

**VEHICLE TO VEHICLE PHYSICAL SIDELINK
SHARED CHANNEL CAPACITY ESTIMATION
AND RESOURCE ALLOCATION FOR 5G
NETWORK**

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by

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LIST OF ABBREVIATIONS

3GPP	Third Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
5G V2V	Fifth Generation Vehicle to Vehicle
5G V2X	Fifth Generation Vehicle to Everything
5G NR	Fifth Generation New Radio
5G NR V2X	Fifth Generation New Radio Vehicle to Everything
AI	Artificial Intelligence
BTP	Basic Transport Protocol
BSA	Basic Set of Applications
CA	Carrier Aggregation
CAM	Cooperative Awareness Message
C-ITS	Cooperative Intelligence Transportation System
C V2X	Cellular Vehicle to Everything
CV	Connected Vehicle
CAV	Connected Autonomous Vehicles
CPM	Collaborative Perception Message
DCI	Downlink Control Information
D2D	Device to Device Communication

DENM	Decentralized Enviromental Notification Message
DDQN	Double Deep Q-Network
DDQ-L	Double Deep Q-Learning
DL	Deep Learning
DMRS	Demodulation Reference Signal
DNN	Deep Neural Network
DQN	Deep Q-Network
DRL	Deep Reinforcement Learning
DSRC	Dedicated Short Range Communication
ETSI	European Telecommunications Standards Institute
FCFS	First Come First Serve
FD	Full-Duplex
gNB	G-UTRAN Node B
GPS	Global Positioning System
IMT-2020	International Mobile Telecommunication 2020
IEEE	Institute of Electrical and Electronic Engineers
ITS	Intelligence Transportation System
ITS-G5	Intelligence Transportation System Generation 5
LiDAR	Light Detection and Ranging
LTE	Long Term Evolution
LTE-A	Long Term Evolution Advanced

LTE V2X	Long Term Evolution Vehicle to Everything
LTE V2V	Long Term Evolution Vehicle to Vehicle
MCM	Maneuvere Coordination Message
MCR	Minimum Communication Range
ML	Machine Learning
MCS	Modulation and Coding Scheme
M/G/1	Poisson Arrival General Service and one Server
MoT	Mobility of Things
NLOS	NoneLine of Sight
NR V2X	Fifth Generation Vehicle to Everything
NR	New Radio
NR V2X	New Radio Vehicle to Everything
N-R	Newton Raphson
OBD	On-Board Diagnostic
PSCCH	Physical Sidelink Control Channel
PDSCH	Physical Downlink Shared Channel
PSSCH	Physical Sidelink Shared Channel
PUSCH	Physical Uplink Shared Channel
QS	Queuing System
QoS	Quality of Service
RADAR	Radio Detection And Ranging

RBED	Reward Based Epsilon Decay
RB	Resource Block
RHW	Road Hazard Warning
RL	Reinforcement Learning
RRA	Radio Resource Allocation
RRM	Radio Resource Management
SAE	Society of Automotive Engineers
SB-SPS	Sensing Based Semi Persistent Scheme
SINR	Signal to Interference plus Noise Ratio
SCI	Sidelink Control Information
TB	Transport Block
TTI	Time Transmission Interval
TS	Transportation System
UE	User Equipment
US FCC	United State Federal Communication Commission
V2V	Vehicle to Vehicle
V2I	Vehicle to Infrastructure
V2N	Vehicle to Network
V2P	Vehicle to Pedestrian
V2X	Vehicle to Everything

**ANGGARAN KAPASITI DAN PERUNTUKAN SUMBER SALURAN
DIKONGSI PAUTAN SISI FIZIKAL KENDERAAN KE KENDERAAN
UNTUK RANGKAIN 5G**

ABSTRAK

Pengguna 5G V2V boleh berkomunikasi dengan kenderaan jiran menggunakan komunikasi Peranti ke Peranti (D2D) untuk bertukar-tukar mesej keselamatan; Mesej Kesedaran Koperasi (CAM) dan Mesej Alam Sekitar Terdesentralisasi (DENM). Menghantar mesej ini melalui saluran 5G V2V yang sama juga dikenali sebagai Saluran Kongsi Pautan Sisi Fizikal (PSSCH) menjadi cabaran kepada kapasiti saluran kerana saluran itu banyak digunakan dan sesak dan komunikasi mesti memastikan keperluan 5G V2V QoS dipenuhi. Satu lagi cabaran komunikasi D2D berasaskan V2V ialah pengurusan sumber disebabkan turun naik dalam kualiti saluran yang dibawa oleh mobiliti pengguna V2V. Oleh itu, tesis ini mencadangkan anggaran kapasiti dan pengoptimuman dengan mesej CAM untuk Pautan Sisi Fizikal Saluran Kongsi (PSSCH) dalam komunikasi 5G V2V. Sumbangan kerja ini adalah dalam tiga cara. Pertama, rangka kerja model rangkaian 5G V2V dibangunkan. Kedua, anggaran berangka kapasiti 5G V2V PSSCH dipertimbangkan. Ketiga, algoritma DDQN untuk peruntukan dan pengurusan sumber radio dengan Pereputan Berasaskan Ganjaran (RBED) untuk penilaian dasar dan kemas kini lembut untuk kemas kini dasar dicadangkan. Keputusan yang diperolehi daripada baris gilir M/G/1 menunjukkan bahawa, bagi setiap peningkatan sebanyak 100 bait dalam PSSCH, akan terdapat pertumbuhan minimum 150 Mbps kapasiti sistem iaitu kira-kira 36.3% berbanding ketika hanya muatan CAM digunakan. Keputusan DDQN yang disepadukan dengan dua kaedah yang dicadangkan menunjukkan bahawa pengurangan 50% dalam

kependaman dan 66.7% peningkatan dalam prestasi model diperlukan untuk mendapatkan kadar kejayaan 99% dan kadar jumlah yang lebih tinggi dalam penghantaran mesej 5G V2V dengan kependaman 10 ms masa.

