Performance analysis of the key Radio Access Technologies (RAT) of Vehicular Communications

PROJECT REPORT

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CERTIFICATE

This is to certify that this thesis (or project report) entitled ***"Performance analysis of the key Radio Access Technologies (RAT) of Vehicular Communications "*** submitted by **Toparapu Bhargavi** to the Indian Institute of Technology Madras, for the award of the degree of **Masters of Technology** is a bona fide record of the research work done by him under my supervision. The contents of this thesis (or project report), in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma..

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Abstract

V2X (Vehicle-to-Everything) is a new vehicular interaction technology that allows for the efficient transfer of data between vehicles and between vehicles and infrastructure. To improve road safety and traffic efficiency, this technology aids in the communication of real-time traffic updates and other road hazard information.

Depending on the underlying technology, there are two main forms of V2X communication technologies: 1) Wi-Fi based and 2) cellular based (C-V2X). Wi-Fi technology, often known as 802.11p, is the first standardised technology for vehicle networks followed by C-V2X. Long-term evolution-V2X (LTE-V2X) and New Radio V2X (NR-V2X) are the two versions of C-V2X currently available. After researching several radio access technologies, we discovered that NR-V2X provides better results for V2X communication. Along with those connected to the basic safety service provided by LTE-V2X, NR-V2X also supports new applications such as Vehicle platooning, extended sensors, advanced and remote driving which require low latency and high reliability. NR V2X sidelink supports sub-carrier spacings of 15, 30, 60 and 120 kHz, using the Cyclic Prefix Orthogonal Frequency Division Multiplexing (CP-OFDM) waveform exclusively. In this project, we analyse to find out which SCS can be chosen for increasing PRR.

WiLabV2Xsim is a dynamic MATLAB simulator that replaces LTEV2Vsim to support sidelink 5G-V2X. In this simulator, we investigated and analysed several simulation settings by changing input parameters like Distance between vehicles, Modulation and Coding Schemes, Density of vehicles, Sub Carrier Spacing and Transmission power and the performance metrics(Packet Reception Ratio, Data Age and Update Delay). Based on the data and analyses, we proposed an adaptive resource allocation algorithm which helps to improve PRR by adjusting Sub Carrier Spacing. The results show that PRR was improved when we use the proposed adaptive algorithm when compared to the default resource allocation algorithm.

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ABBREVIATIONS

3GPP	3rd Generation Partnership Project
C-V2X	Cellular V2X
CP	Cyclic Prefix
DL	Down Link
DSRC	Dedicated Short-Range Communication
ETSI	European Telecommunications Standards Institute
IoT	Internet of Things
IoV	Internet of Vehicles
KPI	key performance indicators
LTE	Long-Term Evolution
MCS	Modulation and Coding Schemes
NR-V2X	New Radio V2X

OFDM	Orthogonal Frequency-Division Multiplexing
PRR	Packet Reception Ratio
PSSCH	Physical Sidelink Shared Channe
RAT	Radio Access Technologies
SC-FDMA	Single carrier frequency division multiple acces
SCS	Sub Carrier Spacing
TB	Transport Blocks
TTI	Transmission Time Interva
UE	User Equipment
UL	Up Link
VANET	Vehicular Ad hoc network
V2X	Vehicle to everything
WLAN	Wireless Local Area Network

Chapter 1

Introduction

1.1 Introduction to vehicle communication

Transportation is an important aspect of our lives; it impacts our daily lives, but it must be operated by intelligent systems. One day in the future, it will be controlled entirely by things rather than humans; therefore, we must begin and improve V2V and Vehicle-to-Infrastructure ”V2I” technologies in order to improve safety.

To get a better understanding about vehicle communication technology, let us consider a typical urban environment with several road users, vehicles, road infrastructure, buildings and cellular network coverage. All the vehicles in this scenario may or may not have the capability or the modems to communicate wirelessly having the V2X modules installed vehicles will communicate with each other. However the wireless link directly or via cellular network are used to inform each other about their location, speed, heading direction and any relevant warnings for collision.

When vehicles are communicating to other vehicles, to the infrastructure, to the pedestrians or to the mobile network, it is termed as vehicle to everything (V2X) communication[1].

V2X communication is a complete road safety and traffic efficiency solution that allows vehicles to communicate with its surrounding objects. For the short-range communication, vehicles and other road users often use direct communication between each other in an ad hoc manner whereas for the long-range communication or Internet of Things application they rely on 4G and 5G cellular networks. The ad hoc v2x communication also known as side link or PC5 is a short-range and direct communication. It is for the distances under one kilometer. There are different technology alternatives available for short-range communication for example based on the Wi-Fi standard IEEE 802.11p or cellular standard named C-V2X[2].

Forward collision warnings, emergency vehicle assistance, vulnerable pedestrian collision mitigation, blind intersection warnings, and hazardous location alerts are some of the vehicular safety applications that can be realised using vehicular networking.

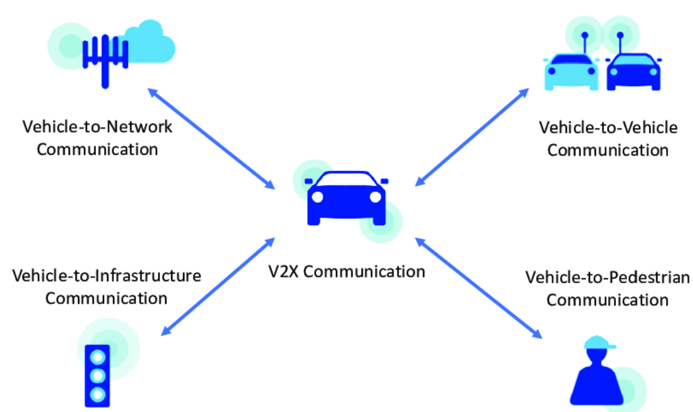

Figure 1.1: Components of V2X technology

These applications enable the collection and dissemination of useful contextual information between vehicles (vehicle-to-vehicle (V2V) communication), vehicles and infrastructure (vehicle-to-infrastructure (V2I) communication), vehicles and supporting network (vehicle-to-network (V2N) communication), and vehicles and vulnerable road pedestrians (vehicle-to-pedestrian (V2P) communication), thereby strengthening the basis of V2X communication, as shown in figure1.1.

The ability to communicate securely and quickly between vehicles, as well as between vehicles and the supporting infrastructure and network, is vital to the success of the vehicular safety applications.

The information from the vehicle sensors and other sources passes across high-bandwidth, high-reliability links in a V2X communication system, enabling it to communicate with other vehicles, infrastructure like parking spots and traffic lights, and smartphone-tossing people.

1.2 Importance of V2X technology

V2X technology improves the driver's awareness of potential threats by sharing information such as speed with other entities around the car. This helps lessen the severity of injuries, road accident fatalities, and collisions with other vehicles. The technology also improves traffic efficiency by alerting vehicles of impending traffic, proposing other routes to avoid congestion, and identifying vacant parking spaces. The carbon footprint of automobiles could be decreased with V2X technology. Long traffic delays and queuing at traffic lights can be reduced with V2X.

The Internet of Things (IoT) includes a significant portion devoted to vehicular communication, which has helped give rise to a new paradigm, known as the Internet of Vehicles (IoV). The IoT has advanced applications in intelligent transportation systems, including the IoV. Smart cities, in which intelligent things can connect with one another, are primarily enabled by IoT technology. Making it possible for automobiles to communicate in real time with other vehicles, roadside infrastructure, and pedestrians is the primary objective of the IoV.

1.3 Motivation

The advancements in the cellular communications and automobile industries have increased significantly during the past ten years. The newly imposed safety procedures and the desire to develop the well-known completely autonomous vehicles have sparked a research topic on cellular communications and their potential significance in the race to develop the ideal of developing completely autonomous vehicle.

V2X technology has emerged in this context to capture all of these specifications The phrase ”vehicle to everything” (V2X) describes how a vehicle interacts with any other system or object. The Third Generation Partnership Project (3GPP) has introduced the Cellular V2X (C-V2X), which depends on standardised mobile cellular communication by the same 3GPP such as 4G LTE or 5G, in order to meet the requirements defined by V2X communications. In release 16, the first V2X standard based on the 5G New Radio (NR) air interface was introduced.

The global automotive V2X market is being driven by factors like rising disposable income, a rapid rate of industrialization as well as urbanisation, and an expanding economy. Additionally, throughout the forecast period, growth in the worldwide automotive V2X market is anticipated to be supported by rising automation and technological innovation. V2X communication system implementation has numerous advantages, but there are also some drawbacks, such as the need for a strong legal framework and the necessity to construct a safe system that guarantees privacy, authenticity, and security for all sorts of V2X communication.

1.4 Aim of the project

The key objectives of our project are: To understand the evolution and working of the various Radio Access Technologies (RAT) of V2X communications. The resource allocation techniques used for vehicular communications needs to be explored in detail. The modifications of these techniques for reducing the collisions and increasing the Packet Reception Rate (PRR) need to be surveyed.

