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Performance Analysis of Vehicle-to-Anything (V2X) Operation of 5G under Different Propagation Environments and Mobility Levels

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CERTIFICATE OF RESEARCH

This is to certify that the work presented in this thesis paper is the outcome of research carried out by the candidate under the supervision of Dr. Mohammad Tawhid Kawser, Associate Professor, Electrical and Electronic Engineering (EEE). It is also declared that neither this thesis paper nor any part thereof has been submitted anywhere else for the reward of any degree or any judgment.

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Table of Contents

List of Tables

List of Figures

List of Acronyms

3GPP	Third-generation partnership project
AAS	Active antenna systems
ACIR	Adjacent channel interference ratio
ACK	Acknowledgment (in ARQ protocols)
ACLR	Adjacent channel leakage ratio
ACS	Adjacent channel selectivity
AGC	Automatic gain control
AIFS	Arbitration interframe space
AM	Acknowledged mode (RLC configuration)
A-MPR	Additional maximum power reduction
APT	Asia-Pacific telecommunity
ARI	Acknowledgment resource indicator
ARIB	Association of radio industries and businesses
ARQ	Automatic repeat-request
AS	Access stratum
ATC	Ancillary terrestrial component
ATIS	Alliance for telecommunications industry solutions
AWGN	Additive white Gaussian noise
BC	Band category
BCCH	Broadcast control channel
BCH	Broadcast channel
BL	Bandwidth-reduced low complexity
BM-SC	Broadcast multicast service center
BPSK	Binary phase-shift keying
BS	Base station
BW	Bandwidth
CA	Carrier aggregation
CACLR	Cumulative adjacent channel leakage ratio
CC	Component carrier
CCA	Clear channel assessment
CCCH	Common control channel
CCE	Control channel element
CCSA	China Communications Standards Association
CDMA	Code-division multiple access
CITEL	Inter-American Telecommunication Commission
B-MTC	Critical MTC
C-CN	Core network
CoMP	Coordinated multi-point transmission/reception
CP	Cyclic prefix
CQI	Channel-quality indicator

CRC	Cyclic redundancy check
D-RNTI	Cell radio-network temporary identifier
CRS	Cell-specific reference signal
CS	Capability set (for MSR base stations)
CSA	Common subframe allocation
CSG	Closed Subscriber Group
CSI	Channel-state information
CSI-IM	CSI interference measurement
CSI-RS	CSI reference signals
CW	Continuous wave
D2D	Device-to-device
DAI	Downlink assignment index
DCCH	Dedicated control channel
DCH	Dedicated channel
DCI	Downlink control information
DCF	Distributed coordination function
DFS	Dynamic frequency selection
DFT	Discrete Fourier transform
DL	Downlink
DL-SCH	Downlink shared channel
DM-RS	Demodulation reference signal
DMTC	DRS measurements timing configuration
DRS	Discovery reference signal
DRX	Discontinuous reception
DTCH	Dedicated traffic channel
DTX	Discontinuous transmission
DwPTS	Downlink part of the special subframe (for TDD operation)
ECCE	Enhanced control channel element
EDCA	Enhanced distributed channel access
EDGE	Enhanced data rates for GSM evolution; enhanced data rates for global evolution
eIMTA	Enhanced Interference mitigation and traffic adaptation
EIRP	Effective isotropic radiated power
EIS	Equivalent isotropic sensitivity
EMBB	Enhanced MBB
eMTC	Enhanced machine-type communication
eNB	eNodeB
eNodeB	E-UTRAN NodeB
EPC	Evolved packet core
EPS	Evolved packet system
EREG	Enhanced resource-element group
ETSI	European Telecommunications Standards Institute
E-UTRA	Evolved UTRA

UTRAN	Evolved UTRAN
EVM	Error vector magnitude
FDD	Frequency division duplex
FDMA	Frequency-division multiple access
FEC	Forward error correction
FFT	Fast Fourier transform
GP	Guard period (for TDD operation)
GPRS	General packet radio services
GPS	Global positioning system
GSM	Global system for mobile communications
GSMA	GSM Association
HARQ	Hybrid ARQ HII High-interference indicator
HSFN	Hypersystem frame number
HSPA	High-speed packet access
IEEE	Institute of Electrical and Electronics Engineers
LAA	License-assisted access
LAN	Local area network
LBT	Listen before talk
LCID	Logical channel identifier
LDPC	Low-density parity check code
LTE	Long-term evolution
MAC	Medium access control
MAN	Metropolitan area network
MBB	Mobile broadband
MBMS	Multimedia broadcastemulticast service
MC	Multi-carrier
MCCH	MBMS control channel
MCE	MBMS coordination entity
MCG	Master cell group
MCH	Multicast channel
MCS	Modulation and coding scheme
MIB	Master information block
MIMO	Multiple inputemultiple output
MLSE	Maximum-likelihood sequence estimation
MME	Mobility management entity
MPR	Maximum power reduction
MSA	MCH subframe allocation
MSI	MCH scheduling information
MSP	MCH scheduling period
MSR	Multi-standard radio
MSS	Mobile satellite service
MTC	Machine-type communication
MTCH	MBMS traffic channel

NAK	Negative acknowledgment (in ARQ protocols)
NAICS	Network-assisted interference cancelation and suppression
NAS	Non-access stratum (a functional layer between the core network and the terminal that supports signaling)
NB-IoT	Narrow-band internet of things
OFDM	Orthogonal frequency-division multiplexing
OI	Overload indicator
OOB	Out-of-band (emissions)
OSDD	OTA sensitivity direction declarations
OTA	Over the air
PA	Power amplifier
PAPR	Peak-to-average power ratio
PAR	Peak-to-average ratio (same as PAPR)
PBCH	Physical broadcast channel
PCCH	Paging control channel
PCFICH	Physical control format indicator channel
PCG	Project Coordination Group (in 3GPP)
PCH	Paging channel
PCID	Physical cell identity
PCRF	Policy and charging rules function
PDC	Personal digital cellular
PDCCH	Physical downlink control channel
PDCP	Packet data convergence protocol
PDSCH	Physical downlink shared channel
PDN	Packet data network
PDU	Protocol data unit
P-GW	Packet-data network gateway (also PDN-GW)
PHY	Physical layer
PMCH	Physical multicast channel
PMI	Precoding-matrix indicator
PRACH	Physical random access channel
PRB	Physical resource block
P-RNTI	Paging RNTI ProSe Proximity services
PSBCH	Physical sidelink broadcast channel
PSCCH	Physical sidelink control channel
PSD	Power spectral density
PSDCH	Physical sidelink discovery channel
PSLSS	Primary sidelink synchronization signal
PSM	Power-saving mode
PSS	Primary synchronization signal
PSSCH	Physical sidelink shared channel
PSTN	Public switched telephone networks
PUCCH	Physical uplink control channel

PUSCH	Physical uplink shared channel
QAM	Quadrature amplitude modulation
QCL	Quasi-colocation
QoS	Quality-of-service
QPP	Quadrature permutation polynomial
QPSK	Quadrature phase-shift keying
RAB	Radio-access bearer
RACH	Random-access channel
RAN	Radio-access network
RAT	Radio-access technology
RB	Resource block
RE	Resource element
REG	Resource-element group
RF	Radio frequency
RI	Rank indicator
RLAN	Radio local area networks
RLC	Radio link control
RNTI	Radio-network temporary identifier
RNTP	Relative narrowband transmit power
RoAoA	Range of angle of arrival
ROHC	Robust header compression
PDCCH	Relay physical downlink control channel
RRC	Radio-resource control
Q-RRM	Radio resource management
RS	Reference symbol
RSPC	Radio interface specifications
RSRP	Reference signal received power
RSRQ	Reference signal received quality
RV	Redundancy version
RX	Receiver
SBCCH	Sidelink broadcast control channel
SCG	Secondary cell group
SCI	Sidelink control information
SC-PTM	Single-cell point to multipoint
SDMA	Spatial division multiple access
SDO	Standards developing organization
SDU	Service data unit
SEM	Spectrum emissions mask
SF	Subframe
SFBC	Spaceefrequency block coding
SFN	Single-frequency network (in general, see also MBSFN); system frame number (in 3GPP).
SGW	Serving gateway

SI	System information message
SIB	System information block
SIC	Successive interference combining
SIFS	Short interframe space
SIM	Subscriber identity module
SINR	Signal-to-interference-and-noise ratio
SIR	Signal-to-interference ratio
SL-DCH	Sidelink discovery channel
SLI	Sidelink identity
SL-SCH	Sidelink shared channel
SLSS	Sidelink synchronization signal
SNR	Signal-to-noise ratio
SORTD	Spatial orthogonal-resource transmit diversity
SR	Scheduling request
SRS	Sounding reference signal
R-SLSS	Secondary sidelink synchronization signal
S-SSS	Secondary synchronization signal
STCH	Sidelink traffic channel
STBC	Spaceetime block coding
STC	Spaceetime coding
STTD	Spaceetime transmit diversity
TAB	Transceiver array boundary
TCP	Transmission control protocol
TDD	Time-division duplex
TDMA	Time-division multiple access
TF	Transport format
TPC	Transmit power control
TR	Technical report
TRP	Time repetition pattern; transmission reception point
TRPI	Time repetition pattern index
TS	Technical specification
TSDSI	Telecommunications Standards Development Society, India
TSG	Technical Specification Group
TTA	Telecommunications Technology Association
TTC	Telecommunications Technology Committee
TTI	Transmission time interval
TX	Transmitter
UCI	Uplink control information
UE	User equipment (the 3GPP name for the mobile terminal)
UL	Uplink
UL-SCH	Uplink shared channel
UM	Unacknowledged mode (RLC configuration)
UMTS	Universal mobile telecommunications system

URLLC	Ultra-reliable low-latency communication
UTRA	Universal terrestrial radio access
UTRAN	Universal terrestrial radio-access network
VoIP	Voice-over-IP
WCDMA	Wideband code-division multiple access
WCS	Wireless communications service
WG	Working group
WiMAX	Worldwide interoperability for microwave access
WLAN	Wireless local area network
WMAN	Wireless metropolitan area network

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Abstract

Our thesis topic is related to V2X ,its applications and its performance analysis. This thesis book contains an in-depth study of V2X technologies which has been carried out by our team. It also contains the analysis of BLER and throughput for varying numbers of frames, Doppler frequencies and modulation schemes. Performance analysis is done for multiple mobility factors in two different propagation environments namely- EVA and ETU. EPA was avoided in this case because mobility factor doesn't play a huge role due to absence of high speed entities in this particular propagation model.

Chapter 1

Introduction

1.1 Background

In modern dominantly capitalist society income per head are increasing day by day. Women along with men are leaving home for work, some are engaging themselves in more than one job. Life has become too fast to seat in a chair along a fireplace and cherish it's beauty.

Increased income and dynamic life has lead into the boosting of automobile industry. People need more personal vehicles to cope up with their dynamic life. But this increment is creating a mass congestion in the roads.

According to U.S. Department of Transportation, the number of households with two or more cars has increased substantially, from 22% in 1960 to 58% in 2017. A visual depiction of percentage of households by number of vehicles from 1960-2017 are as follows.

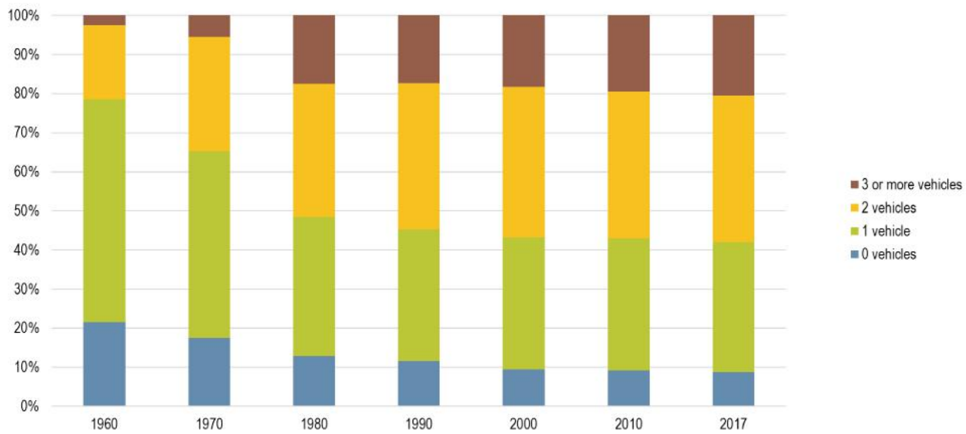

Figure 1: Number of vehicles per household

Source: U. S. Department of Transportation, Volpe National Transportation Systems Center, Journey-to-Work Trends in the United States and its Major Metropolitan Area, 1960–1990, Cambridge, MA, 1994, p. 2-2. 2000 data – U.S. Bureau of the Census, American Fact Finder, factfinder.census.gov, Table QT-04, August 2001. 2010-2014 data – U.S. Bureau of the Census, American Community Survey, Table CP04, 2016.

The EU passenger car fleet grew by 5.7% over the last five years; the number of vehicles on the road went from 243 to 257 million.There are

6.3 million trucks on the EU’s roads. With more than 1 million trucks, Poland has the largest truck fleet in the EU, followed closely by Germany and Italy.

		Austria	Belgium	Czech Republic	Denmark	Finland	France	Hungary	Netherlands	Poland	Slovenia	Sweden
		2016	2016	2016	2016	2016	2016	2014	2016	2016	2014/2015	2016
Households with no cars	%	23.0	17.0	-	39.7	26.0	16.6	48.3	28.7	36.3	18.1	17.3
Households with at least one car	%	77.0	83.0	-	60.3	74.0	83.4	51.7	71.3	63.7	81.9	82.7
Households with one car	%	50.0	55.0	-	44.5	54.0	48.0	86.6	48.2	-		-
Households with two cars	%	21.0	24.0	-	13.8	17.0	30.3	11.7	18.8	-		-
Households with three or more cars	%	6.0	4.0	-	1.6	3.0	5.2	1.7	4.2	-		-
Average ownership period	years	-	-	-	-	3.5	5.6	-	-	-		-
Share of second-hand cars	%	-	-	-	-	-	58.7	-	-	-		-
Average distance travelled	km	13,900	14,999	10,100	-	15,501	12,020	13,000	13,216	-	12,653	12,240
Average distance travelled (petrol)	km	-	9,570	-	-	13,204	8,160	12,400	10,620	-	10,235	9,520
Average distance travelled (diesel)	km	-	18,721	-	-	21,748	14,540	14,700	23,707	-	16,879	17,270

Figure 2: Vehicles in use per country-Europe 2018

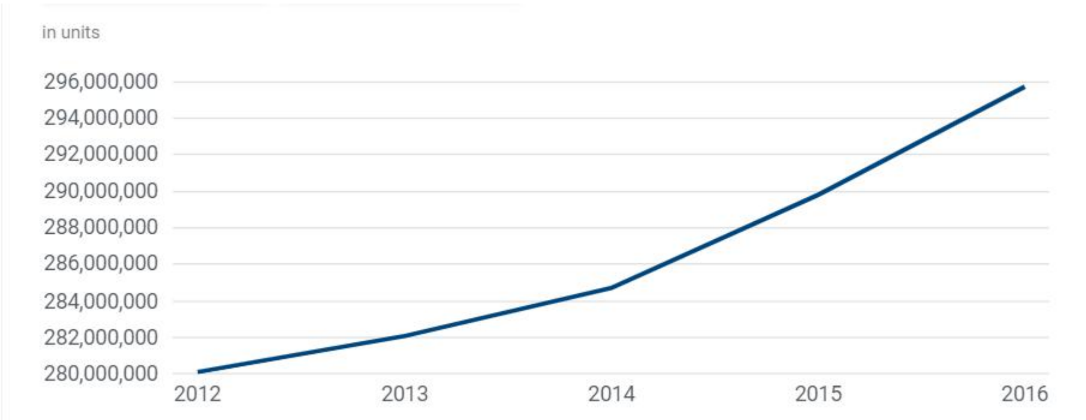

Figure 3: Total number of vehicles in Europe

Source: ACEA Report: Vehicles in use-Europe 2018

Same scenario has been found in other countries over the whole world. This over congestion has lead to increased vehicular crashes and long traffic jams. Millions of working hours are being wasted in the roads and in some case, severe accidents are making lives much harder.

According to the World Health Organization (WHO) report, 1.25 millions of road traffic deaths occurred in the year 2013. Traffic jam also causes a tremendous waste of time and fuel leading to huge economic loss. These major problems can be well addressed if drivers or smart vehicles are updated timely with the current traffic conditions. This sort of promising applications can be offered by Vehicular Communication, presently referred to as Vehicle-to-Everything (V2X) communication. In this case, the different user equipment (UEs) form a network among themselves and share data, for various purposes, for example, to help each other to take the correct decision at the current moment. Its advantages can include ensuring efficient traffic flow, improving vehicular safety and optimizing traffic congestion and accidents.

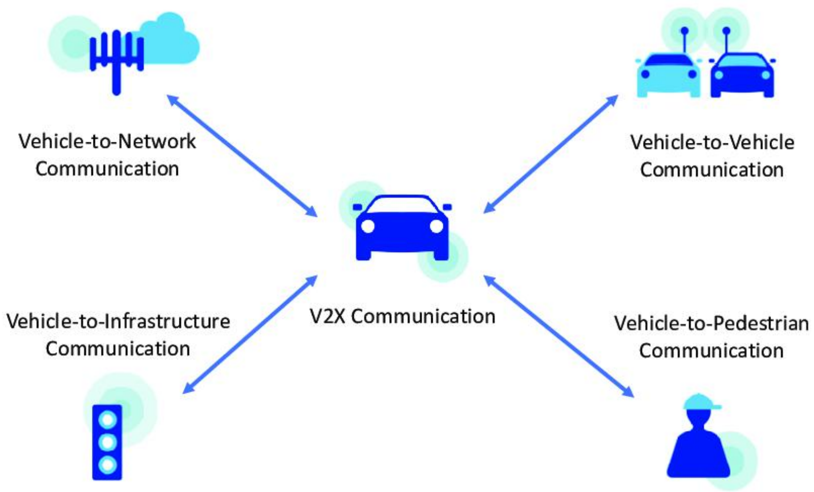

Figure 4: Different types of Vehicular Communication

1.2 V2X and its Prospective

In the not-too-distant future the cars we drive will not only be talking to us, but communicating with each other and the roads below us. Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) technologies, collectively referred to as “V2X,” are currently being developed and tested, with initial integration into new car models planned for 2017. This technology allows the cars to be “connected,” providing the capability of alerting or warning the driver of conditions or hazards around him, with the potential to reduce traffic jams, prevent accidents and save lives.

V2V is a mesh network in which each vehicle is a node with the ability to transmit, receive and re-transmit messages to each other. The resulting network is based on three sets of standards. The first is IEEE 1609, titled “Family of Standards for Wireless Access in Vehicular Environments” (WAVE), which defines the architecture and procedures of the network. The second is the pair of SAE J2735 and SAE J2945, which define the information carried in the message packets. This data would include information from sensors on the car, such as the location, direction of travel, speed, and braking. The third standard is IEEE 802.11p, which defines the physical standards for automotive-related “Dedicated Short Range Communications” (DSRC). In the U.S., V2V will operate in the 5.9 GHz band, compared to your current Wi-Fi device that mainly use 2.4 and 5 GHz.

Automakers such as GM, Ford, Toyota, Hyundai/Kia, Honda, Volkswagen/Audi, Mercedes-Benz and Nissan/Infiniti took part in 2500-vehicle joint project with University of Michigan and National Highway Traffic Safety Administration (NHTSA) to test various V2X concepts. After analysis of the test data, the NHTSA estimated that over a half-million accidents could be prevented and more than a thousand lives saved annually by the technology.

V2I allows the vehicle to communicate with traffic lights and other stationary infrastructure components which also would become nodes in the mesh network. This allows the vehicle to receive information relating to the timing of traffic lights and road signs, or warn the driver of a potential hazard in a blind spot of an intersection.

Chapter 2

Device-to-Device Connectivity

2.1 Overview

Device-to-Device connectivity was introduced in release 12 of the 3GPP LTE specifications. The name itself suggests, a direct radio link among devices which can exchange data among themselves. D2D connectivity is only possible between devices in relatively close proximity, thus the name *proximity service,* or *"ProSe"*.

D2D connectivity was introduced in LTE specifications as an explicitly expressed interest to use the LTE radio-acces technology for public-safety-related communication services. It is seen as an important and in some cases even a requirement to support at least a limited degree of local connectivity between devices even when there is no infrastructure available. Support for direct D2D communication was thus regarded as a critical component to ensure that LTE met all the criteria of the case for public safety use. Nonetheless, support for D2D communication may also enable new types of commercial services, thereby increasing the functionality of LTE radio-access technology in general.

According to LTE, D2D connectivity has been classified into two categories:

- *D2D communication,* which is direct exchange of data between two devices.

- *D2D discovery,* implies the possibility of a device to transmit a signal which enable other devices to know the presence of the prior.

2.2 Sidelink Transmission

The notion of uplink and downlink are not applicable in D2D. 3GPP has introduced *sidelink* to characterize direct D2D link. LTE sidelink connectivity is possible both in paired FDD and unpaired TDD spectrum. Sidelink connectivity also takes place in spectrum not used by commercial cellular networks. Specific spectrum has been assigned in several countries and regions for public safety use case. This can be used for sidelink communication.

In paired spectrum i.e. FDD, sidelink connectivity occurs in the uplink part of the spectrum. Regulatory rules are mainly concerned with what and how devices transmit rather than how devices receive. Besides, it is less complex to include additional receiver functionality. Thus uplink is being used. Similar operation is being performed in case of TDD. Uplink subframes deal with sidelink connectivity.

Sidelink connectivity is basically an unidirectional transmission since all are of broadcast type.

