ความกว้างลำคลื่นที่เหมาะสมของระบบสลับลำคลื่นเพื่อการสื่อสาร
ระหว่างยานพาหนะในระบบขนส่งอัจฉริยะ

นายเศรษฐวิทย์ ภูฉายา

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรดุษฎีบัณฑิต

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มหาวิทยาลัยเทคโนโลยีสุรนารี

ปีการศึกษา 2558

OPTIMUM BEAMWIDTH OF SWICTHED-BEAM SYSTEM FOR VEHICLE TO VEHICLE COMMUNICATION IN ITS

Settawit Poochaya

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Telecommunication Engineering

Suranaree University of Technology

Academic Year 2015

OPTIMUM BEAMWIDTH OF SWICTHED-BEAM SYSTEM FOR VEHICLE TO VEHICLE COMMUNICATION IN ITS

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

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เศรษฐวิทย์ ภูฉายา : ความกว้างลำคลื่นที่เหมาะสมของระบบสลับลำคลื่นเพื่อการสื่อสารระหว่างยานพาหนะในระบบขนส่งอัจฉริยะ (OPTIMUM BEAMWIDTH OF SWICTHED-BEAM SYSTEM FOR VEHICLE TO VEHICLE COMMUNICATION IN ITS) อาจารย์ที่ปรึกษา : รองศาสตราจารย์ ดร.พีระพงษ์ อุฑารสกุล 173 หน้า

ระบบขนส่งอัจฉริยะ (Intelligent Transportation System) เป็นระบบที่ได้รับความสนใจมากเพราะระบบขนส่งมีผลกระทบอย่างมากต่อการดำรงชีวิตในปัจจุบัน ความอัจฉริยะของการขนส่งนี้สามารถทำได้โดยอาศัยเทคโนโลยีเฉพาะทางด้านการสื่อสารระยะใกล้ (Dedicated Short Range Communication) เทคโนโลยีนี้ทำให้ยานพาหนะสามารถติดต่อสื่อสารกับป้ายสัญญาณหรืออุปกรณ์ริมถนน รวมถึงสามารถติดต่อสื่อสารระหว่างยานพาหนะด้วยกันเองได้ ระบบขนส่งอัจฉริยะแบบเดิมใช้สายอากาศที่มีแบบรูปการแผ่พลังงานแบบรอบตัวในระนาบเดียวซึ่งแผ่พลังงานออกไปทุกทิศทาง ทำให้มีการสูญเสียพลังงานในทิศทางที่ไม่ต้องการ ส่งผลให้อัตราขยายของสายอากาศต่ำ ระยะครอบคลุมการสื่อสารระหว่างยานพาหนะต่ำ และมีโอกาสได้รับผลกระทบจากสัญญาณแทรกสอดจากรอบทิศทางเพิ่มขึ้น สายอากาศที่มีแบบรูปการแผ่พลังงานแบบมีทิศทางจึงถูกนำมาใช้แก้ข้อจำกัดดังกล่าว ด้วยอัตราขยายของสายอากาศเพิ่มขึ้น เนื่องจากมีการแผ่พลังงานในทิศทางที่ต้องการ ทำให้สมรรถนะการสื่อสารระหว่างยานพาหนะเพิ่มขึ้น แต่ยังมีโอกาสในการได้รับผลกระทบจากสัญญาณแทรกและไม่สามารถใช้งานได้ในบางสถานการณ์บนถนน ระบบสายอากาศเก่งชนิดสลับลำคลื่นจึงถูกนำเสนอขึ้นมาเป็นอีกวิธีหนึ่ง ที่ช่วยปรับปรุงคุณภาพสัญญาณที่ภาครับ ด้วยความสามารถในการหันลำคลื่นหลักไปยังทิศทางที่ต้องการได้ ทำให้คุณภาพของสัญญาณที่ภาครับมีคุณภาพที่ดีขึ้น อีกทั้งยังช่วยลดผลกระทบของสัญญาณแทรกสอด แต่ยังมีข้อมีจำกัดด้านความกว้างลำคลื่นครึ่งกำลังมีค่าเท่ากันในทุกๆ ลำคลื่น นอกจากนี้แบบรูปการแผ่พลังงานงานของสายอากาศที่มีความกว้างลำคลื่นครึ่งกำลังแคบ ส่งผลดีต่อยานพาหนะที่อยู่ห่างกัน แต่ไม่เหมาะกับยานพาหนะที่อยู่ใกล้กัน เนื่องจากโอกาสในการขาดการสื่อสารเพิ่มมากขึ้นเพราะมีพื้นที่ครอบคลุมการสื่อสารต่ำ ด้วยเหตุนี้จึงทำให้แบบรูปการแผ่พลังงานแบบของสายอากาศที่ติดตั้งบนยานพาหนะนั้นไม่เหมาะสมและไม่สอดคล้องกับโครงสร้างของถนนในสภาพแวดล้อมต่างๆที่เปลี่ยนไป เมื่อพิจารณาตำแหน่งยานพาหนะในสภาพแวดล้อมแบบในเมืองและแบบชานเมืองที่มีระยะห่างระหว่างยานพาหนะที่แตกต่างกัน ล้วนมีผลต่อการพิจารณาความกว้างลำคลื่นครึ่งกำลังของระบบทั้งสิ้น ในการพิจารณาแบบรูปการแผ่พลังงานของสายอากาศแบ่งเป็น 2 ระนาบ คือ ระนาบแอซิมัท และ ระนาบมุมเงย เมื่อพิจารณาความกว้างลำคลื่นครึ่งกำลังสำหรับสภาพแวดล้อมแบบในเมืองและแบบชานเมือง ซึ่งมีระยะห่างระหว่างยานพาหนะสั้น เปรียบเสมือนยานพาหนะอยู่

ในระนาบเดียวกัน ทำให้การเปลี่ยนแปลงในระนาบแอซิมัท มีความสำคัญมากกว่าระนาบมุมเงย จากการสำรวจงานวิจัยที่ผ่านมา ยังไม่มีงานวิจัยใดบ่งชี้ถึงความกว้างลำคลื่นครึ่งกำลังที่เหมาะสมกับสภาพแวดล้อมของถนนและตำแหน่งของยานพาหนะ ดังนั้นวิทยานิพนธ์นี้จึงเสนอแนวทางในการหาความกว้างลำคลื่นครึ่งกำลังที่เหมาะสมสำหรับระบบสลับลำคลื่นในระนาบแอซิมัท โดยคาดหวังว่าด้วยความกว้างลำคลื่นครึ่งกำลังที่เหมาะสม จะทำให้การสื่อสารระหว่างยานพาหนะในระบบขนส่งอัจฉริยะจะมีประสิทธิภาพที่ที่ดีขึ้น ช่วยเพิ่มคุณภาพของสัญญาณที่ภาครับ เพิ่มความน่าเชื่อถือในการสื่อสาร อีกทั้งยังช่วยเพิ่มความปลอดภัยในการใช้ถนน และยังสามารถปรับใช้กับสภาพแวดล้อมของถนนที่แตกต่างกันได้

สาขาวิชา วิศวกรรมโทรคมนาคม ลายมือชื่อนักศึกษา ____________________

ปีการศึกษา 2558 ลายมือชื่ออาจารย์ที่ปรึกษา ______________

SETTAWIT POOCHAYA : OPTIMUM BEAMWIDTH OF SWICTHED-BEAM SYSTEM FOR VEHICLE TO VEHICLE COMMUNICATION IN ITS. THESIS ADVISOR : ASSOC. PROF. PEERAPONG UTHANSAKUL, Ph.D., 173 PP.

ITS/DSRC/OPTIMIZATION/BEAMWIDTH/SMART ANTENNA

Recently, Intelligent Transport System (ITS) gains a lot of attention from many researchers because the transportation has a huge impact on daily life. In order to provide such a successful ITS, dedicated short range communication (DSRC) becomes a necessary technology to fulfill the requirements. Traditional ITS systems use an antenna having omni-directional radiation pattern for the message dissemination in ITS services. An antenna having omni-directional pattern broadcasts signals for all directions. Then, the signal power reduces in undesired directions. Consequently, antenna gain and a coverage range between vehicles decreases. Moreover, the chances of interference effect increases at the receiving side. Then, the researchers propose an antenna having directional pattern for the solution. The antenna gain is increased by disseminating signal power to desired directions. Also, the performance of communication link increases. However, hidden node problems and improper for some applications are the limitations of an antenna having directional pattern. Also, smart antenna system introduces a signal quality improvement at the receiving vehicle by steering main beam to desired directions. Also, interference effect decreases. As a result, the signal quality at the receiving end has been improved. However, equality HPBW of each beam is the limitation of conventional switched-beam smart antenna system. Moreover, a narrow half power

beamwidth introduces high antenna gain and long coverage range. In contrast, low coverage area increases a chance of connection loss. Also, the half power beamwidth of the antenna is improper for the road structure and vehicles position. Focusing on antenna half power beamwidth, half power beamwidth separates in two planes: azimuth and elevation planes. Focusing on the variation in azimuth plane, the distance between vehicles in an urban and suburban is short. Then, the vehicle is assumed for the same plane. Also, the variation of system performance in the azimuth plane is more effective than elevation plane. Moreover, an improper half power beamwidth with the road environment and vehicle position promote an encouragement for the optimum beamwidth determination of V2V in ITS communication system. Also, this dissertation proposes the optimum beamwidth determination for switched-beam system in V2V ITS by using SQP optimization algorithm. Finally, the signal quality at the receiving side and the communication link reliability are improved by the optimum antenna half power beamwidth.

School of Telecommunication Engineering Student's Signature_________________

Academic Year 2015 Advisor's Signature_________________

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Settawit Poochaya

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SYMBOLS AND ABBREVIATIONS

DSRC	=	Dedicated Short Range Communication
ITS	=	Intelligent Transportation System
WAVE	=	Wireless Access for Vehicular Communication
V2I	=	Vehicle to Infrastructure communication
V2V	=	Vehicle to Vehicle communication
OBU	=	On Board Unit
RSU	=	Road Side Unit
BER	=	Bit Error Rate
PER	=	Packet Error Rate
PDR	=	Packet Dropping Rate
SNR	=	Signal-to-Noise Ratio
T_{safe}	=	Time to Collision
R_{safe}	=	Effective Communication Range
WBSS	=	WAVE Basic Service Set
FCC	=	Federal communication commission
ETSI	=	European Telecommunication Standard Institutes
OFDM	=	Orthogonal Frequency Division Multiplexing
BPSK	=	Binary Phase Shift Keying
QPSK	=	Quadrature Phase Shift Keying
QAM	=	Quadrature Amplitude Modulation

SYMBOLS AND ABBREVIATIONS (Continued)

SQP = Sequential Quadratic Programming

DoT = Department of Transportation

CHAPTER I

INTRODUCTION

1.1 Background of problems

After the February 2014 decision of the US Department of Transportation (DoT) to mandate Dedicated Short Range Communications (DSRC) radios in all vehicles, DSRC is now considered to be a major component of intelligent transportation systems (ITS). In fact, reducing the accidents on the road and improving the traffic safety without new road construction are the major purposes of ITS/DSRC. Traditional transportation system is improved by the DSRC communication. DSRC communication provides a fast data transmission in a short period. A short period of ITS/DSRC message transmission improves a safety to drivers due to a fast warning message before they enter an accident area. Thus, a fast data dissemination is important for ITS/DSRC communication. The communication procedure of DSRC communication is separated into two main categories: Vehicle to Infrastructure (V2I) communication and Vehicle to Vehicle (V2V) communication. Focusing on V2V communication, V2V equips with On Board Unit (OBU) installed inside the vehicles according to figure 1.1 which DSRC messages are exchanged between vehicles. Focusing on another scheme, V2I communication operates the data transmission between vehicles and the traffic signs along the road. Exchanging DSRC message between Road Side Unit (RSU) and OBU is the major task of this scheme.

In addition, OBU/RSU devices are operated under the different standard in different country

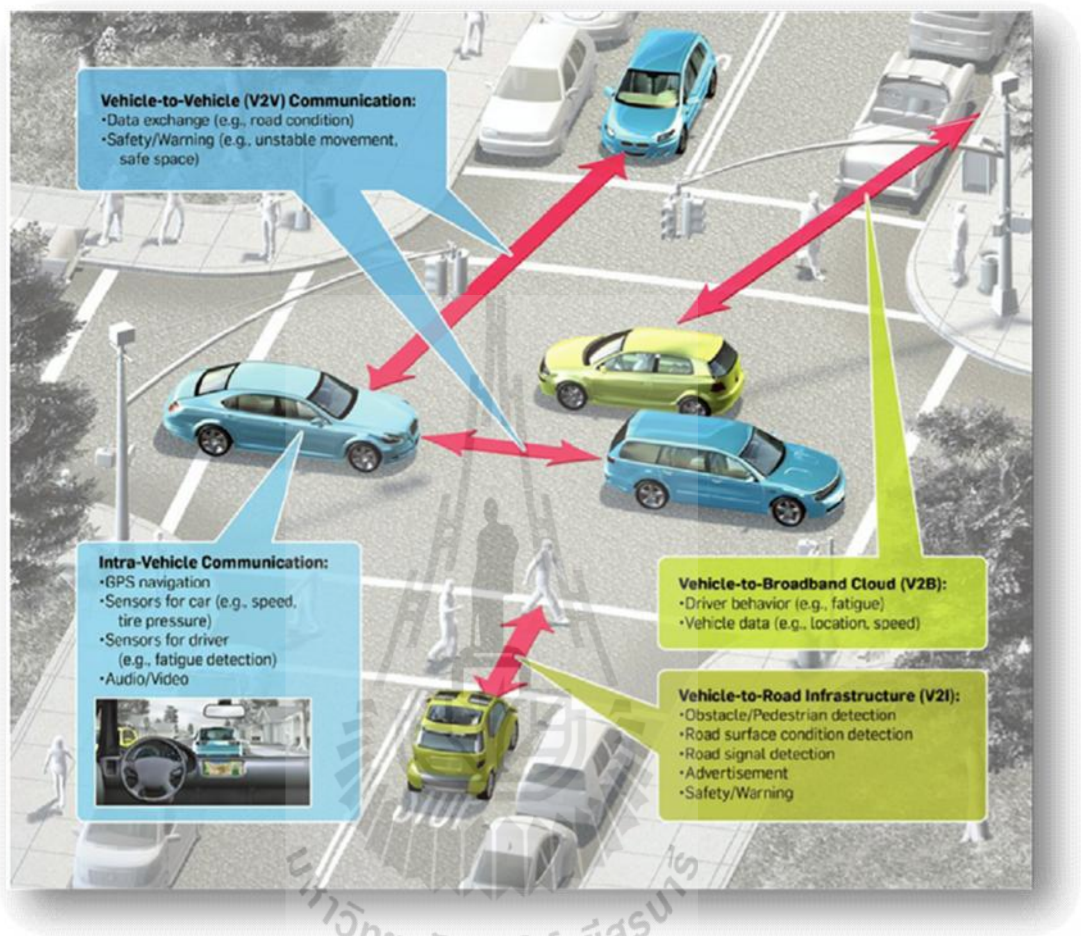


Figure 1. 1 Intelligent Transportation System

"A comprehensive survey on vehicular Ad Hoc network", Journal of network and computer applications 2014.

The standard of DSRC is separated into three major zones. Firstly, ARIB standard is used by Japan. ARIB standard operates at 5.8 GHz band. Secondly, CEN-DSRC is operated by Europe. CEN-DSRC operates at 5.8 GHz band. Finally, IEEE802.11p (WAVE-Wireless Access for Vehicular Environments) operates at 5.8-

5.9GHz band which is defined by the north of America. IEEE802.11p were chosen by many countries in the world. This is because IEEE802.11p can operates data transmission when vehicle moves on the road. IEEE802.11p can eliminate the drawback of traditional DSRC communication system such as multi-path fading and Doppler Effect. Moreover, IEEE802.11p can provide a fast data transmission, high tolerance communication link. With above reasons, IEEE802.11p standard is selected for this dissertation. WAVE standard is firstly started from ASTM E2213-03 and IEEE802.11a. The difference between IEEE802.11a and WAVE standard is the increasing of symbol duration for two times. Thus, data transmission occurs when vehicles move on the road. The applications of IEEE802.11p are separated into two major applications: safety and non-safety applications. Focusing on safety application, this application requires for more reliable communication link. This is because data dissemination in safety applications directly affect to behaviors of the drivers. Then, the high reliability of a communication link provides an accurate data reception at the receiving vehicle.

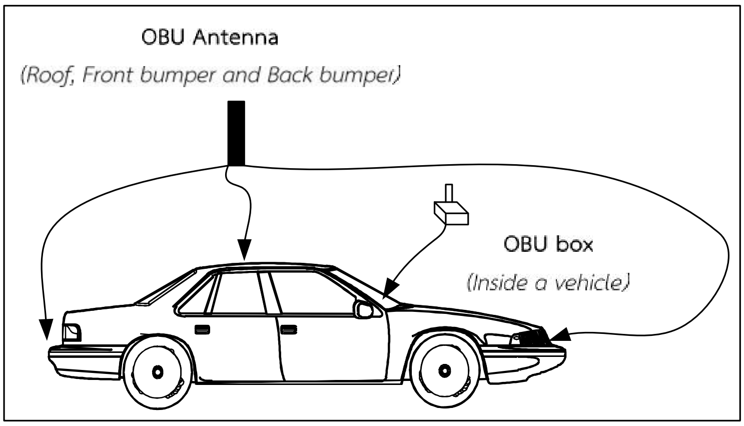


Figure 1. 2 On Board Unit: (OBU)

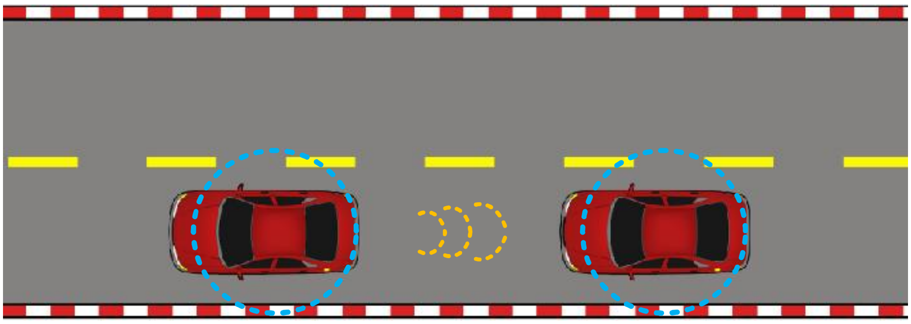


Figure 1. 3 Conventional V2V data transmission.

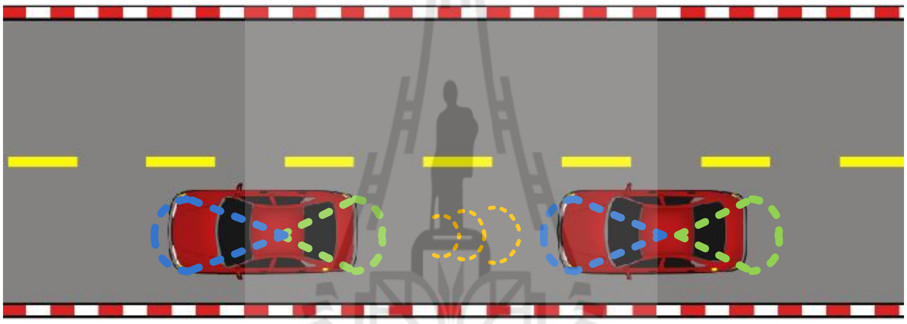


Figure 1.4 V2V message dissemination using an antenna having directional radiation pattern**.**

Also, improving the quality of signal reception at the receiving vehicles is the major challenge for safety message dissemination. This is because there are many factors which are affected to the quality of radio signal inside a communication area such as tall buildings and obstacles along the road. Also, the signal quality improvement is important for DSRC data transmission. Focusing on the traditional DSRC system according to figure 1.2. , an antenna having omni-directional radiation pattern has been chosen for DSRC message dissemination. OBU device is installed inside the vehicle. In addition, DSRC antenna can be installed at the roof, front bumper and back bumper. As a result, the signal is transmitted overall 360 degree according to figure 1.3. Thus, vehicles around the communication area can receive the signal. However, the coverage area is reduced by signal depletion in undesired directions. As a result, the receiving vehicle receives a weak signal strength. Then, the performance metrics are reduced due to the above issues. Consequently, the system reliability is reduced. The above reasons introduce the improvement of signal quality which is important for data transmission and reception in V2V DSRC safety application. Then, an antenna having directional radiation pattern has been proposed for the solution. Vehicles equipping with an antenna having directional radiation pattern is presented in figure 1.4. Directional antenna points the main beam to desired directions. Also, no signal power losses in undesired directions. As a result, signal strength at the receiving vehicle is increased. Also, packet collision, BER and other performance metrics have been improved. Then, the system reliability of V2V data transmission is increased. However, an antenna having direction radiation pattern cannot be used in some applications which are required forward and backward directions. In addition, hidden node problem is occurred. As a result, packet collision at the receiving vehicle, packet drop and packet error rate are increased.

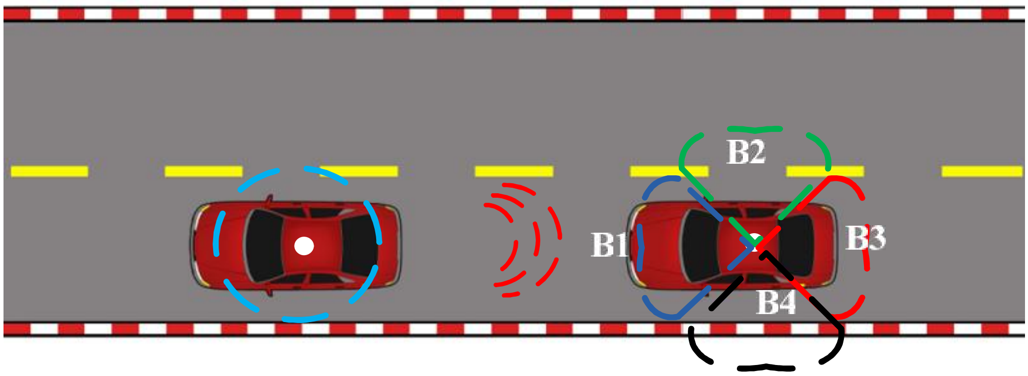


Figure 1. 5 V2V with switched beam antenna system

The, smart antenna technology has been proposed for the solution. Smart antenna technology steers the main beam to the desired directions which increases the signal quality at the receiving side. Smart antenna technology is separated into two main types: adaptive array antenna system and switched-beam antenna system. Requirements of more processing time and more system complexity are the difference between two types. Focusing on the requirements of safety application, short latency is the major requirement message dissemination for safety application. Also, adaptive type is improper for the requirement due to the above reasons. Then, switched beam system is the solution. Switched beam type for V2V communication is presented in figure 1.5. However, the fixed beamwidth in switched beam system cannot respond adequately to the change of vehicle positions, road width, and distance between vehicles which is changed by time. Due to such problems, the system cannot achieve a stable communication link. The mentioned drawbacks and shortcomings motivate the solutions proposed in this dissertation. Note that the consideration on beamwidth for elevation plane is beyond the scope for this thesis. This is because a short range is the focus of V2V communications, all communicating vehicles are expected to be positioned on nearly the same elevation plane. Therefore, connection loss concerning the change in elevation plane is relatively small with respect to the azimuth plane. So far, the quality of V2V communication link has not been considered in terms of beamwidth optimization. Therefore, this thesis aims to investigate an optimum antenna beamwidth for reliability enhancement. In this thesis, SQP optimization method has been chosen for the optimum beamwidth determination. Moreover, performance metrics such as Bit Error Rate (BER), Packet Error Rate (PER), average Signal-to-Noise Ratio (SNR), average antenna gain, Time to Collision (T_{safe}) and Effective Communication Range (R_{safe}) are used to assess the benefit introduced by the proposed solution.