WiLabV2X is a MATLAB based simulator, used to simulate resource allocation techniques of the cellular LTE, IEEE 802.11p, and 5G NR for V2X communication. An in-depth understanding of the Matlab code of this simulator is required. Using the simulator, we need to analyse the different RAT technologies and compare the results. The key performance indicators of the vehicular communications are: 1)PRR, 2)Data Age and 3)Update Delay . The performance of these KPIs with a variation in the following parameters needs to be studied: Distance between the vehicles, MCS (Modulation and Coding Scheme), SCS (Sub Carrier Spacing) and Density of vehicles.

1.5 Outline Of Report

The first chapter provides an introduction to the V2X communication and its importance. The literature survey on V2X communication, different technologies for V2X communication is presented in chapter 2. We also discussed about the various improvements proposed to improve the Key Performance Indicators (KPIs). In chapter 3 a detailed discussion on Vehicle communication and various Radio Access technologies used for V2X communication is presented. The evolution of technologies and their resource allocation algorithms are discussed.

In chapter 4 the simulator setup and the structure of the simulator (WiLabV2Xsim) is presented. The performance metrics that are studied and the simulation settings for the performance evaluation are described. Chapter 5 contains a record of all simulation work completed and analysis of the results. All the plots showing the variation of output parameters (PRR, Data Age and Update Delay) with given input parameters (Distance, density of vehicles, MCS and Transmission power) are analysed in this chapter. Chapter 6 describes the proposed Adaptive resource allocation algorithm in order to improve the performance in terms of PRR and the simulation results of the modified algorithm showing the improved performance are presented. Chapter 7 provides the conclusion and summarizes the report.

Chapter 2

Theory and background

Vehicle-to-everything (V2X) communication is a critical paradigm for future cooperative autonomous driving since it allows any vehicle to communicate with other vehicles and any other V2X-enabled entity nearby. In this chapter, we are going to discuss about the V2X technologies in detail.

It employs VANETs[3] (vehicular ad hoc networks), which are wireless networks that allow vehicles to communicate and share information about their driving habits. Speed, location, braking, stability, and travel direction, among other things, are all included in the data. This technology is important because it improves road safety by sending incident alerts before a driver sees or detects them.

2.1 V2X technologies

After investigations on short-range communications between vehicles in the 1980s and 1990s, the allocation of dedicated bandwidth in the United States in 1999 was certainly the first milestone. Around 5.9 GHz, seven channels of 10 MHz each were allocated for what was known as dedicated short range communication (DSRC).

2.1.1 DSRC

DSRC was the first V2X technology introduced in the Institute of Electrical and Electronics Engineers (IEEE)'s 802.11p standard. It employs WLAN technology to create dedicated short-range communication (DSRC) channels, allowing vehicles to connect directly with other entities across short to medium distances.

Since the original purpose of DSRC was to communicate short range (about 300 m) basic safety messages between vehicles, it is not designed to handle the high bandwidth demands of V2N applications. Moreover, according to how the standard was designed, it cannot be improved to satisfy the new, more sophisticated needs that are being considered recently.

2.1.2 LTE-V2X

Release 14 specified short-range LTE-V2X based on Release 12's device-to-device (D2D). It's also known as sidelink LTE-V2X (as opposed to downlink/uplink) and has the PC5 communication interface. At the PHY and MAC layers, sidelink LTE-V2X (hereafter simply LTE-V2X) uses the same single carrier frequency division multiple access (SC-FDMA) as LTE uplink in the:

- frequency domain, subcarrier spacing is fixed to 15 kHz, and subcarriers are used in groups of 12 (i.e., 180 kHz).
- time domain, 14 symbols form a subframe of 1 ms, also known as transmission time interval. MCSs are abundant in LTE-V2X.

Cellular V2X[4] employs 3GPP-standard 4G LTE or 5G mobile cellular connectivity to send and receive signals from a vehicle to other vehicles, pedestrians, or fixed objects in its environment, such as traffic lights. It frequently communicates via the 5.9 GHz frequency spectrum.

14 OFDM symbols with a normal cyclic prefix are used in each subframe. Nine of these symbols are commonly used to transmit data, while four are used to send demodulation reference signals (DMRSs) for channel estimation and Doppler effect minimization at high rates. The last symbol is used as a guard symbol to allow vehicles to switch between transmission and reception across subframes and for timing adjustments.

Sub Channels

Sub-channels are group of Resource blocks(RBs). Only RBs from the same subframe can be included in a sub-channel. The number of RBs per sub-channel is preconfigured and can vary. When a User Equipment(UE)is in network coverage, the network defines the configuration and the cellular base station (eNB or gNB) signals it to the UE; when the UE is out of network coverage, the UE defines the configuration. Data and control information are transmitted via sub-channels. The information is grouped into Transport Blocks (TBs), which are sent across the Physical Sidelink Shared Channel (PSSCH). A entire packet is contained in a TB. Depending on its size, a TB can occupy one or more subchannels.

2.1.3 NR-V2X

Release 14 C-V2X (i.e., LTE-V2X) will be the only core of basic safety communications, and future releases of 5G NR will bring enhancements to support advanced services[5]. Unlike Wi-Fi, the idea does not have backward compatibility; instead, it adds a second interface with greater performance on different channels. NR V2X sidelink can operate at frequencies within the two following frequency ranges:

- Frequency range 1 (FR1): 410 MHz – 7.125 GHz
- Frequency range 2 (FR2): 24.25 GHz – 52.6 GHz

Because of the multicarrier orthogonal frequency-division multiplexing (OFDM) enabled by the adaptability of the NR numerology, 5G-V2X enhances LTE-V2X with the capabilities of the 5G NR physical layer and supports sophisticated V2X applications with a wide variety of requirements.

The V2X communication operating modes supported by the 5G system architecture are V2X communication over the PC5 reference point or interface and V2X communication over the Uu reference point or interface. For NR and LTE, the PC5 interface allows SL V2X communications. Under NR Non-Standalone (NSA) and Standalone (SA) deployments, V2X communications over Uu for UL and DL broadcasts are possible. Only unicast communications are supported in V2X communication over Uu in Rel. 16. Rel. 17 does, however, feature an ongoing SI [33] that discusses 5G multicast and broadcast transmission upgrades. V2X messages sent over LTE-Uu can also be transmitted in DL using Multimedia Broadcast Multicast Services (MBMS).

Enhancing Rel. 16 NR V2X resource allocation mode 2 is one of the goals of this Rel. 17 work item. Some of the proposed improvements are focused on reducing power consumption and improving key performance indicators like dependability and latency. With Rel. 16 NR V2X, all upgrades must be able to share the same resource pool (co-channel coexistence). In Rel. 16 NR V2X, Mode 1 and Mode 2 were created for UEs with low power requirements, like vehicles or RSUs.

2.2 Numerology

The orthogonal frequency division multiplexing (OFDM) waveform with a cyclic Prefix is used in NR V2X SL transmissions. The sidelink frame structure is divided into radio frames (also known as frames) with a duration of 10 milliseconds each. A radio frame is divided into ten subframes, each lasting one millisecond. For NR V2X, the number of slots per subframe and the subcarrier spacing (SCS) for the OFDM waveform can be adjusted. For NR V2X, a scalable OFDM numerology based on Rel.15 NR Uu is being studied to support a variety of requirements and operating frequencies in FR1 and FR2. An SCS and a Cyclic Prefix (CP) are used to define each OFDM numerology. Multiples of 15 kHz (i.e., the SCS in LTE V2X) are supported by NR V2X for data transmission.

Table 2.1: Numerologies of NR-V2X

μ	SCS	Frequency range	Symbols per slot	Slot Duration
0	15KHz	FR1	14	1ms
1	30KHz	FR1	14	0.5ms
2	60KHz	FR1,FR2	14	0.25ms

With a scalable SCS of $2\mu \times 15KHz$, Where is a μ is SCS configuration factor, various OFDM numerologies can be achieved. The SCS configuration factor for NR V2X can be set to 0, 1, 2, or 3, resulting in SCS values of 15 kHz, 30 kHz, 60 kHz, or 120 kHz. The SCS is supported in FR1 at 15 kHz, 30 kHz, and 60 kHz, and in FR2 at 60 kHz and 120 kHz. Supporting a higher SCS enhances the OFDM waveform's robustness over frequency impairments caused by Doppler effects, carrier frequency offsets, and hardware phase noise, that are more significant in FR2.

2.3 Resource Allocation

The resource allocation is generally related with a semi-persistent scheduling (SPS) method since LTE-V2X was primarily developed to support the cooperative awareness service, which is the sending of periodic messages by each vehicle to notify about its condition and movements.

2.3.1 LTE-V2X Mode 3 and Mode 4

3GPP defines two possible ways for resource allocation, namely Mode 3 and Mode 4, depending on the entity in charge of the allocation. The cellular infrastructure (eNB) manages V2X SL communications in mode 3. This includes deciding on and configuring communication resources(sub-channels). Mode 4 can function without the need of cellular infrastructure. Vehicles select, manage, and configure sub-channels autonomously in this case.