Devices involved in sidelink connectivity can be *under-coverage* or *out-of-coverage*. Again, under-coverage devices can be under same cell or different cells. Release 12 supported only sidelink communication out-of-coverage while sidelink discovery was only possible under network coverage. Release 13 has introduced support for out-of-coverage sidelink discovery for the public-safety use case.

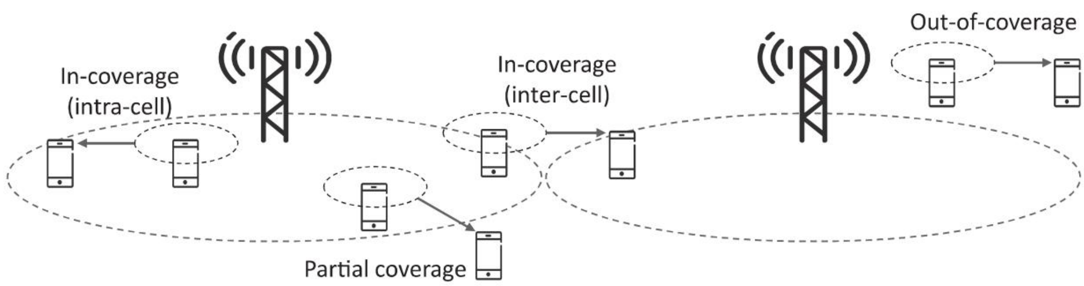

Figure 5: Different coverage scenarios of sidelink connectivity

For devices under network coverage, sidelink connectivity can take place in RRC_CONNECTED state, that is, when the device has an RC connection to the network. However, sidelink connectivity can also take place in RRC_IDLE state, in which case the device does not have a dedicated connection to the network. It should be noted that being in RRC_IDLE state is not the same thing as being out of coverage. A device in RRC_IDLE state may still be under network coverage and will then have access to, for example, the network system information even if there is no RRC connection established.

2.3 Sidelink Synchronization

Before connecting with each other, every devices must be synchronized reasonably and to the overlaid network if present.

Synchronization is done to ensure that sidelink transmissions take place within intended time-frequency resources, thereby reducing the risk for uncontrolled interference to other sidelink and non-sidelink (cellular) transmissions in the same band.

However, to allow for network control of transmission timing to extend beyond the area of direct network coverage LTE sidelink connectivity also includes the possibility for devices to transmit special sidelink synchronization signals (SLSSs). A device under network coverage may transmit SLSS in line with the transmission timing acquired from the network. This signal can then be received and used as timing reference for sidelink transmissions by nearby out-of-coverage devices. These devices can then, in turn, transmit their own SLSS that can be detected and used as timing references by other out-of-coverage devices. In this way, the area over which devices are synchronized to and derive their transmission timing from the overlaid network can be further expanded beyond the area of direct network coverage.

A device not within network coverage and not detecting any sufficiently strong SLSS will autonomously transmit SLSS which can then be detected and forwarded by other out-of-coverage devices. In this way, local synchronization between out-of-coverage devices can be achieved even without the presence of an overlaid network.

In addition to its function as a timing reference for sidelink transmissions for out-of-coverage devices, a SLSS can also serve as a timing reference for sidelink reception.

To ease the reception of sidelink transmissions, a receiving device should preferably have good knowledge of the timing of the signal to be received. For sidelink connectivity between devices using the same transmission-timing reference, for example, in case of in-coverage devices having the same serving cell, a receiving device can use its own transmission timing also for reception.

To enable sidelink connectivity between devices that do not rely on the same reference for transmission timing, a device may transmit SLSS in parallel to its other sidelink transmissions. These synchronization signals can then be used as reference for reception timing by receiving devices.

An example of this is illustrated in following figure. In this case, device A uses the synchronization signal of its serving cell (SS_A) as timing reference for its sidelink transmissions. Similarly, device B uses SS_B as timing reference for its sidelink transmissions. However, as timing reference for the reception of sidelink transmissions from device A, device B will use the synchronization signal $SLSS_A$ transmitted by device A and derived from SSA. Likewise, device A will use $SLSS_B$ as timing reference for the reception of sidelink transmissions from device B.

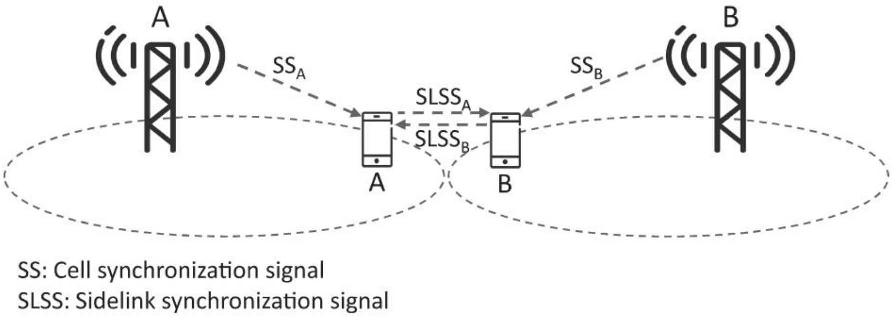

Figure 6: Use of sidelink synchronization signals (SLSS) as timing references.

2.4 Configuration for Sidelink Connectivity

Configuration must be done properly before any sort of sidelink connectivity. Such configuration includes, parameters defining the set of resources (subframes and resource blocks) that are available for different types of sidelink transmission.

Sidelink-related configuration parameters are partly provided as part of the cell system information. More specifically, two new SIBs have been introduced for sidelink-related configuration parameters:

- *SIB18 for configuration parameters related to sidelink communication.*
- *SIB19 for configuration parameters related to sidelink discovery.*

In addition to this common configuration provided via the cell system information, devices in RRC_CONNECTED state that are to engage in sidelink connectivity will also be individually configured by means of dedicated RRC signaling.

Configuration by means of system information or dedicated RRC signaling is obviously not possible for devices that are not under network coverage. Such devices instead have to rely on pre-configured sidelink-related configuration parameters. This pre-configuration essentially serves the same purpose as the common configuration provided as part of the sidelink-related system information.

An out-of-coverage device may, for example, have been provided with the pre-configured parameters at an earlier stage when it was under network coverage. Other possibilities include providing the pre-configuration on the SIM card or hard-coded into the device. Note that out-of-coverage operation is currently only targeting the public-safety use case. Out-of-coverage operation is thus typically associated with special devices/subscriptions.

2.5 Architecture for Sidelink

Following figure illustrates the network architecture related to sidelink connectivity. To support sidelink connectivity a new ProSe Function has been introduced in the core network together with a number of new network interfaces. Among these interfaces, PC5 corresponds to the direct link between devices while PC3 is the interface between sidelink-capable devices and the ProSe Function.

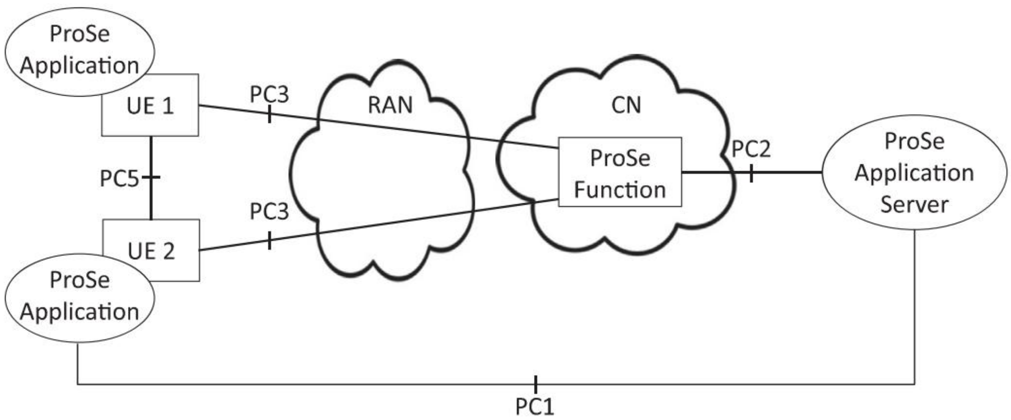

Figure 7: Architecture for sidelink connectivity.

The ProSe Function is responsible for all sidelink functionality within the core network. It provides devices with the parameters needed to establish sidelink connectivity (discovery or communication). The ProSe Function also provides the mapping between discovery message codes and the actual discovery message.

2.6 D2D to V2X

The proximity service (ProSe) known as a Device-to-Device (D2D) communication, defined in Release 12, refers to a direct communication between two or more devices in proximity to each other rather than travelling through the eNodeB. Therefore, several kinds of advantages can be offered due to the proximity, reuse, and hop gain. D2D communications were initially proposed to improve network performance (i.e., enhancing spectrum utilization, improving UEs throughput, increasing cellular capacity, and extending UEs battery lifetime) in cellular technologies. Since V2X technologies have stringent reliability and latency requirements, it was declared in Release 14 that the D2D communication can be applied in vehicular technologies to support V2V communications. As V2X is based on the D2D communication, resources are allocated in the V-UEs either in the overlay mode or in the underlay mode. For that reason, radio resource management (RRM) plays an important role in V2X system performances.

- *LTE-D2D Communication Mode Using PC5 Interface:* LTE-D2D communication refers to the communication mode between two V-UEs in proximity to each other, bypassing the eNB. 'is mode is appropriate for V2V safety services that require low latency delay (e.g., advanced driver assistance systems (ADAS). This communication mode is based on Release 12 proximity services (ProSe) which exploit direct communication between neighboring devices. Two transmission modes are introduced in Release 12 (mode 1 and mode 2) for LTE sidelink (or D2D communication) public safety. These modes are designed in order to prolong the devices' battery lifetime at the cost of increasing the latency. Therefore, mode 1 and mode 2 are not convenient for V2X applications since connected vehicles require low latent and highly reliable V2X communications. Recently, two new sidelink communication modes are introduced in Release 14, which are typically intended for V2V communications, the mode 3 and the mode 4. In mode 3, the radio resources used by the direct V2V communications and the interference management are managed and assisted by the cellular infrastructure (e.g., eNB). However, vehicles autonomously select and assign the radio resources in mode 4 for their direct V2V communications without infrastructure assistance (i.e., this mode can be operated out of cellular coverage).

- *V2V-Based D2D Communication Modes:* There are two V2V communication modes: the overlay mode (which is the orthogonal resource allocation) and the underlay mode (which is the non-orthogonal one) as shown in the following figure. In the overlay mode, specific radio resources from cellular resources are dedicated to the D2D/V2V communication. Thus, the C-UEs cannot achieve the full capacity of the eNB; consequently, this mode decreases the spectrum utilization. The advantage of the overlay mode is that the interference between C-UEs and V2V-UEs does not need to be managed. In the underlay mode, the eNB allows V2V-UEs and C-UEs to share the same radio resources, which can achieve a greatest spectrum efficiency. However, the eNB needs to manage the strong interference among V2V-UEs communications and the C-UEs communications.

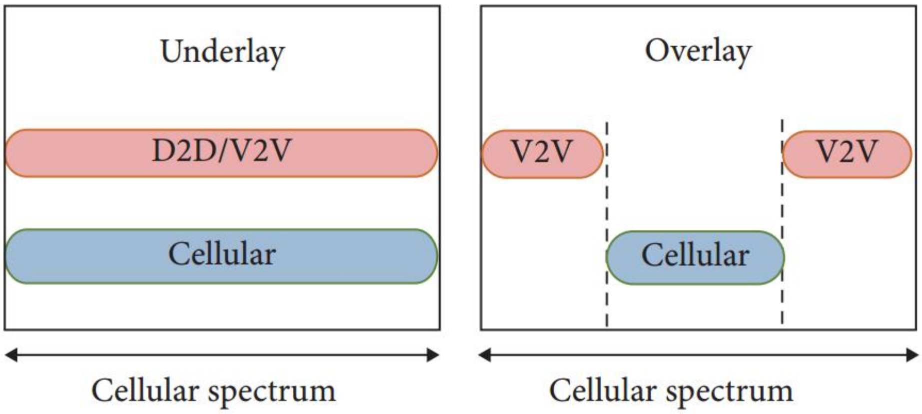

Figure 8: Underlay vs Overlay modes

Both of the overlay and the underlay modes can utilize either the Downlink (DL) or the Uplink (UL) subframe. The set of resources that will be allocated to V2V communication are chosen from the UL subframe owing to their minor peak-to-average power ratio (PAPR) and because it is less utilized than the DL subframe.

Chapter 3

Antecedents of V2X

3.1 Technological Overview

There are two sorts of V2X conversation science depending on the underlying science being used namely WLAN based and Cellular based.

- *WLAN based:* Standardization of WLAN based V2X supersedes that of cellular-based V2X systems. IEEE first posted the specification of WLAN based V2X (IEEE 802.11p) in 2012. It supports direct verbal exchange between vehicles (V2V) and between vehicles and infrastructure (V2I). This technological know-how is referred to as Dedicated Short Range Communication (DSRC). DSRC uses the underlying radio conversation supplied by using 802.11p.

  In 2016, Toyota became the first automaker globally to introduce cars equipped with V2X. These cars use DSRC technological know-how and are only for sale in Japan. In 2017, GM grew to be the 2nd automaker to introduce V2X. GM sells a Cadillac mannequin in the United States that also is geared up with DSRC V2X.

- *Cellular based:* in 2016, 3GPP published V2X specifications based totally on LTE as the underlying technology. It is typically referred to as *Cellular V2X (C-V2X)* to differentiate itself form the 802.11p based V2X technology. In addition to the direct conversation (V2V, V2I), C-V2X additionally helps extensive vicinity verbal exchange over V2N.

  As of December, 2017 European automotive producer has introduced to install V2X technology based totally on 802.11p from 2019. While some research analysis in 2017 and 2018 all carried out via the 5G Automotive Association (5GAA)- the enterprise aiding and growing the C-V2X technological know-how indicate that C-V2X science in direct conversation mode is optimum to 802.11p in multiple aspects, such as performance, conversation range, and reliability, many of these claims are disputed, e.g. in a whitepaper posted by using NXP, one of the businesses lively in the 802.11p based V2X technology, however also posted by using peer-reviewed journals. Industry analysts advise that each applied sciences will proceed to be used in extraordinary areas with the mounted base of V2X equipped cars achieving 6 million with the aid of 2022.

3.2 Standardization History

- *IEEE 802.11p:* WLAN based V2X verbal exchange is based totally on a set of standards drafted by means of the American Society for Testing and Materials (ASTM). The ASTM E2213 sequence of requirements appears at Wi-Fi communication for high-speed data alternate between automobiles themselves as well as avenue infrastructure. The first general of this series was once posted 2002. Here the acronym Wireless Access in Vehicular Environments (WAVE) was first used for V2X communication.

  From 2004 onwards the Institute Electrical and Electronics Engineers (IEEE) commenced to work on Wi-Fi access for vehicles beneath the umbrella of their standards family IEEE 802.11 for Wireless Local Area Networks (WLAN). Their preliminary widespread for wireless verbal exchange for automobiles is recognized as IEEE 802.11p and is primarily based on the work carried out via the ASTM. Later on in 2012 IEEE 802.11p was integrated in IEEE 802.11.

  Around 2007 when IEEE 802.11p got stable, IEEE started out to boost the 1609.x requirements family standardizing applications and a security framework (IEEE makes use of the time period WAVE), and quickly after SAE started out to specify standards for V2V conversation applications. SAE makes use of the time period DSRC for this science (this is how the time period used to be coined in the US). In parallel at ETSI the technical committee for Intelligent transportation machine (ITS) was once headquartered and started out to produce requirements for protocols and applications (ETSI coined the time period ITS-G5). All these requirements are primarily based on IEEE 802.11p technology.

  Between 2012 and 2013, the Japanese Association of Radio Industries and Businesses (ARIB) specified, additionally based totally on IEEE 802.11, a V2V and V2I communication machine in the 700 MHz frequency band.

  In 2015 ITU posted as summary of all V2V and V2I standards that are global in use, comprising the structures special by means of ETSI, IEEE, ARIB, and TTA (Republic of Korea, Telecommunication Technology Association).

- *3GPP:* 3GPP began standardization work of cellular V2X (C-V2X) in Release 14 in 2014. It is based on LTE as the underlying technology. Specifications were posted in 2016. Because of this C-V2X functionalities are primarily based on LTE, it is frequently referred to as LTE-V2X. The scope of functionalities supported via C-V2X includes each direct verbal exchange (V2V, V2I) as well as broad area mobile network conversation (V2N).

  In Release 15, 3GPP continued its C-V2X standardization to be based on 5G. Specifications are published in 2018 as Release 15 comes to completion. To point out the underlying technology, the time period 5G-V2X is frequently used in contrast to LTE-based V2X (LTE-V2X). Either case, C-V2X is the regularly occurring terminology that refers to the V2X technological know-how the use of the cellular science irrespective of the precise era of technology.

  In Release 16, 3GPP similarly enhances the C-V2X functionality. The work is currently in progress. In this way, C-V2X is inherently future proof by using supporting migration direction to 5G.

  Study and evaluation were done to examine the effectiveness of direct conversation technologies between LTE-V2X PC5 and 802.11p from the viewpoint of accident avoided and reduction in deadly and serious injuries. The find out about suggests that LTE-V2X achieves higher stage of accident avoidance and reduction in injury.

  V2X also leads to the opportunity of defending different types of road customers (for example, pedestrian, cyclist) by using PC5 interface which is to be built-in into smartphones, successfully integrating these street users into the universal C-ITS solution. Vehicle-to-Pedestrian (V2P) includes vulnerable road user (VRU) situations to realize pedestrians and cyclists to avoid accident and accidents involving these avenue users.

  As both direct conversation and large vicinity mobile network communication are defined in the same general (3GPP), both modes of verbal exchange will possibly be integrated into a single chipset. Commercialization of those chipsets further enhances economic system of scale and leads to possibilities to wider vary of business fashions and services the use of both types of communications.

3.3 Early Development

Experiments have been performed on automatic driving structures (ADS) for few decades; trials began in the 1950s. The first semi-automated automobile was once developed in 1977, by using Japan's Tsukuba Mechanical Engineering Laboratory, which required mainly marked streets that had been interpreted by way of two cameras on the vehicle and an analog computer. The car reached speeds up to 30 kilometers per hour (19 miles per hour) with the aid of a multiplied rail.

The first surely self-reliant motors appeared in the 1980s, with Carnegie Mellon University's Navlab and ALV tasks funded via the United States' Defense Advanced Research Projects Agency (DARPA) starting in 1984 and Mercedes-Benz and Bundeswehr University Munich's EUREKA Prometheus Project in 1987. By 1985, the ALV had validated self-driving speeds on two-lane roads of 31 kilometers per hour (19 mph) with obstacle avoidance added in 1986 and off-road using in day and night time prerequisites through 1987. A fundamental milestone was once finished in 1995, with CMU's NavLab 5 completing the first independent coast-to-coast pressure of the United States. Of the 2,849 mi (4,585 km) between Pittsburgh, Pennsylvania and San Diego, California, 2,797 mi (4,501 km) had been independent (98.2%), achieved with an common pace of 63.8 mph (102.7 km/h).From the Sixties via the 2d DARPA Grand Challenge in 2005, automatic car lookup in the United States was exceptionally funded by means of DARPA, the US Army, and the US Navy, yielding incremental advances in speeds, using competence in greater complex conditions, controls, and sensor systems. Companies and research companies have developed prototypes.

The US allocated US$650 million in 1991 for research on the National Automated Highway System, which tested computerized driving thru a combination of automation, embedded in the motorway with computerized technology in cars and cooperative networking between the motors and with the motorway infrastructure. The application concluded with a successful demonstration in 1997 but barring clear course or funding to put into effect the gadget on a large scale. Partly funded with the aid of the National Automated Highway System and DARPA, the Carnegie Mellon University Navlab drove 4,584 kilometers (2,848 mi) across America in 1995, 4,501 kilometers (2,797 mi) or 98% of it autonomously. Navlab's report fulfillment stood unmatched for too many years until 2015 when Delphi improved it by means of piloting an Audi, augmented with Delphi technology, over 5,472 kilometers (3,400 mi) thru 15 states while remaining in self-driving mode 99% of the time. In 2015, the US states of Nevada, Florida, California, Virginia, and Michigan, together with Washington, DC, allowed the checking out of automated cars on public roads.

In 2017, Audi cited that its cutting-edge A8 would be automated at speeds of up to 60 kilometers per hour (37 mph) the usage of its "Audi

AI". The driver would not have to do protection exams such as often gripping the steering wheel. The Audi A8 was once claimed to be the first manufacturing car to reach Level three automated driving, and Audi would be the first producer to use laser scanners in addition to cameras and ultrasonic sensors for their system.

In November 2017, Waymo introduced that it had begun trying out driverless automobiles barring a security driver in the driver position; however, there was still a worker in the car. In October 2018, Waymo announced that its check automobiles had traveled in automated mode for over 10,000,000 miles (16,000,000 km), growing by means of about 1,000,000 miles (1,600,000 kilometers) per month. In December 2018, Waymo used to be the first to commercialize a thoroughly self-reliant taxi provider in the US

A*STAR's Institute for Infocomm Research (I2R) has developed a self-driving vehicle which was the first to be approved in Singapore for public avenue testing at one-north in July 2015. It has ferried quite a few dignitaries such as Prime Minister Lee Hsien Loong, Minister S. Iswaran, Minister Vivian Balakrishnan, and countless ministers from different countries.