1.2 Research objectives

The objective of this research are as follows:

1.2.1 To study the impact of antenna half power beamwidth for V2V communication.

1.2.2 To determine the optimum half power beamwidth of V2V communication which is categorized in the difference road environments: urban and suburban.

1.2.3 To study the performance metrics of proposed system which is equipped with the optimum half power beamwidth comparing to the conventional system.

1.3 Scope and limitation of the study

1.3.1 The optimum antenna half power beamwidth for V2V communication is investigated. The configuration of the simulation and experimentation is adjusted following IEEE802.11p (WAVE-DSRC) standard. The operating frequency is 5.86 GHz with channel 172. Basic safety message dissemination is considered. The vehicle speed is fixed as a constant value. In addition, the road environments include with urban road and suburban road which are impacted to performance determination. Performance metrics have been analyzed by statistical method.

1.3.2 The prototype antenna can be any types that can produce antenna half power beamwidth according to the simulation results. Basic safety message is disseminated by DSRC devices installed by the proposed switched beam system. The performance metrics are investigated in different road environments.

1.4 Contributions

1.4.1 The performance in terms of SNR, BER, PER, TTC and ECR employing switched beam antenna and optimum antenna half power beamwidth are improved when comparing to the conventional V2V communication system. From the literatures, the switched beam antenna system with optimum half power beamwidth has never been presented.

1.4.2 The comparison of performance metrics consists of conventional system, equal beamwidth system and optimum half power beamwidth system confirm that the proposed system improves the signal quality. Consequently, the traffic safety is increased due to the reliable communication link providing the effective communication system in V2V data exchanging.

1.4.3 The optimum half power beamwidth of the main beam directions provide maximum SNR at the receiving vehicles. The increasing of SNR at the receiving vehicles indicates a reliability improvement of V2V message dissemination

1.4.4 R_{safe} : RSSI enhancement introduces the increasing of coverage range of V2V message communication. The transmitting vehicle can communicate with receiving vehicle at a long distance. So, the vehicles receive the message at a long range which means that the drivers have more time to prepare for the bad situation on the road such as accidents and chain collisions. Thus, the outcome of the proposed system enhances the safety for the drivers. As a result, the proposed system will support the requirements of V2V DSRC safety applications.

1.4.5 T_{safe} : this parameter indicates the preparing time for a bad situation on the road. In addition, T_{safe} refers to the collision time. The proposed system produces more T_{safe}. Also, the traffic safety has been improved due to the increasing of T_{safe}.

1.5 Thesis organization

The remainder of this thesis is organized as follows. Literature review is introduced in Chapter 2. Then, conventional system is introduced. The advantages and disadvantages of an antenna having either omni-directional pattern or directional pattern are presented. Then, switched beam antenna system is introduced for the solution. In this chapter, the performance metrics and example application are introduced.

Chapter 3 presents the basic concept of optimum half power beamwidth determination which is consisted of appropriate optimization method. Then, constrained nonlinear multivariable optimization is explained. Moreover, the description of the research problem formulation is explained. It is consisted of the determination of average antenna gain, angle spread between beam, and vehicle position probability. Also, the objective function and optimization constraint are discussed in this chapter.

Chapter 4 introduces the results of simulation and experiment. Then, optimum beamwidth determination of the proposed system is introduced. Corner reflector is introduced for shaping antenna half power beamwidth corresponding to the optimum beamwidth values. The instrument and equipment in experimental setup are presented in this chapter. Then, the measurement scenarios and key performances are discussed. Finally, the performance metrics such as SNR, BER, PDR, R_{safe} and T_{safe} of V2V safety message dissemination are presented. Finally, Chapter 5 presents the conclusion of this thesis and future work.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

The details of this section introduce for the literature reviews relating to the objective of this dissertation. ITS/DSRC is integrated with DSRC technology. A communication range is not exceed 1000 meters. The communication format of ITS/DSRC is separated into two types: V2V and V2I. The devices of ITS/DSRC included with OBU and RSU. These devices operated at 5.825-5.925GHz bands. The standard of ITS/DSRC is separated into three zones: North America (IEEE802.11p WAVE-DSRC), Japan (ARIB STD-T75) and Europe (CEN-DSRC). IEEE802.11p WAVE-DSRC have been selected for this dissertation due to the benefits of this standard. Most of OBU and RSU devices are equipped with an antenna having omni-direction radiation pattern which is disseminated DSRC message in all directions. As a result, the signal power losing in undesired direction introduces the reduction of receiving power level. Then, an antenna having directional antenna radiation pattern was introduced. But, an antenna having directional radiation pattern cannot use in some applications. Thus, smart antenna is presented for the solution. The antenna HPBW is separated into two planes: azimuth and elevation plane. The effect of azimuth antenna HPBW adjustment is more than elevation plane. Then, azimuth antenna HPBW has been considered in this work. However, antenna HPBW of switched beam antenna system is fixed. Then, the vehicle cannot connect the proper beam when comparing to the vehicle position on the road. Then, the receiving signal level is reduced. Consequently, the signal quality is reduced too. So far, the improvement of DSRC quality link using switched beam with optimum HPBW optimization has not been considered. Then, the study of antenna HPBW determination for V2V communication is more attractive. Thus, the previous reasons inspired the determination of optimum antenna HPBW in vehicular communication. The expected results are DSRC link reliability enhancement.

2.2 The study of Intelligent Transportation System and Dedicated Short Range Communication

The increasing of vehicles in the world promotes the traffic congestions and accidents on the road. ***John B. Kenny (2011)*** introduced the fundamental of DSRC technology in USA. The main objective of DSRC development is the reduction of accidents on road. Also, collision prevention applications inspired the improvement of DSRC technology. DSRC standard are separated into three zones. Europe used CEN-DSRC which is established by ETSI. ARIB was used in Japan and U.S. used IEEE802.11p WAVE-DSRC for the operation of ITS services. IEEE802.11p standard is the most well-known in the world. IEEE802.11p standard supports the communication of moving vehicles with high speed due to the increasing of symbol interval. Thus, WAVE-DSRC standard tolerated for propagation effects such as multi-path fading and Doppler Effect. Also, IEEE802.11p standard has been selected for V2V configuration. Focusing on U.S. standard, the operation of ITS/DSRC services under IEEE802.11p standard reduced 82% of accidents on the road. ITS/DSRC communication regime operates at 5.9GHz. FCC allocated 75MHz bandwidth for

DSRC operation. DSRC bandwidth separated into seven channels. WAVE-DSRC separated seven channels as the following: six SCH (Service Channels) and one CCH (Control Channel). The bandwidth of each channel is 10 MHz and the guard channel is 5 MHz. The channels of DSRC operated in different manners. The communications inside the same WBSS include with one CCH and at least one SCH channel. WAVE devices disseminated important message for avoiding the collision or accidents prevention to the vehicles locating inside the communication area. Focusing on the data dissemination, there are two differences of data dissemination schemes which are categorized into V2V (Vehicle to Vehicle communication) and V2I (Vehicle to Infrastructure communication).The equipment inside ITS/DSRC network include with OBU (On Board Unit) and RSU (Road Side Unit). OBU installs on the vehicle dashboard. RSU appears on the tower of traffic signs beside the road. The devices inside DSRC network are operated for the transmission and reception of DSRC applications. Focusing on DSRC applications, they are separated into two main types: safety and non-safety applications. DSRC safety applications establishes for the improvement of road safety by using the dissemination of safety message. Non-safety applications introduces for the improvement of driver convenience such as navigation system, infotainments and traffic information. DSRC safety application directly affected to the driver. This is because the information inside safety message notifies the drivers in order to avoid for a bad situation on the road.

Lei Zhao (2013) presented that the intelligence of conventional transportation system is made by DSRC technology which provides a fast data transmission and a high reliability of the communication link. DSRC network for safety applications allows a high speed message transmission. Focusing on the communication link reliability, performance metrics introduce for a communication link reliability presenting in BER, SNR, PER, PDR and RSSI. A Lower BER, A Lower PDR and A Lower PER introduce a high reliability of a communication link. A higher SNR and A higher RSSI present a high reliability of a communication link. Moreover, another performance metric related to the vehicle travelling on the road are significant such as time to collision and effective communication range. The increment of time to collision introduced an improvement of traffic safety for the drivers. Because the drivers have more preparing time for emergency events on the road. Thus, the previous reasons introduced the major requirements of DSRC communication link. Many researchers determined the solution for the enhancement of DSRC link.

Brian Gallagher (2006) introduced that IEEE and ASTM established DSRC standard for wireless communications in vehicular network. DSRC communication range did not exceed 1000m. IEEE802.11p is adopted from ASTM E2213-03 standard. DSRC standard used a similar physical layer parameter comparison with IEEE802.11a. The difference between IEEE802.11p and IEEE802.11a is that IEEE802.11p supports for the communication of vehicles moving on the road with a high velocity. Moreover, DSRC specification defined 25% PER for the reference limit. As a result, PER limit introduced a high reliability of the communication link. Moreover, the field test was introduced including with V2V and V2I communication schemes. The maximum communication range was determined by the distance that data transmission between vehicles produces PDR equally 0.9 corresponding to IEEE802.11p standard.

Y.L. Morgan (2010) introduced the comparison between other wireless technology and DSRC. US-FCC allocated the 5.850-5.925 GHz radio frequency band for the enhancement of road safety. WAVE-DSRC used OFDM mechanism. The modulation schemes include with BPSK, QPSK, 16-QAM and 64-QAM. Moreover, the minimum and maximum data rate operated with 3 – 27 Mbps. Focusing on the communication range, satellite technology produced a maximum communication range. High data rate was established by satellite technology. Satellite is the famous technology for navigation system, racing and hiking. However, the cost is too high. Moreover, satellite communication did not communicate under an indoor environments such as the road under toll way. Also, the technology supported for a data transmission between moving vehicles introducing in DSRC technology. Focusing on the benefits of DSRC technology, DSRC provided a fast data communication to keep the connection with vehicles at all times. A low latency was presented in DSRC because safety message is directly affected to the drivers. Consequently, the receiving vehicles can receive a safety message in a short period. Also, the traffic safety was occurred. Moreover, the increasing of symbol interval for two times in DSRC standard introduced that DSRC can operate data transmission for moving vehicles.

The literature reviews present that the major requirements of DSRC link are as the following:

- DSRC standard categorizes into three zone: Japan, North-America and Europe.

- IEEE802.11p is the famous standard in the world due to the capability of data dissemination with high speed vehicles movement.

- IEEE802.11p standard was adopt from IEEE802.11a.

- DSRC channels separate into seven channels: one CCH and six SCH.

- DSRC safety message was transmitted in a short period.

- High reliability of DSRC communication link.

- A coverage range is not more than 1,000 meters.

Also, the next topic describes about the conventional DSRC V2V communication system. An important topic for ITS/DSRC communication is the antenna radiation pattern issues. The formant of antenna radiation pattern introduced for the travelling direction of DSRC message. The study of antenna radiation pattern will increase the communication link performance when using a proper antenna for DSRC applications. The most of conventional DSRC devices included with an antenna having omni-directional pattern. Then, DSRC message disseminated all directions. The DSRC devices in the communication area can hear DSRC messages. However, there are some signal power lost in undesired directions. As a result, the level of receive power decreased. Then, the quality of DSRC link is reduced. The next section introduces the benefits and the drawbacks of an antenna having omni-direction pattern for the conventional DSRC system.

2.3 Conventional DSRC V2V equipped with omni-directional antenna

Conventional ITS antennas disseminate DSRC message for all directions. The vehicles inside a communication area can receive DSRC messages. As a result, the drivers can prepare for the situations on the road. Thus, an antenna having omni-directional radiation pattern was introduced. Several studies in the literature present the advantages and disadvantages of the omni-directional antenna. There are more disadvantages related to omni-directional antenna pattern. For example, the signal power is lost in the undesired direction. Moreover, omni-directional antenna provides a short communication range. However, the increasing of omni-directional antenna gain promotes the unnecessary interference problem for other nodes. Also, Table 2.1 presents the advantages and disadvantages of an omni-directional antenna.

Table 2.1 Advantages and disadvantages of using an antenna having omni-directional radiation pattern

Advantages	Disadvantages
- ***A. Duzdar (2011) , M. Li (2011) and V. Shivaldova (2012)*** introduced that antenna having omni-directional is suitable for DSRC message dissemination via OBU. Because DSRC message is transmited in all directions. As a result the vehicles inside the communication area can receive their message. -***J. Harri (2013)*** presented the integration of DSRC antenna appearing at the center of the roof. The coverage area considers in azimuth plane. - ***M. A. Westrick (2012)*** indicated that the energy radiated in all directions due to the capability of an antenna having omni-directional radiation pattern. Focusing on the receiving side, vehicles equip with DSRC device and an antenna having omni-directional pattern communicating with vehicles-roadside in the front, back, and along both sides of the vehicle. - ***C.F. Mecklenbraüker (2011)*** presented that vehicle movement in horizontal (azimuth) plane is considered for V2V coverage area. The coverage area of V2V is indicated by the raidiation pattern of omni-directional radiation pattern. Also, an antenna having omni-directional radiation pattern radiates the energy in all directions. - ***R.T. Juang (2012)*** introduced that vehicles equipping with an antenna having omni-directional radiation pattern can transmit signal in all directions. - ***S. Yi (2003)*** indicated that an antenna having omni-directional radiation pattern received DSRC single equally in all directions. Moreover, the radiated signal is equal in all directions.	- ***M.W. Li (2011)*** indicated that the transmission of DSRC messages passing through the tall building along the roads is more difficult. In addition, small coverage area in sparse network. - ***R.T. Juang (2012)*** introduced that the using of an antenna having omni-directional radiation pattern increasing the number of packet collision, and latency. - ***S. Yi (2003)*** introduced that an antenna having omni-directional radiation pattern concentrated the energy into the undesired directions. Also, the received power level at the receiver is reduced. - ***O. Klemp (2010)*** indicated that an antenna having omni-directional radiation pattern cannot concentrate the energy to certain directions. - ***D. Li (2007)*** introduced that contention and collision packet at the intersection increase when using an antenna having omni-directional radiation pattern. - ***Y. Li (2012)*** introduced that the accuracy of DSRC communication link is reduced due to the energy losing in undesired directions. - ***T. Acharya (2008)*** presented that the high inefficience of transmitted RF power is occurred when using an antenna having omni-directional radiation pattern. Moreover, RF power spreading in the surrounding space, unwanted and harmful interference to other neighbor nodes are occurred. - ***R. Ramanathan (2001)*** presented that unnecessary interfering to other nodes is occurred due to the energy dissemination in all directions. Moreover, an antenna having omni-directional radiation pattern sometime received interference signal. - ***V. Shivaldova (2012)*** introduced that transmitting signal in undesired directions reduced the range of the transmission (due to lower RSSI and multipath components).

2.4 DSRC V2V with an antenna having directional radiation pattern

The previous section introduced the benefits and the drawbacks of an antenna having omni-direction radiation pattern. In addition, the solution for the improvement of DSRC communication link is more important. ***S. Ghosh (2011)*** has presented that an antenna having directional pattern is the solution. This is because an antenna having directional pattern can radiate the signal to the desired directions. Then, there are no signal power losing in undesired directions. Also, the signal quality such as RSSI performance is improved.

Due to the aforementioned disadvantages, omni-directional antennas might not be a good choice for DSRC communication. Then, the determination of antenna technology for DSRC link was introduced. Table 2.2 presents more benefits of directional antennas. Directional antenna can focus the total radiated power to a certain desired directions. Directional antenna increases the communication range. Directional antennas could also reduce the packet collision. Moreover, directional antennas can reduce the latency and delay inside DSRC communication system. All of these features show the potential benefits of directional antennas. Furthermore, directional antennas seem to have a lot of advantages in comparison to the Omni-directional antennas. Due to these reasons, the directional antenna should be selected. However, there are some limitations of an antenna having directional pattern such as hidden node problem and sometime cannot be used in some applications. The advantages and disadvantages of an antenna having directional radiation pattern are presented in Table 2.2. Focusing on the limitations of an antenna having directional radiation pattern, an antenna having directional radiation pattern cannot use in some applications. ***A. P. Subramanian (2008)*** has presented that emergency brake light applications requires for backward and forward beam. However, an antenna having directional radiation pattern cannot operate only forward and backward beams but all directions. Thus, the vehicle locating outside a DSRC communication area cannot be received emergency brake light message. As a result, the chance of accident is increased. Moreover, the chance of chain collision is increased too.

Table 2.2 Advantages and Disadvantages of directional antennas

Advantages	Disadvantages
- ***O. Klemp (2010)*** has introduced that an antenna having directional radiation pattern can concentrate the main beam to a certain directions. -***M.W. Li (2011)*** has presented that an antenna having directional radiation pattern increases a enetwork capacity, alleviate the interference, focus the energy to a desired direction. As a result, the enhancing of receiving power increase the SNR at the receiver side. Moreover, narrowing antenna HPBW introduced for the increasing of communication range. - ***M. A. Westrick (2012)*** has indicated that the energy can radiate in a desired directions. High directivity introduces the capability of concentrating energy to the desired directions. Then, the receiving power increases. Also, the communication range is increased. -***R.T Juang (2012)*** has presented that an antenna having directional radiation pattern can concentrate the signal to certain directions. In addition, an antenna having directional radiation pattern promotes for more antenna gain. A latency can be decreased and unsuccessful packet receptions can be reduced due to the capability of this antenna type.	-***M.W. Li (2011)*** has introduced that an antenna having directional radiation pattern cannot use in some applications such as emergency brake light application. - ***S. Guo (2009)*** has introduced that large beamwidth must be applied to cover all its desired receiving nodes. Thus, a large beamwidth introduced for the decreasing of antenna gain. Then, the received power is reduced. The energy-saving feature of directional antennas has to be somewhat weakened. Also, directional antennas degenerate into omni-directional antenna.

Table 2.2 Advantages and Disadvantages of directional antennas (continued)

Advantages	Disadvantages
- ***S. Guo (2009)*** has introduced that the transmission power is saved by concentrating RF energy to desired direction. - ***V. Shivaldova (2012)*** has introduced that the coverage range is improved by suppression of undesired multipath effects and frequency selective fading . Moreover, higher antenna gain promotes the increasing of throughput and coverage range. In addition, the reliability of communication link is increased. - ***S. Yi (2003)*** has presented that the average throughput is improved two-three times over that obtained by using CSMA/CA. Moreover, the utilization of wireless medium is improved. Capacity of networks using directional antennas is improved.	

The information inside Table 2.2 introduces the advantages and disadvantages of DSRC communication link with an antenna having directional radiation pattern. Focusing on using an antenna having directional radiation pattern for DSRC communication, there are more advantages that improve the link quality. However, an antenna having directional radiation pattern cannot be used in some applications such as emergency brake light or the configuration of RSU. RSU with an antenna having directional radiation pattern can concentrate the main beam to the desired directions on the road. As a result, the vehicle can exchange message with RSU. Also, this communication scheme was appropriate for V2I communication scheme but not for V2V communication. These limitations of an antenna having directional radiation pattern inspired the determination of V2V communication link enhancement based on antenna technology. Also, the literature reviews of appropriate antenna technology is presented in the next section.

2.5 DSRC with smart antenna technology

A.P. Subramanian (2008), ***S. Panngam (2010)***, ***M. Uthansakul(2010)***, ***S. A. Mitilineos (2007)*** and ***S. K. Sanyal (2006)*** indicated the powerful smart antenna technology which provided the reduction of interference effect and increasing the signal quality at the receiving vehicles. There are two types of smart antenna technology including a switched-beam antenna and an adaptive array antenna. The adaptive array antenna requires more processing times due to feedback control bits for adjusting the phase and amplitude of the transmitting signal. Switched-beam system does not require complexity and intelligent methodology. Also, the processing time of switched beam system is less than adaptive array system.

However, the works presented in ***Z. Zhang (2008)*** and ***F. Liu (2010)*** have introduced other significant factors to the performance of switched-beam system. One of these factors is the antenna half power beamwidth (HPBW). A conventional switched-beam system has an equal HPBW for each beam. The equal HPBW is determined without the consideration of vehicle positions on the road and the environments of the road so this causes the inefficiency of using conventional HPBW for V2V applications. Due to the impairments mentioned earlier, smart antenna systems have been envisaged to be the solution for vehicular networks. This is because the systems provide automatic beam steering depending on the change of desired and undesired signal. This results in high diversity gain, interference reduction, and an increase in system reliability. Moreover, the expansions of coverage area and link quality enhance against multipath fading using smart antennas. From the literatures, researchers have gain lots of attention in consideration of switched-beam antennas into V2V communication system. However, this still leaves some drawbacks for V2V communication systems as follows. The fixed beamwidth in switched-beam system cannot well response to the change of vehicle positions, road width and distance between vehicles which alters from time to time. According to this, the system cannot achieve a stable communication link. The mentioned drawbacks encourage the motivation of this dissertation. Note that the consideration on beamwidth for elevation plane is out of scope for this dissertation according to the following reasons. As a short range is the nature of V2V communication, all communicating vehicles are expected to be positioned on nearly the same elevation plane. Therefore, connection loss concerning the change in elevation plane is relatively small in comparing to azimuth plane. However, the literature reviews presented only antenna half power beamwidth and antenna gain values according to Table 2.3. The narrowing HPBW introduced high antenna gain. Thus, the details of the literature reviews presented the significant of antenna HPBW which affected to DSRC V2V communication system. Also, antenna half power beamwidth influenced for V2V communication link. So far, the quality link of V2V communication has not been considered in terms of half power beamwidth optimization. Then, the study of antenna half power beamwidth determination for V2V communication is more attractive. In addition, another important issue is the vehicle position probability. This factor related to the average antenna gain determination. The information of vehicle position probability is significant. This is because the vehicle can connect a correct beam direction corresponding to the vehicle position on the road. Also, ***V.L. Knoop (2012)*** has revealed that the determination of vehicle position probability can be calculated using the amount of vehicles passing the sensors installed in each lane. According to this, the probability of vehicles position on the road can be calculated.

