HARQ RETRANSMISSION TOGETHER WITH ORIGINAL TRANSMISSION ON THE SAME SUBFRAME FOR C-V2X COMMUNICATION

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List of Acronyms

3GPP	Third-generation partnership project
ACK	Acknowledgment (in ARQ protocols)
ADAS	Advanced Driver assistance Systems
AI	Artificial intelligence
ALV	Autoliv
ANPRM	Advance Notice of Proposed Rule
ARIB	Association of radio industries and businesses
AS	Access stratum
ASTM	American Society for Testing and Materials
AWGN	Additive White Gaussian Noise
BSS	Fundamental Benefit Set
BW	Bandwidth
CA	Carrier Aggregation
CAM	Co-operative Awareness Message
CEN	European Committee for Standardization
CRC	Cyclic Redundancy Check
CSMA	Carrier Sense Multiple Access
D2D	Device to Device
DARPA	Defense Advanced Research Projects Agency
DCC	Decentralized Congestion Control
DCI	Downlink Control Information
DENM	Distributed Environmental Notification Message
DFT	Discrete Fourier Transform
DSRC	Dedicated Short-Range Communication
ECC	Excise Control Code
EPS	Evolved Packet System
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FDD	Frequency Division Duplex
FDM	Frequency Division Multiplexing
GNSS	Global Navigation Satellite System
HARQ	Hybrid automatic repeat request
HD	Higher Definition
IC	Intersection Collision Risk Warning
ICRW	Intersection Collision Risk Warning
IEEE	Institute of Electrical and Electronics Engineers
ITS	Intelligent Transport System
ITU	International Telecommunication Union
LCRW	Longitudinal Collision Risk Warning
LCRW	Longitudinal Collision Risk Warning
LDPC	Low-Density Parity Check Code

LTE	Long-Term Evolution
MAC	Medium Access Control
NACK	Negative acknowledgment (in ARQ protocols)
NHTSA	National Highway Traffic Safety Administration
NLOS	Non-Line of Sight
NXP	Next Experience
OFDM	Orthogonal Frequency-Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PAPR	Peak-to-Average Power Ratio
PKI	Public Key Infrastructure
PSBCH	Physical Sidelink Broadcast Channel
PSCCH	Physical Sidelink Control Channel
PSDCH	Physical Sidelink Discovery Channel
PSSCH	Physical Sidelink Shared Channel
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase-Shift Keying
RHS	Road Hazard Signaling
RRC	Radio Resource Control
RRM	Radio resource management
RV	Redundancy Version
SAE	Society of Automotive Engineers
S-BCCH	Sidelink Broadcast Control Channel
S-BCH	Sidelink Broadcast Channel
SC-FDMA	Single Carrier Frequency Division Multiple Access
SCI	Sidelink Control Information
SDOSs	Standards Developing Organizations
SFN	Subframe Number
SIB	System Information Block
SIM	Subscriber Identity Module
SL-DCH	Sidelink Discovery Channel
SLI	Specific Sidelink Identity
SL-MIB	Sidelink Master Information Block
SL-SCH	Sidelink Shared Channel
SLSS	Sidelink Synchronization Signal
SL-TCH	Public Key Infrastructure
SNR	Signal to Noise Ratio
SS	Synchronization Signal
STCH	Sidelink Traffic Channel
TDD	Time Division Duplexing
TDM	Time Division Multiplexing
TPC	Transmit Power Control
TRP	Time Repetition Pattern; Transmission Reception Point
TRPI	Time Repetition Pattern Index

TS	Technical Specification
TTA	Telecommunications Technology Association
UE	User equipment
USDOT	US Department of Transportation
V2I	Vehicle to infrastructure
V2N	Vehicle to network
V2P	Vehicle to pedestrian
V2V	Vehicle to vehicle
V2X	Vehicle to everything
WLAN	Wireless Local Area network

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We would like to thank our supervisor Dr. Mohammad Tawhid Kawser, Professor, Department of EEE, IUT for providing precious guidance, inspiring discussions and constant supervision throughout the course of this work. His help, constructive criticism, and conscientious efforts made it possible to present the work. It's our goodness that in spite of having a tight and busy schedule our supervisor has found time to help and guide us. For this, we again express our sincere thanks to him. We are also grateful to EEE Department of IUT for providing us the opportunity to present this work.

Abstract

Cellular vehicular to everything (C-V2X) is a feature which incorporates vehicular communication to cellular network. V2X technology makes its way into the cellular communication with 3gpp release 14. The introduction of C-V2X makes it possible for nearby vehicles to propagate safety related information to avoid any kind of collisions and traffic jam. C-V2X mainly utilizes the Sidelink channel introduced in 3gpp release 12 for D2D connectivity for the direct communication. But one of the main drawbacks of Sidelink channel is of having no feedback which prompts the transmitting UE to send one blind HARQ retransmission after a certain subframe to ensure the reliability of the system. In this paper we present another retransmission scheme which is also based on the blind retransmission but on the same subframe. Due to the choice of the same subframe to send original and three HARQ retransmission, the latency becomes very much less than the conventional retransmission scheme and also the reliability of the C-V2X system is also sustained making it perfect retransmission scheme for C-V2X communication which key requirements are low latency and high reliability.

Chapter 1

Introduction

1.1 Background:

With the advent of time vehicle becomes an integral part of the human civilization. With the increase in population the number of people going out for work is also increasing and with that the necessity of vehicle is also increasing. To save time and to efficiently increase the working hours the importance of vehicles is irreplaceable. As a result, with the course of time the number of vehicles also increase in a great number. Even in Bangladesh we can see the no of vehicles increase greatly compared to earlier years. In figure 1.1 we can see the number of registered motor vehicles in Bangladesh during 1996-2018. The figure clearly showcases the ever-increasing number of vehicles in Bangladesh.

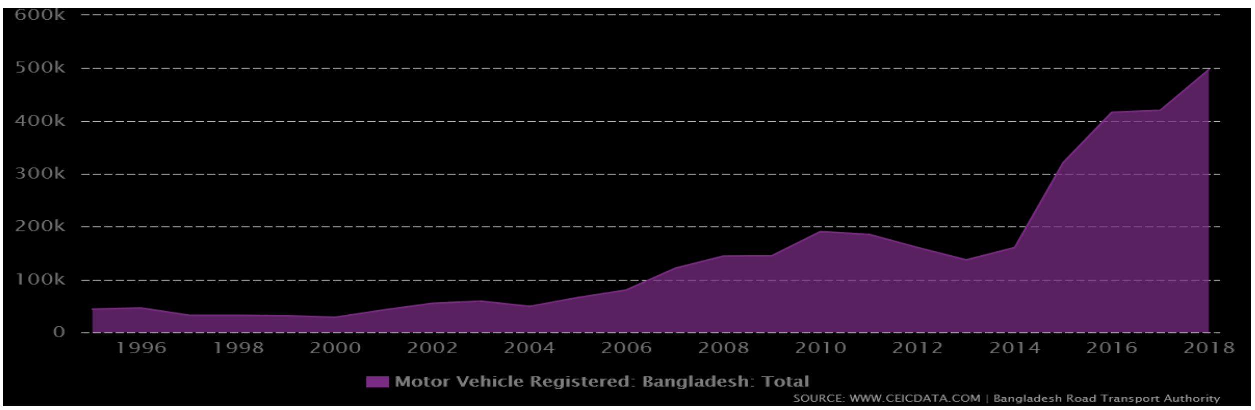


Figure 1.1: Number of motor vehicle registered in Bangladesh

Also, in figure 1.2 shows the number of passenger cars in use in Bangladesh. We can clearly see with the advent of time the number is also increasing gradually.

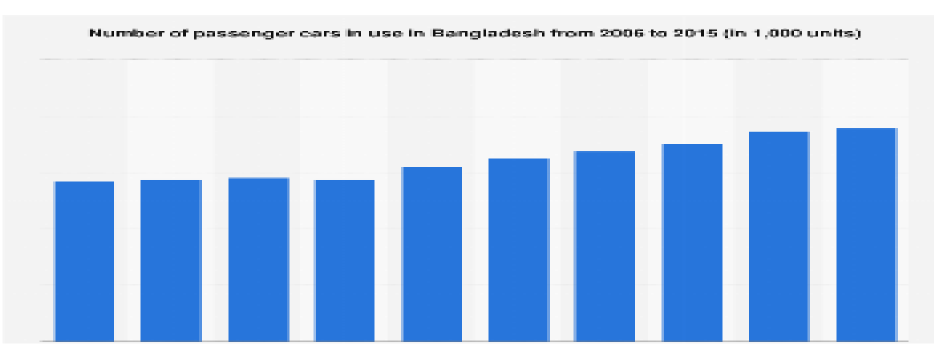
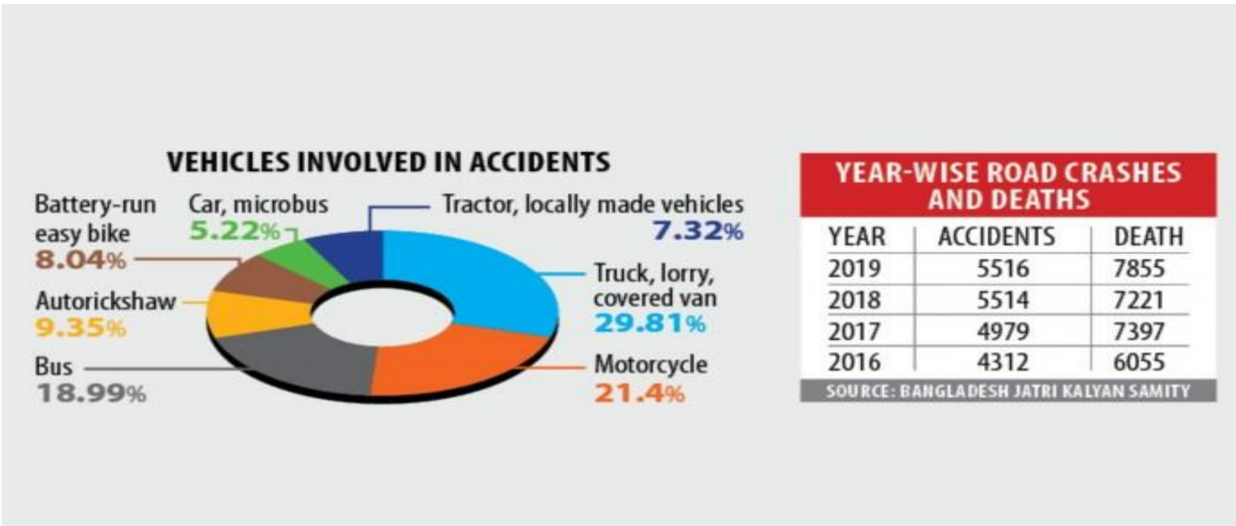


Figure 1.2: Number of passengers' cars in use in Bangladesh

With the increase in the number of vehicles the number of road accidents also increase drastically. The increasing traffic accident cause great deal of harm not only by taking lives but also economically due to severe injuries and the damage of vehicle parts. The increasing number of vehicles also make it difficult to control the traffic flow which causes traffic jam and it consumes a great deal of time. Fig 1.3 clearly shows how the number of accidents increase with the advent of time.



YEAR	ACCIDENTS	DEATH
2019	5516	7855
2018	5514	7221
2017	4979	7397
2016	4312	6055

SOURCE: BANGLADESH JATRI KALYAN SAMITY

Figure 1.3: Road accident statistics in Bangladesh (2016-2019)

Figure 1.4 showcases a report of Dhaka tribune indicating the effect of road accidents on our day to day life as well as to the country's economy.

