PERFORMANCE ANALYSIS OF V2X SIDELINK

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List of Acronyms

3GPP	Third generation partnership project
ACK	Acknowledgement
AM	Acknowledged Mode
APN	Access Point Name
APN	Access point name
ARQ	Automatic Repeat Query
AS	Access Stratum
AWGN	Additive White Gaussian Noise
BCCH	Broadcast Control Channel
BCH	Broadcast Channel
BER	Bit Error Rate
BLER	Block Error Rate
CAM	Co-operative Awareness Message
CCCH	Common Control Channel
CDMA	Code Division Multiple access
CFI	Control Format Indicator
CLW	Control loss warning
CQI	Channel Quality Indicator
CRC	cyclic redundancy check
CSG	closed subscriber group
D2D	Device to Device
DCCH	Dedicated Control Channel
DENM	De-centralized Environmental Notification Message
DL-SCH	Downlink Shared Channel
DSRC	Dedicated short-range communication
DSRC	Dedicated Short Range Communication

DTCH	Dedicated Traffic Channel
EDCA	Enhanced Distributed Channel Access
EDGE	Enhanced Data GSM Environment
eMBMS	Evolved Multimedia Broadcast Multimedia Services
eNodeB	E-UTRAN Node B
EPC	Evolved Packet Core
EUTRAN	Evolved Universal Mobile Telecommunication System
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
EVA	Extended Vehicular A
FCW	Forward Collision Warning
FDD	Frequency-division Duplexing
GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
GTP	GPRS Tunneling Protocol
HARQ	Hybrid Automatic Repeat Query
HeNB	Home eNodeB
HSDPA	High Speed Downlink Packet Access
HSPC	High-Speed Packet Access
HSS	Home Subscriber Server
IP	Internet Protocol
ITS	Intelligent transportation system
ITS	Intelligent Transportation System
LTE	Long Term Evolution
MAC	Medium Access Control
MBMS	Multimedia Broadcast Multimedia Services
MCCH	Multicast Control Channel
MCH	Multicast Channel
MCS	Modulation and Coding Scheme
MIB	Master Resource Block
MME	Mobility Management Entity
MMSE	Minimize Mean Square Error

MTCH	Multicast Traffic Channel
NACK	Negative Acknowledgement
NAS	Network-attached storage
OFDM	Orthogonal frequency-division multiplexing
PBCH	Physical Broadcast Channel
PBCH	Physical Broadcast Channel
PBSCH	Physical Sidelink Broadcast Channel
PCCH	Paging Control Channel
PCEF	Policy Control Enforcement Function
PCFICH	Physical Control Format Indicator Channel
PCH	Paging Channel
PCRF	Policy Control and Charging Rules Function
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Convergence Protocol
PDN	Packet Data Network
PDU	Packet Data Unit
P-GW	Packet Data Network Gateway
PHICH	Physical Hybrid ARQ Indicator Channel
PLMN	Public land Mobile Network
PRACH	Physical Random Access Channel
PRB	Physical Resource Block
ProSe	proximity service
PSCCH	Physical SL Control Channel
PSSCH	Physical SideLink Shared Channel
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
QAM	Quadrature Amplitude Modulation
QCI	QoS Class Identifier
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RACH	Random Access Channel
RACH	Random Access Channel

RB	Resource Block
RE	Resource Element
RLC	Radio Link Control
RMS	Root Mean Square
RRC	Radio Resource Control
RSU	Road Side Unit
SAP	Service Access Point
SBCCH	Sidelink Broadcast Control Channel
SC	Scheduling
SC-FDMA	Single Carrier Frequency Division multiple Access
SCI	Sidelink Control Information
SCTP	Stream Control Transmission Protocol
SDU	Service Data Unit
SGSN	Serving GPRS Support Node
S-GW	Serving gateway
SL-BCH	Sidelink Broadcast Channel
SL-SCH	Sidelink Shared Channel
SNR	Signal to Noise Ratio
SRS	Sounding Reference Signal
STCH	Sidelink Traffic Channel
TDD	Time-division Duplexing
TTI	Transmission time Interval
UE	User Equipment
UL-SCH	Uplink Shared Channel
UM	Unidirectional Mode
UMTS	Universal Mobile Telecommunications Service
Uu	U-tran and User equipment
V2I	Vehicles to Infrastructure
V2N	Vehicle to Network
V2P	Vehicle to Pedestrian
V2V	Vehicle to everything
V2X	Vehicle to Everything

VLSI	Very Large Scale Integration
Wi-Fi	Wireless Fidelity

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Abstract

The industry is moving rapidly to establish standards for V2X communications. V2X is a form of technology that allows vehicles to connect with moving parts of the traffic system around them. DSRC and LTE-V are prime candidates being considered for connected vehicular applications. Among them, LTE-V has established itself as the frontrunner due to its usage of newer technologies and compatibility with existing cellular systems. This paper analyzes the throughput for vehicular sidelinks using LTE-V under various channel conditions.

Chapter 1
Introduction

LTE is a standard for high-speed wireless communication for mobile devices and data terminals, based on the GSM/EDGE and UMTS/HSPA technologies. It increases the capacity and speed using a different radio interface together with core network improvements. In Release 12, the third generation partnership project (3GPP) introduced D2D communications for public safety application. In Release 14, LTE-V was proposed as a means to realize V2X communications.

In Chapter 2, we look at the architecture and protocols involved in LTE systems. In Chapter 3, LTE Sidelink has been described. Chapter 4 discusses Intelligent Transportation Systems. Chapter 5 looks at V2X technologies and the various scenarios it entails. Chapter 6 details various kinds of fading and Chapter 7 looks at Jakes's model for frequency selective fading. The simulation model used to obtain the results is expanded upon in Chapter 8. The results are presented in Chapter 9.

Chapter 2

LTE Overview

In Telecommunication, Long-Term Evolution (LTE) is a standard for high-speed wireless communication for mobile devices and data terminals, based on the GSM/EDGE and UMTS/HSPA technologies. This standard is developed by the 3GPP (3rd Generation Partnership Project) and is specified in its Release 8 document series, with minor enhancements described in Release 9. Also LTE is the upgrade path for carriers with both GSM/UMTS networks and CDMA2000 networks.

2.1 LTE Network Architecture

The high-level network architecture of LTE technology is comprised of following three main components:

- The User Equipment (UE).
- The Evolved UMTS Terrestrial Radio Access Network (E-UTRAN).
- The Evolved Packet Core (EPC).

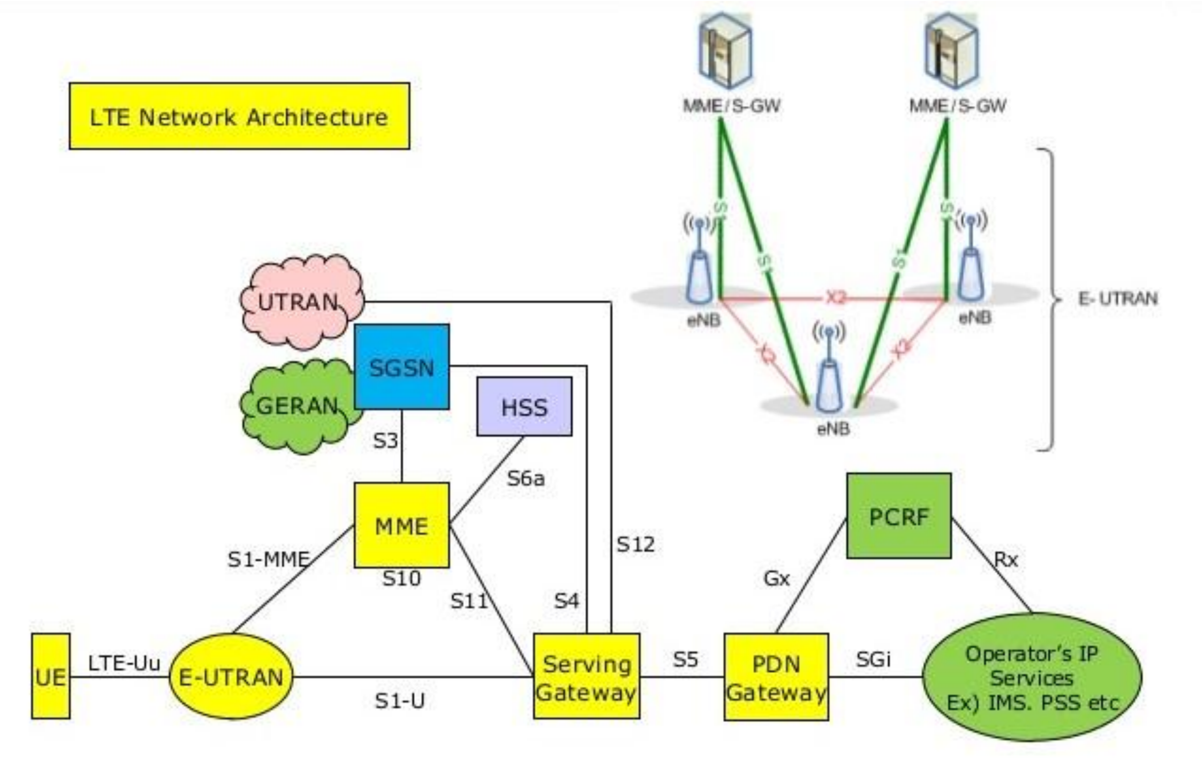


Figure 2:1: LTE Network Architecture

The User Equipment (UE) is any device used directly by an end-user to communicate. It can be a hand-held telephone, a laptop computer equipped with a mobile broadband adapter, or any other device.

The E-UTRAN handles the radio communications between the mobile and the evolved packet core and just has one component, the evolved base stations, called eNodeB or eNB. This includes only the base station called eNodeB. Therefore it is said to have a flat architecture. The flat architecture creates fewer nodes in network and causes lower latency. Each eNB is a base station that controls the mobiles in one or more cells and the base station that is communicating with a mobile is known as its serving eNB.

LTE Mobile communicates with just one base station and one cell at a time and there are following two main functions supported by eNB:

- The eNodeB sends and receives radio transmissions to all the mobiles using the analogue and digital signal processing functions of the LTE air interface.
- The eNB controls the low-level operation of all its mobiles, by sending them signaling messages such as handover commands.

Each eNB connects with the EPC by means of the S1 interface and it can also be connected to nearby base stations by the X2 interface, which is mainly used for signaling and packet forwarding during handover. A home eNB (HeNB) is a base station that has been purchased by a user to provide femtocell coverage within the home. A home eNB belongs to a closed subscriber group (CSG) and can only be accessed by mobiles with a USIM that also belongs to the closed subscriber group.

The functions of the components of the The Evolved Packet Core (EPC) (The core network) include:

- The Home Subscriber Server (HSS) component has been carried forward from UMTS and GSM and is a central database that contains information about all the network operator's subscribers.
- The Packet Data Network (PDN) Gateway (P-GW) communicates with the outside world i.e. Packet data networks PDN, using SGi interface. Each packet data network is identified by an access point name (APN). The PDN gateway has the same role as the GPRS support node (GGSN) and the serving GPRS support node (SGSN) with UMTS and GSM.

- The serving gateway (S-GW) acts as a router, and forwards data between the base station and the PDN gateway.
- The mobility management entity (MME) controls the high-level operation of the mobile by means of signaling messages and Home Subscriber Server (HSS).
- The Policy Control and Charging Rules Function (PCRF) is a component which is not shown in the above diagram but it is responsible for policy control decision-making, as well as for controlling the flow-based charging functionalities in the Policy Control Enforcement Function (PCEF), which resides in the P-GW.

2.2 LTE Protocol Stack

At user plane side, the application creates data packets that are processed by protocols such as TCP, UDP and IP, while in the control plane, the radio resource control (RRC) protocol writes the signaling messages that are exchanged between the base station and the mobile. In both cases, the information is processed by the packet data convergence protocol (PDCP), the radio link control (RLC) protocol and the medium access control (MAC) protocol, before being passed to the physical layer for transmission.

The User Plane protocol stack between the e-Node B and UE consists of the following sub-layers:

- PDCP (Packet Data Convergence Protocol)
- RLC (radio Link Control)
- Medium Access Control (MAC)

On the user plane, packets in the core network (EPC) are encapsulated in a specific EPC protocol and tunneled between the P-GW and the eNodeB. Different tunneling protocols are used depending on the interface. GPRS Tunneling Protocol (GTP) is used on the S1 interface between the eNodeB and S-GW and on the S5/S8 interface between the S-GW and P-GW.

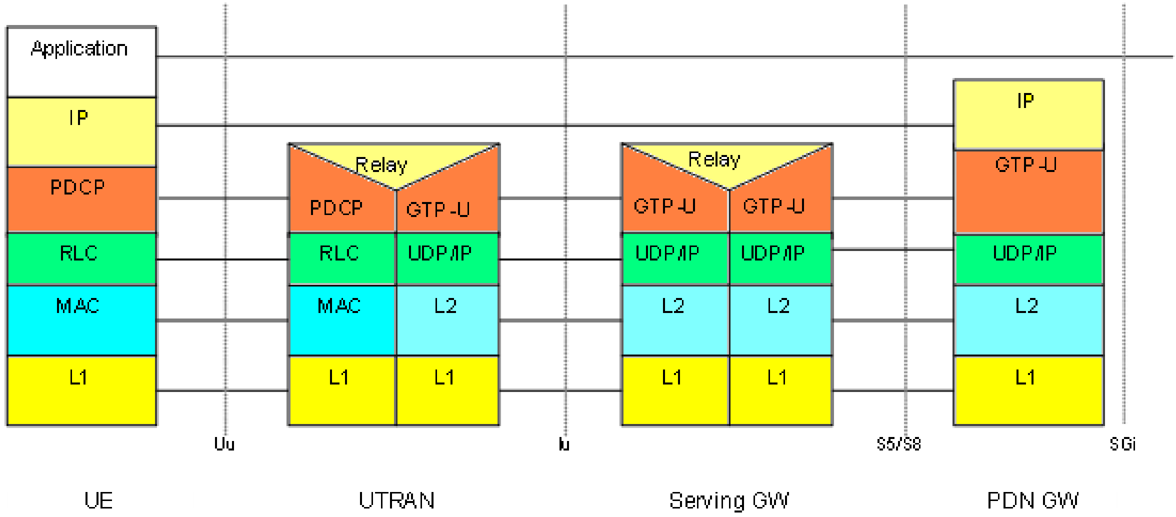


Figure 2:2: LTE User Plane

Packets received by a layer are called Service Data Unit (SDU) while the packet output of a layer is referred to by Protocol Data Unit (PDU) and IP packets at user plane flow from top to bottom layers.

The Control Plane includes additionally the Radio Resource Control layer (RRC) which is responsible for configuring the lower layers. The Control Plane handles radio-specific functionality which depends on the state of the user equipment which includes two states: Idle or Connected.

Idle Mode – The user equipment camps on a cell after a cell selection or reselection process where factors like radio link quality, cell status and radio access technology are considered. The UE also monitors a paging channel to detect incoming calls and acquire system information. In this mode, control plane protocols include cell selection and reselection procedures.

Connected - The UE supplies the E-UTRAN with downlink channel quality and neighbor cell information to enable the E-UTRAN to select the most suitable cell for the UE. In this case, control plane protocol includes the Radio Link Control (RRC) protocol.

The protocol stack for the control plane between the UE and MME is shown below. The grey region of the stack indicates the access stratum (AS) protocols. The lower layers perform the same functions as for the user plane with the exception that there is no header compression function for the control plane.

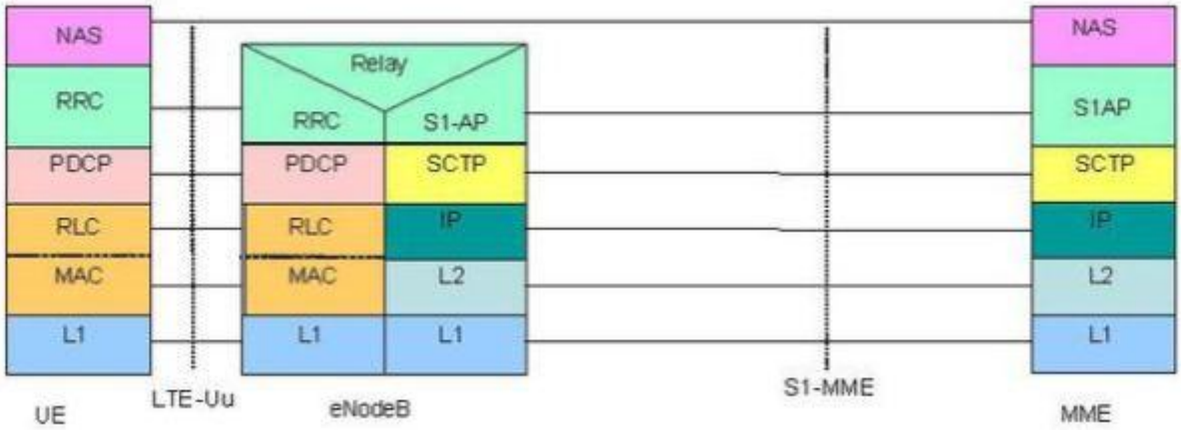


Figure 2:3: LTE Control Plane

2.3 LTE Resource Blocks

Resources are allocated to the UEs in terms of Resource Blocks (RB). In time, the length of a RB is 1 slot. In frequency, the length of a RB is 12 subcarriers or 180 kHz. A resource block (RB) is the smallest unit of resources that can be allocated to a user. Using sub-carriers in the frequency axis and symbols in the time axis, a time-frequency resource grid is considered. Each element in the time-frequency resource grid is called a resource element.

