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Master Thesis

Performance Enhancement in Two-Hop Direct V2X communication system

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Statement

I have prepared this work on the initiative and under the guidance of my supervisor. When creating, I did not use any other than the specified tools.

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Content

Abstract:

In recent years, Vehicle-to-Everything(V2X) communication has been an emerging area of interest attracting both the industry and academy societies to develop. Which is a new emerging service for the next generation of cellular network(5G). V2X communication can provide plenty of applications such as transmitting safety-related messages to drivers in order to avoid collision or transmitting multimedia for infotainment. However, V2X communication faces certain technical challenges. For example, the fast mobility of vehicles in highway scenario requires much larger transmission range which cannot be guaranteed by a single-hop direct V2X communication. A two-hop direct V2X communication has been proposed to increase the packet transmission range and improve the reliability of the system. In this work, the transmitter in highway tries to communicate with all nearby receivers in the proximity of itself by transmitting packets. And some vehicles will be selected as relays to retransmit the received packets among these receivers. In order to select proper receivers as relays, certain context information like real-time location of vehicles or local environment is collected and applied for relay selection. Through selecting relay and retransmitting packets, the receivers which are inside the targeted communication range but far away from the transmitter have a possibility to receive the packet successfully and therefore packet reception ratio can be increased. Moreover, resource allocation among different hops has been related to the optimization problem according real-time system condition. Last but not least, in order to inspect on the performance of the direct V2X communication with different resource allocations, we have implemented a system-level simulator.

List of Abbreviation

BLER	Block Error Ratio
BMBF	Federal Ministry of Education and Research of the Federal Republic of Germany
C-ITS	Cooperative Intelligent Transport Systems
C2C-CC	CAR 2 CAR Communication Consortium
CSI	Channel State Information
CAM	Cooperative Awareness Message
CSMA/CA	Carrier Sensing Multiple Access Collision Avoidance
DSRC	Dedicated Short Range Communications
5G	Fifth Generation
IVD	Inter-Vehicle-Distance
MAC	Medium Access Layer
Mp3	Moving Picture Experts Group Audio Layer-3
MCS	Modulation and Coding Scheme
PHY	Physical Layer
QoS	Quality of System
SINR	Signal to Noise Ratio
USA	United States of America
UE	User Entity
V2X	Vehicle-to-Everything
WHO	World Health Organization
WAVE	Wireless Access in Vehicular Environment

List of Symbol

A	Amplitude
BW	Bandwidth
C_H	Antenna height correction factor
C	Capacity
d	Distance
f	Carrier frequency
h_M	Height of mobile station antenna
h_B	Height of base station antenna
I	Interference
L	Length of highway
La	Lane of highway
N	Number of user
NF	Noise figure
PL	Pathloss
P	Power
P_{Tx}	Transmission power
PL	Pathloss
R	Transmission range of vehicle
Rx	Receiver
S	Packet size
Tx	Transmitter
W	Width of highway
γ	Path loss exponent
σ^2	Noise power.

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Chapter.1 Introduction

1.1 Background

In recent decades, issues emerge with the development of transportation: about traffic congestion, especially in urban centers; about the impacts on energy consumption and air pollution; and about highway-related fatalities and injuries due to crashes [1]. Governments and organizations all over the world have recognized the need to address these issues. According to the World Health Organization (WHO) fact sheet about road traffic injuries, on a global scale, around 1.25million people die from traffic crashes every year [2]. Between 20 and 50 million more people suffer non-fatal injuries, with many incurring a disability as a result of their injury. Between 20 and 50 million people suffer from a disability as a result of traffic crashes. Without sustained action, road traffic crashes are predicted to become the seventh leading cause of death by 2030. Human error is the main reason leading to traffic crashes. World Health Organization [3]. So it is urgent to create wireless communication to enable the vehicles to exchange their datum with each other and roadside infrastructures. This new creating wireless communication technology is designed to provide a solution to ensure high reliability under challenging vehicular environment, such as high relative speed between transmitters and receivers. Also, low latency is required for safety-related applications. Such as vehicle trash ahead of the highway. Messages should be broadcast to all vehicles close to the location in a short time [4].

1.2 History of C-ITS

In the recent times, the development of Cooperative Intelligent Transport Systems(C-ITS) has the potential to play a significant role in addressing the increasing problems of congestion, safety and environment in Europa [5]. The C-ITS Platform has been launched in 2014 and has delivered the final report of its first phase in January 2016.Preparatory work for the Delegated Act has started in May 2016 with a first meeting of Member State experts. And the preparatory work builds on the findings of the first phase of the Platform for the Deployment of C- ITS in the EU. The Amsterdam Group complements the work of the C-ITS Platform through connecting the C-ITS pilots and deployment initiatives with the goal of interoperable deployments which is facilitated by sharing information as well as discussing and mitigating possible divergent approaches. The Amsterdam Group was formed in 2011 as a strategic partnership between the automotive industry within the CAR 2 CAR Communication

Consortium (C2C-CC) and infrastructure organizations (CEDR, ASECAP, POLIS) as committed core stakeholders in the C-ITS deployment [6].

C-ITS is an innovation way of vehicular management which is utilized for increasing safety and reduce congestion on road traffic scenario. Different applications have been studied to make the journey by vehicles on a highway scenario or on urban area scenario more pleasant and efficient.

1.3. Solution for the Issue

Recently, governments and companies are supporting the development about C-ITS and Vehicle-to-Everything (V2X) communication. Direct V2X communication involved with automatically connected vehicles and road infrastructures has arisen great attention [7]. which serves as one of the key technologies for realizing a plenty of applications related to vehicles, drivers, passengers and pedestrians. Some obvious benefits of V2X communications, including improving road safety by warning drivers under some dangerous condition, reducing time delays when vehicles pass the tollbooths, reducing energy consumption, enhancing mobility, increasing service reliability, enabling groups of cars to exchange multimedia information, and supporting economic development [8]. And V2X communication is a remarkable embodiment to support road safety and traffic efficiency applications in future C-ITS. Investigations on all aspects of ITS are rapidly increasing [9]. Also, the governments, industries and academia have invested plenty of capital for V2X and C-ITS [8].
United States of America (USA) is one of the leading countries in this field. On July 6, 2012, President Obama signed into law a two-year transportation reauthorization bill, the Moving Ahead for Progress in the 21st Century Act. Part of this law is dedicated to ITS activities. The possibility to reduce crashes in USA brought about the focus on a set of critical crash V2X safety applications [10].
Also in china, State Council announced plan to build Intelligent Connected Vehicles Pilot Area in Shanghai on September 2015 [11].

Germany focuses on the research activities on increasing safety and efficiency of traffic. This includes for example the development of assistance and automation systems within the automotive domain. Three different degrees of assistance are possible: information, warnings and recommendations are provided to the driver.

1.4 Main challenge

In contrast to the traditional cellular mobile radio link, the V2X communication propagation channel is much more dynamic, since it consists of two non-stationary transceivers, closely located to the ground level. So it is of greater concern to choose the actual channels for V2X communications. Current legacy solutions for V2X communications are based on 802.11p standard with infrastructure assistance in Long Term Evolution (LTE) network [12].

Another most important issue is about fast movement of vehicles in some scenarios such as highway scenario, which requires a much larger transmission range that must be guaranteed. Also, the whole system should be reliable in despite of the larger transmission range.

On the other hand, the operating performance for vehicular communication is not enough, especially in the field of latency and reliability. So the new generation of wireless communication should be able to meet the high requirements of reliability and availability. In order to meet the demand of new developing service types like vehicular communications, 5G is designed to fulfil these requirements [13] [14] [15].

1.4.1 IEEE 802.11 standard

IEEE 802.11 standard supports the environments where the physical layer properties are rapidly changing and requires the short-duration communications exchanges. The main purpose of this standard is to provide the minimum set of specifications required to ensure interoperability between wireless devices trying to communicate with the communication environment which is rapidly changing. And it is designed to support the situations where information transactions must be completed in a time that is much shorter than the minimum time possible with infrastructure or ad hoc 802.11 networks [13].

1.4.2 IEEE 802.11p

In may 2010, IEEE Task Group approved IEEE802.11p. It is the amendment to IEEE 802.11 which is based on extensive testing and analyses of wireless communication in a mobile environment. There are some standard specifications for telecommunications and information exchange between roadside and vehicle systems, such as 5,9GHc band Wireless Access in Vehicular Environment (WAVE), Dedicated Short Range Communications (DSRC), Medium Access Control (MAC) and Physical Layer (PHY) specifications.

However, 802.11p legacy solution is mainly optimized for a WLAN-type of environment with much lower mobility. V2X communications are often divided into varied environments, such as highway, urban, and rural areas. Vehicles under these scenarios always need higher velocity [8], especially under highway scenario. In this paper, highway is the main scenario which used for analyzing the performance of direct V2X communication through side link.

1.5 Thesis Structure

The structure of this master thesis is organized as the following chapters.

Chapter 2 Describes V2X communication and the user cases of V2X communication. It also describes the system architecture of V2X communications and advantages and disadvantages.

Chapter 3 Describes the system models, and analyze system parameters. Meanwhile, it explains the dedicated channel model for V2X communication system in our work.

Chapter 4 Describes the two-hop network and resource allocation between the two hop direct V2X communications. And introduces the advantages of this network with mathematics support. Also, we decide the way how we assign frequency bandwidth for these two hops with mathematics analysis.

Chapter 5 Describes the relay selection algorithm and compares different relay selection methods. And introduces the advantages of our algorithm.

Chapter 6 Analyses the system performance according to results, and achieve some important conclusions through chart analysis. In addition, we summarize the achievements of our work.

Chapter 7 Presents the conclusion of our work, and underlines the objectives achieved in this paper. Next step is to set up for future development.

Chapter 2 Direct V2X Communication

As mentioned in chapter 1, direct V2X communication is essential in order to cooperate with C-ITS. For a common understanding of this communication, standardization organizations like IEEE has released IEEE 802.11p standard for V2X communication covering PHY and MAC layers in 2010. This includes data exchange between high-speed vehicles and the roadside infrastructure, so called V2X communication [16].

2.1 Wireless Communication Technology

There are plenty of wireless communication technologies like cellular, Bluetooth, LTE or WI-FI, which are examined for use in ITS application. But not all of them can be satisfied for the safety-related requirement of direct V2X communication.

- **Bluetooth:** is a standardized short range radio link technology for fixed and mobile devices. It can satisfy the direct device-to-device requirement, but the transmission range is less than 100m with larger delay for direct V2X communication.
- **Long-Term Evolution(LTE):** is one promising radio access technology to be considered in the standardization work of the ITU for 4G systems. It can support high speed on a highway scenario with unlimited transmission range. However, it cannot support direct device-to-device mode.
- **Wireless Access for Vehicular Environments (WAVE) or Dedicated Short Range Communication(DSRC) technology [17]:** is the main enabling wireless technology for V2X communications, which is safety critical. Major communication system parameters of WAVE combine IEEE802.11a PHY and 802.11 Carrier Sensing Multiple Access Collision Avoidance (CSMA/CA) MAC protocols. DSRC uses the proposed protocols as a base element for short range and medium range wireless communication in vehicular scenario. 5.9 GHz bandwidth was allocated for ITS in Europe and USA.

New technologies like 5G or LTE are in development. They may also satisfy the security reliability and privacy requirements for various V2X communication.