VEHICLE TO VEHICLE PHYSICAL SIDELINK SHARED CHANNEL CAPACITY ESTIMATION AND RESOURCE ALLOCATION FOR 5G NETWORK

ABSTRACT

5G V2V users can communicate with the neighboring vehicles using Device to Device (D2D) communication to exchange safety messages; Cooperative Awareness Message (CAM) and Decentralized Environmental Notification Message (DENM). Transmitting these messages over the same 5G V2V channel also called the Physical Sidelink Shared Channel (PSSCH) becomes a challenge to the channel capacity as the channel is heavily utilized and congested and the communication must ensure satisfying 5G V2V QoS requirements. Another challenge of V2V-based D2D communications is resource management due to the fluctuations in channel quality brought by V2V user mobility. Thus, this thesis proposed capacity estimation and optimization with CAM message for PSSCH in 5G V2V communication. The contribution is in three ways. First, mathematical model of 5G V2V network is developed for utilizing only CAM payload. Second, a numerical approximation of the 5G V2V PSSCH capacity is considered. Third, a DDQN algorithm for radio resource allocation and management with Reward Base Epsilon Decay (RBED) for policy evaluation and soft update is proposed. Results obtained from the M/G/1 queuing showed that, For every increase of 100 bytes in PSSCH, there will be a minimum growth of 150 Mbps for system capacity which is about 36.3% compared to when only CAM payload is used. Results of the DDQN integrated with RBED and soft update methods indicated that a 50% reduction in latency and a 66.7% improvement in model performance are required to obtain a 99% success rate and a higher sum rate

in 5G V2V message transmission with the 10 ms latency time.

CHAPTER 1

INTRODUCTION

This chapter provides an overview of the research, which is the estimation and optimization of 5G V2V Physical Sidelink Shared Channel (PSSCH) capacity. The research problem, objectives, contributions and thesis organizations are all discussed in the chapter.

1.1 Introduction

In 1999, the United State Federal Communication Commission (US FCC) allocated a 75 MHz spectrum band on 5.850-5.925 GHz for high-priority and traffic management applications. The FCC allocated band is divided into 30 uppers (180, 182, and 184) and 45 lower bands (172,174, 176, and 178). The 30 MHz is for the current and future Cooperative Intelligence Transportation System (C-ITS) needs while the 45 MHz is for unlicensed operations as shown in Figure 1.1 (GroupR.S, 2020). Dedicated Short Range Communication (DSRC) is the first protocol introduced in the United States with its counterpart Intelligence Transportation System Generation 5 (ITS-G5) in Europe. The two protocols are based on Institute of Electrical and Electronic Engineers (IEEE) 802.11p and operate within the established 5.9 GHz frequency band. However, IEEE 802.11p supports V2V communication but fails to guarantee Quality of Service (QoS) support and suffers from bounded latency or stipulated time. (Bazzi *et al.*, 2019a; Khan *et al.*, 2021).

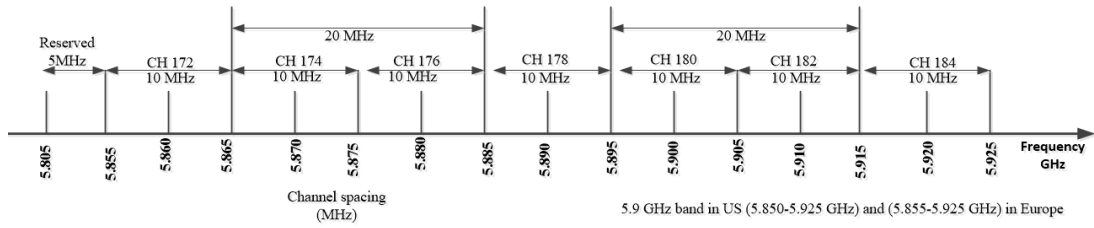


Figure 1.1: FCC Spectrum Allocation within 5.9 GHz Frequency Band

Due to the increase in high number of connected devices and dynamic changes in vehicular topology with the complexity of the vehicular system, the Third Generation Partnership Project (3GPP) established a Cellular Vehicle to Everything (C V2X) protocol in Release 14 Long Term Evolution (LTE). 3GPP enhances the physical layer of the European Telecommunications Standards Institute (ETSI) Intelligence Transportation System (ITS) architecture to enable cellular communication while leaving other layers the same. The protocol consider four types of applications, namely; (Vehicle to Vehicle (V2V), Vehicle to Pedestrian (V2P), Vehicle to Infrastructure (V2I), and Vehicle to Network (V2N)) communications. The latter two depend on infrastructure assistance, while the former are based on Device to Device Communication (D2D).

One of the most promising applications of Fifth Generation (5G) technology that enables V2V communications using the so-called D2D communications is the Fifth Generation Vehicle to Everything (5G V2X). The D2D communication allows two or more devices to communicate when in proximity and was first introduced in Long Term Evolution Advanced (LTE-A) and continues in the 5G and beyond technologies. 3GPP introduced 5G V2X technology in Release 15 to allow higher automation driving with 25 use cases categorized into advanced driving, platooning, extended sensor, and remote driving.

In V2V communications, a vehicle transmits information about its location, speed, and direction with other surrounding vehicles to warn drivers of potential collisions that sensors are unable to detect. Different type of message forwarding used by the vehicles include; unicast, broadcast, multicast, and groupcast. 5G V2X technology attracts much attention due to its variety of applications in ensuring the services of ITS. The tremendous applications in 5G V2X, with increase in consumer demand for services in the mobile environment, high data rate requirements, and the technologically developed mobile broadband communication require system capacity estimation and optimization to ensure safe communication between the devices in the future (Ancans *et al.*, 2017).