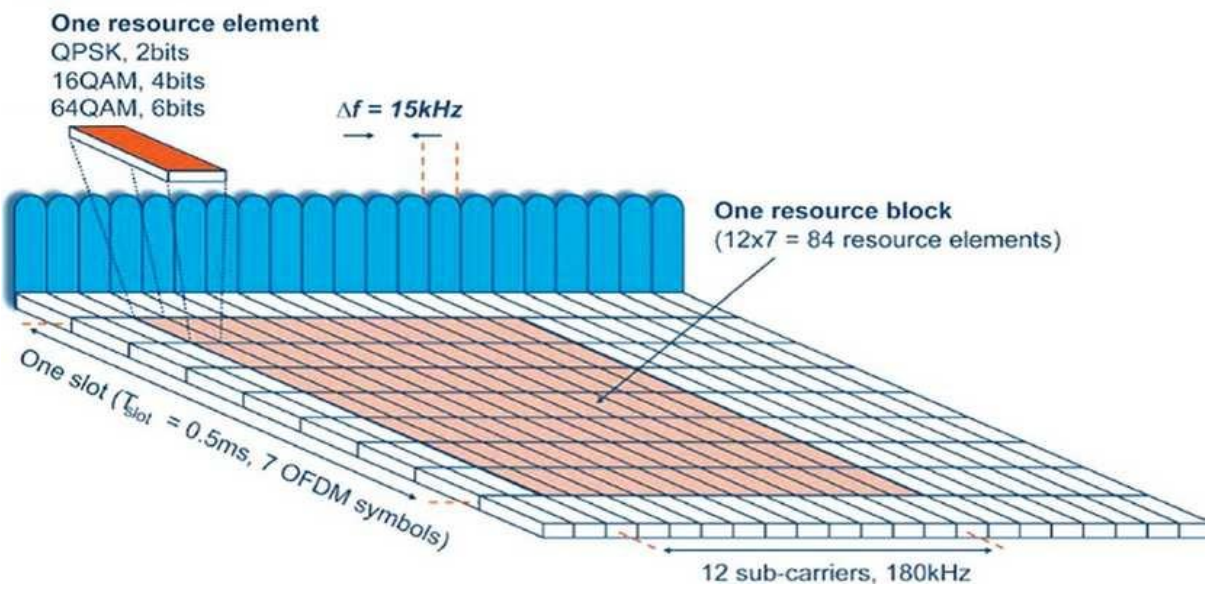


Figure 2:4: LTE Resource Blocks

The building block of LTE is a physical resource block (PRB) and all of the allocation of LTE physical resource blocks (PRBs) is handled by a scheduling function at the 3GPP base station (eNodeB).

In LTE Frame Structure, one frame is 10ms and it consists of ten sub-frames. One LTE subframe is 1ms and contains two slots. One slot is 0.5ms in time domain and each 0.5ms assignment can contain N resource blocks [6 < N < 110] depending on the bandwidth allocation and resource availability. One resource block is 0.5ms and contains 12 subcarriers for each OFDM symbol in frequency domain. There are 7 symbols (normal cyclic prefix) per time slot in the time domain or 6 symbols in long cyclic prefix for LTE. This equates to 84 resource elements with normal cyclic prefix and 72 with extended cyclic prefix.

TTI, Transmission Time Interval, is a parameter in UMTS related to the summary of data from higher layers into frames for transmission on the radio link layer. TTI refers to the duration of a transmission on the radio link. The TTI is related to the size of the data blocks passed from the higher network layers to the radio link layer.

The length of time required to transmit one block determines the TTI. In networks with link adaptation techniques based on the estimated BER the shortest interval between reports of the estimated performance, which are used to adapt to the conditions on the link, is at least one TTI. In order to be able to adapt quickly to the changing conditions in the radio link a communications system must have shorter TTIs. In order to benefit more from the effect of interleaving and to increase the efficiency of error-correction and compression techniques a system must, in general, have longer TTIs. These two contradicting requirements determine the choice of the TTI.

In UMTS Release '99 the shortest TTI is 10 ms and can be 20 ms, 40 ms, or 80 ms. In UMTS Release-5 the TTI for HSDPA is reduced to 2ms. This provides the advantage of faster response to link conditions and allows the system to quickly schedule transmissions to mobiles which temporarily enjoy better than usual link conditions.

2.4 LTE Channels

There are three categories into which the LTE Channels may be grouped.

- Physical Channels: These are transmission channels that carry user data and control messages.
- Transport channels: The physical layer transport channels offer information transfer to Medium Access Control (MAC) and higher layers.
- Logical channels: Provide services for the Medium Access Control (MAC) layer within the LTE protocol structure.

The LTE Physical Channels vary between the uplink and the downlink as each has different requirements and operates in a different manner. The LTE Transport Channels vary between the uplink and the downlink as each has different requirements and operates in a different manner. Physical layer transport channels offer information transfer to medium access control (MAC) and higher layers. The LTE Logical Channels cover the data carried over the radio interface. The Service Access Point, SAP between MAC sublayer and the RLC sublayer provides the logical channel.

2.4.1 LTE Physical Channels in Downlink

- Physical Broadcast Channel (PBCH): This physical channel carries system information for UEs requiring to access the network. It only carries what is termed Master Information Block, MIB, messages. The modulation scheme is always QPSK and the information bits are coded and rate matched - the bits are then scrambled using a scrambling sequence specific to the cell to prevent confusion with data from other cells. The MIB message on the PBCH is mapped onto the central 72 subcarriers or six central resource blocks regardless of the overall system bandwidth. A PBCH message is repeated every 40 ms, i.e. one TTI of PBCH includes four radio frames. The PBCH transmissions has 14 information bits, 10 spare bits, and 16 CRC bits.
- Physical Control Format Indicator Channel (PCFICH): As the name implies the PCFICH informs the UE about the format of the signal being received. It indicates the number of OFDM symbols used for the PDCCHs, whether 1, 2, or 3. The information within the PCFICH is essential because the UE does not have prior

information about the size of the control region. A PCFICH is transmitted on the first symbol of every sub-frame and carries a Control Format Indicator, CFI. The CFI contains a 32 bit code word that represents 1, 2, or 3. CFI 4 is reserved for possible future use. The PCFICH uses 32, two block coding which results in a 1/16 coding rate, and it always uses QPSK modulation to ensure robust reception.

- Physical Downlink Control Channel (PDCCH) : The main purpose of this physical channel is to carry mainly scheduling information of different types:
    - Downlink resource scheduling
    - Uplink power control instructions
    - Uplink resource grant
    - Indication for paging or system information
- Physical Hybrid ARQ Indicator Channel (PHICH): As the name implies, this channel is used to report the Hybrid ARQ status. It carries the HARQ ACK/NACK signal indicating whether a transport block has been correctly received. The HARQ indicator is 1 bit long - "0" indicates ACK, and "1" indicates NACK. The PHICH is transmitted within the control region of the subframe and is typically only transmitted within the first symbol. If the radio link is poor, then the PHICH is extended to a number symbols for robustness.

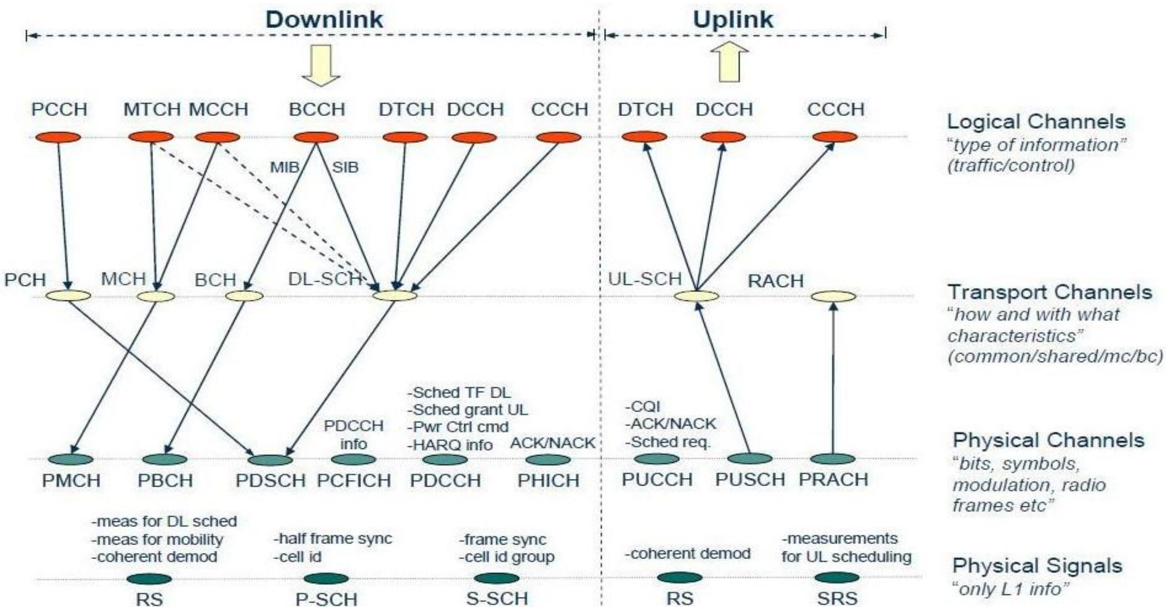


Figure 2:5: Uplink and Downlink Channels in LTE

2.4.2 LTE Physical Channels in Uplink

- Physical Uplink Control Channel (PUCCH): The Physical Uplink Control Channel, PUCCH provides the various control signaling requirements. There are a number of different PUCCH formats defined to enable the channel to carry the required information in the most efficient format for the particular scenario encountered. It includes the ability to carry SRs, Scheduling Requests.
- Physical Uplink Shared Channel (PUSCH) : This physical channel found on the LTE uplink is the Uplink counterpart of PDSCH
- Physical Random Access Channel (PRACH): This uplink physical channel is used for random access functions. This is the only non-synchronized transmission that the UE can make within LTE. The downlink and uplink propagation delays are unknown when PRACH is used and therefore it cannot be synchronised.The PRACH instance is made up from two sequences: a cyclic prefix and a guard period. The preamble sequence may be repeated to enable the eNodeB to decode the preamble when link conditions are poor.

2.4.3 LTE Transport Channels in Downlink

- Broadcast Channel (BCH): The LTE transport channel maps to Broadcast Control Channel (BCCH).
- Downlink Shared Channel (DL-SCH): This transport channel is the main channel for downlink data transfer. It is used by many logical channels.
- Paging Channel (PCH): To convey the PCCH.
- Multicast Channel (MCH): This transport channel is used to transmit MCCH information to set up multicast transmissions.

2.4.4 LTE Transport Channels in Uplink

- Uplink Shared Channel (UL-SCH): This transport channel is the main channel for uplink data transfer. It is used by many logical channels.
- Random Access Channel (RACH): This is used for random access requirements.

2.4.5 LTE Logical Control Channels

These LTE control channels carry the control plane information:

- Broadcast Control Channel (BCCH): This control channel provides system information to all mobile terminals connected to the eNodeB.
- Paging Control Channel (PCCH): This control channel is used for paging information when searching a unit on a network.
- Common Control Channel (CCCH): This channel is used for random access information, e.g. for actions including setting up a connection.
- Multicast Control Channel (MCCH): This control channel is used for Information needed for multicast reception.
- Dedicated Control Channel (DCCH): This control channel is used for carrying user-specific control information, e.g. for controlling actions including power control, handover, etc.

2.4.6 LTE Traffic Channels

These LTE traffic channels carry the user-plane data:

- Dedicated Traffic Channel (DTCH): This traffic channel is used for the transmission of user data.
- Multicast Traffic Channel (MTCH): This channel is used for the transmission of multicast data.

2.4.7 MCS Selection for Downlink Data Transfer

- The UE sends Channel Quality Indicator (CQI) as an indication of the data rate which can be supported by the downlink channel. The UE determines CQI to be reported based on measurements of the downlink reference signals. CQI is a 4 bit information with 15 CQI values. The UE selects a CQI based on the estimation that the Modulation and Coding Scheme (MCS) corresponding to the CQI value is the highest possible MCS that will allow the UE to decode transport blocks with error rate probability not exceeding 10%.
- The eNodeB selects one of the 27 MCS levels based on one of 15 CQI values.
- The reported CQI is not actually a direct indication of the downlink channel quality. A UE with receiver of better quality can report better CQI for the same downlink channel quality and can receive downlink data with higher MCS. Thus, the CQI report indicates the downlink channel quality but taking the capabilities of the UE's receiver into account.

2.4.8 MCS SelectionS for Uplink Data Transfer

The eNodeB can estimate uplink channel quality based on Reference Signals (SRS) and also, based on the error rate in the current uplink data transfer. In LTE levels are assigned between 1-27 depending on the channel quality. [1]

Chapter 3

LTE Sidelink

3GPP Release 12 saw the introduction of device-to-device (D2D) or proximity services (ProSe) communications.

3.1 Scenarios

3GPP Release 12 saw the introduction of device-to-device (D2D) or proximity services (ProSe) communications. Their application was limited to public safety usage. ProSe communication has to work in regions where network coverage cannot be guaranteed and as such, ProSE is specified for the following scenarios:

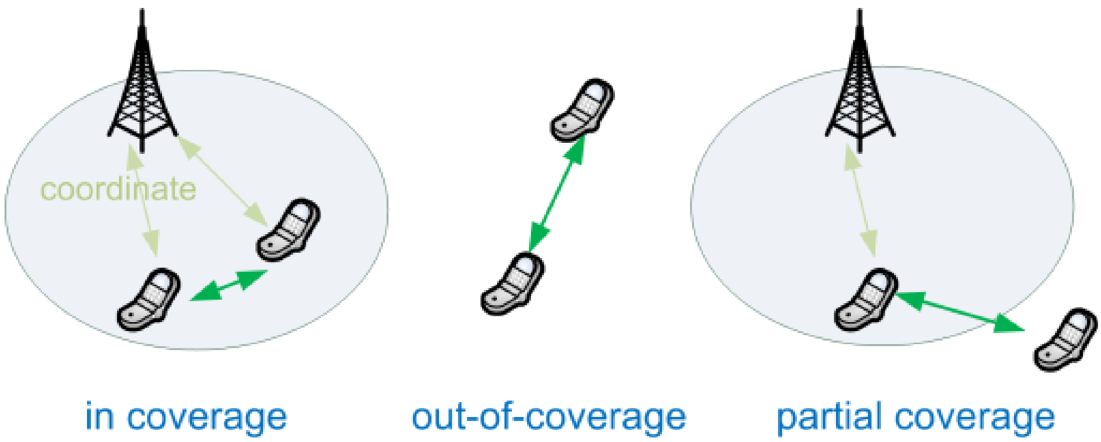


Figure 3:1: Coverage Scenarios for D2D Sidelink

For the in coverage scenario, the resources used for ProSe communication are controlled by the network. The transmitting UE may have specific resources assigned to it, or it may have a pool of resources to choose from. Interference with cellular traffic is avoided this way.

This kind of control is not possible for the out-of-coverage scenario. The UE uses resources which have been preconfigured, either in the mobile device or in the USIM of the UICC card. The term out-of-coverage does not necessarily mean there is no connection at all. It only means that there is no coverage on the frequency for ProSe direct communication – there may be coverage on a different carrier for cellular traffic.

The partial coverage scenario is a special case. The UE out of coverage uses the preconfigured resources while the UE in coverage gets its resources assigned by the eNB. Careful coordination between the network and the preconfigured values is required to limit interferences to UEs at the cell boundary.

3.2 Network Architecture

For ProSe communication, several new interfaces have been introduced. The PC5 interface between two UEs and the PC3 interface to a new defined node, the ProSe Function are most pertinent to the UE.

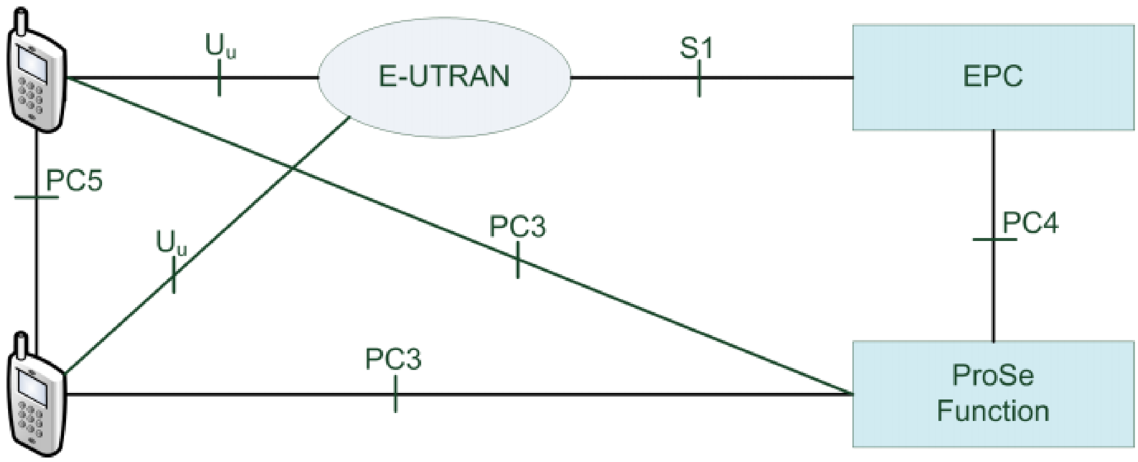


Figure 3:2: Network Architecture of LTE Sidelink

In release 12, the PC5 is specified as a one-to-many interface for group communication. From the perspective of higher layers, this is reflected in the assignment of destination IDs, which are always group IDs.

Using the PC3 interface, the UE contacts the ProSe Function. There is only one ProSe Function specified in each PLMN in release 12. The IP address of the ProSe Function may or may not be preconfigured in the device. If it is not, the device identifies the IP address of the ProSe Function by DNS look-up. To contact the ProSe Function, the device has to establish a connection with the network and be in RRC_CONNECTED state. For the information exchange between the UE and the ProSe Function, IP messages are used with its related syntax.

The UE receives information for network related actions from the ProSe Function. This includes the authorization and provisioning of PLMN specific information.

The UE is not required to be registered in the PLMN in which it wants to do ProSe communication even though the authorization is always done a per PLMN basis. The UE contacts the ProSe Function in its HPLMN, which in turn requests authorization information from the ProSe Function in the local PLMN. The authorization also comprises the information, whether and where the UE is allowed to perform ProSe communication when it is out-of-coverage.