Dynamic scheduling and Semi-Persistent Scheduling(SPS) are the two types of scheduling schemes defined. Vehicles must request sub-channels from the eNB for each TB when using dynamic scheduling. The eNB reserves sub-channels for SPS scheduling so that a vehicle can transmit multiple TBs. Because transmission scheduling is concentrated at the eNB, mode 3 can outperform mode 4. However, it necessitates network coverage and creates other challenges.

2.3.2 5G-V2X Mode 2

Similar to Mode 4, in Mode 2 the UEs independently select side link resources for their transmission without network assistance. The dynamic scheduling and allocation system for non - periodic traffic is explicitly introduced by 5G-V2X in addition to the SB-SPS. In the dynamic method, the chosen resource is only needed for one transmission, and resources can be allocated for it's own re-transmission. Hence, with the dynamic method, new resources must be chosen for each transfer.

Chapter 3

Literature survey

3.1 Introduction to V2X communication

These days, vehicle networks constitute a significant and expansive research area that attracts both the automotive and telecommunications industries. The automobile industry's top priority continues to be road safety. In this context, Vehicle-to-Everything (V2X) communication has emerged as a result of the integration of wireless communication technologies in this industry.

Hongye Mei et al. have given an overview of vehicle communication technology. The difficulties in V2V communication were also discussed in this paper[1]. Daxin Tian et al. have investigated the potential of V2V communications, the limitations of the multi-channel operations envisioned by IEEE 802.11p, and realistic scenarios for signal propagation and vehicle mobility in actual surrounding. Experimental analysis to verify the proposed the V2V system with DSRC were presented[2].

3.2 Various V2X technologies

3.2.1 LTE-V2X

Gaurang Naik et al. have evaluated the impact of Wi-Fi transmissions on C-V2X performance in both co-channel and adjacent channel scenarios using a comprehensive and systematic simulation analysis. The simulations show that existing procedures either fall short of adequately protecting C-V2X performance or render the spectrum useless for Wi-Fi operations if Wi-Fi devices coexist with C-V2X in the same spectrum[6]. Miling Chen et al. have presented an overview of C-V2X Mode 4 communication and highlight several significant improvements over long-term evolution (LTE), such as subframe structure design, synchronisation mechanism, resource pool configuration, and resource scheduling mechanism, such as sensing-based semi-persistent scheduling (S-SPS), among others[4]. Pierre Roux explored on the performance degradation due to co-channel coexistence between LTE-V2X and ITS-G5 technologies. Also investigated the loss of ITS-G5 performance when ITS-G5 vehicles coexist along with PC5 mode 4 vehicles, as well as the possible benefits of coexistence mechanisms in reducing this loss[7].

Shanzhi Chen et al. has introduced the architecture, core technologies, and standards of C-V2X, with an emphasis on the technological evolution path from LTE-V2X to NR-V2X[8].

3.2.2 NR-V2X

Waqar Anwar et al. has studied and evaluated various V2X technologies and from the results concluded that NR-V2X outperforms all the other standards[5]. Vittorio Todisco et al. have analysed the performance of side link mode 2 of 5G-NR V2X technology and detailed study of flexible numerology is given [9].

Mario H. Castañeda Garcia et al. have given a detailed information about the new releases of V2X communication. An in depth focus was made on the key features of 5G NR V2X communication. [10] Jie Chen et al. has analysed the design of NR-V2X with a focus on Mode 2 and evaluated its performance [11]. Jinling Hu et al. have examined the design of NR-V2X side link synchronisation signals. Then, in order to promote higher side link synchronisation signal(SLSS) detection performance and mitigate frequency error, side link synchronisation signals were improved[12]. Muhammad Nur Avcil et al. have investigated the effect of NR flexible numerology, i.e., scalable Transmission Time Interval (TTI) duration and sub-carrier spacing (SCS), on the C-V2X autonomous access mode, in which vehicles self-allocate transmission resources[13].

3.3 Resource Allocation algorithms

In this section we will look into the papers describing resource allocation algorithms in different technologies and the proposed modifications in the Resource allocation algorithms to enhance the performance.

Khabaz Sehla et al. have investigated about the resource allocation algorithms in C-V2X and NR-V2X [14]. Khabaz Sehla et al. have proposed a new clustering based resource allocation algorithm. The resources are organized into orthogonal resource sets, with each set allotted to a cluster[15]. Youngjoon Yoon et al. proposed a modification to the SB-SPS method to protect against the packet dropping by randomly selecting resource locations. The proposed countermeasure can even surpass the un-attacked SPS in terms of PRR, with the side effect of resolving persistent collisions[16]. Inam Ullah et al. have presented the performance of relay selection algorithms in 5G New Radio (NR) network[17].

Claudia Campolo et al. evaluated the effects of NR flexible numerology, which includes scalable Transmission Time Interval (TTI) duration and sub-carrier spacing (SCS), on the C-V2X autonomous access mode, in which vehicles self-allocate transmission resources [18]. Tommaso Zugno et al. has investigated the impact of several system-level parameters, including the numerology, the MCS, the antenna array size, the RLC reordering timer, the propagation scenario, and the communication distance [19].

3.4 Simulation environment

Giammarco Cecchini et al. described a MATLAB-based LTE-V2V dynamic simulator. The simulator, which is accessible to all researchers,that allows to evaluate the performance of various radio resource allocation algorithms for the cooperative awareness service in a variety of scenarios, including those involving the lower layers of LTE, application parameters, and a scenario with moving vehicles[20]. Kemal Mert Makinaci et al. have constructed VANET, an NS3 simulator linked with an SUMO simulator to enable scalable simulation of various traffic situations in order to analyse and test the LTE deployment. The performance of a fast and lossless ad-hoc connection in road traffic is tested using a set of physical channel setup parameters[3].

3.5 Performance evalution

Jian Gao et al. launched a field test in real traffic for three different types of scenarios and studied various parameter configurations to verify large scale communication performance[21]. Jeong-Kyu Bae et al. have implemented two testbeds to evaluate the performance of V2X technology based on measurement campaign and key performance indicators (KPIs).The test was carried out on DSRC-based

V2X communication system[22]. Sihun Heo et al. preseneted a hybrid V2X (H-V2X) strategy, in which C-V2X is adaptively controlled to meet KPI requirements as much as possible, and DSRC transmission is used when C-V2X necessary performance cannot be consistently supported[23]. Qifeng Ding et al. have analysed and studied the reasonable use of spectrum resources and the smoothness of communication pipelines, appropriate resource scheduling approaches based on diverse infrastructure and operational circumstances, to optimize the LTE-V2X direct communication performance[24]. Rafael Molina et al. have analysed the appropriate configurations for the parameters that have the highest effect on the operation and performance of C-V2X or LTE-V Mode 4. This study is carried out under various channel loads and traffic circumstances[25].

Chapter 4

Simulation setup and Procedure

The simulations in our project were run on the WilabV2Xsim simulator. This simulator's first release is version 6.1, in order to maintain continuity with LTEV2Vsim, whose most recent shared version was 5.4. The key change from version 5.4 to version 6.1 is the addition of 5G-V2X, along with NR and other relevant parameters (including numerology). To generalise the parameters that are common for LTE and 5G, which are now referred to as CV2X, a broad refactoring was undertaken. Minor adjustments and enhancements were also made. It's an open source dynamic MATLAB simulator. It was created to investigate resource allocation in side link C-V2X networks, with a focus on the cooperative awareness service, although it can also be used to simulate IEEE 802.11p/ITS-G5.

4.1 Simulator structure

The figure4.1 shows the structure of the simulator and how it works.

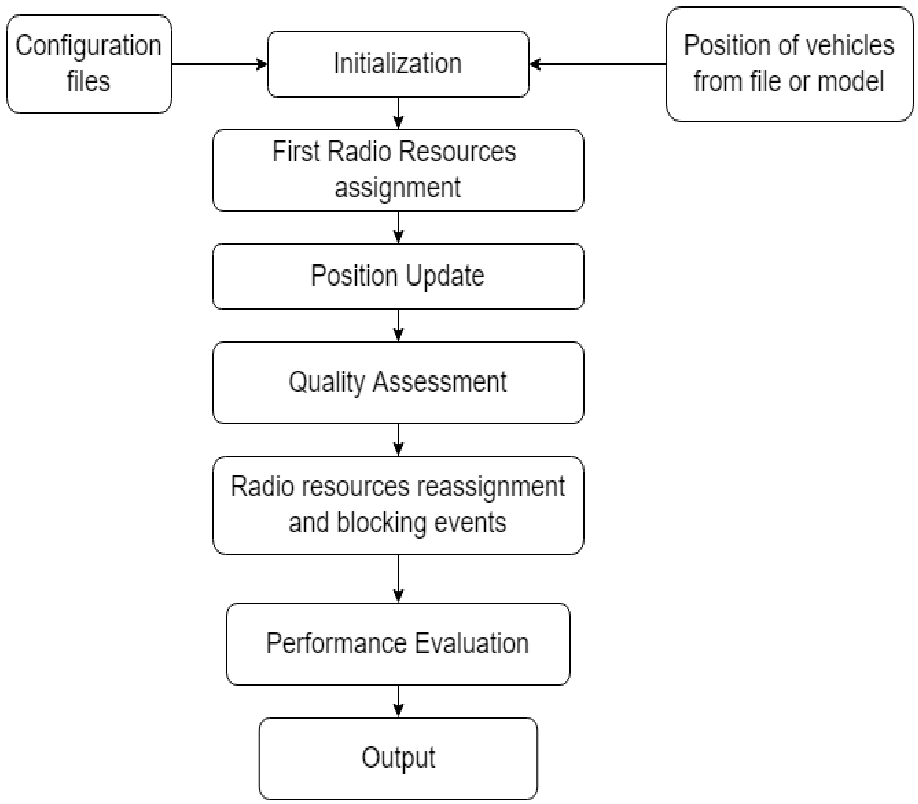

Figure 4.1: Flowchart showing structure of the simulator

4.1.1 Positions

The positions of the vehicles can be derived from a variety of sources.