3.4 Regulatory History

- *USA:* In 1999 the US Federal Communications Commission (FCC) allocated 75 MHz in the spectrum of 5.850-5.925 GHz for wise transport systems. Since then the US Department of Transportation (USDOT) has been working with a range of stakeholders on V2X. In 2012 a pre-deployment assignment was applied in Ann Arbor, Michigan. 2800 cars masking cars, motorcycles, buses and HGV of one of a kind manufacturers took part the usage of equipment with the aid of distinct manufacturers. The US National Highway Traffic Safety Administration (NHTSA) noticed this model deployment as proof that avenue safety should be extended and that WAVE fashionable technological know-how was interoperable. In August 2014 NHTSA posted a document arguing vehicle-to-vehicle technological know-how was technically confirmed as ready for deployment. On 20 August 2014 the NHTSA posted an Advance Notice of Proposed Rule Making (ANPRM) in the Federal Register, arguing that the safety benefits of V2X communication may want to only be carried out if a giant phase of the cars fleet was equipped. Because of the lack of an immediate advantage for early adopters, the NHTSA proposed a mandatory introduction. On 25 June 2015 the US House of Representatives held a hearing on the matter, the place once more the NHTSA, as nicely as different stakeholders argued the case for V2X.

- *Europe:* To collect EU-wide spectrum, radio purposes require a harmonized standard, in case of ITS-G5 ETSI EN 302 571, first published in 2008. A harmonized general in turn requires an ETSI System Reference Document, here ETSI TR 101 788. Commission Decision 2008/671/EC harmonizes the use of the 5.875-5.905 MHz frequency band for transport protection ITS applications. In 2010 the ITS Directive 2010/40/EU was adopted. It aims to assure that ITS applications are interoperable and can operate across national borders, it defines priority areas for secondary legislation, which cover V2X and requires technologies to be mature. In 2014 the European Commission's industry stakeholder “C-ITS Deployment Platform” commenced working on a regulatory framework for V2X in the EU. It identified key methods to an EU-wide V2X security Public Key infrastructure (PKI) and data protection, as well as facilitating a mitigation standard to stop radio interference between ITS-G5 based totally V2X and street charging systems. The European Commission acknowledged ITS-G5 as the preliminary communication technology in its 5G Action Plan and the accompanying explanatory document, to shape a conversation surroundings consisting of ITS-G5 and cellular conversation as estimated by EU Member States. Various pre-deployment initiatives exist at EU or EU Member State level, such as SCOOP@F, the Testfeld Telematik, the digital testbed Autobahn, the Rotterdam-Vienna ITS Corridor, Nordic Way, COMPASS4D or C-ROADS.

Chapter 4

Vehicle-to-Everything (V2X) Communication

4.1 Modes of Operation

There are mainly four modes of operation currently deployed in V2X. They are Vehicle-to-Vehicle Communication (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Pedestrian (V2P), and Vehicle-to-Network (V2N). These four modes can be used simultaneously for safety, autonomous vehicle control enhancement by using data from nearby sensors and accident prevention. These four modes are discussed below.

1. *Vehicle-to-Vehicle (V2V):* V2V allows vehicles at proximity to form a mesh network and exchange data, which helps to make better decisions through information exchange among the existing nodes. This is done by subscribing into a network operator and gaining authorization. V2V applications work by transmitting messages carrying V2V application information, such as traffic dynamics, the location of the vehicle, vehicle attributes, etc. The message payloads are kept flexible for better communication. Besides, 3GPP messages are predominantly broadcast. Thus, ensuring the one-to-many transmission of data with minimum latency involved, which is a prerequisite for V2V.

2. *Vehicle-to-Infrastructure (V2I):* V2I application information is transmitted through a Remote Switching Unit (RSU) or locally available application server. RSUs are roadside stationary units, which act as a transceiver. RSUs or available application servers receive the broadcast message and transmits the message to one or more UEs supporting V2I application. V2I can provide us with information, such as available parking space, traffic congestion, road condition, etc. Due to the high cost and lengthy deployment time, its application or installation is more challenging. A remedy to this problem is V2N, discussed afterward.

3. *Vehicle-to-Pedestrian (V2P):* V2P transmission occurs between a vehicle and Vulnerable Road Users (VRUs) like pedestrians, bicyclists, etc. The UEs carried by the drivers and pedestrians will be able to receive and send messages and alerts. Vehicles can communicate with VRUs even when they are in Non-Line of Sight (NLOS) and under

low visibility cases such as dark night, heavy rain, foggy weather, etc. The sensitivity of pedestrian UEs is lower than vehicular UEs because of the antenna and battery capacity difference. So V2P application supported UEs cannot transmit continuous messages like V2V supported UEs.

4. *Vehicle-to-Network (V2N):* V2N transmission is between a vehicle and a V2X application server. A UE supporting V2N applications can communicate with the application server supporting V2N applications, while the parties communicate with each other using Evolved Packet Switching (EPS). V2X services are required for different applications and operation scenarios. It will help mobile operators to communicate the tasks of the RSU over its network, reducing time to market, cost and eliminating the complexity of designing and running a purpose-built network for V2I as it could include communication between vehicles and the server via 4G or even 5G network. It does not need to be as precise as V2V but reliability is crucial.

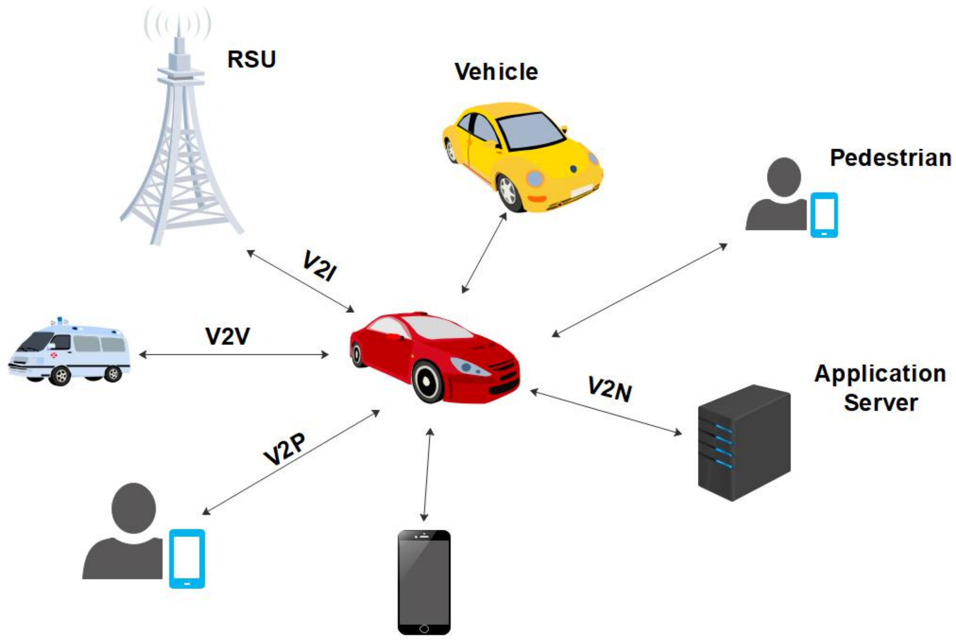

Figure 9: Different types of V2X applications in 3GPP

4.2 Specifications

There are a few different standards supporting V2X communication and two of them, considered seriously for use in America and in Europe, are known as Dedicated Short Range Communication (DSRC) and

Cooperative Intelligent Transport Systems (C-ITS), respectively. Due to parallel development in this volatile field, these two standards have similarities as well as differences. The organizations responsible for developing these standards are known as Standards Developing Organizations (SDOs). In America, they are IEEE and SAE, whereas in Europe they are ETSI and CEN. Different standards are discussed below.

1. *C-V2X:* C-V2X is the cellular counterpart of DSRC, which is based on LTE technologies. The main feature of it is the use of a D2D interface termed as PC5, which supports enhanced V2V use cases with more emphasis on V2X requirements. The 5G system is introduced in 3GPP Release 15, which is completed in 2018. Later 3GPP Release 16 is introduced and expected to be completed within 2019. The 5G radio interface is known as 5G New Radio (NR). 3GPP Releases 15 and 16 will introduce more V2X services by increasing ability to deal with high relative vehicle speed up to 500 km/h, ensuring longer range communication and efficient resource allocation, enhanced services in higher density, very high throughput, high reliability, highly precise positioning, and most importantly ultralow latency. This system operates in the spectrum between 30GHz and 300GHz. It also ensures data rates higher than 7Gbps, an end-to-end latency less than 10ms and link establishment latency of 1ms. Downlink and uplink access technologies are based on Single Carrier Frequency Division Multiple Access (SC-FDMA) for 3GPP Release 15 and Orthogonal Frequency Division Multiple Access (OFDMA) for 3GPP Release 16. Resource multiplexing across vehicles uses TDM and FDM techniques for 3GPP Release 15 and also possibly for 3GPP Release 16. Data channel coding uses turbo method for 3GPP Release 15 and LDPC for 3GPP Release 16. Modulation supports up to 64 QAM for 3GPP Release 15 and up to 256 QAM for 3GPP Release 16. Both the schemes cover over 450 meters using direct mode and a very large area using cellular infrastructure.

2. *DSRC:* These standards are mainly derived from IEEE 802.11-2012 where Physical Transmission (PHY) and MAC are clearly defined though they are adjusted according to the requirements of V2X. As a derivative of IEEE 802.11, it also operates in the 5 GHz frequency band, the difference being the use of dedicated channels instead of the regular WiFi channels. The range of this dedicated channel is 5.825 to 5.925 GHz where the spectrum is divided into 10 MHz channels. The multiplexing technology used here is OFDM. The specialty of the OFDM used here compared to the common usage in WiFi is the use of half clock. This reduces the 20 MHz bands to 10 MHz doubles the

OFDM symbol duration with the cyclic prefix. This compensates the Doppler spread due to the high speed of vehicles.

Various SDOs have defined different aspects of DSRC. For example, IEEE 802.11 has defined the Basic Service Set (BSS), which provides different network topologies with an access point or mesh network. IEEE 1609.4 defines a management extension to the MAC to ensure the best utilization of the allocated multiple wireless channels in the 5 GHz band. Security is defined in terms of authentication and optional encryption, which are based on digital signatures and certificates in IEEE 1602.2. It ensures the privacy of the user in V2X.

3. *C-ITS:* The European Telecommunications Standards Institute (ETSI) is an independent, not-for-profit, standardization organization in the telecommunications industry. C-ITS is a European development for vehicle-to-vehicle communication. There are some fundamental similarities between C-ITS and DSRC in the sense that, for access technologies, networking and transport, and V2X messages they use the same structure of horizontal layers whereas for management and security entities, the same vertical layers. It also operates in the 5 GHz band, where the spectrum allocation is subdivided into part A to D where ITS-G5A (30 MHz) is the primary frequency band. It uses the half clock OFDM in the physical layer with the added feature of an adapted spectrum mask. Another feature of CITS is the use of EDCA with CSMA/CA and access categories to aid in data traffic prioritization. For V2X messages it uses Co-operative Awareness Message (CAM), which is similar to BSS. For spreading safety information, Distributed Environmental Notification Message (DENM) is used, which is not automatic as CAM and needs triggering from an application. The aforementioned features along with the other features of C-ITS are indirectly standardized by setting a minimum requirement for three groups of applications, namely Road Hazard Signaling (RHS), Intersection Collision Risk Warning (ICRW) and Longitudinal Collision Risk Warning (LCRW).

4. *Advanced ITS:* Telecommunications Technology Association (TTA) is a South Korea based organization. Advanced ITS is a modified version of IEEE 802.11p, which is deployed in the Republic of Korea. TTA established four standards for advanced ITS radio communications, as shown below.

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

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)

The advanced ITS radio communications considers the described V2V/V2I communication schemes and its service requirements for international harmonization. In V2V applications, it considers the low packet latency because the life-saving time of safety message is useful in the span of 100ms. Also, it requires a highly activated radio channel when many vehicles try to activate radio channel simultaneously. In V2I applications, it needs to adopt the long packet transmission, which includes a short message, map information and image information to be an order of 2 kilobytes in a packet size in high mobility condition.

5. *ARIB Development:* This technology has been developed in Japan by Association of Radio Industries and Businesses (ARIB). For the use of safe driving support systems, a part of the 700 MHz band (755.5-764.5 MHz) has been assigned in a new spectrum allocation on a primary basis in the digital dividend band. A 9 MHz channel width in the 700 MHz radio frequency band will be used for the safe driving support systems. The data transmission rate is variable based on the selection of different modulation scheme and coding rate. The single channel accommodates both V2V and V2I communications based on CSMA/CA media access control.

Table 1: Comparison of Different Specifications of V2X

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
Throughput	Very high	Moderate	Moderate	Moderate	Moderate
Reliability	Very high	Moderate	Moderate	Moderate	Moderate
Synchronization	Synchronous	Asynchronous	Asynchronous	Asynchronous	Asynchronous
Resource multiplexing across vehicles	TDM and FDM	TDM only	TDM only	TDM only	TDM only
Data channel	Turbo coding and LDPC	Convolutional code	Convolutional code	Convolutional code	Convolutional code

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

Chapter 5

Level of Automation

The degree to which a task is automated is referred to as levels of automation. Society of Automotive Engineers (SAE) defined 6 levels of driving automation starting at level zero which is No Automation and ending to level five which is Full Automation.

- *Level 0 (No Automation):* Most of the cars on road today define this level. It includes all the cars without at least adaptive cruise control.

- *Level 1 (Driver Assistance):* Defines cars with the driver assistance system of either steering or acceleration/braking. The system monitors just some of the total driving environment. The human must supervise the system for all remaining driving task because hand off can happen at any time and the driver must always be ready to take over. This level is typically associated with cars that offers adaptive cruise control. Many high-end cars now offer this feature. This is meant to be used in highways. On local roads, proper care must be taken if there is no car in front of it and it approaches to red light or stops. Unlike the normal cruise control, the car won't stop, however at red light the car will stop if there is another car in front of it.

- *Level 2 (Partial Automation):* Defines cars with multiple driving assistance system that include both steering and acceleration/braking. System monitors just some of the total driving environment. A human must supervise the system and perform all remaining tasks. Hand off can happen at any time and the driver must always be ready to take over.

- *Level 3 (Conditional Automation):* Cars will have multiple driving assistance system and it will monitor the complete driving environment and perform all the driving tasks. However there is an expectation that the human driver will respond appropriately to a request to intervene. This is similar to level 2 automation apart from the fact that the car should be able to perform many more driving tasks and perhaps give the human more notice when it needs assistance.

- *Level 4 (High Automation):* The car will have multiple driving assistance systems to monitor the complete driving environment and perform all the driving tasks even if the human driver does not respond properly to a request to intervene. This is very close to full automation, however this is assumed that the car is perhaps operating in a controlled area, for example, ones with limited speed or certain times of the day or even under certain weather conditions.

- *Level 5 (Full Automation):* Cars will have a full time automated driving system and perform all driving tasks under all roadways and environments. The human can simply manage the system and is not used to intervene. None of the companies till now are close to achieving true level 5 automation.

Chapter 6

Different Use Cases

6.1 Applications

V2X can be used for various purposes. Their application can make mobility much smoother and free from danger. The major types of V2X applications are as follows.

1. *Safety Application:* It operates by notifying the drivers and the pedestrians about the current road condition. Drivers and pedestrians are periodically updated about their surroundings. In an intersection, vehicles are warned about the different complexities they might face, thus helping them in decision making. From the information shared by different vehicles, RSUs broadcast it throughout the UEs for better deliberations and maneuvers. This shared information can also be used to distinguish and locate endangered sections of a road.

   i. Forward Collision Warning: Forward Collision Warning (FCW) application serves by alerting a Host Vehicle (HV) about a possible collision with a Remote Vehicle (RV). With V2V service, FCW helps drivers to mitigate or avoid rear-end collisions.

   ii. Control Loss Warning: Control Loss Warning (CLW) works by broadcasting a message about the loss of self-generated control. Surrounding RVs are notified about the HV's condition, thus they perform maneuvers to avoid collisions in such conditions.

   iii. V2V Use for Emergency Vehicle: An emergency vehicle like an ambulance or fire brigade vehicle broadcast messages, which ask RVs to make a gap for fast mobility.

   iv. V2V Emergency Stop Use Case: This operation is performed to keep a vehicle away from any sort of eminent obstruction. This ensures a safer maneuver and collision-free environment.

   v. Wrong Way Driving Warning: This use case enables communication between two vehicles moving in opposite directions. In this scenario, the wrong sided vehicle is warned about its wrong heading and a safety behavior is triggered for cars in the vicinity.

vi. Pre-Crash Sensing Warning: Alerts are generated and onboard safety measures are activated in this case. The moment where a crash cannot be omitted, the application warns the driver about the imminent contact and activates all the available safety measures.

vii. Pedestrian Warning: Pedestrians are warned about their surroundings periodically. Alerts are sent to road users to avoid collision with a moving vehicle.

2. *Non-Safety Application:* Non-safety based applications mainly focus on reducing traffic, increasing traffic efficiency, improving traffic flow, ensure improved traffic coordination and provide assistance to the drivers. Moreover, they supply updated information, maps, and real-time data to each other.

   i. V2N Traffic Flow Optimization: V2N traffic flow works by managing the speed of the vehicles for smooth driving. The priority of vehicles can be taken into consideration to ensure a harmonious surrounding.

   ii. Co-operative Adaptive Cruise Control (CACC): This application focuses on improving traffic efficiency by controlling the navigation vehicles, where a vehicle with V2V capability can leave and join a group of CACC vehicles. This application can provide safety and convenience for CACC vehicles. This application also helps in reducing traffic congestion, thus improving traffic efficiency. The latency-tolerant applications also fall in this category. These applications include discovering unoccupied parking slots, traffic flow control, and cloud-based sensor sharing.

6.2 Potential Cases

- *Safety:* Driving protection experts predict that as soon as the driverless technology entirely develops, site visitors' collisions (and ensuing deaths, injuries and costs), caused via human error, and such as delayed response time, tailgating, rubbernecking, and other types of distracted or aggressive driving should be drastically reduced.

Consulting association McKinsey & Company estimated that vast use of independent cars could eliminate 90% of all auto accidents in the United States, stop up to US$190 billion in damages and health-costs annually and save hundreds of lives.

To help limit the possibilities of the confounding factors, some organizations have begun to open-source parts of their driverless systems.

- *Welfare:* Automated automobiles may reduce labor costs, relieve travelers from riding and navigation chores, thereby replacing behind-the-wheel commuting hours with greater time for entertainment or work; and additionally would raise constraints on occupant capability to drive, distracted and texting while driving, intoxicated, susceptible to seizures, or otherwise impaired. For the young, the elderly, humans with disabilities, and low-income citizens, computerized cars may provide improved mobility.

  The removal of the guidance wheel along with the final driver interface and the requirement for any occupant to expect a forward-facing position would provide the indoors of the cabin increased ergonomic flexibility. Large vehicles, such as motorhomes, would gain notably superior ease of use.

- *Traffic:* Additional advantages should encompass greater velocity limits, smoother rides, and accelerated roadway capacity, and minimized vehicle congestion due to decreased want for protection gaps and greater speeds. Currently, most controlled-access motorway throughput or capability according to the US Highway Capacity Manual is about 2,200 passenger cars per hour per lane, with about 5% of the handy avenue space is taken up by cars. One study estimates that automated vehicles should make bigger capability by means of 273% (≈8,200 automobiles per hour per lane). The learn about also estimated that with a hundred percent related cars the usage of vehicle-to-vehicle communication, potential could reach 12,000 passenger motors per hour (up 545% from 2,200 vehicles/h per lane) touring safely at a hundred and twenty km/h (75 mph) with a following gap of about 6 m (20 feet) of each other. Drivers at dual carriageway speeds maintain between 40 to 50 meters (130 to 160 feet) away from the vehicle in front. These increases in dual carriageway potential ought to have a substantial effect in visitors' congestion, particularly in cities areas and even effectively stop dual carriageway congestion in some places. The capability for authorities to manipulate visitors flow would increase, given the greater data and riding conduct predictability mixed with less want for traffic police and even road signage.

- *Parking Space:* Manually pushed vehicles are suggested to be used only 4–5% of the time, and being parked and unused for the last 95–96% of the time. Autonomous taxis could be used always after it has reached its destination. This ought to dramatically reduce the want for parking space. For example, in Los Angeles a 2015 study discovered 14% of the land is used for parking alone, equal to some 1,702 hectares (4,210 acres).This blended with the practicable reduced want for street house due to expanded visitors flow, could free up massive amounts of land in urban areas, which may want to then be used for parks, recreational areas, buildings, amongst different uses; making cities more livable.

  Besides this, privately owned self-driving cars, additionally capable of self-parking would provide some other advantage: the ability to drop off and select up passengers even in locations the place parking is prohibited. This would gain park and experience facilities.

6.3 Potential changes for different industries

The traditional automobile industry is an issue to adjustments driven via technology and market demands. These changes consist of breakthrough technological advances and when the market demands and adopts new science quickly. In the rapid strengthen of each factors, the quit of the generation of incremental change was once recognized. When the transition is made to a new technology, new entrants to the automotive industry present themselves, which can be uncommon as mobility carriers such as Uber and Lyft, as well as tech giants such as Google and Nvidia. As new entrants to the industry arise, market uncertainty naturally occurs due to the changing dynamics. For example, the entrance of tech giants, as well as the alliances between them and common auto producers motives a version in the innovation and production procedure of autonomous vehicles. Additionally, the entrance of mobility companies has brought about ambiguous person preferences. As a result of the upward thrust of mobility providers, the variety of vehicles per capita has flat lined. In addition, the upward push of the sharing economic system also contributes to market uncertainty and motives forecasters to query whether non-public ownership of cars is still applicable as new transportation science and mobility companies are becoming desired among consumers.

- *Taxis:* With the aforementioned ambiguous consumers' desire regarding the personal possession of autonomous vehicles, it is viable that the contemporary mobility provider fashion will continue as it rises in popularity. Established vendors such as Uber and Lyft are already substantially existing within the industry, and it is probable that new entrants will enter when enterprise possibilities arise.