2.2 System Architecture of V2X Communications.

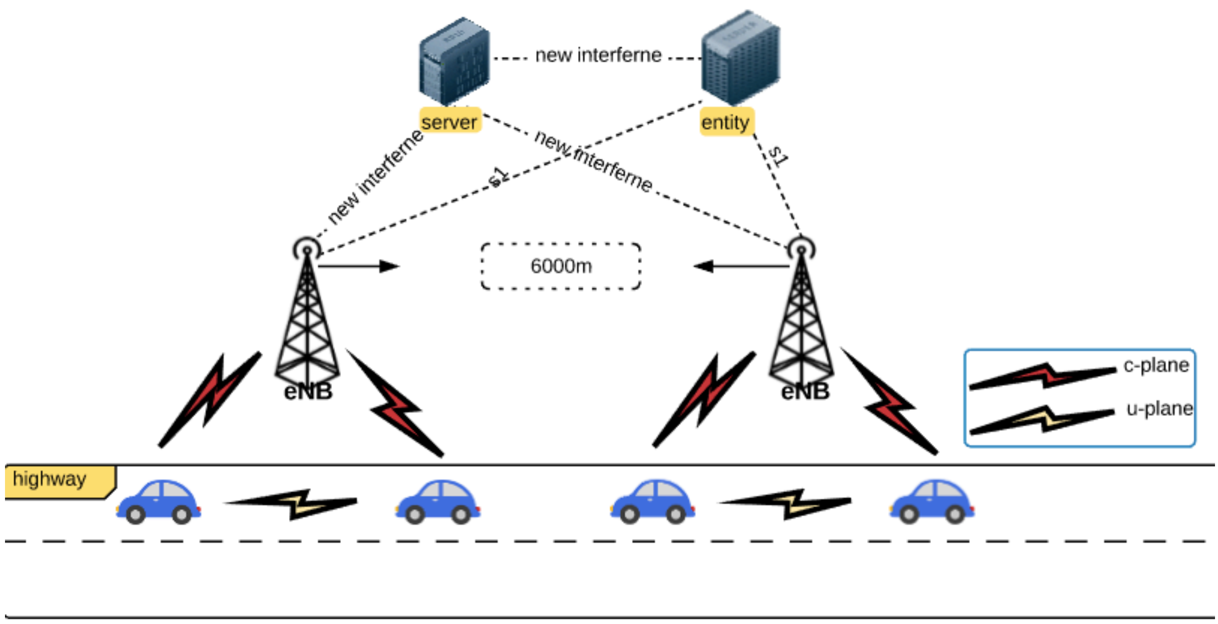

Figure.2.1: System Architecture

As shown in Fig.2.1, in V2X communication system on a highway scenario, all vehicles are connected to base station and are under the control of base stations. Also, vehicles in U-plane communicates directly from transmitter to receivers which are located in the proximity of the transmitter through side link. So the direct V2X communication can contribute to a low-latency performance without network infrastructures.

2.3 Scenarios

In order to improve driving safety or traffic efficiency and provide safety-related information and abundant infotainments to the driver, V2X communication enables large number of use cases. This part introduces the use cases and shows how the use cases imply certain requirements to the system [18].

Base Coverage Urban Scenario: The key characteristics of this test environment are continuous and ubiquitous coverage in urban areas. This scenario will therefore be interference-limited.

Urban Macro-Cell Scenario: In typical urban macro-cell scenario, the mobile station is located outdoors at street level and the fixed base station clearly above the surrounding building heights.

Microcellular Scenario: The microcellular test environment focuses on small cells and high user densities and traffic loads in city centers and dense urban areas. The key characteristics of this test environment are high traffic loads, outdoor and outdoor-to-indoor coverage. This scenario will therefore be interference-limited.

High-Speed Test Environment: The high-speed test environment focuses on larger cells and continuous coverage. The key characteristics of this test environment are continuous wide area coverage supporting high speed vehicles. This scenario will therefore be noise-limited and/or interference-limited [19].

2.3.1 Test Environment

Our test environment is based on highway, as we know, highway is the high-speed test environment focusing on larger mobile stations and continuous coverages. The key characteristics of this test environment are continuous wide area coverage supporting high speed. Therefore, this scenario will be noise-limited and/or interference-limited [19]. However, we consider a more special test environment based on highway. It’s assumed that all vehicles on the highway with the same speed and the same Inter-Vehicle-Distance (IVD).
The Fig.2.1 involves the main parts for V2X communication. There are as following:

Driver: the drivers receive warning information and benefit from this kind of system.

Vehicle: it is the main character on the highway. Maybe in future, it will replace the driver to implement driving and connecting to others smartly. Internet service providers: it provides internet service for vehicles and drivers [20].

2.4 Application of V2X Communications

V2X communication system is the solution to prevent drivers and passengers from road-related accidents. By using of V2X communication, all vehicles in the vicinity are connected. So the drivers can be made aware of all potentially hazardous conditions and dangerous situations through receiving warning information.

2.4.1 Safety-Related Application

The main purposes of safety-related application are to reduce the occurrence of overtaking, rear-end collision, and check pre-cash situation and hazardous location.

Safe Overtaking: Regarding safe overtaking, the use of V2X communication by its very nature requires that all vehicles in the vicinity be connected, so drivers can be made aware of all potentially hazardous conditions and situations [20].

Cooperative Forward Rear-End Collision warning: Regarding rear-end collision, it occupies a significant percentage of all accidents. The cooperative forward rear-end collision warning provides assistance to drivers to avoid rear-collision with other vehicles. In order to avoid a rear-end collision, each vehicle transmits own information such as location and speed to others, and monitors continuously the position and behavior of other vehicles in the proximity of itself. Thus, this will give the driver enough time to react and avoid rear-end collision.

Pre-cash Situation Sensing: This situation is similar to the cooperative forward rear-end collision warning. This requires all vehicles periodically share information to predict a crash. Under this situation, we assume this is an unavoidable crash that is no enough for driver to steer or brake. This requires vehicles exchange more detailed position data and situation. Also, extra information like air bags and seat belts need to be optimized.

Hazardous Location Notification: Regarding hazardous location, V2X communication system share information related to dangerous location on the roadway, for example, frozen and slippery highway, rolling stones or potholes on the roadway. Therefore, it is urgent to generate the information about exact location and broadcast to vehicles. So if a vehicle experiences the situation of its system, it will share the information with other vehicles in its proximity. So the driver will receive the notification automatically, and pay attention to this hazardous location and avoid accident [20].

2.4.2 Efficiency-Related Application

Efficiency-related application in V2X communication system considers improving the efficiency of transportation network through sharing information to the drives or reducing energy consumption. The more efficient the transportation network is; the less delay of transportation system is.

Fast Pass the Tollbooths: when vehicles get close to these tollbooths, the drivers will receive information collected from other vehicles. Then they can decide which one is better with less vehicles. So these vehicles can pass the tollbooths with less time.

Enhancing Navigation and Mobility: Vehicles uses the information constantly collected from others regarding the traffic congestion on the roadways over large area. Then, the vehicle utilizes the information about current traffic conditions through the area to decide the optimal route, which increases the mobility of the roadways.

Reducing Energy Consumption: As mentioned before, with enhancing navigation, the vehicle can find a better route with less traffic congestion and less delay. Also with high mobility, the energy consumption is decreased at the same time.

2.4.3 Infotainment

In V2X communication system, infotainment can enable groups of cars to exchange multimedia information. Such as sharing Moving Picture Experts Group Audio Layer-3 (Mp3) songs or having a phone call.

2.4.4 Other Applications

Also, V2X communication can support economic and social development. With such an abundant communication system, we believe it will bring economic benefit and bring more pleasant experience with the vehicles.

2.5 Drawbacks and Challenges of V2X Communication

2.5.1 Drawbacks

Data Load: One drawback identified by the researchers themselves is that the data load of the channel increased rapidly when groups of vehicles are about to meet.
Hardware Equipment: Under certain complicated scenario, if the vehicles are not equipped enough hardware to detect and sense current environment, or the connection to the internet is lost for any amount of time. The V2X communication could not be efficient as expected [21].
Amount of Time: If all vehicles in V2X communication system benefit from this system, the amount of time will be the biggest issue.

2.5.2 Challenges

Complex Scenarios: In real world, there are too many scenarios that we expect, and most of them are complicated and hard to analyze, which is really hard to analyze each different scenario.

Low Usage: Rarely real V2X communication system have established in the market, even the top ranked auto companies have no communication systems and protocol be installed in their vehicle. Before real application in the market, plenty of researches and testing work need to be completed and improved.

Regional Standard: And the big challenge is that the standard just regional standard which cannot obtain consensus on the same point in a short time.

So we still have a long way to go for V2X communications. But some initiate product has been established in the market.

Chapter 3 System Model

In order to improve traffic efficiency and safety and to assist drivers to reduce the traffic accident and energy consumption, therefore, it is an efficient method that selecting relay transmits information to more vehicles in the transmission of one transmitter in V2X transmission. In this way, vehicles in the transmission range of the transmitter should listen to the multiple transmitted package concurrently. This communication process is a kind of twice hopping network where multiple receivers try to receive the same packet from one transmitter through selecting relay vehicles. In this part, we describe the models utilized in this work.

3.1 Environment Model

C-ITS can address the increasing problems of congestion, safety and environment. So it requires V2X communication working efficiently in any environment, such as urban, rural or highway scenario. In this research, under highway scenario is considered to detect the system performance of V2X communication.

As shown in Fig.2.1, network assisted direct V2X transmission model under highway scenario is implemented for packet transmission. All vehicles are connected to the operator in the C-plane. Meanwhile, in the U-plane transmitter can directly communicate with the receivers in the proximity of itself. In order to provide network-assisted direct V2X communication, a traffic-related and safety-related server has been assumed in the system architecture, which is embedded in the core network. It can support location information exchange with another mobility management entity which regularly collect the location information from vehicles. According to the collecting context information, this server can allocate radio resources efficiently for the two-hop direct V2X communication through side link [13].

In Tab.3.1, the main configuration parameters are including a 20-kilometer highway that is used for simulation and the highway has 3 lanes. According the requirement, we assume the width of this highway is 20 meters. It is assumed that the inter base station distance is 6000 meters.

Table.3.1: Main Parameters

Scenario: Highway		
Key parameter	value	unit
Length of highway	L=20	km
Width of highway	W=20	m
Inter-Vehicle-Distance	Ls=10/15	m
Lane of highway	La=3	
Range of base station	db=6	km
Height of the antenna of base station	h_B1.5	m
Height of the antenna of mobile station	h_M=1.5	m
Transmission range of vehicle	R=1000	m

3.2 Deployment Model

As Tab.3.1 shows, the IVD is 10 meters or 15 meters which is changeable according to the different requirements of simulation.

The overall number of vehicles served by one base station is UE.

$$UE = 1000/IVD \cdot La \cdot db \tag{3.1}$$

In 3GPP, a direct V2X communication over side link can be used to facilitate this information exchange procedure [22]. In order to enable the fully automated driving in highway and to support more vehicles receiving safety-related messages, a 1000-meter transmission range of direct V2X communication is applied to simulate the system performance.

3.3 Radio Propagation Channel Model

Wireless channels are sensitive to the propagation environment. Signal can be reflected, absorbed, diffracted, or scattered by objects in the environment. In case of channels for direct V2X communication, signal level fluctuation may be affected due to reflection by roads and vehicles in the transmission range or scattering by trees and terrains. This part illustrates the channel modeling in the particular vehicular use case.