- A Poisson distribution is used to simulate a highway in this theoretical model.
- Linear density, road length, road width, number of lanes per direction, mean and variation of speed are the main characteristics.
- Realistic traffic patterns: highway or urban

4.1.2 Initialization

Each setting has a default value to help with the initialization. The settings of the parameters included in the configuration file (LTEV2Vsim.cfg) overwrite the default values at the start of the simulation. Settings can also be passed through the command line, which takes precedence over the previous two methods and so overwrites these settings.

We can also add our own configuration file and customise the simulation settings. This will aid in the exploration and simulation of a wider range of scenarios.

4.1.3 Radio resource assignment

To minimize the duration of the initial transient period, a first resource assignment is made for all of the vehicles in the scenario at the start of the simulation, exactly as they would be if they were all under cellular coverage and the network could accurately predict their positions. This strategy, which is also used when investigating autonomous resource allocations, eliminates unrealistic bursts of collisions during the first beacon periods caused by a large number of vehicles entering the simulation at the same time.

4.1.4 Position Update

When the simulation starts, the input settings passed by the configuration file, command line, or default settings are used to update the position of all the vehicles. To recreate differing levels of localization accuracy at the eNodesB, a positioning error or delay can be added.

4.1.5 Quality assessment

If the signal-to-noise plus interference ratio (SINR) of a beacon is greater than the minimal threshold MIN calculated according to the 3GPP standard, given the MCS and packet size, the beacon is regarded successfully received.

SINR = C/(N+I)

where C represents useable received power, N represents noise contribution, and I represents interfering power.

4.1.6 Radio resources reassignment and blocking events

Radio resource assignment is the main part of the simulator. Based on the BRAlgorithm selected, the resources are reassigned. In mode 3, central entity is followed with perfectly synchronized eNBs. Whereas in mode 4, distributed schemes are followed

When the selected algorithm does not assign any resource for the transmission of next packet, a blocking event occurs.

4.1.7 Performance evaluation

The key performance indicators are the following:

Packet Reception Ratio (PRR)

PRR is the percentage of nodes which received packets successfully, when all receivers are within the transmission range. It is defined as the ratio of number of successfully received beacons to the sum of number of neighbors.

Update Delay

The delay time between two successive successfully received beacons from the same node within the specified awareness range is known as the update delay.

Data Age

Data Age is the time interval between the time of transmission of a successfully received packet to the time at which the next successful packet is received. If there are any packets missed the transmission and reception of that packet will not be considered.

4.2 Simulation settings

The simulator provides 6 different type of configuration files. These configuration files contains the all the parameters required to initialise the simulation. We can change an input parameters, through configuration file or by directly entering the command line. We have used the Highway3GPP configuration file for all the simulations. The type of scenario is ETSI Highway, which has Road length of 2000 m and Road width of 4 m.

The table4.1 shows the simulation settings describing the parameters and their values used for simulation. BRAlgorithm was set to default value 18 which is Autonomous with sensing (3GPP 5G mode 2 when Technology is 5G-V2X).

Table 4.1: Simulation settings

Parameter	Value
SimulationTime(s)	150
Technology	NR-V2X
BeaconSizeBytes	190
Bandwidth(BwMHz)	10
Contention Window(CW)	15
Density of vehicles(rho)	35
Mean speed of vehicles(vMean)	240
Resource keep probability(pk)	0.8
Noise figure of the receiver(dB)	9
Modulation and Coding Scheme(MCS)	7
channel model	Winner+
Delay resolution(s)	0.001
Duplexing type	HD

While varying a parameter, the remaining parameters are set to default value. In our simulations, when Transmission power is varied, MCS is set to 7 and Density of vehicles is set to 35vehicles/km. When Density of vehicles is varied, Transmission power is set to 23dBm and MCS is set to 7. Similarly when MCS is varied, Transmission power is set to 23dBm and Density of vehicles is set to 35 vehicles/km.

Chapter 5

Performance evaluation

In this project, we varied different input parameters and from the output we analysed the results. The input parameters are given below

- Distance between Vehicles
- Density of vehicles (rho - vehicles/km)
- Modulation and Coding Scheme (MCS)
- Transmission power (Ptx - dBm)

All the above parameters were varied for three different values of Sub Carrier Spacing(SCS) - 15KHz, 30KHz and 60KHz. The output metrics that were plotted are given below.

- Packet Reception ratio (PRR)
- Update Delay
- Data Age

5.1 Output

5.1.1 Packet Reception Ratio

When printPacketReceptionRatio command is given as true, the output file named as packet_reception_ratio_simID.xls will be generated. The first column of the file prints the distance between vehicles and the last column prints the corresponding PRR value.

5.1.2 Update Delay

When printUpdateDelay command is given as true, the output file named as update_delay_simID.xls will be generated. The last column prints the CDF of Update Delay values. From the CDF we can find the expected value or mean value of Update Delay.

5.1.3 Data Age

When printDataAge command is given as true, the output file named as data_age_simID.xls will be generated. The last column prints the CDF of Data Age values. From the CDF we can find the expected value or mean value of Data Age.

5.2 Effect of distance on PRR

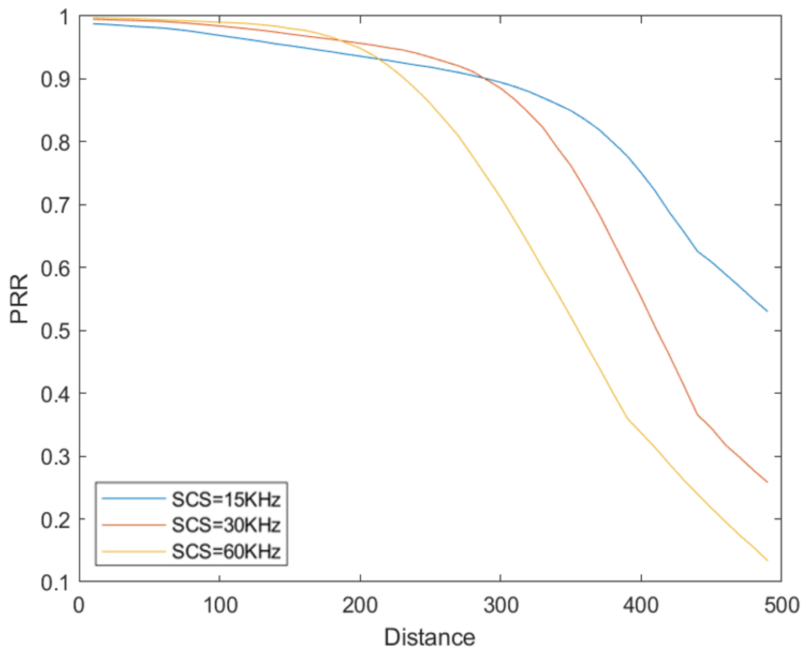

Figure 5.1: PRR vs distance between vehicles

The figure5.1 shows PRR vs Distance plot for different values of SCS (sub carrier spacing). When the subcarrier spacing (SCS) is high the performance is better in terms of PRR upto certain distance and when distance is increased lower SCS has better performance than others. As the distance between vehicles increases the successful reception of packets will decrease and hence the PRR decreases with increasing distance between vehicles.

When the distance between vehicles is less than 200 meters, the PRR is higher for SCS 60KHz. For distance 200 to around 300 meters, the PRR is higher for SCS 30KHz and for distance between vehicles beyond 300 meters, PRR is higher for SCS 15KHz. For SCS 15KHz, the PRR falls from 0.98 to 0.53, where as for SCS 60 KHz, the PRR falls from 0.99 to 0.12. Hence we can conclude that for lower distances, higher SCS (60KHz) performs better and for higher distances lower SCS (15KHz) performs better.

5.3 Effect of Density of vehicles

The density of vehicles is represented by the input parameter called 'rho' and is expressed in terms of Vehicles/km. The default value of rho for ETSI type of scenario is 35 Vehicles/km.