ROAD ACCIDENTS IN 2018

- 4,580 fatalities from road accidents
- 7% increase from 2017
- 1,735 fatalities from August to December
- 679 children and 591 women were killed
- 10,828 injured in road accidents
- Road accidents increased during the two Eids
- During Eid-ul-Fitr, there was 211 road accidents that killed 248 people
- 717 were injured during that holiday
- During Eid-ul-Azha, 142 people were killed in 96 road accidents
- 318 were injured during that holiday
- Accidents cost Bangladesh around 2% of its GDP annually

Figure 1.4: Effect of road accidents in Bangladesh in 2018

The numbers can be greatly reduced if the drivers can be updated timely about the road condition. Vehicular communication offers a greater solution in that matter. This type of communication commonly refers to as V2X communication. V2X communication establishes communication between two vehicles or between vehicle to infrastructure, vehicle to network, vehicle to pedestrian as shown in figure 1.5. V2X communication allows the vehicles to share safety related information which reduces the traffic jam and accidents to a greater extent.

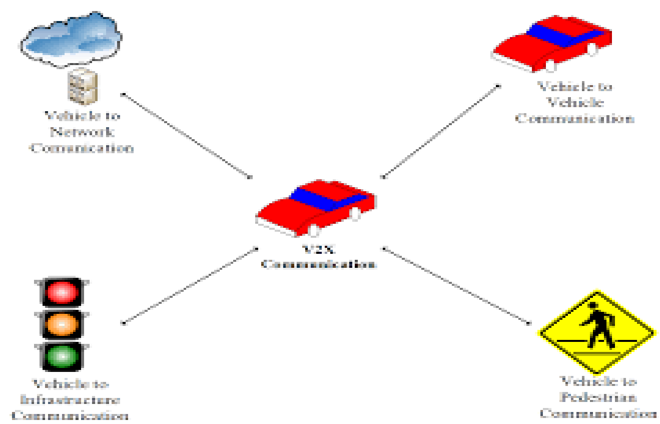


Figure 1.5: Different types of V2X communication

1.2 C-V2X and its Prospective:

To support D2D communication a new channel is introduced in 3gpp release 12. Based on the sidelink channel in 3gpp release 14 V2X is introduced. C-V2X is equivalent of the 802.11p. with the releases of the later versions of the 3gpp more feature has been added to the V2X communication making it more reliable, faster and also the throughput is very high which paved way for a much more efficient V2X communication environment. With the advent of time more development has been done which makes it possible to propagate safety related information between the vehicles more secure way. This helps a lot in case of preventing the accidents and controlling the traffic of the ever-increasing vehicles. Figure 1.6 showcases the evolution of the V2X communication with the advent of the new 3gpp releases.

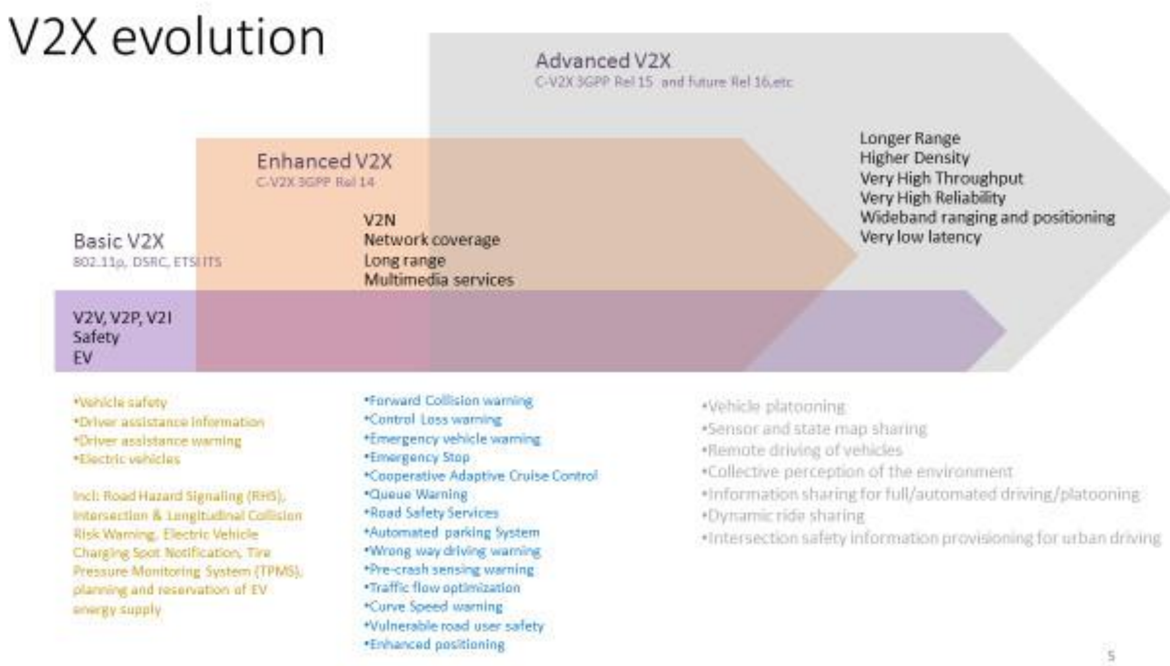


Figure 1.6: Evolution of V2X communication with the course of time

Figure 1.7 depicts the compatibility of the C-V2X technology showcasing the advanced features of the technology.

Figure 1.7: C-V2X features

Clearly C -V2X focuses on mainly 3 points. They are-

- Low latency (< 10ms)
- More reliability
- Higher throughput

But C-V2X has a limitation in terms of feedback channel. As it utilizes the sidelink channel for direct data transmission it is not possible to send ACK or NACK to the transmitter UE as Sidelink has no feedback. So, to increase the reliability of the system blind retransmission scheme has been introduced in the V2X communication. in this work we will basically try to introduce a blind retransmission system which will along with ensuring the high reliability of the C-V2X communication also will lower the latency making it faster.

As depicted in figure 1.5 C-V2X mainly works in 4 modes. They are-

- V2V
- V2I
- V2N
- V2P

These 4 modes can again operate under two conditions:

1. Mode 3: under the cellular coverage
2. Mode 4: without the cellular coverage

In this work we will focus on the mode 4 of C-V2X communication. We will try to introduce a new retransmission scheme which will maintain the higher throughput and will lower the latency to a minimum value. Also, another unique thing about the retransmission scheme is that rather than completing one HARQ retransmission after some subframe we focus on doing three HARQ retransmissions in the same subframe. So, the redundancy versions are separated in the frequency domain only. Through this retransmission scheme we will try to achieve the following two goals:

- Maintaining the high reliability that is already offered by the conventional retransmission process.
- Reducing the latency as much as possible. In this case the receiving UE gets all the redundancy versions in the same subframe.

1.3 Literature review:

Multiple researchers have proposed several schemes to cope up with the absence of feedback channel in V2X communication. Many of the works tried to introduce several types of retransmission scheme.

JUYEOP KIM proposed an index coded retransmission scheme to enhance the performance of V2X communication. In this scheme the index coding process is incorporated with the retransmission process to eliminate the redundant retransmission process in V2X direct communication. This type of retransmission scheme eradicates the problem of consumption of radio resources due to redundant retransmission. The basic concept of this scheme is basically doing x-or of the redundant blocks of the two-initial transmission then transmits them after the two initial systematic blocks has been transmitted. The introduction of the resource block greatly reduces the use of the resource blocks due to redundant retransmission scheme. Which makes it more cost friendly.

Donglin Wang proposed another retransmission scheme which basically does one blind retransmission after the initial transmission regardless of the success of the initial transmission. In this scheme after the transmission of the initial message one blind retransmission is done with different traffic schemes to check the reliability of the system. The redundant transmission is done randomly after some time gap. Based on the condition of the channel the success of the transmission scheme also varies. In this scheme the redundant retransmissions are not dependent on the success of the initial transmission. So even if the receiver UE successfully decodes the message the transmitter UE will send redundant transmission. So redundant retransmission is prevalent in this scheme and it uses more resources than the previously discussed scheme. So, it is a bit costly in terms of using resources than the previously discussed index coded retransmission process.

Md. Imrul Hassan proposed and evaluated a retransmission scheme on the performance of the IEEE 802.11p for dedicated short range communication. In this paper two retransmission-based schemes are proposed to improve the reliability and efficiency of broadcast in a contention-based mac in dedicated short-range communication.

Chapter 2

Device-to-Device Connectivity

2.1 Overview

3GPP release 12 first introduced the Device to Device (D2D) connectivity in the cellular environment. From the name it can be clearly understood that, direct D2D availability suggests between devices a radio connection is established. D2D can be realizable only when the devices are close proximity with each other which is why it got another name as proximity services (ProSe).

The main purpose of introducing D2D network was to use the LTE cellular network to communication concerning to public safety. D2D network is very much important especially when there is no access to the infrastructure through which devices can connect to the main network. Due to its efficiency in public safety case D2D connectivity becomes a key requirement in LTE and also it ushers new ways of utilizing the LTE radio connectivity.

D2D connectivity in LTE can be divided into two types-

1. D2D communication: As the name suggests it means exchange of client information directly between the devices in question.
2. D2D revelation, inferring the plausibility for transmission of signal by a device that empower its presence which can be directly recognized by the devices in its neighborhood. D2D disclosure has as of now from the starting focused on a more extensive extend of use cases, counting commercial administrations unlike D2D communication.

To accommodate and differentiate the D2D connectivity from the normal cellular use case a new interface is introduced in the LTE to connect the devices directly. This new interface is named as Sidelink.

2.2 Sidelink Transmission

The idea of uplink and downlink are not pertinent in D2D. 3GPP has presented sidelink to characterize coordinate D2D connect. LTE sidelink connectivity is conceivable both in combined FDD and unpaired TDD range. Sidelink network moreover takes put in range not utilized by commercial cellular systems.

Particular range has been allotted in several countries and locales for open security utilize case. This may be utilized for sidelink communication. In combined range i.e. FDD, sidelink network happens within the uplink part of the range. Administrative laws are mainly concerned about gadgets transmission rather than gadgets reception. Other than, it is less complex to incorporate extra collector usefulness. In this way uplink is being utilized. Comparative operation is being performed in case of TDD. Uplink subframes bargain with sidelink network.

Sidelink network is essentially a unidirectional transmission since all are of broadcast sort.

Devices included in sidelink network can be under-coverage or out-of-coverage. Once more, under-coverage devices can be beneath same cell or different cells. Discharge 12 bolstered as it were sidelink communication out-of-coverage whereas sidelink disclosure was as it were conceivable beneath network coverage. Discharge 13 has presented back to accommodate out-of-coverage sidelink discovery in case of public-safety case.

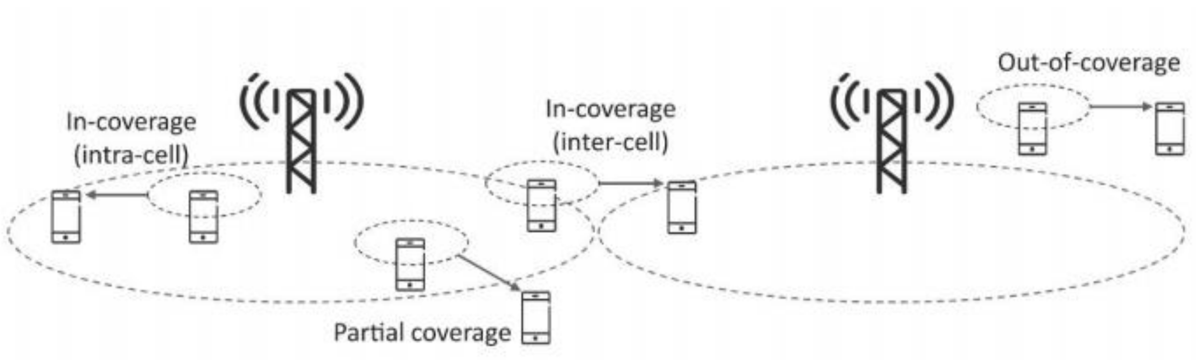


Figure 2.1: Different coverage scenarios of sidelink connectivity

For devices beneath organize scope, sidelink network can occur in RRC_CONNECTED condition means having an RC connection to the arrange. In any case, sidelink network can moreover occur in RRC_IDLE condition, means having no dedicated association with the arrange. It ought to be famous that RRC_IDLE condition isn't the similar thing as the device being out of scope. A device being in RRC_IDLE condition may still be beneath organizing scope and will then have get to, for case, the organize framework data indeed in case there is no RRC association set up.