- *Healthcare, Car repair, and Car insurance:* With the growing reliance of self-reliant vehicles on interconnectivity and the availability of big records which is made usable in the structure of real-time maps, riding decisions can be made a whole lot faster in order to prevent collisions. Numbers made available by using the US government that 94% of the automobile accidents are due to human failures. As a result, primary implications for the healthcare enterprise turn out to be apparent. Numbers from the National Safety Council on killed and injured human beings on US roads elevated by means of the common costs of a single incident disclose that an estimated US$500 billion loss can also be drawing close for the US healthcare industry when self-sufficient cars are dominating the roads. It is probable the expected limit in visitors' accidents will positively make a contribution to the tremendous acceptance of self-sufficient vehicles, as nicely as the possibility to better allocate healthcare resources. As collisions are less in all likelihood to occur, and the threat for human mistakes is decreased significantly, the restore industry will face a tremendous discount of work that has to be achieved on the reparation of car frames. Meanwhile, as the generated records of the self-sustaining automobile is probable to predict when positive replaceable parts are in need of maintenance, vehicle owners and the restore industry will be capable to proactively substitute a phase that will fail soon. This "Asset Efficiency Service" would implicate a productivity reap for the automobile restore industry. As fewer collisions implicate less cash spent on repair costs, the function of the insurance plan industry is possibly to be altered as well. It can be predicted that the expanded protection of transport due to autonomous vehicles will lead to a decrease in payouts for the insurers, which is high quality for the industry, however fewer payouts may additionally suggest a demand drop for insurances in general. The insurance industry may additionally have to create new insurance fashions in the near future to accommodate the changes. An unexpected downside of the sizeable acceptance of self-sustaining automobiles would be a reduction in organs handy for transplant.

- *Rescue, emergency response, and military:* The method used in self-reliant riding additionally ensures life savings in different industries. The response, and navy functions have already led to a reduce in death. Military personnel use self-sufficient cars o attain unsafe and far flung places on earth to supply fuel, meals and usual supplies and even rescue people. In addition, a future implication of adopting self-sufficient vehicles should lead to a discount in deployed personnel, which will lead to a reduce in injuries, seeing that the technological development approves autonomous vehicles to turn out to be extra and greater autonomous. Another future implication is the discount of emergency drivers when independent vehicles are deployed as fire vehicles or ambulances. An advantage should be the use of real-time site visitors' information and other generated records to decide and execute routes greater successfully than human drivers. The time financial savings can be beneficial in these situations.

- *Interior design and entertainment:* With the driver decreasingly focused on operating a vehicle, the interior layout and media-entertainment industry will have to rethink what passengers of autonomous vehicles are doing when they are on the road. Vehicles need to be redesigned, and possibly even be prepared for multipurpose usage. In practice, it will exhibit that travelers have greater time for commercial enterprise and/or leisure. In both cases, this offers increasing possibilities for the media-entertainment enterprise to demand attention. Moreover, the commercial enterprise is able to provide location based ads besides risking driver safety.

- *Telecommunication Energy:* All vehicles can take advantage from statistics and connections, but self-sustaining vehicles *will be entirely successful of running besides C-V2X.* In addition, the beforehand referred to amusement industry is also rather structured on this network to be active in this market segment. This implies greater revenues for the telecommunication industry.

  Since many independent cars are going to count on electrical energy to operate, the demand for lithium batteries increases. Similarly, radar, sensors, lidar, and high-speed internet connectivity require greater auxiliary energy from vehicles, which manifests as higher strength drawn from batteries. The larger battery requirement reasons a vital change in the types of chemical industry.

On the different hand, with the anticipated bigger battery powered (autonomous) vehicles, the petroleum enterprise is predicted to bear a decline in demand. As this implication relies upon on the adoption charge of self-reliant vehicles, it is not sure to what extent this implication will disrupt this particular industry. This transition phase of oil to electrical energy approves businesses to explore whether or not there are commercial enterprise possibilities for them in the new power ecosystem.

- *Restaurants, hotels and aeroplane:* Driver interactions with the car will be much less common within the near future, and after a long time the responsibility will lie completely with the vehicle. As indicated above, this will have implications for the entertainment and indoors plan industry. For roadside restaurants, the implication will be that the need for customers to cease driving and enter the restaurant will vanish, and the self-reliant vehicle will have a double function. Moreover, accompanied with the rise of disruptive structures such as Airbnb that have shaken up the hotel industry, the quick expand of developments inside the autonomous vehicle industry might reason every other implication for their client bases. In the more distant future, the implication for accommodations may be that a limit in company will occur, since autonomous cars could be redesigned as fully equipped bedrooms. The upgrades related to the interior of the automobiles would possibly additionally have implications for the airline industry. In the case of particularly short-haul flights, waiting times at customs or near the gates suggest lost time and trouble for customers. With the extended comfort in future vehicle travel, it is feasible that clients may go for this option, causing a loss in customer bases for airline industry.

- *Elderly, disabled, and children:* Autonomous vehicles will have a severe influence on the mobility options of elderly persons and people who are not capable to drive themselves. In addition to the perceived freedom of the elderly humans of the future, the demand for human aides will decrease. When we also reflect on consideration on the extended health of the elderly, it is protected to nation that care centers will experience a reduction in the variety of clients. Not solely aged people face difficulties of their reduced physical abilities, additionally disabled humans will pick out the benefits of independent automobiles in the near future. Both industries are generally relying on informal caregivers, who are on the whole household of the humans in need. Since there is less of a reliance on their time, employers of informal caregivers or even governments will trip a minimum of fees allocated to this matter. Children and teens, who are not capable to drive a vehicle themselves, are additionally benefiting from the introduction of self-sustaining cars. Day-cares and schools are capable to come up with automated choose up and drop off systems, inflicting a reduction in reliance on parents and childcare workers. The extent to which human actions are vital for riding will vanish. Since contemporary vehicles require human moves to some extent, the using faculty enterprise will no longer be disrupted till the majority of self-sufficient transportation is switched to the emerged dominant design. It is attainable that in the distant future driving a vehicle will be considered as a luxury, which implies that the shape of the enterprise is based on new entrants and a new market.

Chapter 7

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. *Hardware Requirements:* To implement V2X, the vehicle needs to have this hardware incorporated.

i. Cameras: Works as the vision of the system. Data accessed through the camera is used for further decision making.

ii. Radars: Augments the camera in NLOS cases, low sunlight and bad weather.

iii. Lidar: Lidar (Light Detection And Ranging) technology creates the 3D images of the objects nearby, giving the user more information about the surroundings.

iv. Ultrasonic sensors: Ultrasonic sensors use ultrasonic sound waves and measure the distance by calculating the time between the transmitted and received signals.

v. V2X wireless sensors: These sensors are used mainly to see through objects and to get 360 NLOS view, which aids in the better judgment of overall road conditions.

vi. 3D HD Map: Provides the user with full HD maps in order to navigate accurately.

vii. Global Navigation Satellite System (GNSS): GNSS provides highly precise data on the position of the vehicle. This can be used for deriving accurate speed, accurate heading, and time synchronization.

2. *Capacity Requirements:* As road safety is of utmost concern when planning to implement V2X on a mass scale, the system itself has some strict requirements, as shown below.

i. Low Latency: End-to-End delay occurs due to delay in gathering data from local sensors, processing delay in the protocol levels and transmission delay over wireless media. Security mechanisms (signature and certificate verification) add some more delay in the process. In G-V2X, the latency is kept at 300ms [ETSI TS 102 539-1]. But autonomous driving demands more attention to this matter. A very small delay can result in a disaster in autonomous vehicles. Hence, this field requires more attention.

ii. Data Load Control: Smaller inter-vehicular distance and high vehicle-density results in a heavy flow of data. This is amplified by the high message rate and by additional data load for the exchange of control messages. In order to ensure uniform flow of data, utilization of the current frequency spectrum, effective prioritization of messages using Decentralized Congestion Control (DCC) function and strict control of forwarding operations are required.

High Message Rate: In 1G-V2X vehicles broadcast periodically within every 100ms to 1s. Here the data flow is controlled by the dynamics of the generating vehicle and the capability of the wireless channel. But autonomous vehicles need more data with lower latency. They need to know about the neighboring vehicles to make the correct decision. Autonomous vehicles require a complete and real-time environmental model to coordinate maneuvers in a safe manner.

Chapter 8

Spectrum

The spectrum use of V2X services based on LTE sidelink is described in this section. 3GPP specifies the RF requirements based on adjacent coexistence of LTE based V2V operation in different regions, as shown below.

- *ITU Region 1:* In Europe Intelligent Transport Systems (ITS) are regulated in the ETSI within the band 5.855 GHz to 5.925 GHz. ECC Decision (08)01 defined the spectrum utilization conditions within the band 5.875 GHz to 5.905 GHz. It aims for non-safety ITS and proposes CEPT frequency with sub-band 5.905 GHz to 5.925 GHz for the spread of ITS spectrum. ECC Recommendation (08)01 states that spectrum utilization should be within the range 5.855 GHz to 5.875 GHz for non-safety ITS. For safety-related ITS applications, 5.875 GHz to 5.905 GHz is considered in the Commission Decision 2008/671/EC.

- *ITU Region 2:* The Americas and Greenland are under this region. Here IEEE Working Group 802.11 and 1609 have standardized the V2V architecture and protocols in the name of Wireless Access Vehicular Environments (WAVE), which operates in the band 5.850 GHz to 5.925 GHz. A guard band of 5 MHz is considered from 5.850 to 5.855 GHz. Three types of channels are there in V2X, namely control channel 178, shard channels 172, 174, 176, 180, 182 and 184 and aggregated channels 175 and 181. Aggregated channels have a bandwidth of 20 MHz and are used for multi-channel operations. According to FCC 06-110, channel 172 is reserved for V2V safety communications. Channel 184 is used for higher power and long-distance communication. It is also used for public safety operations.

- *ITU Region 3:* This region covers all parts of Asia except Middle-East and includes Australia. A revised edition, ITS standardization 2014, was published by the Telecommunications Technology Association (TTA) in South Korea, which supports vehicular communication at a maximum speed of 200 kph. Between 2012 and 2013, the Japanese Association of Radio Industries and Business (ARIB) has also specified, based on IEEE 802.11, a V2V and V2I communication system in the 700 MHz frequency band.

Chapter 9

PSSCH and PSCCH

9.1 Sidelink Channel Structure

In this subsection we demostrate the sidelink connectivity channel structure which includes logical channels, transport channels and physical channels.

- 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 user data for sidelink communication. It is mapped to the SL-SCH which, in turn, is mapped to the PSSCH. In parallel to the PSSCH, PSCCH carries Sidelink Control Information (SCI) which enables a receiving device to properly detect and decode the PSSCH.

- For sidelink discovery, there is no logical channel, Sidelink Discovery Channel (SL-DCH) is the transport channel and Physical Sidelink Discovery Channel (PSDCH) is the physical channel. As there is no logical channel related to sidelink discovery, that is, the discovery message is inserted directly into the SL-DCH transport block on the MAC layer. The SL-DCH used for discovery announcements which is mapped to the PSDCH.

- Finally, sidelink synchronization is based on two channels/signals:

    - Sidelink Synchronization Signal (SLSS) which is associated with a specific sidelink identity (SLI). A device under network coverage transmits SLSS in line with the transmission timing acquired from the network. Nearby out of coverage devices receive this signal and use it as timing reference for sidelink transmissions. These devices can also transmit their own SLSS that can be detected and used as timing references by other out of coverage devices as well. In this way, the area over which devices are synchronized to and derive their transmission timing from the network can be further expanded beyond the area of direct network coverage.

A device can also autonomously transmit SLSS though it is not within the network coverage and also not detecting any necessarily strong SLSS. This SLSS can be detected and forwarded by other out of coverage devices and consequently forms local synchronization among these devices even without the presence of a network.

- In this case, Sidelink Broadcast Control Channel (S-BCCH) is the logical 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 used to convey the Sidelink Master Information Block (SL-MIB) between devices which is known as very basic sidelink related system information.

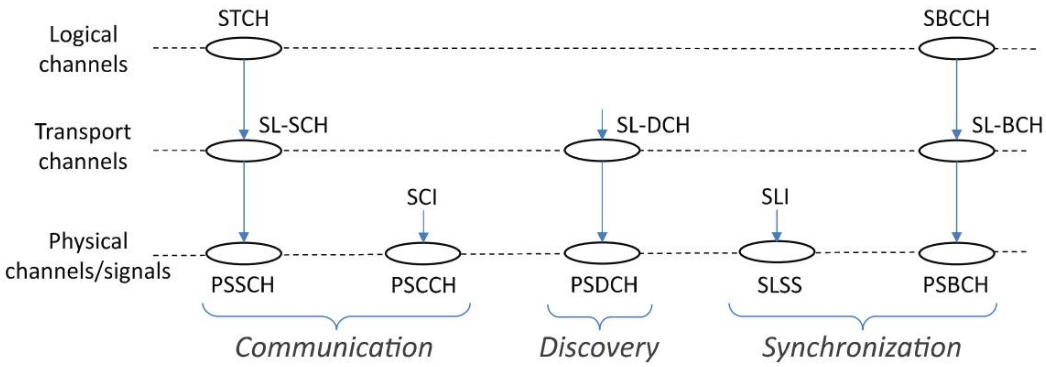

Figure 10: Sidelink Channel Structure

9.2 Sidelink Communication

Sidelink communication means the exchange of user data directly between proximity devices. In practice sidelink communication is limited to group communication which means

- Sidelink transmission device transmits signals with no assumptions of receiving device.

- The sidelink transmission may be received and decoded by any sidelink communication capable device in the proximity of the transmitting device.

- To make receiver understand whether it is one of the intended receivers of data or not, a group identity is included in the control part of the sidelink transmission.

As previously mentioned, sidelink communication is based on two physical channels:

- The PSSCH which carries the actual transport-channel (SL-SCH) data.

- The PSCCH which carries SCI that enables receiving devices to properly detect and decode the PSSCH.

9.3 Resource Pools and Assignment

A resource pool is a set of physical resources, in practice subframes and resource blocks, available to a device for sidelink transmissions. The exact set of resources to use for a specific sidelink transmission is then selected from the resource pool. There are different ways by which a device can be configured with a resource pool:

- By System Information Block (SIB 18 in case of sidelink communication).

- By dedicated RRC signaling for devices in RRC_CONNECTED mode.

- By pre-configured resource pools for out-of-coverage devices.

For sidelink communication each resource pool consists of:

- A *PSCCH subframe pool* defining a set of subframes available for PSCCH transmission

- A *PSCCH resource block pool* defining a set of resource blocks available for PSCCH transmission within the PSCCH subframe pool
- A *PSSCH subframe pool* defining a set of subframes available for PSSCH transmission

- A *PSSCH resource block pool* defining a set of resource blocks available for PSSCH transmission within the PSSCH subframe pool.

There are also two modes of sidelink communication. The two modes differ in terms of how a device is assigned or selects the exact set of resources to use for the sidelink transmission from a configured resource pool.

- *Sidelink communication mode 1:* In this mode network selects PSCCH/PSSCH for a device by means of a scheduling grant. It is only possible for in-coverage devices in RRC_CONNECTED state.

- *Sidelink communication mode 2:* In this mode a device by itself selects PSCCH/ PSSCH resources. It is possible for both in coverage and out of coverage devices and in both RRC_IDLE and RRC_CONNECTED state.

9.4 PSCCH Periods

The block of resources is repeated with a period, known as the PSCCH period. In the time domain, sidelink communication is based on PSCCH periods. Each System Frame Number (SFN) period, consisting of 1024 frames or 10240 subframes, is divided into equal lengths PSCCH periods.

For both the cases of sidelink communication mode 1 and mode 2, the set of transmission resources assigned by the network or selected by the device itself respectively are carried out on a PSCCH period basis.

In case of FDD, the length of the PSCCH period can be configured to 40, 80, 160, or 320 subframes. In case of TDD, the set of possible lengths for the PSCCH period depends on the downlink or uplink configuration.

9.5 PSCCH Transmission

There are several steps for the PSCCH transmissions which are discussed below:

- As already mentioned, the PSCCH carries control information, referred to as sidelink control information (SCI), which enables a receiving device to properly detect and decode the data transmission on PSSCH. The SCI includes, for example, information about the time-frequency resources (subframes and resource blocks) used for the PSSCH transmission. So channel coding and modulation for SCI is important to do and consists of the following steps:

    - 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 modulated symbols are then DFT precoded before being mapped to the physical resources (subframes and resource blocks) assigned/selected for the PSCCH transmission.

- The PSCCH subframe pool, that is, the set of subframes available for PSCCH transmission within each PSSCH period is given by a subframe bitmap provided as part of the sidelink configuration.

- The PSCCH resource-block pool, that is, the set of resource blocks available for PSCCH transmission within the subframe pool, consists of two equal-size sets of frequency-wise consecutive resource blocks. The resource-block pool can thus be fully described 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.

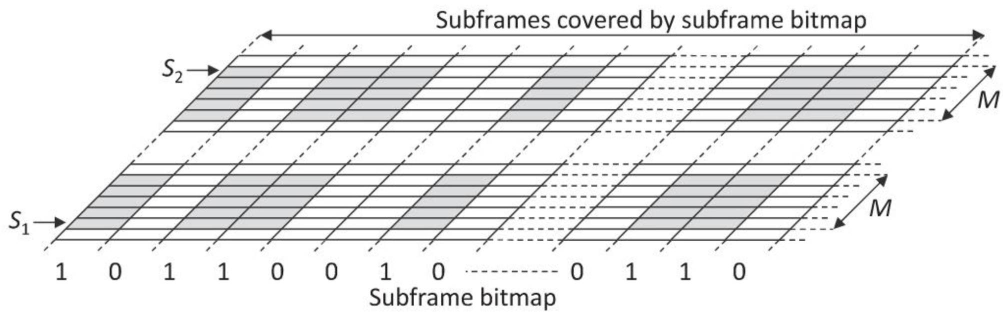

Figure 11: PSCCH resource pool structure

- A PSCCH transmission is carried out over two subframes and within one resource block pair in each subframe. Exactly what subframes and resource blocks, within the configured resource pool, to be used for a certain PSCCH transmission is jointly given by a parameter n_{PSCCH}. n_{PSCCH} is either provided in the scheduling grant delivered by the network (for sidelink communication mode 1) or autonomously selected by the transmitting device (sidelink communication mode 2).

- The mapping from n_{PSCCH} to actual set of PSCCH resources is such that if the transmission in the first subframe takes place in the lower set of resource blocks, the transmission in the second subframe will take place in the upper set of resource blocks and vice versa. The mapping is also such that if two different values of n_{PSCCH} imply mapping to the same first subframe, the second transmission will take place in different subframes or vice versa. Thus, PSCCH transmissions corresponding to different values of n_{PSCCH} will, time-wise, only collide in one of the two subframes.

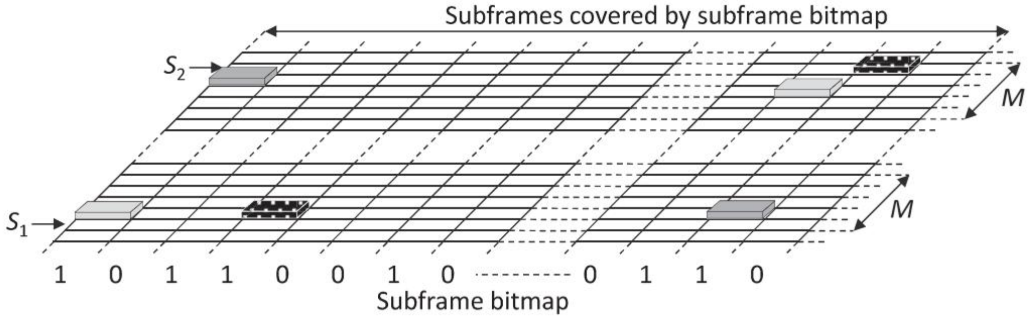

Figure 12: PSCCH transmission

9.6 PSSCH Transmission

Similar to the PSCCH transmission, there are also some steps for the PSSCH transmissions which are discussed below:

- Actual transport channel (SL-SCH) data is transmitted in the form of transport blocks on the PSSCH. Each transport block is transmitted over four consecutive subframes within the PSSCH subframe pool. Transmission of M transport blocks within a PSCCH period thus requires 4M subframes. Note that a single SCI on PSCCH carries control information related to PSSCH transmission for the entire PSCCH period. Channel coding and modulation for SL-SCH consists of the following steps:

    - CRC insertion
    - code-block segmentation and per-code-block CRC insertion
    - rate 1/3 Turbo coding
    - rate matching (based on physical-layer hybrid-ARQ functionality)
    - bit-level scrambling
    - data modulation (QPSK/16QAM)

- After channel coding and modulation, DFT precoding is applied followed by mapping to the physical resource assigned/selected for the PSSCH transmission.

- PSSCH set of subframes for PSSCH transmission:

    - *For sidelink communication mode 1:* The PSSCH subframe pool, that is, the set of subframe available for PSCCH transmission, consists of all uplink subframes after the last subframe of the PSCCH subframe pool. The exact set of subframes to use for PSSCH transmission in a PSCCH period is given by a time repetition pattern index (TRPI) provided as part of the scheduling grant. The TRPI points to a specific time repetition pattern (TRP) within a TRP table explicitly defined within the LTE specifications. Periodic extension of the indicated TRP then gives the uplink subframes assigned for the PSSCH transmission. The TRPI is then included in the SCI in order to inform receiving devices about the set of subframes in which the PSSCH is transmitted.

- *For sidelink communication mode 2:* The PSSCH subframe pool, that is, the set of (uplink) subframes available for PSSCH transmission, consists of a subset of the mode 1 subframe pool. More specifically, a periodic extension of a bitmap defined in the sidelink configuration indicates what subframes are included in the PSSCH subframe pool. In this way the network can ensure that certain subframes will not be used for PSSCH transmissions. The device then autonomously decides on the exact set of subframes to use for the PSSCH transmission by randomly selecting a TRP from the TRP table. Similar to sidelink communication mode 1, the receiving device is informed about the selected TRP by including the corresponding TRPI in the SCI.