3.3.1 Large Scale Fading

Large scale fading is due to path loss of the signal as a function pf distance and shadowing by large objects such as buildings and hills. Large scale fading usually combines overall effect of the path loss and shadow. This occurs as the mobile moves through a distance of the order of the cell size, and is typically frequency.

3.3.2 Small Scale Fading

Small-scale fading is due to the constructive and destructive interference of the multiple signal paths between the transmitter and receiver. This occurs at the spatial scale of the order of the carrier wavelength, and is frequency dependent.

3.3.3 Channel Model

The channel model plays an important role in the direct V2X communication system. In this work, we take the large scale fading into consideration that is path loss.

First we take Rural Macro(RMa) Los and NLos as channel models, but after simulation, we found the height of Antenna of the base station should be 35 meters which is much greater than required in our system. Because of the variation, so the path loss will change a lot which really has a great effect on the last performance of the V2X communications. After comparison the performance, we decide the hata model as our simulation channel model.

The hata model is a radio propagation model for predicting the path loss of mobile transmissions in exterior environments. The model is suited for both point-to-point and broadcast communications. So we applied this channel mode in this V2X communication.

$$C_H = 0.8 + (1.1log_{10}f - 0.7)h_M - 1.56log_{10}f \tag{3.2}$$

where C_H is the antenna height correction factor and f is the carrier frequency which is changeable according to different applications and requirements. And h_M is the constant height of mobile station antenna.

Hata model describes the path model between transmitter (Tx) and receiver(Rx). The distance between transmitter and receiver is considered as parameter to measure received power.

$$PL = 69.55 + 26.16log_{10}f - 13.82log_{10}h_B - C_H + [44.9 - 6.55log_{10}h_B]log_{10}d \tag{3.3}$$

where PL represents the path loss in areas and h_B is the height of base station antenna. And d is the real-time distance between the transmitter and the receivers.

Table.3.2: Channel model Parameters

Channel model: Hata model		
Key parameter	value	unit
Transmitter power	24	dBm
Transmitter antenna gain	0	dBi
Receiver antenna gain	3	dBi
Carrier frequency	2	GHz
Operational bandwidth	10/20	MHz
Package size	212	Byte
Noise figure of mobile station	7	dB
Thermal noise level	-174	dBm/Hz

In Tab.3.2, each vehicle transmits packages with a constant allowed transmitting power of 24 dBm. In this work, V2X communication utilize a carrier frequency of 2 GHz as transmission frequency. Different Frequency bandwidth resources are utilized for efficiency-related and safety-related applications in direct V2X communication system.

3.4 Antenna

The effective of V2X applications require low latency and high reliability. So a stable radio link is the necessary condition to obtain high reliability. There are some differences between cellular network and V2X communication. In cellular communications the base station is at an elevated position and has a sectored coverage around it. But in V2X communication, both transmitter and receiver antennas are isotropic and at the same 1.5-meter height relatively close to the ground level. Moreover, we assume the transmitter antenna gain is 0 dBi, and the receiver antenna gain is 3dBi in this communication system.

Also each base station is installed the same antenna. we do not consider any movement of vehicles in order not to add any additional effects which have not been considered in the analysis.

3.5 Traffic Model

Traffic model specific for safety-related issue in V2X communication includes both periodic and event-driven package transmission.

- **Event-driven package transmission:** For this transmission, once a vehicle experiences certain events from local environment. The event-driven messages will be delivered to all the vehicles in the proximity. However, the frequency of generating messages is much lower.
- **Periodic transmission:** Compared to event-driven package transmission for V2X communication, the periodic transmission is more reliable by continuously transmitting information including location, speed or roadway situation. We utilize a periodic package transmission of 212 Bytes with 10 Hz periodicity for each vehicle.

3.6 Modulation and Coding Scheme

An appropriate Modulation and Coding Scheme (MCS) is very important for transmission every time. Because of near-far effect, the links between transmitter and receivers in its proximity can experience varied channel states.
At the same time, it is a hard work to collect the real time Channel State Information(CSI) for at the transmitter side under highway scenario. So it's vital to adapt to an appropriate MCS with a more robust link performance in case of links experiencing worse channel states [13].
A more robust transmission means that a lower MCS is required. However, a lower MCS means that more frequency and time resources are required to transmit the same size package. Therefore, the MCS is controlled by central service for each transmission based on real time system load.
According to the definition, we can decide the MCS efficiency according to the number of mobile stations, bandwidth and required size of packets. Decided efficiency to make sure these parameters such as how many users can be supported by using these transmission resources. In order to make sure resources can support the requirements in the direct V2X communication, if the system has the certain number of users without abundant bandwidth resource, then a much larger MCS efficiency is required to transmit the same packets. Also, the larger MCS means the robustness decreasing. But if the total number of users is smaller than required, then each user can be allocated more time and frequency resources to transmit more packets.

In addition, if the overall packets in the communication is too large than the system capacity, the communication system is overloaded. Under this situation, some users cannot receive the packets successfully. Thus the performance of the system will be decreased. Because of the limitation of MSC and bandwidth, the total number of users that can be served in V2X communication system is limited.

When we get the efficiency value, we should select the appropriate value according to Tab.3. The value selected should be equal to or just greater than the calculated efficiency.

Table.3.3: CQI-MCS Mapping Table

CQI	**Modulation**	**Spectral Efficiency**
0	Out of range	
1	QPSK	0.1523
2		0.2344
3		0.3770
4		0.6016
5		0.8770
6		1.1758
7	16 QAM	1.4766
8		1.9141
9		2.4063
10	64 QAM	2.7305
11		3.3223
12		3.9023
13		4.5234
14		5.1152
15		5.5547

3.7 Thermal Noise Model

Noise power in a receiver is usually dominated by thermal noise. Thermal noise (Nyquist noise) is the electronic noise generated by the thermal agitation of the change carriers inside of electrical conductor at equilibrium spectrum, which happens regardless of any applied voltage. Thermal noise level is -174 dBm/Hz for highway scenario.

$$P_{dBm} = -174 + 10log_{10}BW + NF \quad (3.4)$$

where P_{dBm} is the noise power received by the receiver. BW is the transmission radio bandwidth. And NF is the noise figure of the user.

Chapter 4 Two-hop Network and Resource Allocation

Over the past few years, single-hop vehicular transmission or multi-hop vehicular transmission in direct V2X communication has be widely used to deliver messages, such as hazardous situation information, road congestion information and traffic warning messages in direct V2X communication. These are all safety-related applications in order to reduce the possibility of vehicle trashes. So the transmission range and time delay concerned messages transmitting between transmitter and receivers count.

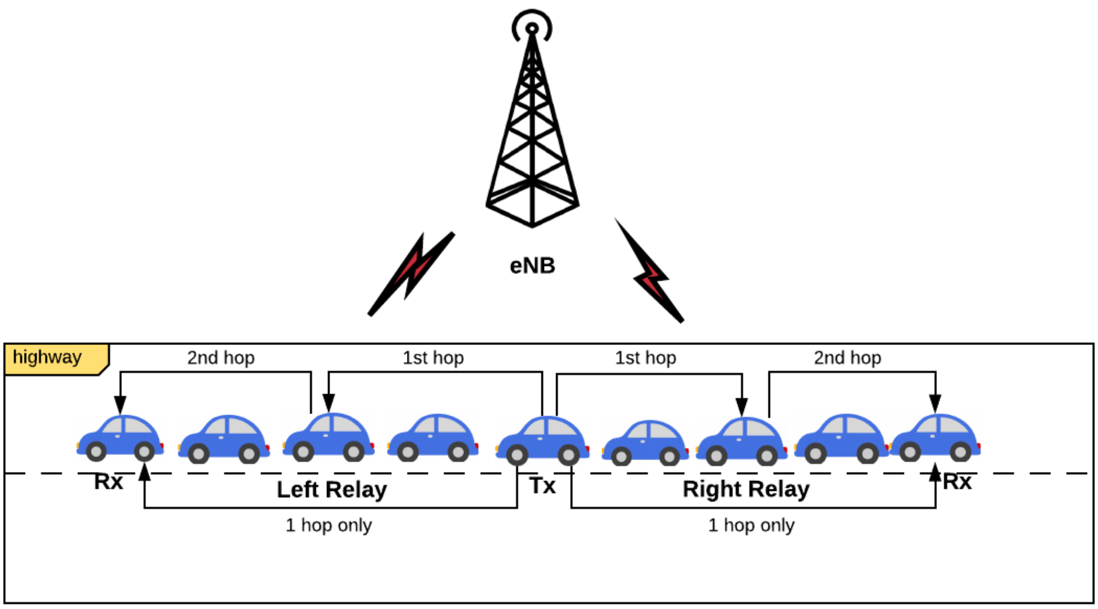

Figure.4.1: Two-Hop Network

4.1 Single-Hop Network

As Fig.4.1 illustrates, the two concepts for a basic highway scenario where just two dissemination directions are considered. One concept is single-hop network, which is consisted of the transmitter and receivers in the proximity of the transmitter. The periodic status messages are transmitted by the only transmitter to other vehicles in the transmission range of the transmitter directly. Radio propagation only depends on the distance between transmitter and receiver. Single hop network can also deliver the messages to all intended receivers. But the successful transmission ratio matters.

4.2 Limitation of Single-Hop Network

In the literature, the performance of V2X communication under cellular network control is restricted by using a single-hop direct V2X communication. Because single-hop direct V2X communication cannot fulfil the ultra-high reliability requirement of V2X communication in certain scenarios. For instance, as mentioned before, a V2X communication range up to 1000 meters should be achieved on a highway scenario in order to obtain a good perception of the environment and avoid accidents [23].

However, packets transmission over single-hop direct V2X communication will reach the receivers far away from the transmitter with a bad signal quality. Because of the bad-quality of the receiving signals, the receivers have a high probability to not successfully receive the packets and therefore the reliability of the V2X communication is decreased. So the allocated resources only for single hop is not efficient and cannot get the optimum performance.

4.3 Limitation of Multi-Hop (more than two hops) Network

Also, the use of multi-hop transmission in V2X communication is spectrally inefficient as, in most cases, they need to transmit on orthogonal channels. And the performance of relaying processes along multiple-hop is unsuitable [24]. In a multi-hop network, the same problem can be defined as hop selection and a related scheme is proposed in L. Ruan and V. K. N. Lau [25], which involves power control as well to co-exist with the primary users. A common denominator in all these papers is that the secondary nodes are assumed to adapt their transmission power in order to always satisfy the interference constraint in underlay settings. However, this may not be the case in every network and the secondary nodes may have fixed transmission power [26]

4.4 Two-Hop Transmission Network

To improve traffic safety and efficiency, each vehicle on highway is required to broadcast its information like geometrical location, mobility pattern and its sensed environment information to other traffic participants within certain radius. And the radius is often referred to as the transmission range and its value is related to detailed service requirements. On this highway scenario, a communication range of 1000 meters is required. But the signal propagation loss can be quite high with such a large transmission distance. Also, the direct V2X communication over side link corresponds to a point-to-multi-point multicast transmission [22]. The transmitter of the single-hop direct V2X communication cannot be aware of the channel condition to all receivers. So the single-hop direct V2X cannot be guaranteed that all receivers can receive transmission packets with a good quality for successful packet decoding. In order to increase packet transmission range and increase V2X communication reliability, we propose a two-hop direct V2X communication over side link in this work. The packet transmission range is defined in this work as the range over which a packet can be successfully received. As figure.1 shows, two selected relays retransmit the messages received from the transmitter and consist the twice-hop communication network with the transmitter. The transmitter generates the packets and transmits over the side link. After the first-hop transmission, a selected vehicle which has successfully received the packets from the first-hop can be triggered as a relay and retransmits the received packets to other receivers that have not received the packets successfully in the proximity of the relay. So the transmission link between the relay and its receivers is called as the second hop. Therefore, all receivers under the transmission range of the transmitter try to receive the packets successfully from at least one of the two hops. In the two hops transmission network, messages are transmitted with a low frequency or a low transmit power in the first hop, and then retransmitted by selecting relays until the desired dissemination range is covered [27]. The fundamental purpose of this work is to maximize the performance of the communication systems with limited frequency and time resources.