The basis of Transportation System (TS) is the interaction of humans and technologies, and as technologies advance, TS becomes a more and more popular subject of study. Greenshields (1935) carried out one of the early studies on transportation where he designed a simple model that represents density, flow, and speed. Since then, transportation research has advanced significantly both in breadth and depth, more specifically with the evolution of ITS technologies since the 1990s.

Despite the technological innovations, modern vehicles are equipped with sensors (such as Light Detection and Ranging (LiDAR), Radio Detection And Ranging (RADAR), and camera), a navigation system, and communication devices to allow data collection and information sharing with vehicles being aware of their environment (Anwar *et al.*, 2019). Through the C-ITS a vehicle becomes more than just a simple mode of transportation when these sensor devices are integrated; they produce, store, process, and send the vast amounts of data that make driving safer and

more convenient.

C-ITS facilitates cooperative data sharing between vehicles and comprises of a wide range of communications-related applications designed to improve traffic management, reduce environmental impact, and boost the benefits of transportation for both commercial and public users (ETSI:TS22.261, 2021). The exchange of safety and non-safety applications in Fifth Generation Vehicle to Vehicle (5G V2V) through sidelink communication involves larger messages that have a significant impact on the channel capacity and hence call for an increase in data rate to satisfy the strict latency requirements and to ensure reliable communication among the device users.

Sidelink is a direct vehicle-to-vehicle (V2V) communication using LTE direct interface named PC5. In LTE V2V, two Modes of communications are introduced namely, Mode 3 and Mode 4. The two Modes support direct V2V communications but differ on how they allocate radio resources. Resources are allocated by the cellular network under Mode 3, the cellular network selects and manages the radio resources used by vehicles for their direct communications. Mode 4 does not require cellular coverage, and vehicles autonomously select their radio resources using a distributed scheduling scheme supported by congestion control mechanisms (3GPP:TS36.300, 2016). Mode 4 is considered the baseline V2V Mode since safety applications cannot depend on the availability of cellular coverage and represent an alternative to 802.11p. The two Modes are later enhanced to Mode 1 and Mode 2 for NR V2X. In NR V2X Mode 1, sidelink resources are scheduled by gNB while in Mode 2 the vehicles select resources from a (pre-) configured sidelink resource pool (s) based on the channel sensing mechanism. New Radio (NR) Mode 2 resource allocation is categorized into

sub-Modes namely; 2(a), 2(c), and 2(d) to enable in-coverage, out-of-coverage, and partial-coverage communications (Naik *et al.*, 2019).

The channel used for V2V communication is termed as Physical Sidelink Shared Channel (PSSCH) which is adjacent or non-adjacent with the Physical Sidelink Control Channel (PSCCH). PSSCH carries data while PSCCH carries control information that is transmitted first followed by data transmission. Sidelink V2V communication improves safety among drivers and vulnerable road users by allowing every vehicle to broadcast a Cooperative Awareness Message (CAM) over the PSSCH as soon it enters the network.

The dissemination of CAM messages by every vehicle makes CAM a higher priority V2V safety message having great impact on the V2V channel capacity. 5G V2X technology has made it possible for sidelink V2V channel services to go beyond simply disseminating CAM messages. The 5G V2V PSSCH is anticipated to transmit safety messages CAM and Decentralized Environmental Notification Message (DENM) and to share Collaborative Perception Message (CPM) and Maneuver Coordination Message (MCM). Delivering these messages over the 5G V2V channel with many connected and autonomous vehicles requires higher data rates which becomes a challenge to the PSSCH capacity.

While latency is regarded as the main performance indicator for applications related to vehicle safety, ensuring sufficient capacity (resources) is also crucial to enable vehicles to exchange PSSCH with CAM or DENM messages. To enhance the existing data rates to several Gigabytes per second (Gigabyte/s), International Mobile

Telecommunication 2020 (IMT-2020) intend to improve the channel capacity (Series, 2015). IMT-2020 covers 5G V2X access technology, as stated in the 3GPP Technical Performance and Service Requirements (3GPP:TR38.913, 2017). In every communication system, if resources are not managed well and available, vehicles cannot exchange CAM or DENM to determine situational safety within the surrounding environment.

Some of the factors that influence 5G V2V system capacity include cell size which determine the clump of roads connected together to obtain the total density of the moving vehicles. The total density of vehicles is the sum of all the vehicles that transmit the messages allocated to the PSSCH at any time. Other factors that affect the system capacity are the choice of the message size and the generation rate which is in turn influence by the mobility of the vehicles on the road and the behavioural aspect of the drivers (Seon *et al.*, 2022).

CAM and DENM are two safety messages introduced by the ETSI with CAM considered a periodic message generated and broadcast by each vehicle to reduce the risk of road accident. DENM is on-demand message triggered by a vehicle under road hazard conditions called the Road Hazard Warning (RHW) message. With the evolution of 5G technology, 3GPP in Release 15 introduced the autonomous driving services for 5G V2X with some enhancement on Release 14 features to enable the deliberation of six levels of automation as published by the Society of Automotive Engineers (SAE) in (J3016) standard (Association *et al.*, 2016) as shown in Figure 1.2.