The azimuth radiation pattern was considered from the literature. The narrow azimuth HPBW promoted a high antenna gain. As a result, the communication length is increased. The narrow HPBW is suitable for the long communication range. On the other hand, wide HPBW radiation pattern promotes a low antenna gain. The wide antenna HPBW provides a small coverage range. Also, the information from the literatures confirmed the importance antenna HPBW for V2V DSRC communication link.

Table 2.3 Antenna gain and half power HPBW in azimuth plane

Literature reviews References	**Radiation Pattern types Azimuth (degree)**		**Antenna Gain**	
	RSU	**OBU**	**RSU**	**OBU**
L. Zhao (2013)			16dBi	6dBi
V. Shivaldova (2012)	60° 35° 42° 40°	-	6 dBi 10 dBi 13 dBi 14 dBi	-
Y. Li (2012)	-	45°	-	-
S. Panichpapiboon (2012)	-	30°	-	-
A.P. Subramanian (2008)	omni-directional 45°	-	15dBi	9dBi
Z. Zhang (2008)		82°	-	11.5dBi
J. Karedal (2010)	-	-	-	<6 dBi
W. Y. Lin (2010)	omnidirectional antenna	-	5 dBi	
N. Agafonovs (2012)	-	omnidirectional	-	10dBd
F. Kamal (2012)	-	omnidirectional	-	9 dBi
A. Timm-Giel (2007)	-	45°	-	7dBi
S. Demmel (2012)	-	Sticky antenna Omni	-	8 dBi
W. Cho (2011)	omni-directional antenna		8±1dBi	-
F. Martelli (2011)		directional antenna		5dBi
W.Cho (2011)	directional antenna	directional antenna	8dBi	8dBi
V. Shivaldova (2013)	35/35 40/30	Omni-directional	10 dBi 14 dBi	5dBi
	> ±45° > ±63°	-	-	-
NTIA (2013)	65° to 90°	-	-	-
M.K. Marina (2010)	30° 45° 60°	-	-	-
I. Shimada (2005)	-	76°	6.6dBi	-
J. Mittag (2009)	-	30°	-	-
R. Ramanathan (2005)	-	45°	-	6dBi

Table 2.4 The advantages and disadvantages of switched beam antennas**.**

Advantages	Disadvantages
- ***C. F. Mecklenbraüker (2011)*** has introduced that RX diversity improved system reliability in VANET. Smart antenna technology improved system robustness, enhancing network scalability enhancing interference management in heavily loaded V2V. - ***R.T. Juang (2012)*** has indicated that the latency is reduced. Then, unsuccessful packet receptions are decreased. - ***A. G. Anbaran (2013)*** has presented that smart antenna technology improved system capacity more than 2 bps/Hz. In addition, smart antenna technology provides interference cancellation. Then, SNR of the communication system is improved. Moreover, power consumption is enhanced due to higher antenna gain. - ***IY. Li (2012)*** has introduced that switched-beam antenna system improved the system's achievable performance. - ***V. Shivaldova (2012)*** has introduced that smart antenna produces more advantage comparing to an antenna having directional radiation pattern. - ***S. Yi (2003)*** has introduced that beamforming can increase system throughput and delay reduction reduction in delay. - ***R. Ramanathan (2001)*** has presented that smart antenna reduced interference problem. As a result, signal-to-noise ratio is improved. In addition, multipath fading is mitigated.	- ***C. F. Mecklenbraüker (2011)*** has presented that the number of mounting positions for the car company is restricted. Smart antenna requires multiple connection lines from the antenna housing to the control unit. -***R.T. Juang (2012)*** has shown that the antenna HPBW is a significant issue. Narrower antenna HPBW provides a higher antenna gain and higher communication range. But, lower coverage area. - ***F. Liu (2010)*** has introduced that azimuth antenna HPBW affected to performance of communication system. The improper antenna HPBW introduced for a low quality of a communication link. - ***A.P. Subramanian (2008)*** has introduced that beam steering antenna improved the communication throughput. However, this system requires more intelligent processing unit due to the capability of beam steering. Moreover, the delay is increased due to the amount of main beams. -***V. Navda (2007)*** has shown that beam steering system is more complexity. Then, the system process requires more processing time. Thus, the system cannot provide a latency according to the major requirement of DSRC standard. - ***S. Gou (2009)*** has introduced that using single narrow-beam in multiple transmissions is usually impractical due to its lack of scalability in resource-constrained VANETs.

Focusing on the benefits and drawbacks of switched beam antenna system, the benefits of switched beam antenna system is presented in Table 2.4. There are more advantages that improved the DSRC V2V communication link. Also, the literature reviews inspired the determination of optimum antenna half power beamwidth for V2V DSRC communication link. The main purpose is the enhancement of communication link reliability. Consequently, the improvement of link quality introduces the indirectly enhancement of road safety according to the main purpose of ITS/DSRC establishment.

2.6 Performance metrics

The performance metrics of ITS/DSRC communication link introduced the measurement of communication link quality. There are more performance metrics which present for communication link stability and reliability. This dissertation focuses on the performance metrics for V2V communication link. Also, the average antenna gain is the first performance metric which transfers to the average SNR calculation. Moreover, the average SNR is the powerful performance metric which introduces a communication quality. High SNR presents a high communication link quality. As a result, the received power level at the receiver increased which produced a low BER and PER values. Then, the receiver can receive for more accurate ITS/DSRC packets.

The SNR presents the quality of V2V communication link. A higher SNR indicates a better communication link. However, there are other performance indicators for V2V communication link which are BER and PER. These parameters are also related to SNR. The relationship between SNR and BER has been presented in ***L. Zhao (2013)*** .The authors have presented the calculation of BER performance for OFDM wireless communication in which a good communication link can be achieved when BER is low. According to this, a good communication link refers to a higher receiving signal level at the receiving side. Thus, the higher receiving signal can improve system performance and also system reliability. ***R. Sabouni (2012)*** has discussed about an importance of BER and PER calculation for V2V communication link. Moreover, the computation of communication delay time corresponding to BER and PER values has been shown in ***R. Sabouni (2011)***. The maximum acceptable communication delay time is 0.1 s or 100 ms in the distance of 150 m between vehicles. In addition, another important parameter for communication delay time is a contention window. According to this, ***IEEE Working Group (2002)*** has revealed that the DSRC message types for IEEE802.11p standard are separated into 2 types: safety message and non-safety message. The minimum contention window size is suitable for safety message due to the requirement of low latency and a small packet size for safety message. On the other hand, the maximum contention window size is proper for non-safety application. The BER, PER and communication time of V2V communication link are investigated. Moreover, BER and PER of DSRC/ITS introduced for the reliability of the communication link. Lower BER and PER presented a high communication link reliability. As a result, the road safety indirectly increased due to a high link reliability. In addition, a high link reliability introduced the increasing of correct received packets. Also, the performance metrics considering in this dissertation include with average SNR, BER and PER. Moreover, another important performance metric has been introduced in terms of R_{safe} (Effective Communication Range) and T_{safe} (Time to Collision). R_{safe} is introduced for the communication range which produced a packet dropping rate less than 0.9. These performance metrics dedicated for the vehicle can receive more accurate packet inside a DSRC coverage range. Focusing on T_{safe}, this value introduces for a time to collision. A high T_{safe} introduced for the increasing of preparing time for the drivers. As a result, the driver can aware of a situation on the road. So far, V2V improvement in terms of switched-beam antenna system for V2V communication link has not been considered in the literature. Also, this dissertation introduced the enhancement of R_{safe} and T_{safe} which are determined by the improvement of average SNR. As a result, the road safety increases due to the benefits of the proposed system.

2.7 Optimization methods.

The previous section introduced the performance metrics which presented the quality of V2V communication link. The average SNR is the main role. Average SNR was determined by the relationship between antenna HPBW and receiving power level inside the Friis Transmission equation. The Friis transmission equation included with significant parameters such as transmit antenna gain, transmission power, distance between vehicles and operating frequency. Moreover, the antenna gain function inside Friis formular included with antenna HPBW value. The antenna HPBW value separated into two planes: azimuth and elevation. As mentioned earlier, antenna HPBW in azimuth plane has been considered. Narrowing antenna HPBW produced high antenna gain. Consequently, the average SNR at the receiver increased due to a high antenna gain. Also, all parameters send to Friis transmission equation. Then, the average SNR was calculated. Focusing on the optimization process, the objective function of the proposed system is more important issue. The main objective function determines maximum average SNR according to a proper antenna HPBW.

Accordingly, a proper antenna HPBW provides an improvement of signal quality and enhancing the road safety with the reliability improvement of V2V message dissemination. Thus, average SNR is the main objective of optimization problem.

The details from above session introduced for antenna gain function including antenna HPBW and other significant parameters. The antenna gain function categorized into nonlinear multivariable equality constrained optimization. ***D. E. Kirk (2012) and H.P. Geering (2007)*** have introduced Jacobean and Lagrange methods which are suitable for a single equality constraint. However, the above methods cannot choose a suitable gain function, vehicle position probability and angle spread between beams according to vehicle position on the road. Moreover, the difficulty of the computation presents the improper method for the proposed optimization problem. Because, mentioning methods require for more processing time. Other methods are direct and indirect methods. Search method is the simplest way to determine the optimum HPBW. But, it requires more processing time due to the amount of possible input HPBW cases according to the constraint. Focusing on the objective function, the objective function is categorized into nonlinear multivariable optimization problem. According to this, there are the powerful optimization processes which are proper for this objective function. Also, ***P. Venkataraman (2009)*** has presented that the proper methods for this objective function is Sequential Quadratic Programming (SQP) methods. SQP method is the powerful method for determining the optimum value for the objective function which is related with quadratic equation. Moreover, SQP methods require for low processing time. Also, SQP method has been selected for the determination of optimum HPBW for V2V RHW application.

2.8 Chapter Summary

The objective of the proposed system is the determination of optimum antenna half power beamwidth for V2V communication. Firstly, the introduction of ITS/DSRC is explained including with the fundamental of ITS/DSRC communication structures. In addition, the antenna for V2V DSRC network is described. An antenna having omni-directional radiation pattern frequently uses in ITS/DSRC. Then, the drawbacks and the limitations of the conventional antenna for ITS/DSRC are discussed. Then, the antenna having directional radiation pattern is introduced for the solution. The limitations of directional antenna are presented. Also, smart antenna technology is described due to the drawbacks of the antenna having directional radiation pattern. However, due to the limitations of conventional switched beam antenna system then the proposed system is introduced. Next, the proper optimization techniques for optimum antenna half power beam width are discussed. In addition, the performance metrics including with BER, PER, SNR, RSSI, T_{safe} and R_{safe} are investigated to present the successful of the proposed system.

CHAPTER III

BACKGROUND THEORY

3.1 Introduction

The related background theory are separated into three major topics. Firstly, the physical layer technologies of ITS/DSRC are introduced. Secondly, the related antenna theories are explained. Finally, the related optimization theories are presented. Focusing on ITS/DSRC topics, the standard of ITS/DSRC is separated into three major zones: North-America, Europe and Japan. The operating frequency band are 5.8 GHz and 5.9GHz. The difference of each standard is the operating frequency, data rate and coverage range. Due to the benefits of IEEE802.11p standard then this standard has been chosen. IEEE802.11p standard operates at 5.9GHz band. 27 Mbps is the maximum data rate. The coverage range does not exceed 1000m. Moreover, this standard provides the data exchange between moving vehicles. The structures of DSRC technology based on IEEE802.11p standard are presented. Moreover, the study of IEEE802.11p standard is introduced including with OSI layer. The enhancement of physical layer is the main objective of this work. Next, the antenna theory is described which included with fundamental antenna characteristics. Another significant issue is the radiation pattern of the antenna. The radiation of the antenna presents an important parameter. The significant parameter is antenna HPBW. Wide HPBW introduces for high coverage area but low communication range. As a result, the antenna gain is reduced when antenna HPBW is wide. Consequently, a low gain antenna introduces a low receiving power. Then, the communication performance such as PER, BER and RSSI are reduced. An antenna having omni-directional radiation pattern introduces for a losing received signal power in undesired directions. Thus, directional antenna is introduced due to the capability of concentrating the total power to the desired directions. However, an antenna having directional radiation pattern cannot be used in some applications. Then, smart antenna technology is proposed due to the capability of beam steering in a desired directions. However, the consideration of antenna HPBW does not concern in conventional smart antenna system. But, the shape of the antenna and the antenna HPBW make an importance for ITS/DSRC service. Thus, this work presents the study of related antenna theory which improves ITS/DSRC communication link performance. In addition, the proposed concept introduces the determination of optimum antenna HPBW. Thus, the theory of optimization technique is introduced. Finally, the performance metrics evaluation are described.

3.2 Intelligent Transportation System and Dedicated Short Range Communication

The amount of the vehicles on the road is increased rapidly. In contrast, the number of the road infrastructures are not increased. As a result, the traffic congestion and the chance of accidents are raised. There are more solutions such as new road construction to increase the road area supporting the vehicles. However, the mentioned solution required for more government budget. Thus, the increasing of road area only introduced for solving traffic congestion problem. Focusing on the accident issue, the increasing of the vehicles increased the chance of accidents on the road. The increasing of road area introduced for the appending of high speed moving vehicles. The vehicles with high speed movement increased the chance of an accident. Thus, the government in the world determined for the solutions for reducing travel time and accidents on the road with a low budget. Recently, the researchers propose the technology which increased the convenience for the drivers and enhancing the traffic safety by the communication technology. The communication technology called a communication based applications which are based on the installation of electronics devices on the vehicles. The vehicles on the road can talk with each other by transmitting and receiving the importance message. Focusing inside the messages, the heading or directions, speed, position can send to the vehicles inside a communication area. The benefits of these information are introduced for the development of the application for the vehicles to reduce the accidents on the road and improve the traffic problems without new road construction. The technology providing the mentioned information is called as vehicular communication. The integration of conventional transportation system and smart communication technology produced Intelligent Transportation System (ITS). The main purpose of ITS is the increasing of traffic safety without new road construction. ITS is operated by Dedicated Short Range Communication (DSRC) technology. ITS introduced a low operations costs of traffic problem reduction. Thus, the mentioned reason made an attractiveness for the government in the worlds. The introduction of related ITS theory are described in this chapter. Firstly, the ITS/DSRC standard is introduced. ITS/DSRC standard separated into three major zones: North America, Europe and Japan.

Table 3.1 ITS/DSRC standard comparison

Parameter	Japan	Europe (CEN-DSRC)	North-America
Frequency band	5.8 GHz	5.8 GHz	5.85-5.925 GHz
Data transmission rate	1 or 4 Mbps	500 Kbps (Downlink) 250 Kbps (Uplink)	27 Mbps
Standard	ARIB STD-T75 & T88	CEN	IEEE802.11p (WAVE-DSRC)
Coverage range	Up to 30 m.	Up to 30 m.	Up to 1,000 m.

The different of each standard is presented following Table 3.1. But, the low latency of the communication link and high reliability are the major requirements of three standards. Because, ITS/DSRC applications directly effect to human lives. Table 3.1 presents the famous standard in the world. This work selected IEEE802.11p WAVE-DSRC for the experimental configuration.

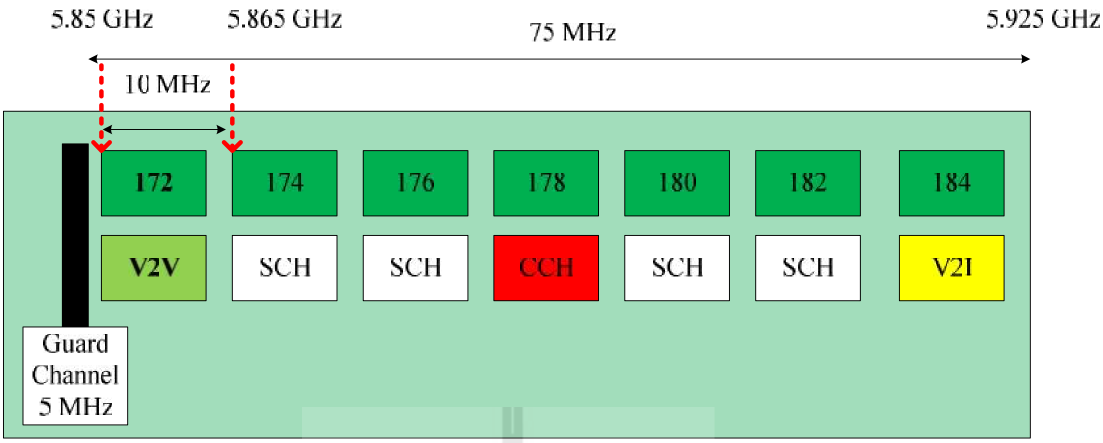


Figure 3.1 IEEE802.11p Spectrum Allocation.

Focusing on the frequency spectrum allocation, FCC defined 5.825-5.925 GHz band for the operating of ITS/DSRC services. The spectrum allocation and the tasks of IEEE802.11p standard are introduced in Fig. 3.1. IEEE802.11p spectrum allocation is separated into seven channels including with one control channel and six services channels. The bandwidth of DSRC spectrum is 75 MHz. Channel 178 is assigned for control channel. Channel 172 is assigned for V2V communication. Channel 184 is assigned for V2I. The guard channel is located at the low end.

Focusing on IEEE802.11p specifications, the modulation types are BPSK, QPSK 16-QAM, 64-QAM. OFDM technology has been selected. The using of OFDM technology is increased the system reliability when communicating with high speed vehicles. IEEE802.11p is developed from IEEE802.11a. The difference between two standards is the two times increasing of symbol interval. As a result, IEEE802.11p can communicate with vehicles moving in a high speed. The data rate is separated into two groups: data rate for 10MHz and 20 MHz bandwidth. Focusing on 10MHz, the data

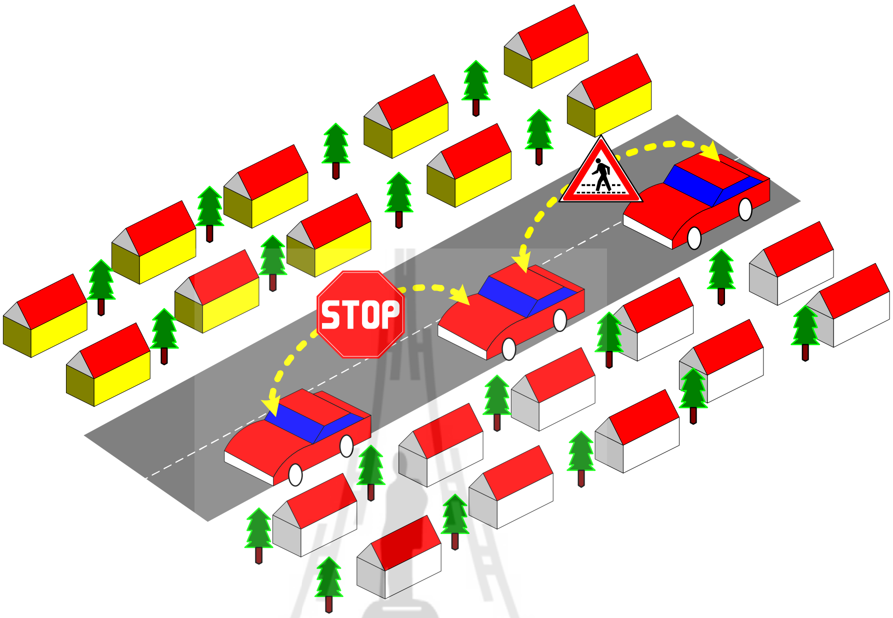


Figure 3.2 V2V communication scheme

rate initiated as following: 6, 9,12,18,24 and 27 Mbps. In other words, 6, 9, 12, 18, 24, 36, 48 and 54 are the data rate for 20 MHz. Then, IEEE802.11p can transmit a huge information in a short period. Then, the latency is lower than other standards. This benefit indicates that IEEE802.11p standard is proper for safety application. Safety message dissemination in a short period introduced that the vehicles can receive the messages suddenly. Also, the safety of the drivers is increased. Then, IEEE802.11p standard is chosen for the study of ITS/DSRC communication in this work. The communication scenarios of IEEE802.11p using DSRC technology is categorized into two main types: Vehicle to Vehicle communication (V2V) and Vehicle to Infrastructure communication (V2I).

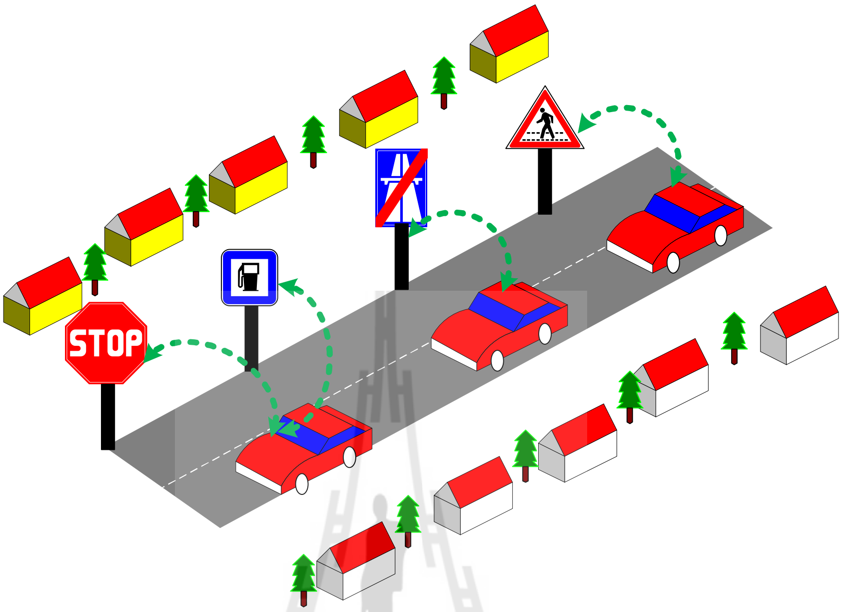


Figure 3.3 V2I communication scheme

Focusing on the devices related to this standard, ITS/DSRC included with two main devices. Firstly, On Board Unit (OBU) or On Board Equipment (OBE) is installed on the dashboard inside the vehicles. Secondly, Road Side Unit (RSU) or Road Side Equipment (RSE) is installed along the road. This work calls OBU and RSU. The message transmission between OBU calls V2V scheme presenting in Fig.3.2. The vehicles exchange their safety or non-safety information with each other. Then, the vehicles inside DSRC communication area can receive the message. As a result, the driver can prepare for the situation on the road. The message transmission between OBU and RSU calls V2I scheme presenting in Fig.3.3. The vehicles exchange their significant message with the RSU unit installing along the road. In contrast, the message transmission between vehicle and the devices along the road is the major tasks of RSU devices. In addition, an antenna having omni-directional radiation pattern is the famous antenna coming with DSRC devices due to the benefits of transmitting DSRC message for all directions. However, two-ray radio communication is another requirement of V2V communication. Thus, the traditional antenna cannot support this requirement. Then, the antenna issue is significant for the enhancement of vehicular communication link. Moreover, the beam directions could increase or decrease the link loss 6-12dB. Then, the antenna development techniques is more important.