In the PLMN specific information provisioning, the following parameters sent to the UE by the ProSe Function are as follows:

- Security parameters
- Group IDs
- Group IP multicast addresses, including the indication whether the UE shall use IPv4 or IPv6 for the group
- Radio resource parameters for usage in out-of-coverage scenarios

3.3 D2D Protocol Stack

ProSe communication is connectionless in the air interface. There is no equivalent to the RRC connection. Messages are created on the application level of the UE and are transmitted on the next opportunity. Connections are made within the application if required. The following protocol stack is used for transmitting and receiving the associated data packets:

UE A		UE B
Application	↔	Application
IP, ARP	↔	IP, ARP
PDCP	↔	PDCP
RLC	↔	RLC
MAC	↔	MAC
PHY	↔	PHY
	PC5-U	

Figure 3:3: D2D Protocol Stack

One PCDP/RLC pair has to be kept by the receiving UE for each transmitting UE and each established logical channel. These are not configured in advance by the UE. This is done on reception of the first RLC PDU. As a consequence of there being no procedure to delete it since ProSe communication is connectionless, the UE implementation decides on the duration to keep an RLC/PDCP pair after the reception of a message.

The PDCP utilizes Unidirectional Mode (UM) for header compression. The RLC is operated in the UM. HARQ process, restricted to blind retransmissions, are supported by MAC.

The following identities are provided in each message to identify the transmitting UE and the group for which the data packet is intended:

- ProSe UE ID
- ProSe Layer-2 Group ID

These IDs may be preconfigured in the UE or may be provided by the network.

3.4 Sidelink Transmission

In conventional cellular traffic over U_u, the eNB communicates over DL and UL channels with the UE for signaling and data. In ProSe, this concept is extended with the introduction of the sidelink:

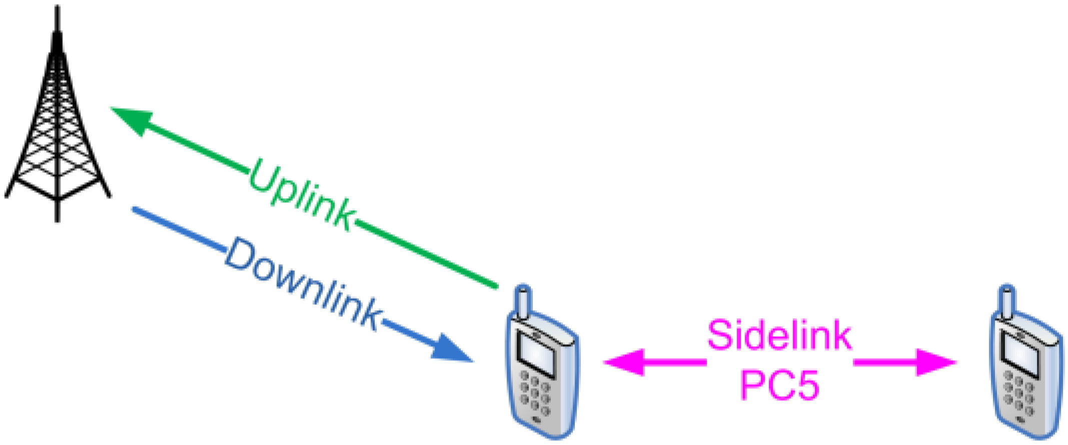


Figure 3:4: Visualization of the Sidelink

The SL corresponds to the PC5 interface. Resources assigned to the SL are taken from the subframes on the UL frequency in FDD or from the subframes assigned to UL in TDD. This is so for two reasons. First, the UL subframes are not occupied as often as the DL subframes. Second, the majority of DL subframes are never empty. There are always cell specific reference signals (CRS) being transmitted using the DL subframes

.

There is a distinction to be made between ProSe and sidelinks. ProSe describes the end to end application, whereas sidelink refers to the channel structure.

3.5 Sidelink Channels

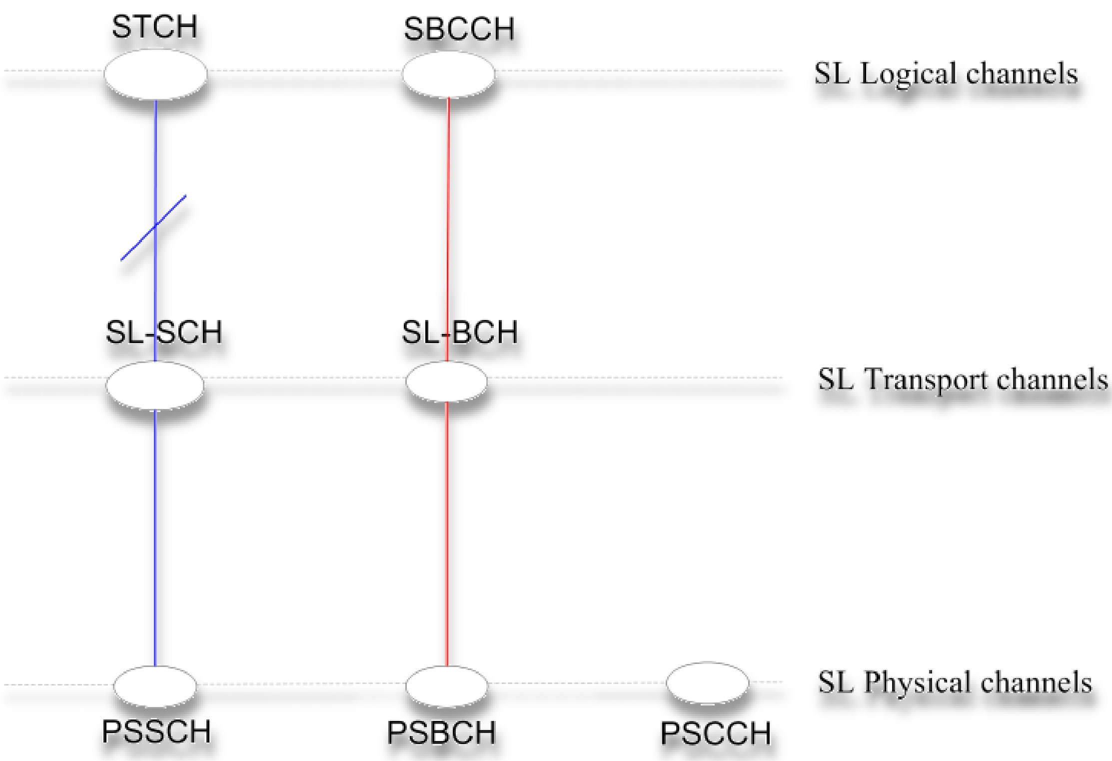


Figure 3:5: Sidelink Channels for the Air Interface

There are two SL logical channels defined for communication, the SL Traffic Channel (STCH) and the SL Broadcast Control Channel (SBCCH).

The STCH is used for the transmission of data carrying the user information from the ProSe application. The group call property of ProSe communication is reflected in the point-to-multipoint nature of the STCH. It is connected with the SL Shared Channel (SL-SCH), a transport channel. Depending on the resource assignment from the eNB, there may be a collision risk. It interfaces to the Physical SL Shared Channel (PSSCH), which transports the data over the air.

The SBCCH carries signaling information used for synchronization in the out-of-coverage or partial coverage scenarios, or for synchronization between UEs located in different cells. It is connected with the SL Broadcast Channel (SL-BCH), a transport channel with a predefined transport format, which is possible because the blocks from the SBCCH are all of the same size. The SL-BCH interfaces with the Physical SL Broadcast Channel (PBSCH).

The Physical SL Control Channel (PSCCH) is equivalent to PDCCH in cellular traffic over Uu. The PSCCH contains the Sidelink Control Information (SCI), which carries the information required by the receiving UE in order to receive and demodulate the PSSCH. The SCI is always sent in advance to an STCH data block because of this.

3.6 Resource Pool

The figure shows the resources for SL communication. Whether a subframe is available for the sidelink is indicated in a subframe bitmap. After a configurable period, the SL control period (SC Period), the whole pattern repeats.

Within such a subframe, the resources used for SL are in two bands, identified by the occupied Physical Resource Blocks (PRBs). One band is starting at PRB-Start, one is ending and PRB-End, each one having a width of PRB-Num resource blocks. This construction allows nesting several resource pools within one subframe, and using the remaining resource blocks for other UEs for cellular traffic. Each UE uses a subframe in a given carrier for either cellular traffic or for sidelink, but not for both.

According to the PSCCH / PSSCH structure of SL communication, the set of subframes, i.e. the subframe bitmap, is split into two regions, the control region and the data region.

The first SC Period starts at an offset from SFN=0 and is periodically repeated with a configurable length between 40ms and 320 ms. It starts with the control region which contains the SCI0 control element carried by the PSCCH. SubframeBitmapSL indicates the subframes used for the PSCCH. Directly after the last bit of the SubframeBitmapSL which is set to 1, the data region starts. It consists of another bitmap, the T-RPT bitmap, which is a bitmap indicating the subframes which are used for the data transmission. This bitmap is repeated until the end of the SC Period, where the last occurrence may be truncated.

The T-RPT bitmap is dynamic and may therefore be different for each UE and for each SC Period. To be more precise, the set of all subframes which are allocated for the resource pool is restricted by using a periodic pattern with a periodicity of 8 for FDD, and a shorter one for some TDD configurations. Necessary parameters to determine this bitmap in order to receive the data part is signaled via the PSCCH.

For Mode 2 this structure is quite similar. The main difference is that start of the data part does not depend on the content of the SubframeBitmapSL, but has a fixed offset from the start of the SC Period. In addition, the algorithm to determine the bitmap pattern is somewhat different and may explicitely exclude some configurations.

Chapter 4

Intelligent Transportation System

The intelligent transportation system (ITS) was the result of workshop in Dallas, Texas where participants came up with brilliant ideas about the improvement of transportation efficiency with the help of modern technology. This process will involve the advancement of computation, sensors, information theory [2]. Concepts presented were widely accepted and they got fund to implement their ideas in real life.

The conceptual idea of inter-vehicular communication was already existing since the starting of ITS. There was project called “Automated highway system program” to build a fully operational test track with intelligent vehicles those could be controlled by a central monitoring system in 1997.

Shortly after the foundation of ITS, main concern was to minimize the no of accident and to introduce crash avoidance system. This gives rise to the further development of further vehicle-infrastructure interaction. In the 10th world congress of ITS, 75 MHz was reserved for dedicated short range communications (DSRC).

The aim of ITS is to provide safer, comfortable, and more enjoyable use of vehicles and infrastructure beside the road by inter-connecting all the vehicles and road side unit. The concept of ITS is to collect all the relevant data from the surrounding using sensors, process them by using on board processors and exchange processed data with other nearby vehicles. From using the collected data, each of vehicles on the road will have a fair idea about traffic pattern and condition of the road ahead. This exchange of messages can be extremely useful in cases of unexpected condition on the road, by warning all the vehicles in the surrounding area about an upcoming clash and thus avoiding unpleasant clashes or accidents. Implementing the idea of ITS has become easier with the improvements in other relevant fields like microelectronics, telecommunication, VLSI, computer science etc. [3]

4.1 Standardization of ITS and current scenario

As ITS is a very emerging field, different companies, institutes and organizations are working together for development of standard of it for the past years. Most of standards have basic similarities in physical and media access control layers but they differ in the upper layers and protocol stack. Research on ITS first started in Europe but now it is running all over the world because of its huge popularity and positive response. Researches so far have resulted in many renowned projects like Coopers, CVIS and DSRC (IEEE 1609.x). Different organizations are working together for a standard transportation system that can be implemented all over the world by sharing their knowledge and ideas.

4.2 Communication Patterns

There are two communication patterns in ITS. It depends on the needs and circumstances. The first communication pattern can be defined by each vehicle transmitting a short message called Cooperative Awareness massage (CAM) and contains information regarding position and velocity of the car. These messages are transmitted in regular interval with a high rate of transmission. It is the very basic form of ITS messages.

The second form of message is defined by the transmission of additional messages, which are called Event Triggered messages, which aim at warning the other vehicles about condition of the road to avoid any kind of unexpected accident. These messages are not transmitted in a regular interval like the CAM messages. Transmission of these messages is triggered by certain incident on the road. Event triggered messages constitutes a small portion in the overall messages. Though these messages are not transmitted at a regular interval, it is more vital than the CAM messages. It gets priority over the CAM messages. Delay reception of these messages will be nothing but irony for the driver in the receiving side. [4]

Event triggered messages can also be called DENM (De-centralized Environmental Notification Message). In the case of uploading any data, unicast is perfect solution. But is the case of downloading, both unicast and broadcast mode are used. In uplink case, the problem is to select appropriate channel without creating any congestion. In downlink case, broadcast mode is more efficient than unicast mode, although it could incorporate longer delay due to extra set up time. We can also transmit to or receive from the concerned vehicles only.

4.2.1 CAM

The main challenge in supporting CAMs is to overcome the system overload due to huge amount messages broadcasted by large number of vehicles. Situation worsens in the densely populated area during the peak hours. It will be very difficult handle such a situation when eNodeB unicasts CAMs to every vehicles in the neighboring cell. So we need to go through a filtering process as all the vehicles in the cell does not need all messages that can be broadcasted in the unicast mode. We can also use Multimedia Broadcast Multicast Services (MBMS) to improve the downlink capacity. [5]

4.2.2 DENMs

Message frequency of event triggered messages are much lower than the CAMs. So it generates a lower traffic load compared to CAMs. Cell capacity is temporarily and partially used by DENMs. It is generated in the critical situation for shorter period of time and it is generated by a significantly lower number of vehicles compared to CAMs. The main challenge is to overcome the situation where most of vehicles in the same cell simultaneously trying to broadcast the same warning message due to the same hazardous situation. So we can also apply filtering process here according the location, time, heading fields of broadcasted message. By doing this, system scalability and reliability can be improved, valuable system resource can be saved, and uplink congestion can be avoided. [5]

Table 4:1 Summary of CAM and DENM Messages

Cooperative awareness message (CAM)	Periodic time-triggered position messages: –Frequency: 1–10 Hz –Max latency: 100 ms –Length: up to 800 bytes (security overhead included) depending on the type of application	Use cases: –Emergency vehicle warning –Slow vehicle indication –Intersection collision warning –Motorcycle approaching indication –Collision risk warning –Speed limits notification –Traffic light optimal speed advisory
Decentralized environmental notification message (DENM)	Event-driven hazard warnings: –Max latency: 100 ms –Length: typically shorter than CAMs	Use cases: –Emergency electronic brake light –Wrong way driving warning –Stationary vehicle accident –Stationary vehicle –Traffic condition warning

[5]

4.3 ITS Classes and Applications

The possible applications of ITS are increasing day by day and each of the application needs a different sets of requirement. These ITS applications can be divided roughly in three categories according type of applications. The most important requirement is the delay requirement which is vital in the case of event triggered messages. There are three main classes: co-operative (active) road safety, co-operative traffic efficiency, co-operative local services and global internet services

4.3.1 Co-operative (Active) Road Safety

The primary of target of this class is the improvement of road safety. In this class, frequency of the generated message is as high as 20 Hz and the latency requirements are 50-100 ms. some applications of this class are collision avoidance, pre-crash sensing, emergency brake lights etc.

4.3.2 Co-operative Traffic Efficiency

The primary objective of this class is to improve the traffic flow. Improvement of traffic flow will lead to overall improvement of traffic management system. In this class, frequency of the generated message is as high as 1-5 Hz and the latency requirements are 100-500 ms. some applications of this class are optimal use traffic light, traffic information and recommended itinerary etc.

4.3.3 Co-operative local services and global internet services

Application of this class is to provide information according to the necessity of the nearby passing vehicles. This service can be done on commercial or non-commercial basis. The main component of this class are infotainment, comfort and other vehicle related services. Latency requirement of this class is not that much tight and it is normally above 500 ms. some examples of this class are: E-commerce, media content sharing, Google maps, advertisement etc.

In real life, latency requirement and message frequency may vary according to the necessity of that specific application. We have to do some real time evaluation of the requirement of that application.

Chapter 5

V2X

V2X means vehicle to everything. It enables exchange of information between Vehicle to Vehicle (V2V), Vehicle to Infrastructure (V2I), Vehicle to Pedestrian (V2P), and Vehicle to Network (V2N). These information allow a vehicle to be better aware of its surroundings and traffic ahead of it. Efforts have been made during recent years to develop V2X communication using IEEE 802.11p. But 802.11p uses an access scheme called Carrier Sensed Multiple Access with Collision Avoidance Medium and it suffers for guarantying some strict reliability levels that is mandatory for V2X operation. It also faces challenges in network scalability as the load increases [5]. As an alternative, the Third Generation Partnership Project (3GPP) published the first version of Release 14 in September 2016, which includes support for V2X communications [6]. The standard is commonly referred to as LTE-V, LTE-V2X, or cellular V2X. The LTE-V physical layer improves the link budget with regard to 802.11p [7]. In addition, LTE-V can increase the reliability, under certain conditions, by adding a redundant transmission per packet.

The LTE-V standard includes two radio interfaces. The cellular interface (named Uu) supports vehicle-to infrastructure communications, while the PC5 interface supports V2V communications based on direct LTE sidelink. LTE sidelink (or device-to-device communication) was introduced for the first time under Release 12 for public safety, and includes two modes of operation: mode 1 and mode 2. Both modes were designed with the objective of prolonging the battery lifetime of mobile devices at the cost of increasing the latency. Connected vehicles require highly reliable and low-latent V2X communications; therefore, modes 1 and 2 are not suitable for vehicular applications.

Release 14 introduces two new communication modes (modes 3 and 4) specifically designed for V2V communications. In mode 3, the cellular network selects and manages the radio resources used by vehicles for their direct V2V communications. In mode 4, vehicles autonomously select the radio resources for their direct V2V communications. In contrast, mode 4 can operate without cellular coverage, and is therefore considered the baseline V2V mode since safety applications cannot depend on the availability of cellular coverage. Mode 4 includes a distributed scheduling scheme for vehicles to select their radio resources and includes the support for distributed congestion control.