Many improvements have been made since the development of the 5G V2X

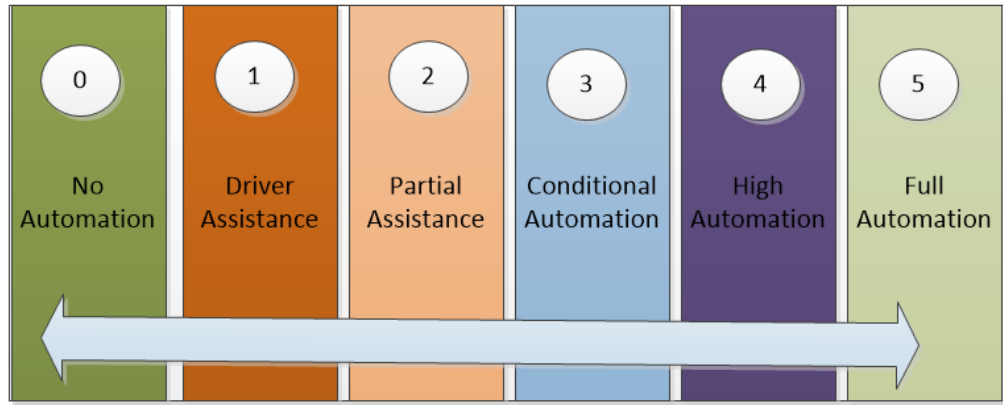


Figure 1.2: Six Levels of Automation in 5G V2V

network to improve performance, spanning from the architecture to the services and more. According to Release 16 standards, 5G V2X users will communicate with Release 14 vehicles using Release 14 waveform, and Release 16 vehicles using Release 16 waveform. In Release 17 there is a subsequent upgrade of 5G V2X architecture to support advanced services and enable phase 2 deployment as well as power saving.

Release 18 standards aims to introduce futuristic concepts such as Artificial Intelligence (AI), Machine Learning (ML), Full-Duplex (FD) operations, and many more services. All the mentioned services are realized through the exchange of messages between the vehicles using the specifically defined 5G controlled message for V2V which is the PSSCH. Figure 1.3 shows Vehicle to Everything (V2X) technology features that continue to evolve over multiple 3GPP releases.

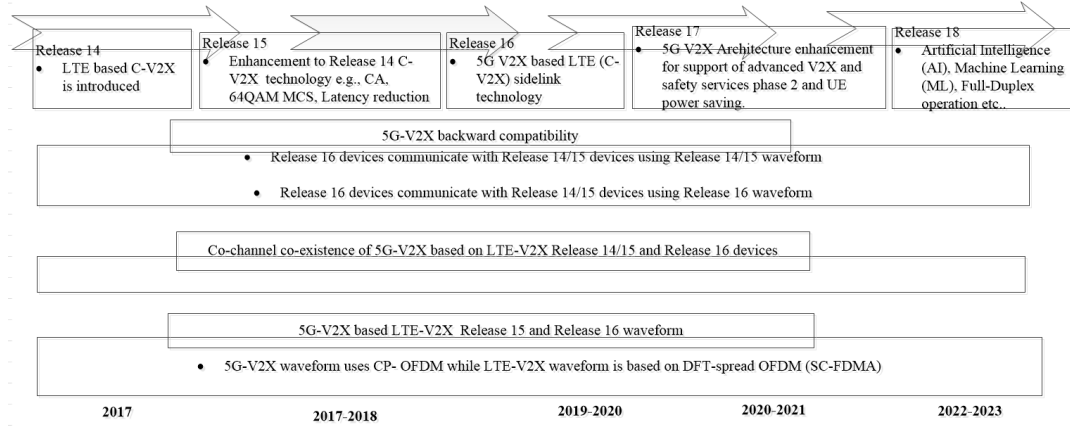


Figure 1.3: V2X Release 14, 15, 16, 17, and 18 Timeline

1.2 5G V2X Services and Their Quality of Service (QoS) Requirements

The evolution of 5G V2X services enables the automotive industry market to tackle valuable technological transformation with the advancement of sensing, computing, positioning techniques, and communication devices that makes self-driving vehicles no longer science fiction but set to become a reality (Campolo *et al.*, 2018). Combining the local perception provided by the On-Board Diagnostic (OBD) sensors, e.g., the Global Positioning System (GPS), LiDAR, RADAR, and cameras, of the automated vehicles with the information provided by other vehicle sensors and by the roadside infrastructure (e.g., obstacles, road surface conditions, and planned maneuvers) will improve the perception of the surroundings and the overall vehicle safety.

Among the 5G V2X services that will benefit from the technological advancement of LiDAR, RADAR, and camera is the meta-mobility known as Mobility of Things (MoT). Meta mobility is a recent concept introduced by Hyundai motors to enable inanimate objects from small to community spaces gain mobility at ultra-high speed or beyond normal using the company's robotic technologies (Jung *et al.*, 2020). With meta-mobility applications, higher data rate will be required to ensure safe driving

among the integrated devices. The 5G V2X use cases that will benefit from meta-mobility service include advanced and platooning driving.

Due to the introduction of more services and the evolution of new technologies, QoS has been receiving wide attention in many communication research including networking, multimedia, real-time, and distributed systems. In large distributed systems such as those used in defense, on-demand service, and inter-networked systems applications contending for system resources must satisfy latency, reliability constraints as well as the application-specific QoS requirements. Allocating sufficient resources to different applications to satisfy various requirements is the basic problem in these situations. Applications can operate at a high level of quality or acceptability lower levels of quality based on the resources allocated to them. Some of the factors that ensure QoS of 5G V2X services as stated in 3GPP standard include, maximum latency (ms), achievable data rate (Mbps), Payload size (bytes), transmission rate (message/s), Reliability (%) and minimum communication range (m).