4.5 Transmission Range Maximization for Two-Hop Direct V2X Communication

As mentioned before, the two-hop direct V2X communication over side link can be applied to extend packet transmission range. The amount of resource allocated to the first hop and second hop should be adapted by the network in an efficient way in order to maximize the overall packets transmission range.

So the problem about the maximum transmission range shows as following,

Maximize(BW_1, BW_2) $$D(BW_1) + D(BW_2) \tag{4.1}$$

Subject to $$BW_1 + BW_2 \leq BW \tag{4.2}$$

$$BW_1 \geq 0 \tag{4.3}$$

$$BW_2 \geq 0 \tag{4.4}$$

Eq. (4.1) represents the maximization of the transmission range by allocating bandwidth BW_1 and BW_2 for the two hops respectively. The function $D(BW)$ represents as the transmission

range function and used to calculate the packet transmission range if bandwidth resources are allocated to the direct V2X hops. So $D(BW_1)$ and $D(BW_2)$
stand for the packet transmission range for the first and second hop correspondingly. Also, BW_1 and BW_2 stand for the bandwidth allocated to the two hops. Eq. (4.2) - (4.4) present the constraints, which mean allocated bandwidth resource cannot exceed the overall available bandwidth.

4.5.1 Maximize the Packet Transmission Range

in order to get the maximum transmission distance, a general formula to calculate the path loss is used here, as:

$$PL = A \cdot d^{\gamma} \tag{4.5}$$

A is the amplitude which is a constant value and d is the distance between transmitter and receiver. Empirically, the relation between the average received power and the distance is determined by the expression where γ is called the path loss exponent that is related with the concrete communication signal.
Therefore, we calculate the receiving power at the i-th receiver for a packet transmitted by j-th transmitter, as:

$$P_{Rx}(i,j) = \frac{P_{Tx}}{A \cdot d(i,j)^{\gamma}} \tag{4.6}$$

P_{Tx} is the transmission power and $d(i,j)$ is the distance between the j-th transmitter and i-th receiver. And we assume that all transmitters use the same transmission power with $24\ dBm$. Furthermore, the Signal to Interference plus Noise Ratio (SINR) of i-th receiver is expressed as:

$$SINR(i,j) = \frac{P_{Tx}/[A \cdot d(i,j)^{\gamma}]}{\sum_{m \neq j}\{P_{Tx}/[A \cdot d(i,j)^{\gamma}]\} + \sigma^2} \tag{4.7}$$

where the $m \neq j$ stands for the interference from the transmitters that transmits the packets over the resource of the j-th transmitter. And σ^2 represents the noise power. For simplification, $I(i,j)$ is used to present the interference power, if the i-th receiver is trying to receive a packet from
j-th transmitter, as:

$$I(i,j) = \sum_{m \neq j}\{P_{Tx}/[A \cdot d(i,j)^{\gamma}]\} \tag{4.8}$$

Therefore, Eq. (4.7) can be represented as

$$SINR(i,j) = \frac{P_{Tx}/[A \cdot d(i,j)^{\gamma}]}{I(i,j) + \sigma^2} \tag{4.9}$$

In order to receive packets successfully from the j-th transmitter, the SINR value of the i-th receiver should be better than a threshold value. We can calculate the threshold SINR value from Shannon-Hartley theorem which represents the maximum rate at which information can be transmitted over a communications channel of a specified bandwidth in the presence of noise, as:

$$C = BW \cdot log_2(1 + SINR) \tag{4.10}$$

C is the capacity and is also the maximum rate of information. W is the transmission bandwidth. Therefore, the SINR threshold value for successful receiving a packet can be calculated as:

$$SINR_{required} = 2^{(C/Bw)} - 1 \tag{4.11}$$

So the calculated $SINR(i, j)$ value should be greater than the $SINR_{required}$, as:

$$SINR(i,j) \geq \ 2^{(C/B\square} - 1 \tag{4.12}$$

therefore,

$$\frac{P_{Tx}/[A \cdot d(i,j)^{\gamma}]}{I(i,j)+\sigma^2} \geq \ 2^{\left(\frac{C}{Bw}\right)} - 1 \tag{4.13}$$

In order to fulfil the equality in Eq. (4.13),

$$P_{Tx}/[A \cdot d(\square j)^{\gamma}] \geq (2^{\left(\frac{C}{Bw}\right)} - 1) \cdot [I(i,j) + \sigma^2] \tag{4.14}$$

Therefore, the maximum distance where a packet can be successfully received can be derived as:

$$D(BW) = \frac{\sqrt[\gamma]{P_{Tx}/A}}{\sqrt[\gamma]{[I(i,j)+\sigma^2] \cdot (2^{C/BW} - 1)}} \tag{4.15}$$

From Eq. (4.15), the transmission range of a single hop direct V2X over side link is not only affected by the allocated resource BW, but also it has the relation with the interference. The interference of the first hop transmission is impacted by the allocated resource scheme.

In addition, the capacity of the transmission system can be derived from the real V2X communication scenario, as:

$$C = S \times R \times N \tag{4.16}$$

where N vehicles in total are in coverage of a base station, and each vehicle tries to transmit a packet with size of S bits periodically with a frequency R packets per second.

From Eq. (4.1) and Eq. (4.15), we get the equation as:

$$D(BW_1) + D(BW_2) = \frac{\sqrt[\gamma]{P_{Tx}/A}}{\sqrt[\gamma]{[I(i,j)+\sigma^2] \cdot (2^{C/BW_1} - 1)}} + \frac{\sqrt[\gamma]{P_{Tx}/A}}{\sqrt[\gamma]{[I(i,j)+\sigma^2] \cdot (2^{C/BW_2} - 1)}} \tag{4.17}$$

So Eq. (4.17) represents the maximal transmission range between two hops direct V2X communication over side link. Also the maximum transmission range is the radius of transmission.

4.6 Resource Allocation Between Two Hops

As mentioned before, the resource allocation between the first hop and the second hop transmissions should be adapted to increase the packet transmission range. As Eq. (21) shows that the maximum transmission range is also related with the sum of the interference power and noise power. Noise power is affected by resource allocation. Because we take thermal noise into consideration which is -174 dBm/Hz. For example, if the allocated bandwidth is 10MHz, and then the noise power is -97 dB. Also, the interference power is not constant and related with the position of the transmitters which transmit the packets on the same radio resource.

4.6.1 Resource Allocation Modes

V2X side link transmission mode 3 and V2X side link transmission mode 4 which are used to allocate the resource to a V2X transmitter in LTE [28]. V2X side link transmission mode 3: The transmission resource is scheduled by network and therefore network can allocate the same radio resource to different transmitters.

- V2X side link transmission mode 4: A V2X transmitter autonomously selects a resource from a resource pool which is either configured by network or pre-configured in the user device.

Network can allocate the same resource to different zones if they are satisfied with a distance larger than a threshold. The distance threshold value for both modes should be decided in a way that the mutual interference power is small enough. In order to estimate the interference, so the network should be aware of the path loss model of the communication system.

in this work, the distance threshold value is large enough, so the mutual interference power is much lower than the noise power. Therefore, the Eq. (4.17) can be simplified as:

$$D(BW_1) + D(BW_2) = \frac{\sqrt[\gamma]{P_{Tx}/A}}{\sqrt[\gamma]{\sigma^2 \cdot (2^{C/BW_1} - 1)}} + \frac{\sqrt[\gamma]{P_{Tx}/A}}{\sqrt[\gamma]{\sigma^2 \cdot (2^{C/BW_2} - 1)}} \tag{4.18}$$

To differentiate the objective function as:

$$[D(BW_1) + D(BW_2)]' = -\frac{c \cdot ln2}{\gamma}\left[\frac{1}{Bw_1^2} \cdot 2^{C/BW_1}\left(2^{C/BW_1} - 1\right)^{-\frac{1}{\gamma}-1} - \frac{1}{(Bw - Bw_1)^2} \cdot \frac{1}{Bw_1^2} \cdot 2^{C/(BW-BW_1)}\left(2^{C/(BW-BW_1)} - 1\right)^{-\frac{1}{\gamma}-1}\right] \tag{4.19}$$

with the constraint function in Eq. (4.2) – Eq. (4.4), the objective function will be maximized if Eq. 20 is satisfied, as:

$$BW_1 = BW - BW_1 \tag{4.20}$$

so

$$BW_1 = \frac{1}{2} BW_1 \tag{4.21}$$

when $BW_1 = BW_2$, the transmission range is maximized.

Chapter 5 Relay Selection

Relay selection is one of the main buildings blocks of cooperative relaying and commonly channel conditions of relay links are main selection criteria. The impact of choosing a given relay node on communication of surrounding nodes and overall network has to be taken into account. The relay selection is mainly done once at network start up periodically at transmitting section. Many papers have been published based on different relay selection approaches [29]. Also, Unreasonable selection of the relays to retransmit important information could seriously degrade the ITS applications performance in terms of latency, overhead, and reception rate. The terrible performance of the decision might have devastating consequences on the performance of the ITS applications and consequently on the safety of drivers and pedestrians [30].

However, many relay selection schemes demand the continuous monitoring of all available channel links, Regarding the relay selection mechanism, threshold-based relay selection has been proposed as an efficient technique for improving performance [31].

5.1 Relay Selection Methods

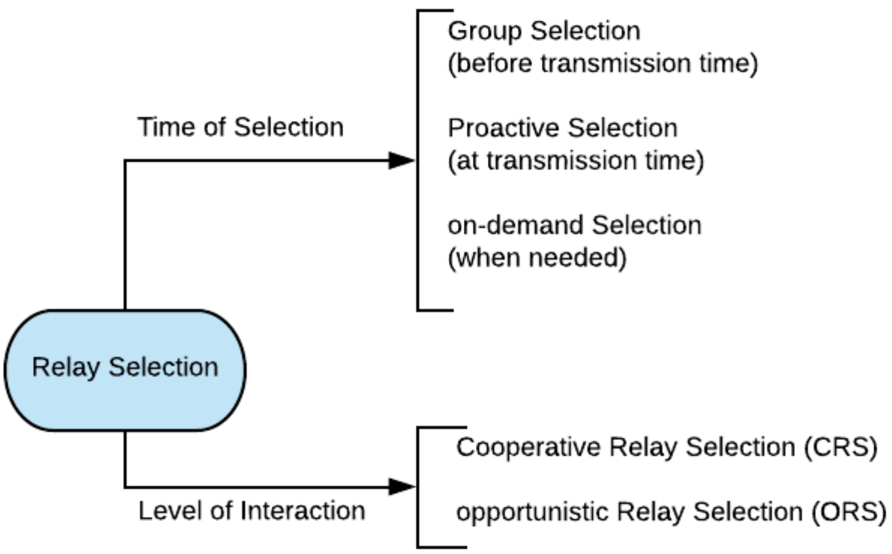

Figure.5.1: Relay Selection Taxonomy

According to the Fig.5.1, based on the time of selection, it is divided into the following three categories.