5.3.1 PRR for different SCS

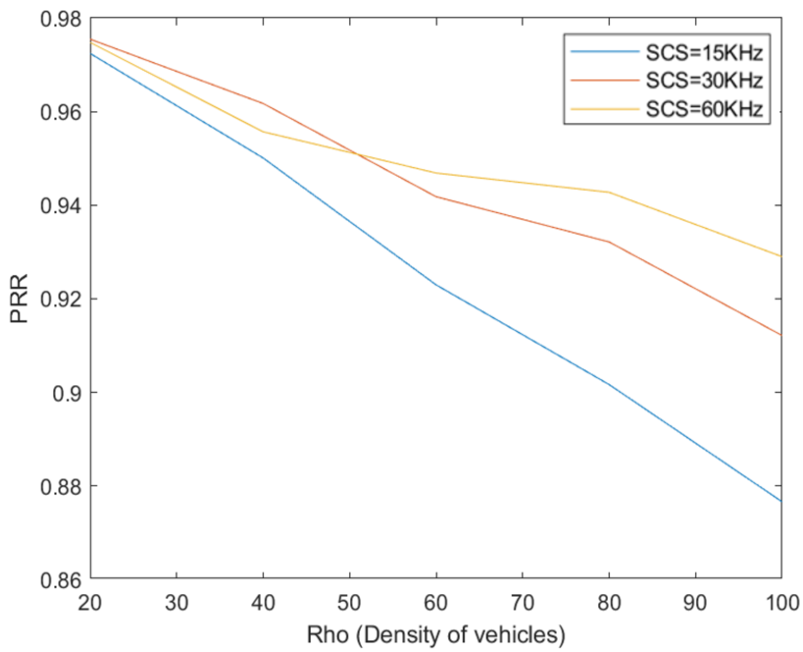

Figure 5.2: PRR for different SCS

The figure5.2 shows the effect of density of vehicles on PRR. The density of vehicles is varied from 20 to 100 vehicles/km. With increasing rho within given range of distance there will be more vehicles so the successful reception of packet decreases and hence PRR decreases with density of vehicles.

When rho is less than 55 vehicles/km, the PRR is higher for SCS of 30KHz. When rho is more than 55 vehicles/km, the SCS of 60KHz has higher PRR.

5.3.2 Data Age for different SCS

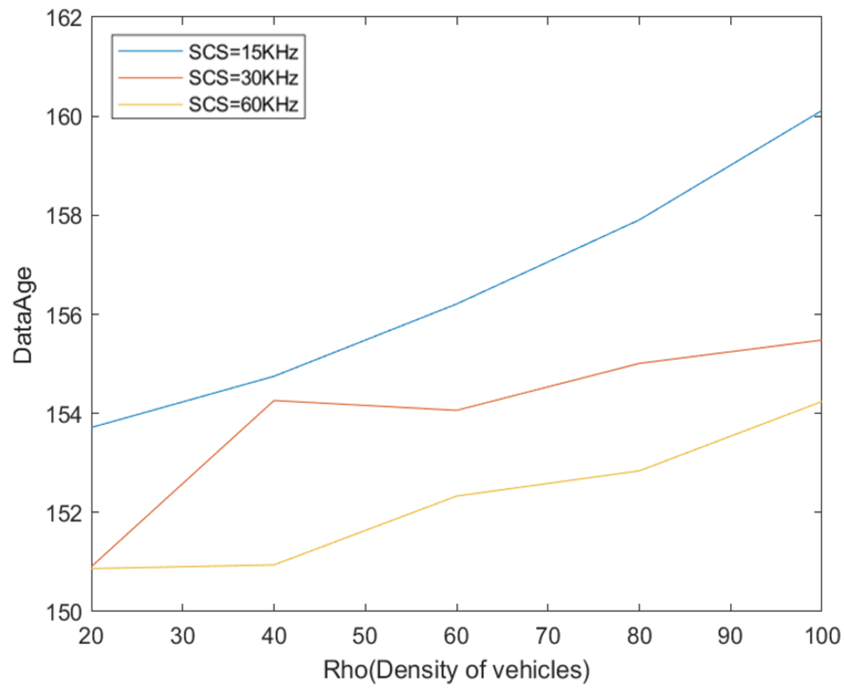

Figure 5.3: Data Age for different SCS

The figure5.3 shows the effect of varying density of vehicles(rho) from 20 to 100 vehicles/km over Packet Reception Ratio(PRR). As the density of vehicles increases the probability of missing a packet on receiver end will be more. Therefore Data Age increases with density of vehicles.

The Data Age value is increasing from 153.9 to 160.4 milliseconds when rho increased from 20 to 100. For any given value of rho, SCS 15KHz has the highest Data Age value. This is because of the higher slot time for less SCS value.

5.3.3 Update Delay for different SCS

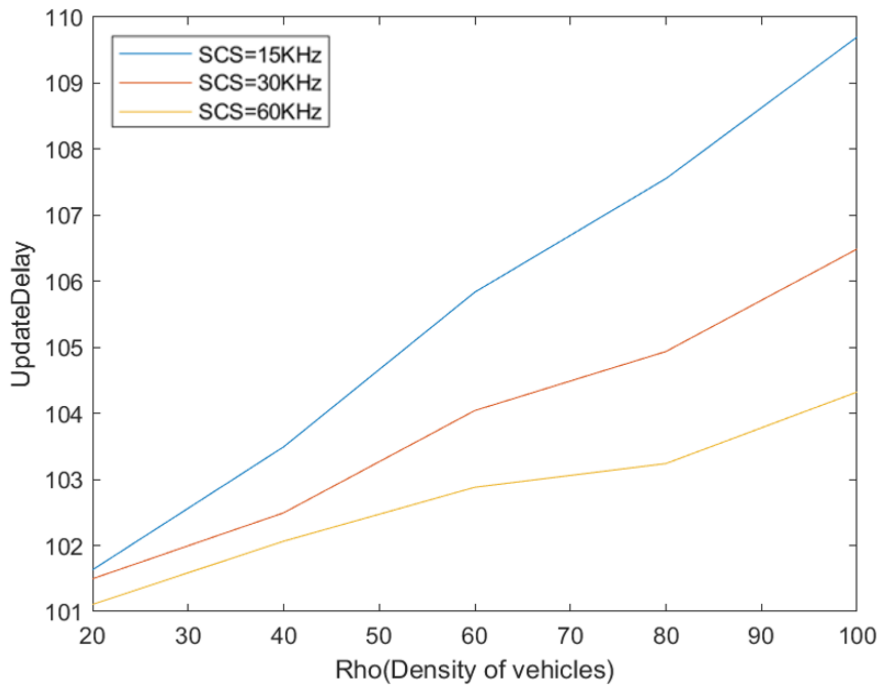

Figure 5.4: Update Delay for different SCS

The update delay is defined as the time interval between two consecutive successfully received beacons from the same node within the selected awareness range As the density of vehicles increases the channel or base station will be busy for longer time and therefore the Update Delay will also increase with rho.

The figure5.4 shows the plot of Delay varying with rho. Here rho is varied from 20 to 100 vehicles/km and the corresponding values of Delay are noted down.When the SCS is less(15 KHz), the slot duration is 1ms, which is comparatively greater than that of the other SCS. Hence the Delay will be more when SCS is 15KHz and from the results we can infer that, as rho increases the Delay increases gradually and is more in the case of SCS 15KHz.

5.4 Effect of Transmission power

The Transmission power is represented by the input parameter called 'Ptx_dBm' and is expressed in terms of dBM. Ptx_dBm refers to the power adopted over 10 MHz and it is scaled in case the signal uses only a portion. The default value of rho for ETSI type of scenario is 23 dBm.

5.4.1 PRR for different SCS

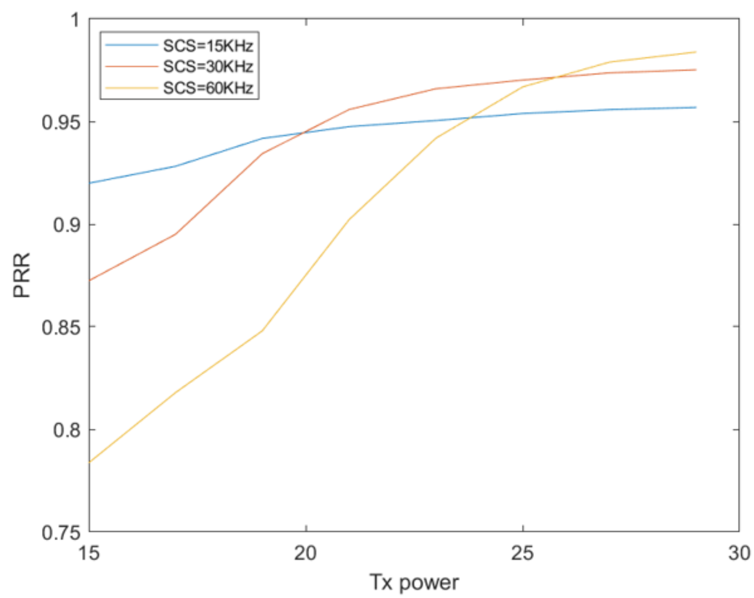

Figure 5.5: PRR for different Sub Carrier spacing

The figure5.5 shows the plot varying transmission power from 15dBm to 29dBm. As the transmission power increases, more packets can be successfully received, resulting in an increase in PRR.