In addition to limiting the set of subframes that are part of the PSSCH subframe pool, in case of sidelink communication mode 2 there are also limitations in the TRP selection. In general, the TRP table consists of TRPs with different number of ones, corresponding to different fractions of subframes assigned for the PSSCH transmission. This includes, for example, the all-one TRP corresponding to assigning all subframes of the PSSCH pool for PSSCH transmission from a specific device. However, in case of sidelink communication mode 2 the TRP selection is restricted to TRPs with a limited number of ones, thus limiting the PSSCH transmission duty cycle. For example, in case of FDD, the TRP selection is limited to TRPs with a maximum of four ones, corresponding to a 50% duty cycle for the PSSCH transmission.

➢ In addition to the set of subframes, a device also needs to know the exact set of resource blocks to be used for the PSSCH transmission.

- *For sidelink communication mode 1:* In this case, information about the resource blocks to use for the PSCCH transmission are given in the scheduling grant provide by the network. Thus the resource grant includes a 1-bit frequency-hopping flag and a resource-block assignment, the size of which depends on the system bandwidth. Note that there is no restriction in terms of what resource blocks can be assigned except that it should be a set of consecutive resource blocks. In other words, in case of sidelink communication mode 1, the PSSCH resource-block pool consists of all resource blocks within the carrier bandwidth.

- *For sidelink communication mode 2:* In this case, there are restrictions in terms of what resource blocks are available for PSSCH transmission. This PSSCH resource block pool has the same structure as the PSCCH resource-block pool, that is, it consists of two sets of frequency-wise consecutive resource blocks defined by three parameters S_1, S_2, and M. Note that the parameters defining the PSSCH resource block pool are configured separately from those defining the PSCCH resource block pool. A device configured to operate in sidelink communication mode 2 will then autonomously select a set of consecutive resource blocks from the PSSCH resource-block pool.

➢ Information about the assigned/selected set of resource blocks is provided to receiving devices as part of the SCI.

9.7 SCI Contents

As discussed earlier, the SCI carries information needed by a receiving device to properly detect and decode the PSSCH and extract the SL-SCH data. This includes information about the exact set of resources (subframes and resource blocks) in which the PSSCH is transmitted:

➢ The TRPI, indicating the set of subframes used for the PSSCH transmission.

➢ A frequency hopping flag indicating whether or not frequency hopping is used for the PSSCH transmission.

- A resource block and hopping resource allocation indicating what resource blocks, within the subframes indicated by the TRPI, are used for the PSSCH transmission.

- A five bits indicator of the modulation and coding scheme (MCS) used for the PSSCH transmission.

- An eight bit group destination ID, indicating the group for which the sidelink communication is intended.

- An eleven bit timing-advance indicator.

9.8 Scheduling Grants and DCI Format 5

As described above, devices within network coverage can be configured to only initiate sidelink communication when having been provided with an explicit scheduling grant by the network (sidelink communication mode 1). Sidelink scheduling grants are provided via the PDCCH/ePDCCH using DCI format 5. DCI format 5 includes the following information:

- The parameter n_{PSCCH} indicating the physical resource (subframes and resource blocks) on which PSCCH is to be transmitted.

- The TRPI indicating what subframes within the PSSCH subframe pool to use for the PSSCH transmission.

- A frequency hopping flag indicating whether or not frequency hopping should be applied for the PSSCH transmission.

- A resource block and hopping resource allocation indicating what resource blocks, within the subframes indicated by the TRPI, should be used for the PSSCH transmission.

- A 1-bit transmit power control (TPC) command that applies to both PSCCH and PSSCH.

The sidelink scheduling grant is valid for the next PSCCH period starting at least four subframes after the arrival of the scheduling grant. Its transmission is supported by buffer status reports (BSRs) provided to the network by devices involved in sidelink communication. The sidelink BSRs are conveyed as MAC control elements and indicate the amount of data available for transmission at the device.

9.9 Reception Resource Pools

In addition to the transmission resource pool, a device that is to take part in sidelink communication is also configured with one or several reception resource pools related to sidelink communication.

A reception resource pool describes the set of resources (subframes and resource blocks) in which a device can expect to receive sidelink communication related transmissions. Especially, the PSCCH part of the reception resource pool describes the set of resources in which the device should search for PSCCH transmissions. Furthermore, the PSSCH part of the resource is needed for the receiver to be able to properly interpret the resource information in the SCI.

The reason why a device may be configured with multiple reception pools is that it may receive sidelink communication from multiple devices and these devices may be configured with different transmission pools. This may be the case regardless of whether the devices are within the same cell or within different cells. In principle, a device should be configured with a reception pool that is the union of the transmission resource pools of the devices with which it is to communicate. In practice, this is realized by configuring the device with multiple reception pools that jointly covers the transmission pools of the relevant devices.

Chapter 10

BLER and Throughput Performance

V2X is still at its early stage. Before implementing it, much research has to be done by means of simulation. 2018 marked the introduction of V2X. Within this very short period, the development has basically been limited to theoretical field, with a few exceptions.
Simulation has to be done to get the optimal condition for V2X. The hindrance towards its implementation, the factors affecting it, the room for development etc are to be determined by means of simulation.
To perform this simulation research, we generated comparative curves with values of Block Error Rate (BLER) and percentage throughput with respect to various Signal to Noise Ratio (SNR) and doppler frequencies.

BLER: Block Error Rate (BLER) is a ratio of the number of erroneous blocks to the total number of blocks transmitted on a digital circuit.

Throughput: In general terms, throughput is the rate of production or the rate at which something is processed. When used in the context of communication networks, throughput is the rate of successful message delivery over a communication channel. The data these messages belong to may be delivered over a physical or logical link, or it can pass through a certain network node. Throughput is usually measured in bits per second (bit/s or bps), and sometimes in data packets per second (p/s or pps) or data packets per time slot.

Doppler Frequency: The Doppler frequency is the change in frequency of a wave in relation to an observer who is moving relative to the wave source.

10.1 QPSK

Number of Frames: 4

Doppler Frequency: 500 Hz

Modulation Scheme: QPSK

Environment: EPA

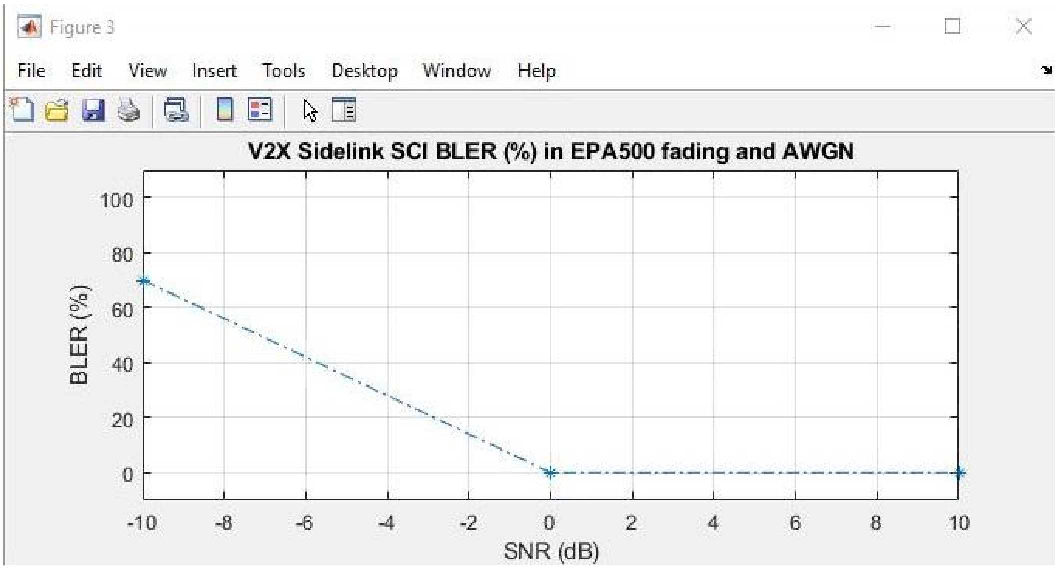

Figure 13: SNR vs BLER performance (N4_500 Hz_QPSK_EPA)

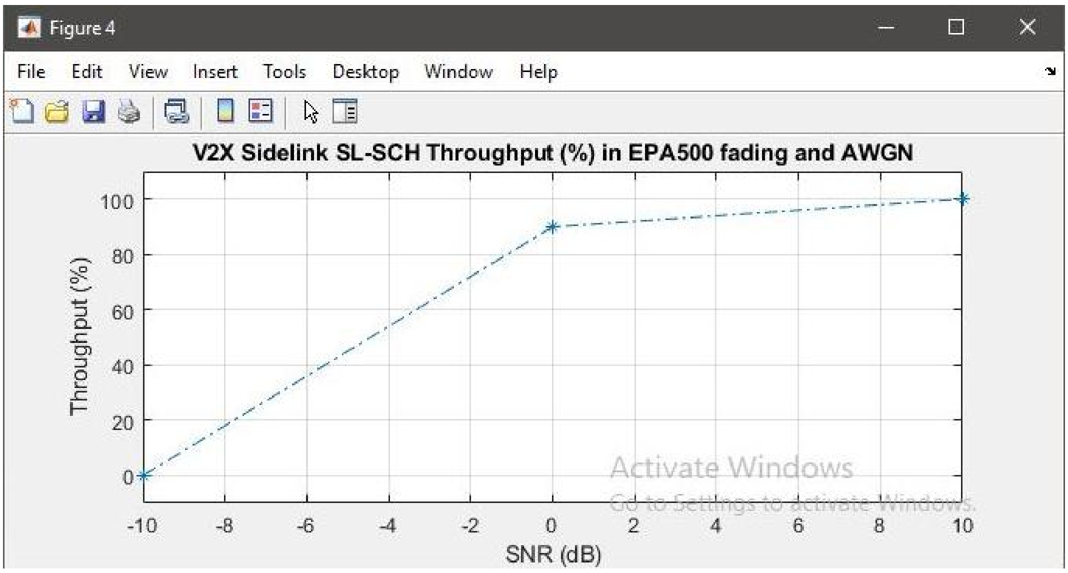

Figure 14: SNR vs throughput performance (N4_500 Hz_QPSK_EPA)

Number of Frames: 4 **Doppler Frequency: 500 Hz**

Modulation Scheme: QPSK **Environment: ETU**

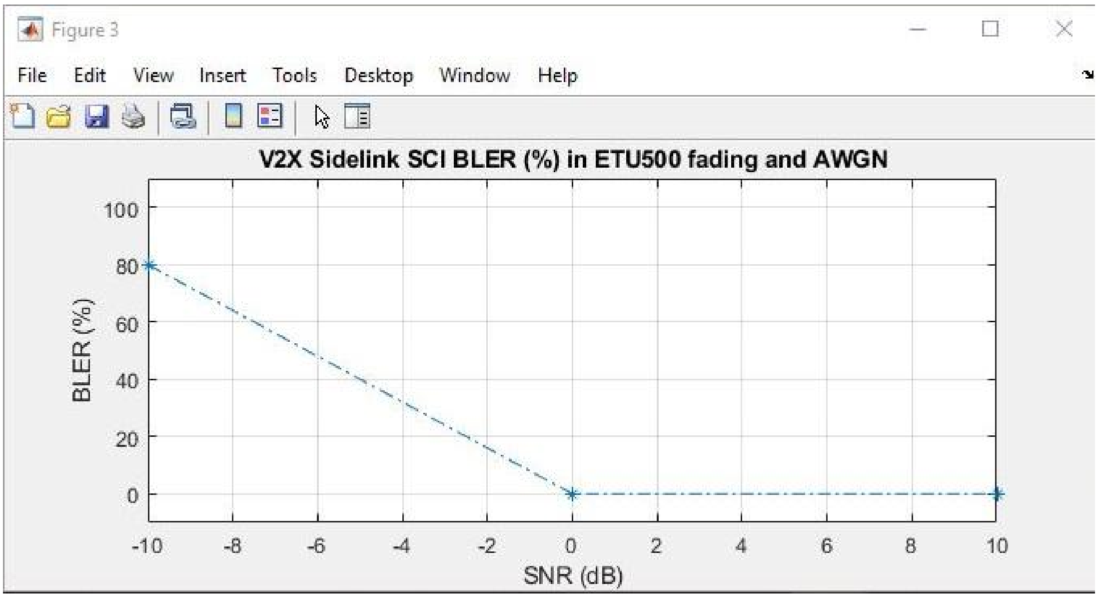

Figure 15: SNR vs BLER performance (N4_500 Hz_QPSK_ETU)

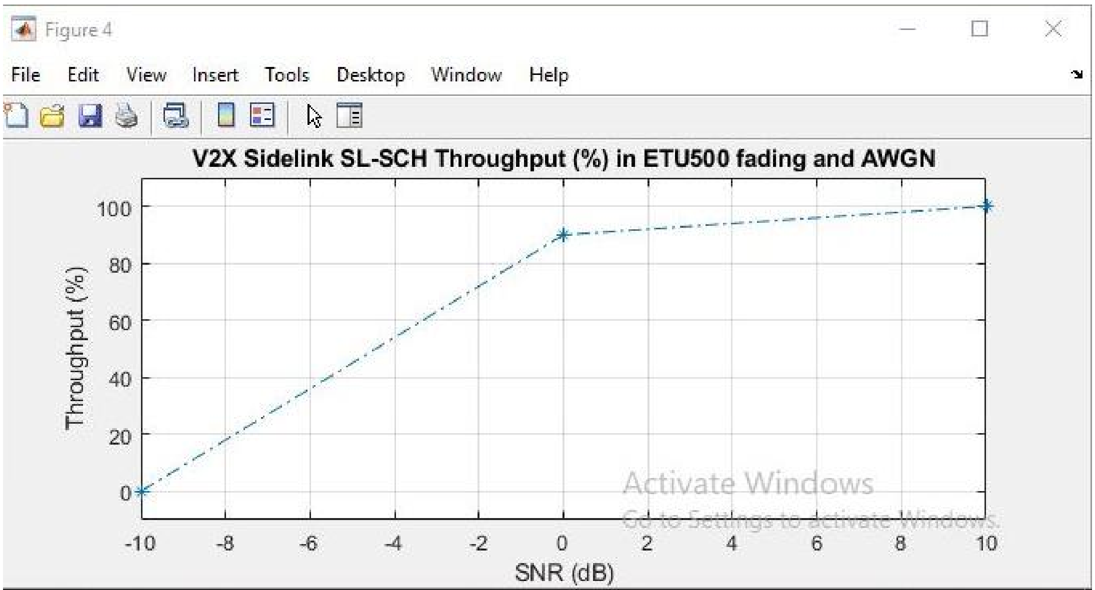

Figure 16: SNR vs throughput performance (N4_500 Hz_QPSK_ETU)

Number of Frames: 4 **Doppler Frequency: 500 Hz**

Modulation Scheme: QPSK **Environment: EVA**

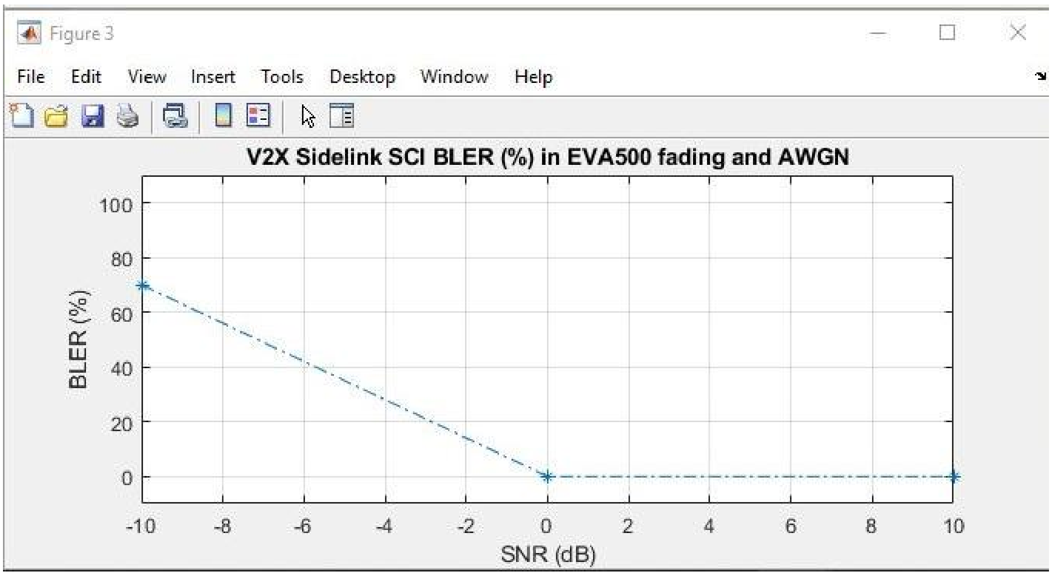

Figure 17: SNR vs BLER performance (N4_500 Hz_QPSK_EVA)

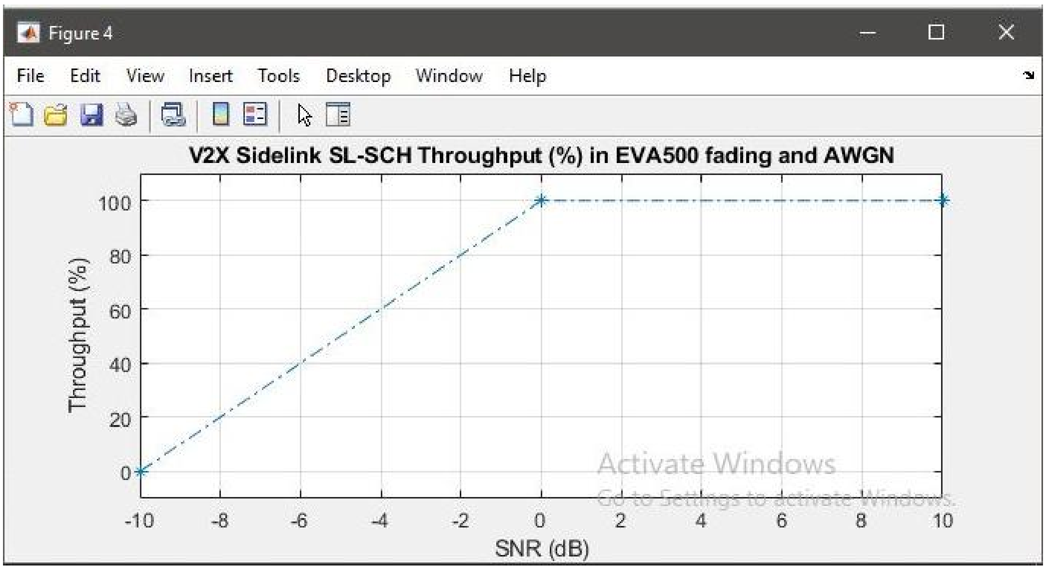

Figure 18: SNR vs throughput performance (N4_500 Hz_QPSK_EVA)

For Number of Frames: 4, Doppler Frequency: 500 Hz and Modulation Scheme: QPSK, we can observe from the above graphs-

EVA has the best performance in terms of throughput.

EPA and EVA have the best performance in terms of BLER.