Focusing on the applications in V2V and V2I communications, the applications in ITS commination are categorized into two main types. Firstly, safety applications are important applications. This application requires more link reliability and high quality of the communication link. The safety applications are separated into two types: Hard safety and Soft safety. Figure 3.4 presents the applications in Safety applications. The hard safety application affect directly to the drivers. Then, the results from these applications impact to the decision of the drivers. As a result, the information dissemination in hard safety application need a high reliable of the communication link and low error rate. In example, the data transmission in Forward Collision Warning requires more accuracy information to make a decision of the drivers. High error rate message receiving introduces for a wrong decision. Then, the chance of an accident increases due to the mentioned above. Next, soft safety applications are introduced. The impact of soft safety applications are lower than hard safety applications. In example, the construction zone application needs for the construction location notification. Thus, the message transmission requires good link

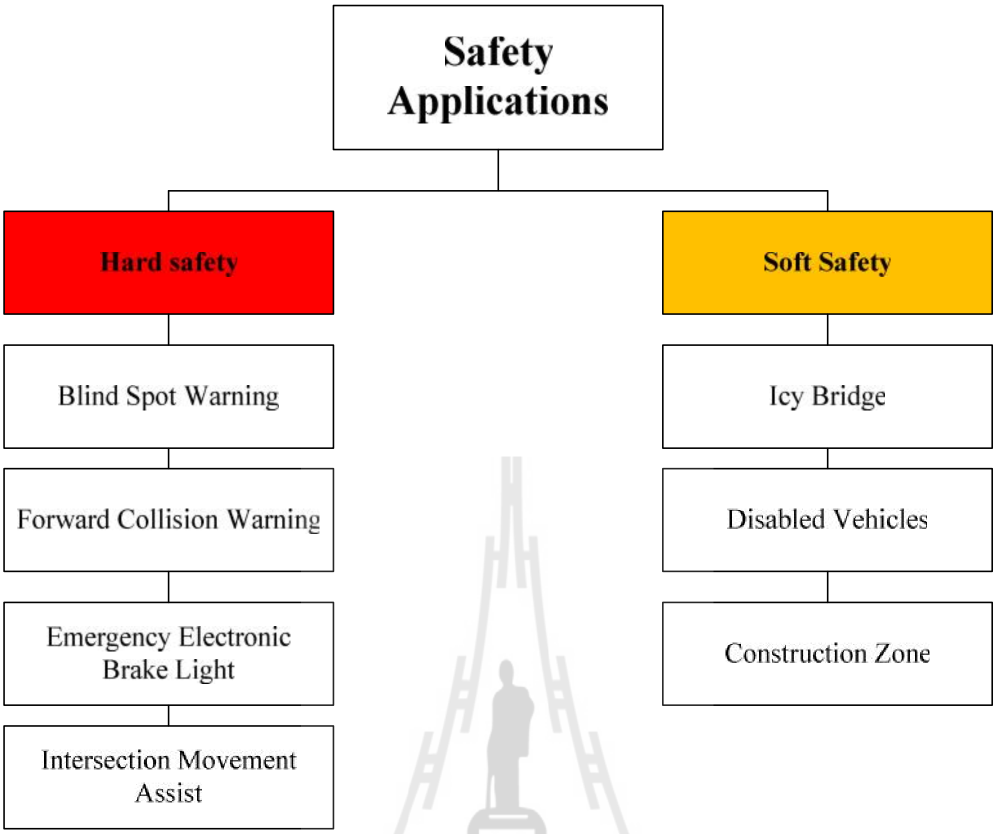


Figure 3.4 Safety applications

quality but not similar to the hard safety applications. In summary, the hard safety application requires more accuracy link quality. Because avoiding crashes and minimizing the vehicle and human lives damage are the major objective of the hard safety applications. Secondly, non-safety applications introduce for the increasing of driver's convenience. The data transmission in non-safety applications does not need a high link reliability. These applications transmit the message only for the improving of vehicle movement on the road. However, the increasing of communication link reliability is the significant topics. This is because the better communication link introduces a high reliability ITS/DSRC link. However, the conventional ITS/DSRC devices integrated with an antenna having omni-directional radiation pattern disseminate DSRC message in all directions. Then, the information transmitting in undesired directions introduce a low received signal level at the receiving side. Also, the topics of transmitting signal in desired directions is more important issue. The appropriate antenna techniques increase the receiving signal power level. As a result, a high correct received information enhances the road safety indirectly. Thus, this work investigates the proper and low complexity of the antenna techniques which increase the communication link quality.

3.3 Related Antenna Theory

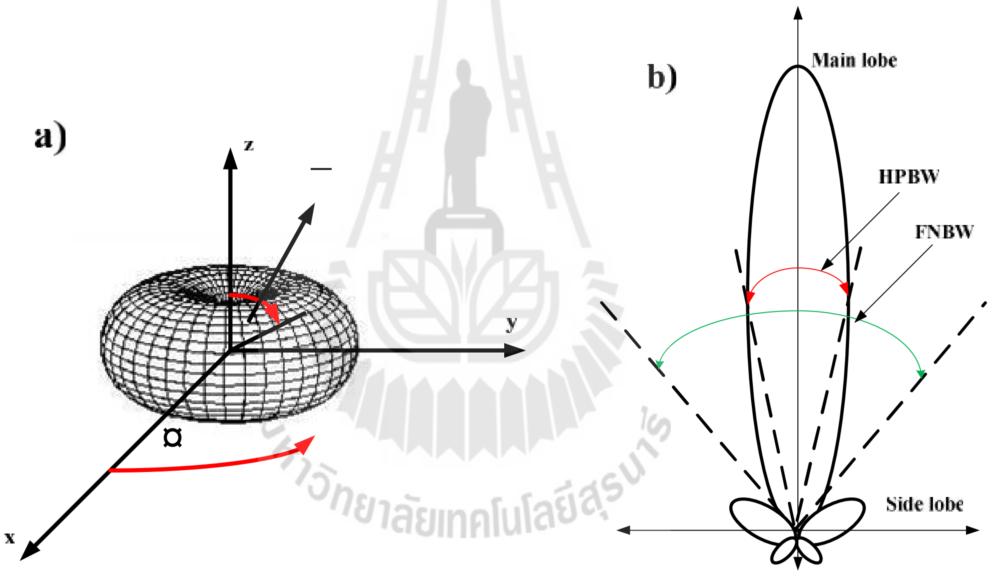
Recently, ITS/DSRC is developed widely in the world. The major goals of ITS/DSRC is the reduction of traffic congestion and accident on the road with an intelligent communication technology. Then, ITS/DSRC introduces the attractiveness to the government in the world concerning for the development of ITS/DSRC technology. Focusing on wireless communication, antenna is the key element. The newest vehicles equipped with AM/FM antenna, GPS antenna, Cellular or LTE antenna and Digital video (DVB) or Digital Audio (DAB) antenna. Other significant antenna are automotive radar, sensors and Electronic Toll Collection (ETC). In addition, there are more automotive wireless devices require for the intelligent antenna techniques which increase the communication link performance. To indicate the antenna ability, the studying of basic related antenna parameters and definitions are important. Especially, the antenna radiation pattern is the significant topic which indicates the antenna HPBW and antenna gain.

3.3.1 Radiation Pattern

The radiation pattern indicates the capability of the antenna. ***C.A.Balsnish (2005)*** introduced the definition of antenna radiation pattern. The definition of the radiation pattern is presented as follows:

"A *mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates. In most cases, the radiation pattern is determined in the far field region and is represented as a function of the directional coordinates. Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization.*"

The formats of antenna radiation pattern in this work are categorized into an antenna having directional radiation pattern and antenna having omni-directional radiation pattern. The consideration of antenna radiation pattern is separated into two formats: 2D and 3D. The radiation pattern is presented in a logarithmic scale. The radiation pattern of the antenna is separated into three formats: field pattern, power pattern (linear scale) and power pattern (in dB). The radiation pattern is included with antenna pattern lobes. The antenna pattern lobes are presented in Fig.3.5. The key parameter is the antenna half power beamwidth (HPBW). The main lobe indicates the directions of maximum radiation. The antenna radiation pattern included with E and H planes. E-plane is the electric field vector. H-plane is the magnetic field vector. The antenna radiation pattern presents the ability of the antenna. HPBW indicates the antenna gain. The wider antenna HPBW introduces for a lower gain but higher coverage area. However, the wider antenna HPBW introduces lower communication range. In contrast, the narrow antenna HPBW introduces more antenna gain. As a result, the communication performance is improved due to the increasing of antenna gain. Focusing on an antenna having omni-radiation pattern, the transmitting signal is disseminated in undesired directions. Thus, the receiving side can receive a lower received power. As a result, the performance of the communication link is decreased due to the drawbacks of an antenna having omni-directional radiation pattern. Focusing on the main lobe of the radiation pattern, the main lobe of the antenna radiation pattern contains a maximum radiation. Then, the maximum radiation indicates the directions of the main beam. The antenna radiation pattern is measured in far field region. Next, the field region is presented in Fig.3.6.



a) An antenna having omni-directional radiation pattern.

b) An antenna having directional radiation pattern.

Figure 3.5 Radiation pattern: HPBW and FNBW

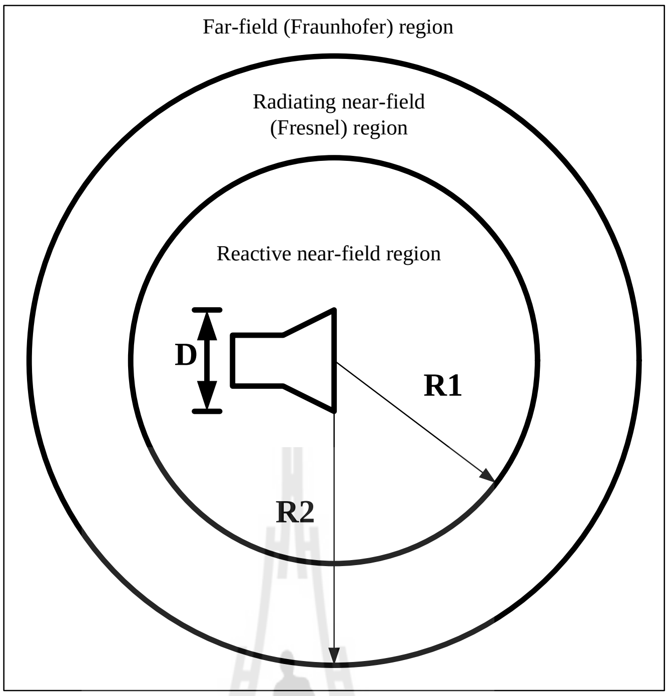


Figure 3.6 The antenna field regions.

3.3.2 Radiation Field Regions

The radiation regions separated into three zones: reactive near-field, radiating near-field (Fresnel) and far-field (Fraunhofer) presenting in Fig.3.6.

- *Reactive Near-field Region*

$$R_1 \approx 0.62\sqrt{\frac{D^3}{a}} \tag{3.1}$$

Where; R_1 A distance between antenna and the field region

D A largest dimension of the antenna

a Wavelength

The reactive near-field region indicated the portion of the radiated power closely to the antenna. The relationship is expressed in (3.1).

-Radiating near-field (Fresnel) Region

$$0.62\sqrt{\frac{D^3}{a}} \leq R \leq \frac{2D^2}{a} \quad (3.2)$$

Where; R A distance between reactive near-field and far-field region

A Fresnel region introduce the region between reactive near-field and far-field region.

- *Far-field (Fraunhofer)*

$$R_2 \geq \frac{2D^2}{a} \quad (3.3)$$

โดยที่ R_2 A distance from reactive near-field region

In the most cases of antenna radiation pattern measurement, Fraunhofer region has been selected. The far-field region presents a clearness of the measurement result. The amplitude of the antenna is changed from reactive near-field to far-field region. Moreover, the far-field region clearly expresses the main lobes, minor lobes and side lobes. Due to the benefit of far field region then far field region makes an attractiveness of far-field region antenna radiation pattern measurement. Thus, the comparison of radiation pattern measurement is presented in Fig3.7.

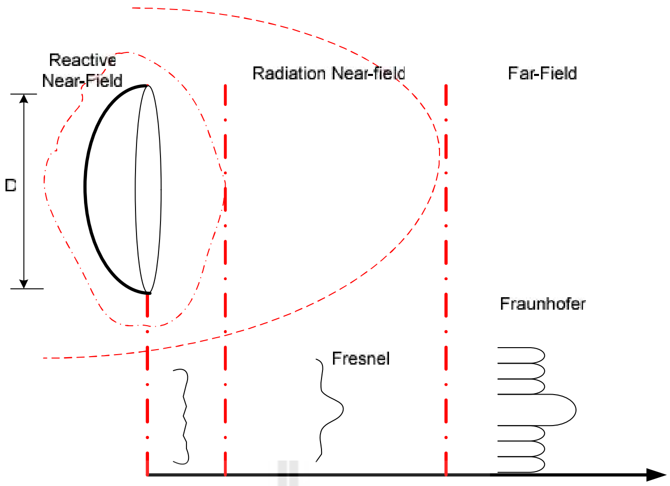


Figure 3.7 The amplitude variation from reactive near field to far-field.

3.3.3 Antenna Half Power Beam Width (HPBW)

Another significant parameter of antenna radiation pattern is the antenna half power beamwidth (HPBW). The antenna HPBW indicates the angle spreading between two points. Focusing on Fig. 3.5, the illustration indicates that two points are located the radiation intensity equally 0.5 times of the maximum directions. HPBW is an important parameter. When decreasing antenna HPBW, then the number of side lobe increases. The consideration of antenna HPBW is separated into two planes: azimuth and elevation planes. Focusing on vehicular communication, the azimuth plane is affected to the quality of the communication link more than elevation plane because a lower distance between vehicles. Moreover, the width of antenna HPBW affect to other significant antenna parameters. The narrow antenna HPBW produces more antenna gain, increasing a communication range and enhancing the received signal power level. Thus, the variation of antenna HPBW affect to the performance of a communication system.

3.3.4 Antenna Directivity

The important topic of the antenna is how much radiated power disseminate to the desired directions. Directivity of the antenna is one parameter which introduces for the energy concentration to the desired directions. Directivity of the antenna is the ratio of the radiation intensity in a desired directions and the average radiation intensity in all directions. The antenna directivity does not express the unit. The directivity is presented:

$$D(\theta,\phi)=\frac{U(\theta,\phi)}{U_{av}}=\frac{4\pi U(\theta,\phi)}{P_{tot}} \tag{3.4}$$

$$D(\theta,\phi)=\frac{4\pi U(\theta,\phi)}{\int_0^{2\pi}\int_0^{\pi} U(\theta,\phi)\sin\theta \, d\theta \, d\phi} \tag{3.5}$$

Where;

$D(\theta,\phi)$	Antenna directivity in desired direction
$U(\theta,\phi)$	Antenna radiation intensity in a given directions
U_{av}	Average radiation intensity in all directions
P_{tot}	The total power radiated

3.3.5 Antenna gain

The above section introduced the directionality of the antenna. The directivity indicates the ability of the antenna which concentrates the energy to the desired directions. The determination of antenna directivity does not concern for antenna losses, dielectric losses, transmission line miss matches. Thus, the above topics have been considered for the determination of antenna gain. The expression of antenna gain is presented in (3.6). Where e refers to the antenna efficiency consisting of losses and miss matches effect.

$$G(\theta,\phi)=eD(\theta,\phi) \tag{3.6}$$

The antenna gain depends on the antenna HPBW. The reducing of antenna HPBW introduces the increasing of antenna gain. However, there is no related topic which investigated the optimum antenna HPBW for vehicular communication.

3.4 Smart antenna

Smart antenna technology is established for the enhancement of wireless communication link in terms of steering the main beams to the desired directions. The using of smart antenna technology increases the antenna gain. As a result, the coverage range and coverage area are increased. Moreover, the receiving signal power level is improved due to no signal lost in undesired directions. In addition, the communication link stability and the effect of interference signal have been solved with the benefits of smart antenna technology. Smart antenna technology is categorized into two types: switched-beam antenna system and adaptive array antenna system. The difference between two types is feedback control bit sending to the transmitter for adjusting the transmitted signal which is better than the previous transmission sequence. Thus, adaptive array needs for the intelligent processing unit. Moreover, the process needs for more processing times. Thus, using adaptive array with vehicular communication is not proper. Because vehicular communication needs a low latency of the communication link. In contrast, switched-beam antenna system does not require feedback control bit. Thus, switched-beam antenna system has been selected for the improvement of vehicular communication link. In addition, the followings indicate the benefits of smart antenna technology.

- The capacity of the communication link is increased.
- SNR is higher than SIR.
- The receiving signal power level is increased.
- The interference level is decreased.

- Switched-beam antenna system

Switched-beam antenna system is established for the enhancement of receiver side by a simple method. Switched-beam system is consisted of N antenna array connecting with beam forming networks and beam selection process. The illustration of switched-beam antenna system is presented in Fig.3.8. The output signal passing through the proposed process improves the communication performance at the receiving side. In the most cases, switched-beam antenna system is installed at the receiving side. The mechanism of beam switching system is initiated with receiving signal strength from all input ports. Next, the beam selection process is presented for maximum signal strength detection. Then, the maximum receiving signal strength has been selected for the connection between the receiver and transmitter. As a result, the received signal is increased. As a result, the quality of the communication link has been enhanced.

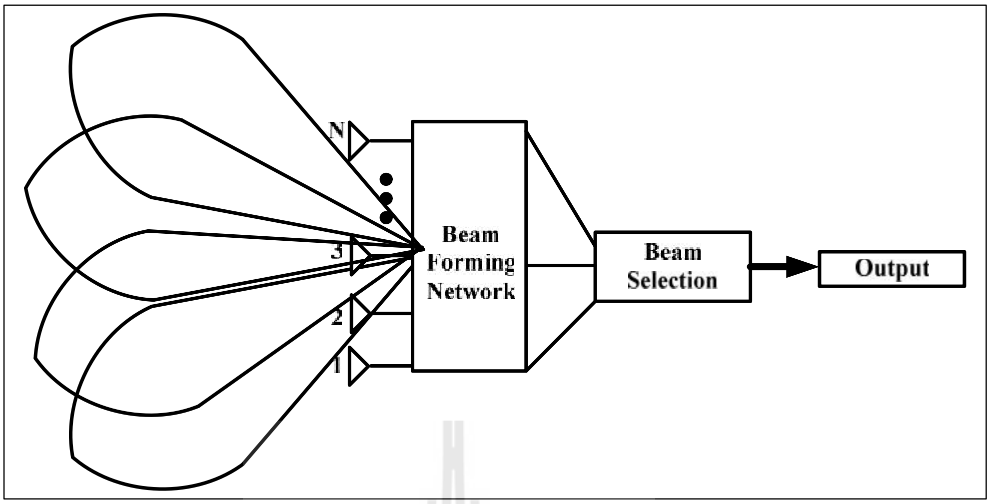


Figure 3.8 Switched-beam antenna system

Moreover, switched-beam system is arranged as following: linear array, planar array, single antenna element for switched-beam system and multiple antenna element for switched-beam system. Focusing on the single and multiple antenna element switched beam system, the multiple antenna element is more attractive than single antenna system. Because the construction of single antenna element is more difficult than the multiple antenna element.

-**Single antenna switched-beam system**

The single antenna switched-beam system equipped with a small electronic device for beam steering process. The single element antenna steered to the desired direction according to the command of the electronic device. However, the configuration of a small electronic device for beam switching mechanism is the major challenge. Moreover, providing only one antenna HPBW is another drawbacks of the single element. But a small system and flexible beam steering mechanism are the benefits of this system. In addition, the previous subsection introduces the tradeoff between the drawbacks and the benefits. Focusing on vehicular communication system and the proposed system, single element is not proper for the proposed system due to the single elements cannot provide for the optimum antenna HPBW. Single element provides only one HPBW value. Thus, the mentioned above introduce that single element system is not selected.

-**Multiple antenna switched-beam system**

Multiple switched-beam antenna system equipped with multiple antenna element. The separating of feeding points introducing that each antenna element can produce the antenna HPBW value corresponding to the proposed system. However, this system requires radio frequency switch for the process of beam selection mechanism. The radio frequency switch can operate the switching process from port one to port four. Radio frequency switch changes the position in each input port. The radio frequency switch to port one then the receiving signal strength are measured. Also, the comparing process is occurred after radio switch changing to port four. The maximum signal strength has been chosen for the data transmission. The new process of switched-beam system is started again from port one to port four. This mechanism provides a maximum signal strength for vehicular communication. Thus, multiple switched-beam antenna system has been chosen for the performance of vehicular communication determination. The comparison of these systems is presented in Table 3.2.

Table3.2 The comparison of multiple switched-beam antenna and single switched-beam antenna.

Comparison Topics	**Multiple antenna switched beam system**	**Single antenna switched beam system**
Feeding points	Separating in each beams changing via radio frequency switch.	Using RF-MEM for the beam steering, complex and difficult adjustment.
Budget	Require a low budget	High value such as RF-MEM technology.
Complexity	Low complexity	High complexity and difficult for the installation.
Signal Processing	Fast, Processing data in a small period.	The ability of signal processing depends on the radio frequency switched.
Antenna HPBW	Adjustment available	Adjustment available but difficult.

The comparison table introduces the attractiveness of multiple antenna switched-beam system. The multiple antenna switched-beam system can operate the HPBW according to the proposed system.