2.3 Sidelink Synchronization

Sometime recently interfacing with each other, each gadget must be synchronized reasonably and to the overlaid arrange in case display.

Synchronization is done to guarantee that sidelink transmissions occur within the desired time-frequency resources, subsequently lessening any chance for undesired obstructions to other sidelink and cellular transmissions occurring within the same band.

LTE network adds another feature in sidelink network. It allows the gadgets to transmits SLSS to extend the transmission time beyond the region of coordinate organize scope. Gadgets which are beneath the arrange scope mainly transmits SLSS according to the transmission time derived from cellular connectivity. Using this flag, the other adjacent out of coverage devices can get their timing references. Those devices can transmit the SLSS that they got and this way the other out of coverage devices can get the timing references. This way the synchronized devices under the coverage of network can extend past area of the coordinate arrange scope.

A device outside the organize scope and unable to identify any kind of adequate strong SLSS will independently transmit a SLSS that can be detected and sent by other devices (out of the network coverage). This process helps to attain local synchronization between the devices that are not under any network coverage. Along with working as timing reference used for the sidelink connectivity SLSS can be used as timing reference used for the sidelink gathering. If the receiving device have enough information about the flag timing, the sidelink gathering becomes very much smooth. For sidelink network between gadgets utilizing the same transmission-timing reference, for case, in case of in-coverage devices having the same serving cell, an accepting gadget can utilize its own transmission timing too for gathering. When Devices have different transmission timing references that time a device can transmit SLSS alongside other ongoing sidelink connection. By accumulating devices these synchronization signals can be used as reference for gathering timing. From figure 2.2 we can get closer look about all the points. In the figure, device A employments the SSA as timing reference for its sidelink transmissions. Additionally, device B employments SSB as timing reference for its sidelink transmissions. Device B will use the SLSSA (synchronization flag) transmitted by device A to gather sidelink transmissions from device A and derived from SSA. Same way, device A will use SLSSB for the same thing.

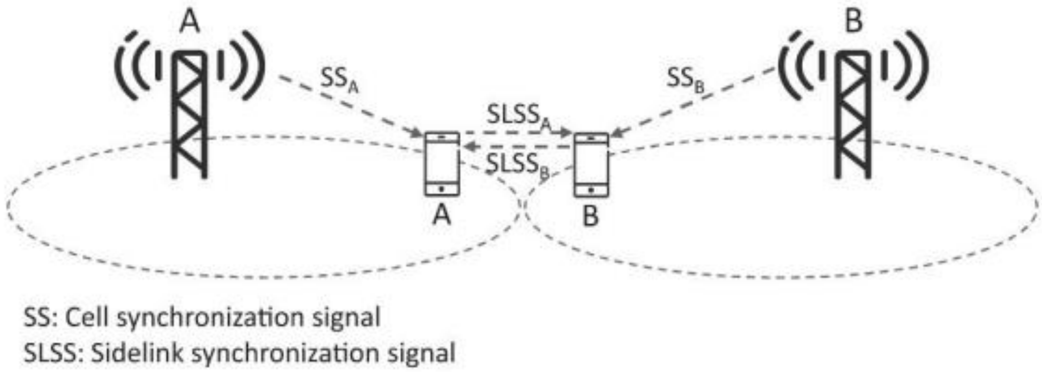


Figure 2.2: Timing references derived from sidelink synchronization signal (SLSS)

2.4 Sidelink Connectivity Configuration

Setup must be done legitimately some time recently any sort of sidelink connectivity. Such arrangement incorporates, parameters characterizing resource set (subframes and asset pieces) that are accessible for various types of sidelink transmission. These setup parameters related to sidelink connectivity are incompletely given as portion of the cell framework data. More particularly, two unused SIBs are used for this purpose:

• SIB18: sidelink communication’s configuration parameters.

• SIB19: sidelink discovery’s configuration parameters.

in addition to the standard setup given by means of the cell framework data, gadgets in RRC_CONNECTED condition going through sidelink network will too be separately designed with the implication of committed RRC signaling.

For gadgets if not under arrange scope, setup via framework data or committed RRC signaling is probably not conceivable. Conversely, those very gadgets must depend on well before sidelink-related setup variables. The said well before works on the same principle as the typical synthesis included in the sidelink-related framework data.

For example, an out-of-coverage device might've been given the well before variables at a continuing relationship while it was within arranging scope. Other conceivable outcomes include pre-configuration upon this SIM card or hard-coding the setup into the unit. Recognize that the focal point of the out-of-coverage service is on the public-safety purpose scenario. Out-of-coverage service in this way ordinarily relates with uncommon devices.

2.5 Sidelink Architecture

Taking after figure outlines the arrange engineering in connection with sidelink networking. For the purpose of backing sidelink networking an unused Composition Work has been presented within the core arrange at the side a slew of brand-new networks interfacing. Of these interfacing, PC5 compares to the direct connection among gadgets whereas the PC3 interface connects sidelink-capable gadgets to the Prose Work.

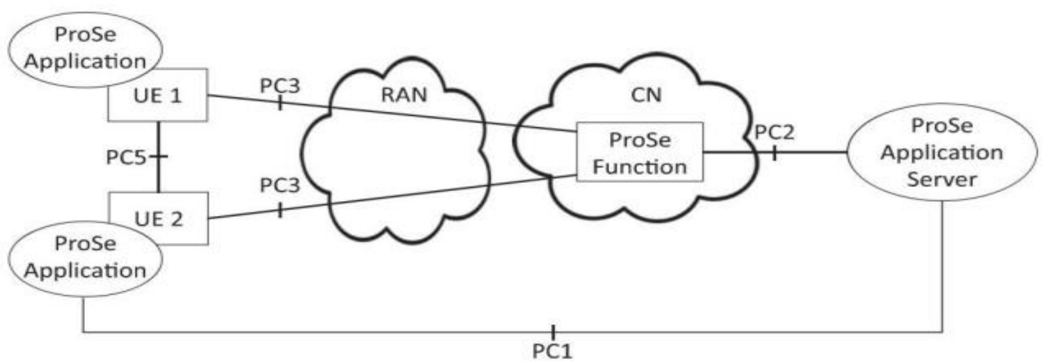


Figure 2.3: Architecture for sidelink connectivity

The Prose work is mindful of every sidelink usefulness within the center arrange. This gives gadgets with the variables required to form sidelink network. The correlation among revelation communication symbols and the genuine disclosure communication is too given by the ProSe Feature.

2.6 D2D to V2X

The nearness benefit (Composition) known as a Device-to-Device (D2D) communication, characterized in Discharge 12, alludes to a coordinate exchange of information between more than one gadget near to each other or instead going via the eNodeB. Hence, a few sorts of preferences are being advertised because of vicinity, recycle, and bounce pick up. At first, D2D communications were suggested to better the efficiency. (i.e., make use of upgrading range, moving forward UEs data-rate, expanding cellular capacity, and amplifying UEs power supply lifespan) in cellular innovations. As V2X innovations must meet rigid consistency and idleness necessities, Discharge 14 introduced a feature that the D2D communication will be connected in vehicle innovations to back V2V communications. As V2X is done on the basis of D2D, resources are distributed within the V-UEs either within the overlay mode or within the underlay mode. That's why, radio asset administration (RRM) performs an integral part over V2X framework exhibitions.

1. LTE-D2D Communication Mode Utilizing PC5 Interface: LTE-D2D communication alludes direct link among two nearer devices without going through network infrastructure. 'is mode being appropriate for V2V security administrations demanding moo inactivity delay (progressed driver help frameworks (ADAS). Discharge 12 vicinity services (ProSe) which abuse coordinate communication between neighboring devices is the basis of it. Discharge 12 introduced two modes (mode 1 and mode 2) for sidelink. These are outlined in arrange to drag out gadgets' power source lifespan for making the networking faster. Subsequently, these two modes are not helpful for V2X cases since the vehicles require moo idle as well as profoundly solid V2X networking. As of late, two unused modes are presented in Release 14 in compliance with V2V communications. They are mode 3 and the mode 4. In mode 3, assets utilized in the communication is overseen and helped by eNB. Be that as it may, vehicles independently choose assets in mode 4 for their coordinate V2V communications which is not controlled by eNB.

2. V2V-Based D2D Communication Modes: Looking at the figure we can identigy two modes off V2V. They are overlay and underlay mode. Within the overlay mode, particular radio assets from cellular assets are set aside for V2V communication. Hence, the C-UEs cannot accomplish the maximum capacity of the eNB; subsequently, this mode diminishes the bandwidth use. One of the benefits is that the interference between C-UEs and V2V-UEs does not ought to be controlled. Within the underlay mode, the eNB permits V2V-UEs and C-UEs to use the common assets, which can accomplish a far better bandwidth effectiveness. However, the eNB must oversee collisions between V2V-UE's communications and C-UE's communications.

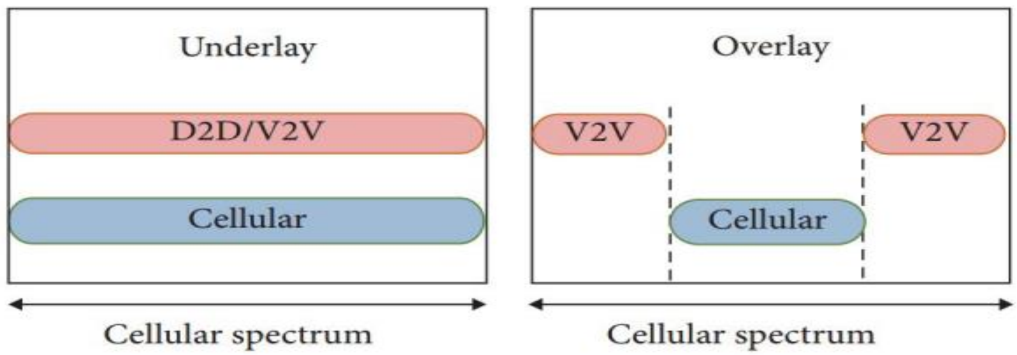


Figure 2.4: Comparison between the modes

These two modes may use any of the subframe (DL or UL)). The set of assets that will be designated to V2V are selected from UL subframe due to their minor PAPR and because of scarcity of utilization in DL.

Chapter 3

Vehicle-to-Everything (V2X) Communication

3.1 Modes of Operation

There are basically four modes of operation as of now conveyed in V2X. They are illustrated in the figure 3.1 where we can see the connectivity of vehicles to other entity. These four modes can be utilized simultaneously for security, independent vehicle control improvement by utilizing information from nearby sensors and mishap avoidance. These four modes are discussed below.

1. Vehicle-to-Vehicle (V2V): V2V permits vehicles at nearness to create a mesh arrange and exchange information, which makes a difference to form better decisions through data trade among the existing hubs. This is often done by subscribing into a organize administrator and gaining authorization. V2V applications work by sending messages carrying V2V functions data, for example activity elements, the location of the vehicle, vehicle properties, etc. The message payloads are kept adaptable for way better communication. Other than, 3GPP messages are overwhelmingly broadcast. Hence, guaranteeing the one-to-many transmission of information with least inactivity included, which is a prerequisite for V2V.
2. Vehicle-to-Infrastructure (V2I): V2I application data is transmitted through a Farther Exchanging Unit (RSU) or locally available application server. RSUs are roadside stationary units, which act as a handset. RSUs or accessible application servers get the broadcast message and transmits the message to one or more UEs supporting V2I application. V2I can give us with data, such as accessible stopping space, activity blockage, street condition, etc. Due to the tall fetched and long sending time, its application or installation is more challenging. A cure to this issue is V2N, examined a while later.
3. Vehicle-to-Pedestrian (V2P): V2P transmission happens between a vehicle and Helpless Street Clients (VRUs) like people on foot, bicyclists, etc. The UEs carried by the drivers and people on foot will be able to receive and send messages and alarms. Vehicles can communicate with VRUs indeed when they are in Non-Line of Locate (NLOS) and under low perceivability cases such as dim night, overwhelming rain, foggy climate, etc. The

affectability of person on foot UEs is lower than vehicular UEs because of the receiving wire and battery capacity distinction. So V2P application supported UEs cannot transmit nonstop messages like V2V supported UEs.