From the figure, we can observe that upto 20dBm the PRR is higher for SCS 15KHz. From 20 to 25dBm PRR is better for SCS 30 KHz and for transmission power greater than 25dBm.

5.4.2 Data Age for different SCS

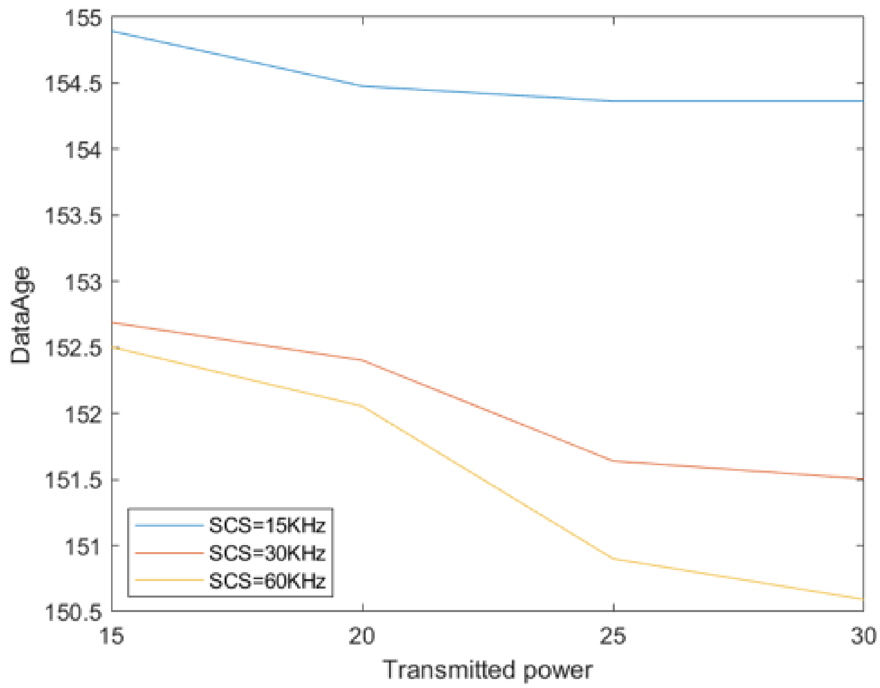

Figure 5.6: Data Age for different SCS

Data Age is the time interval between newly transmitted packet which is successfully delivered and the next successfully received packet.As the transmission power increases the probability of successful transmission may increase and therefore the Data Age will decrease.

The figure5.6 shows the plot of Data Age with varying transmission power from 15 to 30 dBm. At any point, the value of Data Age is higher for SCS of 15KHz. This is because, the slot duration is more in the case of lower SCS, as shown in table2.1. The drop of data age is very less and the graph almost looks constant with change in Transmission power. The value of Data Age is decreasing from 154.8 to 154.38 milliseconds for SCS of 15KHz. Hence, we can conclude that Transmission power doesn't have considerable impact on Data Age.

5.4.3 Update Delay for different SCS

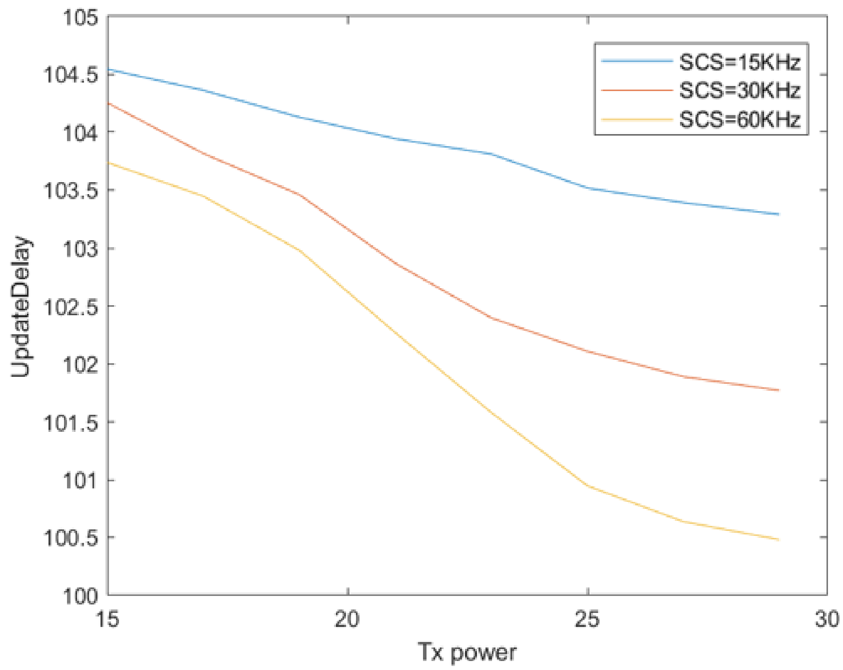

Figure 5.7: Update Delay changing with transmitted power for different SCS

The update delay is defined as the time interval between two consecutive successfully received beacons from the same node within the selected awareness range. When transmission power increases the probability of successfully received beacons increases, and thus the time gap between successful received beacons decreases (Update Delay).

The figure5.7 shows the plot of Delay varying with Ptx. Here Ptx is varied from 15 to 29 dBm and the corresponding values of Delay are noted down.When the SCS is less(15 KHz), the slot duration is 1ms, which is comparatively greater than that of the other SCS. Hence the Delay will be more when SCS is 15KHz and from the results we can infer that, as Ptx increases the Delay decreases and is the drop is more in the case of SCS 60KHz.

5.5 Effect of MCS

The MCS (Modulation and Coding Scheme) determines the maximum number of usable bits that can be transmitted for each Resource Element (RE). Its value depends on the radio link quality. Higher the MCS more valuable data may be sent with higher quality and vice versa.

5.5.1 PRR for different SCS

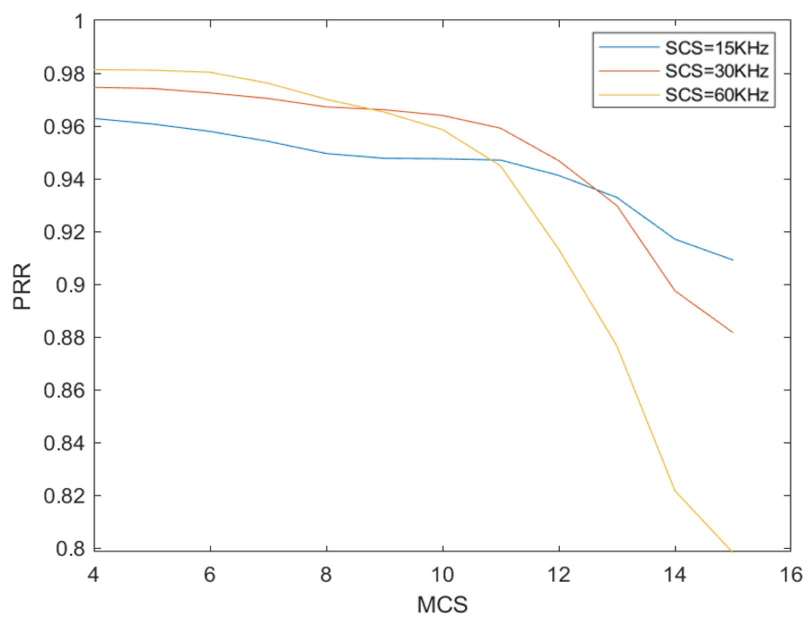

Figure 5.8: PRR Vs MCS varying Sub Carrier Spacing

The figure5.8 shows the plot varying MCS from 4 to 15 for different values of SCS (15, 30 and 60KHz). With increasing MCS the PRR is decreasing. For SCS 15 KHz the fall in PRR is less compared to higher SCS graphs.

The default value of rho for ETSI type of scenario is 23 dBm.Hence we can conclude that for smaller values of MCS, higher SCS (60 KHz) performs better and for higher MCS values, lower SCS (15 KHz) has better PRR.