3.5 Optimization Methods

The objective of the proposed system is the determination of optimum antenna HPBW. Also, optimization techniques are significant tool for optimum antenna HPBW observation. Another important topic is the categorizing of objective function. The correct type of the objective function introduces for a proper optimization method. As a result, the optimum antenna HPBW can be determined. In addition, an important issue is the categorizing of problem constraint. Focusing on the objective function, the objective function is categorized into constrained nonlinear multi-variable function. The proposed objective function included with multi-variable presenting in the input antenna HPBW values inside the antenna gain function. However, the summation of the input antenna HPBW values cannot be exceeded 360 degree. Thus, the related optimization techniques are explained in this chapter. The objective function is separated into linear and non-linear paradigm. Moreover, linear objective function is separated into single variable and multi-variable. Next, the constraint is categorized into equality and inequality constraint. Also, the related optimization theory is described.

The proposed objective function express as non-linear multi-variable equality constraint optimization problem. Also, the related optimization methods are presented as follows;

-Sequential Quadratic Programming: SQP

SQP algorithm has been chosen. Because SQP method is proper for the objective function which presents in quadratic form. SQP is constructed for the solution of non-linear constraint optimization

$$\max_{x} f(x) \quad (3.7)$$

$$subject\ to: \ c(x) = 0 \quad (3.8)$$

SQP method is a nonlinear programming method. SQP is implemented by Schittkowski. The approximation of SQP method is made of the Hessian of the Lagrangian function using a quasi-Newton updating method. SQP subproblem is constructed. The solution is used to form a search direction for a line search procedure. In the initial state, the formulation of a SQP subproblem is constructed with a quadratic approximation of the Lagrangian function.

$$L\left(x, \text{ª}\right) = f(x) + \sum_{i=1}^{m} \text{ª}_i \cdot g_i(x) \quad (3.9)$$

Quadratic Programming (QP) Subproblem

$$\min_{d \in \Re^n} \frac{1}{2} d^T H_k d + \nabla f(x_k)^T d \quad (3.10)$$

$$\nabla g_i(x_k)^T d + g_i(x_k) = 0,1..., m_e \quad (3.11)$$

Then, the solutions are transfered to form a new iteration.

$$xk\ +\ 1\ =\ xk\ +\ {\sim}kdk \quad (3.12)$$

~k is introduced for step length. ~k is gathered by line search procedure. Matrix H_k is the approximation of the Hessian matrix of the Lagrangian function. H_k is updated by quasi-Newton methods. SQP provides a fast and high reliability of the solution determination. Also, this work selected SQP for the determination of optimum antenna HPBW.

3.6 Chapter Summary

Intelligent transportation system is the technology increasing road safety and reducing traffic congestion. ITS uses the benefits of dedicated short range communication for data dissemination in vehicular networks. ITS/DSRC consists of three major zone for standard categorization: North America, Japan and Europe. In the famous cases of vehicular communication, IEEE802.11p has been selected. The data dissemination in ITS/DSRC is separated into two schemes: V2V and V2I. This work introduces the enhancement of the communication link in V2V scheme. The antenna technology is presented. Smart antenna in switched-beam antenna system provides the requirements of the proposed system. In addition, antenna HPBW is more important topic. Antenna HPBW indicates the capability of the antenna. There have never been presented the study of optimum antenna HPBW. Thus, the related optimization methods are presented. The objective function of the proposed system categorized into multi-variable and equality constraints. Also, the SQP optimization has been selected. The applying of appropriate optimization method can solve the objective function and producing the optimum antenna HPBW values. Finally, the optimum antenna HPBW values can bring to V2V communication performance evaluation.

CHAPTER IV

PROBLEM FORMULATION AND PROPOSED SYSTEM

4.1 Introduction

This section introduces details of problem formulation. The problem formulation focuses on explanation of related parameters relating to Friis transmission equation such as antenna gain, transmission power and operating frequency. Applying antenna technology in V2V communication is presented. An antenna gain function is introduced which is consisted of the most important parameters presenting in antenna HPBW values. The varying of input antenna HPBW values is affected to the variation of average antenna gain. The average antenna gain is computed from 0 degree to 360 degree. Focusing on the other significant parameters, the vehicle position probability is gathered from the installation of sensor on the road. Vehicle positions probability introduce the probability of vehicles locating in each positions on road. Also, the road infrastructure such as number of lanes, vehicle position and number of counted vehicles passing the sensor are shown. Then, average antenna gain is calculated. Also, the average antenna gain is sent to the performance evaluation. Friis transmission equation is introduced for the determination of received power. The computation of received power is described in this section. Moreover, the received power is sent to the average SNR determination which is included with average noise power at the consideration location. Finally, the problem formulation is introduced. Then, the expected performance metrics evaluation are explained.

4.2 Problem formulation

According to the drawbacks of an antenna having omni-directional pattern as mentioned, the directional antenna as well as switched-beam antenna have been introduced to V2V communication systems so far. However, this still leaves some limitations as the HPBW is not designed suitably to take care of the probability of vehicle positions, road width and distance between vehicles. As a result, the chance of worse communication link decreases V2V reliability. Thus, the reasons mentioned so far encourages the approach of optimum HPBW determination for increment of V2V system reliability. ***Z. Zhang (2008)*** and ***F. Liu (2010)*** have motivated an investigation of HPBW for vehicular communication with smart antenna technology to achieve more quality V2V link. A narrower HPBW introduces more unstable communication link due to a smaller coverage area, even the communication range increases. The switched-beam system provides a maximum RSSI which is selected from the best beam. However, in literatures the authors do not address any proper HPBW for vehicular communication system. In this light, this dissertation proposed the issue of optimum HPBW determination. The consideration of optimum HPBW is separated into two major parts. First, average antenna gain is considered. ***O. Klemp (2010)*** and ***K. Xu (2010)*** have introduced the determination of average gain using antenna gain function and the probability density function of vehicle positions on the road according to the mentioning of ***V.L. Knoop (2012)***. Thus, communication link quality is improved using optimum HPBW. Then, this work proposes switched-beam system with the optimum HPBW determination. Also, the proposed system formulation comparing with the conventional system are presented. However, the comparison of two different systems are based on the same transmission power for an impartiality comparison. Thus, the gain comparator factor are investigated for adjusting the antenna gain function of the two cases in a fairness comparison. ***K. Mase (2008)*** has shown that the antenna gain function depends on main beam directions. The main beam directions are related to the antenna HPBW. Focusing on the performance metrics of V2V communication system, ***J. Harri (2013)*** has presented that the Effective Communication Range (ECR) or R_{safe} is configured according to BER threshold and PDR threshold related to IEEE802.11p standard. According to this, when vehicle is traveling inside communication area, this vehicle guarantees for getting a high link reliability. Moreover, R_{safe} can be related to time to collision or T_{safe} as shown in (4.1) and (4.2). The safety range R_{safe} is related to the speed of the vehicle (¢).Note that it can only be used in a road with asphalt material. In addition, R_{safe} indicates the distance for the driver preparation to control vehicle into a bad situation on the road. Moreover, the relationship between the proposed system and time to collision or safety time T_{safe} is presented in (4.2). According to this, antenna technology is related with V2V applications in terms of effective communication range R_{safe} . Thus, R_{safe} and T_{safe} are important to V2V applications.

$$R_{safe} = \frac{(¢ \cdot 3.6)^2}{100} \tag{4.1}$$

$$T_{safe} = \frac{R_{safe} - R}{¢} \tag{4.2}$$

The proposed system including with omni-directional antenna installing at the transmitting vehicle and the receiving vehicle equipping with switched-beam system following with Fig.4.1. Also, the relationship between transmitting and receiving signals is presented in (4.3).

$$y = hx + n \tag{4.3}$$

where y is a receiving signal. h is a wireless channel and x is the transmitting signal. From (4.3), the average received power can be expressed as shown in (4.4).

$$P_r = |x|^2 \overline{|h|^2} + \overline{|n|^2} \tag{4.4}$$

$$P_r(¤_r, ¤_t) = P_t(¤_r, ¤_t) G_t(¤_r, ¤_t) G_r(¤_r, ¤_t) \left(\frac{a}{4® R} \right)^2 \overline{|h|^2} \tag{4.5}$$

$$¥(¤_r, ¤_t) = \frac{P_r(¤_r, ¤_t)}{N(¤_r, ¤_t)} \tag{4.6}$$

$$¥(¤_r, ¤_t) = \frac{P_t(¤_r, ¤_t) G_t(¤_r, ¤_t) G_r(¤_r, ¤_t) \left(\frac{a}{4® R} \right)^2 \overline{|h|^2}}{N} \tag{4.7}$$

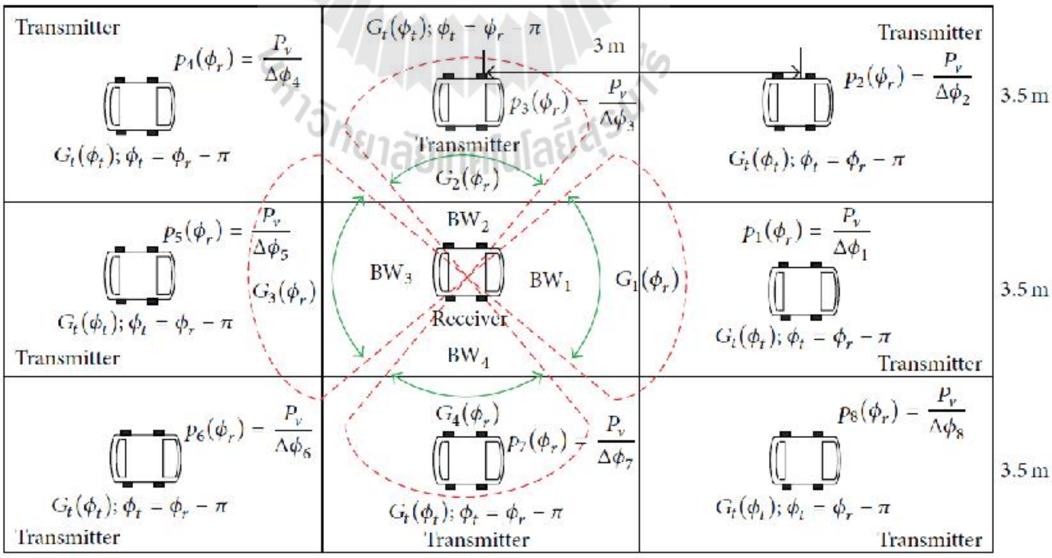


Figure 4.1 Proposed system when applying switched-beam antennas at receiving vehicles.

where P_r presents the average received power including with the multiplication of transmitting signal power and propagation channel coefficient and the average noise power level. The channel coefficient is introduced using Friss formula. Then, the equation in (4.4) is rewritten as (4.5). Let N be the average noise power as $\overline{|n|^2} = N$. Then, the Signal to Noise Ratio (SNR) is calculated using (4.6) and (4.7). However, there are more obstacles around communication area. The scattering signal and interference signal from the nearby radio equipment get impact to the receiving vehicle. According to this, the probability of interference effect at the receiving side and the effect from the obstacles are increased. This is because the receiving vehicle can receive signals from all directions. Also, the quality of V2V communication link is decreased. Thus, V2V communication link needs for improving radio link quality. As a result, high performance link provides a high reliability data exchanging between vehicles. Focusing on the structure of the proposed system, Fig.4.1 presents the angle parameters $P_r(¤_r, ¤_t)$ .Assuming $N(¤_r, ¤_t) = N; \forall(¤_r, ¤_t)$ and $SNR = ¥(¤_r, ¤_t)$, then the average signal to noise ratio depends on the average antenna gain according to vehicle position probability and angle spread between beams as expressed in (4.6) and (4.7).

$$\overline{¥} = E\left\{\frac{P_r(¤_r, ¤_t)}{N}\right\} \tag{4.8}$$

$$G_i(¤) = g_i \times 10^{0.1\left(G_{max} - 12\left[\frac{¤ - ¤_{MB_i}}{BW_i}\right]^2\right)} \tag{4.9}$$

$$p_i = \frac{P_v}{\Delta ¤} \tag{4.10}$$

$$\Delta ¤ = 2 \cdot \arctan\left(\frac{W_r}{D_v}\right) \tag{4.11}$$

Where;

W_r is road width

D_v distance between vehicle

g_i is the antenna gain comparator

¤ is the angle of incoming received signal

BW_i is the input antenna HPBW

Before average SNR determination according to (4.8), another important issue is the calculation of average antenna gain. Moreover, the antenna gain function $G_i(¤)$ is significant for the determination of average antenna gain too. The average antenna gain is included with the relationship of main beam directions and the antenna HPBW. The relationship of antenna HPBW and main beam directions are presented in (4.9), where $\left(¤_{MB_i} - \frac{BW_i}{2}\right) \leq ¤ \leq \left(¤_{MB_i} + \frac{BW_i}{2}\right)$.However, another important issue is a comparison of transmission power between a conventional systems and a proposed system. The comparison realized on equal transmission power. Then, the adjustment factor is computed by gain comparator parameter (g_i) which will adjust the transmission power equally to an antenna having omnidirectional radiation pattern.

In addition, another important parameter is the vehicle position probability. As mentioned in a previous section, the vehicle position probability indicates the density of a vehicles in a consideration area on the road. The appropriate antenna HPBW and the main beam direction concentrate to a correct vehicle position introducing for the increment of received signal level. As a result, the reliability of the proposed system is improved. Next, the probability density function is expressed in (4.10) which includes the vehicle position probability (P_v) and the angle spread between beams (Δ¤). Focusing on the angle spread between beams, this factor is indicated for the road width (W_r) and the distance between vehicle (D_v). Angle spread between beams present in (4.11). Also, the mentioned parameters are used to categorizing the road environments. Focusing on the antenna gain function, the antenna gain function includes with antenna HPBW (BW_i), main beam directions (MB_i). The average antenna gain is firstly introduced with Friis transmission equation which is expressed in (4.7). G_t(¤$_r$,¤$_t$) and G_r(¤$_r$,¤$_t$) are the antenna gain function at transmitter and receiver antenna. The proposed system investigated at the receiving side. Also, the determination of average antenna gain as the follow $\overline{G_r} = \frac{1}{2®}\int_0^{2®} G_i(¤)p_i(¤)d¤$ is changed to (4.12).

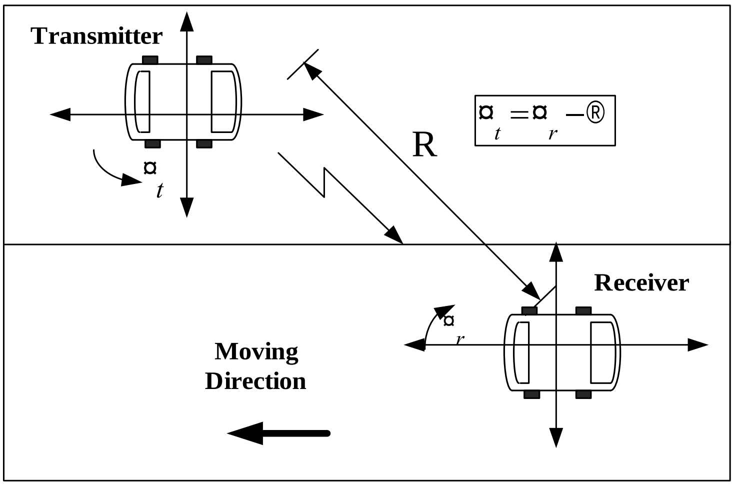


Figure 4.2 The structure and relationship between ¤$_r$ and ¤$_t$

$$\overline{G_r} = \frac{1}{2®}\int_0^{2®} G_r(¤_r)p_r(¤_r)d¤_r \qquad (4.12)$$

An antenna having omni-directional radiation pattern is installed at transmitting vehicle. Then, DSRC safety message is transmitted to receiving vehicle in a communication area. Focusing on the proposed system, switched-beam antenna system is installed at receiving vehicle. Switched beam system receive DSRC safety message via the benefits of smart antenna technology. As a result, RSSI improvement is the expectation of the proposed system. Moreover, the distance between two vehicles is presented in terms of R.The related parameters are described as the following. Let $P_t(¤_r,¤_t) = P_t$, $G_t(¤_r,¤_t) = G_t(¤_t)$ and $G_r(¤_r,¤_t) = G_r(¤_r)$. The relationship of $¤_r$ and $¤_t$ is presented as the following $¤_t = ¤_r - ®$. The relationship as mentioned earlier presented in Fig.4.2. Transmitting and receiving vehicle move in a forward directions. Also, Friss transmission equation in (4.5) is rewritten in (4.13).

$$P_r(¤_r,¤_t) = P_r(¤_r) = P_t G_t(¤_t)\overline{G_r(¤_r)}\left(\frac{a}{4®R}\right)^2\overline{|h|^2} \qquad (4.13)$$

$$P_r(¤_r) = P_t G_t(¤_r - ®)\overline{G_r(¤_r)}\left(\frac{a}{4®R}\right)^2\overline{|h|^2} \qquad (4.14)$$

$$\overline{¥} = E\left\{\frac{P_t G_t(¤_r - ®)\overline{G_r(¤_r)}\left(\frac{a}{4®R}\right)^2}{N}\right\}\overline{|h|^2} \qquad (4.15)$$

$$\overline{¥} = \frac{P_t}{N}\overline{|h|^2}\left(\frac{a}{4®R}\right)^2\int_0^{2®} G_t(¤_r - ®)\overline{G_r(¤_r)}p(¤_r)d¤_r \qquad (4.16)$$

$$\bar{\gamma} = \frac{P_t}{N}\overline{|h|^2}\left(\frac{\lambda}{4\pi R}\right)^2 \int_0^{2\pi} G_r(\theta_r)p(\theta_r)d\theta_r \quad (4.17)$$

Focusing on noise power presenting in N, noise power is gathered from the measurement. The measurement value is collected five times per points. Then, average noise power is collected. In addition, performance metrics are determined. Vehicles traveling in a communication area maintain a stable link according to BER and PER threshold. Focusing on IEEE802.11p standard, PDR is configured at 90%. This value introduces more link reliability. This is because DSRC safety application requires more communication link reliability. The expression in (4.18) indicates a result of HPBW adjustment for V2V communication link. Also, the expression in (4.19) introduces the relationship between PER and BER, where L refers to packet size of V2V safety application. ***H. Alturkostani (2015)*** introduced that the relationship between BER and PER relates with packet length. However, PER causes a wrong decision of the driver when receiving high PER of safety message. A received DSRC safety message with high PER introduces the increasing of accident on road. Also, PER and BER are the performance metrics which indicate performance of vehicular network. Moreover, PER and BER indicate road safety indirectly.

$$BER_{BPSK} = \frac{1}{2}erfc\left(\sqrt{\frac{\bar{\gamma}}{2}}\right) \quad (4.18)$$

$$PER = 1-(1-BER)^{8L} \quad (4.19)$$

4.3 Optimum half power beamwidth determination

The optimum HPBW determination process is started with the constraint function which checks condition of input HPBW values. Summation of antenna

HPBW value are not exceed 360 degree. Also, average antenna gain and average SNR are calculated using the proposed objective function. Focusing on the objective function according to (4.20), the proposed objective function can be categorized into multivariable optimization and linear equality constrained. ***D. E. Kirk (2012)*** and ***H. P. Geering (2007)*** have introduced Jacobian and Lagrange methods. The mentioned earlier method are proper for single equality constraint. Focusing on the constraint of the proposed system, the constraint of the proposed system is followed the requirement of Jacobian and Lagrange method. However, the proposed system requires a correctness of antenna gain function corresponding to the vehicle position on road. Thus, selection suitable antenna gain function, vehicle position probability, and the angle spread between beams are introduced that the mentioning methods from above are not suitable for the proposed system. Moreover, the difficulty of the computation presents improper antenna gain function for the optimization problem. ***P. Venkatarama (2009)*** has expressed that suitable method for similar objective function as the proposed system is SQP method. SQP method is the powerful method for the determination of the optimum value according to the proposed objective function. Moreover, SQP method produces low processing time. Also, SQP optimization method is selected for optimal HPBW determination. To apply SQP method for the determination of optimum HPBW for V2V communication, the objective function can be given in (4.20). This function consists of input HPBW values, exact antenna gain function, and probability density function of vehicle position probability.

$$f(BW_1,...,BW_M) = \frac{P_t}{N}\overline{|h|^2}\left(\frac{\lambda}{4\pi R}\right)^2 \int_0^{2\pi} G_r(\theta_r)p(\theta_r)d\theta_r \qquad (4.20)$$

The objective function is illustrated in (4.21). Maximize average SNR is the objective of the proposed system. Note that, the summation of input antenna HPBW are not exceed 360 degree according to the constraint in (4.22). Where M presents number of beam. The solution can be obtained by applying SQP method on the optimization problem as presented in the following:

$$\textbf{Maximize:} \quad f(BW_1, ..., BW_M) \tag{4.21}$$

$$\text{Subject to:} \quad \sum_{i=1}^{M} BW_i = 2® \tag{4.22}$$

The maximum average SNR is the main purpose of the objective function according to the constraint which is shown in (4.22). The simulation program computes all cases according to the optimization constraint to guarantee the goal of objective function. Also, the maximum average SNR indicates the best solution of HPBW values. Then, the best solution of HPBW producing a maximum average SNR is selected to be the optimum HPBW. Then, V2V communication link reliability can be computed. Moreover, the performance evaluations in terms of R_{safe} and T_{safe} corresponding to IEEE802.11p standard can be determined by (4.19). Improving of V2V communication link performance in terms of RSSI is the main objective.

4.4 Chapter summary

In summary, related parameters in Friis transmission equation such as antenna gain, transmission power and the operating frequency are introduced. The construction of objective function for maximum average SNR determination is presented. The most significant topic is azimuth antenna gain function. The variation of input antenna HPBW values can affect to the average antenna gain. Then, the determination of antenna HPBW values producing maximum average SNR is presented. Maximum average SNR is introduced for the optimum antenna HPBW values. Also, the proper optimization method is presented. SQP optimization method is chosen. The correct antenna gain selection and the proper vehicle position probability are indicated by the capability of SQP optimization method which can produce the optimum antenna HPBW values. Then, these values are sent to the performance evaluation which presents the benefits of the proposed method. The performance metrics are investigated for the proposed system evaluation. BER, PER, R_{safe} and T_{safe} are presented the performance of the proposed system. BER and PER present the reliability of V2V communication link. Also, the improvement of BER and PER performance is the significant issue for V2V communication.