4. Vehicle-to-Network (V2N): A vehicle and a V2X operating system communicate via V2N connectivity. A UE that supports V2N applications will connect with an operating system that supports V2N applications, with both sides using Advanced Packet Switching (EPS). Various programs and service environments necessitate V2X administrations. It'll offer assistance portable administrators to communicate the assignments of the RSU over its organization, decreasing time to advertise, cost and dispensing with the complexity of planning and running a purpose-built network for V2I because it might incorporate communication between vehicles and the server by means of 4G or indeed 5G arrange. It does not get to be as exact as V2V but unwavering quality is significant.

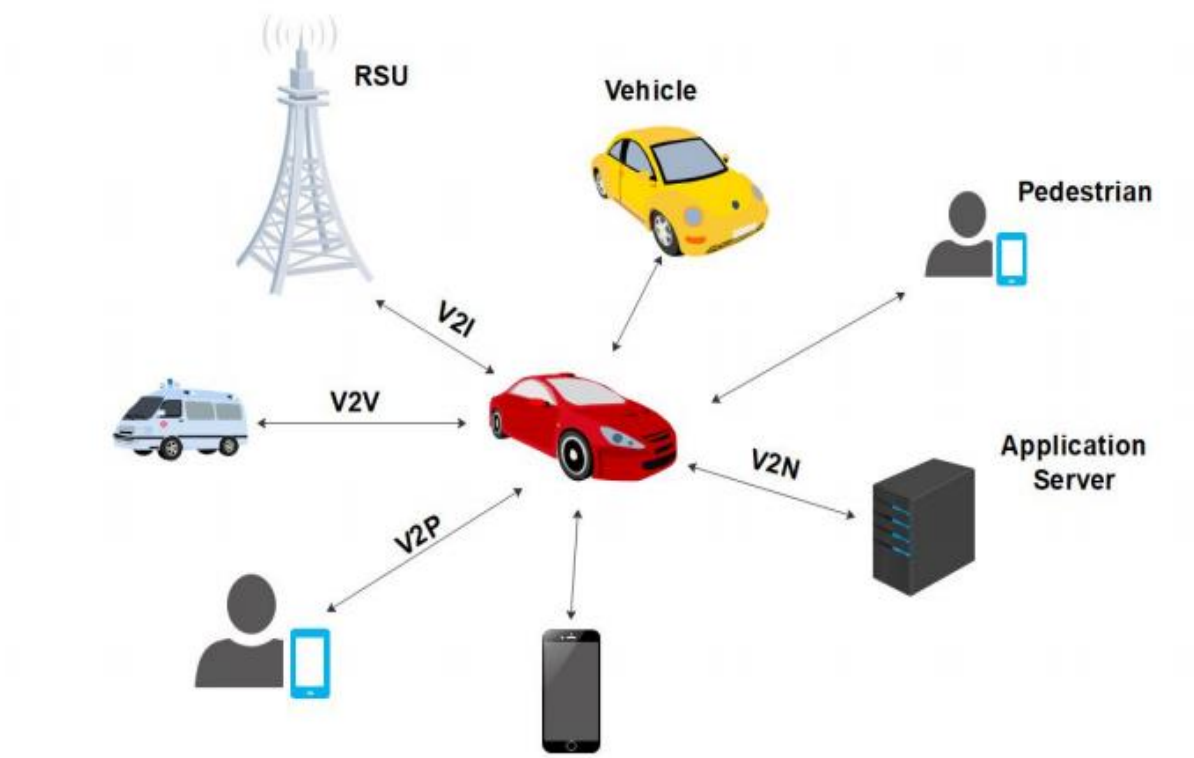


Figure 3.1: V2X applications in cellular communication

3.2 Specifications

There are some diverse guidelines supporting V2X communication and two of them, considered truly for utilize in America and in Europe, are known as Dedicated Short-Range Communication (DSRC) and 20 Cooperative Intelligent Transport Systems (C-ITS), separately. Due to advancement at the same time, these two benchmarks have similarities as well as contrasts. The organizations dependable for developing these measures are known as Standards Developing Organizations (SDOs). In America, they are IEEE and SAE, though in Europe they are ETSI and CEN. Distinctive guidelines are examined underneath.

1. C-V2X: C-V2X is the cellular partner of DSRC, which is based on LTE innovations. The most include of it is the utilize of a D2D interface termed as PC5, which underpins improved V2V utilize cases with more emphasis on V2X necessities. The 5G framework is presented in 3GPP Release 15, which is completed in 2018. Afterward 3GPP Discharge 16 is introduced and anticipated to be completed inside 2019. The 5G radio interface is known as 5G Unused Radio (NR). 3GPP Discharges 15 and 16 will present more V2X administrations by expanding capacity to bargain with high doppler speed up to 500 km/h, guaranteeing longer range communication and effective asset allotment, upgraded administrations in higher thickness, exceptionally tall throughput, tall unwavering quality, profoundly precise positioning, and most critically ultralow inactivity. This system operates within the range between 30GHz and 300GHz. It moreover ensures throughput more than 7Gbps, latency less than 10ms and connect foundation inactivity of 1ms. Downlink and uplink access technologies are based on Single Carrier Recurrence Division Multiple Access (SC-FDMA) for 3GPP Discharge 15 and Orthogonal Frequency Division Different Get to (OFDMA) for 3GPP Discharge 16. Resource multiplexing over vehicles employments TDM and FDM techniques for 3GPP Discharge 15 additionally conceivably for 3GPP Discharge 16. Data channel coding employments turbo strategy for 3GPP Discharge 15 and LDPC for 3GPP Discharge 16. Balance bolsters up to 64 QAM for 3GPP Release 15 and up to 256 QAM for 3GPP Discharge 16. Both the schemes cover over 450 meters utilizing coordinate mode and a really large area utilizing cellular framework.

2. DSRC: These guidelines are primarily inferred from IEEE 802.11-2012 where Physical Transmission (PHY) and MAC are clearly defined though they are balanced concurring to the necessities of V2X. As a derivative of IEEE 802.11, it too works within the 5 GHz frequency band, the contrast being the use of devoted channels rather than the regular WiFi channels. The extend of this committed channel is 5.825 to 5.925 GHz where whole range is separated into 10 MHz channels. The multiplexing innovation utilized here is OFDM. The strength of the OFDM utilized here compared to the common utilization in WiFi is the utilize of half clock. This decreases the 20 MHz groups to 10 MHz copies the OFDM image term with the cyclic prefix. This compensates the Doppler spread due to the tall speed of vehicles. Different SDOs have characterized distinctive angles of DSRC. For example, IEEE 802.11 has characterized the Fundamental Benefit Set (BSS), which provides distinctive organize topologies with an get to point or mesh network. IEEE 1609.4 characterizes an administration extension to the MAC to ensure the finest utilization of the apportioned different remote channels in the 5 GHz band. Security is characterized in terms of verification and optional encryption, which are based on advanced marks and certificates in IEEE 1602.2. It guarantees the protection of the client in V2X.
3. C-ITS: The European Broadcast communications Benchmarks Established (ETSI) is an autonomous, not-for-profit, standardization organization in the telecommunications industry. C-ITS may be a European advancement for vehicle-to-vehicle communication. There are some fundamental similarities between C-ITS and DSRC within the sense that, for access technologies, organizing and transport, and V2X messages they use the same structure of level layers though for management and security substances, the same vertical layers. It moreover works within the 5 GHz band, where the range allotment is again divided into portion A to D where ITS-G5A (30 MHz) is the essential recurrence frequency range. Its employments the half clock OFDM within the physical layer with the included highlight of an adapted range cover. Another highlight of CITS is the utilize of EDCA with CSMA/CA and get to categories to help in information traffic prioritization. For V2X messages it employs Co-operative Awareness Message (CAM), which is comparative to BSS. For spreading safety information, Distributed

Environmental Notification Message (DENM) is utilized, which isn't programmed as CAM and needs triggering from an application. The previously mentioned highlights at the side the other features of C-ITS are in a roundabout way standardized by setting a minimum requirement for three bunches of applications, specifically Road Hazard Signaling (RHS), Longitudinal Collision Risk Warning (LCRW) and Intersection Collision Risk Warning (ICRW) and Longitudinal Collision Risk Warning (LCRW).

4. Progressed ITS: Telecommunications Technology Association (TTA) is a South Korea based organization. Progressed ITS could be a modified version of IEEE 802.11p, which is conveyed within the Republic of Korea. TTA set up four guidelines for progressed ITS radio communications, as appeared underneath.

    i. Vehicle communication system Stage 1: Requirements (TTAK.KO-06.0175/R1) 22

    ii. Vehicle communication system Stage 2: Architecture (TTAK.KO-06.0193/R1)

    iii. Vehicle communication system Stage 3: PHY/MAC (TTAK.KO-06.0216/R1)

    iv. Vehicle communication system State 3: Networking (TTAK.KO-06.0234/R1)

Progressed ITS radio communications considers the described V2V/V2I communication plans and its benefit necessities for international harmonization. In V2V applications, it considers the low packet idleness since the life-saving time of security message is valuable in the span of 100ms. Too, the system needs an exceedingly actuated radio channel while a number of vehicles attempt to actuate radio channel at the same time. For V2I cases, it must receive lengthy parcel information containing a brief data, outline data also picture data about 2 kilobytes in a parcel estimate in tall portability scenario.

5. ARIB Advancement: This innovation has been created in Japan by Association of Radio Industries and Businesses (ARIB). For safe driving back frameworks, portion of the 700 MHz band (755.5- 764.5 MHz) has been allotted in an unused range assignment on a primary premise within the

computerized profit band. 9 MHz channel breadth from the 700 MHz radio recurrence frequency range will be utilized for the secure driving support frameworks. The information transmission rate is variable based on the distinctive tweak conspire also coding rate choice. The single channel suits both V2V and V2I communications based on CSMA/CA media get to control.

Parameters	C-V2X	DSRC	C-ITS	Advanced ITS	ARIB Development
Standards	3GPP	IEEE 802.11p	ETSI	TTA	ARIB
Specification completion	Expected to be completed within 2019	Completed	Completed	Completed	Completed
Operating frequency range	30 GHz-300GHz	5.85 GHz-5.925 GHz	5.855MHz-5.925MHz	5.855MHz-5.925MHz	755.5MHz-764.5MHz
RF channel bandwidth	10/20/40/60/80/100 ...MHz	10MHz or 20MHz	10MHz	<10MHz	<9MHz
RF transmit power	Maximum 33dBm	N/A	Maximum 33dBm	23dBm	
End to end latency	<10ms	<10ms	<10ms	<10ms	<10ms
Link establishment latency	1ms	Very small	Very small	Very small	Very small
Bitrate	>7Gbps	3Mbps-27 Mbps	3Mbps-27Mbps	3Mbps-27Mbps	3Mbps-18Mbps
Out of network operation	Yes	Yes	Yes	Yes	Yes
V2P support	Yes	Yes	Yes	Yes	Yes
V2I support	Yes	Limited	Limited	Limited	Limited

V2V support	Yes	Yes	Yes	Yes	Yes
Network coverage support	Yes	Limited	Limited	Limited	Limited
Broadcast support	Yes	Yes	Yes	Yes	Yes
Multimedia services support	Yes	No	No	No	No
MIMO	Yes	No	No	No	No
Throughpu t	Very high	Moderate	Moderate	Moderate	Moderate
Reliability	Very high	Moderate	Moderate	Moderate	Moderate
Synchroniz ation	Synchronous	Asynchrono us	Asynchronous	Asynchronous	Asynchronous
Resource multiplexin g across vehicles	TDM and FDM	TDM only	TDM only	TDM only	TDM only
coding					
Waveform	SC-FDMA and OFDMA	OFDM	OFDM	OFDM	OFDM
Modulation	Supports up to 256 QAM	Supports up to 64 QAM	Supports up to 64 QAM	BPSK, QPSK, 16QAM, Option: 64QAM	BPSK, QPSK, 16QAM
Covering distance	>450 meters using direct mode and very large area using cellular infrastructure	Up to 225 meters			
Coverage	Ubiquitous	Intermittent	Intermittent	Intermittent	Intermittent

Table 1: Various Specifications of V2X

Chapter 4

System Requirements

The requirements to deploy V2X services can be categorized as hardware requirement and capacity requirement. Both of these categories are discussed below

1. Equipment Necessities: To execute V2X, the vehicle needs to have this equipment consolidated.

i. Cameras: Works as the vision of the framework. Information gotten to through the camera is utilized for assist choice making.

ii. Radars: Expands the camera in NLOS cases, moo daylight and bad weather.

iii. Lidar: Lidar (Light Discovery and Extending) innovation makes the 3D pictures of the objects adjacent, giving the client more information aboutthe environment.

iv. Ultrasonic sensors: Ultrasonic sensors utilize ultrasonic sound waves and measure the separate by calculating the time between the transmitted and gotten signals.

v. V2X remote sensors: These sensors are utilized primarily to see through objects and to urge 360 NLOS see, which helps within the better judgment of generally street conditions.

vi. 3D HD Outline: Gives the client with full HD maps in arrange to navigate accurately.

vii. Worldwide Route adj. Framework (GNSS): GNSS gives highly precise information on the position of the vehicle. This will be utilized for deriving exact speed, precise heading, and time synchronization.