Group Selection: it selects relay before transmission in order to achieve some pre-defined performance.

Proactive Selection: it selects relay during transmission according to the source and the destination.

On-demand Selection: it selects relay when the relay is needed.

Also, based on the level of interaction, it is divided into the following two categories.

Opportunistic Relay Selection: it selects relay based on the information which is about the network each potential relay.

Cooperative Relay Selection: it selects relay based on the useful information about the acceptance to relay and local situation from relay broadcasting.

For a better understanding of the existing relay selection methods, the following figure.2 will be helpful to identify the similarities among these relay selection methods.

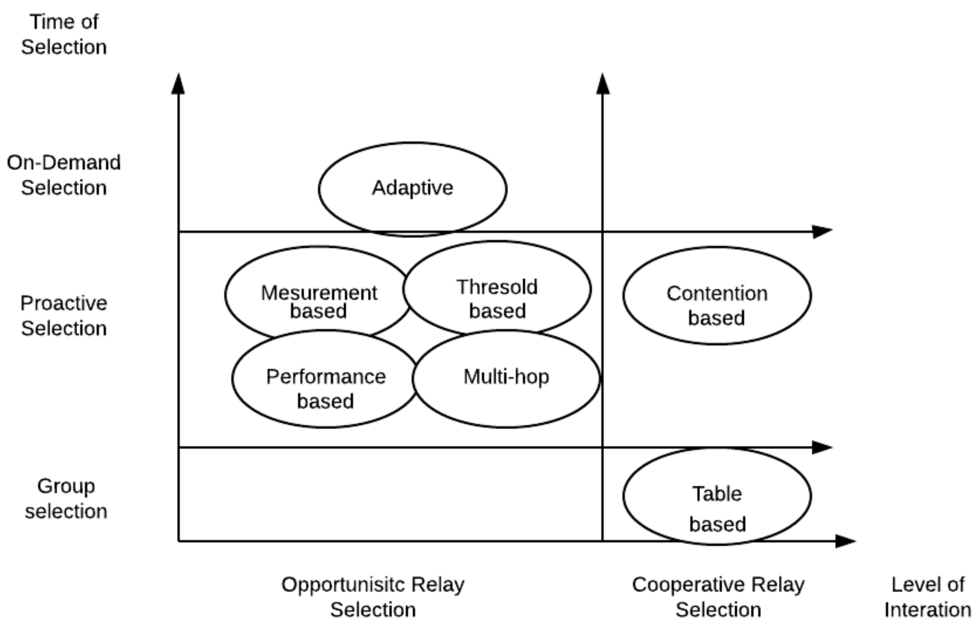

Figure.5.2: Classification of Relay Selection Methods

As shown Fig.5.2, measurement-based, threshold-based and performance-based relay selection approaches are proactive and opportunistic relay selections, which means a relay that is always selected based on local information during transmission. The adaptive relay selection is an on-demand and opportunistic selection category, which means a relay that is selected if needed.

Also, we can find that two categories are divided under cooperative relay selection. One based on the selection of group of relays is called table-based relay selection. Another one based on the selection of a set of a variable number of relays is called contention-based relay selection.

5.1.1 Measurement-Based Relay Selection

The measurement-based relay selection is based on the local measurements of instantons channel conditions. Each potential relay estimates channel conditions. However, as we mentioned before, it is a hard work to collect the real time channel state information(CSI) for at the transmitter side under highway scenario. So this relay selection approach is not our choice for relaying messages for the next transmission.

5.1.2 Performance-Based Relay Selection

The performance-based relay selection is based on the performance on delay and energy efficiency. All potential relays estimate their channel condition as well as the measurement-based relay selection. However, the channel estimation overhead will be limited with the measurement-based relay selection. This method is not suitable for our V2X communication system [29].

5.1.3 Threshold-Based Relay Selection

The threshold-based relay selection relies on Signal to Noise Ratio (SINR) and Block Error Ratio (BLER) thresholds to decide from a set of N available ones which node is satisfied for cooperation between the source and the destination. MCS is adapted to reach a target BLER value below 1%.

5.2 Threshold-Based Relay Selection Algorithm

The objective for designing the transmission system is to deliver the safety-related road information in a high speed with quite low latency. On the other hand, it is efficient to utilize the limited frequency and time resources. The threshold-based relay selection algorithm can meet these requirements in V2X communication systems.

5.2.1 Advantages of Threshold-Based Relay Selection Algorithm

The threshold-based relay selection tries to increase network lifetime and transmission throughput. Also, it doesn't need to collect the instant CSI information which is really a tough work. In addition, this algorithm can be combined with other algorithms in order to transmit safety-related information to drivers.

5.3 Context-Aware Selection of Relays

From the efficiency perspective, relay selection procedure should be executed and adapted. Thus some context information such as geometrical location and nearby traffic participants and environment information should be applied to optimize system performance. Thus, there are two technical components of context information that should be considered to selecting relays.

- Selection of relay User Entity(UE)
- Collection of the useful context information

Before a packet is retransmitted over the first hop direct V2X communication, the transmitter needs to locally select proper receivers act as the relays. The main aim of the relay selection is to extend the transmission range that can support the most receivers which have the difficulty to successfully receive packets from the first hop direct V2X communication.

Moreover, the selection of relays should have limitation number, which cannot be arbitrarily large. Because we need to control the mutual interference and reduce the consumption of radio resource. However, if the number of the relays is too small, certain receivers will not be in the transmission range of any relay and therefore they cannot successfully receive the packet. So the performance of the direct V2X communication will be decreased.

In this work, since we inspect on the two-hop direct V2X communication on a highway scenario and potential receivers for traffic-related packets are either in the front side or in the back side of the transmitter, two relays will be selected to perform the second hop transmission for packets.

5.3.1 Context Information

Context information should be collected and presented at each V2X transmitter in order to operate relay selection procedure. For example, the real-time location and mobility pattern of data packet generator are embedded in each V2X data packet. Therefore, a V2X UE can receive and cache the information of the nearby traffic participants to predict their geometrical location in future.

5.4 Relay Selection Algorithm

Algorithm 1: Relay Selection

Step 1: Deciding the appropriate MCS and the threshold BLER.
Step 2: BLER is derived from the SINR value of each transmitter.
Step 3: Mapping the distance between each receiver and the transmitter to the BLER of each receiver.
Step 4: Depending on the mapping table of distance and BLER calculated before, the distances of receivers which BLER values satisfied the threshold value are selected.
Step 5: The distance of the receiver satisfied the maximal distance is the relay.

Algorithm 2: Two Side Relays Selection

Step 1: First, the receivers in the transmission range of the transmitter are divided into front and back two groups according to the position.
Step 2: Deciding the appropriate MCS and the threshold BLER.
Step 3: Also, each receiver in two groups has its BLER.
Step 4: Mapping the distance between each receiver of two groups and the transmitter to the BLER of each receiver.
Step 5: Depending on the mapping table of distance and BLER calculated before, the distances of receivers which BLER values satisfied the threshold BLER value are selected for these two groups separately.
Step 6: There are two groups of satisfied the threshold BLER value selected. The distance of the receiver satisfied the maximal distance is the relay. So the two relays are selected according to the two maximum distances in the two groups correspondently.

5.4.1 Interference in Second Hop

It is worth noticing here because of the two side relays. They are both responsible for the second hop transmission of each packet and transmit the same packets for the second hop transmission by multiplexing the same radio resource or using the two same size radio resources respectively, which will also affect the second interference calculation.

- **Two Same Size Radio Resources**: Because the network can also allocate the same resource to different zones for the second hop direct V2X communication. So the receiver in the proximity of the relay will be affected by the transmitter using the same resource. Also, due to two same size radio resources. The front and the back relays transmitters will not affect the receivers in their transmission range respectively.
- **Multiplexing the Same Radio Resource**: As mentioned in two same size radio resources, the interference of the transmitter will not only have related with others using same resource. But also the front and the back relays transmitters will affect the receivers in their transmission range respectively. Because the two relays multiplexing the radio resource.

Therefore, a much higher interference power density for the second hop can be experienced at a receiver than the first hop.

5.4.2 Mapping Table

As mentioned in the relay selection algorithm, a mapping table from the packet transmission distance to the packet reception ratio is required, in order to select which receiver has a high probability to receive a packet from the first hop successfully and can act as relay. The transmission of Cooperative Awareness Messages(CAMs) can contribute to obtain the information. Since CAM messages are periodically transmitted, a V2X receiver can record the successful reception or not of the CAM messages from the Transmitter to itself. As the location information of the transmitter has already embedded in the CAM message, the V2X receiver can calculate the distance between the transmitter and itself. Based these collected and calculated information, the mapping table from the distance and the estimated packet reception ratios can be created.

As mentioned before, the modulation is worth noticing which has been applied in LTE and it can provide different robustness. Therefore, the mapping table is created with different MCSs. For instance, if there are 15 optional MCSs and the estimated packet reception ratios should be collected with a communication range of 1000 meters and with a resolution of 5 meters, so the mapping table should have a dimensions of 15×200.

As the following Fig.5.3, Fig.5.4 and Fig.5.5 show, all of them represent the 15×200 mapping tables of 10MHZ, 8MHZ and 6MHz respectively.