Table 5:1 Comparison Between Different Candidates for V2X

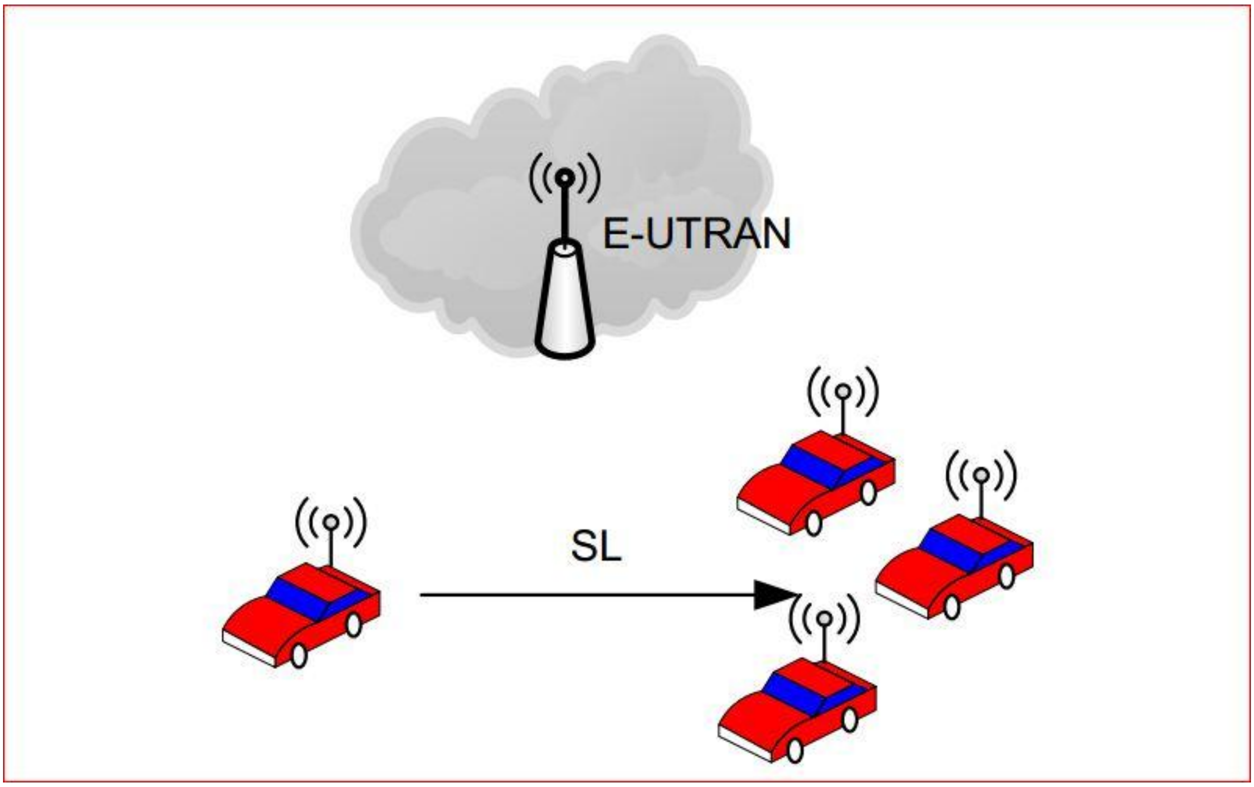
Feature	Wi-Fi	802.11p	UMTS	LTE	LTE-A
Channel width	20 MHz	10 MHz	5 MHz	1.4,3,5,10,15,20 MHz	Up to 100 MHz
Frequency band(s)	2.4 GHz,5.2 GHz	5.86–5.92 GHz	700–2600 MH	700-2690 MHz	450 MHz-4.99 GHz
Bit rate	6-54 Mb/s	3–27 Mb/s	2 Mb/s	Up to 300 Mb/s	Up to 1 Gb/s
Range	Up to 100m	Up to 1 km	Up to 10 km	Up to 30 km	Up to 30 km
Capacity	Medium	Medium	Low	High	Very high
Coverage	Intermittent	Intermittent	Ubiquitous	Ubiquitous	Ubiquitous
Mobility support	Low	Medium	High	Very high(up to 350 Km/h)	Very high(up to 350 km/h)
Quality of Service(QoS) support	Enhanced Distributed Channel Access (EDCA)	Enhanced Distributed Channel Access (EDCA)	QoS classes and bearer selection	QCI and bearer selection	QoS class identifier (QCI) and bearer selection
Broadcast/Multicast support	Native broadcast	Through MBMS	Through eMBMs	Through eMBMS	Through eMBMS
V2I support	Yes	Yes	Yes	Yes	Yes
V2V support	Native(ad hoc)	No	No	No	Potentially, through D2D
Market penetration	High	Low	High	Potentially high	Potentially high

[5]

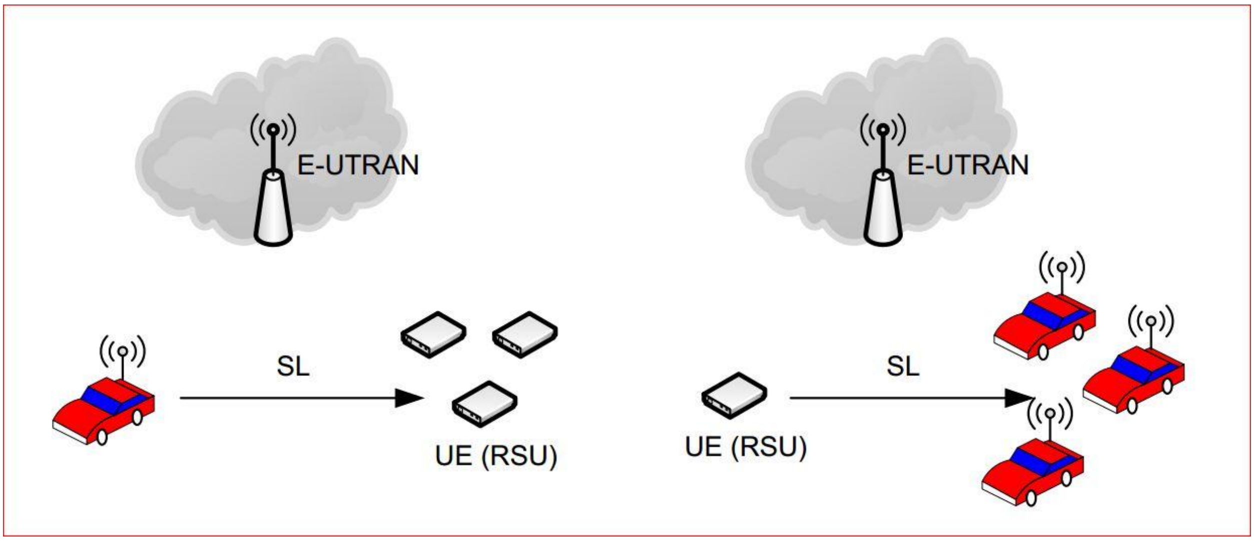
5.1 Scenario 1

Here V2X communication will be established based on PC5. In this case a User transmits a V2X over sidelink channels to surrounding UEs.

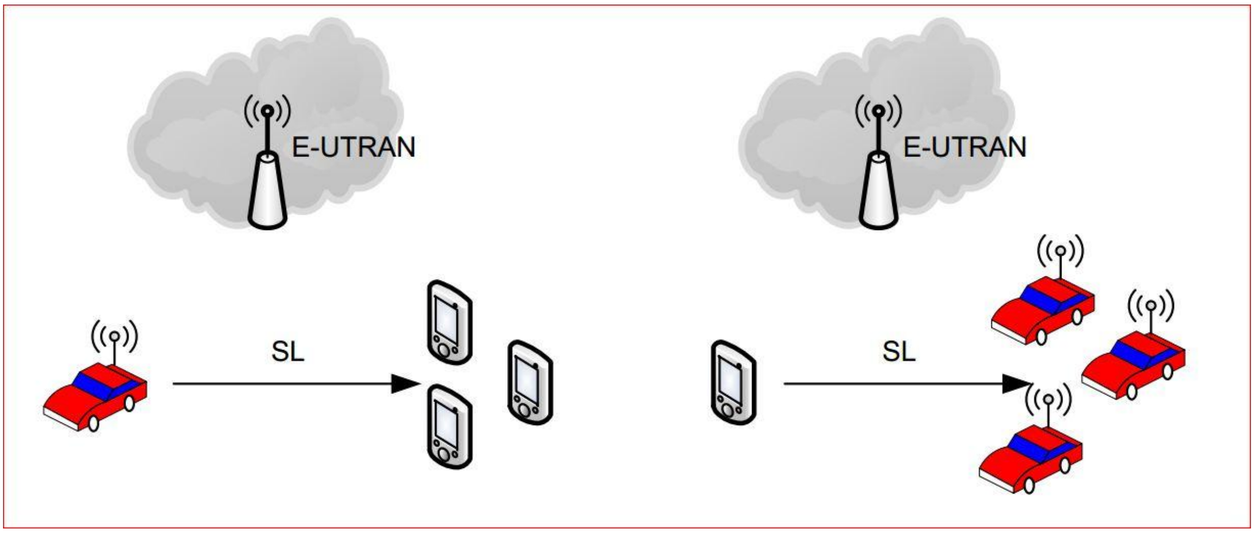
For V2I, either transmitter UE or receiver UE(s) are UE-type RSU. For V2P, either transmitter UE or receiver UE(s) are pedestrian UE.



(a) V2V Operation



(b) V2I operation



(c)V2P operation

Figure 5:1: Scenario 1

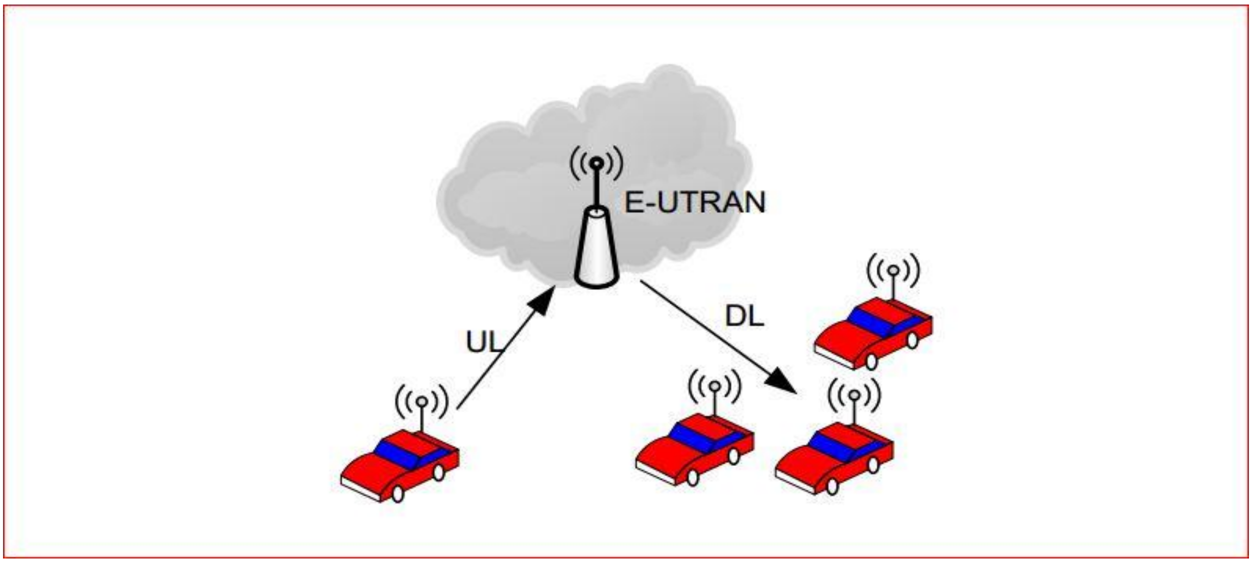
5.2 Scenario 2

In this scenario V2x operation is based on only Uu.
Here for V2V and V2P,a UE transmits it's V2x messages to E-UTRAN in uplink channel and E-UTRAN transmits these to multiple UE's at local area in downlink.

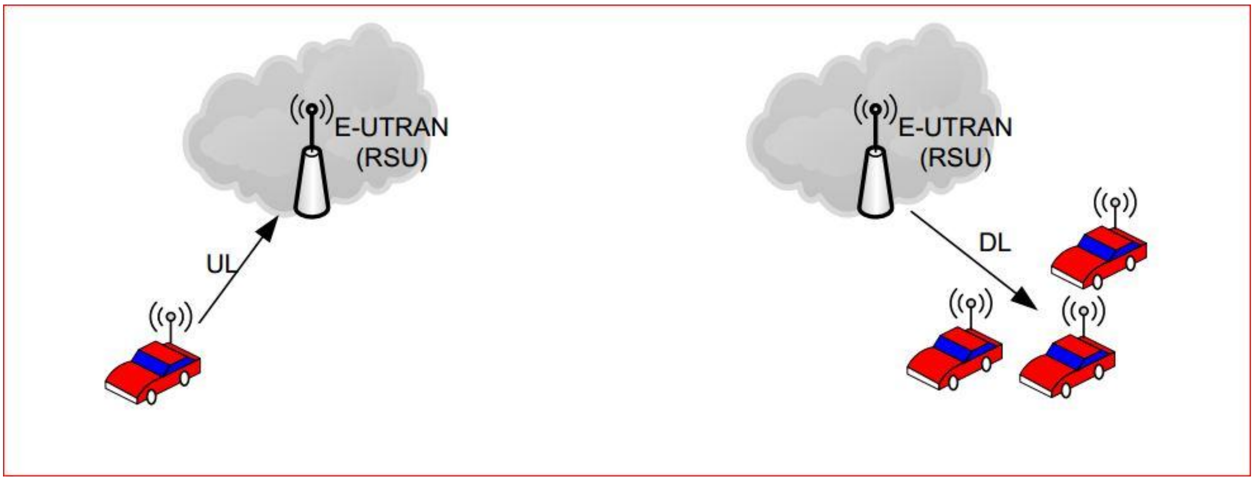
For V2I, when receiver is eNB type RSU, a UE transmits a V2I message to that RSU in uplink; when transmitter is eNB type RSU, RSU transmits a I2V message to multiple UEs at a local area in downlink.

For V2P, either transmitter UE or receiver UE(s) are pedestrian UE.
For V2N, the UE communicates with an application server.

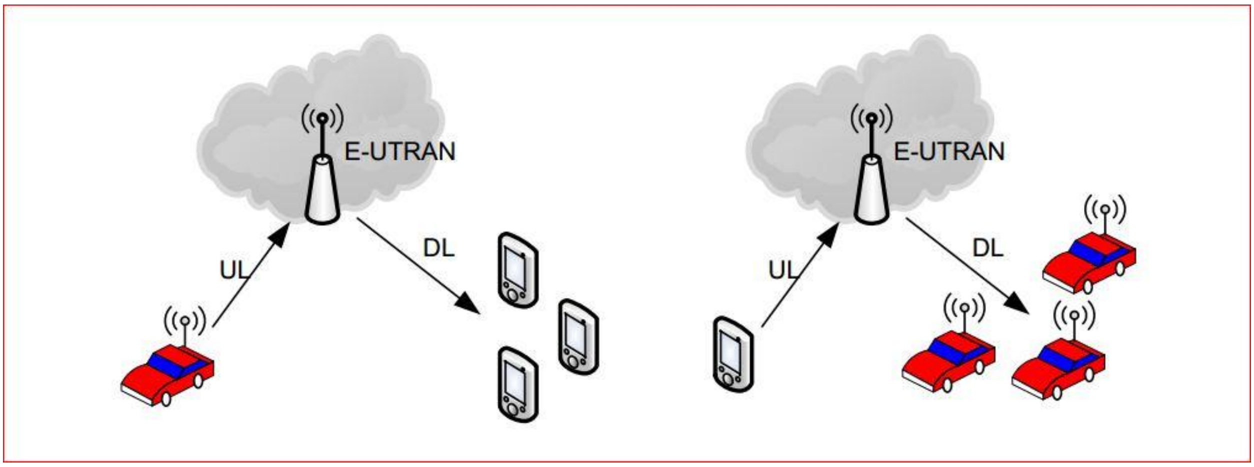
To support this scenario, E-UTRAN performs uplink reception and downlink transmission of V2X messages. For downlink, E-UTRAN may use a broadcast mechanism. It is Frequency selective scheduling (FFS) whether E-UTRAN supports RSU for V2V and V2P operation.



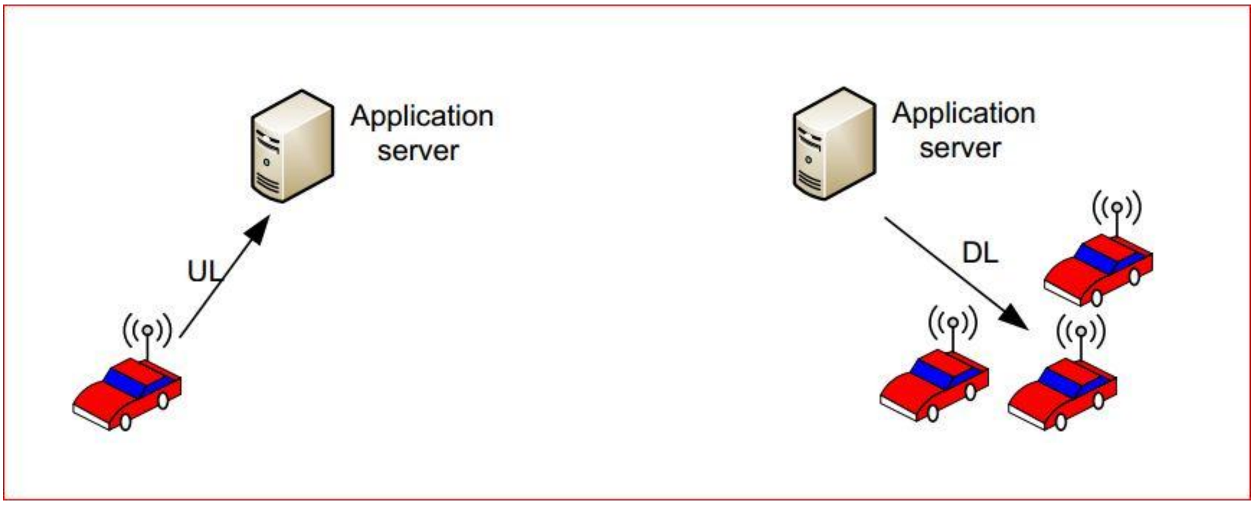
(a) V2V operation



(b) V2I operation



(c) V2P operation



(d) V2N operation

Figure 5:2: Scenario 2

5.3 Scenario 3

Here both PC5 and LTE Uu is supported by V2X.