5.5.2 Data Age for different SCS

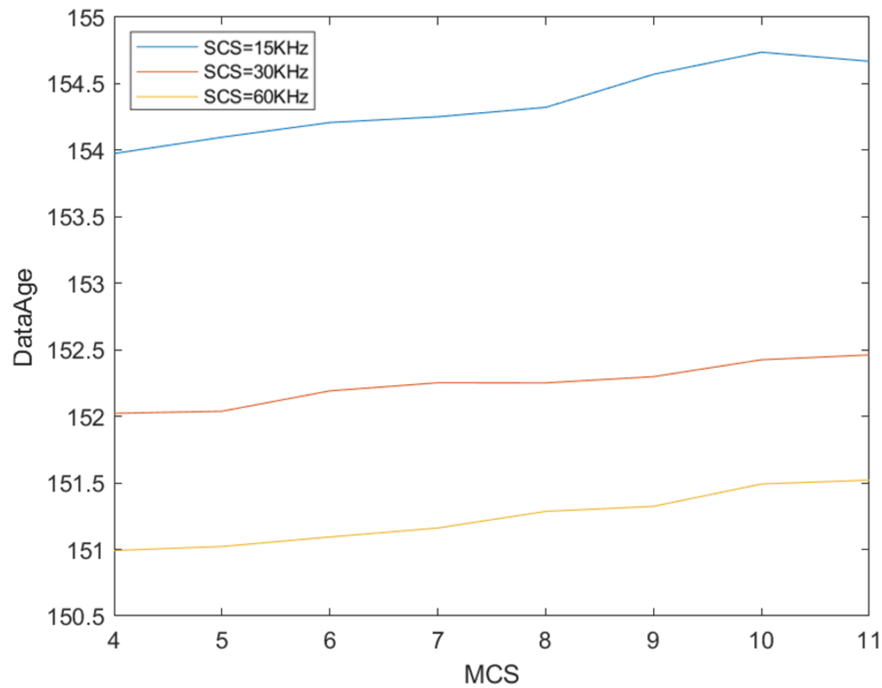

Figure 5.9: Data Age varying with MCS

The figure5.9 shows the plot varying MCS for different values of SCS. For a particular SCS, Data Age has nearly remained constant. This is because MCS depends on the radio link quality and doesn't have considerable impact on Data Age.

When comparing Data Age variation with SCS, it's value is higher for minimum sub carrier spacing i.e., 15KHz. This is because, the slot duration is more in the case of lower SCS. The Data Age value ranges from 154 to 154.7 milliseconds for SCS KHz, 152.08 to 152.46 milliseconds for SCS 30 KHz and it ranges from 151 to 151.5 milliseconds for SCS 60 KHz.

Therefore, we can conclude that Modulation and Coding Scheme (MCS) has limited effect or no effect on the Data Age.

5.5.3 Update Delay for different SCS

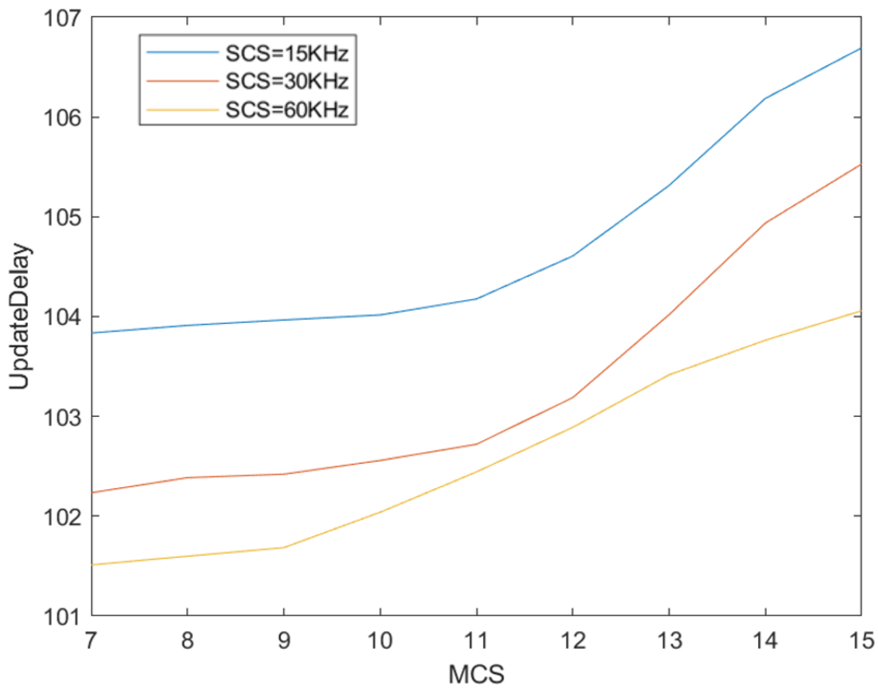

Figure 5.10: Update Delay variation with MCS

The figure5.10 shows the plot varying MCS for different values of SCS. The Update Delay increases with increase in MCS. Here the value of Update Delay is increasing from 103.8 to 106.7 milliseconds for the Sub Carrier Spacing of 15KHz, which has the highest PRR among all SCS. Upto around 11 MCS the Delay is nearly constant for any given SCS. For higher MCS values (greater than 11), Delay is increasing with MCS.

Hence we can conclude that Update Delay increases with increasing MCS and it is more significant for higher values of MCS.

Chapter 6

Adaptive Resource Allocation algorithm

From the simulation results obtained, we have analysed the changes in PRR with variation in the input parameters like Density of vehicles, Modulation and Coding Scheme and the transmission power for different values of Sub Carrier Spacing.

We have proposed a new adaptive algorithm which selects the Sub Carrier Spacing depending on the inputs(rho, MCS and Ptx) from from the command line. When there no input in command line default values of inputs are considered and the SCS is also set to default value, which is 15KHz.

When there is any input from the command line among MCS, Ptx and rho, during the initialization the input parameter(which is initially set to default value) gets overwritten. Depending the value of the input parameter from the command line, the if-else condition gets executed and SCS is selected and initialized accordingly. The resource allocation now uses the updated SCS value.

The figure6.1 shows the modified flow of the algorithm or the simulator. Here the highlighted step shows the modification of Sub carrier spacing, which is added to the existing simulator code to improve the Packet Reception Ratio.

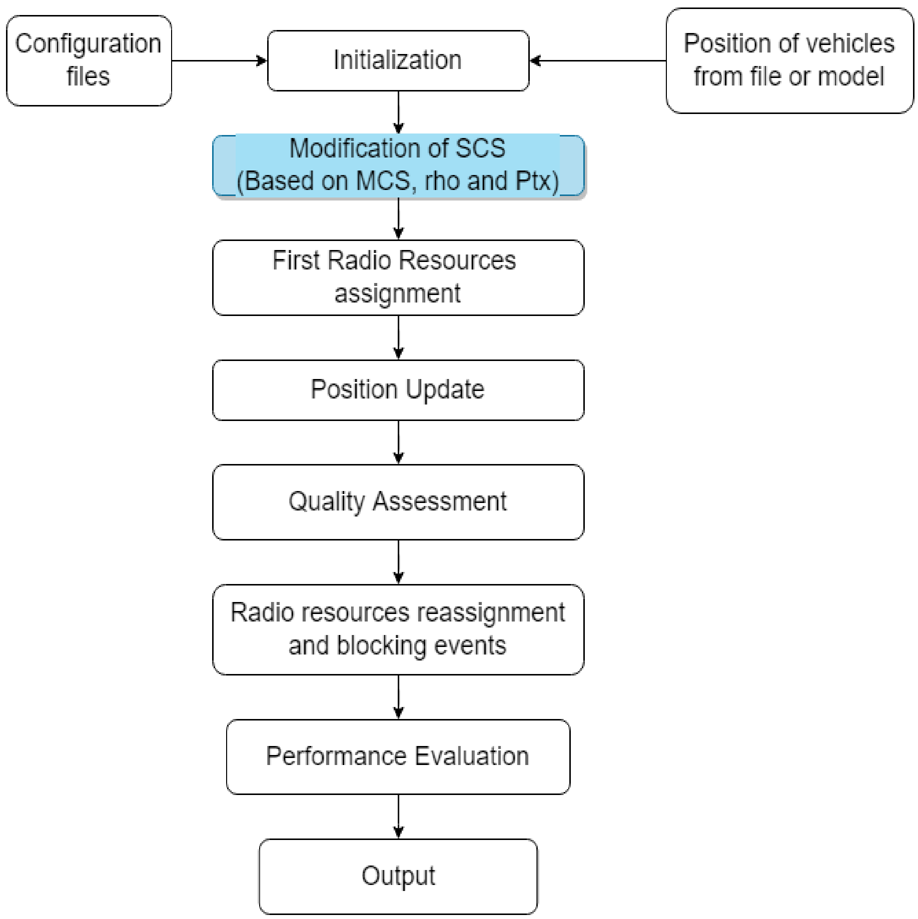

Figure 6.1: Flow chart showing the modified structure of simulator

6.1 Modification for Transmission power

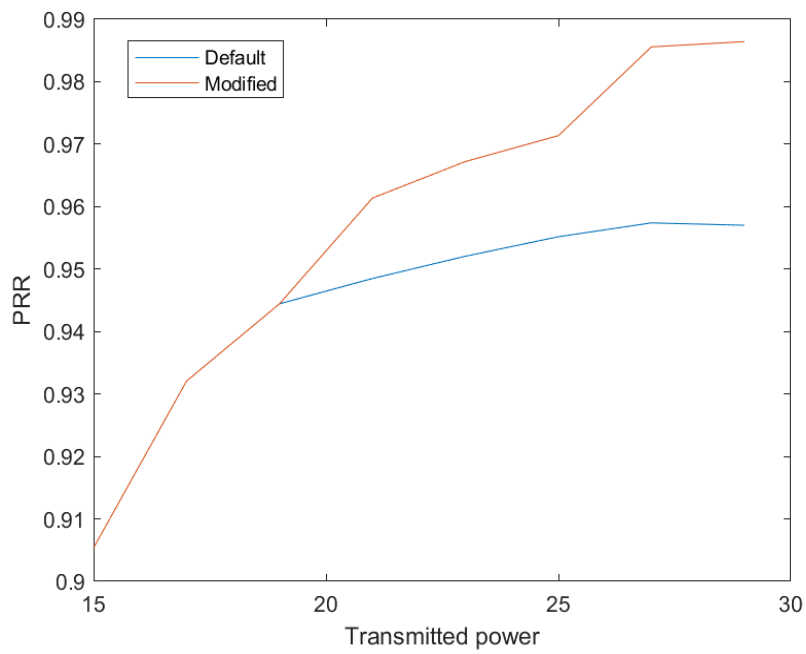

Figure 6.2: Comparison of Default and modified algorithm for Transmission power

The figure6.2 shows the comparison of PRR with change in Transmission power for the default algorithm and the modified algorithm. The transmission power ranges from 15dBm to 29dBm. For transmission power less than 20dBm, the Sub Carrier Spacing of 15KHz (which is the default value) gives the highest PRR. Hence in this range there is no difference between default and the modified algorithm.