Number of Frames: 4 **Doppler Frequency: 1000 Hz**

Modulation Scheme: QPSK **Environment: EPA**

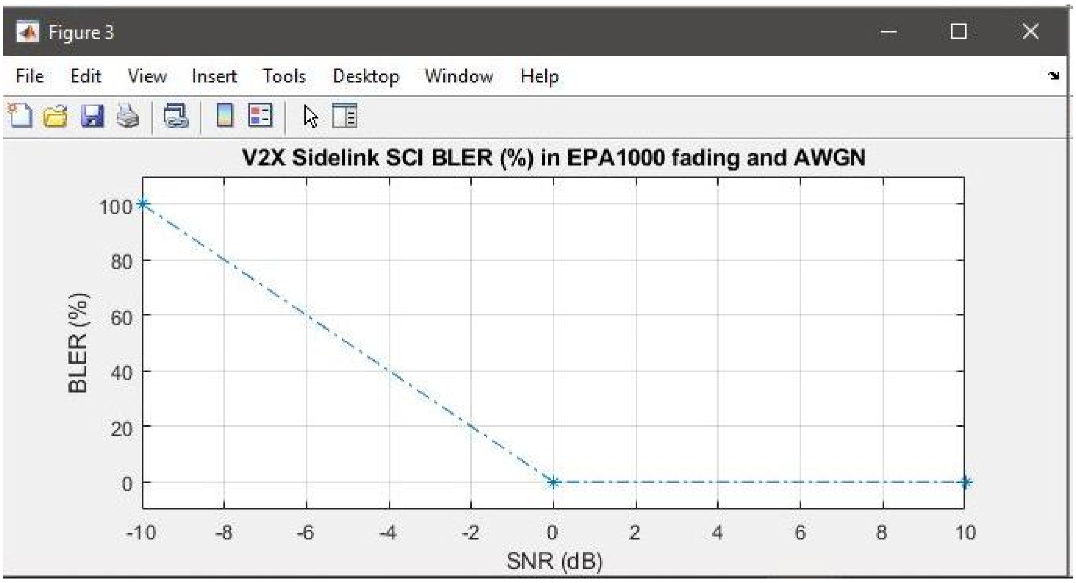

Figure 19: SNR vs BLER performance (N4_1000 Hz_QPSK_EPA)

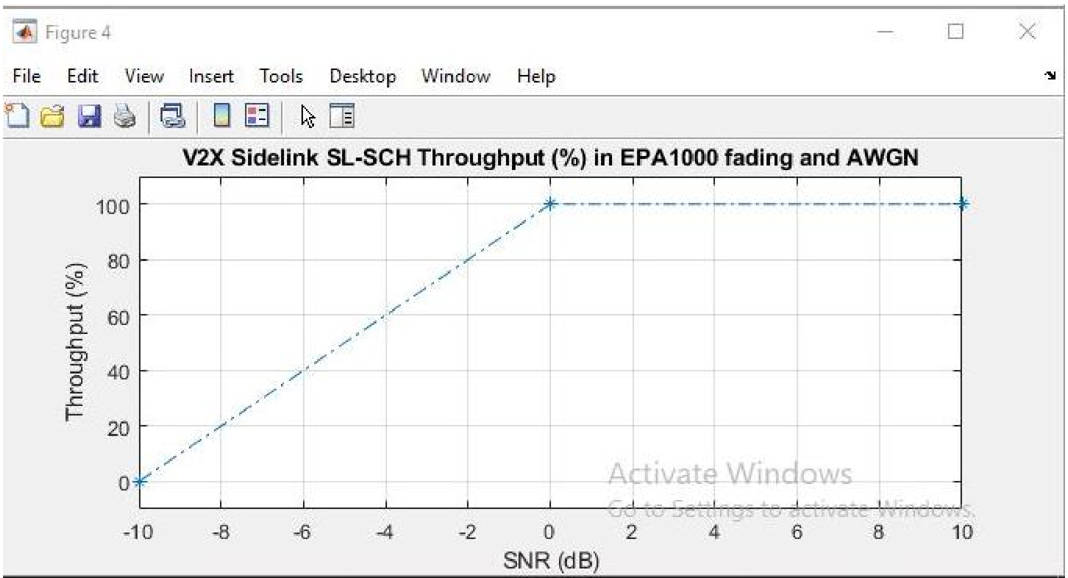

Figure 20: SNR vs throughput performance (N4_1000 Hz_QPSK_EPA)

Number of Frames: 4
Doppler Frequency: 1000 Hz
Modulation Scheme: QPSK
Environment: ETU

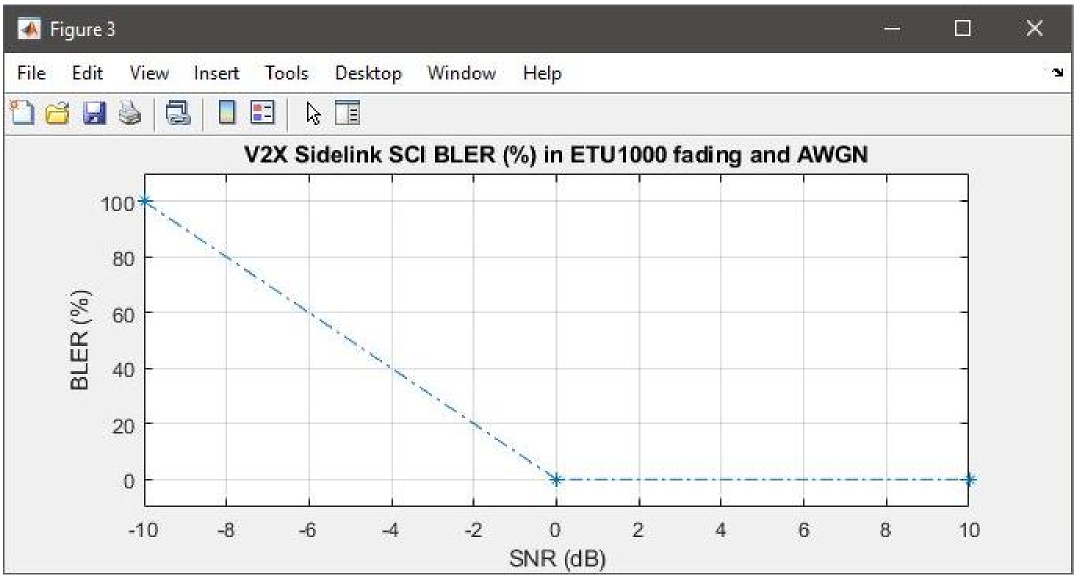

Figure 21: SNR vs BLER performance (N4_1000 Hz_QPSK_ETU)

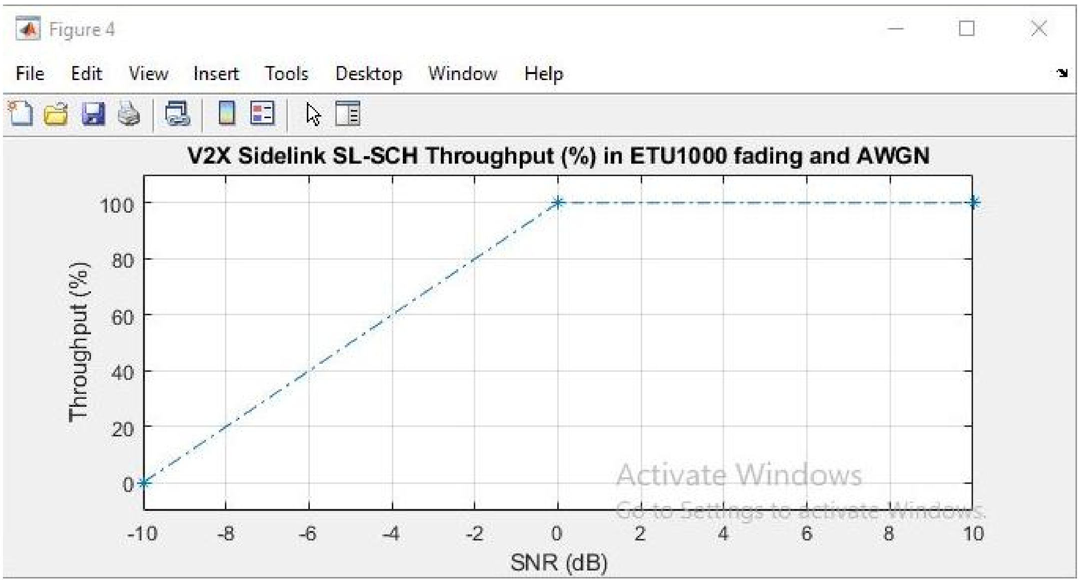

Figure 22: SNR vs throughput performance (N4_1000 Hz_QPSK_ETU)

Number of Frames: 4 **Doppler Frequency: 1000 Hz**

Modulation Scheme: QPSK **Environment: EVA**

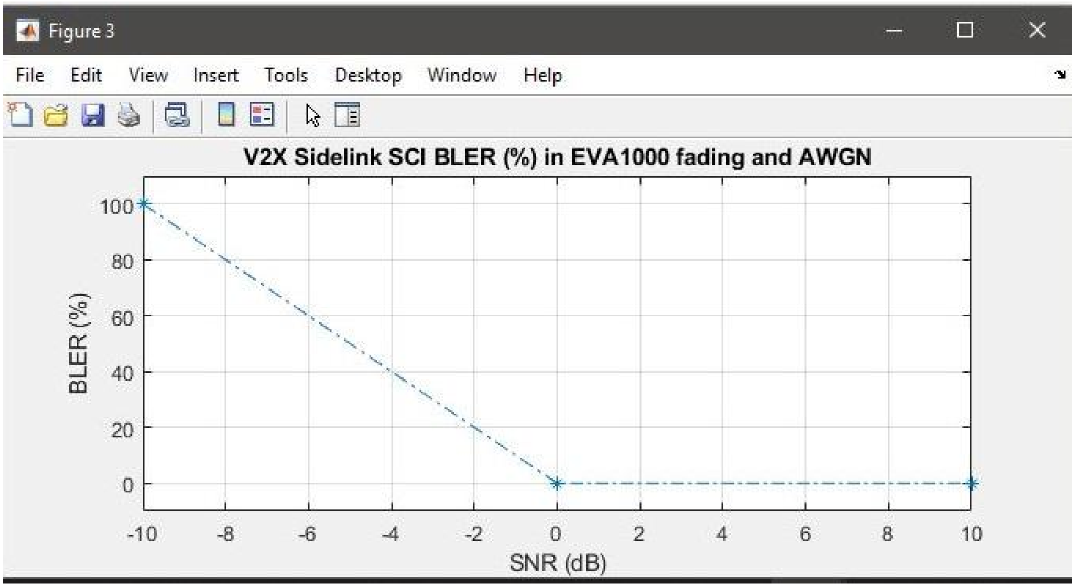

Figure 23: SNR vs BLER performance (N4_1000 Hz_QPSK_EVA)

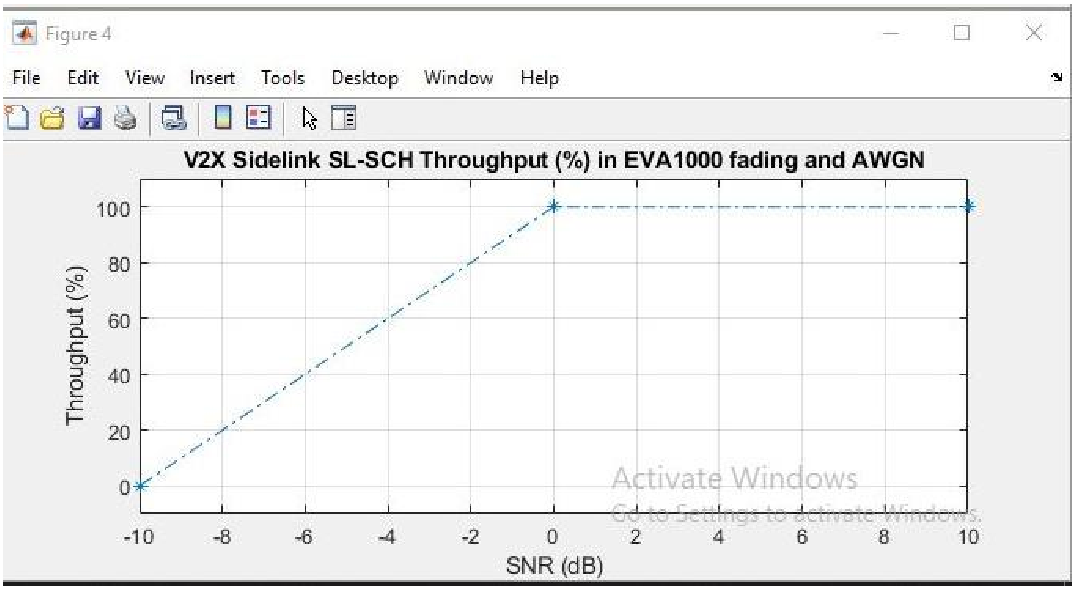

Figure 24: SNR vs throughput performance (N4_1000 Hz_QPSK_EVA)

For Number of Frames: 4, Doppler Frequency: 1000 Hz and Modulation Scheme: QPSK, we can observe from the above graphs-

No significant change has been observed in terms of either throughput or BLER.

Number of Frames: 8 **Doppler Frequency: 500 Hz**

Modulation Scheme: QPSK **Environment: EPA**

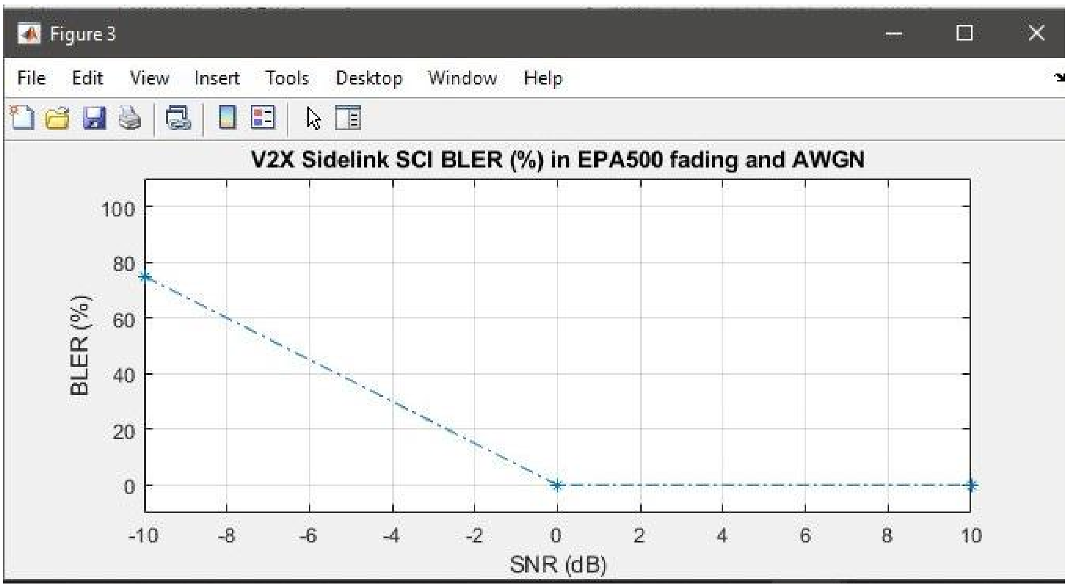

Figure 25: SNR vs BLER performance (N8_500 Hz_QPSK_EPA)

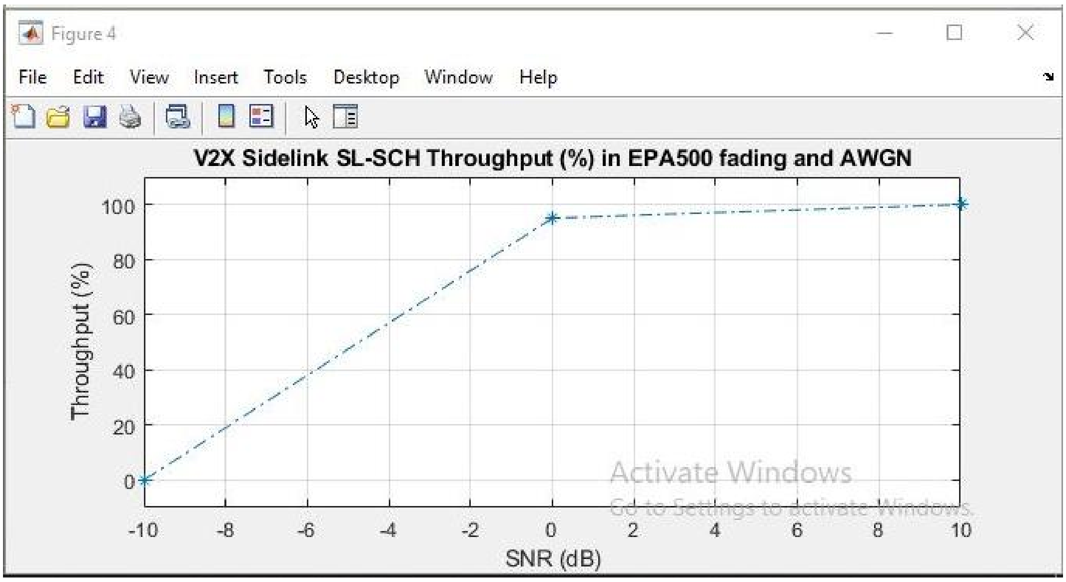

Figure 26: SNR vs throughput performance (N8_500 Hz_QPSK_EPA)

Number of Frames: 8 **Doppler Frequency: 500 Hz**

Modulation Scheme: QPSK **Environment: ETU**

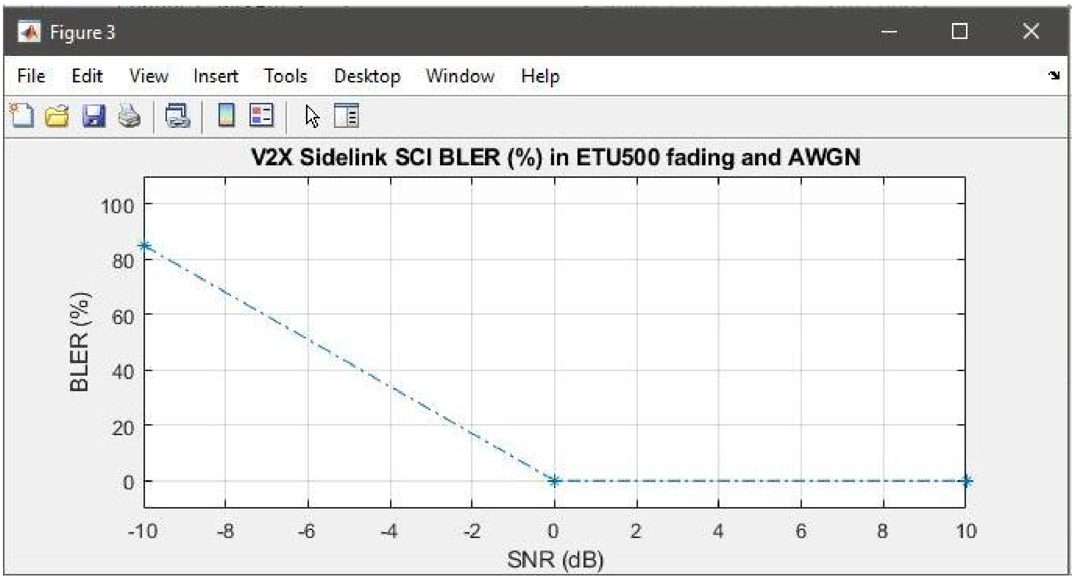

Figure 27: SNR vs BLER performance (N8_500 Hz_QPSK_ETU)

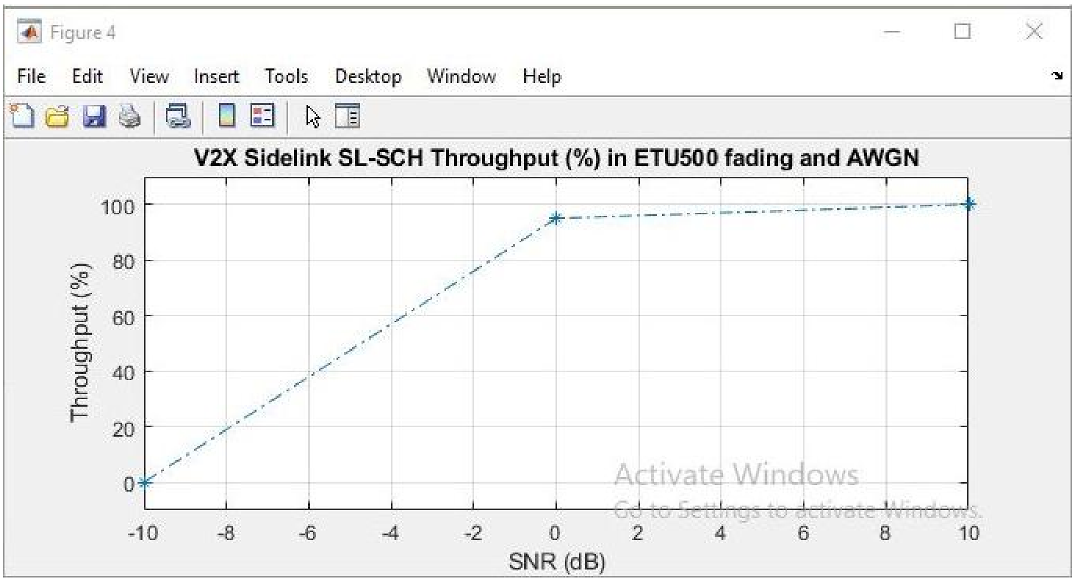

Figure 28: SNR vs throughput performance (N8_500 Hz_QPSK_ETU)

Number of Frames: 8 **Doppler Frequency: 500 Hz**

Modulation Scheme: QPSK **Environment: EVA**

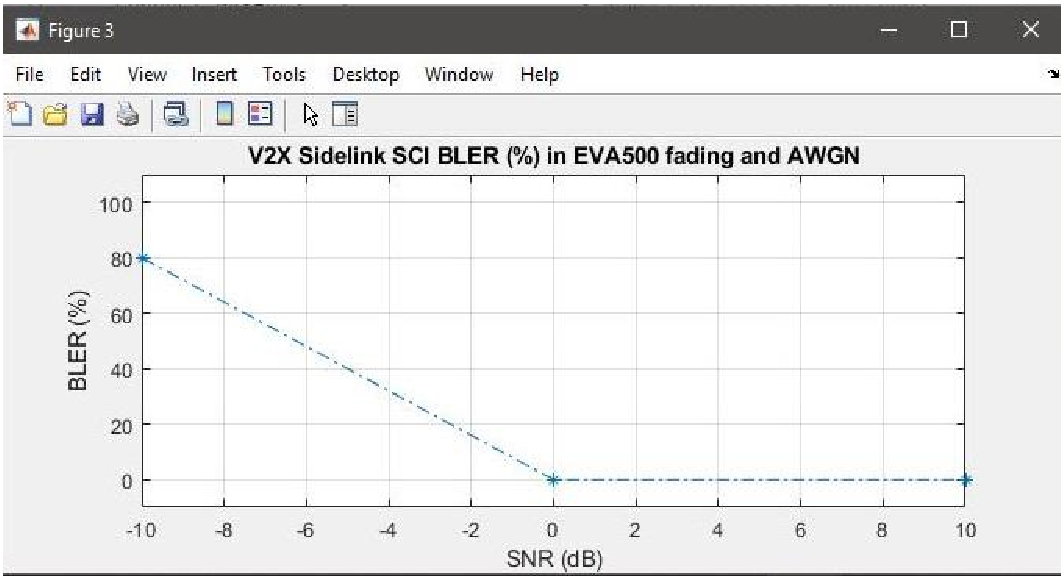

Figure 29: SNR vs BLER performance (N8_500 Hz_QPSK_EVA)

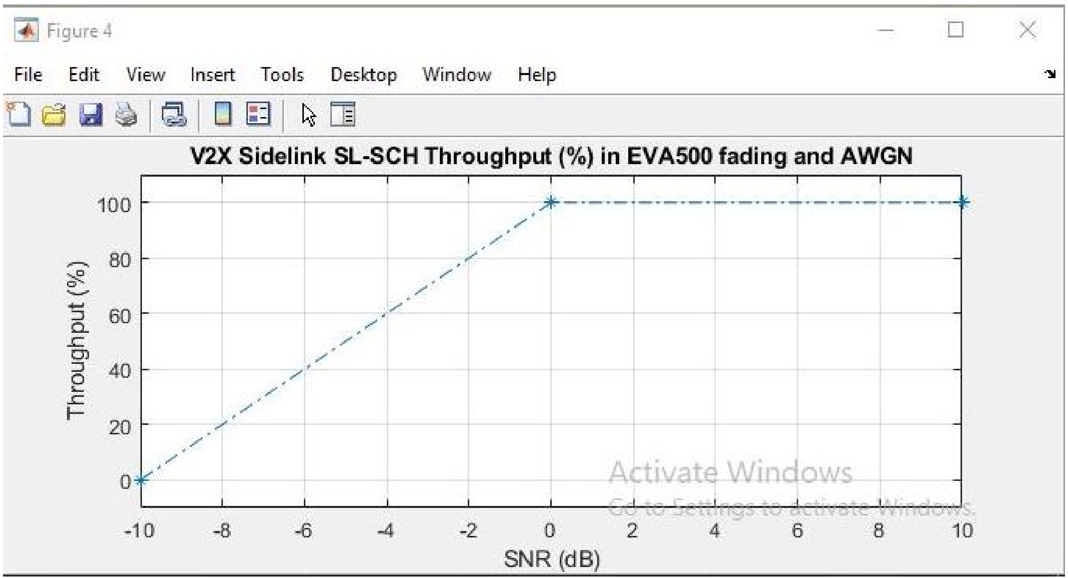

Figure 30: SNR vs throughput performance (N8_500 Hz_QPSK_EVA)

For Number of Frames: 8, Doppler Frequency: 500 Hz and Modulation Scheme: QPSK, we can observe from the above graphs-

EVA has best performance in terms of throughput.