5.3.1 Scenario 3A

Here a UE transmits v2x messages to a UE which is RSU type in the sidelink channel. This RSU ten sends the messages to E-UTRAN in the uplink and then EUTRAN transmits the messages to multiple UEs in the downlink. Here E-UTRAN receives message in the uplink and transmits in the downlink. For transmission it can use a broadcast mechanism.

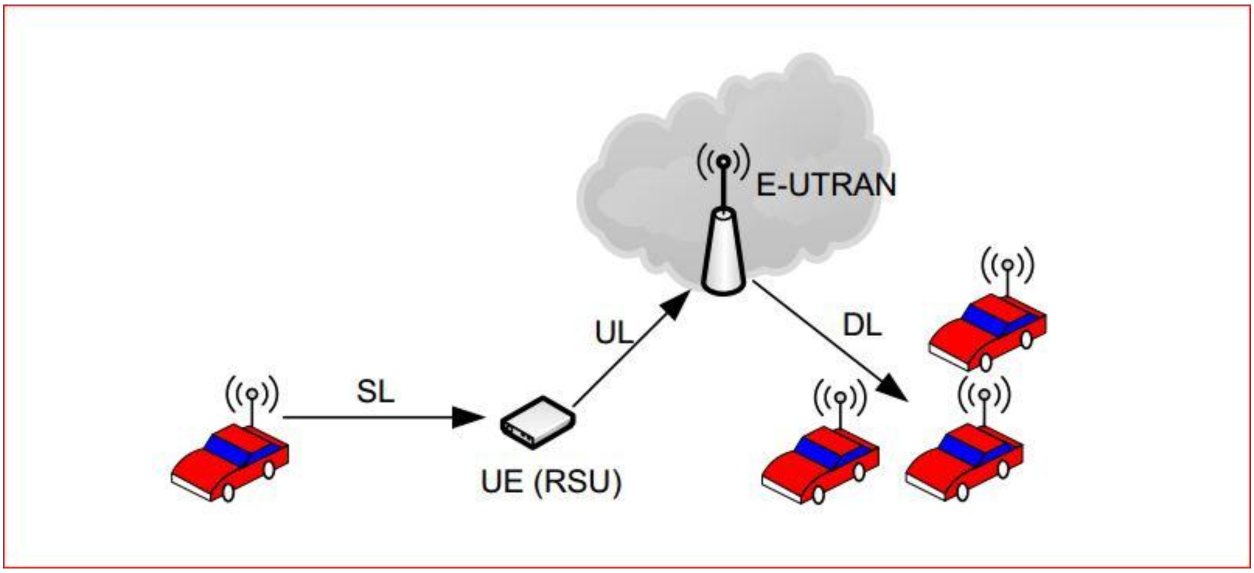


Figure 5:3: Scenario 3A

5.3.2 Scenario 3B:

In this case a UE directly transmits a V2X message to E-UTRAN in uplink and E-UTRAN transmits it one or more RSUs of UE type. After that that RSU transmits the V2X message to other UEs in the sidelink channel.

To support this scenario, E-UTRAN performs uplink reception and downlink transmission of V2X messages. For downlink, E-UTRAN may use a broadcast mechanism. It is FFS whether E-UTRAN also supports RSU function in this scenario. [8]

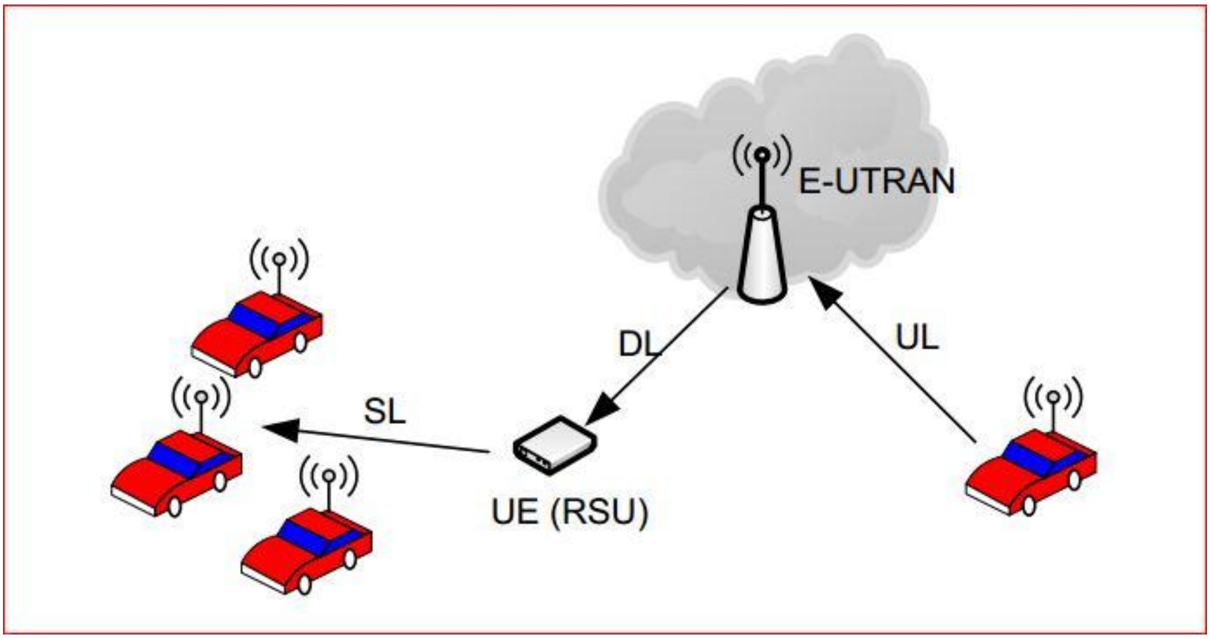


Figure 5:4: Scenario 3B

In cellular based V2X technology, latency is one of the most important performance indicator. Slightest delay in receiving the messages will result in deadly accidents. Where in general cellular technology throughput is regarded as one of the important performance indicator. So latency is a crucial factor. The size of messages that is being exchanged among the vehicles is smaller in size. The latency can be divided in two types depending on the proportionality to the TTI which is the minimum transmission time unit in cellular system. Each data transmission, i.e., control signaling, scheduling configuration, retransmission process, and so on, consumes at least one TTI [9] [10]. On the other hand, other latency elements, such as backhaul transmissions, core network processing time, and the time for wireless link configuration processes are not related to the TTI duration. Consequently, these other latency elements are not proportional to the TTI.

5.4 V2X Services, Use Cases and Latency Requirement

Table 5:2 V2X Services and Latency Requirement

Service Type	Use cases	Description	Latency requirement
Safety related services	Forward collision warning(FCW)	The FCW warns the driver of the host vehicle(HV)in case of imminent rear-end collision with a remote vehicle(RV) that is ahead in traffic in the same line and direction of travel is also same.	100 ms
	Control loss warning(CLW)	This triggers a HV to broadcast its control loss event to nearby RVs.	
	Emergency warning	This allow each vehicle on the road to acquire the directional information, speed and location of a nearby emergency vehicles.	
	Emergency stop	A nearby stationary vehicle triggers this message for the safety of others running cars in the Proximity.	
	Queue warning	Drivers could get pertinent queuing information beforehand and it saves lots of energy which would have been wasted for just inconsistent acceleration and deceleration. Reduces the likelihood of crashes.	
	Road safety services	Basic road safety messages is been transferred from on vehicles to other vehicles via road side units (RSU).	
	Pre-crash sensing warning	This message is generated when maintain the available speed of a vehicles would inevitably result into a crash with surrounding vehicles. Necessary steps is then automatically taken if the driver is reluctant to the message.	20 ms
Automated driving related services	Automated overtake	For safe overtaking maneuvers, velocity and directional information is provided to quickly merge into a new queue or lane.	10 ms
	Cooperative collision avoidance	Accidents are avoided by controlling the longitudinal speed and displacement of the surrounding cars.	100 ms
	High density platooning	Cars traveling in the same direction forms a chain on the highway and it saves fuel, also prevents accident.	10 ms
	See-through	For the safety of nearby pedestrian ,a warning is generated	50 ms

The V2X services can be categorized into three groups: safety-related services, non-safety-related services, and automated driving-related services.

Safety-related services are concerned with real-time safety messages, such as warning messages (e.g., abrupt brake warning message) to reduce the risk of car accidents. In these types of services, timeliness and reliability are considered to be key requirements.

Non-safety-related services are intended to optimize the traffic flow on the road so that travel time is reduced. Thus, these services enable a more efficient and comfortable driving experience with no stringent requirements in terms of latency and reliability.

Automated driving related services are now being developed as key transformations begin to occur in the automotive industry. These automated driving-related services require more rigorous latency, data rate, and positioning accuracy requirements. Therefore, the latency requirements for automated driving-related services are more stringent than those required for safety-related services. [11]

Chapter 6

Jakes's Model

The Jakes fading model is deterministic method for simulating time-correlated Raleigh fading waveforms [12]and is still widely used today [13] [14] [15]. The model assumes that N equal-strength rays arrive at a moving receiver with uniformly distributed arrival angles α_n, such that ray n experiences a Doppler shift $\omega_{n=}\ \omega_n \cos(\alpha_n)$,where $\omega_M=2\pi f/c$ is the maximum Doppler shift, v is the vehicular speed and c is the carrier frequency and c is the speed of light.

Using $\alpha_{n=}2\pi n/N$ [12], there is quadrantal symmetry in the magnitude of the Doppler spread, except for angles

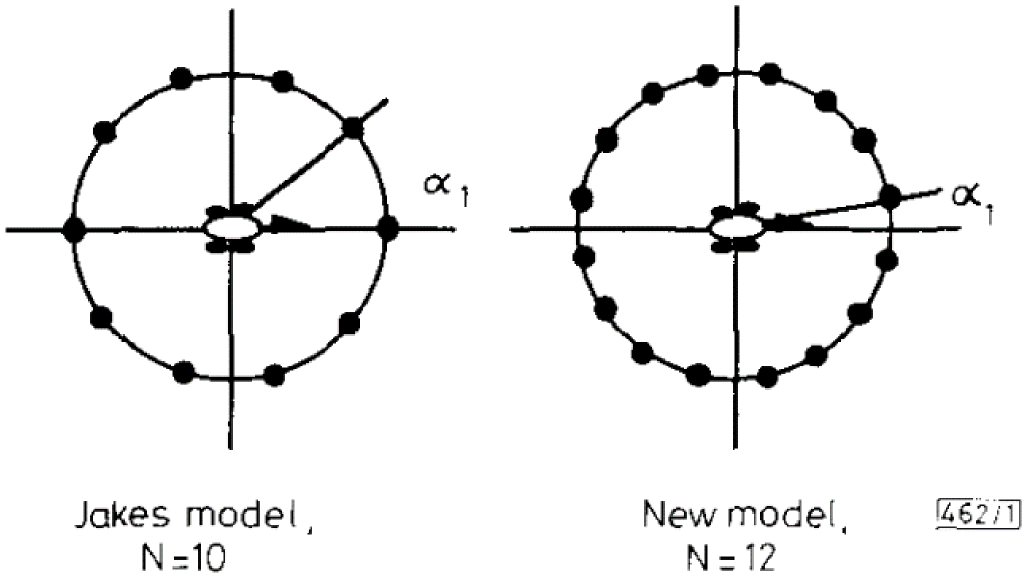


Figure 6:1: Jakes Model for Different Values of N

Figure: Ray arrival angles in Jakes (N=10) and new models (N=12)
0 and π. As a result, the fading waveform can be modelled with N_0+1 complex oscillators, where $N_0=(N/2-1)/2$.
This gives

$$T(t) = K\left\{\begin{array}{l} \frac{t}{\sqrt{2}}[\cos(\alpha) + Isin(\alpha)]\cos(\omega_M t + \theta_0) \\ + \sum_{n=1}^{N_0}[\cos(\beta_n) + Isin(\beta_n)]\cos(\omega_M t + \theta_0)\} \end{array}\right.$$

Where I denotes$\sqrt{-1}$,, K is a normalization constant, α and βn are phases, and θn are initial phases usually set to zero. Setting α=0 and $\beta_n = \pi n/(N_0+1)$ gives zero cross correlation between the real and imaginary parts of T (t).

To generate multiple uncorrelated waveforms, Jakes [12] suggests using phases $\theta_{n,j} = \beta_n + 2\pi(j-1)/(N_0+1)$, where j=1 to N0 is the waveform index. However, this gives almost uncorrelated waveforms j and k only when $\theta_{n,j} - \theta_{n,k} = i\pi + \frac{\pi}{2}$, for some integer i. otherwise, the correlation between certain waveform pairs can be significant. [16]

In this letter, a remedy of this problem is proposed in which orthogonal functions (Walsh-Hadamard codewords) weight the oscillator values before summing. To eliminate correlation, the oscillators must have equal power. This is achieved by reformulating the Jakes model in terms of slightly different arrival angles.

Model reformulation: To provide quadrantal symmetry for all Doppler shifts, which leads to equal power oscillators, the following arrival angles are used $\alpha_n=2\pi(n-.5)/N$. Following the procedure, this leads to the model

$$T(t) = \sqrt{\left(\frac{2}{N_0}\right)}\sum_{n=1}^{N_0}[\cos(\beta_n) + Isin(\beta_n)]\cos(\omega_n t + \theta_n)$$

where $N_0=N/4$ and the normalization factor $\sqrt{\left(\frac{2}{N_0}\right)}$ gives E{T(t)T*(t)}=1. Moment and correlation expressions are similar to those in reference 1, with the absence of the terms depending on α.

By using $\beta_n=\pi n/N_0$, the real and imaginary part of T(t) have equal power and are uncorrelated. Randomizing θ_n provides different waveform realizations.

Multiple uncorrelated waveforms: Many application simulation require multiple uncorrelated waveforms. Waveforms croscorrelation is determined by the sum of the product of the oscillator coefficients, which can be viewed as Walsh-Hadamard (WH) codewords [17], give zero inner product values with one another. Thus, with N0 a power of two, the jth waveform can be generated using

$$T(t,j) = \sqrt{\left(\frac{2}{N_0}\right)}\sum_{n=1}^{N_0} A_j(n) \times \{[\cos(\beta_n) + Isin(\beta_n)]\cos(\omega_n t + \theta_n)\}$$

where $A_j(n)$ is the jth WH code sequence in n(±1 values). This gives N_0, groups of N_0/N_w complex oscillators can be pre-summed before being passed through an N_w -point FWT. It is recommended that the pre-sums draw evenly from the Doppler spectrum, e.g. 1+5+9+13, 2+6+10+14, etc. for $N_0=16$, $N_w=4$. This corresponds to the first stages of decimate-in-frequency from FWT. Thus, if such an FWT is used after pre-summing, the same fading waveforms will be reproduced should less pre-summing be used in another simulation run. [18]

Chapter 7

Fading

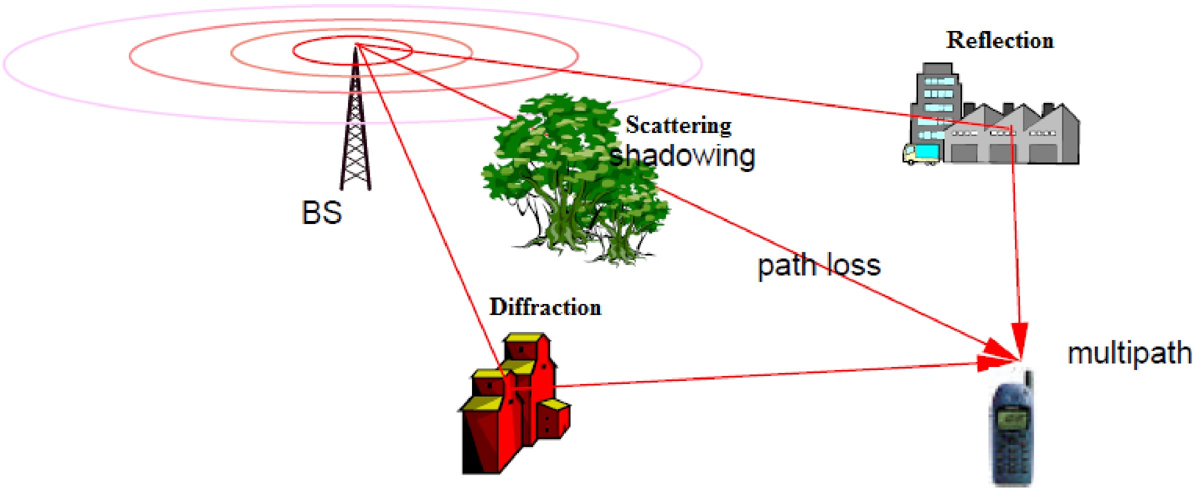


Figure 7:1: Multipath Fading in Wireless Communication

The term fading is used to describe rapid fluctuation of the amplitude of a radio signal over a short period of time or travel distance. It is caused by destructive interference between two or more versions of the transmitted signal being slightly out of phase depending on the distribution of the intensity and relative propagation time of the waves and the bandwidth of the transmitted signal. This is also called multipath propagation. The different components are due to reflection and scattering form trees buildings and hills etc.

7.1 Small-Scale Multipath Propagation

The existence of Multipath in the radio channel creates small scale fading effects. Due to this multipath there can be

• Rapid changes in signal strength over a small travel distance or time interval;

• Random frequency modulation due to varying Doppler shifts on different multipath signals;

• Time dispersion (echoes) caused by multipath propagation delays.

In city areas fading occurs as the height of the mobile antennas are well below the height of the surrounding structure, there is hardly a single line-of-sight path to the base station. And even if line-of-sight exists multipath could still occurs due to reflection from the ground and surrounding structures.

The incoming radio waves arrives from different directions with different propagation delays. The signal received by the mobile at any point in space may consists of large number of plane waves having randomly distributed amplitudes, phases and angle of arrival. Each of the factor given above is random.

The multipath components combine vectorially at the receiver and produce a fade or distortion.