Achieving a higher Gbps data rate requires a low latency of 3 to 10 ms and ultra-reliability of 99.999% for higher degree automation. Ensuring safety in 5G V2X applications require a higher bandwidth to operate efficiently. According to the literature, the worldwide market for autonomous or self-driving vehicles will reach up to \$20 billion by 2024 from \$3 billion in 2015 (Mei *et al.*, 2018). The estimate of high device connectivity with various V2X services calls the attention of many researchers and industries on how to improve the capacity of V2X network using advanced technologies to enable faster speed, increased connectivity, and high coverage for simultaneous access. Machine Learning ML is one of the techniques used in 5G to

maximize the capacity of a network using an efficient resource allocation algorithm. ML is a subfield of AI that consists several algorithms to enable the analysis of huge amount of dataset by looking for patterns involving various structures. To utilize and mine vast streams of data gathered in a vehicle environment, ML provides adaptable sets of rules (Ye *et al.*, 2018). Figure 1.4 presents a scenario where 5G V2V vehicles as well as the vehicular environment are integrated with LiDAR, RaDAR, camera, communications and other sensor devices to enable safe and fully autonomous driving services which require efficient resource allocation and management.

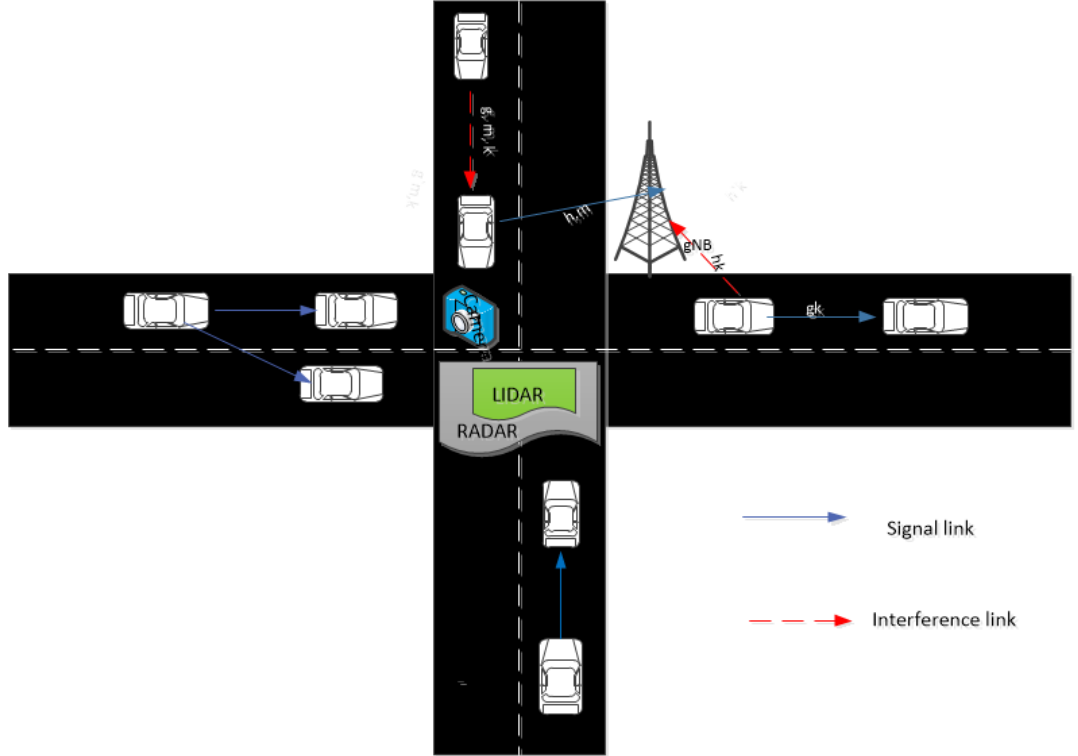


Figure 1.4: Illustration of 5G V2V Communication Environment

From the Figure, h_m is the channel gain corresponding to m -th cellular users, g_k is channel gain for k -th device users, $h_{k,m}$ is the interference on V2I due to V2V communications and $g_{m,k}$ is the interference on vehicles due to V2I communications.

Different QoS requirements are provided by ETSI for LTE V2V and 3GPP for both safety and advanced driving services in (3GPP:TR22.185, 2018) and (3GPP:TR22.186, 2020) as reported in Table 1.1, to ensure reliable communication between the vehicles.

Table 1.1: 5G V2V Communication Requirements for ETSI and 3GPP Services

Use Case	Payload (byte)	Tx rate (message/s)	Maximum latency (ms)	Reliability (%)	Data rate (Mbps)	Minimum communication range (m)
ETSI CAM	50-300	100	100	99.99	10	300-500
ETSI DENM	400-1200	-	100	99.99	-	300-500
Platooning	50-600	2-50	10-25	90-99.99	≤ 65	80-350
Adv. Driving	300-12000	10-100	3-10	90-99.99	10-50	360-700
Extended Sensor	1600	10	3-100	90-99.99	10-1000	50-1000
Remote Driving	16000-47100	33-200	5	99.999	UL:25 DL:1	1000 and above

1.3 5G V2X Challenges

The latency that occurs during resource scheduling procedure, the shift in spatial traffic patterns due to mobility, and resource allocation and management are just a few of the issues that pose a challenge to 5G V2X services. Latency and Resource allocation will be addressed in this study.

1.3.1 Latency in 5G V2X Services

3GPP Release 15 (3GPP:TR22.186, 2020) defined latency as the maximum tolerable elapsed time from generating a data message at source to receiving it at destination applications. In 5G V2X application, latency is considered a drawback to the system's performance. Latency reduction is one of the features introduced in 3GPP Release 15, to enhance the performance of 5G V2X together with sidelink Carrier Aggregation (CA) and higher-order Modulation and Coding Scheme (MCS) (Fodor *et al.*, 2019). The performance and firmness of V2V communication can be affected by the reliability and latency in service for exchange of safety messages and sharing of information.