EPA has best performance in terms of BLER.

Number of Frames: 8 **Doppler Frequency: 1000 Hz**

Modulation Scheme: QPSK **Environment: EPA**

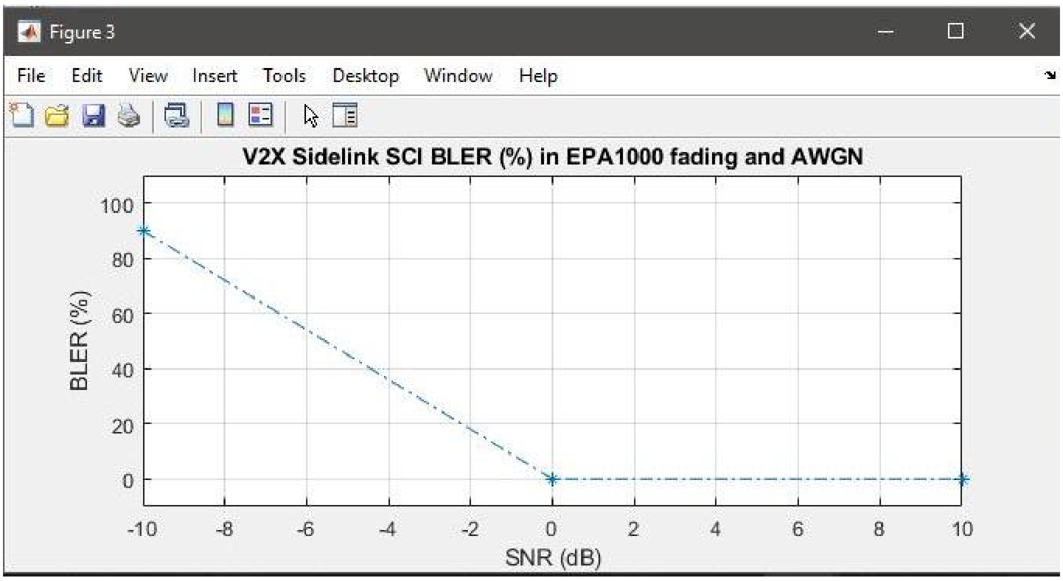

Figure 31: SNR vs BLER performance (N8_1000 Hz_QPSK_EPA)

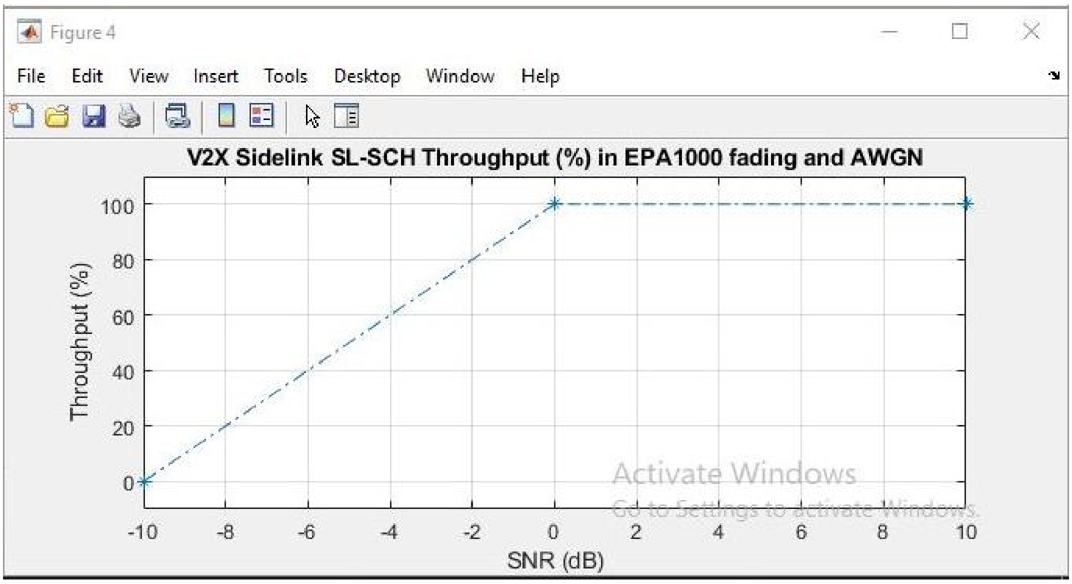

Figure 32: SNR vs throughput performance (N8_1000 Hz_QPSK_EPA)

Number of Frames: 8 **Doppler Frequency: 1000 Hz**

Modulation Scheme: QPSK **Environment: ETU**

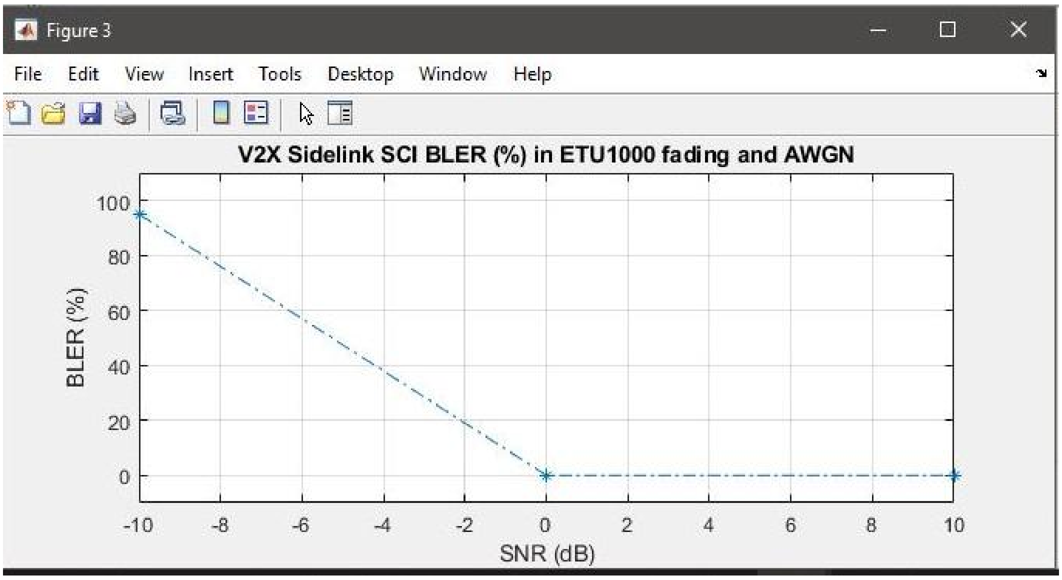

Figure 33: SNR vs BLER performance (N8_1000 Hz_QPSK_ETU)

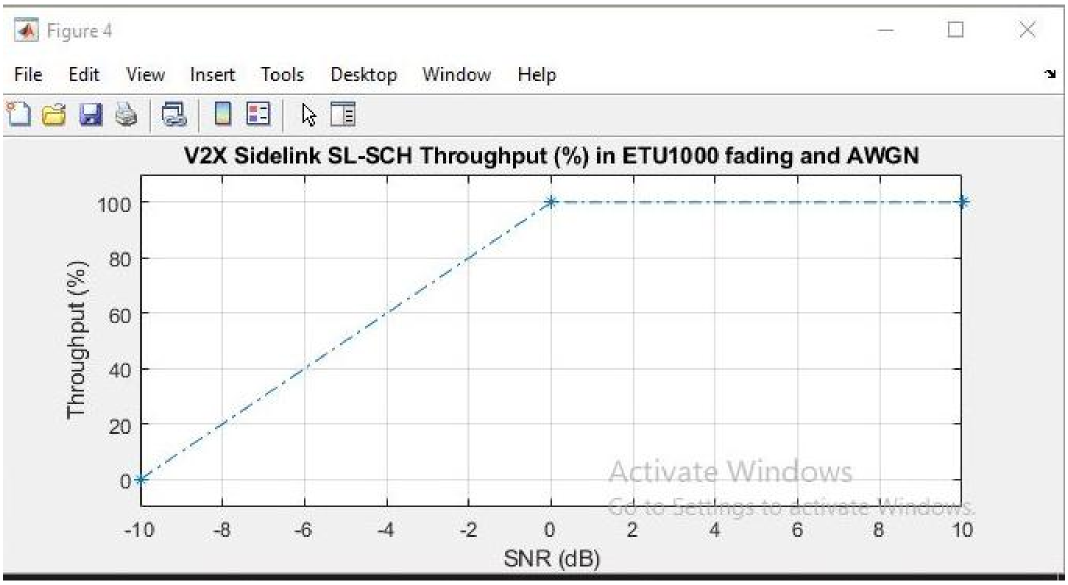

Figure 34: SNR vs throughput performance (N8_1000 Hz_QPSK_ETU)

Number of Frames: 8 **Doppler Frequency: 1000 Hz**

Modulation Scheme: QPSK **Environment: EVA**

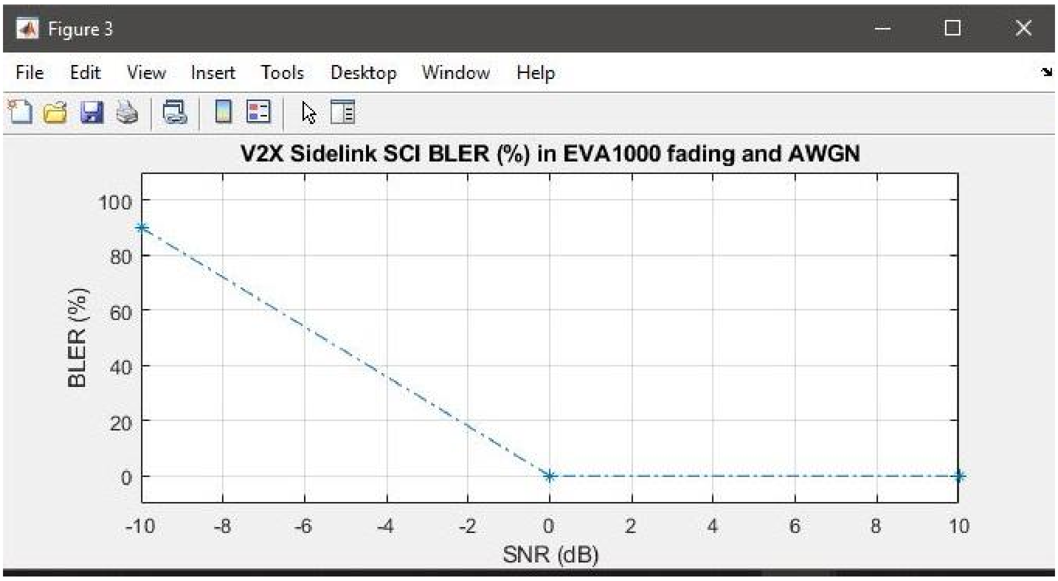

Figure 35: SNR vs BLER performance (N8_1000 Hz_QPSK_EVA)

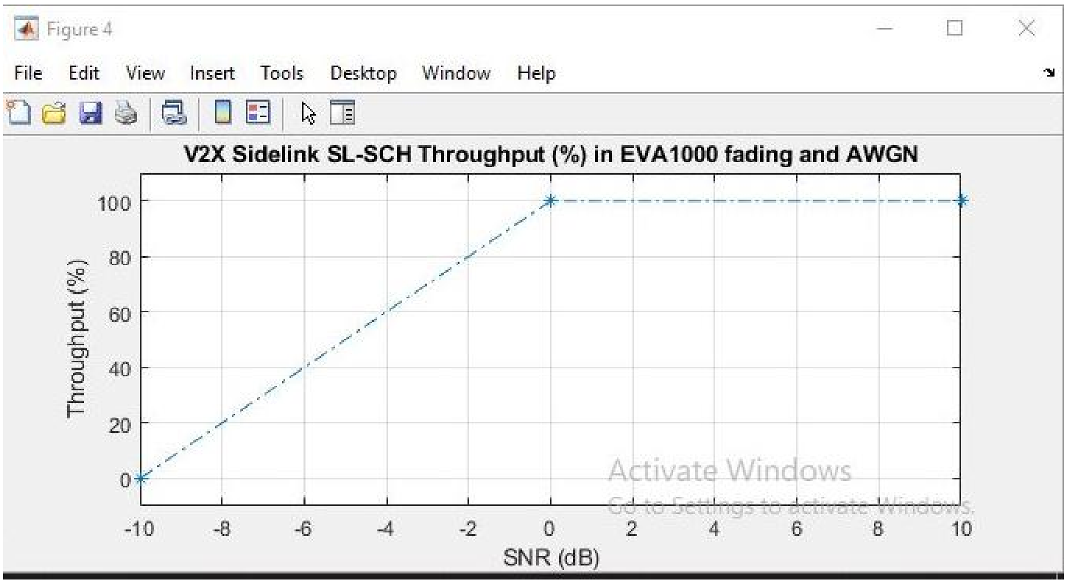

Figure 36: SNR vs throughput performance (N8_1000 Hz_QPSK_EVA)

For Number of Frames: 8, Doppler Frequency: 1000 Hz and Modulation Scheme: QPSK, we can observe from the above graphs-

No significant change has been observed in terms of throughput.

EPA and EVA have best performance in terms of BLER.

10.2 QAM

Number of Frames: 8

Doppler Frequency: 500 Hz

Modulation Scheme: 16 QAM

Environment: EPA

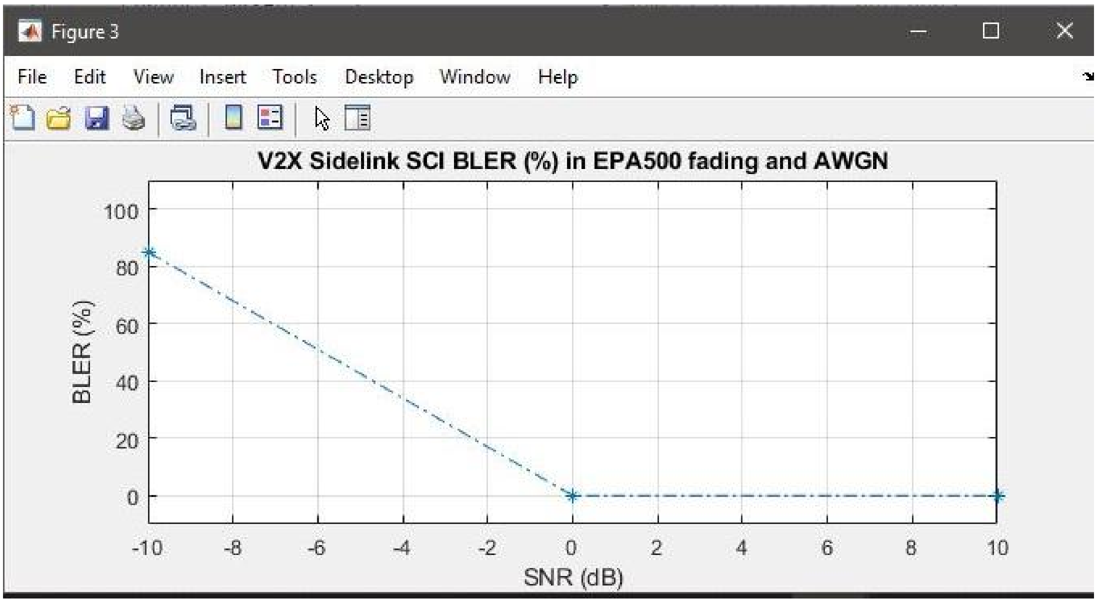

Figure 37: SNR vs BLER performance (N8_500 Hz_16QAM_EPA)

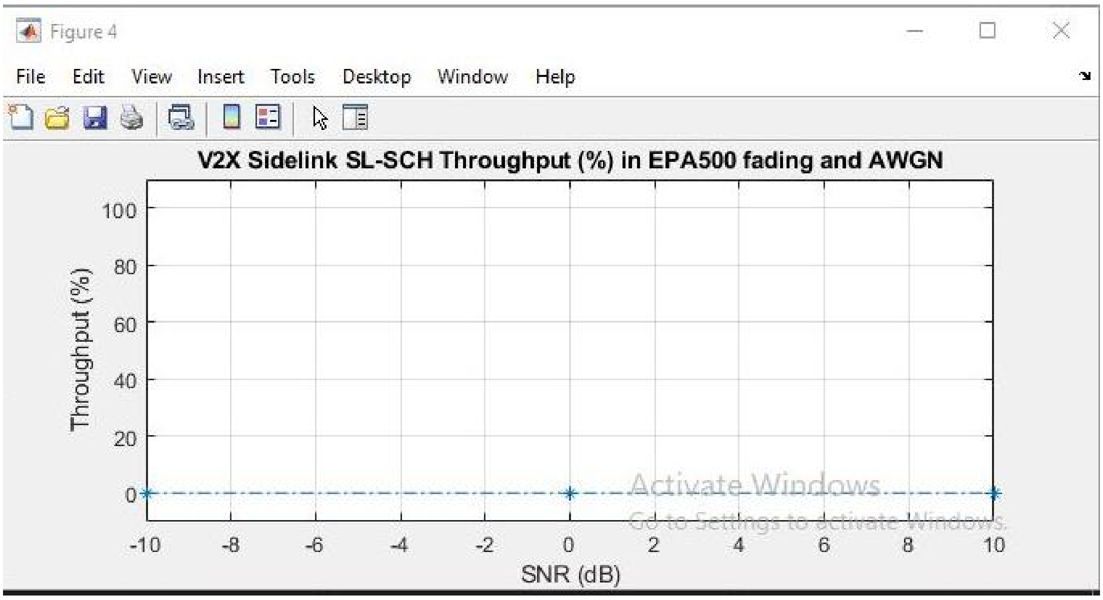

Figure 38: SNR vs throughput performance (N8_500 Hz_16QAM_EPA)

Number of Frames: 8 **Doppler Frequency: 500 Hz**

Modulation Scheme: 16 QAM **Environment: ETU**

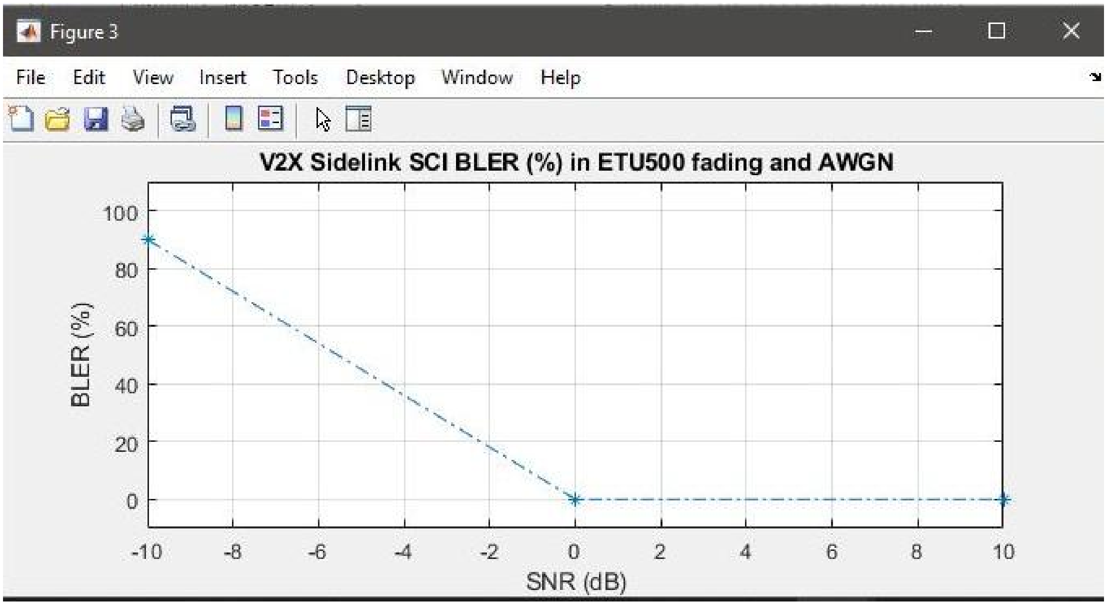

Figure 39: SNR vs BLER performance (N8_500 Hz_16QAM_ETU)