2. Capacity Prerequisites: As street security is of most extreme concern when planning to execute V2X on a mass scale, the framework itself has some strict necessities, as appeared underneath.

i. Moo Inactivity: End-to-End delay happens due to delay in gathering data from nearby sensors, handling delay within the convention levels and transmission delay over remote media. Security mechanisms (signature and certificate confirmation) include a few more delay in the process. In G-V2X, the inactivity is kept at 300ms ETSI TS 102 539-1. But independent driving requests more attention to this matter. A really little delay can result in a calamity in autonomous vehicles. Thus, this field requires more consideration.

ii. Information Stack Control: Littler inter-vehicular remove and high vehicle-density results in an overwhelming stream of information. This is often intensified due to tall data rate also due to extra information stack used in exchanging of control messages. In arrange to guarantee uniform stream of information, utilization of the current recurrence range, compelling prioritization of messages utilizing Decentralized Congestion Control (DCC) function and stern command of sending functionalities are required.

High Message Rate: In 1G-V2X vehicles broadcast intermittently within every 100ms to 1s. Here the information stream is commanded by the elements of the generating vehicle and the capability of the remote channel. But autonomous vehicles require more information with lower inactivity. They require to know almost the neighboring vehicles to create the proper choice. Independent vehicles require a total and real-time environmental model to arrange maneuvers in a secure way.

Chapter 5

Spectrum

The range utilize of V2X administrations based on LTE sidelink is described in this area.

- ITU Region 1: In Europe Cleverly Transport Frameworks (ITS) are regulated within the ETSI inside the band 5.855 GHz to 5.925 GHz. ECC Decision (08)01 characterized the range exertion conditions inside the band 5.875 GHz to 5.905 GHz. It points for non-safety ITS and proposes CEPT recurrence with sub-band 5.905 GHz to 5.925 GHz for the spread of ITS range. ECC Proposal (08)01 states that spectrum utilization ought to be inside the run 5.855 GHz to 5.875 GHz for non-safety ITS. For safety-related ITS applications, 5.875 GHz to 5.905 GHz is regarded within the Commission Decision 2008/671/EC.
- ITU Region 2: The Americas and Greenland are beneath this locale. Here IEEE Working Bunch 802.11 and 1609 have standardized the V2V design and conventions within the title of Remote Access Vehicular Environments (WAVE), which works within the band 5.850 GHz to 5.925 GHz. A watch band of 5 MHz is considered from 5.850 to 5.855 GHz. Three sorts of channels are there in V2X, namely control channel 178, shard channels 172, 174, 176, 180, 182 and 184 and amassed channels 175 and 181. Amassed channels have a bandwidth of 20 MHz and are utilized for multi-channel operations. Concurring to FCC 06-110, channel 172 is saved for V2V safety communications. Channel 184 is used for higher control and long-distance communication. It is additionally utilized for open safety operations.
- ITU Region 3: This locale covers all parts of Asia but Middle-East and incorporates Australia. A changed version, ITS standardization 2014, was distributed by the Broadcast communications Innovation Association (TTA) in South Korea, which bolsters vehicular communication at a maximum speed of 200 kph. Between 2012 and 2013, the Japanese Association of Radio Businesses and Commerce (ARIB) has also specified, based on IEEE 802.11, a V2V and V2I communication system within the 700 MHz recurrence band.

Chapter 6

PSSCH and PSCCH

6.1 Sidelink Channel Structure

In this subsection we demonstrate the sidelink network channel structure which incorporates coherent channels, transport channels and physical channels.

1. For sidelink communication, Sidelink Traffic Channel (STCH) is the logical channel, Sidelink Shared Channel (SL-SCH) is the transport channel and Physical Sidelink Shared Channel (PSSCH) and Physical Sidelink Control Channel (PSCCH) are the physical channels. The STCH carries client information for sidelink communication, which is mapped to the SL-SCH. This again, is mapped to the PSSCH. PSCCH carries Sidelink Control Information (SCI) in parallel to the PSSCH, which allows a getting gadget to legitimately distinguish and translate the PSSCH.
2. For sidelink disclosure, there's no consistent channel, Sidelink Discovery Channel (SL-DCH) is the transport channel and Physical Sidelink Discovery Channel (PSDCH) is the physical channel. The discovery message is inserted directly into the SL-DCH transport piece on the MAC layer because there is no logical channel connected to sidelink revelation. The SL-DCH utilized for disclosure declarations which is mapped to the PSDCH.
3. Finally, sidelink synchronization is accomplished by the use of two channels/signals:
    - Sidelink Synchronization Signal (SLSS) which is associated with a specific sidelink identity (SLI). When a system is under network coverage, it transmits SLSS in accordance with the network's transmission timing. This signal is received by nearby out-of-coverage units, which use it as a timing guide for sidelink transmissions. These devices can also send out their own SLSS, which can be detected and used by other devices. The area over which devices are synchronized to and derive their transmission timing from the network can thus be extended beyond the direct network coverage area in this way. A gadget can moreover independently transmit SLSS in spite of the fact that it is not inside the arrange scope additionally not identifying any necessarily solid SLSS. This

SLSS can be identified and forwarded by other out of scope gadgets and consequently forms nearby synchronization among these gadgets indeed without the nearness of a organize.

- In this case, Sidelink Broadcast Control Channel (S-BCCH) is the coherent channel, Sidelink Broadcast Channel (SL-BCH) is the transport channel and Physical Sidelink Broadcast Channel (PSBCH) is the physical channel. The S-BCCH along with SL-BCH and PSBCH are utilized to communicate the Sidelink Master Information Block (SL-MIB) between gadgets which is known as exceptionally essential sidelink related framework data.

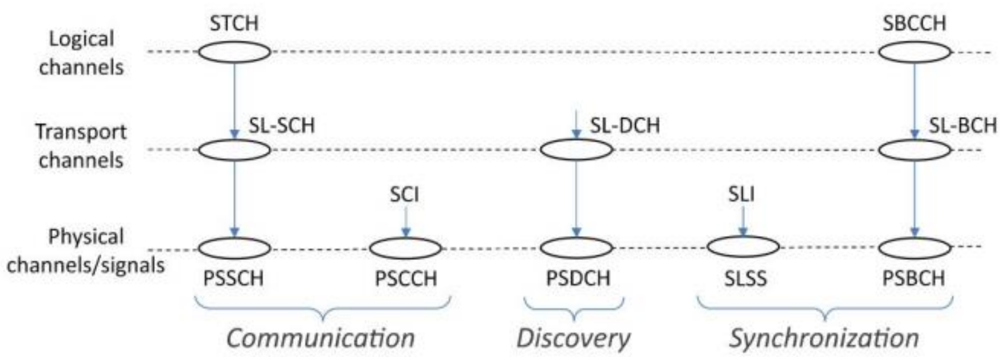


Figure 6.1: Sidelink Channel Structure

6.2 Sidelink Communication

The term "sidelink communication" refers to the direct exchange of user data between proximity devices. In practice sidelink communication is limited to group communication which means

- Sidelink transmission gadget transmits signals with no suspicions of receiving gadget.
- Any sidelink communication capable gadget within range of the transmitting system will receive and decode the sidelink transmission.
- To form recipient get it whether it is one of the expecting receivers of data or not, a gather personality is included within the control portion of the sidelink transmission.

As already said, sidelink communication is based on two physical channels:

- The PSSCH which carries the real transport-channel (SL-SCH) information.
- The PSCCH which carries SCI that empowers getting gadgets to properly distinguish and interpret the PSSCH.

6.3 Resource Pools and Assignment

A physical asset pool, in the form of hone subframes and resource bits, could be made available to a gadget for sidelink transmissions. The precise collection of assets to use for a specific sidelink transmission is then chosen from the asset pool. There are various methods for configuring a gadget with an asset pool:

- By Framework Data Square (SIB 18 in case of sidelink communication).
- By committed RRC signaling for gadgets in RRC_CONNECTED mode.
- By pre-configured asset pools for out-of-coverage gadgets.

For sidelink communication each asset pool comprises of :

- A PSCCH subframe pool characterizing a set of subframes accessible for PSCCH transmission
- A PSCCH asset square pool characterizing a set of asset blocks available for PSCCH transmission inside the PSCCH subframe pool
- A PSSCH subframe pool characterizing a set of subframes accessible for PSSCH transmission
- A PSSCH asset square pool characterizing a set of asset blocks available for PSSCH transmission inside the PSSCH subframe pool

Sidelink communication can be done in two ways. The two modes vary in how a gadget is allocated or selects the exact collection of resources to use for sidelink transmission from a pool of resources.

- Sidelink communication mode 1: In this mode arrange selects PSCCHPSSCH for a gadget by implies of a planning allow It is only possible for incoverage gadgets in RRC_CONNECTED state
- Sidelink communication mode 2: In this mode a gadget by itself selects PSCCH PSSCH assets It is conceivable for both in scope and out of scope gadgets and in both RRC_IDLE and RRC_CONNECTED state

6.4 PSCCH Periods

The piece of assets is rehashed with a period, known as the PSCCH period. Sidelink communication is focused on PSCCH intervals within the time space. Each Framework Outline Number SFN period, which consists of 1024 frames or 10240 subframes, is divided into PSCCH periods with break even lengths. The collection of transmission assets relegated by the organizer or chosen by the system itself individually is carried out on a PSCCH period assumption in both cases of sidelink communication mode 1 and mode 2. The duration of the PSCCH period in FDD can be set to 40, 80, 160, or 320 subframes. In the case of TDD, the range of possible PSCCH period lengths is determined by the downlink or uplink arrangement.

6.5 PSCCH Transmission

There are a few steps for the PSCCH transmissions which are discussed underneath:

- As of now said, the PSCCH carries control data, alluded to as sidelink control data (SCI), which empowers a receiving gadget to legitimately identify and translate the information transmission on PSSCH. The SCI incorporates, for case, data almost the time-frequency assets (subframes and assetpieces) utilized for the PSSCH transmission. So channel coding and balance for SCI is important to do and comprises of the taking after action:
  - 16-bit CRC calculation
  - Rate 1/3 tail-biting convolutional coding
  - Rate matching to match to the number of coded bits to the size of the PSCCH resource • Bit-level scrambling with a predefined seed
  - QPSK modulation
- The tweaked images are at that point DFT precoded sometime recently being mapped to the physical assets (subframes and asset blocks) assigned/selected for the PSCCH transmission.
- A subframe bitmap provided as part of the sidelink setup determines the PSCCH subframe pool, or the collection of subframes available for PSCCH transmission during each PSSCH cycle.
- The PSCCH resource-block pool, or the pool of asset blocks available for PSCCH transmission within the subframe pool, is made up of two equal-

sized sets of frequency-wise sequential asset bits. The resource-block pool can hence be completely portrayed by

- The index S1 of the first resource block in the lower set of resource blocks.
- The index S2 of the last resource block in the upper set of resource blocks.
- The number M of resource blocks in each of the two sets.