CHAPTER V

SIMULATION RESULTS AND DISSCUSSION

5.1 Introduction

Conventional V2V communication devices equip with an antenna having omni-directional radiation pattern. Then, DSRC safety message is transmitted in all directions. However, the transmission of DSRC signal in undesired directions introduces a decreasing of V2V received power level. As a result, V2V link quality is reduced. Then, an antenna having directional pattern is presented. Signal quality increases when using an antenna having directional radiation pattern. Because an antenna having directional radiation pattern transmits signal in a certain directions. However, directional radiation pattern antenna cannot be used in some applications. The mentioned drawback is occurred in V2V data dissemination requiring for simultaneously forward and backward beam communication such as emergency brake light applications. Thus, smart antenna system is presented in terms of switched-beam system. Focusing on Friis formula, receiving power is enhanced due to the increasing of antenna gain at the receiving or transmitting vehicle. Thus, the consideration of antenna HPBW is significant in V2V communication system. The consideration of antenna HPBW is separated into two planes: azimuth and elevation. This work focuses on azimuth antenna HPBW because the adjustment effect from azimuth planes is more than elevation plane. Thus, the optimum antenna HPBW in azimuth plane is determined. The antenna HPBW appears inside the antenna gain function.

The varying of antenna HPBW values produces antenna gain variation. Moreover, the literatures present the average antenna gain determination. Then, this work determines average antenna gain which includes the vehicle position probability. The vehicle position probability is gathered from counter sensors installing in each lanes. Thus, the average antenna gain has been calculated. Also, the simulation of the proposed system can present as the following subsection. In addition, the simulation results of the proposed system is categorized in the following:

Urban

- Four beams switched beam system
- Eight beams switched beam system

Suburban

- Four beams switched beam system
- Eight beams switched beam system

Also, the performance evaluation of optimum antenna HPBW for switched beam antenna system are presented. The simulation results introduce the enhancement of V2V commination link quality. BER and PER of the proposed system is lower than the conventional V2V system which installs an antenna having omni-direction radiation pattern. Thus, simulation results confirm the success of the proposed system which increases traffic safety without new road construction. Traffic safety is increased due to a high reliability communication link.

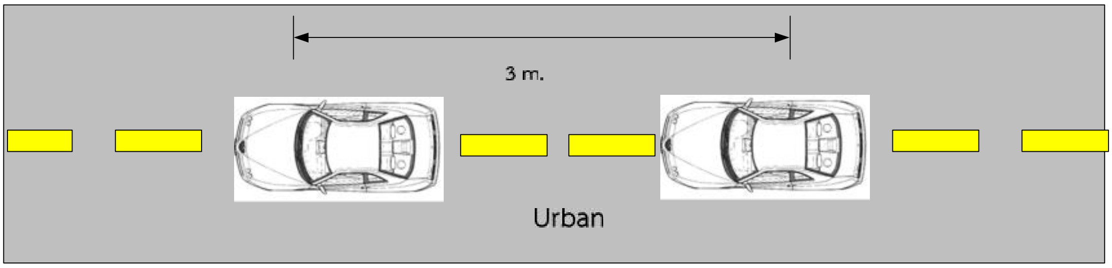


Figure 5.1 The road structure in urban environments

5.2 Related Topics

5.2.1 A distance between vehicles.

The simulation results are initiated with problem formulation. In the first, the road structure such as road width, distance between vehicles are described. These parameters relate to the separation of road environment types. ***Khun C. Lan (2012)*** has presented that a distance between vehicles in urban area is equal 3 meters. Because the traffic inside urban area appears as the vehicles closing to each other.

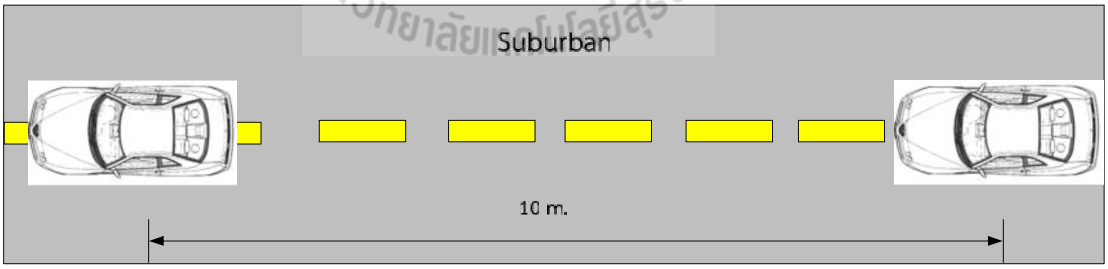


Figure 5.2 The road structure in suburban environments

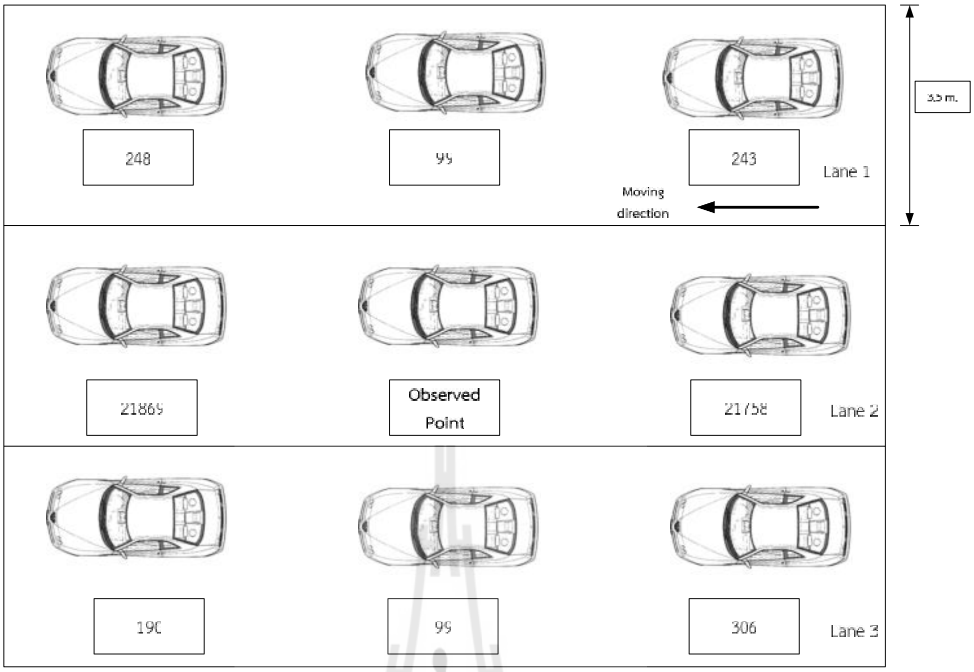


Figure 5.3 Number of vehicles passing through the counter in each lanes

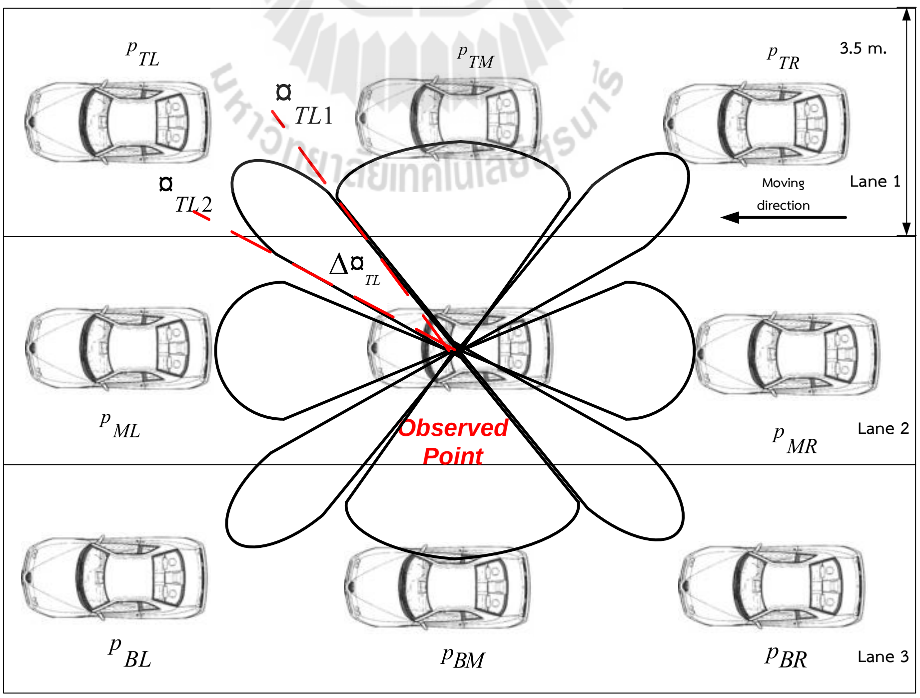


Figure 5.4 Vehicle position probability

In addition, a distance between vehicles of suburban area is equal to 10 meters. Because vehicles travel with high speed. Then, travelling closely to forward vehicles introduce a vehicle collision. Then, a distance between vehicles in suburban road is more than urban environments. Traffic congestion is indicated by a distance between vehicles. Also, urban and suburban structure present in Fig 5.1 and Fig 5.2 respectively.

5.2.2 Vehicle position probability

Another significant parameter is vehicle position probability. The information of vehicle position probability is gathered from the installation of vehicles counter sensor in each lanes. ***V.L. Knoop (2012)*** has presented that the amount of vehicles on the road can be counted. The amount of vehicles is presented in Fig. 5.3. The total vehicles amount is equal 22,505. Also, the amount of forward and backward vehicles appear more than other points. In addition, the vehicle position probability can be calculated using (5.1). Focusing on the road structure consideration, the center vehicle is configured as the observation point. As mentioned, the road environments are separated in to two areas urban and suburban. Also, the vehicle position probability are different between urban and suburban. The vehicle position probability is expressed in Table 5.1 the vehicle position probability of urban environment is equal every points. This is because the traffic jams inside the urban road. Also, the distance between vehicles is lower than suburban area. Then, the vehicle position probability is equally for every points. Focusing on suburban road, the vehicles position are different. This is because the distance between vehicles is more than urban environment. Then, the vehicle position probability is not the same as urban road. Table 5.2 introduces for the vehicle position probability of suburban road environment.

$$
p(¤)=\begin{cases}
\dfrac{p_{TL}}{\Delta ¤_{TL}} & ;¤_{TL1}\leq\Delta ¤_{TL}\leq ¤_{TL2}\\
\dfrac{p_{TM}}{\Delta ¤_{TM}} & ;¤_{TM1}\leq\Delta ¤_{TM}\leq ¤_{TM2}\\
\dfrac{p_{TR}}{\Delta ¤_{TR}} & ;¤_{TR1}\leq\Delta ¤_{TR}\leq ¤_{TR2}\\
\dfrac{p_{ML}}{\Delta ¤_{ML}} & ;¤_{ML1}\leq\Delta ¤_{ML}\leq ¤_{ML2}\\
\dfrac{p_{MR}}{\Delta ¤_{MR}} & ;¤_{MR1}\leq\Delta ¤_{MR}\leq ¤_{MR2}\\
\dfrac{p_{BL}}{\Delta ¤_{BL}} & ;¤_{BL1}\leq\Delta ¤_{BL}\leq ¤_{BL2}\\
\dfrac{p_{BM}}{\Delta ¤_{BM}} & ;¤_{BM1}\leq\Delta ¤_{BM}\leq ¤_{BM2}\\
\dfrac{p_{BR}}{\Delta ¤_{BR}} & ;¤_{BR1}\leq\Delta ¤_{BR}\leq ¤_{BR2}
\end{cases}
\qquad (5.1)
$$

Where;

p_{TL} Vehicle position probability in lane 1 at the left

p_{TM} Vehicle position probability in lane 1 at the center

p_{TR} Vehicle position probability in lane 1 at the right

p_{ML} Vehicle position probability in lane 2 at the left

p_{MR} Vehicle position probability in lane 2 at the right

p_{BL} Vehicle position probability in lane 3 at the left

p_{BM} Vehicle position probability in lane 3 at the center

p_{BR} Vehicle position probability in lane 3 at the right

$\Delta ¤$ Angle spread between beams

Table 5.1 Vehicle position probability of urban environment

Vehicle position	**Vehicle position probability**
p_{TL}	0.125
p_{TM}	0.125
p_{TR}	0.125
p_{ML}	0.125
p_{MR}	0.125
p_{BL}	0.125
p_{BM}	0.125
p_{BR}	0.125

Table 5.2 Vehicle position probability of suburban environment

Vehicle position	**Vehicle position probability**
p_{TL}	0.011
p_{TM}	0.004
p_{TR}	0.01
p_{ML}	0.97
p_{MR}	0.96
p_{BL}	0.0084
p_{BM}	0.004
p_{BR}	0.013

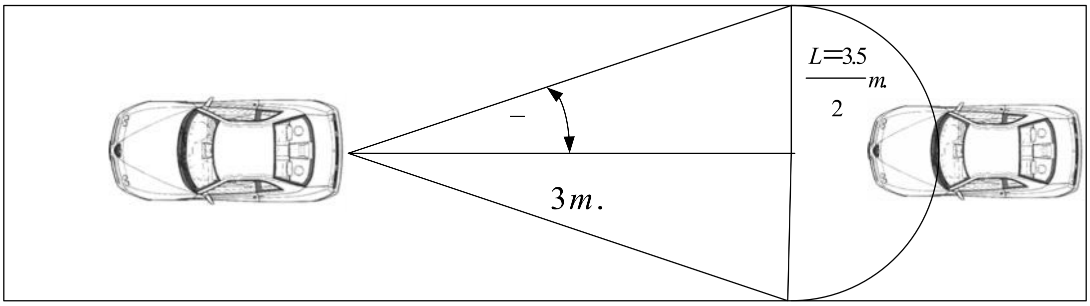


Figure 5.5 Angle spread between beam determinations for urban road environment

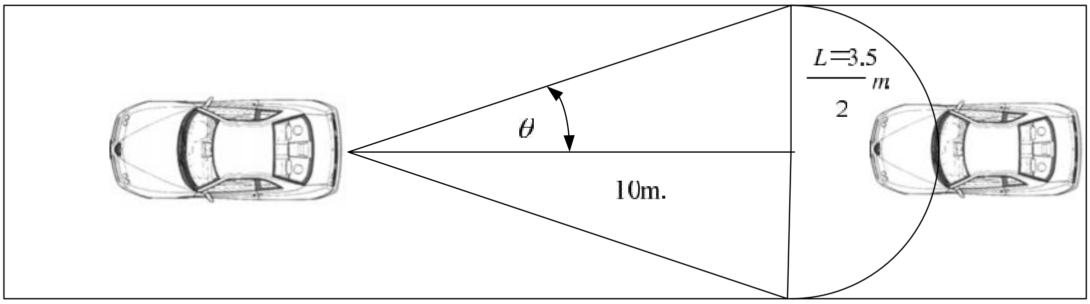


Figure 5.6 Angle spread between beam determinations for suburban road environment

Note that, distance between vehicles is the average value from vehicle position on road. Moreover, problem formulation including with road width is designed under department of Thailand highway standard. Department of Thailand highway designed road width in 3.5 m.

5.2.3 Angle Spread Between beams

Angle spread between beams presents the angle spread in each beam. The determination of angle spread between beams is gathered by the road width and the

$$\Delta ¤ = 2\tan^{-1}\left(\frac{0.5\ (W_r)}{D_v}\right) \tag{5.2}$$

distance between vehicles. The determination of angle spread between beams expressed in (5.2). The distance between vehicles introduces for the difference between urban and suburban areas. Thus, the system evaluation uses different value of $\Delta ¤$. The difference between urban and suburban road present in Fig.5.5 and Fig. 5.6. A wrong selection of $\Delta ¤$ introduces the reduction of RSSI at the receiving vehicle.

Also, Table 5.3 presents the value of Δ¤ . Then, the Vehicle Position Probability Boundary (VPPB) is introduced. VPPB is constructed for creating beam boundary. VPPB is constant value but depending on the road width and distance between vehicles. Next, Beamwidth Boundary (BBound) is introduced. BBound depends on the input antenna HPBW. The simulation program flowchart is presented in Fig.5.7. In addition, the vehicle position probability can be calculated using (5.1). VPPB of the both road environments is different due to the distance between vehicles. Also, the related parameters are sent into the optimization process. The optimization process is solved by SQP optimization method. The simulation program parameters are configured as IEEE802.11p (WAVE-DSRC) standard. However, distance between vehicles are the deputies of almost vehicles locating on road. Then, the optimum antenna HPBW is occurred in urban area at 3 m. and 10 m. for suburban area. In addition, due to a fast variation of vehicle moving in V2V communication then the proposed system can be used according to the following reasons:

1. Average distance between vehicles is gathered from a deputies of the vehicles locating on road in urban and suburban area. The proposed system is designed according to the majority distance between vehicles. Thus, optimum HPBW can use when vehicles moving in a communication area.

2. Vehicle speed in urban and suburban area is change lower than highway. Then, the variation of vehicle speed impact V2V communication link lower than highway scenarios. Thus, the optimum HPBW can use in urban and suburban area when vehicle moving in communication area according to average distance between vehicles.

Table 5.3 Angle Spread between Beams (Δ¤) for Urban scenario

Position	**Δ¤ (degree)**
1	60.5
2	29.5
3	60.5
4	29.5
5	60.5
6	29.5
7	60.5
8	29.5
9	60.5

Table 5.4 Angle Spread between Beams (Δ¤) for Suburban scenario

Position	**Δ¤ (degree)**
1	20
2	20
3	120
4	20
5	20
6	20
7	120
8	20
9	20

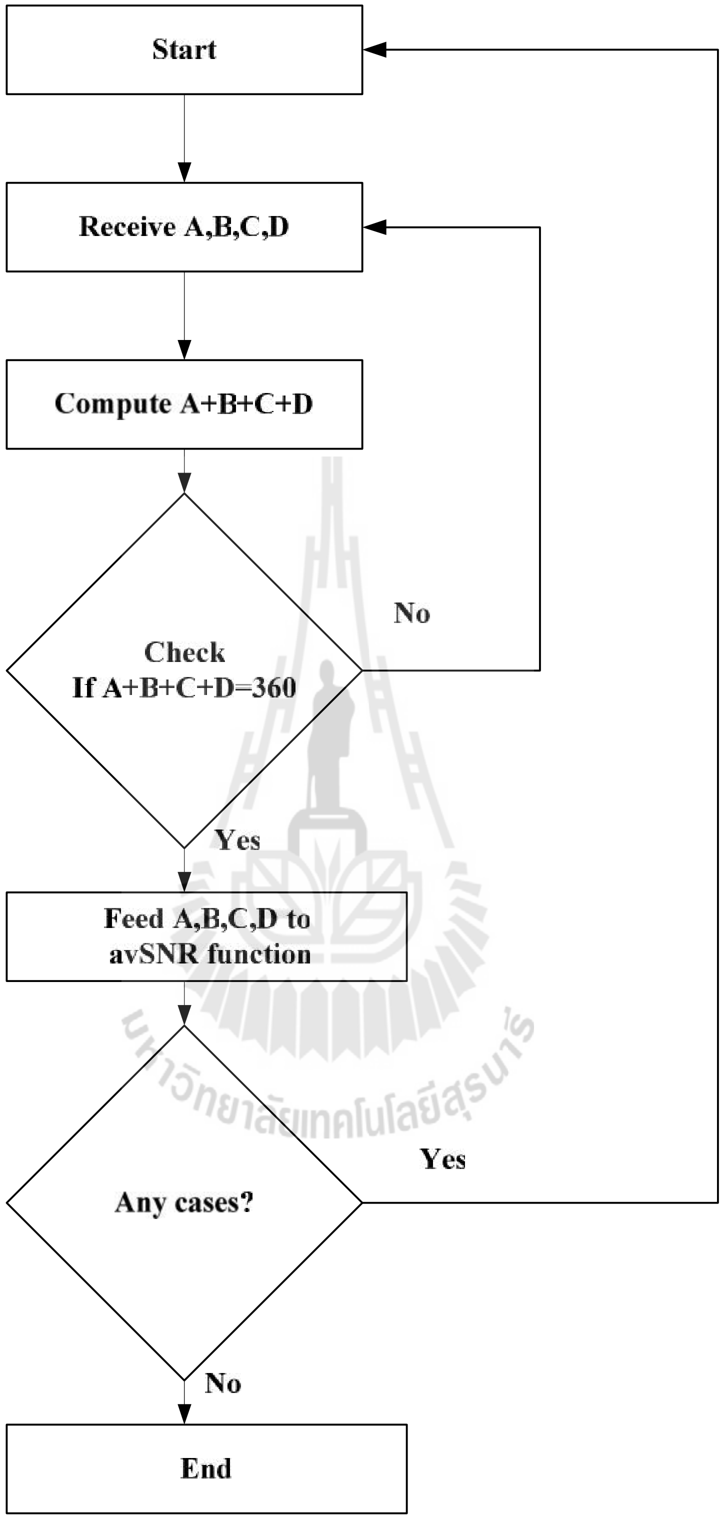


Figure 5.7 A Flow chart of optimum HPBW determination

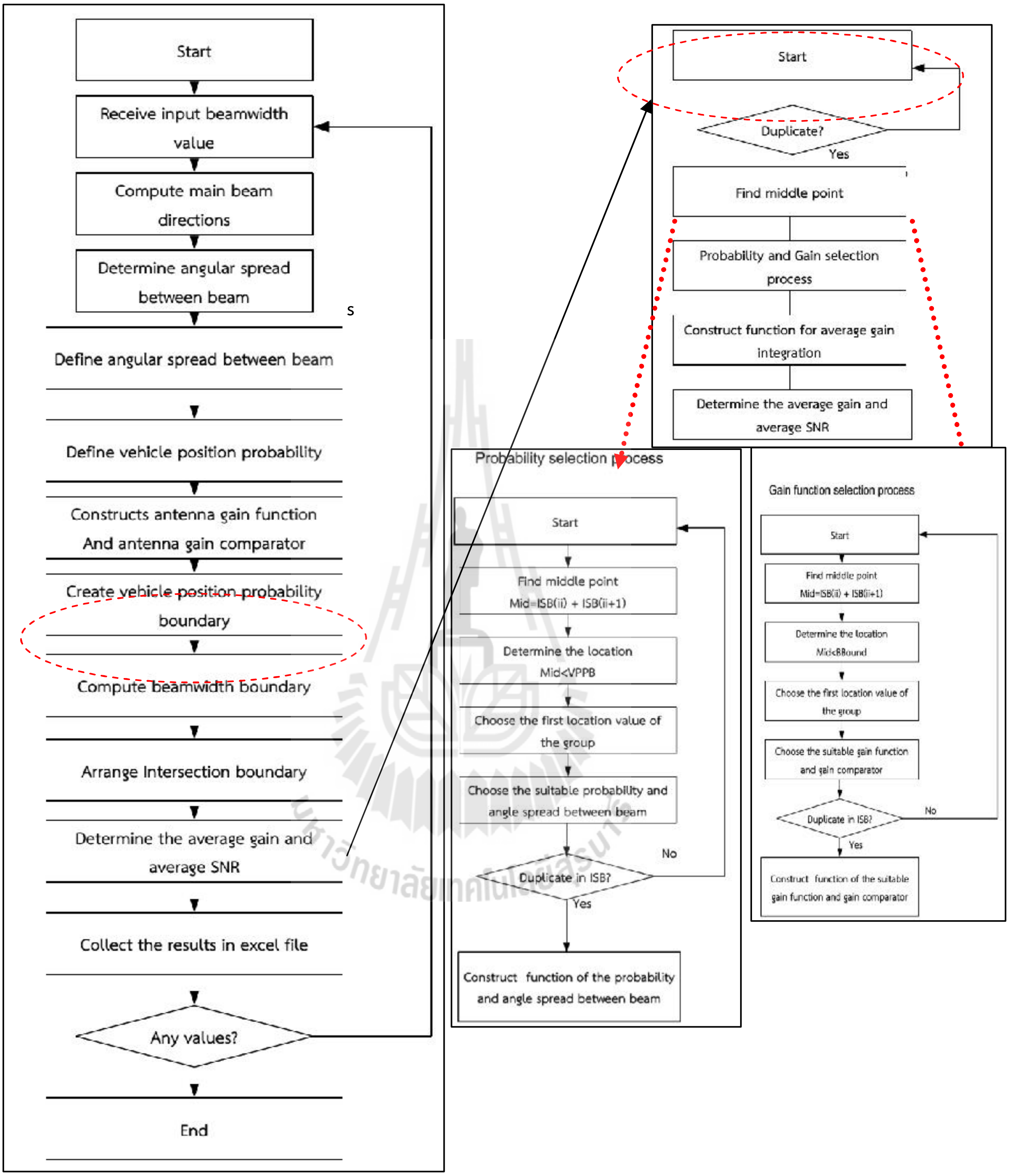


Figure 5.8 Flow chart of avSNR

5.2.4 Simulation Flow Chart

The simulation flow charts and every process of the simulation program are presented. The avSNR function is the main role of the simulation program. Several parameters are described in this section. Angle spread between beams, vehicle position probability, and main beam direction depend on the input antenna HPBW. Based on this idea, the changing of road infrastructure and number of antenna beams can determine the optimum HPBW. The main task of avSNR function is the calculation of maximum average SNR which is produced by the optimum antenna HPBW values. Input antenna HPBW values are pushed to avSNR function. Then, a suitable antenna gain function corresponding to the vehicle positions on road is chosen. Then, antenna gain function is created. Also, a vehicle position probability, angle spread between beams are selected. The upper boundary and lower boundary are presented using VPPB and BBound parameters for a beam selection decision. Next, intersection boundary (ISB) is presented to avoid beam selection ambiguity. Finally, average antenna gain and average SNR are calculated. The overall simulation flow charts are presented in Fig. 5.7 and Fig. 5.8.