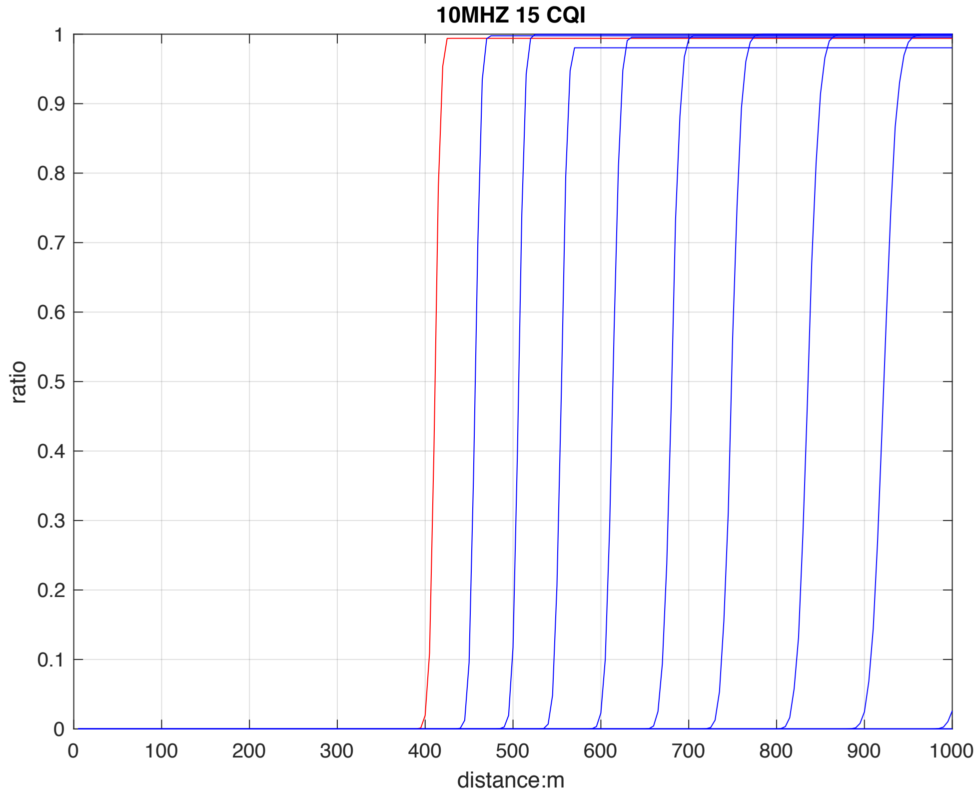

Figure.5.3: 10MHz Mapping Table Graph with 15MCSs

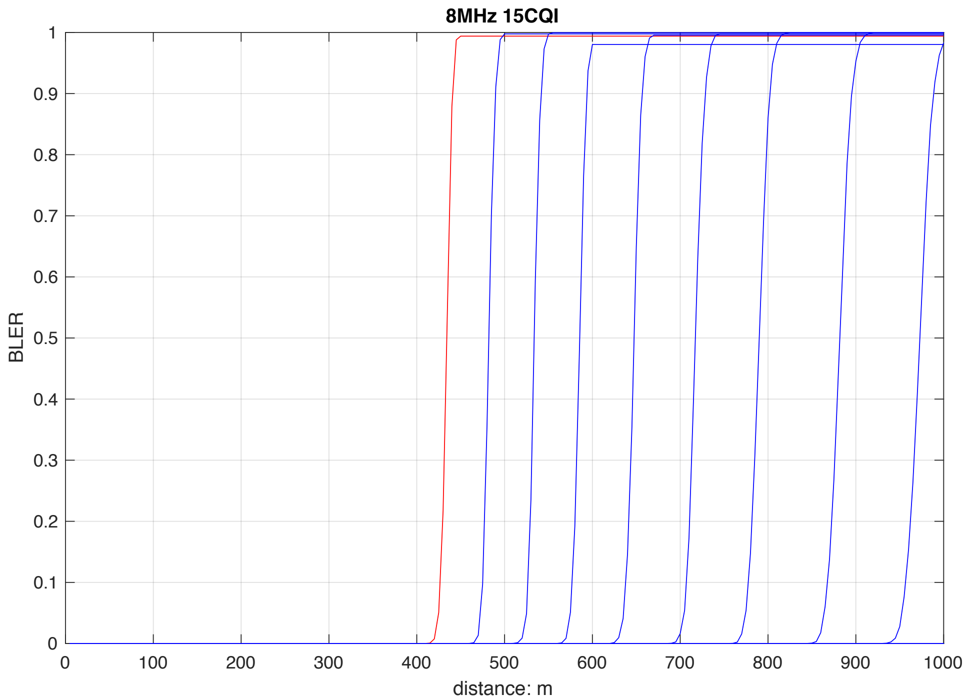

Figure.5.4: 8MHz Mapping Table Graph with 15MCSs

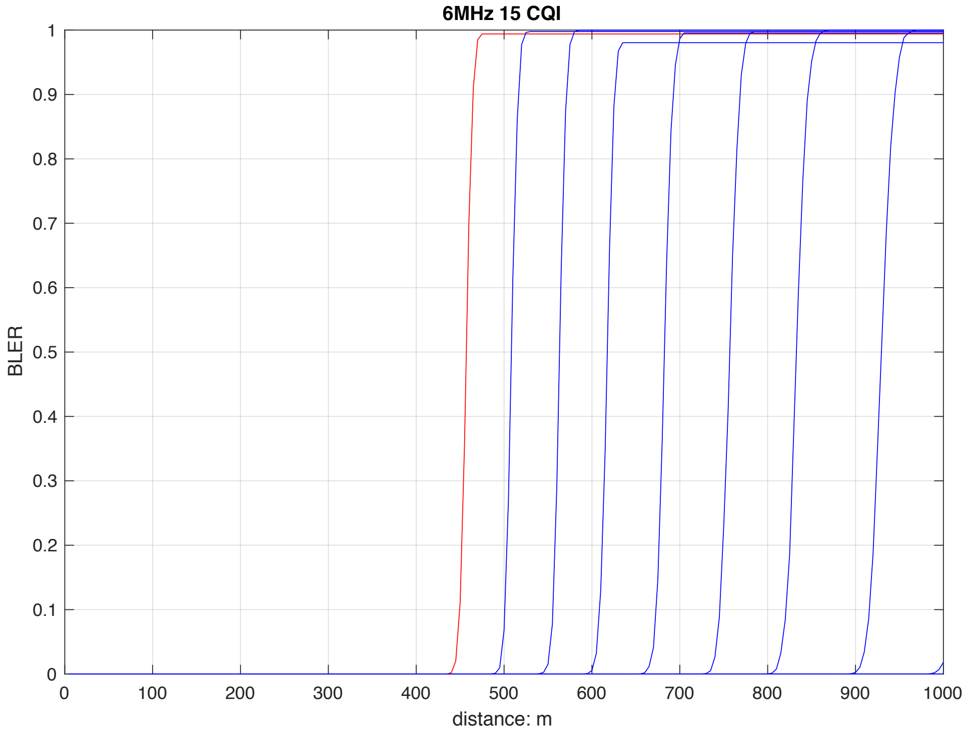

Figure.5.5: 6MHz Mapping Table Graph with 15MCSs

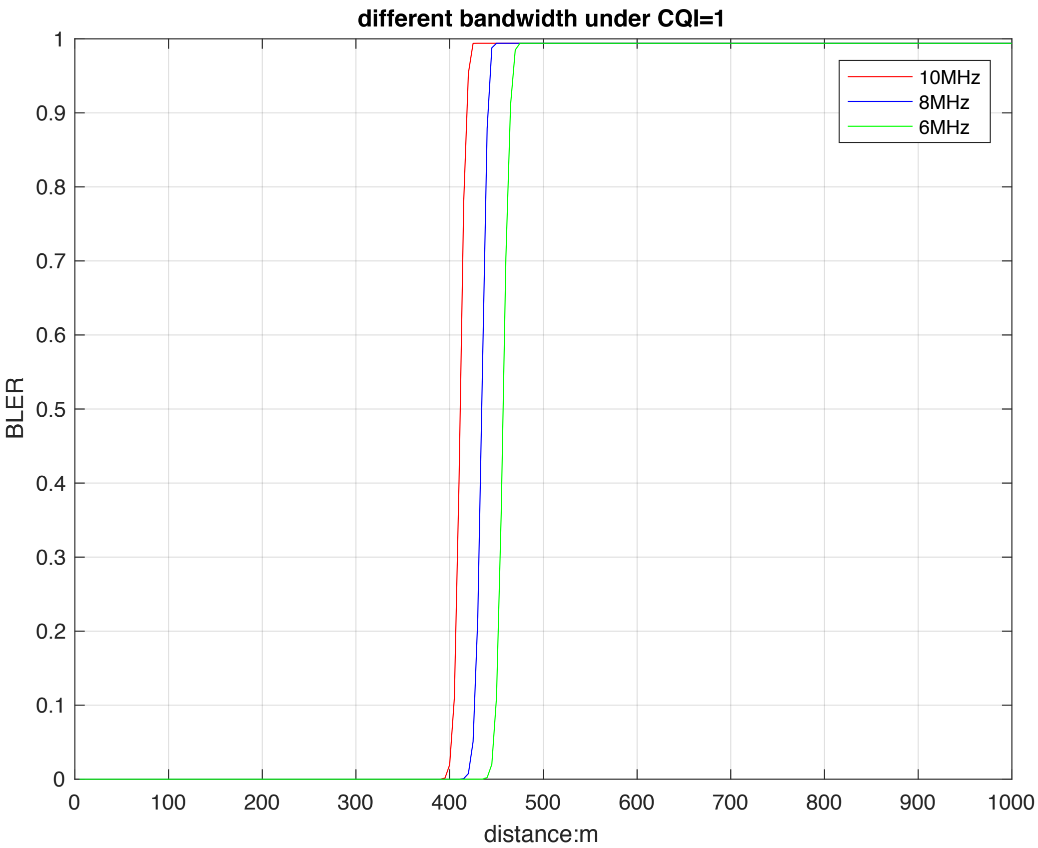

Figure.5.6: Different Bandwidth Mapping Table Graph with $CQI = 1$

As Fig.5.6 illustrates, we abstract the first line from each mapping table. The three different lines represent the BLER changing curves under $CQI = 1$ where efficiency is 0.1523 of 10 MHz bandwidth, 8MHz bandwidth and 6 MHz bandwidth resources correspondently. It is easy to find that the threshold distances under threshold $BLER = 10\%$ of the three bandwidths are not same. The threshold distance of 10 MHz bandwidth is the smaller than 8MHz, and the threshold distance of 6MHz bandwidth resource is the largest.

As Eq.4.9 shown

$$SINR(i,j) = \frac{P_{Tx}/[A \cdot d(i,j)^{\gamma}]}{I(i,j)+\sigma^2} \tag{5.1}$$

$$\sigma^2 = PSD \times \mathrm{BW} \tag{5.2}$$

where σ^2 is the noise power and PSD is -174 dBm/Hz. So with decreasing bandwidth, the noise power is decreased. Therefore, the whole SINR value is improving with decreasing bandwidth. That is why the threshold distance of the 6MHz bandwidth is greater than 10 MHz bandwidth.

5.5 Improving the Performance by Removing Overlapped Vehicles

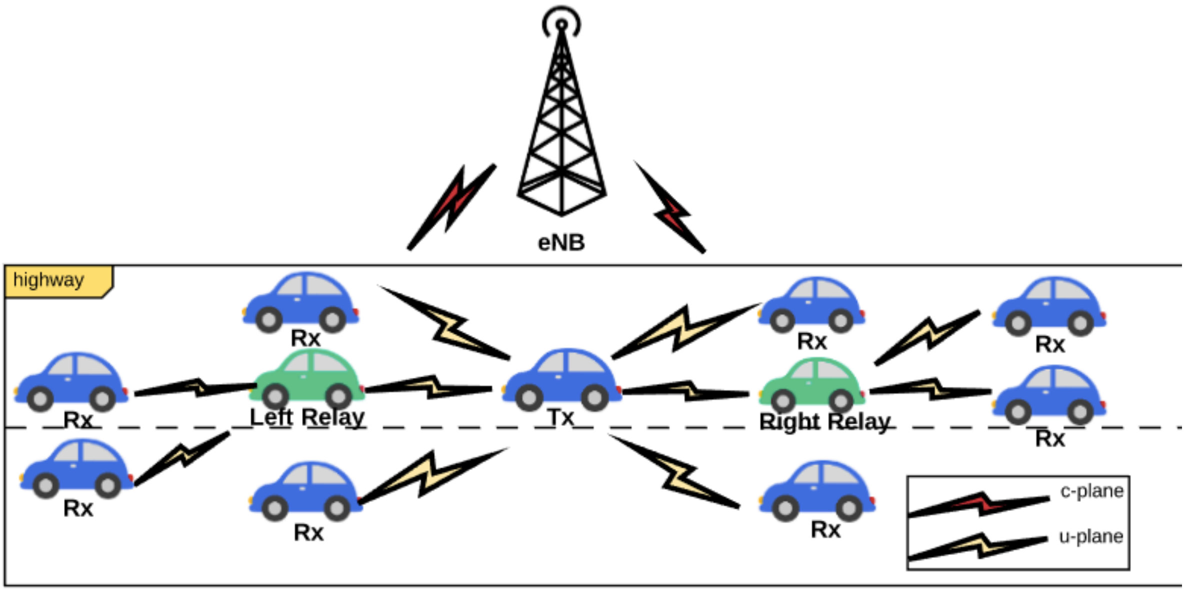

Figure.5.7: V2X Transmission Through Relay

As Fig.5.7 shows, we select right and left relays in the two sides of highway. In general, a receiver which is very close to the transmitter will not be selected. Because the receiver could almost have the same coverage like the transmitter. The dissemination range of the relay is

$$Relay\_range = Tx\_range - Tx\_opt \tag{5.3}$$

where Tx_range is the dissemination range of the transmitter; Tx_opt is the maximum distance satisfied the threshold BLER. As the figure illustrates, the red line is the Tx_range, and the dark line is the Tx_range. The last green line is the Tx_range.