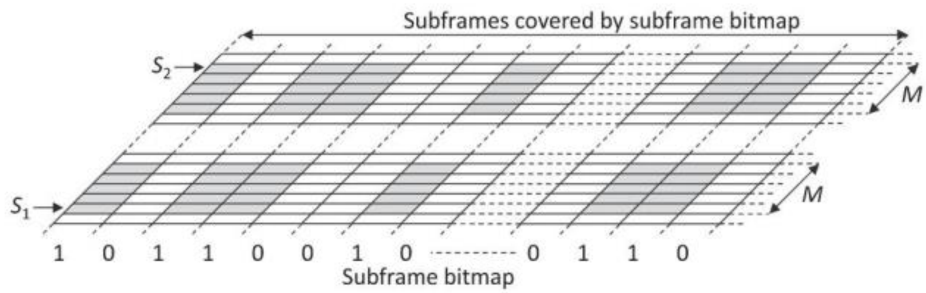


Figure 6.2: PSCCH resource pool structure

- In each subframe, a PSCCH transmission is carried out over two subframes and within one asset square combine. A parameter nPSCCH specifies the subframes and resource pieces within the planned asset pool should be used for a specific PSCCH transmission. nPSCCH is either defined in the network's planning enable (for sidelink communication mode 1) or autonomously selected by the transmitting device (sidelink communication mode 2).
- The mapping from nPSCCH to the genuine set of PSCCH assets is such that if the transmission in the first subframe occurs in the lower set of asset squares, the transmission in the second subframe occurs in the upper set of asset bits, and vice versa. The mapping is also such that if two different values of nPSCCH indicate mapping to the same first subframe, the moment transmission will occur in completely different subframes, or vice versa. As a result, PSCCH transmissions that lead to distinct values of nPSCCH can only collide in one of the two subframes in time.

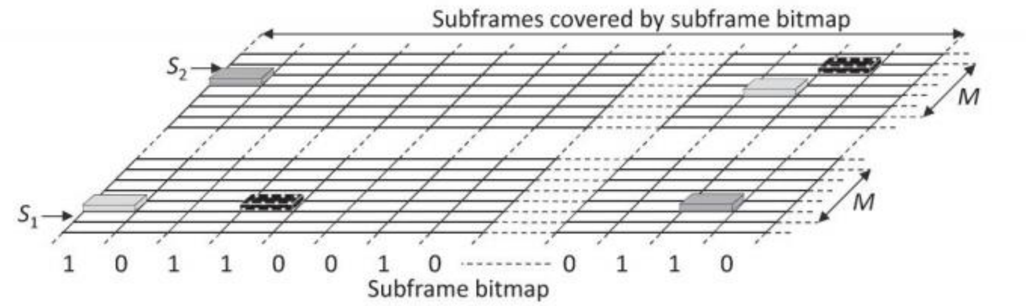


Figure 6.3: PSCCH transmission

6.6 PSSCH Transmission

Comparative to the PSCCH transmission, there are too a few steps for the PSSCH transmissions which are talked about underneath:

- On the PSSCH, real transport channel (SL-SCH) data is transmitted within the frame of transport bits. Within the PSSCH subframe pool, each transport square is transmitted over four subframes in a row. In order to transmit M transport squares within a PSCCH time, 4M subframes are needed. It's worth noting that a single PSCCH SCI carries control data for PSSCH transmission for the duration of the PSCCH cycle. The following measures are involved in SL-SCH channel coding and balance.:

    - CRC insertion
    - code-block division and per-code-block CRC insertion
    - rate 1/3 Turbo coding
    - rate coordinating (based on physical-layer hybrid-ARQ functionality)
    - bit-level scrambling
    - information balance (QPSK/16QAM)

- After channel coding and balance, DFT precoding is applied followed by mapping to the physical asset assigned/selected for the PSSCH transmission.
    - PSSCH set of subframes for PSSCH transmission:

• The PSSCH subframe pool, which is the collection of subframes accessible for PSCCH transmission in sidelink communication mode 1, consists of all uplink subframes after the last subframe of the PSCCH subframe pool. A time redundancy design list TRPI provided as part of the planning give specifies the exact collection of subframes to use for PSSCH transmission in a PSCCH cycle. The TRPI focuses on a specific time repetition design TRP within a TRP table that is explicitly specified in the LTE determinations. The uplink subframes doled out for the PSSCH transmission are sometimes expanded of the indicated TRP at that stage. The TRPI is then included in the SCI in order to inform receiving devices about the collection of subframes in which the PSSCH is transmitted.

• The PSSCH subframe pool, which is the set of uplink subframes available for PSSCH transmission in sidelink communication mode 2, is a subset of the mode 1 subframe pool. A periodic expansion of a bitmap characterized in the sidelink setup, in particular, shows what subframes are included in the PSSCH subframe pool. This allows the network to ensure that such subframes are not used for PSSCH transmissions. The device then selects the exact set of subframes to use for the PSSCH transmission on its own, by choosing a TRP at random from the TRP table. The receiving device is told about the selected TRP by counting the corresponding TRPI inside the SCI, similar to sidelink communication mode 1. In addition to the collection of subframes that are part of the PSSCH subframe pool, there are also constraints within the TRP decision in sidelink communication mode 2. In general, the TRP table contains TRPs with varying numbers of ones, which correspond to different subframe divisions allocated for PSSCH transmission.

This includes, for example, the all-one TRP as opposed to allocating all PSSCH pool subframes for PSSCH transmission from a single device. In any case, the TRP determination in sidelink contact mode 2 is restricted to TRPs with a small number of ones, limiting the PSSCH transmission service cycle. In the case of FDD, for example, the TRP selection is restricted to TRPs with a maximum of four ones, as opposed to a 50 percent service cycle for PSSCH transmission. In expansion to the set of subframes, a gadget too ought to know the exact set of asset pieces to be utilized for the PSSCH transmission

• For sidelink communication mode 1: In this case, information about the asset squares to use for PSCCH transmission is included in the planning permission provided by the arranger. As a result, the asset deliver includes a 1bit frequencyhopping hail as well as a resourceblock operation, the size of which is determined by the device bandwidth. There are no restrictions on what asset pieces can be distributed, but it should be a series of sequential asset squares. To put it another way, in sidelink communication mode 1, the PSSCH resourceblock pool includes all asset parts within the carrier bandwidth.

• In the case of sidelink communication mode 2, there are limitations on which asset squares can be used for PSSCH transmission. This PSSCH asset square pool has the same structure as the PSCCH resource block pool, namely two sets of frequency-wise continuous resource blocks with three parameters S1, S2, and M. It's worth noting that the PSSCH asset square pool has its own collection of parameters that aren't shared with the PSCCH resource block pool. At that point, a system operating in sidelink communication mode 2 will pick a collection of consecutive asset pieces from the PSSCH resource block pool on its own.

- Data around the assigned/selected set of asset pieces is provided to accepting gadgets as portion of the SCI.

6.7 SCI Contents

As previously stated, the SCI contains data that a receiving system needs to properly define and translate the PSSCH and extract the SL-SCH data. This includes information about the exact collection of resources (subframes and asset squares) over which the PSSCH is broadcast:

- The TRPI, demonstrating the set of subframes utilized for the PSSCH transmission.

- A recurrence jumping hail showing whether or not recurrence hopping is utilized for the PSSCH transmission.
- An asset square and bouncing asset assignment showing what resource pieces, inside the subframes shown by the TRPI, are used for the PSSCH transmission.
- A five bits marker of the tweak and coding plot (MCS) used for the PSSCH transmission.
- An eight bit bunch goal ID, showing the bunch for which the sidelink communication is aiming.
- An eleven bit timing-advance pointer.

6.8 Scheduling Grants and DCI Format 5

As depicted over, gadgets inside arrange scope can be configured to as it were start sidelink communication when having been given with an unequivocal planning give by the organize (sidelink communication mode 1). Sidelink planning awards are given by means of the PDCCH/ePDCCH utilizing DCI format 5. DCI format 5 incorporates the following data:

- The parameter nPSCCH showing the physical asset subframes and resource squares on which PSCCH is to be transmitted
- The TRPI showing what subframes inside the PSSCH subframe pool to utilize for the PSSCH transmission.
- A recurrence jumping hail showing whether or not recurrence hopping should be connected for the PSSCH transmission.
- A asset piece and bouncing asset allotment showing what resource squares, inside the subframes shown by the TRPI, ought to be used for the PSSCH transmission.
- A 1-bit transmit control control (TPC) command that applies to both PSCCH and PSSCH.

The sidelink scheduling gran is substantial for the another PSCCH period starting at slightest four subframes after the entry of the planning give. Its transmission is bolstered by buffer status reports (BSRs) given to the network by gadgets included in sidelink communication. The sidelink BSRs are passed on as MAC control components and demonstrate the sum of data accessible for transmission at the gadget.

6.9 Reception Resource Pools

A device that will participate in sidelink communication is often equipped with one or more reception asset pools relevant to sidelink communication, in addition to the transmission asset pool.

A gathering resource pool is a collection of assets (subframes and asset pieces) from which a device can expect to receive sidelink communication transmissions. The PSCCH portion of the reception asset pool, in particular, depicts the collection of assets that the system can search for PSCCH transmissions. Furthermore, the PSSCH portion of the asset is needed for the recipient to be able to decipher the resource data inside the SCI legitimately.

The explanation for having different reception pools on a system is that it can receive sidelink communication from different devices, each of which may have different transmission pools. This may be the case regardless of whether the devices are in the same cell or in different cells. As a general rule, a device should be equipped with a gathering pool that is the sum of the transmission resource pools of the devices with which it will communicate. In reality, this can be accomplished by setting up the gadget with several gathering pools that cover all of the relevant gadgets' transmission pools.

Chapter 7

Proposed Retransmission scheme

7.1 Overview:

To reduce the latency and to maintain the reliability of the conventional retransmission scheme we propose another retransmission scheme in this work.

The main difference between the proposed retransmission scheme and the conventional scheme is than where in conventional scheme one HARQ retransmission scheme is done after some time gap but in our proposed scheme three HARQ retransmission will be done at the same subframe. So, the main difference is in two aspects. They are-

1. The number of HARQ retransmission.
2. The number of subframe gap between the initial transmission and retransmission. In case of the proposed scheme it is zero

As now there is no subframe gap between the initial transmission and the retransmission only processing and decoding time is needed in case of the proposed scheme. Earlier in the conventional system there are two redundancy versions, one initial transmission followed by one HARQ retransmission but in the proposed scheme we use four redundancy versions, one initial transmission followed by three HARQ retransmission in the same subframe. In this scheme the redundancy versions are separated in the frequency domain, the 1st version occupies the lower subchannel and with the increasing of the redundancy version they occupy the upper subchannels. The difference between the conventional and the proposed scheme is shown in the following table-

Subject	Conventional scheme	Proposed scheme
No of HARQ retransmission	One (1)	Three (3)
Subframe Gap	Not more than eight (8)	Zero (0)
Division of the redundancy versions	Time and frequency wise	Only frequency wise
Advantage	Minimal resource usage	Very low latency

Table 2: Difference between conventional and proposed scheme

7.2 System Structure:

The proposed scheme is based on the already existing retransmission scheme only difference is the increase in the retransmission number and no subframe gap between the initial transmission and retransmissions. The main aspects of the proposed scheme are listed below.

- Basically, the scheme is based on the mode 4 of C-V2X direct transmission. The scheduling information of the initial transmission contains the radio resource information of the blind retransmission. By this way nearby UEs recognize the blind retransmission after receiving initial transmission and get ready to recover the unsuccessful information.

- The allocated radio resources of C-V2X is divided into subchannels. The transport block that the UE transmits is mapped onto a particular no of subchannels. The no of the subchannels depends on the size of the transport block.