5.2.5 SQP optimization

This work uses SQP optimization from Matlab optimization toolbox. Chapter V presented the proposed optimization problem categorizing in multivariable optimization with linear equality constraint. The literatures introduced that SQP optimization method is suitable for the proposed optimization problem.

SQP optimization method is a nonlinear programming presenting in fmincon optimization. The fmincon is the optimization tool which is presented by Matlab simulation program. The fmincon optimization method produces a minimum value.

However, a maximum value can determine by multiplying the output values with minus one according to optimality property. Also, the maximum value is appeared. The purpose of this method is determined a constraint multivariable function. Focusing on the proposed objective function, input antenna HPBW values are sent to the objective function. There are four input HPBW variables sending to the objective function. The input antenna HPBW values are referred to multivariable optimization. The multivariable input antenna HPBW is restricted by the optimization constraint. The input antenna HPBW is not exceed 360 degree. Focusing on the components of fmincon optimization method, the format of fmincon function is presented in (5.3).

$$x = \text{fmincon}(fun, x0, A, b, Aeq, beq) \tag{5.3}$$

$$x = \text{fmincon}(fun, [0,0,0,0], [], [], [1,1,1,1], [360]) \tag{5.4}$$

The explanation inside fmincon are described as the following;

fun presents the objective function.

$x0$ presents the initial value.

A presents the equality constraint. Setting A=[ ] when using equality constraint.

b presents the equality constraint. Setting b=[ ] when using equality constraint.

Aeq presents the relationship of the constraint.

beq presents the relationship of the constraint.

Focusing on the proposed objective function and constraint, applying of fmincon function with the proposed system is presented in (5.4). Moreover, simulation process is separated into two main part: avSNR function and beam input function. Firstly, beam input function generated the input HPBW values sending to avSNR function. Note that, input HPBW value correspond to the constraint of the optimization process. Total input HPBW does not exceed 360 degree. However, the output of fmincon function produces the minimum value of the objective function. Then, to determine the maximum value fmincon is multiplied by -1. As a result, the minimum value changes to maximum value. Also, the maximum SNR has been determined.

5.3 Simulation Results

This section presents related results of optimum antenna HPBW determination. Firstly, the comparison between conventional V2V antenna and an antenna having directional radiation pattern have been investigated. Then, comparison of switched beam system and conventional system is introduced. Next, simulation results of each road environments are described. The simulation results of the optimum antenna HPBW radiation pattern is separated into two main schemes: urban and suburban scenarios. Four beams and eight beams switched beam system are observed except six beam dye to a same performance with four beam according to Fig.5.11. The simulation results present average SNR, average antenna gain. Finally, the maximum average SNR are calculated according to the optimum antenna HPBW values.

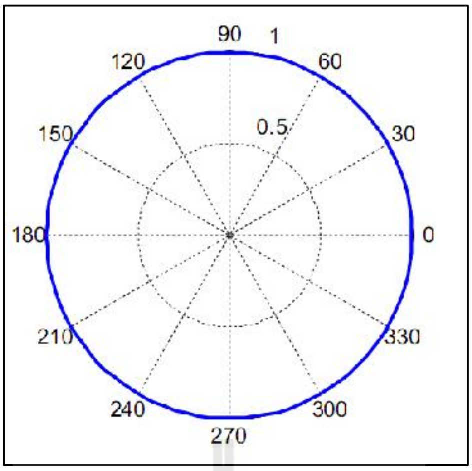


Figure 5.9 The radiation pattern of an antenna having omni-directional pattern

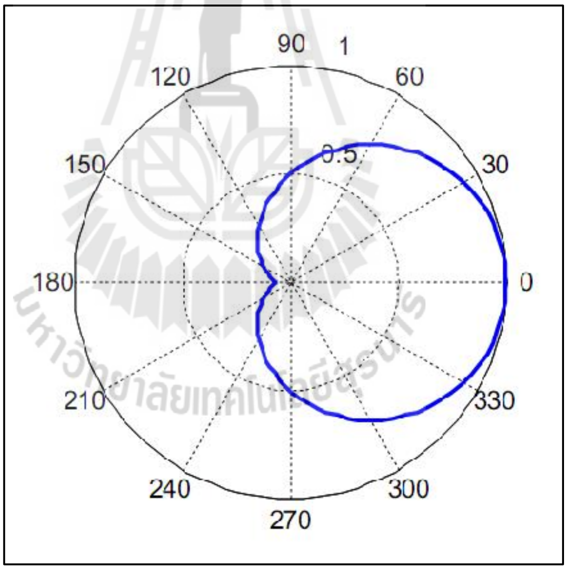


Figure 5.10 The radiation pattern of directional antenna

5.3.1. Omni-directional pattern versus directional pattern

The radiation pattern is presented in Fig. 5.9 introducing the pattern of omni-directional antenna. Omni-directional antenna is a famous antenna in V2V market. The power equally radiated in all directions. Thus, vehicles locating in communication area can receive DSRC safety messages. However, signal transmission over 360 degrees produces signal power losing in undesired directions. However, the benefits of an antenna having omni-directional radiation pattern introduce for safety applications that require for signal transmission for vehicles on road. In contrast, transmitter vehicle cannot transmit and receive the safety message in a certain directions. Also, an antenna having directional radiation pattern has been introduced for the solution. The radiation pattern is presented in Fig 5.10. An antenna having directional radiation pattern concentrates main beam to desired direction. As a result, signal power losing in undesired directions is decreased. Then, receiving vehicle can receive signal power more than the conventional V2V system. However, directional antenna cannot be used in some applications. Also, smart antenna technology is introduced for the solution.

5.3.2 Conventional system versus the proposed system

The comparison of conventional V2V and proposed system are introduced in Fig. 5.11. The signal power in increase more than an antenna having omni-directional pattern. The benefits of smart antenna can increase received signal power level at receiving vehicle. The increasing of received power introduces communication link enhancement. Consequently, other performance metrics are improved when using smart antenna technique. Note that, the consideration of antenna HPBW is interested in azimuth plane. The effect of azimuth antenna HPBW is more than elevation plane. Then, the reasons introduce the inspiration of azimuth antenna HPBW determination.

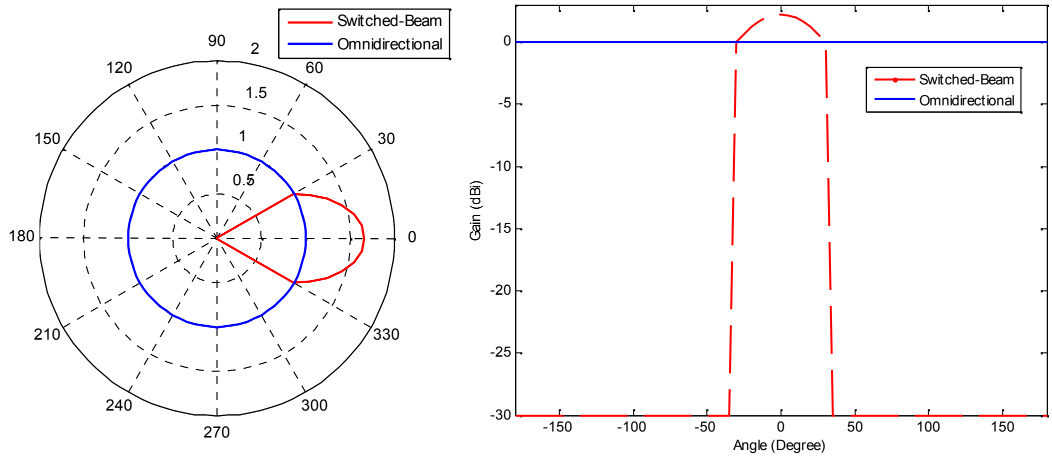


Figure 5.11 The comparison of omni-directional antenna and switched beam antenna radiation pattern.

The simulation results present benefit of switched beam antenna system. Also, investigation of communication link performance is interested. Next, simulation results of the proposed system comparing with conventional system are presented. Simulation results indicate the enhancement of switched beam antenna system with optimum antenna HPBW increasing V2V communication link performance. The maximum SNR is gathered by the appropriate antenna HPBW values. Then, V2V communication link reliability and quality are improved.

5.3.3 Simulation results of urban scenario

The simulation process of optimum HPBW determination in urban road is separated into four and eight beams. The input antenna HPBW values are generated for all possible cases according to the optimization constraints. The difference between urban and suburban roads are the vehicle position probability. Moreover, distance between vehicles are different. The objective of the optimization process is determination of maximum SNR which is generated by the optimum antenna HPBW. The optimum antenna HPBW has been plotted in terms of antenna radiation pattern. The simulation process consider for a fair comparison between conventional system and the proposed system. Then, the antenna gain comparator is constructed. The adjustment of antenna gain between two main systems is done by antenna gain comparator. Also, a fair comparison is occurred. The proposed simulation introduces four and eight beam system. The author simulated the number of beams in many cases from 3 to 8 beams. Finally, the solution of the optimum HPBW 6 beams is equal to 4 beams. Thus, 4 beam system is selected for the determination of optimum antenna HPBW.

Finally, the optimum antenna HPBW value is fed into the radiation pattern construction and the performance evaluation which is presented in Chapter VI. The simulation results present as follows:

5.3.3.1 Four beam system

The simulation process configures parameters following IEEE802.11p (WAVE-DSRC). Channel 172 has been selected. The vehicle position probability is equally for every position. Because distance between vehicles in urban area road is smallest. Then, the vehicles locate nearby other vehicles. Also, the input antenna HPBW value fed into Beaminput. Then, the fmincon optimization function is used. The fmincon requests for avSNR function. Focusing on avSNR, this function is multivariable optimization problem. The purpose of the objective function is the determination of maximum SNR. Focusing on a constraint, a constraint of the optimization problem is equality constraint. Next, simulation program receives the input antenna HPBW values and calculating SNR for all cases correspond to the optimization constraints. Finally, the finishing point is simulation process determining for the maximum SNR. Also, the optimum HPBW is gathered from the mentioned. Four beam radiation pattern is presented in Fig 5.12. The optimum HPBW value is shown in Table 5.5. The average antenna gain is 3.6703 dB. The maximum SNR is 68.9710 dB. Also, the optimum antenna HPBW introduces the enhancement of V2V communication link performance.

Table 5.5 The optimum antenna HPBW for Four beams urban system.

Optimum HPBW	**A**	**B**	**C**	**D**
Urban	113	67	113	67

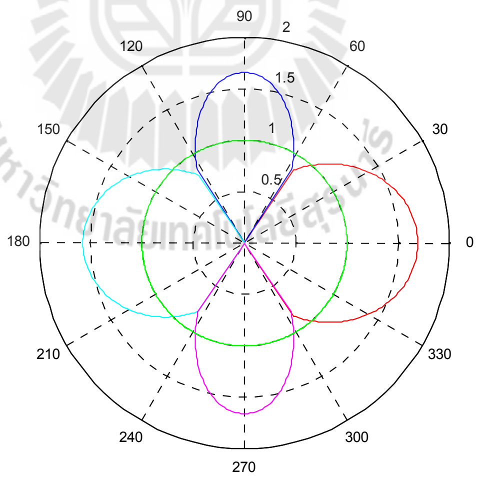


Figure 5.12 The radiation pattern of optimum HPBW for four beam urban system

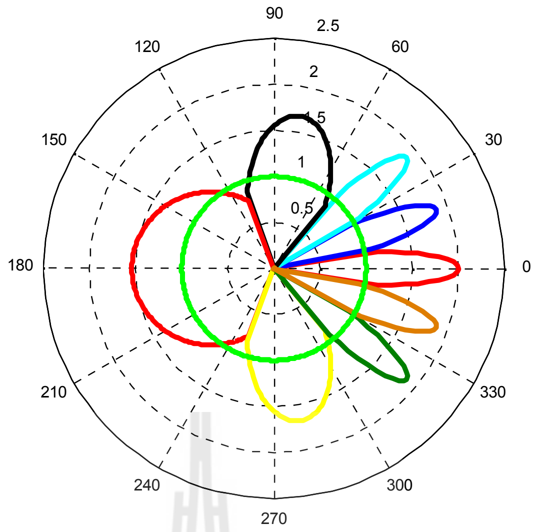


Figure 5.13 The radiation pattern of optimum HPBW for eight beam urban system

Table 5.6 The optimum antenna HPBW for eight beam system.

Optimum HPBW	A	B	C	D	E	F	G	H
Urban	20	20	20	60	140	60	20	20

5.3.3.2 Eight beam system

The simulation process is the same with four beam system. However, the input antenna HPBW values are different. Eight beam input feed into Beaminput function and avSNR function. The determination of maximum SNR presents the optimum antenna HPBW. Simulation result is presented in Fig. 5.13 which are indicated the eight beam optimization HPBW value. Table 5.6 presents the optimum antenna HPBW values. The average antenna gain is 9.3313 dB. The maximum SNR is

64.3099dB. Also, the optimum antenna HPBW introduces the enhancement of V2V communication link performance.

5.3.4 Simulation results of suburban scenario

The simulation process of suburban scenarios is introduced. The difference between urban and suburban are vehicle position and distance between vehicles. Distance between vehicles is equal 10 meters. Vehicle position probability does not equal in every position. Vehicle position probability of backward and forward beam are highest. Because vehicles travelling in front and back of observation vehicle are more than the side vehicles. Then, determination of the optimum antenna HPBW for suburban scenarios is started.

5.3.4.1 Four beam system

The simulation results indicate forward beam concentrating in forward directions. Forward beam communicates with a forward vehicle. Narrow HPBW introduces a long communication range. Thus, forward vehicle and backward vehicle can communicate with a long communication range. Focusing on backward beam, wide HPBW produces a high coverage area. As a result, the chance of detecting incoming signal is increased due to a high coverage area. The simulation results are presented in Table 5.7 and Fig.5.14.

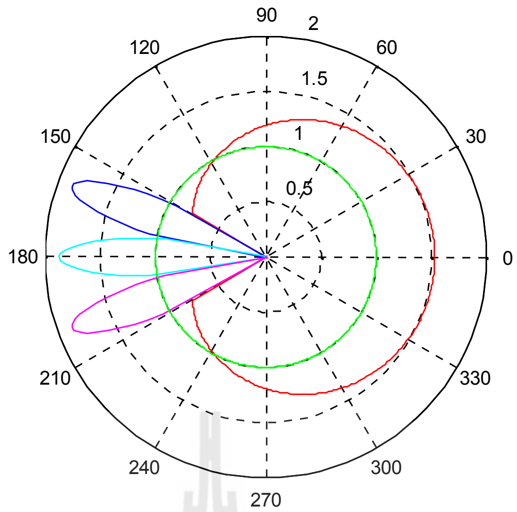


Figure 5.14 The radiation pattern of optimum HPBW for four beam suburban system

Table 5.7 The optimum antenna HPBW for four beam suburban system.

Optimum HPBW	**A**	**B**	**C**	**D**
Urban	300	20	20	20

Also, the maximum SNR is 68.4655dB and average antenna gain is 19.2834 dB. Thus, the optimum antenna HPBW produces a high SNR comparing to the conventional system. Thus, the performance metrics of the proposed system is improved.

5.3.4.2 Eight beam system

The simulation results for eight beam suburban scenario are presented in Fig 5.15 and Table 5.8. The radiation pattern of the optimum antenna HPBW concentrates to a forward and backward beam. Because vehicle position probability in forward and backward directions are more than another points. Also, vehicles can communicate with a high SNR and high V2V link quality. The average antenna gain is 70.6812 dB. This is because the average antenna gain depends on the vehicle position probability. Then, six beam point to forward and backward position which are introduced for high vehicle locating on this point. Then, the average antenna gain is too high. Moreover, the maximum SNR is 119.8633dB.

Table 5.8 The optimum antenna HPBW for eight beam suburban system.

Optimum HPBW	A	B	C	D	E	F	G	H
Urban	30	30	90	30	30	30	90	30

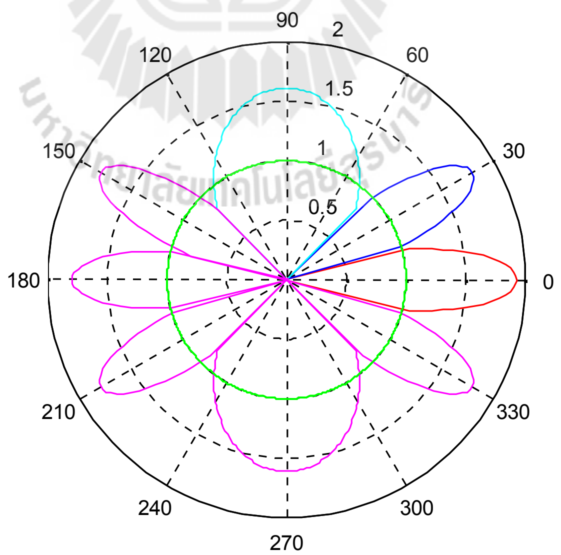


Figure 5.15 The radiation pattern of optimum HPBW for eight beam suburban system

5.4 Chapter Summary

This chapter introduces that the conventional switched-beam antenna system produced a fixed antenna HPBW. When vehicles change their positions, main beam directions are not proper for a communication link between vehicles. As a result, the received power level is reduced due to a main beam concentrating to undesired directions. Then, the system reliability in terms of BER and PER are increased. The indirect results are affected to the road safety. Thus, the consideration of optimum antenna HPBW determination for V2V communication is more important. Simulation results present the success of the proposed system. The average SNR increases. Then, other performance metrics of V2V link are increased due to the benefits of the proposed system. Also, applying the proposed system for V2V communication will enhance the system reliability and communication link quality using smart antenna with switched beam system.

CHAPTER VI

EXPERIMENTAL SETUP AND RESULTS

6.1 Introduction

The experiments and measurements of the proposed system are introduced in this chapter. Focusing on real life scenario, applying of the proposed system is important. The outcome of the proposed system increases road safety indirectly. Thus, applying of the proposed system in a real life is introduced. Focusing on the optimum antenna HPBW values, construction of optimum antenna HPBW is done by many techniques which produce the antenna HPBW corresponding to the optimum antenna HPBW values. Another method is corner reflector which is concentrated total energy to a given directions. Then, construction of optimum antenna HPBW is operated by corner reflector method presenting Balanish ***(2012)***. Computation of corner reflector structures is introduced. In addition, related devices are presented in this section. DSRC devices using in the experimental setup are chosen by Arada System Company. Locomate OBU/RSU are introduced for DSRC V2V/V2I applications which support IEEE802.11p WAVE-DSRC standard. Thus, the proposed switched-beam with optimum HPBW can be prepared using Locomate OBU and radio frequency switches. Beam switching system is made by Mini-circuits RF-Switch. Then, the mentioned devices are installed in vehicle. However, the limitation of eight beam system introduced the difficulty of system design and construction. The complexity of eight beam is too high. Thus, this work presents four-beam switched-beam system with optimum HPBW using Locomate OBU in urban road scenarios. The measurement results present the improvement of the communication link reliability. The measurement results confirm that the proposed system can improve DSRC V2V communication link performance.