Because the transmission of the antenna equipped in the vehicles is isotropic. The coverage of the relay will have some vehicles overlapped with the coverage of the maximum distance of the transmitter, which means certain vehicle successfully receiving the messages would receive the same messages again. In this way, more time and frequency resources are wasted, which leads a low performance of the V2X system.

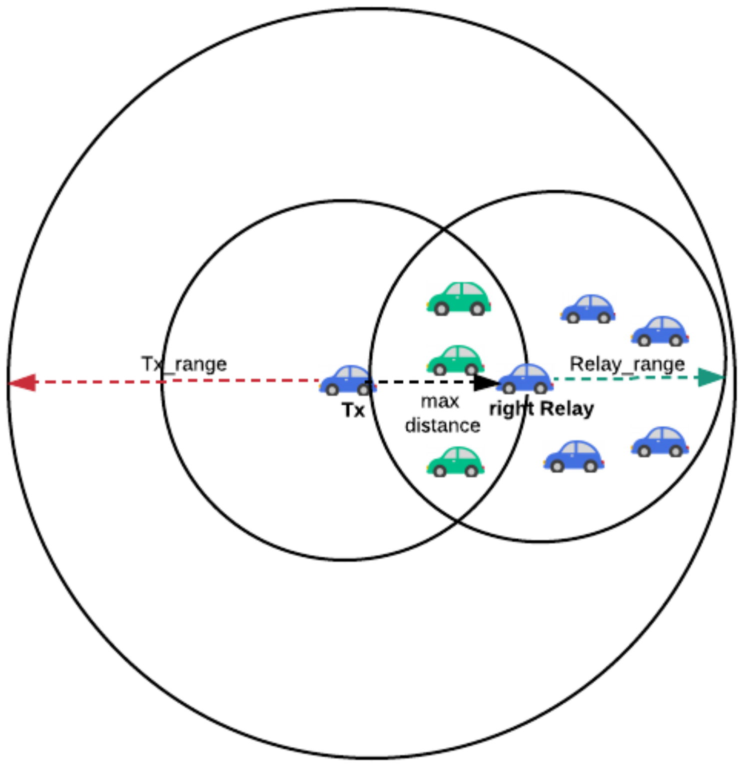

Figure.5.8: Overlapped Vehicles

As Fig.5.8 illustrates, we take the right side relay as an example. The green vehicles are the overlapped vehicles in both proximity of the maximum distance and the right relay. Since the green vehicles are in the transmission of the maximum distance where vehicles have been successfully received the message packets in the first hop. In order to decrease the consumption of the radio resource and improve the performance of the transmission system, these vehicles don't need to receive the same packets transmitted by the relay once again.

There are two ways that can address this kind issue.

- **Removing Overlapped Vehicles**: it solves the issue by finding all the overlapped vehicles which not only have successfully received packets but also in the transmission range of the relays. And then remove them from the large group of vehicles.
- **Finding Single Side Vehicles:** it solves the issue by just transmit the received messages to the vehicle which has the same side with the relay, which is based on the location information of each vehicle. Such as the right relay, we just need to transmit the selecting vehicles in the right side of the right relay.

Through reducing unnecessary transmission, the performance of the V2X system is increased and on extra radio resources are wasted.

The two relays receive the messages transmitted by the transmitter in the two-hop direct V2X communication. And then the same messages are retransmitted to other vehicles in the dissemination range of the relays which do not receive the message successfully.

Through two relays transmitting, successful transmission range has been extended. And more vehicles in the transmission range of the transmitter are received the safety-related messages successfully in the V2X communication systems. Thereby, less traffic accidents will happen, and the traffic efficiency of the highway scenario has been increased on highway.

Chapter 6 Results and Analysis

Based on the simulation results of the two-hop direct V2X communication over side link. We can analyse the performance of the communication system and prove the results to be positive. We employ several results tables.

6.1 Performance Comparison of Single-Hop and Two-Hop Communication

Table.6.1: System Performance of Different Resource Allocation Schemes with 10-meter IVD

Inter-Vehicle-Distance=10 meters		
BW_1	BW_2	**Packet Reception Ratio**
5 MHz	No	39.67%
6 MHz	No	45.74%
8 MHz	No	54.26%
10 MHz	No	56%
5 MHz	5 MHz	77.72%
6 MHz	4 MHz	77.31%
8 MHz	2 MHz	90.90%

In Tab.6.1, the IVD is set to be 10 meters. BW_1 and BW_2 are the amount of resources allocated to the first and second hops respectively. And the packet reception ratios of the different allocation schemes have given. In case that no resource is allocated to the second hop, so the only single hop direct V2X communication is also used here and we can use the results of the single-hop direct V2X communication to compare the two-hop direct V2X communication. From the table, it is clear to find that single-hop direct V2X communication have lower packet reception ratio, since the single hop cannot fulfil the 1000-meter transmission range requirement.

An efficient way to increase the performance of the single-hop communication system is to increase the transmission bandwidth. As Eq. (28)

$$SE \geq C/BW \tag{6.1}$$

As Fig.6.1. shows, with increased bandwidth, the required spectral efficiency of the transmission has been decreased. Therefore, a MCS with a better robustness can be applied in this case and the transmission range have been improved. For example, the 10 MHz transmission range of the first hop is clearly larger than the transmission range by using 6MHz. And from the simulation results, the spectral efficiency is decread with the increased bandwidth. Which are 3.3223 and 5.1152 of 10 MHz and 6MHz correspondently.

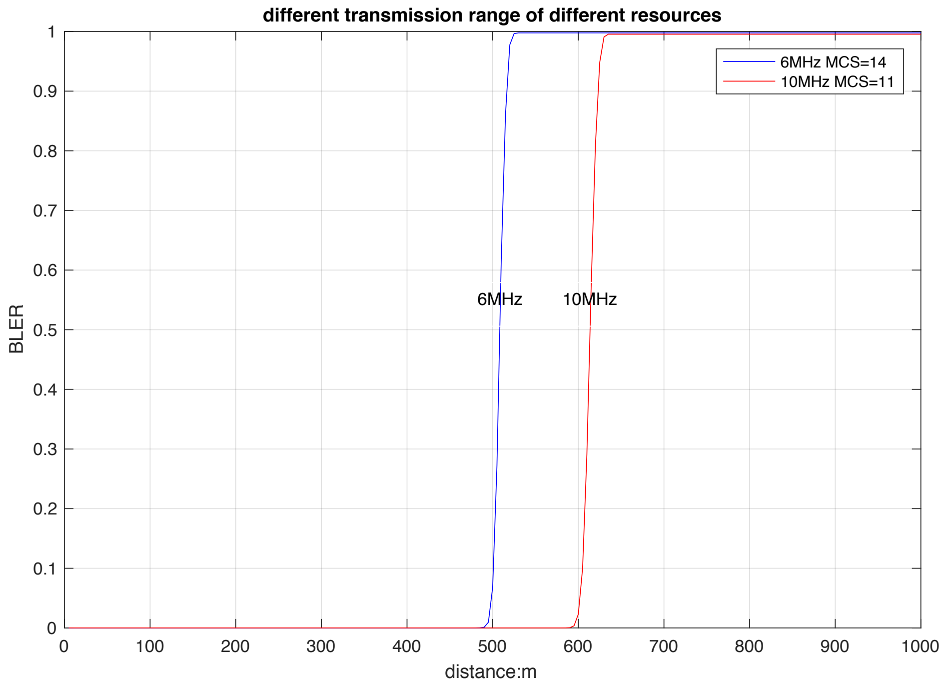

Figure.6.1: The Different Transmission Range of Single-Hop under Different Resources and MCSs

6.1.1 Performance of Two-Hop Communication by Allocating 10MHz

Another efficient way proposed to increase the transmission range and to increase the performance of the communication systems is two-hop direct V2X communication, which can use the frequency resources in an efficient manner. From Fig. 6.2, if the 10 MHz is used only in the single-hop direct V2X communication, the packet reception ratio is about 56%. But if we apply the two-hop direct V2X communication with the same amount of bandwidth, the transmission range can be efficiently improved.

For example, we allocate 8 MHz and 2 MHz, 6MHz and 4MHz, and 5MHz and 5MHz to the first hop and second hop respectively. 5MHz for the first hop and 5MHz for the second hop provides the best performance of the communication system, which increases the packet reception ratio from 56% to 77.72%. it is also deserved to note the packet reception ratio of 77.72% in the two-hop transmission scheme which is to allocate 5MHz for the first hop and 5

MHz for the second hop is slightly lower than two times of the packet reception ratio of 39.67% in the single-hop direct V2X communication with 5MHz bandwidth. This is due to the strongest interference in the second-hop transmission is from the other relay vehicle which transmits the same packets by using the same bandwidth.

6.1.2 Interference in the First and Second Hop

The interference in the first hop transmission is from a transmitter which is served by another base station. And the distance between the two close transmitters using the same bandwidth resource has statistically an average value of 6000 meters in the considered highway scenario. However, the distance between the two relay vehicles transmitting the same packets by using the same resource is lower than two times of the communication range of 2000 meters. Therefore, the second hop can experience a higher interference power density than the first hop.

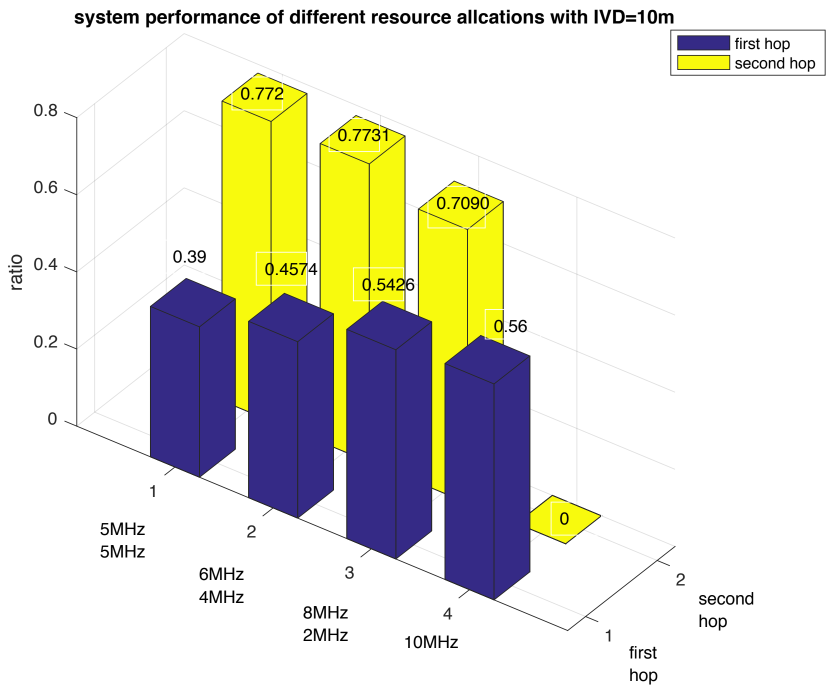

Figure.6.2: System Performance of Different Resource Allocation Scheme with 10-Meter IVD