Latency in message exchange occurs much during the scheduling procedure where the vehicles compete for limited resources. ETSI standard (3GPP:TR22.185, 2018) specifies for collision warning and lane change messages to have 100 ms latency with LTE V2V technology. The evolution of 5G V2X has reduced this need to 3 to 10 ms, as seen in (3GPP:TR22.186, 2020) and reported in Table 1.1. This means the scheduling procedure and the transmission have to be completed in less than 3-10 ms depending on the service category to ensure safety in message exchange under reliable channel conditions. Figure 1.5 depicts the scheduling procedure for sidelink Mode 1 and Mode 2 in 5G V2V communications.

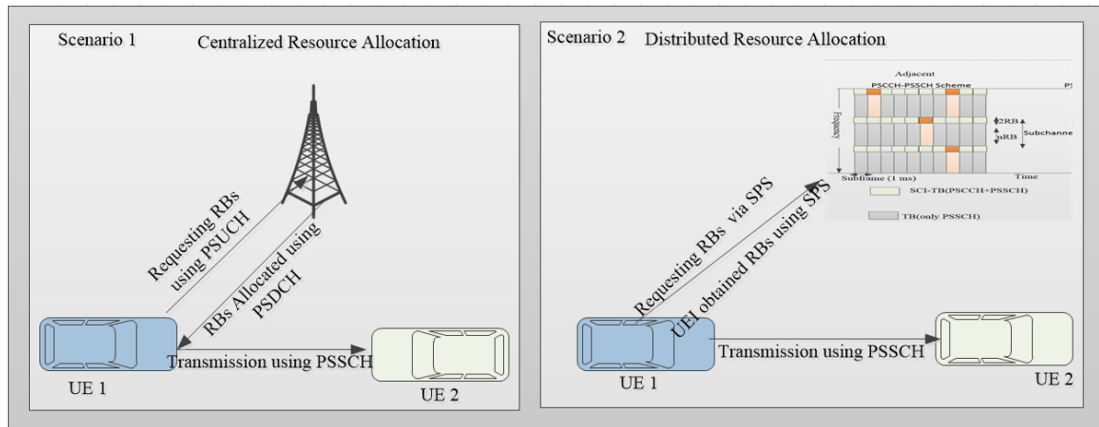


Figure 1.5: 5G V2V Resource Scheduling in Sidelink Mode 1 and Mode 2

In Scenario 1 of Figure 1.5, a transmitter vehicle User Equipment (UE) 1 generates a message and requests transmission resources from G-UTRAN Node B (gNB) through the Physical Uplink Shared Channel (PUSCH). The gNB accepts request and allocates resource to the transmitter vehicle using Physical Downlink Shared Channel (PDSCH) through the Downlink Control Information (DCI) format. The transmitter vehicle selects the grant and transmits the message to the receiver vehicle UE 2 over the PSSCH; this encountered an end-to-end delay from the time a

message is generated to the time it is transmitted.

For Mode 2 (Scenario 2), a transmitter vehicle performs sensing procedure and selects the transmission resource in a distributed manner (no global information is required); as the transmitter vehicle obtains the spectrum resource, it transmits the message to the receiver vehicle using PSSCH. The capacity of Mode 2 communication depends on efficient utilization of sensing algorithm (Molina-Masegosa *et al.*, 2018).

1.3.2 Radio Resource Allocation (RRA)

Future-generation wireless networks 5G and beyond should handle an ever-increasing number of mobile users using a wide range of services and applications, as well as explosive development in mobile data traffic. In the meantime, the networks expand to include a wide variety of different network entities and grow more dense, heterogeneous, decentralised, and ad hoc in nature (Xiong *et al.*, 2019). As a result, resource allocation needs to be planned and optimised in accordance with various service goals, such as high throughput and low latency.

An efficient Radio Resource Allocation (RRA) is the key to resolving the challenges behind Radio Resource Management (RRM). Spectrum allocation schemes are designed either from economic or technical perspective (Yu *et al.*, 2018). However, standard methods for service and resource management that need complete and perfect knowledge of the systems are ineffective or even inapplicable when considering the dynamism and uncertainties that are inherent in wireless network environments.

1.4 Statement of the Problem

Numerous studies have examined the V2V capacity in terms of number of vehicles a network can support in relation to the CAM payload size without accounting for protocol overhead (Bazzi *et al.*, 2017a,b; Gao *et al.*, 2017; Kanavos *et al.*, 2021; Rufino *et al.*, 2019). However, the authors only consider overheads in (Rufino *et al.*, 2019) for security analysis. In addition, with 5G V2V communications, there will be many Connected Vehicle (CV) and Connected Autonomous Vehicles (CAV) competing for limited resources to provide various V2V services over the PSSCH with low latency and higher reliability.

In 5G V2V communications, failing to consider the channel capacity limit in terms of QoS support may lead to significant number of message collisions and channel capacity deterioration, which has much effect of wasteful resources. Safety of 5G V2V users depends on message size which is better determined from the overhead protocol by layer encapsulation. The layered architecture would identify the components, protocols, and message (PSSCH) size required to satisfy the 5G V2V communications.

RRM, according to the literature is the foundation of all communications and is crucial to V2V communications (Loussaief *et al.*, 2020; Masmoudi *et al.*, 2019; Yu *et al.*, 2018). 3GPP:TR36.885 (2016) supports V2V-based D2D communications, where D2D exhibits superior performance in satisfying the quality-of-service (QoS) requirements of V2V applications. However, as the cellular (V2I) and device (V2V) users share the same transmission resources, this causes a scheduling delay. The subsequent synchronization of the 5G V2V mobile devices results in interference

which has a substantial impact on the performance of cellular links and the functionality of mobile devices (Abbas *et al.*, 2018). This puts the efficiency of spectrum under strain. Extensive researches have been conducted on radio resource allocation for D2D-based V2V communications, but most of the approaches are centralized, where a central controller collects network information and makes decisions for each vehicle.