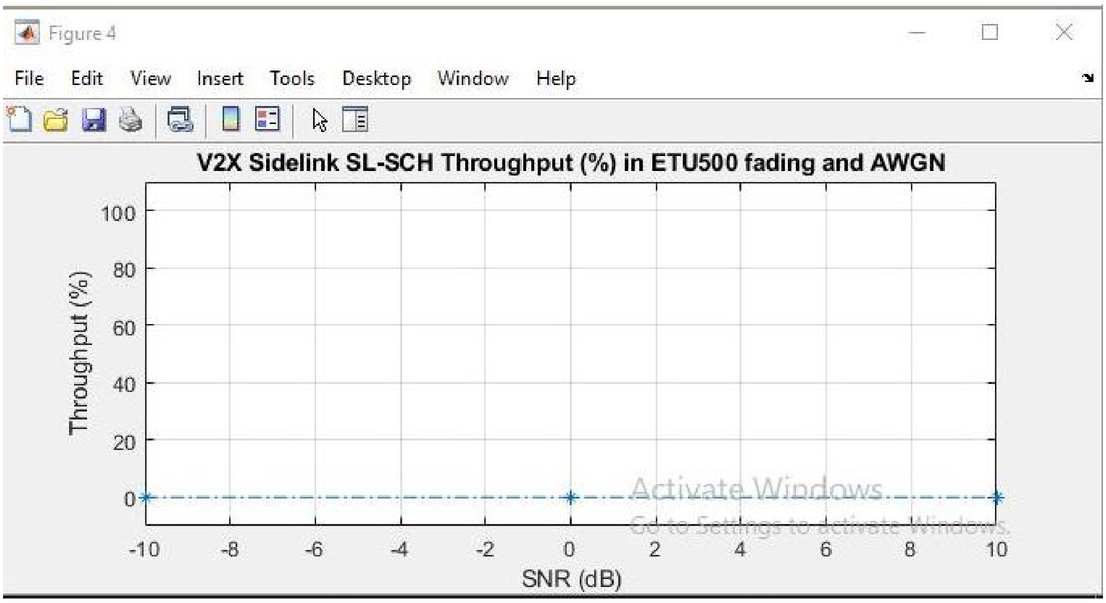

Figure 40: SNR vs throughput performance (N8_500 Hz_16QAM_ETU)

Number of Frames: 8 **Doppler Frequency: 500 Hz**

Modulation Scheme: 16 QAM **Environment: EVA**

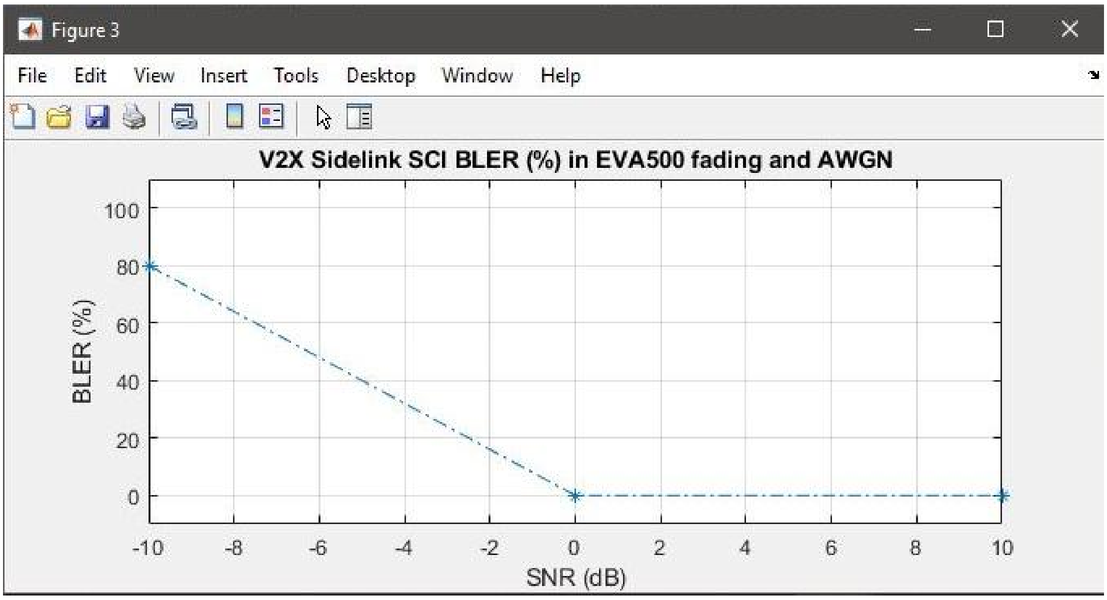

Figure 41: SNR vs BLER performance (N8_500 Hz_16QAM_EVA)

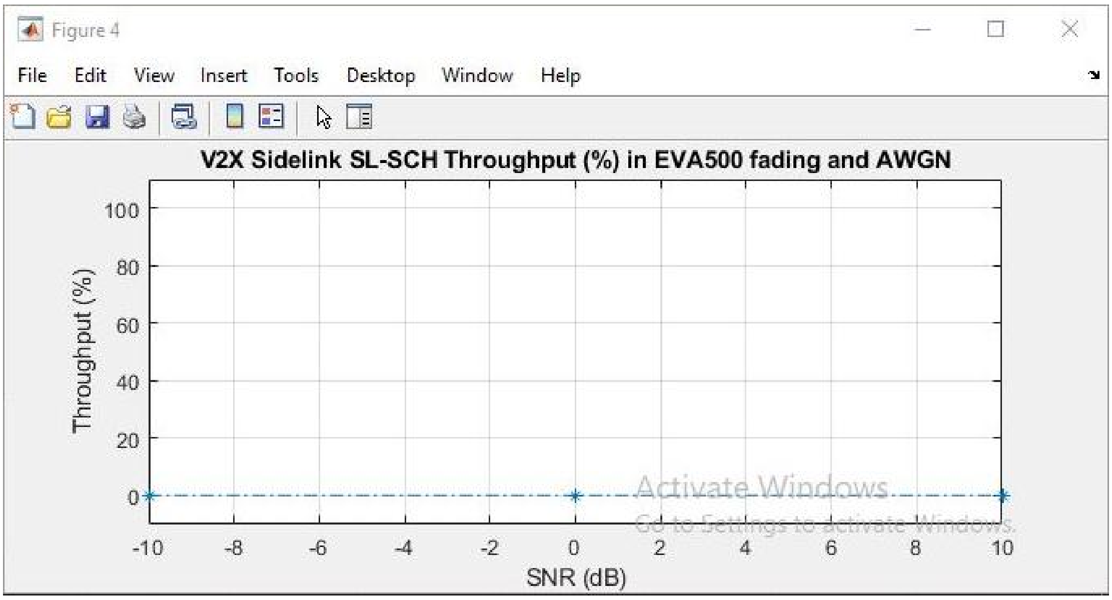

Figure 42: SNR vs throughput performance (N8_500 Hz_16QAM_EVA)

For Number of Frames: 8, Doppler Frequency: 500 Hz and Modulation Scheme: 16 QAM, we can observe from the above graphs-

Output is zero in terms of throughput.

EVA has best performance in terms of BLER.

Same output was observed for 16 QAM in case of different numbers of frames and different frequencies.

10.3 Doppler Frequency vs BLER for ETU

Table 2: Value of BLER at different SNR levels at different Doppler Frequencies for ETU

Doppler Frequency (Hz)	**BLER for ETU**		
	-3dB	-6dB	-9dB
1000	2.4065	55.3578	82.9411
2000	21.7804	60.1128	89.9023
3000	81.6771	83.9927	95.9839

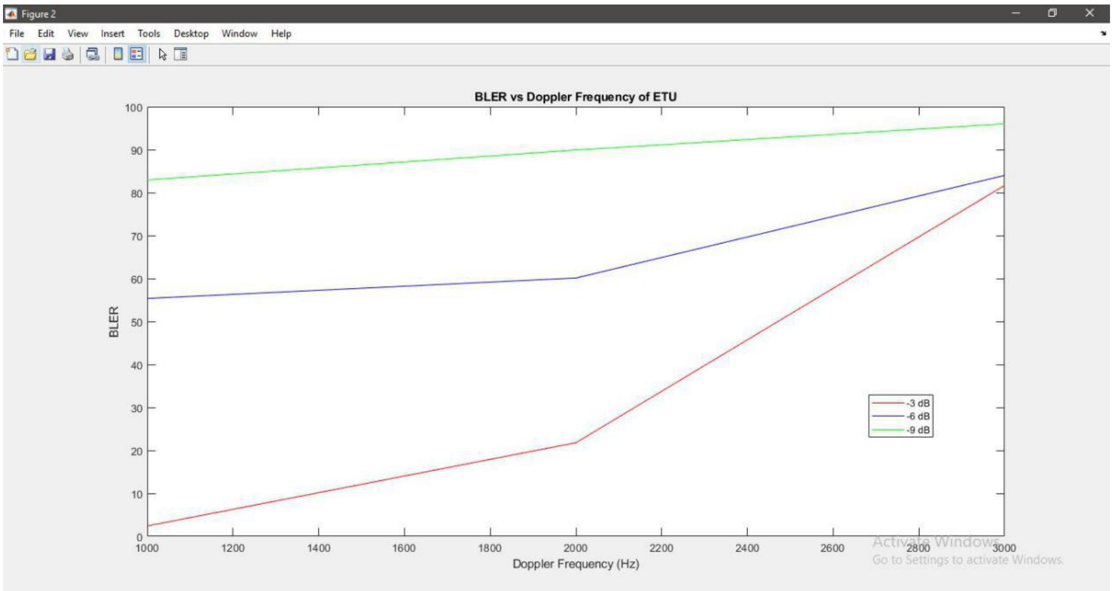

Figure 43: Doppler frequency vs BLER for ETU

10.4 Doppler Frequency vs BLER of EVA

Table 3: Value of BLER at different SNR levels at different Doppler Frequencies for EVA

Doppler Frequency (Hz)	**BLER for EVA**		
	-3dB	-6dB	-9dB
1000	2.4018	50.3171	75.5940
2000	11.2154	59.2139	86.799
3000	79.2575	79.1966	94.8052

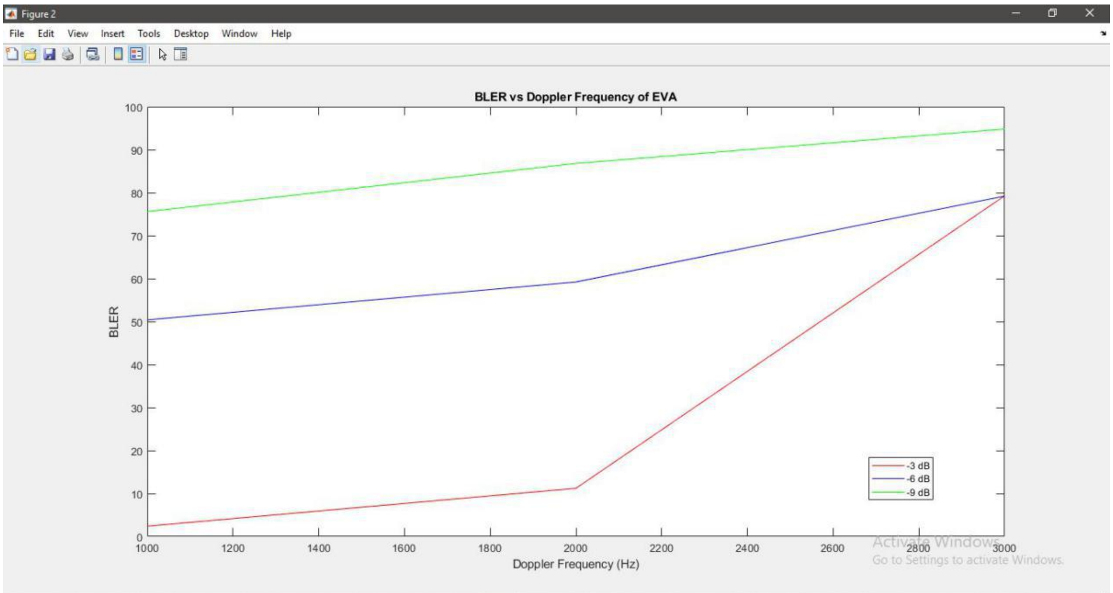

Figure 44: Doppler frequency vs BLER of EVA

10.5 Doppler Frequency vs Throughput of ETU

Table 4: Value of throughput at different SNR levels at different Doppler Frequencies for ETU

Doppler Frequency (Hz)	**Throughput for ETU**		
	-3dB	-6dB	-9dB
1000	54.5966	39.9449	10.2097
2000	25.8017	25.7288	6.3956
3000	0	0	0

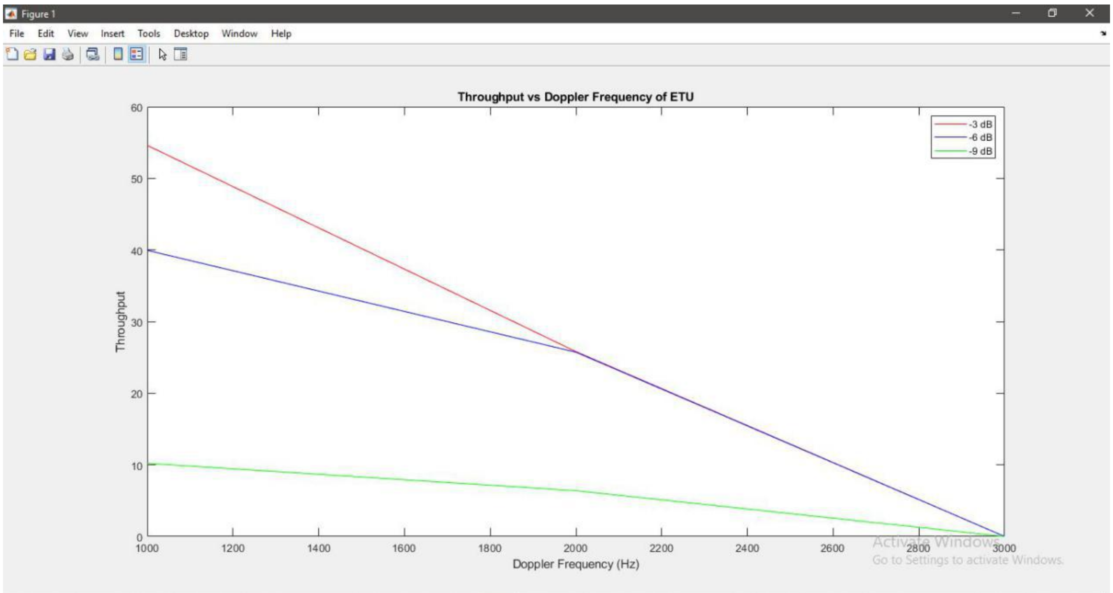

Figure 45: Doppler frequency vs throughput of ETU

10.6 Doppler Frequency vs Throughput of EVA

Table 5: Value of throughput at different SNR levels at different Doppler Frequencies for EVA

Doppler Frequency (Hz)	**Throughput for EVA**		
	-3dB	-6dB	-9dB
1000	61.2138	39.925	9.9897
2000	28.8555	28.8016	7.1969
3000	0	0	0

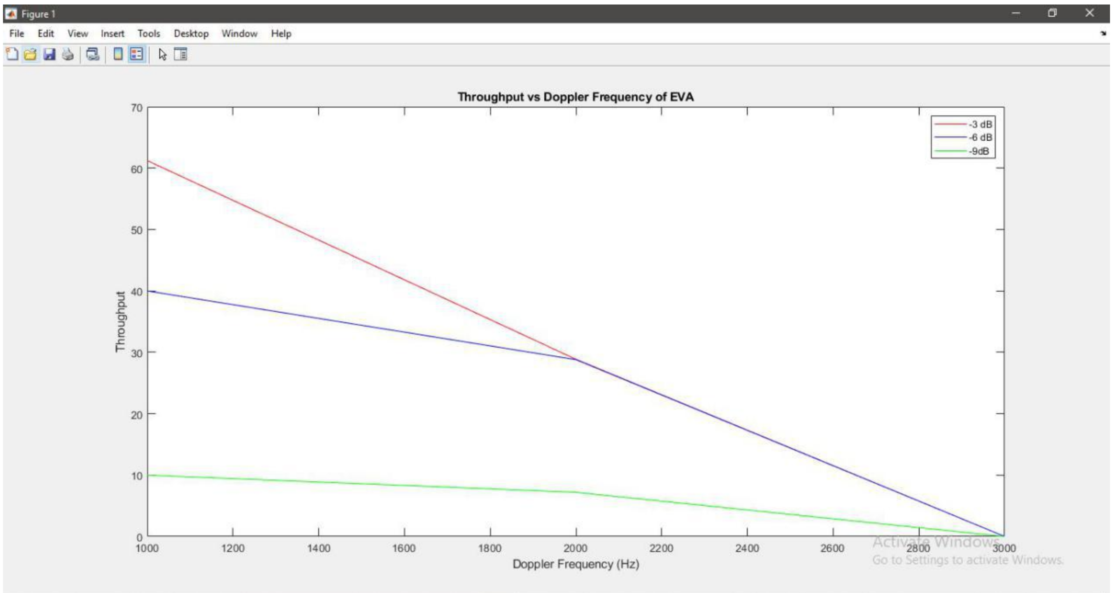

Figure 46: Doppler frequency vs throughput of EVA

Chapter 11

Future Application

11.1 Advanced Applications

i. *Advanced driving with intent/trajectory sharing:* Advanced driving enables semi or fully autonomous driving. Longer inter-vehicle distance is assumed. Each vehicle and/or RSU shares data obtained from its local sensors with vehicles in proximity, thus allowing vehicles to coordinate their trajectories or maneuvers. In addition, each vehicle shares its driving intention with vehicles in proximity. The benefits of this use case group are safer traveling, collision avoidance and improved traffic efficiency.

ii. *Extended Sensors:* Extended sensors refer to the ability of vehicles to obtain information about objects around them located beyond the view of their own onboard sensors. Other nearby vehicles that can detect these objects process them, then broadcast them out to aid other vehicles around in building up a more complete picture of the road world. Overall, this provides vehicles in an area a more complete picture of the traffic environment.

    Extended sensors enable the sharing of raw and processed sensor data (for example: cameras, radar, lidar) among vehicles, RSUs, pedestrians and V2X application servers. The sensor data that a vehicle can share ranges from a photo of a perceived object to its real-time video stream. The availability of sensor data from multiple disparate sources enhances situation awareness of the vehicles and pedestrians, and thus improves road safety. Extended sensors also enable new features and capabilities such as cooperative driving and precise positioning, which is necessary for autonomous driving.

iii. *Platooning:* Platooning allows vehicles to form a tightly coordinated "train" with significantly reduced inter-vehicle distance, thus increasing road capacity and efficiency. It also improves fuel efficiency, reduces accident rate and enhances productivity by freeing up drivers to perform other tasks. Vehicles within a platoon must be able to exchange information periodically (for example, to share status information such as speed and heading) and to send event announcements such as braking and acceleration.

iv. *Remote Driving:* Remote driving enables the remote control of a vehicle by a human operator or by a cloud-based application, via V2N communication. There are several scenarios that can leverage remote driving, including:

- Providing a backup solution for autonomous vehicles
- Providing remote driver services to youth, elderly and others who are not licensed or able to drive
- Enabling fleet owners to remotely control their vehicles
- Enabling cloud-driven public transportation and private shuttles

11.2 On-field Application

Auto makers hope to capitalize on the excitement soon and General Motors has announced that the 2017 Cadillac CTS will be enabled with V2V technology. This technology will be provided by Delphi Automotive, which has selected NXP's RoadLINK chipset with Cohda Wireless's IEEE 802.11p software for use in their V2V modules. Chip-maker Qualcomm has introduced their Snapdragon X12 and X5 LTE modems which work with their VIVE QCA65x4 chipset to support V2V and V2I applications. On the infrastructure side, Cohda is working with Siemens and GM is testing technology from Cisco to ensure that V2V and V2I devices can share the same radio band with causing interference.

As an initial adopter, the 2017 Cadillac will have few cars with which to communicate. In order to realize the benefits of V2V, significant numbers of cars on the road that are equipped with the technology and communicating are necessary. GM estimates that V2V will be effective when 25% of the cars on the road are equipped. At current U.S. scrap rate, this will take about 5 years. The automakers realize that to make this a reality, government regulations will be required. The NHTSA has announced that it will fast-track a proposed rule that would require V2V communication in all new cars, accelerating the proposed schedule by a year.

In addition to GM, Audi has field tested NXP, Cohda and Delphi's V2V technology. Toyota is developing new safety packages to be available worldwide by the end of 2017 that integrate vehicle sensors with V2V and V2I technology. Ford has demonstrated V2V-enabled vehicles. Of course after-market products will also be developed to enable late model, cars to connect and benefit from V2V technology. On the infrastructure side, in addition to wireless products from Cisco, Siemens and Savari, there is the potential for a range of interactive devices such as, signs, traffic lights and cross-walks.

With the reality of V2V just "around the corner," there is plenty of room for innovative technology and products over the forthcoming years.

Chapter 12

Conclusion

The future prospect of V2X is very promising. The research that we have done in order to understand the behavior of throughput and BLER with changes to mobility will pave the way towards making its deployment smoother. The next stage of this research would be to synchronize our findings with a deep learning network control algorithm so that V2X can be implemented on a large scale.

Digitization is the future of modern world. With increasing population and demand, digitization has its share in every field of modern life. But vehicular communication is yet to receive it's due. Vehicle-to-Everything communication is going to fulfill that gap. If implemented properly, this will not only have socio-economic effect, but will be a revolution in communication sector.

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