6.2 Performance Comparison of Different IVDs

Table.6.2: System Performance of Different

Resource Allocation Schemes with 15-Meter IVD

Inter-vehicle-distance=15 meters		
BW_1	BW_2	**Packet Reception Ratio**
5 MHz	No	54.26%
6 MHz	No	57.54%
8 MHz	No	67.02%
10 MHz	No	71.28%
5 MHz	5 MHz	100%
6 MHz	4 MHz	99.82%
8 MHz	2 MHz	84.93%

In Tab.6.2the packet reception ratios are higher than those values in the Tab.4. The reason is the inter-vehicle-distance is increase from 10 meters to 15 meters, which means low density of vehicles mapped on the highway compared to the precious one. A MCS with better robustness can be applied. As Fig.10 shows, we take the 10 MHz only used in the single-hop transmission with a 10-meter IVD and a 15-meter IVD respectively. The transmission range is obviously increased. And the spectral efficiency has increased from 3.3223 to 2.4063. That is why the packet reception ratios in the Tab.6.2 are always better than those values in the Tab.6.1

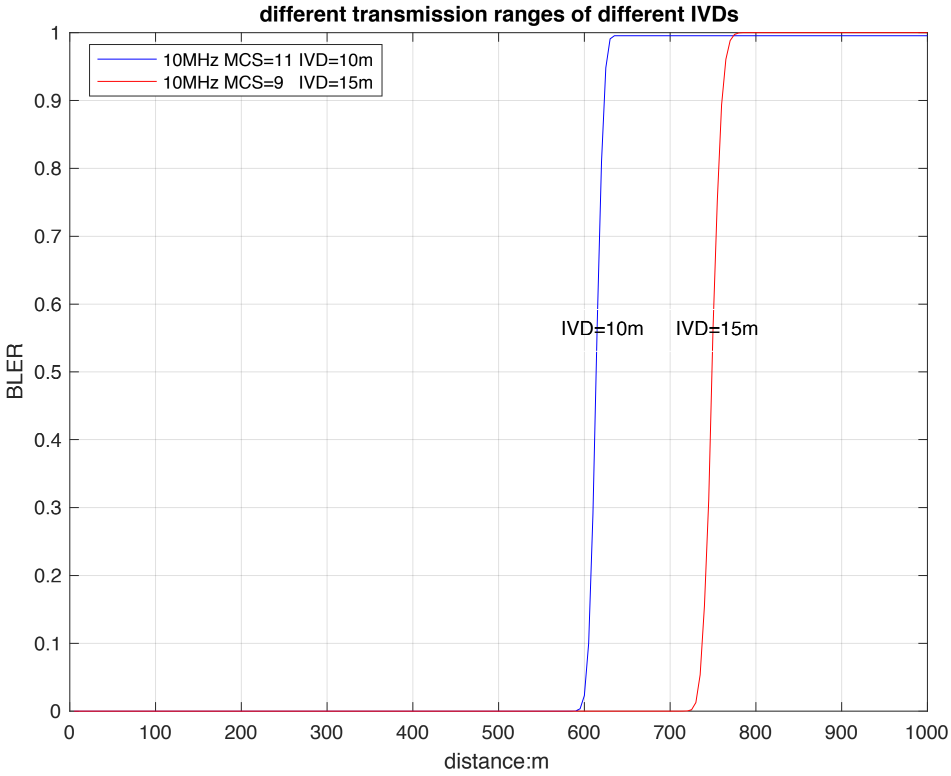

Figure.6.3: Different Transmission Ranges of Different IVDs

In addition, the packet reception ratio of the single-hop direct V2X communication with 15 meters IVD by using 10 MHz is 71.28%, which can be increased to 100% by applying 5MHz for the first hop and 5MHz for the second hop.

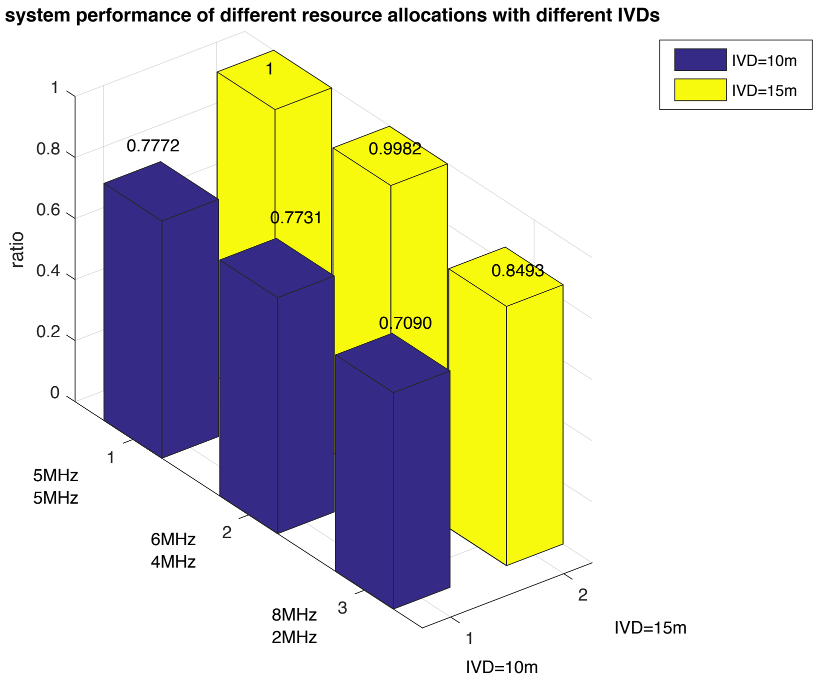

Figure.6.4: System performance of Different Resource Allocation Schemes with Different IVDs

By comparing Fig.6.2 and Fig.6.4, we can find that 5MHz for the first and 5MHz for the second hop transmission always have the best performance compared to other resource allocation schemes such as 6MHz and 4 MHz for the first hop and second hop respectively or 8MHz and 4MHz for the first and second respectively. As mentioned in chapter 4, when $BW_1 = BW_2$, the transmission range is maximized. That is why equal resource allocation scheme has a better performance than other resource allocation schemes. This also means that the system performance can be optimum by adjusting the resource allocation between different hops in direct V2X communication through side link.

6.3 Different Resource Allocation Schemes for the Second Hop

In Tab.6, the total bandwidth is 20 MHz and 10MHz of the bandwidth is allocated to the first hop. So the performance of the different scheme should be same. We need to consider more about the resource allocation in second hop direct V2X communication. The left 10 MHz bandwidth is allocated to the second hop. As mentioned in chapter 5, we have simply introduced the inference in the second hop.

The first allocation scheme is 10 MHz bandwidth allocated to the second hop and the two relays transmit the same packet over the same resource. Thus, the strongest mutual interference for the second hop is introduced by the other relay which transmits the same packets.

The second allocation scheme is 10 MHz divided into two sub-bands for the two relays in the second hop. So each relay transmits the same packet over the different sub-band. Therefore, there is no mutual interference between the two relays transmitting the same packet.

In Tab.3, the packet reception ratio of the first allocation scheme is 99.98% which is slightly larger than the packet reception ratio of the second allocation scheme. The reason is that less resource allocated to the second hop transmission and a MCS with a worse robustness needs to be used. Even though the interference power in the second hop is lower than the interference power in the first hop transmission.

Table.6.3: System Performance Comparison of Different Resource Allocation Schemes for Second Hop Transmission with 10-meter IVD

Inter-vehicle-distance=10 meters		
BW_1	BW_2	**Packet Reception Ratio**
10 MHz	Multiplex 10 MHz	99.98%
10 MHz	5 MHz + 5 MHz	95.90%

Chapter 7 Conclusion and Future Work

In connected vehicles environment, two-hop direct V2X communication has been considered as a promising technology to support ITS applications, which be applied to transmit safety-related messages, increase traffic efficiency, reduce power consumption and decrease traffic accidents.
It can also support the strict Quality of System (QoS) requirements such as lower latency, reliability and scalability.

7.1 Thesis Conclusion

In this work, we have proposed a two-hop direct V2X communication over side link to increase the packet transmission range of traffic-related data packets. As some V2X communication applications require a large communication range which a single-hop direct V2X communication cannot achieve, an increased packet transmission range by the proposed two-hop transmission technology can contribute to a higher packet reception ratio than the single-hop transmission scheme.

To exploit the two-hop direct V2X communication in an efficient manner, we have provided detailed analysis of the resource allocation scheme. In addition, context information such as real traffic location and environment condition has been collected and taken into account to select proper relays. In order to evaluate the proposed technology, we have also implemented a system-level simulator to inspect on the performance of different V2X communication schemes in a highway scenario.

The simulation results have shown the performance improvement by applying the two-hop direct V2X communication over side link with the same amount of spectral resource as for single-hop direct V2X communication. In addition, the results have also shown that the performance of the two-hop direct V2X communication can be optimized by adapting the resource allocation for different hops.

Compared with [30], our relay selection scheme is similar with it by using the maximal distance. But in our two-hop direct V2X communication over side link system, network has been taken into account assisting the communication system allocating the radio resources for different hops V2X communication.

7.2 Future Work

The introduced concepts in this work is completed with MTLAB simulator where performance of the two-hop direct V2X communication through side link on a scenario highway and its applications will be analyzed before implementing in real life and becoming commercially available.

In future, more efforts should be given to more complex scenarios such urban scenarios where have more complicated traffic situation and more obstacles from surrounding buildings or pedestrians. More researches can be implemented to analyse the performance of the direct V2X communication based on an urban or suburban scenario and decide how many hops can be utilized to achieve the optimum performance and how resource allocation between these hops. Moreover, different transmitting power for different hops can also be implemented in order to improve the performance by adapting the transmitting power.

In addition, the transmission between different vehicles with different heights on a highway scenario can be analysed since in this work we assumed all vehicles have the same height of antenna embedded in the vehicles.

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Appendix

Usage of the Software

The final software(SW)s in MATLAB are main10MHz20MHznooberloaded.m, main10MHzonlysecondoverloaded.m, main10MHzbothoverloaded.m, main20MHz.m. which are applied for different resource allocation schemes with different IVDs.

1. Setting Parameters with a certain transmitter, other parameters have shown in the paper.

2. First hop:

1) Mapping vehicle to the highway
(vehiclemapped.m)

2) Selecting all vehicles in the transmission range of the transmitter
(vehicles_in_transrange.m)

3) Selecting the vehicles in the right and the left of the transmitter
(vehicles_in_transrange_left.m), (vehicles_in_transrange_right.m)

4) Deciding the first hop transmission efficiency
(efficiencydecision.m)

5) Selecting two side relays
(relaylocation.m)

6) Calculating successful transmissionratio
(successtransratio.m)

7) Calculating the relay transmission range
(v2vdistance.m)

2) Second hop

1) Mapping vehicle to the highway
(vehiclemapped.m)

2) Selecting the vehicles in the right relay and left relay
(vehicles_in_transrange_left.m), (vehicles_in_transrange_right.m)

3) Generating the random vehicle using the same resource under another base station (randsrc.m)

4) Calculating the second single side interference
(singlesideinterference.m)

5) Deciding the second hop transmission efficiency
(efficiencydecision.m)

6) Calculating the right side and left side BLER

(secondblercalculation.m secondblercalculation.m)

7) Calculating successful transmissionratio

(successtransratio.m)

8) Calculating total successful transmission ratio