- 10 MHZ of bandwidth is allocated and the radio resources are subdivided into further 10 subchannels. The size of the transport block is chosen such that they each occupy 1 subchannel.

- In this scheme UE will use the lower subchannel to complete the initial transmission. The initial transmission will be followed by three HARQ retransmission in the same subframe but in the upper subchannels as shown in figure.

- There will be gap of at least one subchannel between the redundancy versions. This way there will be four redundancy version of a data and all the versions locate in the different frequency region.

- In this proposed scheme one frame can accommodate ten different HARQ processes where each of HARQ process will be followed by three HARQ retransmission in the same subframe.

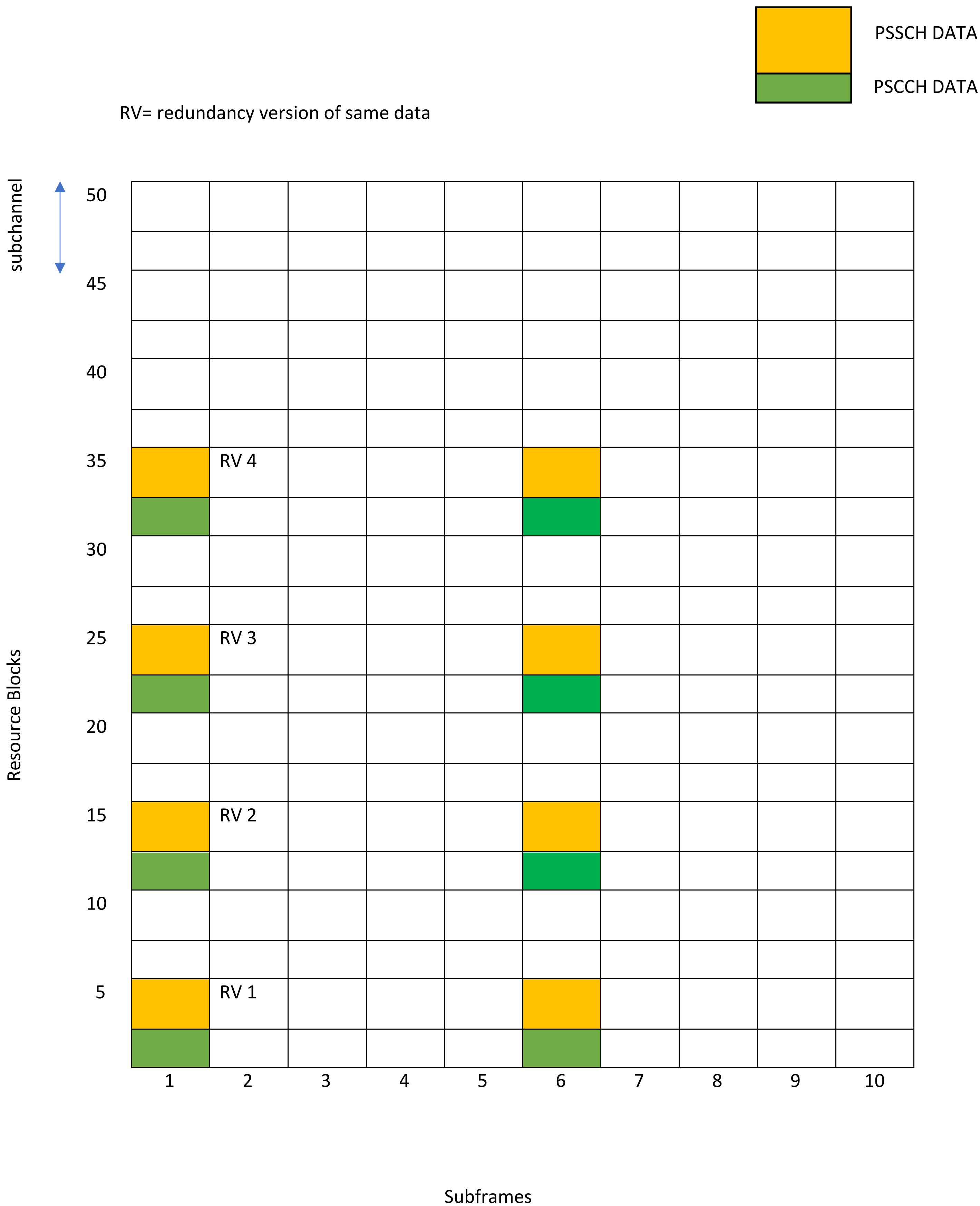


Figure 7.1: C-V2X PSSCH resource pool (FDD)

7.3 Significance of the Scheme:

In the conventional retransmission system, to accommodate as many as different HARQ process the receiving UE has to wait for at least 8 subframe to receive the HARQ retransmission where each subframe indicates time of 1ms. But now the receiving UE can get the four-redundancy version of a data at the same time. So, it doesn't have to wait for 8ms. Only the processing and decoding time is needed now. Which lowers the latency very much than earlier system and raises the speed of the v2x communication much higher. Also, earlier maximum 8 different HARQ processes can be conducted in a time frame but now we can conduct maximum 10 HARQ processes in a time frame where a frame indicates 1s. So, it can be seen that the latency is very much lower than the conventional system. Also, the capacity of the communication also increases. Just one of the drawbacks of this system is that the consumption of radio resources which we can compromise for much higher speed.

Another important requirement of v2x communication is the high reliability. In the lower snr condition how successfully, the system can conduct the communication is a challenging thing. The proposed system reduces latency but to adopt it practically it needs to maintain the high reliability of the communication. We can't trade of latency with the reliability. To check the reliability of the system we will conduct a MATLAB simulation which will provide information about the performance of the proposed scheme under different snr condition to check its reliability and also through simulation we will justify our choice of the HARQ retransmission number. Through simulation we will get a clear picture about the choice of highest number of redundancy versions.

Chapter 8

Simulation

8.1 Overview:

To be a practical retransmission scheme the scheme must provide latency lower than 10ms and should have sufficient throughput and reliability under low snr condition. Then the system will be very efficient to be implemented in C-V2X. As stated earlier the proposed system lowers the latency very much makes it very fast communication but to check the efficiency of the system, we must make sure that the system is reliable and provide good throughput under low SNR condition. Only then the system will be considered as an efficient retransmission scheme. To check the performance of our system in terms of reliability we conduct a MATLAB based simulation. The simulation mainly evaluates throughput (%) of SL-SCH data. Also, the simulation was done with one, two and three retransmission schemes in the same subframe to justify the choice of completing three HARQ retransmission

8.2 Simulation Methodology:

To find out the throughput of SL-SCH data the system goes through the processes chronologically as shown in the figure. After going through the following process, the throughput of SL-SCH data can be measured which gives us a clear picture of the adopted retransmission scheme in terms of reliability.

The simulation is done using the LTE toolbox in MATLAB. The simulation is mainly focused on the reception of PSSCH data which is sent through a noisy channel. The channel basically represents an AWGN channel and also frequency selective fading is incorporated to the channel. In this simulation we send a transport block through the channel and then with the receiver antenna the data is received. Then at first the SCI message is decoded and if it is decoded successfully then the SL-SCH data is decoded. Based on the data sent and decoded successfully a graph is generated showcasing the SL-SCH throughput in terms of percentage vs the different SNR level that is to be simulated. Figure 8.1 shows all the steps chronologically after going through the steps we get the graph.

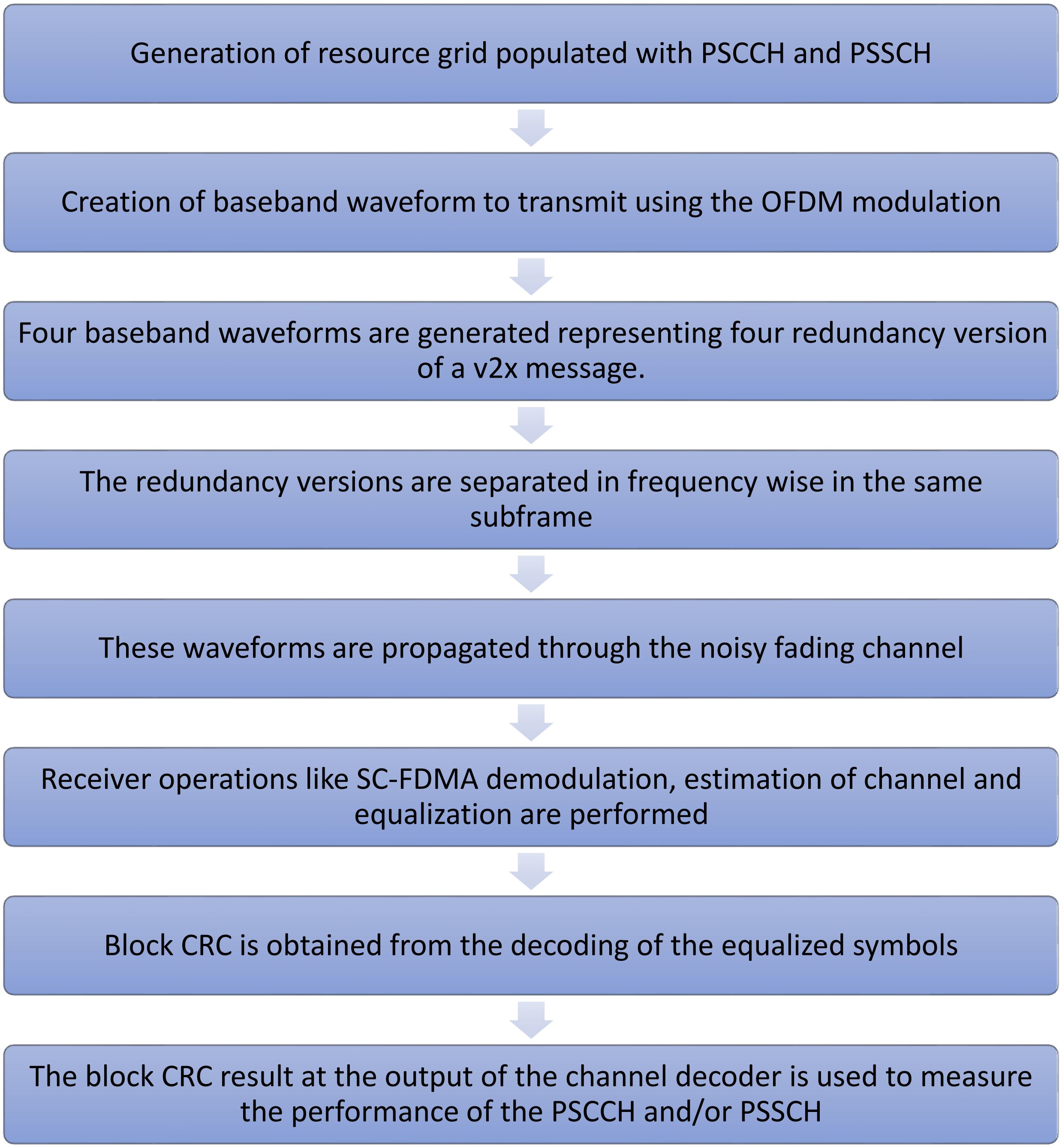


Figure 8.1: The processing chain of finding the SL-SCH throughput

8.3 Simulation Parameters:

While doing the simulation some of the parameters are chosen according to TS 36.101. The necessary parameters are chosen from the following table-

Ch BW	Allocated RB	Payload Size	Total symbols/ subframe
10,20	3	208	360
10,20	4	256	480
10,20	5	328	600
10,20	6	408	720
10,20	8	552	960
10,20	9	632	1080
10,20	10	696	1200
10,20	12	840	1440
10,20	15	1064	1800

Table 3: Fixed Reference measurement channel for V2V Transmitter requirements for QPSK.

Modulation	QPSK
DFT OFDM symbol/subframe	10
Target coding rate	1/3
Transport block CRC	24
No. of code blocks/subframe	1
No. of bits/symbol	2
UE category	>=1

Table 4: Fixed reference measurement channel for V2V transmitter requirements for QPSK

From the above-mentioned table, we set our simulation parameters. Using those parameters, we simulate a V2X environment and measure the SL-SCH throughput in terms of percentage for different SNR. The following table represents the parameters that we choose for the simulation of the proposed scheme.