With global network information, resource allocation can be formulated as an optimization problem with QoS requirements for V2V applications as constraints. However, formulating latency into optimization problems is NP-hard, leading to the proposal of various simplified approaches that decompose the problems into multiple steps to find local or sub-optimal solutions. For instance, Ashraf *et al.* (2017); Yu *et al.* (2017) decomposed the formulated problem into Lyapunov stochastic optimization, while Mei *et al.* (2018) utilized Lagrange dual decomposition and the binary search method.

Reinforcement Learning (RL) based Q-learning is the most current technique used for resource allocation and optimization as applied by (Souhir *et al.*, 2019; Salahuddin *et al.*, 2016). In RL, the Q-function is obtained when the agent performs an action a_t at time t based on specific policy π and rewarded positively for doing well or penalized otherwise. However, if the state-action space is very large, the performance of the model with traditional Q-learning cannot be guaranteed because under these circumstances, the linked Q-values rarely change, which results in a substantially longer convergence time because many states are visited infrequently. In addition, RL based algorithm has some disadvantages such as instability and

inefficiency with large number of nodes in the network (Nguyen *et al.*, 2019).

To resolve the problem, Q-learning is combined with Deep Neural Network (DNN) called Deep Q-Network (DQN) (Mnih *et al.*, 2015) and studied in (Mao *et al.*, 2016; Xiong *et al.*, 2019; Yu *et al.*, 2020). However, due to overestimation issue with the DQN set as target network, this result to a maximum achievable value with some bias. The Double Deep Q-Network (DDQN) is introduced as an improved DQN (Van Hasselt *et al.*, 2016). DDQN is more efficient learning algorithm than DQN. It is considered a powerful and versatile learning algorithm that has been showing to achieve state of the arts results on a variety of task. Ye and Li (2018) proposed DDQN for V2V RRA with unicast message forwarding. The DDQN was utilized by (Ye *et al.*, 2019) to maximize V2V based V2I capacity using broadcast (multi-agent) communications.

In their experiment, they consider 100 ms as the predetermined latency limit for message delivery to address the V2V capacity challenge. However, depending on the service being evaluated, the minimal latency needed for 5G V2V communications as mentioned in the 3GPP standard is 3 to 10 ms. Similarly, the exploration exploitation strategy used in the current research considered decaying epsilon based on the number of episodes, which does not in any way take into account the performance of the agent in the environment. Similarly, the parameters (weights) of the Q-network are periodically copied (direct) to the target network which slow the learning of the model.

Most of the studies applying ML for resource allocation with V2V do not consider

the true latency time as provided in the 3GPP 5G V2V standard which is a serious problem in ensuring safety among the vehicle users and requires further investigation. To enhance resource utilization within the shortest latency time, a DDQN algorithm is proposed in this study with new epsilon decay policy called Reward Based Epsilon Decay (RBED)(Maroti, 2019) and soft update weight technique (Kobayashi and Ilboudo, 2021) to accelerate model performance. The model will be train offline as the gNB has access to more data and computatona resources than the vehicle on-board unit (OBU) which make learning faster and effecient. Offline allow training on a large and diverse dataset of experience to enable the agent explore the environment extensively and learn from it experience.

1.5 Research Objective

This study aims to estimate the 5G V2V capacity limit and ensure optimal resource allocation via satisfying 5G V2V stringent QoS requirements. The objectives are:

- a . To develop a Mathematical Model for 5G V2V ETSI safety and 3GPP services that will investigate the maximum number of users the network can accomodate.
- b . To estimate the capacity limit of 5G V2V PSSCH using M/G/1 queuing model and Newton Raphson polynomial approximation for CAM payload and PSSCH message size regarding the protocol overhead.
- c . To enhance the performance of the Double Deep Q-Learning algorithm with RBED and soft update to minimize reward computation latency to a shortest latency of 10 ms.

1.6 Contribution of the Thesis

- A clear and concise model framework is developed concerning the deployment parameters to enable researchers investigate the capacity limit of 5G V2V network and beyond for ETSI and 3GPP services.
- Regarding the derived queuing model for objective two, the study provides a detailed capacity limit for the 5G V2V PSSCH with CAM messages within the 5.9 GHz frequency band. The model may also be used to solve other relevant dynamic systems problem like flow of water through a pipe, motion of a pendulum and the growth of a population.
- The study demonstrates how the two proposed methods ensured satisfying the 5G V2V minimum latency requirement with DDQN resource allocation and management, which is considered the first research to employed the two methods in the V2V communication.
- Based on the simulation results, Deep Reinforcement Learning (DRL) based resource allocation with the RBED and soft update methods can effectively minimize the latency in the training by allowing the agent to transmit maximum data within a 10 ms shortest latency and to share the channel with V2I and other V2V links under the broadcast scenarios.
- The study will be a guide for future research on network slicing for V2X.

1.7 Thesis Organization

This thesis is organized into seven chapters, as described in the following

Chapter one provides an overview of the thesis. It outlines the issues related to the

research and highlights the importance of the study to humanity and society in general. It also explained the problems of the research area and the way forward in conducting the research.

Chapter two consists of the literature review that examines the standard organization specifications supporting ITS, an overview of Long Term Evolution Vehicle to Everything (LTE V2X) as the basis of 5G V2X, and the 5G V2V service architecture and applications. The chapter also reviews sidelink communication in Long Term Evolution Vehicle to Vehicle (LTE V2V) 5G V2V RA and the related works.

Chapter three consists of methodology followed in conducting the research, which comprises the RDA, V2V communication architecture for the study, description of the study's scenario, the overall system models, and the description of V2X services. Modeling performance and evaluation metrics are also presented in the chapter.