7.2 Factors Influencing Small Scale Fading

7.2.1 Multipath Propagation

The presence of reflecting objects and scatters in the channel creates a constantly changing environment that dissipates the signal energy in amplitude, phase and time. These effects results in multiple versions of the transmitted signal that arrive at the receiving antenna, displaced with respect to one another in time and spatial orientation. The random phase and amplitude of the different multipath components caused fluctuations in signal strength, thereby inducing Small scale fading, Signal distortion, or both. Multipath propagation often lengthens the time required for the base band portion of the signal to reach the receiver which can cause signal smearing due to inter symbol interference.

7.2.2 Speed of the Mobile

The relative motion between the base station and the mobile results in random frequency modulation due to different Doppler Shifts on each of the multipath components. Doppler Shift will be positive or negative depending on whether the mobile receiver is moving towards or away from the base station.

7.2.3 Speed of Surrounding Objects

If objects in the radio channel are in motion, they induced a time varying Doppler Shift on multipath components. If the surrounding objects move at a greater rate than the mobile, then this effect dominates the Small scale fading. Otherwise, motion of surrounding objects may be ignored and only the speed of the mobile need be considered. The coherence time defines the “static ness” of the channel, and is directly impacted by the Doppler shift. Even when a mobile receiver is stationary, the received signal may fade due to a non-stationary nature of the channel (reflecting objects can be moving).

7.2.4 The Transmission Bandwidth of the Signal

If the transmitted radio signal bandwidth is greater than the "bandwidth" of the multipath channel, the received signal will be distorted, but the received signal strength will not fade much over a local area (i.e., the small scale signal fading will not be significant). As will be shown, the bandwidth of the channel can be quantified by the coherence bandwidth which is related to the specific multipath structure of the channel. The coherence bandwidth is a measure of the maximum frequency difference for which signals are still strongly correlated in amplitude. If the transmitted signal has a narrow bandwidth as compared to the channel, the amplitude of the signal change rapidly, but the signal will not be distorted in time.

7.3 Definitions

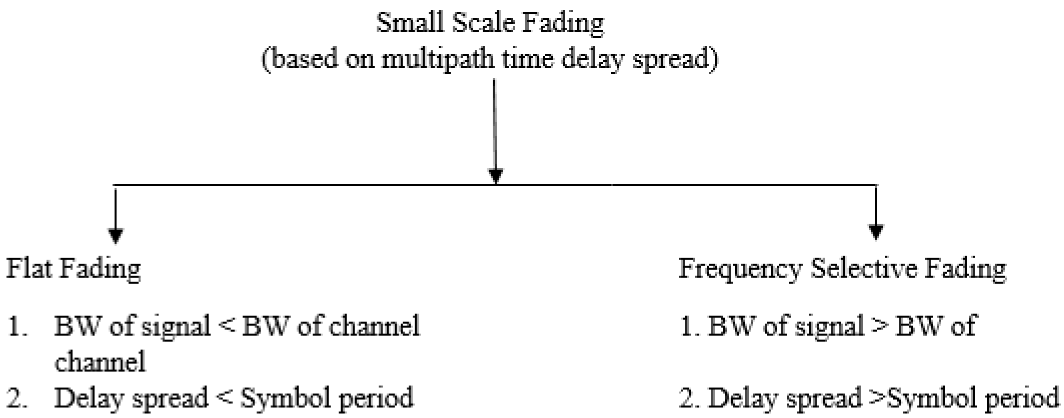
- Level Crossing Rate: Average number of times per sec that the signal crosses a certain level going in positive going direction.
- Fading Rate: Number of times the signal envelop crosses middle value in positive going direction per unit time.
- Depth of Fading: Ratio of mean square value and minimum value of fading.
- Fading Duration: Time for which signal remain below a certain threshold.
- Mean excess delay: The maximum delay time spread is the total time interval during which reflections with significant energy arrive.
- RMS excess delay: The r.m.s. delay spread TRMS is the standard deviation (or root-mean-square) value of the delay of reflections, weighted proportional to the energy in the reflected waves.
- Coherence time T_C is an estimate of the range of time over which the impulse response of the multipath channel does not vary significantly. In general, the coherence time T_C is inversely proportional to Doppler spread. It can be expressed as:

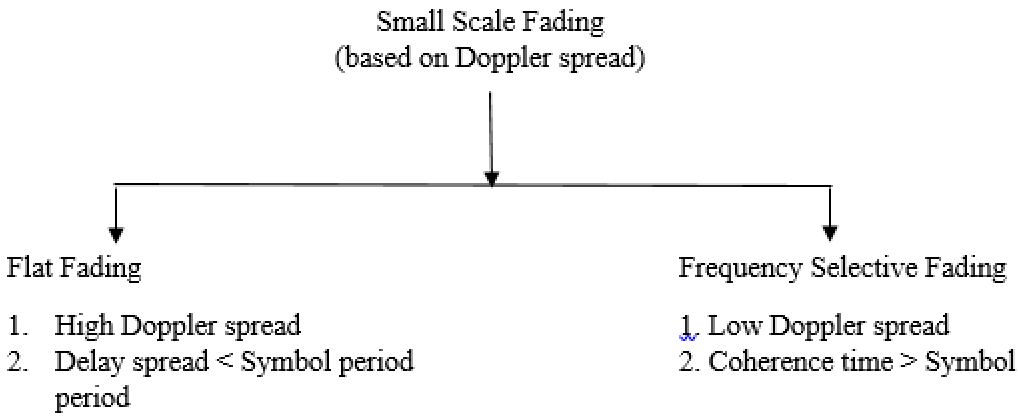
$$T_C \approx \frac{1}{f_m}$$

- Coherence Bandwidth: It is an estimation of the flat range of the frequency response of the multipath channel(i.e. a channel which passes all spectral components with approximately equal gain and linear phase). In the case where the coherence bandwidth is defined as a bandwidth with correlation of 0.9 or above, coherence bandwidth and RMS delay spread are related as:

$$B_C \approx \frac{1}{50T_c}$$

7.4 Types of Small Scale Fading





7.5 Flat Fading

If the bandwidth of the signal is less than the coherence bandwidth of the channel or the delay spread is less than the symbol period. This type of fading is historically the most common type of fading that can be found in any technical literature. Here even though spectral characteristics of the transmitted signal are preserved at the receiver, strength of the received signal varies with time because of the fluctuations in the gain.

Flat fading channels can also be defined amplitude varying channels or narrowband channel as the bandwidth of the signal is narrow compared to the channel flat fading bandwidth. Equivalently, in time domain, as the multipath channel deviates more and more from an impulse response, its convolution with the transmitted symbol will get the symbol more and more smeared out. In case of flat fading, the symbol is little smeared out.

So to sum it up a signal suffers of flat fading if $B_S << B_C$ and $T_S >> \sigma_\tau$. Here σ_τ is the rms delay spread of the channel, B_C is coherence bandwidth of the channel T_S is the symbol period and Bs is the bandwidth of transmitted signal.

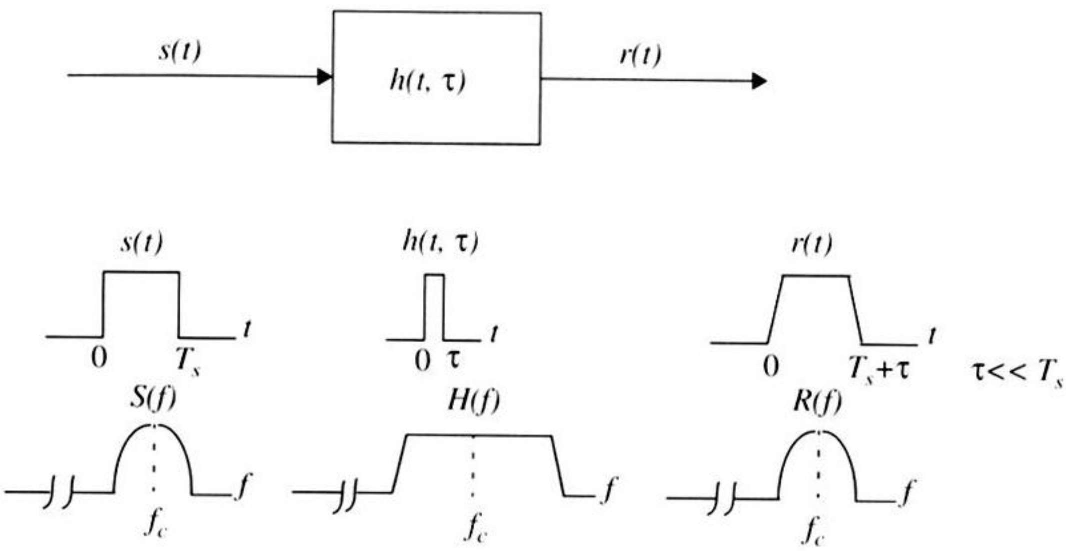


Figure 7:2: Flat Fading Channel Characteristics

7.6 Frequency Selective Fading

If the bandwidth of the signal is greater than the coherence bandwidth of the channel or the delay spread is greater than the symbol period then frequency selective fading occurs. In this case signal bandwidth is wide enough such that it may be filtered out by the limited channel bandwidth of the multipath channel, i.e. different parts of the transmitted signal frequency response is differently affected by the multipath channel causing significant distortion. . In case of frequency - selective fading, the symbol is greatly smeared out causing high distortion.

So a signal goes through frequency selective fading if $B_s > B_c$ and $T_s < \sigma_\tau$ where the symbols carries their usual meaning. In general a channel can be considered frequency selective if $T_s \leq 10\sigma_\tau$ although it depends on what type of modulation scheme is used. Time delay spread can greatly affect bit error rate.

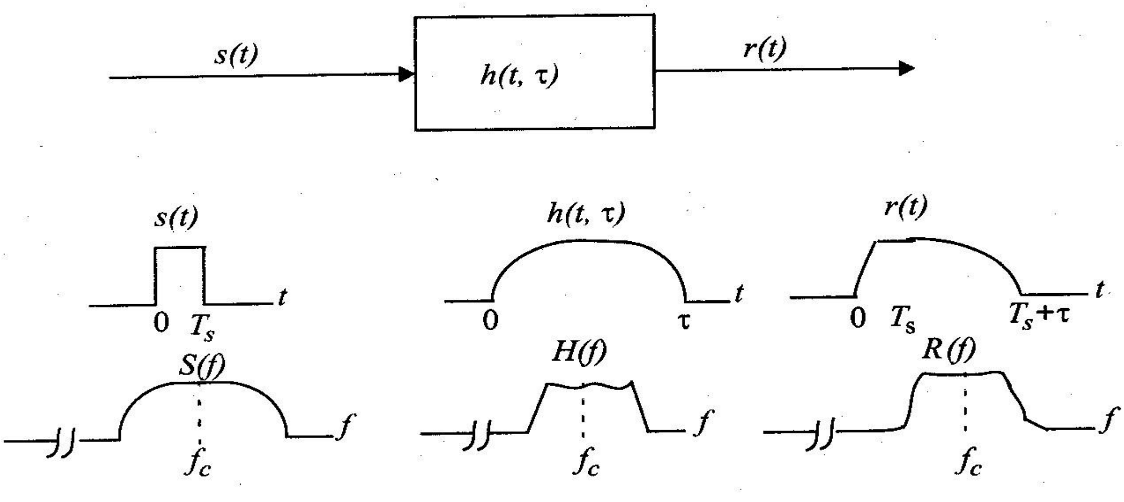


Figure 7:3: Frequency Selective Fading Channel Characteristics

7.7 Doppler Effect

Doppler shift effects wireless v2x communication largely by creating fading in the transmitted signal. Fading cannot be predicted as it does not depend on time and space. As fading is not avoidable, telecommunication engineers needs to build specific algorithm to minimize the effect of Doppler shift in the signal.

Doppler shift happens when the transmitter has a relative motion with the receiver. The relative motion changes the frequency of the signal making it difficult for the receiver to detect. It is easy to understand the scenario with the help of sound waves. Suppose a train is passing by you. As the train is getting closer, the sound is getting louder. When the train starts going away, the pitch of the sound suddenly becomes lower.

This occurs because the transmitter sends sound waves at a constant frequency but as it moves toward the receiver, the distance between the waves in the signal becomes shorter. The waves travel at a speed v and are emitted at a frequency f (cycles/seconds or Hz). As an example, the transmitter has moved a distance of d towards the receiver between the emissions of two succeeding cycles. The cycles thus arrive at the observer at a frequency higher than the emission frequency. The opposite applies when the transmitter is moving away; the distance between each peak (or cycles) increases, and since the wave is moving at the same v speed, the perception of the receiver is that the frequency has diminished.

7.8 Frequency Dispersion and Doppler Spread

All the frequency in all multipath components are affected by Doppler shift. This phenomenon is known as frequency dispersion. The frequency responses of different multipath components are affected differently. Thus, the resultant frequency response signifies signal distortion. The extent of overall frequency response increases and it increases more as Doppler shift increases. The increase in overall frequency response is referred to as Doppler spread denoted as B_D.

The maximum Doppler shift f m can be shown equal to v/ λ. The Doppler spread B_D is often estimated with a deviation of the frequency response equal to f_m on each side. Thus, $B_D = 2f_m$.

7.9 Fast Fading

The transmitted signal is subject to fast fading when the channel impulse response quickly varies within the symbol period causing significant distortion

Equivalently, in frequency domain, the Doppler spread is large compared to the signal bandwidth in case of fast fading. This signifies that the frequency response of the transmitted signal has been significantly spoiled causing significant distortion.

7.10 Slow Fading

The transmitted signal is subject to slow fading when the channel impulse responses varies slowly as compared to the variation in the transmitted signal, i.e. the multipath channel does not change significantly over the duration of one or more symbols.

In case of slow fading, the frequency response of the transmitted signal is insignificantly spoiled. [19] [1]

Chapter 8

Simulation Profile

3GPP Release 14 introduced the support for LTE V2X (Vehicle-to-everything) to enable connected vehicular services with the aim of providing a safer, cleaner, faster and more efficient transportation. V2X offers several modes of operation including Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I) and Vehicle-to-Pedestrian (V2P) direct communication without necessarily relying on network involvement for scheduling. Some of the distinguishing aspects of V2X over the Release 12 device-to-device sidelink are:

- Low latency and high reliability requirements
- Large Doppler shift due to high relative speeds
- Very large number of nodes and high node densities
- Challenges to synchronization especially when out-of-coverage

The simulation generates multiple Release 14 Physical Sidelink Control Channel (PSCCH) periods containing coded PSCCH and Physical Sidelink Shared Channel (PSSCH) transmissions. The resulting PSCCH period waveforms are then passed through a frequency-selective fading channel with AWGN, and the control channel and shared channel Block Error Ratios (BLERs) are calculated for a range of SNRs. The average number of transmission instances of the control and shared channels required for successful decoding at each SNR are also calculated.

A frequency-selective fading channel is configured according to TS 36.101 Table 12.2.1-1. An EVA delay profile with variable Doppler frequency and number of receiver antennas with low correlation is used. The channel seed is specified so that each execution of this example will use the same fading process realization. The Rayleigh fading model uses random phase initialization and the output is normalized so that the average power is unity.
This simulation measures Release 14 V2X sidelink shared and control channel throughput for a number of SNR points. Operating on a subframe by subframe basis for each SNR point, the following steps are performed for the throughput and BLER calculation:

- A resource grid populated with PSCCH and/or PSSCH is generated and OFDM modulated to create the baseband waveform to transmit.
- This waveform is passed through a noisy fading channel.
- Receiver operations (SC-FDMA demodulation, channel estimation, and equalization) are performed.
- The equalized symbols are decoded to obtain the block CRC.
- The performance of the PSCCH and/or PSSCH is determined using the block CRC result at the output of the channel decoder.

8.1 Simulation Configuration

The simulation is executed for a length of 1,000 frames for an of SNR range of -15dB to +15dB. A large number of frames needs to be used to produce meaningful throughput results.

8.2 Transmission Configuration

A set of top-level parameters is initially specified, these include the bandwidth, the cyclic prefix, the modulation scheme and the allocated set of resource blocks. The baseline configuration is taken from the "Reference measurement channel for transmitter characteristics" as defined by TS 36.101 Table A.8.3-1. To simulate a more realistic V2X transmission, multiple HARQ processes and HARQ retransmissions have been introduced in this simulation. The data rate is defined in terms of the subframe gap and transmission time interval.

8.3 Calculating Throughput

To determine the throughput at each SNR point, the subframe by subframe processing chain is as follows:

- Updating the configuration for current HARQ process.
- Creating and encoding the SCI message
- Creating the Transmit Waveform
- Modeling the Noisy Channel
- Performing Blind Detection of PSCCH
- Performing PSCCH symbols and channel estimation
- Performing PSCCH equalization
- Performing PSCCH demodulation
- Performing SCI decoding

The UE either carries new transport data or a retransmission of previously sent PSSCH transport data with a different redundancy version. All this is handled by the HARQ scheduler. The SCI message carries sidelink scheduling information. The SCI message is then encoded and mapped on to the PSCCH for transmission. The CRC of the SCI message is the scrambling identity for PSSCH. The data generated by the UE is passed to the physical layer processing stage to produce an SC-FDMA modulated waveform, containing the PSCCH and PSSCH physical channels and DRS signals. The waveform is passed through a fading channel and AWGN is added. The PSCCH resources and cyclic shift used in the transmitter in the subframe is unknown, so the synchronization, channel estimation and decoding is performed for each PRB set in the PSCCH resource block pool for all cyclic shifts until the SCI is successfully decoded or the entire resource pool is searched. The timing offset for the DM-RS correlation with the strongest peak is used for synchronization. The channel estimator produces an estimate of the noise power which can be used for MMSE equalization. The received PSCCH symbols are extracted from the subframe resource grid, the corresponding channel estimates are extracted and the indices are provided. The PSCCH symbols are MMSE equalized with the channel estimate and noise estimate obtained previously. SCI decoding is attempted. If the decoded CRC is zero and the recovered CRC mask is the expected value, the SCI decoding is considered successful and the decoded message bits are converted into the corresponding message structure. The CRC mask value provides the PSSCH scrambling identity. If SCI decoding was successful, the receiver proceeds with SL-SCH decoding.