Parameter	Value
No of frames	100
No of allocated resource block	5
Transport block size	328
Bandwidth	10 MHz
Duplex mode	FDD
Symbol modulation	QPSK
Cyclic prefix length	Normal
Number of receive antennas	2
Delay profile	Extended vehicular a model
Doppler frequency	500 Hz
Rayleigh fading model type	Generalized method of exact doppler spread
Channel frequency window size	27
Channel time window size	1
Interpolation type	Cubic
No of HARQ processes (in a frame)	10

Table 5: Simulation parameters

Chapter 9

Performance Analysis of the Proposed Scheme

9.1 Overview:

The proposed scheme's main focus is to lessen the latency as much as possible. But to get the best benefit, the proposed scheme must maintain the reliability of the original retransmission scheme otherwise the scheme will not be that much useful. To check whether the proposed scheme can be useful and can replace the original retransmission scheme we will measure the SL-SCH throughput of the C-V2X communication. If the throughput (%) is at satisfactory level even at low SNR than we can say the system is reliable and we can replace the original retransmission scheme with the proposed one as the proposed scheme not only lowers the latency of the C-V2X communication but also maintains the high reliability and throughput.

9.2 Performance Analysis:

After performing the simulation with the parameters as mentioned in the previous chapter, we get a graph of SL-SCH throughput in terms of percentage for different SNR points. As shown in figure we get a graph of SL-SCH throughput (%) vs SNR graph. If we look at the graph, we can see as expected with the improvement in SNR the throughput percentage also increases. Now to justify the choice of conducting highest number of HARQ retransmission we simulate with one, two and three retransmission schemes. As mentioned earlier all the retransmissions are done in the same subframe. Figure demonstrates the performance of C-V2X communication for different number of HARQ retransmission in the same subframe.

From the graph of the simulation we can notice the following points;

- At the very low SNR no matter how many HARQ retransmission number we choose; the throughput result will be very poor. It will give almost zero in terms of percentage. Due to the very low SNR the channel condition is very poor which makes it impossible to recover and decode the data that is sent by the transmitter UE.

- With the improvement in the SNR the throughput percentage also increases for all the three retransmission processes. Here by the word retransmission process we indicate to the number of HARQ retransmission done in a subframe. Here we have three retransmission process:
  1. One-retransmission: only one HARQ retransmission is done in the same subframe.
  2. Two-retransmission: two HARQ retransmissions are done in the same subframe.
  3. Three-retransmission: three HARQ retransmissions are done in the same subframe.

- When the SNR value is less than -5 dB all the processes show very poor performance. When the SNR is >=5 than the processes show some significant performance.

- When the SNR is between -5 dB to 0 dB the three-retransmission process shows better performance than the other two processes. In terms of performance we can write:
  Three-retransmission > Two-retransmission> One-retransmission
  We can clearly see that the three-retransmission process gives more satisfactory result than the other two process. Which clearly indicates the superiority of the three-retransmission process in terms of reliability. As mentioned earlier the process will not only lower the latency but it also maintains the reliability of the original retransmission scheme. Which clearly showcases that we can replace the original retransmission scheme with the proposed one.

- As the SNR is increased beyond 0 dB the throughput condition for all the three processes improve significantly. After 2 dB crossing the throughput percentage value of the three-retransmission process and two-retransmission process becomes identical. Still the one-retransmission process lags behind the other two process which downright makes it not that much reliable as compared to other two retransmission process.

- After the SNR crosses 5 dB, the throughput percentage of the all three processes becomes identical as expected. With the increase in SNR fading and noise doesn't affect the signal that much which makes it possible to receive and decode all the data that is transmitted by the receiver successfully.

Table gives us a quantitative representation of the throughput percentage for different retransmission process. From the table we can clearly see that the three retransmissions at the same subframe clearly gives a better result than the other two process that we simulate alongside our proposed scheme.

SNR	SL-SCH Throughput (percentage)		
	One-retransmission	Two-retransmission	Three-retransmission
-10 dB	0	0	0
-5 dB	< 10%	< 20 %	Almost 30%
-2.5 dB	< 50%	Almost 60%	Almost 70%
0 dB	< 70%	< 80%	< 90%
5 dB	< 80%	Almost 80%	< 100%
> 5 dB	Almost 100%	Almost 100%	Almost 100%

Table 6: Quantitative analysis of the throughput for different number of HARQ retransmission in the same subframe

We can easily see from the table that when we choose maximum number of HARQ retransmission number than it gives better result in terms of throughput percentage (SL-SCH data) even in the lower SNR condition. Based on this data we can justify why we choose maximum number of HARQ retransmission that can be possible. Because it gives more reliability and better throughput performance than the minimum number of HARQ retransmission. So, choosing maximum number of HARQ retransmission not only gives very low latency but also maintains the high reliability and throughput of C-V2X.

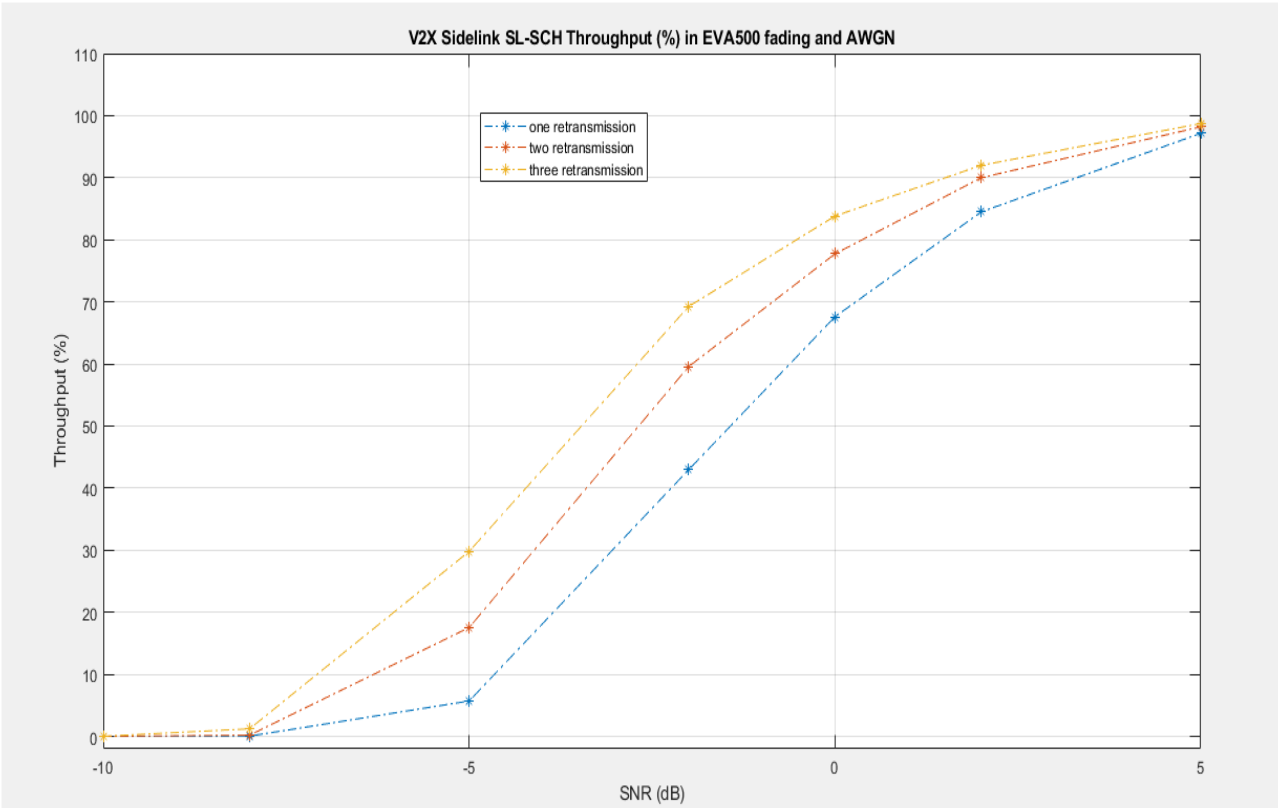


Figure 9.1: SL-SCH throughput (%) vs SNR graph for different number of HARQ retransmission in the same subframe

Chapter 10

Advantages and Drawbacks of the Proposed Scheme

10.1 Overview:

The proposal of sending the HARQ retransmission in the same subframe rather than in different subframe like the original retransmission scheme has the benefit of the low latency but long with this advantage one of the problem pops up which is the excessive usage of the resource elements than the original retransmission scheme as we intend to send three HARQ retransmission. In this chapter we will discuss about this thing more extensively.

10.2 Advantages of the Proposed Scheme:

Mainly we benefit from the proposed scheme two way. They are:

- Reduces the latency: the advantages that we basically looking from the scheme. As mentioned earlier there is always some subframe gap between the initial transmission and corresponding HARQ retransmission which leads to some latency in the C-V2X communication. C-V2X communication supports latency < 10ms. The proposed scheme basically lowers the latency by sending the initial transmission and HARQ retransmission in the same subframe. This way now the receiving UE doesn't have to wait for some subframe to get the redundancy versions of a data. So only the decoding and processing time is needed in case of the proposed scheme. The reduced latency will now make it possible to propagate the safety related information faster as a result it will now reduce the traffic jam and the road accidents to a greater extent.

- Maintaining the reliability: along with reducing the latency one of the most advantageous part of the scheme is that it maintains the high reliability and throughput of the original retransmission scheme. As a result, along with propagating the messages faster the probability of receiving the error free messages also maintains which makes the proposed scheme an interesting and beneficiary choice to replace the original retransmission scheme.

10.3 Drawbacks of the Proposed Scheme:

The proposed scheme lowers the latency very much but with one HARQ retransmission the reliability is not that much satisfactory. As C-V2X is a delay and error sensitive application so we have to maintain a certain level of latency as well as a certain level of reliability. To meet both condition we choose maximum number of HARQ retransmission for the proposed scheme which maintains the reliability like the original retransmission and lowers the latency by accommodating all the redundancy versions in the same subframe. But as we choose maximum number of HARQ retransmission the usage of resource elements also increases significantly. In the original retransmission scheme only one HARQ retransmission is sent but in the proposed scheme three HARQ retransmission is sent which increases the resource usage to three times more than the original scheme. As a result, the proposed scheme is expensive than the original scheme. So, we have to make a tradeoff between latency and the cost due to resource usage.

Chapter 11

Future work

In this scheme of sending all the redundancy versions of a data in the same subframe have a limitation like the original scheme. Like the original scheme the retransmission doesn't depend on the success of the first initial transmission. Irrespective of success of the receiver UE to decode the data the transmitter UE will send the redundancy versions which are actually not needed if the initial transmission is a successful one. The redundancy versions occupy some radio resources which will now be counted as wastage as these radio resources are not needed. Moreover, this radio resources could have been used for other cellular works. This problem is severe in case of our proposed scheme as transmitting UE send 3 HARQ retransmission after the original transmission. So, when the channel is good irrespective of the success of the initial transmission the transmitting UE send all the HARQ retransmissions which are not needed at all leading to wastage of radio resources that could have been used for other purpose. This wastage is almost 3 times than the original scheme as the original scheme only uses one HARQ retransmission. So, in future based on the channel condition the number of retransmissions can be adjusted. When the channel condition is at satisfactory level for speedy communication then minimum retransmission will be adopted (only one HARQ retransmission) and if channel condition is poor then the UE can go back to the maximum retransmission scheme. To measure channel condition the receiving UE can send a random reference signal which will give information about the SNR and the other things.

Conclusion

In this work we propose a retransmission scheme for C-V2X system which generally transmits three HARQ retransmission on the same subframe used for the initial transmission. This way only the decoding and processing time is needed which greatly reduces the latency. While reducing the latency, the proposed scheme also maintains the high reliability of the C-V2X communication and this features make the proposed scheme an ideal replacement of the original retransmission system.

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