Chapter four covers the mathematical model of 5G V2V ETSI and 3GPP services for investigating the maximum number of vehicles that can successfully transmit messages using CAM payload.

Chapter five consists of the system model, the formulated queuing model, the result of the simulation obtained from MATLAB for the CAM payload only and CAM with the protocol overhead for PSSCH capacity estimation and the analysis of the results.

Chapter six consists of the third objective which is the proposed DDQN algorithm that maximizes the system capacity while ensuring minimum latency of the 5G V2V services using the RBED and soft update. The result of simulation and analysis are presented in the chapter.

Chapter Seven is the discussion and conclusion of the study.

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CHAPTER 2

LITERATURE REVIEW

This chapter reviews the existing literature on 5G V2X services and their quality of service (QoS) requirements. Intelligent Transportation System (ITS) and the standard organisations that makes it possible are covered in the first section of this chapter. It also provides an overview of the theoretical framework on machine learning (ML) and previous research findings related to the topic. The chapter concludes with a summary of the research gaps and limitations.

2.1 Background of Intelligent Transportation System (ITS)

According to the World Health Organization (WHO) statistics for 2000, road accident is the major cause of traffic injuries and death (PM, 2013). Later research indicated that there was an increase in the rate of fatalities with up to 1.25 million, with another 20-50 million people injured across the world in 2003. This causes a very high impact of about US \$518 billion equivalent to 1-5% of the gross domestic product in some countries (Fodor *et al.*, 2019; Daniel *et al.*, 2017). Based on these reports and many more, to overcome the problem, there is a need for integrating vehicles with advanced sensing, computing, communication, and artificial intelligence technologies for LTE, NR, and beyond technologies to enable active safety among vehicle users.

Not only for saving human life, but the technologies can also serve as the enablers

of fully autonomous driving which is the basic of ITS. The main objective of ITS is to eliminate the excessive cause of traffic collisions and to ensure safety among vehicle passengers and vulnerable road users. Besides the safety issue, other benefits of ITS include avoiding congestion, finding the most optimal path by processing real-life data, vehicle behavior analysis, examining road capacity, pedestrian flow rate analysis, and so forth (Daniel *et al.*, 2017).

The term ITS evolved in recent years. It emerged as an approach to transforming the transportation system using ICT and its related infrastructures. ITS is one of the 5G enablers that evolved to provide public safety by enhancing the operations of the vehicles, managing vehicle traffic, assisting drivers with other information, and providing a conducive environment through information sharing, and infotainment (video stream and other entertainments) for the passengers in the vehicle. ITS contains is among the communications-related applications meant to improve safety, reduce environmental problems, increase traffic management, and maximize the success of transportation to commercial users and the public.

In Cooperative Intelligent Transportation System (C-ITS), vehicles communicate with each other and with the infrastructure, increasing the quality and reliability of the available information about the vehicles as well as their environments. The importance of ITS is the sharing of information between identical applications within the same ITS station and across other ITS stations, as the ITS stations are operated as bounded secured, and managed domains (Auer *et al.*, 2016). ITS has many benefits towards socialization, improving economic situation, transport efficiency, and road safety.

2.1.1 ITS Standardization

The implementation of the ITS is supported by different organizations including the International Standard Organization (ISO), the European standard organizations, the IEEE industrial consortium i.e., Car-Car-Communication Consortium (C2C-CC) have been working towards a common architecture for the C-ITS system. Others include the IEEE Wireless Access in Vehicular Environment (WAVE), ISO Communication Access for Land Mobile (CALM), and the EU standards Cooperative ITS.

2.1.1(a) European Telecommunication Standard Institute (ETSI)

ETSI is a standard working organization that provides members with a clear understanding of their environment and the way forward to support the development, ratification, and testing of globally applicable standards (Cha *et al.*, 2013). ETSI standards are developed to enable Information and Communication Technology (ICT) systems and services across all sectors of industry and society. ETSI is the initiative of the ITS. In its standard, ETSI introduced the ETSI communication architecture for ITS with two safety applications to be exchanged among the vehicles under low latency and higher reliable communication. ETSI published many ITS documents among which is the C-ITS in Release 1 to make vehicles of different industries communicate with each other and with their environment.

ETSI serves as the initiating body of 3GPP and plays an important role in the development of mobile communications (Lyamin *et al.*, 2018). ETSI extends its capabilities to introduce a document that described the Basic Set of Applications (BSA) for the ITS with V2V, and V2I communications. In the second

stage, functional requirements and operational requirements are introduced while in the third stage higher specification of the protocol layer is identified. In BSA Rel.1, ETSI defined Basic Application Support facilities in the context of Car-to-Car Communication Consortium (C2C-CC) Demonstration in 2008 where the functionalities and related messages are summarized as Basic Services. ETSI introduced CAM and DENM in different releases.

According to the National Highway Traffic Safety Administration (NHTSA), the two applications (CAM, and DENM) will be mandatory in all next-generation vehicles. In January 2017, the U.S NHTSA proposed a new Federal Motor Vehicle Safety Standard (FMVSS) No 150 to enable new vehicles capable of V2V communications to synchronize the Basic Safety Message to and from other vehicles (Gao *et al.*, 2017).

2.1.1(b) Third Generation Partnership Project (3GPP)

The 3GPP was established in 1998, to bring together ETSI and six other regional standardization in Asia and North America, with some market associations and more individual companies. 3GPP is a collaborative project between group of telecommunication associations with initial goal of developing globally applicable specifications for the third generation (3G) mobile system. The project was based on the Global System for Mobile communications (GSM) specifications and the International Telecommunications Unions (ITU). The partnership project has since expanded its focus to include the maintenance and development of GSM (Chaudhury *et al.*, 1999).