8.4 SL-SCH Decoding

For SL-SCH decoding, the following process chain is used:

- Obtaining the PSSCH resource allocation
- Synchronizing and SC-FDMA demodulating subframe carrying PSSCH
- Performing PSSCH channel estimation
- Extracting the PSSCH symbols and channel estimate
- Performing PSSCH equalization
- Performing PSSCH demodulation
- Decoding the Sidelink Shared Channel (SL-SCH) and Storing the Block CRC Error for a UE

The RIV (Resource Indication Value) obtained from the recovered SCI message is then decoded to get the number of subchannels and the starting sub channel allocated for this transmission. This in combination with the PSCCH adjacency, size of each subchannel and first allocated resource block provides the set of allocated PSSCH RBs. The appropriate subframe of the waveform is synchronized. The synchronized waveform is SC-FDMA demodulated. Although the control and shared channel are transmitted in the same subframe, it is sufficient to perform the synchronization and SC-FDMA demodulation only for the PSCCH. However, in this example, since the shared and control channel can be independently received, PSSCH synchronization and SC-FDMA demodulation are performed. This is to enable PSSCH reception when the PSCCH reception is disabled. PSSCH channel estimation is performed. The channel estimator also produces an estimate of the noise power which can be used for MMSE equalization. The received PSSCH symbols are extracted from the subframe resource grid and the corresponding channel estimates are extracted. The PSSCH symbols are MMSE equalized with the channel estimate and noise estimate obtained previously. The equalized PSSCH symbols are demodulated. This function performs the inverse of the transmitter modulation steps (SC-FDMA transform deprecoding, QPSK or 16QAM symbol demodulation and descrambling). The descrambling uses the PSCCH CRC obtained from the SCI decoding stage. The vector of decoded soft bits is used to decode the codeword and return the block CRC error used to determine the throughput of the system. The contents of the new soft buffer, is available to be used when decoding the next subframe.

Chapter 9

Results

The simulations were run varying three parameters: the Doppler Frequency, the number of receiving antennae and the SNR. The results obtained are displayed on the following pages.

The following inferences can be made from the results:

- For a given antenna configuration, BLER increases as Doppler frequency increases. Using more NRxAntennas improves BLER.
- For a given antenna configuration, throughput decreases as Doppler frequency increases. Using more NRxAntennas improves throughput.
- For a fixed Doppler frequency, BLER decreases as SNR increases. Using more NRxAntennas improves BLER. Increasing Doppler frequency exacerbates BLER.
- For a fixed Doppler frequency, throughput increases as SNR increases. Using more NRxAntennas improves throughput. Increasing Doppler frequency exacerbates throughput.
- For a fixed SNR, BLER increases as Doppler frequency increases. Using more NRxAntennas improves BLER. Increasing SNR improves BLER.
- For a fixed SNR, throughput decreases as Doppler frequency increases. Using more NRxAntennas improves throughput. Increasing SNR improves BLER.

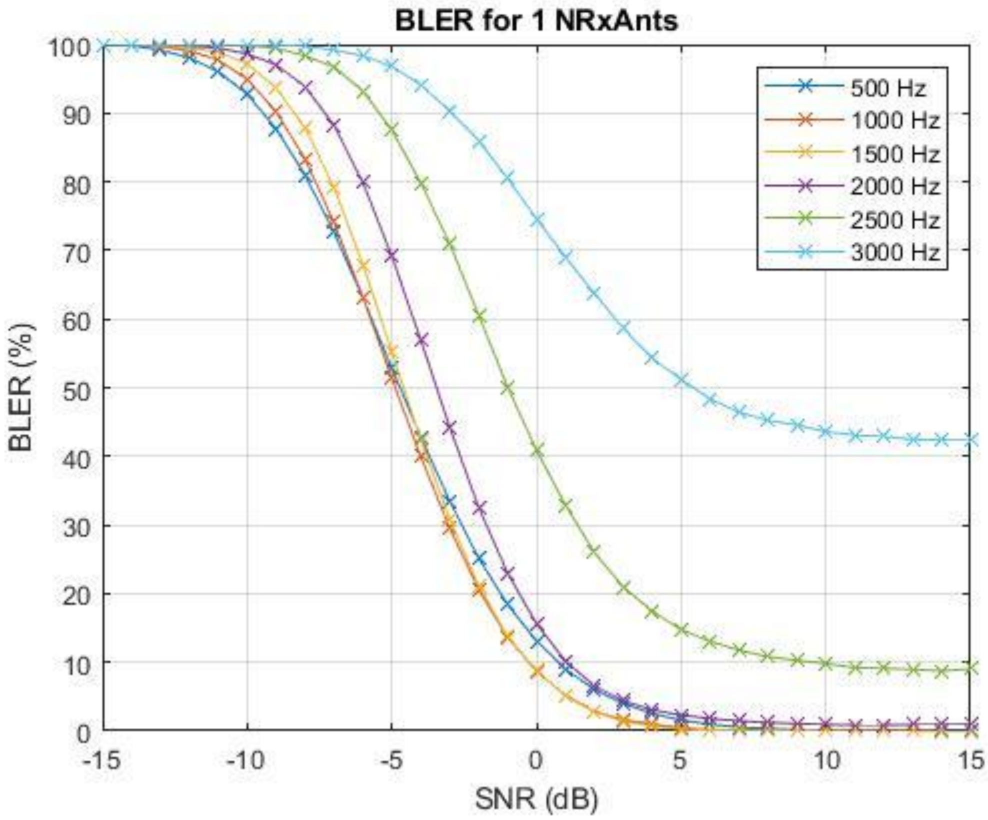


Figure 4: BLER vs SNR at different Doppler Frequencies for 1 Receiving Antenna

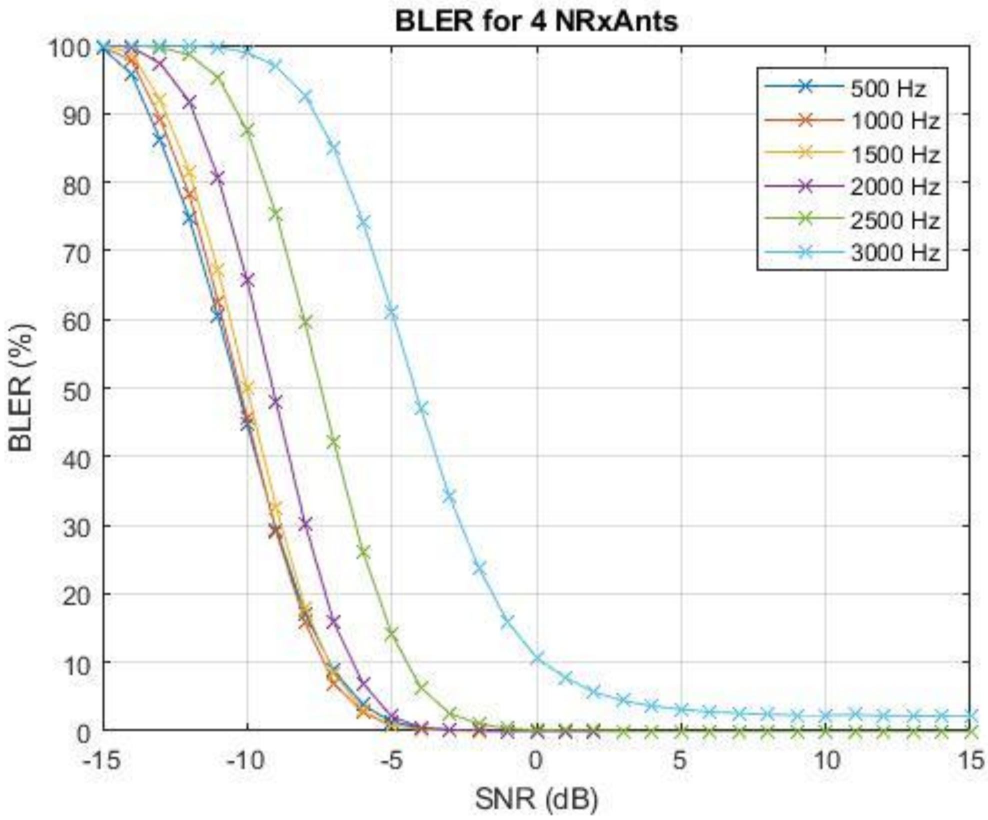


Figure 5: BLER vs SNR at different Doppler Frequencies for 4 Receiving Antennas

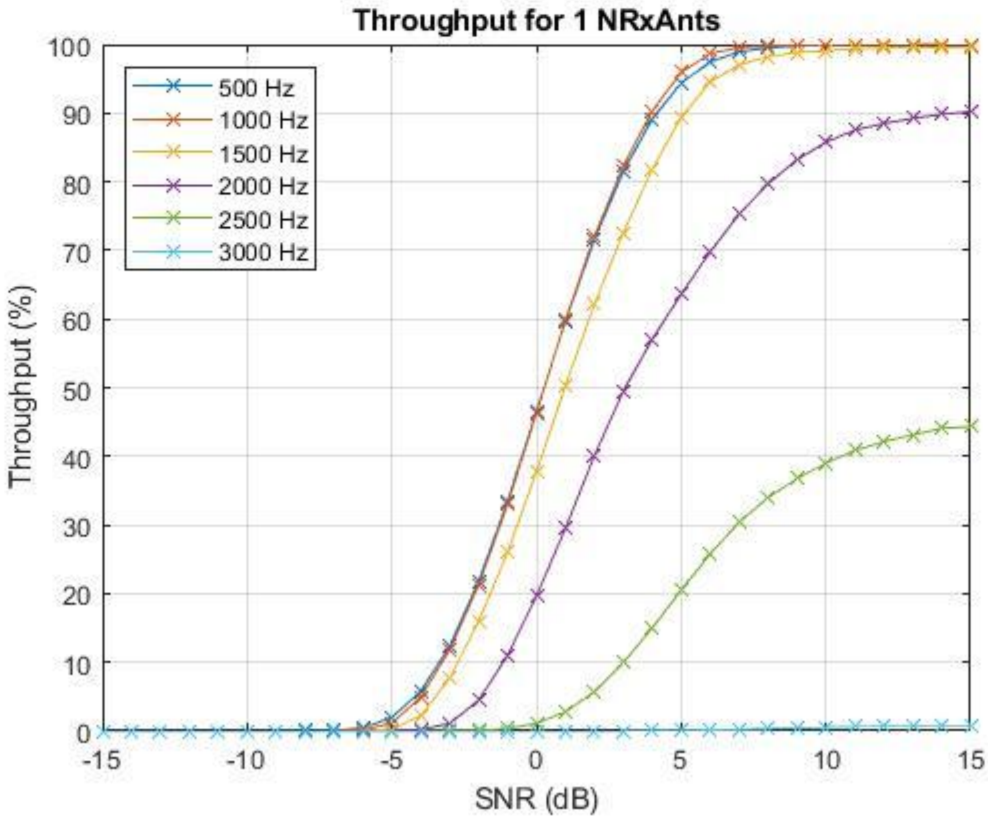


Figure 6: Throughput vs SNR at different Doppler Frequencies for 1 Receiving Antenna

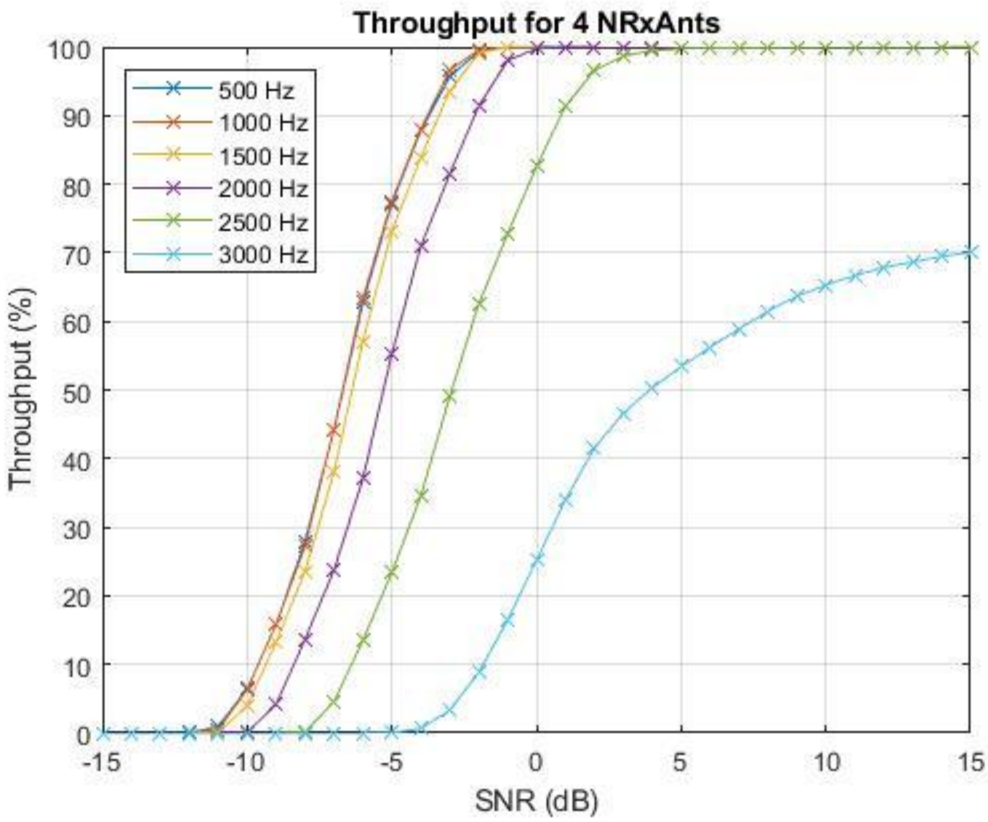


Figure 7: Throughput vs SNR at different Doppler Frequencies for 4 Receiving Antennas

