References

[1] N. V. C. G. S. B. J. C. a. N. G. J. Wang, "Integrated Sensing and Communication: Enabling Techniques, Applications, Tools and Data Sets, Standardization, and Future Directions," *IEEE Internet of Things Journal,* vol. 09, no. 23, pp. 23416-23440, 2022.

[2] Huawei, "Integrated Sensing and Communication (ISAC) — From Concept to Practice," Huawei, Nov 2022. [Online]. Available: https://www.huawei.com/en/huaweitech/future-technologies/integrated-sensing-communication-concept-practice. [Accessed 19 Feb 2023].

[3] F. Liu, "Integrated Sensing and Communications: Toward Dual-Functional Wireless Networks for 6G and Beyond," *IEEE Journal on Selected Areas in Communications,* vol. 40, no. 6, pp. 1728-1767, 2022.

[4] A. Bazzi, B. M. Masini, A. Zanella and I. Thibault, "On the performance of IEEE 802.11p and LTE-V2V for the cooperative awareness of connected vehicles," *IEEE Transactions on Vehicular Technology,* vol. 66, p. 10419–10432, 2017.

[5] V. Torgunakov, V. Loginov and E. Khorov, "A Study of Channel Bonding in IEEE 802.11bd Networks," *IEEE Access,* vol. 10, pp. 25 514–25 533,, 2022.

[6] X. Lin, J. G. Andrews, A. Ghosh and R. Ratasuk, "An overview of 3GPP device-to-device proximity services," *IEEE Communications Magzine,* vol. 52, no. 04, pp. 40-48, 2014.

[7] 3GPP, "LTE; Evolved Universal Terrestrial Radio access (e-utra), radio resource control (rrc), protocol specification, v16.2.1, release 16," Sophia Antipolis, France, 2020.

[8] R. a. G. J. Molina-Masegosa, "LTE-V for Sidelink 5G V2X Vehicular Communications: A New 5G Technology for Short-Range Vehicle-to-Everything Communications," *IEEE Vehicular Technology Magazine,* vol. 12, no. 4, pp. 30-39, 2017.

[9] 3GPP, "3rd generation partnership project; technical specification group services and system aspects; release 16 description; summary of rel-16 work items, v1.0.0," Sophia Antipolis, France, 2020.

[10] M. H. C. a. M.-G. A. a. B. M. a. G. J. a. C.-P. B. a. Ş. T. a. K. A. Garcia, "A Tutorial on 5G NR V2X Communications," *IEEE Communications Surveys & Tutorials,* vol. 23, no. 3, pp. 1972-2026, 2021.

[11] 3GPP, "Tsg ran; nr; medium access control (mac) protocol specification, release 15, v16.3.0," 2021.

[12] J. C. a. H. Kim, "A QoS-Aware Congestion Control Scheme for C-V2X Safety Communications," in *2020 IEEE Vehicular Networking Conference (VNC)*, New York, USA, 2020.

[13] 3GPP, "Intelligent Transport Systems (ITS); Decentralized Congestion Control Mechanisms for Intelligent Transport Systems operating in the 5 GHz range; Access layer part V1.1.1," 2011.

[14] H. a. L. Q. a. J. Y. a. S. G. a. S. R. a. T. C. a. X. M. Jiang, "When machine learning meets congestion control: A survey and comparison," *Computer Networks,* vol. 192, p. 108033, 2021.

[15] 3GPP, "Technical Specification Group Services and System Aspects; Release 14 Description; Summary of Rel-14 Work Items (Release 14)".

[16] E. E. G. D. M.-S. a. J. F. M. D. Garcia-Roger, "V2X Support in 3GPP Specifications: From 4G to 5G and Beyond," *IEEE Access,* vol. 8, p. 190946–190963, 2020.

[17] 3GPP, "Technical Specification Group Services and System Aspects; Release 17 Description; Summary of Rel-17 Work Items (Release 17)," 2022.

[18] S. B. V. T. W. Z. Alessandro Bazzi, "WiLabV2Xsim," [Online]. Available: https://github.com/V2Xgithub/WiLabV2Xsim.

[19] A. K. A. P. E. P. K. S. S. S. Husain, "Ultra-High Reliable 5G V2X Communications," *IEEE Communications Standards Magazine,* vol. 3, no. 2, 2019.

[20] M. C. L.-E. I. M. J. G. A. Larrañaga, "5G NR Configured Grant in ns-3 Network Simulator for Ultra-Reliable Low Latency Communications," in *Procedia Computer Science 201*, 2022.

[21] 3GPP, "Study on Evaluation Methodology of New Vehicle-to-Everything (V2X) Use Cases for LTE and NR (Rel. 15), V15.3.0," 2019.