For higher values of transmission power, SCS is chosen based on the input transmission power. From the graph we can observe the improvement in PRR from default to modified algorithm.

The algorithm1 shows the modified version to select Sub Carrier Spacing(SCS) depending on Transmission power to improve Packet Reception Ratio(PRR).

Algorithm 1 Modifying SCS based on Transmission power(Ptx)

Require: $Ptx \geq 0$
Ensure: $MCS = 7$
  $rho \leftarrow 35$
  if $Ptx \leq 20$ **then**
    $SCS = 15KHz$
  else
    if $Ptx \leq 26$ **then**
      $SCS = 30KHz$
    else
      $SCS = 60KHz$

When the algorithm 1 is executed without any command line input of Transmission power, then the value of SCS is initiated with default value(15KHz). If the Ptx given as input through command has value less than 20dBm, the default value of Ptx gets overwritten with the given value. According to the algorithm the value of SCS gets initiated with 15KHz because it has the highest value of PRR in this range of Ptx5.5. Similarly for the ranges 20dBm to 26dBm and for greater than 26dBm, the SCS gets initaited with 30KHz and 60KHz respectively.

6.2 Modification for MCS

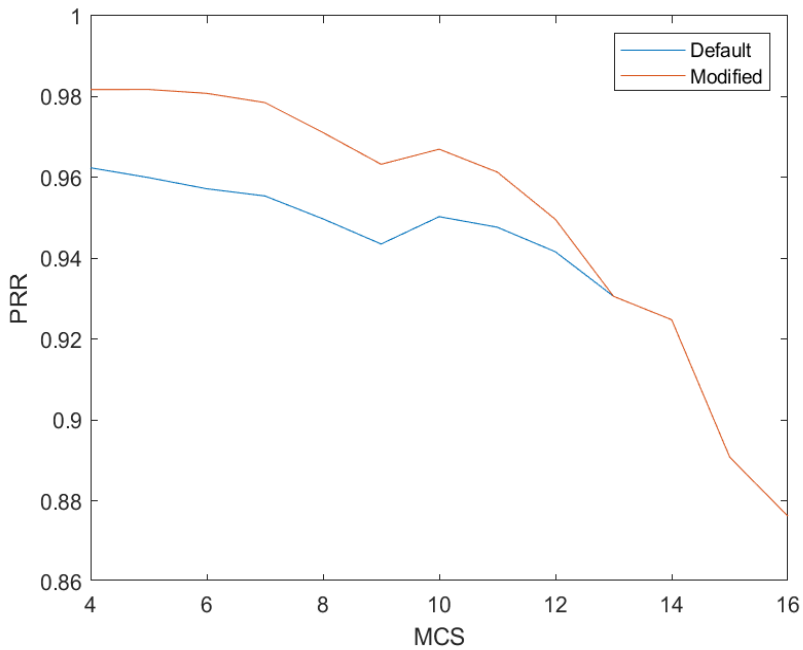

Figure 6.3: Comparison of Default and Modified algorithm for MCS

The figure6.3 shows the comparison of PRR with change in Modulation and Coding Scheme for the default algorithm and the modified algorithm. The MCS ranges from 4 to 16. For MCS greater than 13, the Sub Carrier Spacing of 15KHz (which is the default value) gives the highest PRR. Hence in this range there is no difference between default and the modified algorithm.

For higher values of the Modulation and Coding Scheme, SCS is chosen based on the input value. From the graph we can observe the improvement in PRR from default to modified algorithm.

The algorithm2 shows the modified version to select Sub Carrier Spacing(SCS) depending on Modulation and Coding Scheme(MCS) to improve Packet Reception Ratio(PRR).

Algorithm 2 Modifying SCS based on Modulation and Coding Scheme (MCS)

Require: $MCS \geq 0$
Ensure: $Ptx = 7$
  $rho = 35$
  if $MCS \leq 9$ **then**
    $SCS = 60KHz$
  else
    if $MCS \leq 13$ **then**
      $SCS = 30KHz$
    else
      $SCS = 15KHz$

When the algorithm 2 is executed without any command line input of MCS, then the value of SCS is initiated with default value(15KHz). If the MCS given as input through command has value less than 9, the default value of MCS gets overwritten with the given value. According to the algorithm the value of SCS gets initiated with 60KHz because it has the highest value of PRR in this range of MCS5.8. Similarly for the ranges 9 to 13 and for greater than 13, the SCS gets initaited with 30KHz and 15KHz respectively.

6.3 Modification for Density of vehicles

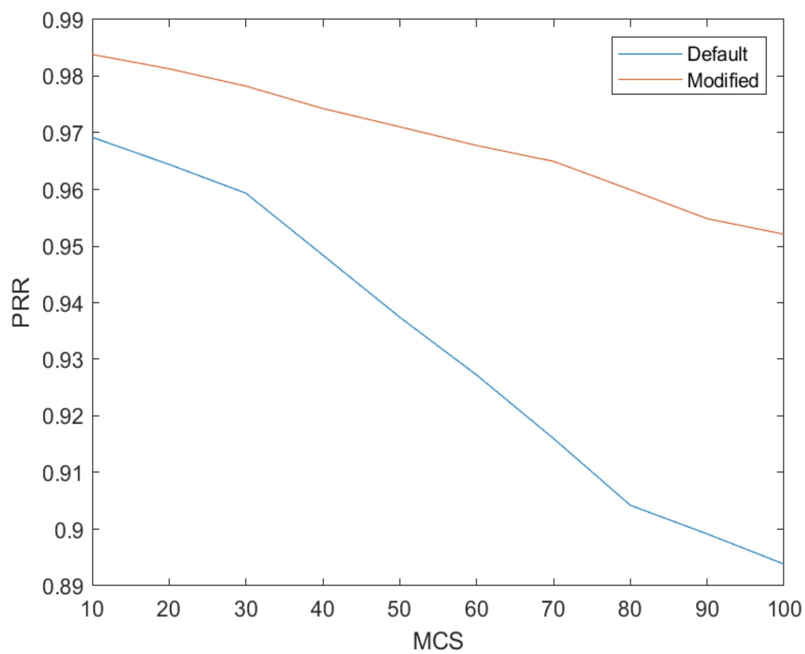

Figure 6.4: Comparison of Default and Modified algorithm for Rho

The figure6.4 shows the comparison of PRR with change in Density of vehicles(rho) for the default algorithm and the modified algorithm. It ranges from 10 to 100 vehicles/km.

SCS is chosen based on the input value of density of vehicles. From the graph we can observe the improvement in PRR from default to modified algorithm.

The algorithm3 shows the modified version to select Sub Carrier Spacing(SCS) depending on Density of vehicles to improve Packet Reception Ratio(PRR).

Algorithm 3 Modifying SCS based on Density of vehicles(rho)

Require: $rho \geq 0$
Ensure: $MCS = 7$
  $Ptx \leftarrow 23$
  if $rho \leq 55$ **then**
    $SCS = 30KHz$
  else
    $SCS = 60KHz$

When the algorithm 3 is executed without any command line input of Density of vehicles(rho), then the value of SCS is initiated with default value(15KHz). If the rho given as input through command has value less than 55vehicles/km, the default value of rho gets overwritten with the given value. According to the algorithm the value of SCS gets initiated with 30KHz because it has the highest value of PRR in this range of rho5.2. Similarly for rho greater than 55vehicles/km, the SCS gets initiated with 60KHz.

Chapter 7

Conclusion

In this project, we have studied about different Radio Access Technologies(RAT) used in vehicular communication. Analysed the performance of NR-V2X technology with variation in Density of vehicles, Modulation and Coding Scheme(MCS) and Transmission power for different numerology or Sub Carrier Spacing(SCS). Simulations were carried out on WiLabV2Xsim simulator.

From the simulation results we can observe that

- With variation in MCS, higher SCS performs better for smaller values of MCS.
- With variation in Transmission power, lower SCS performs better for smaller values of Transmission power.
- With variation in Density of vehicles, higher SCS performs better for all values of Vehicle density in terms of PRR.

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