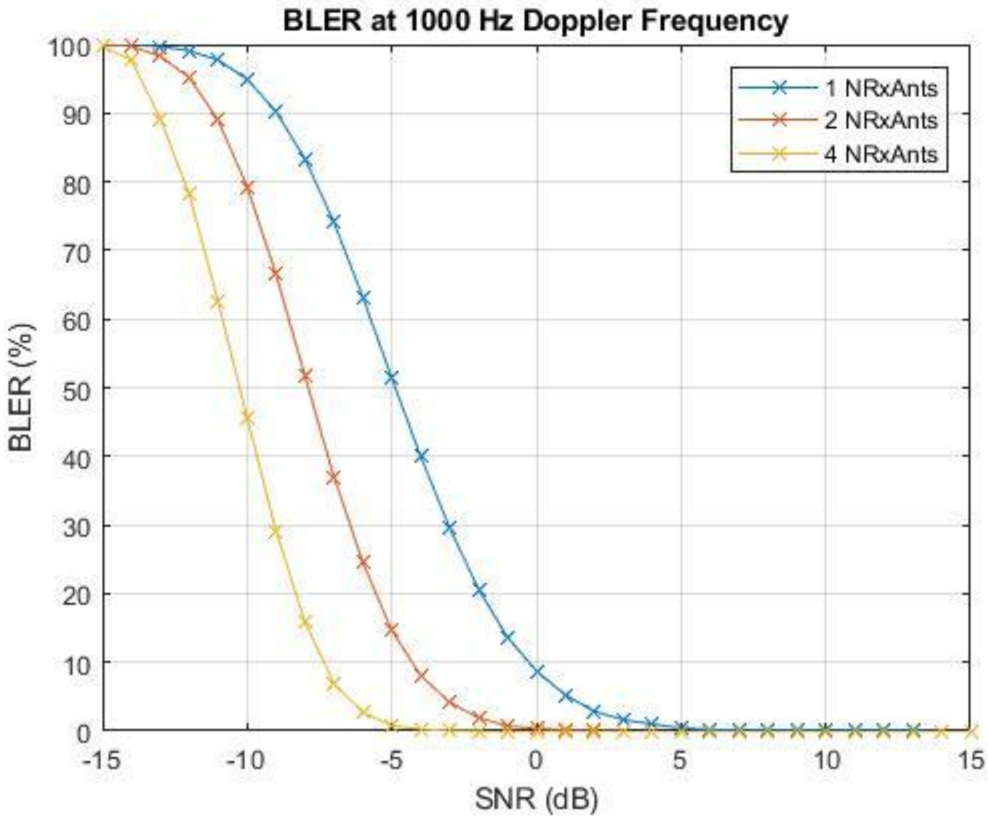


Figure 8: BLER vs SNR for Different Antenna Configurations at 1000 Hz

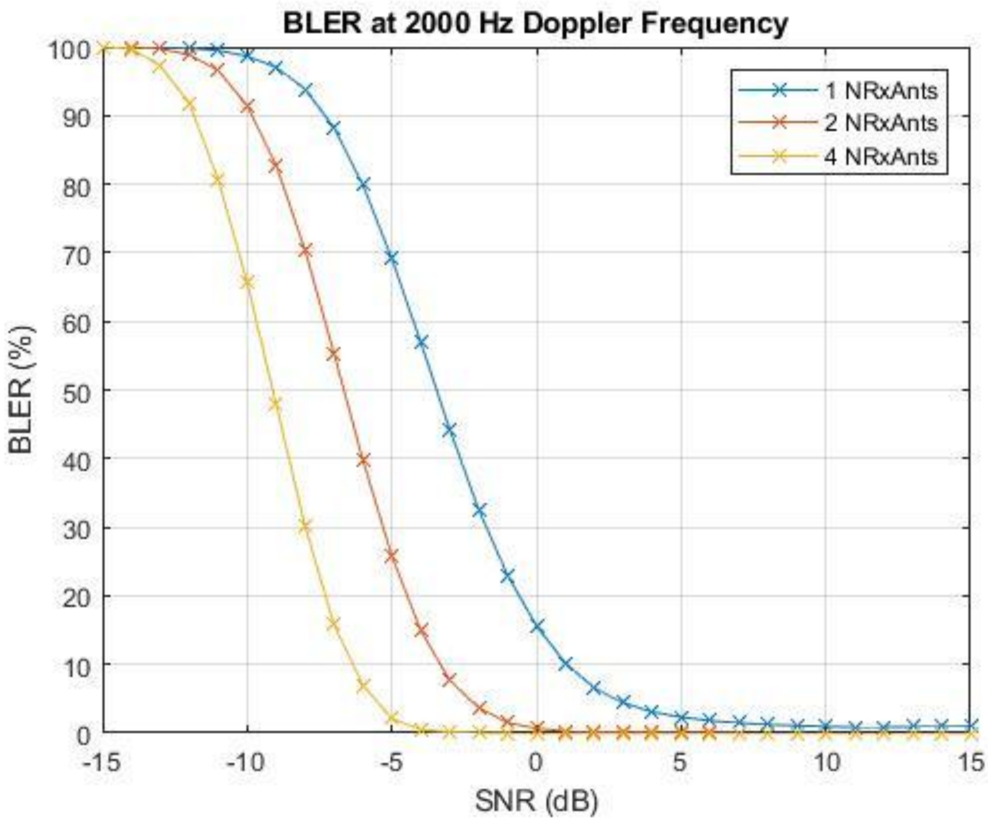


Figure 9: BLER vs SNR for Different Antenna Configurations at 2000 Hz

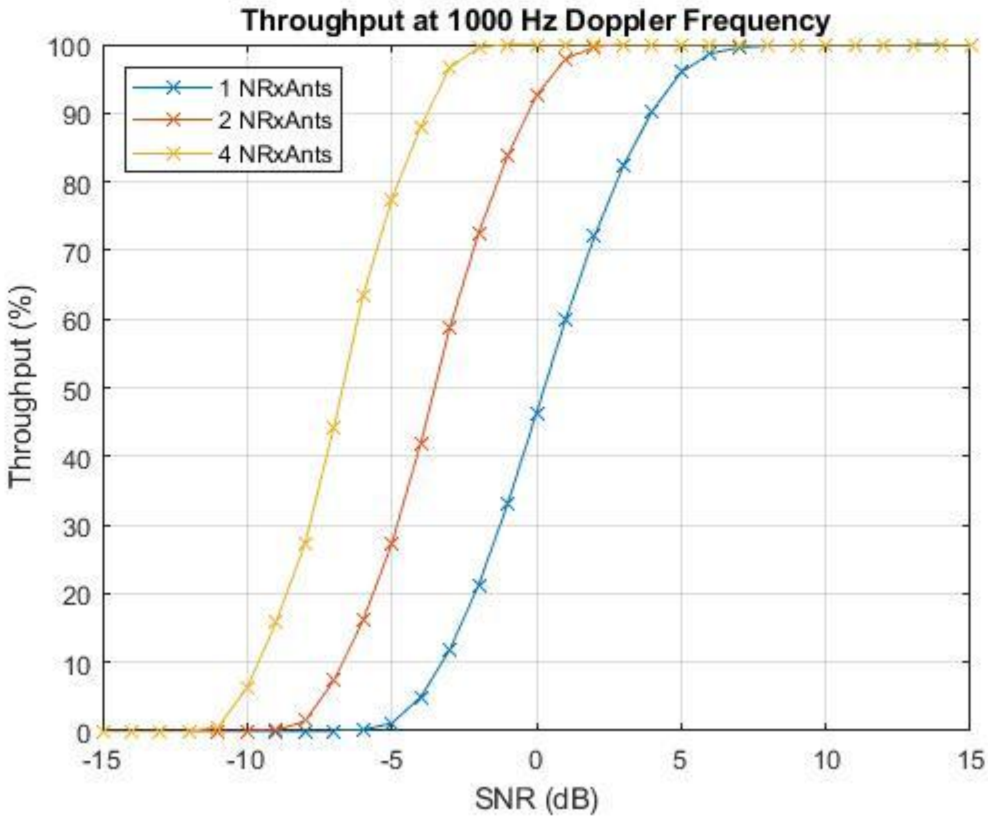


Figure 10: Throughput vs SNR for Different Antenna Configurations at 1000 Hz

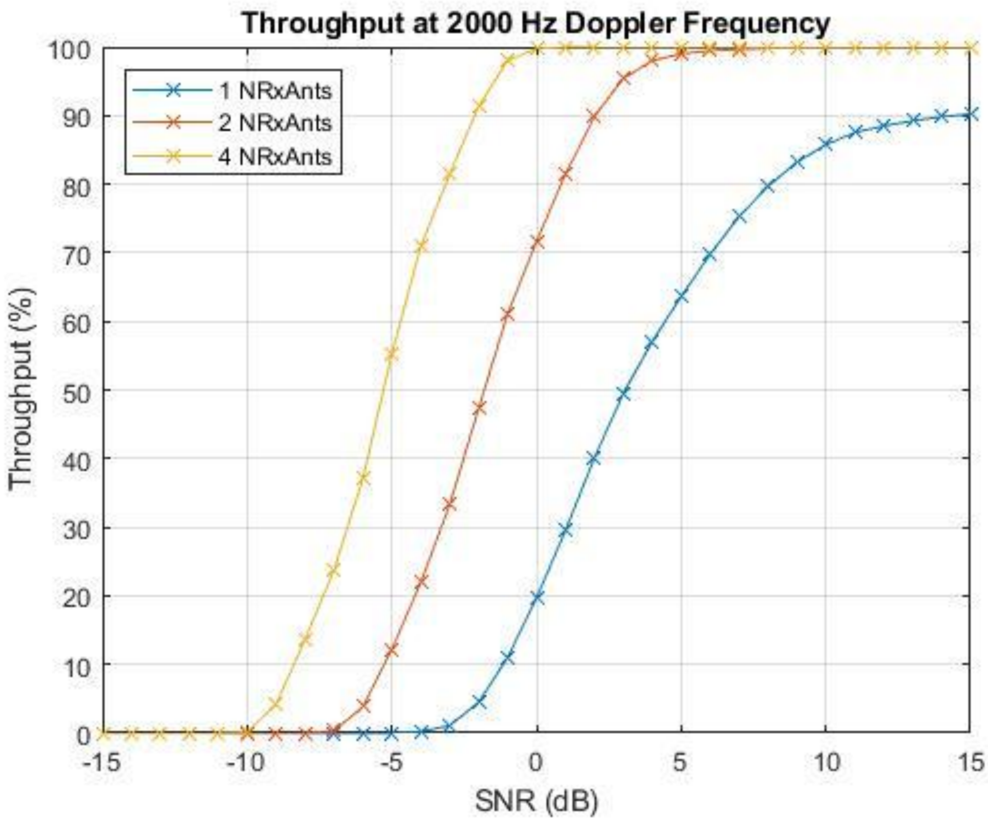


Figure 11: Throughput vs SNR for Different Antenna Configurations at 2000 Hz

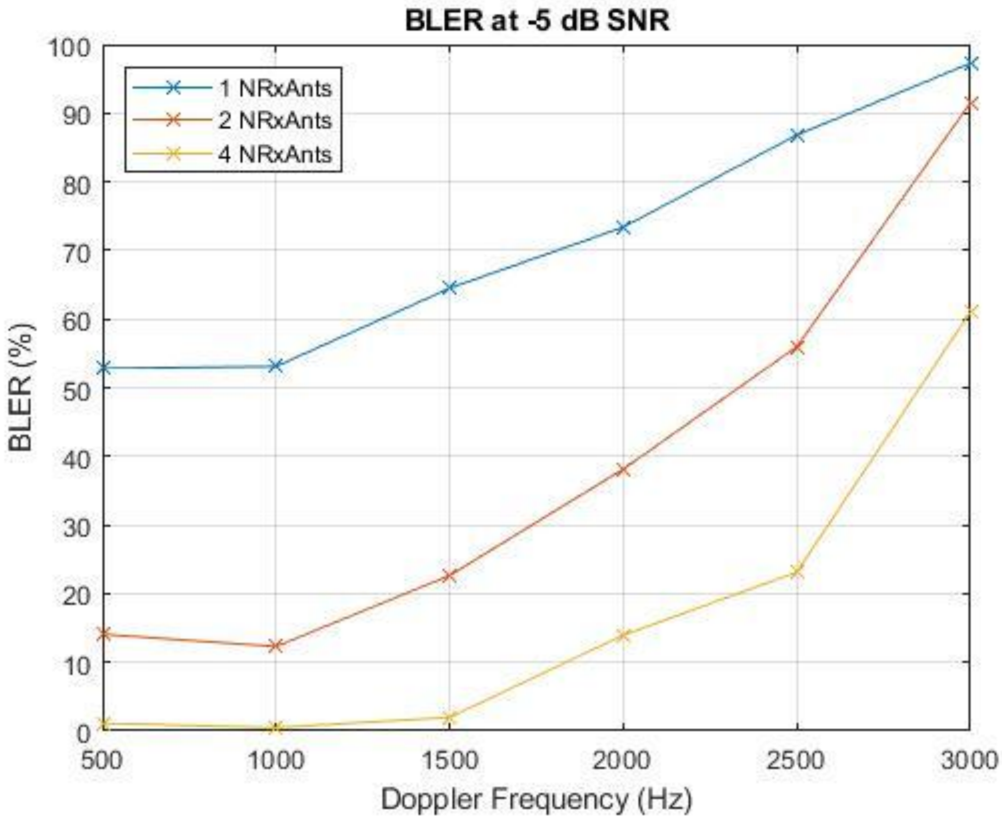


Figure 12: BLER vs Doppler Frequency for Different Antenna Configurations at -5dB SNR

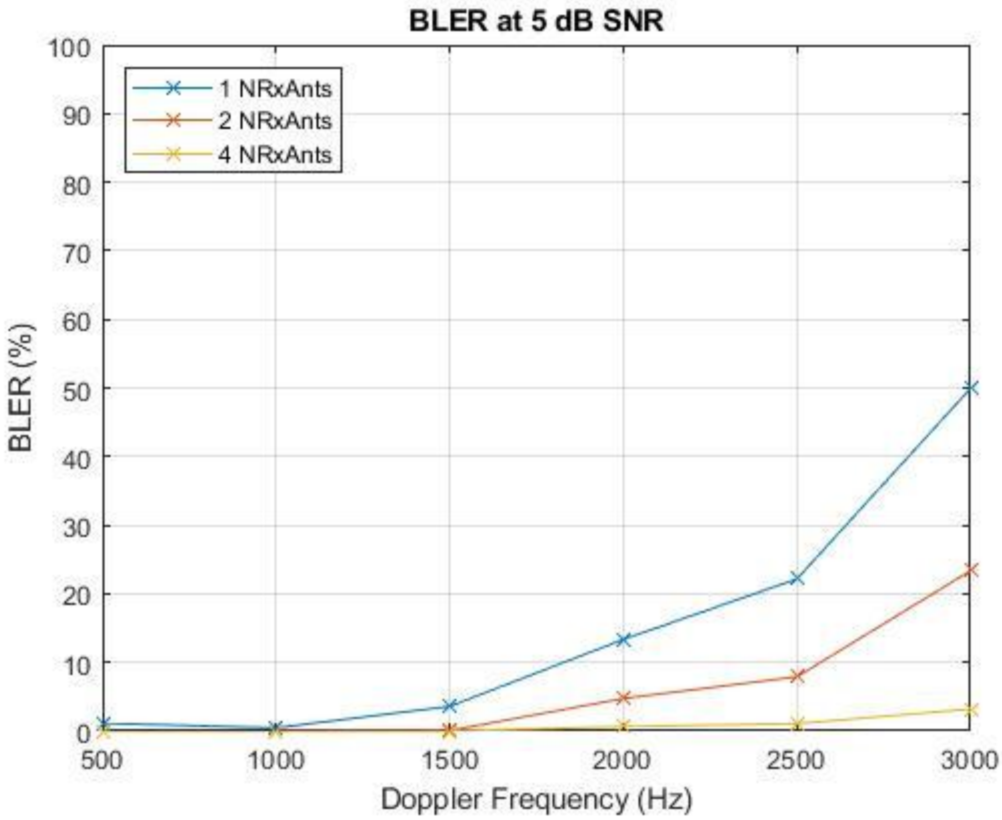


Figure 13: BLER vs Doppler Frequency for Different Antenna Configurations at +5dB SNR

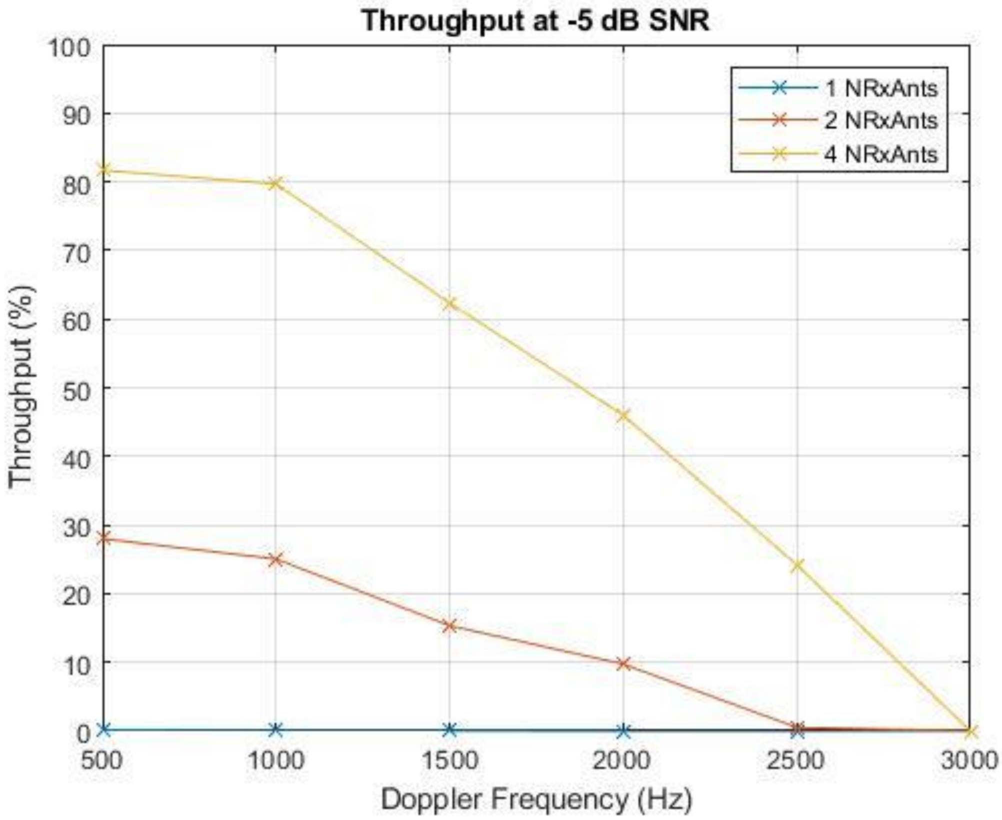


Figure 14: Throughput vs Doppler Frequency for Different Antenna Configurations at -5dB SNR

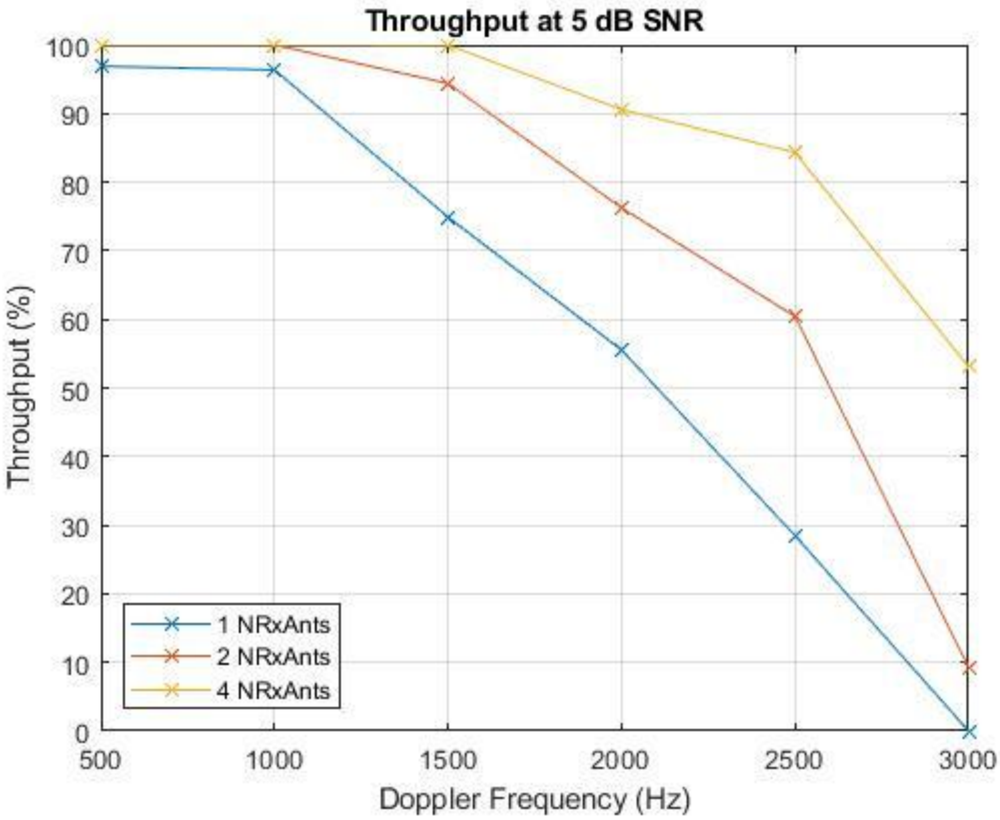


Figure 15: Throughput vs Doppler Frequency for Different Antenna Configurations at +5dB SNR

Chapter 6

Conclusion

V2X communication has been regarded as one of the key ITS technology. Using V2X communication a vehicle can communicate with its environment in order to exchange safety messages between them. The development of autonomous vehicles is taking place in both academia and industry. As the world is progressing towards the rapid advancement of intelligent vehicles, V2X communication will play a vital role. In this thesis, performance analysis of V2X sidelink has been done. Some key parameters, Doppler frequency, no of receiving antennas and SNR have been varied. Due to the change in these parameters, variation in throughput and BLER have been shown. A marked need for link adaptation at high Doppler frequencies has been established. Whether this will lead to compromised latency and if that compromise would be acceptable could be the matter of further study.

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