6.2 Corner Reflector

After getting optimum HPBW values, another problem is the determination of antenna techniques which provide the antenna HPBW corresponding to the optimum HPBW values. Literature reviews introduce corner reflector for beam shaping method. The benefits of corner reflector are as the following:

A. Corner reflector aggregates the energy pointing to a certain directions.

B. Corner reflector is a simple construction method comparing with each other.

C. Corner reflector is widely used at the receiving side.

The dimension of a corner reflector is introduced in (6.1)-(6.3).

$$a < D_a < 2a \tag{6.1}$$

$$l \approx 2s \tag{6.2}$$

$$\frac{a}{3} < s < \frac{2a}{3} \tag{6.3}$$

Also, the method for antenna energy aggregation using corner reflector technique is presented. An important issue is dimension of corner reflector according to the specification of the proposed system. The operating channel is channel 172. Data dissemination of V2V message is the main task of channel 172. The operating frequency band of channel 172 is 5.860 GHz band. Then, the material selection for corner reflector is presented. The proposed system selected three material. Alumina with 99.6%, 96% of dielectric constant and PEC (Perfect Electric Conductor) have been explored. Moreover, simulation of material selection is introduced. Focusing on Table 6.1, the optimum antenna HPBW is 67 degree. Thus, the material producing the antenna HPBW closely to the optimum antenna HPBW has been selected. The simulation result presents in Fig. 6.1. The x-axis presents the variation of corner reflector angle (α). The variation of antenna HPBW produces by the proposed materials which presented in y-axis. Also, alumina with 99.6% of dielectric constant produces 67.2 degree of antenna HPBW. This antenna HPBW value is closely to the optimum antenna HPBW. Also, Alumina with 96% of dielectric constant has been chosen for the creation of corner reflector plate. Another significant issue is the dimension of the corner reflector. The dimension of the corner reflector is presented in Table 6.2.

Table 6.1 The comparison of corner reflector angle (α) when varying feed to vertex distance ($s = 0.55^{a}$)

Materials Types	Antenna HPBW (Degree)					
	α=0	α=30	α=45	α=60	α=90	α=180
Alumina 99.6% $\varepsilon = 9.9$	83.3	90.4	70.4	65.5	65.7	110.5
Alumina 96% $\varepsilon = 9.4$	83.3	87.9	67.5	**67.2**	68.2	108.1
PEC	83.3	39.5	43.7	57.1	62.3	107.3

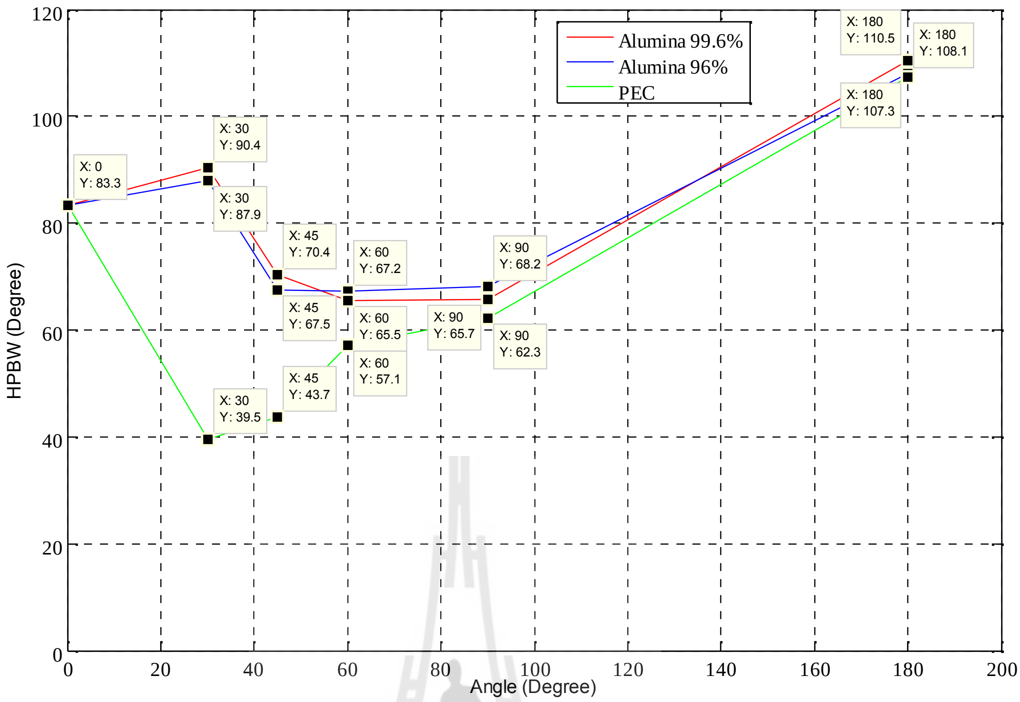


Figure 6.1 The comparison of corner reflector angle (α) and the antenna HPBW

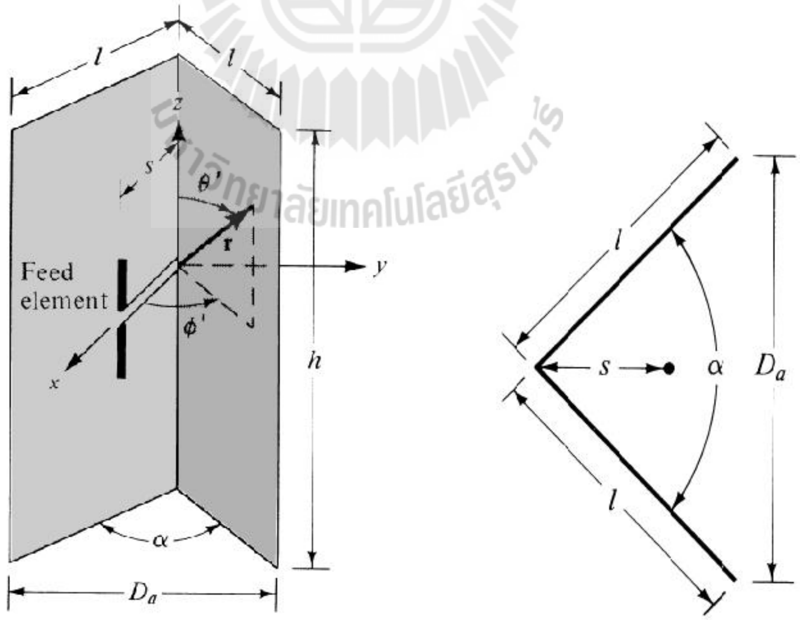


Figure 6.2 The dimension of the corner reflector.

Table 6.2 The dimension of corner reflector.

Parameters	**Values**
Size of aperture	$5.12(cm.) < D_a < 10.24(cm.)$
Length	$l \approx 4 - 6(cm.)$
Height	$h = 20(cm.)$

The illustration of the proposed corner reflector is presented in Fig 6.2. Also, the construction of corner reflector for four switched-beam system is introduced. Aluminum plate according to corner reflector dimension are applied in each antenna. Next, the radiation pattern measurement after applying corner reflector technique to the conventional system is presented. The radiation pattern measurement of the proposed system similar to the simulation result. Also, corner reflector confirms the applying of corner reflector technique for beam shaping method.

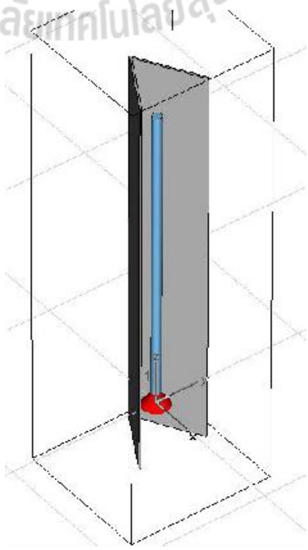


Figure 6.3 The prototype of a proposed corner reflector

6.3 DSRC V2V Devices

Focusing the DSRC device in the market, there are a few of DSRC manufacturers in the market. The vendors do not provide more information due to the secret of commercial products. As a result, the users cannot know a deep information about DSRC devices. Also. The above reasons introduces for the difficulty of DSRC device configuration. Thus, the determination of proper DSRC devices is the important issue. This work presents the comparison of DSRC devices in the market. Frequency band, Operating system and specifications of DSRC devices in the market are investigated. The specifications of DSRC devices are presented in Table 6.3. The requirement of DSRC devices is devices working under IEEE802.11p standard. The devices are operated on Linux operating system. The device is controlled by the engineer. The radio engineer can configure and change their parameters.

Figure 6.4 Mini-Circuits USB-RF switch (USB-1SP4T-A18)

Figure 6.5 Locomate OBUs (DSRC devices)

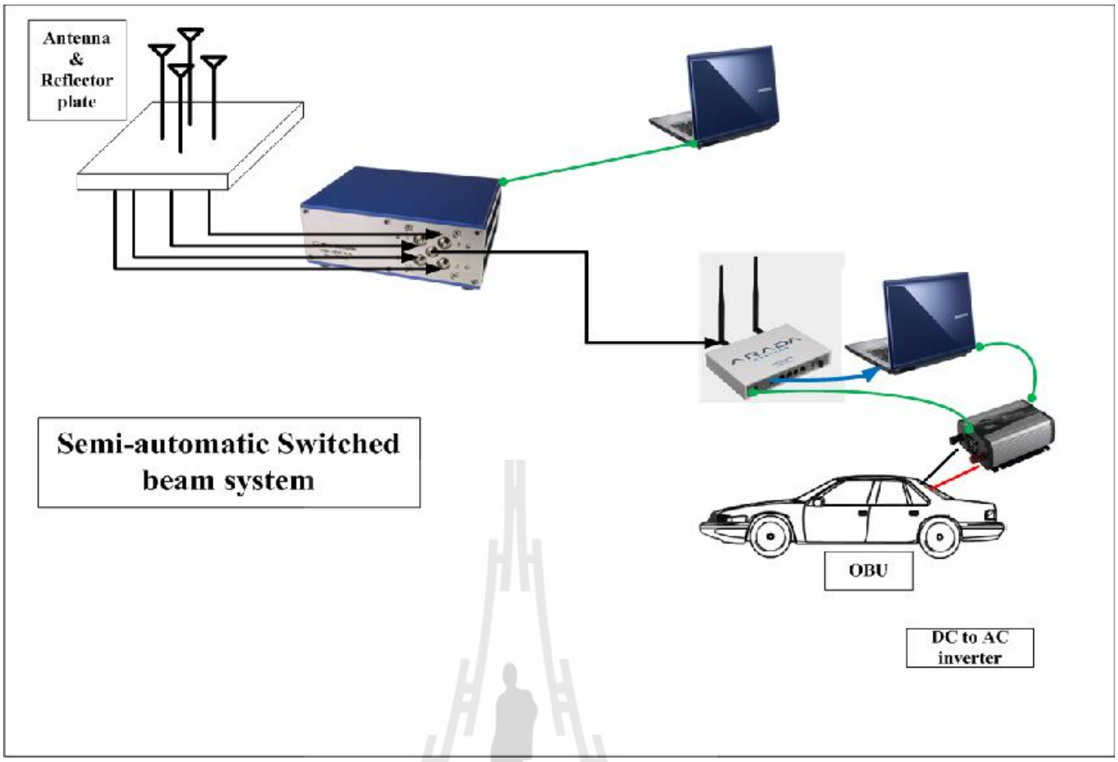


Figure 6.6 Semi-automatic switched beam system

Moreover, devices can configuration as OBU installing on the dashboard of a vehicles. Arada devices are selected for experimental setup. More details of DSRC devices and costs are presented. Arada Locomate OBU is presented in Fig. 6.5. Arada system manufacturer is well known in the market. All of DSRC devices are based on requirements of small, simplest and effective experimental setup.

6.4 Beam Switching System using RF Switch

Beam switching mechanism is provided by USB-RF switch device which is introduced in Fig.6.4. The connection between USB-RF switches and Arada Locomate devices are connected by RG-316 cable. Focusing on USB-RF switches, the RF-switches can provide four input ports and one output port. Radio engineer controls USB-RF switches via personal computer for beam selection mechanism. Firstly, radio engineer adjusts the sequence of USB-RF switches. The switching interval is configured via personal computer. In addition, the input signal information transmitting pass to the output port and delivering to Arada Locomate OBU. Next, the RSSI of the each beam is collected. Finally, maximum RSSI is determined. Then, maximum RSSI has been selected for DSRC V2V data dissemination. Due to the limitation of DSRC devices that provide a closed-source code application then the configuration of switched beam system can be applied into semi-autonomous beam switching. The semi-automatic beam switching system is presented in Fig.6.6. Corner reflector plates integrated with the monopole antennas. The corner reflector is located on Acrylic plate. Then, the connection between switched-beam antenna system and USB-RF switch are made by RG316 cables. USB-RF switch connects with the personal computer. The personal computer controls beam switching mechanism. In the first time, personal computer orders USB-RF switch for port selections process. Next, ports selection are occurred. The measurement of RSSI value is occurred when input port and output port are connected. Then, second personal computer requests RSSI value from Arada Locomate OBU. The same process completely occurs at port

Table 6.3 The comparison of DSRC devices from the manufacturers in the market

No.	Vendors	Frequency	Std. support	GPS	OS	SDK
1	Arada Locomate OBU, RSU Locomate ME	5.9 GHz	IEEE 802.11 a/b/g/n, IEEE 802.11p, IEEE 1609.3, IEEE 1609.4	Yes	Linux Andriod	Yes
2	NEC	5725MHz(14 5CH)	mini-PCI 8 02.11a/b/g/p.	Yes	Linux	NEC C2X-SDK

No.	Vendors	Frequency	Std. support	GPS	OS	SDK
		5925MHz(185CH)	802.11p D3.0, 22 dBm maximum transmit power			
3	Savari Mobiwave (ASD)	2.4- 5.9 GHz	IEEE 802.11 a/b/g/n, IEEE 802.11p, IEEE 1609.3, IEEE 1609.4	Yes	Linux	libraries and header files for WAVE, IP, Web, GPS, Bluetooth,
4	Cohda Wireless MK2 WAVE-DSRC Radio	USA: 5850 MHz – 5925 MHz Europe: 5875 MHz – 5905 MHz	IEEE 802.11p RF/PHY/MAC	Yes	Linux	-
5	Unex	USA: 5850 MHz – 5925 MHz	IEEE 802.11p, IEEE 1609.3, IEEE 1609.4	Yes	Linux	SAE J2735 compliance SDK

number four. Also, the beam selection is process chosen the beam which produced maximum RSSI for V2V data dissemination.

6.5 Radiation Pattern Measurement of the Proposed System

The previous section introduced the devices and system configuration. This section introduces the measurement of the radiation pattern measurement of the conventional devices and the proposed devices. This work focuses on azimuth antenna HPBW or H-plane. Then, the elevation plane radiation pattern is not determined. In the first, the radiation pattern measurement of conventional V2V antenna is presented. The experimental setup follows IEEE802.11p standard. The operating frequency is 5.86 GHz channel 172 which provides a communication in V2V applications. The radiation pattern measurement is measured in Anechoic chamber room at Wireless communication research and Laboratory, F4 buildings, Nakornratchasima, Thailand. Focusing on the radiation pattern measurement, the conventional antenna is measured to confirm the capability of the antenna corresponding with the datasheet. Thus, the azimuth antenna HPBW is presented in Fig. 6.7. The AUT antenna is steered over 360 degree. S21 scattering parameters are collected in each steering angles.

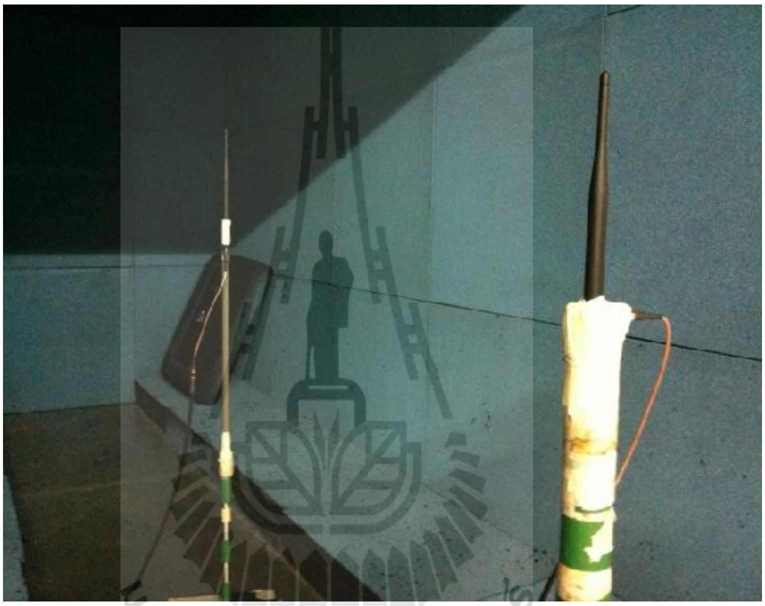
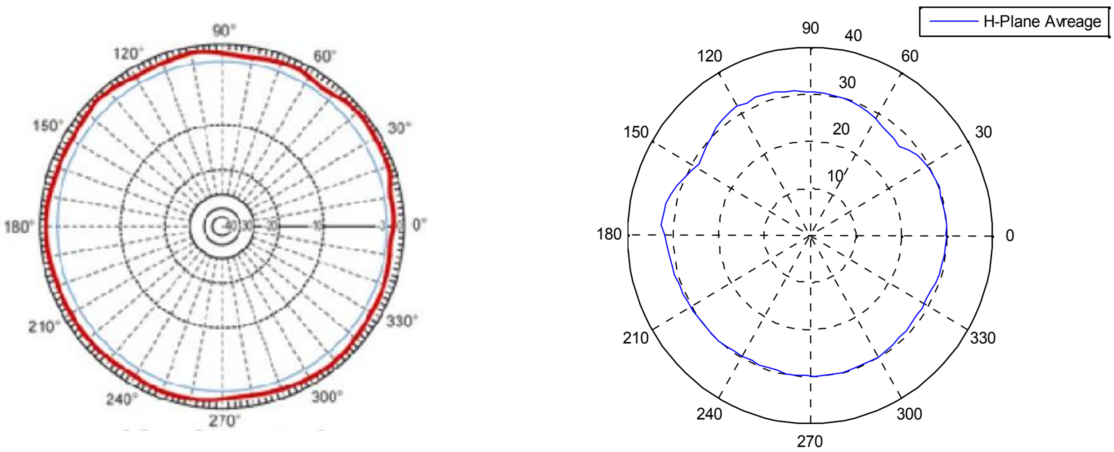


Figure 6.7 H-Plane Radiation pattern measurement



a) Antenna pattern from datasheet b) Antenna pattern from measurement

Figure 6.8 Azimuth radiation pattern

Also, comparison of antenna radiation pattern measurement between information from datasheet and real measurement is presented in Fig 6.8. The radiation pattern measurement introduces that antenna coming with Arada devices produces the radiation pattern similarly to the information from datasheet. Omni-directional radiation pattern is produced by the conventional V2V antenna. Next, the radiation pattern of elevation plane measurement is presented.

Figure 6.9 E-Plane Radiation pattern measurement

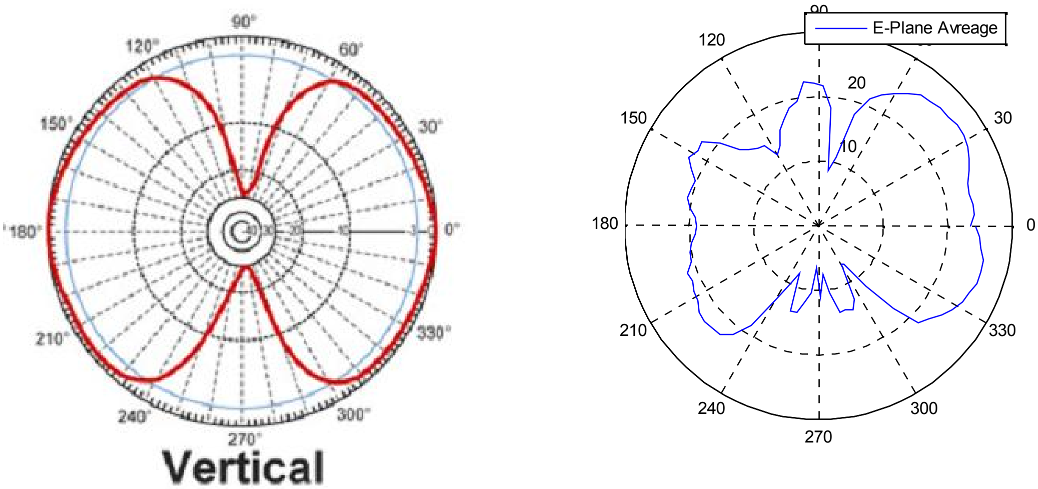


Figure 6.10 Elevation radiation pattern

The configuration of E-plane radiation measurement is presented in Fig.6.9. AUT antenna is steered from 0 degree to 360 degree with 5 degree step size. S21 is the measurement value. The results are measured via Vector Network Analyzer. Thus, S21 are plotted to present the elevation antenna radiation pattern. The elevation radiation pattern is shown in Fig.6.10. The left side introduces the radiation pattern of the antenna coming with Arada deivces. The measurement results in the right side introduces the radiation pattern of Arada devices. Thus, the radiation pattern measurement of the antenna coming with Arada devices can produce antenna radiation pattern corresponding to the datasheet.

Figure 6.11 The configuration of the proposed system with optimum antenna HPBW.

The previous mentioned introduced for the measurement of conventional antenna radiation pattern. The measurement results indicate capability of conventional antenna that produces omni-directional radiation pattern in azimuth plane. Focusing on the proposed system, the optimum antenna HPBW can be produced by many antenna techniques which provide antenna HPBW corresponding to the optimum value. The benefits of corner reflector introduced the applying of corner reflector for the conventional antenna. Then, the measurement of applying corner reflector with the dimension according to the optimum antenna HPBW produce the radiation pattern similarly to the simulation results. Then, the signal power level aggregate into the desired directions.

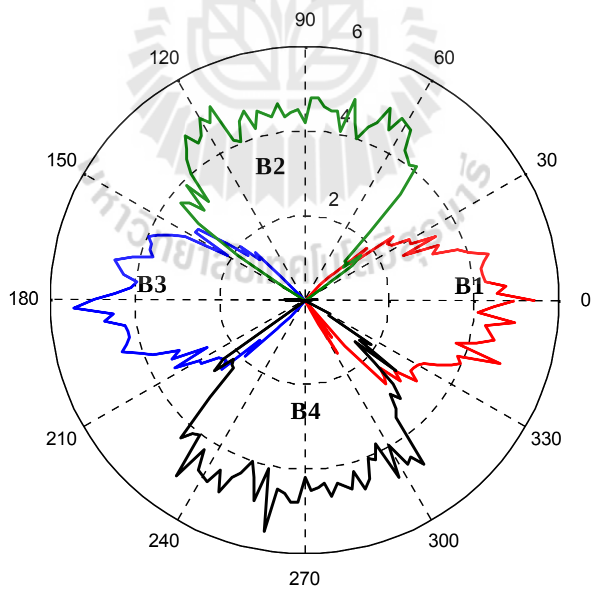


Figure 6.12 Four beams switched-beam radiation pattern

Figure 6.13 The experimental setup a) conventional system b) the proposed system

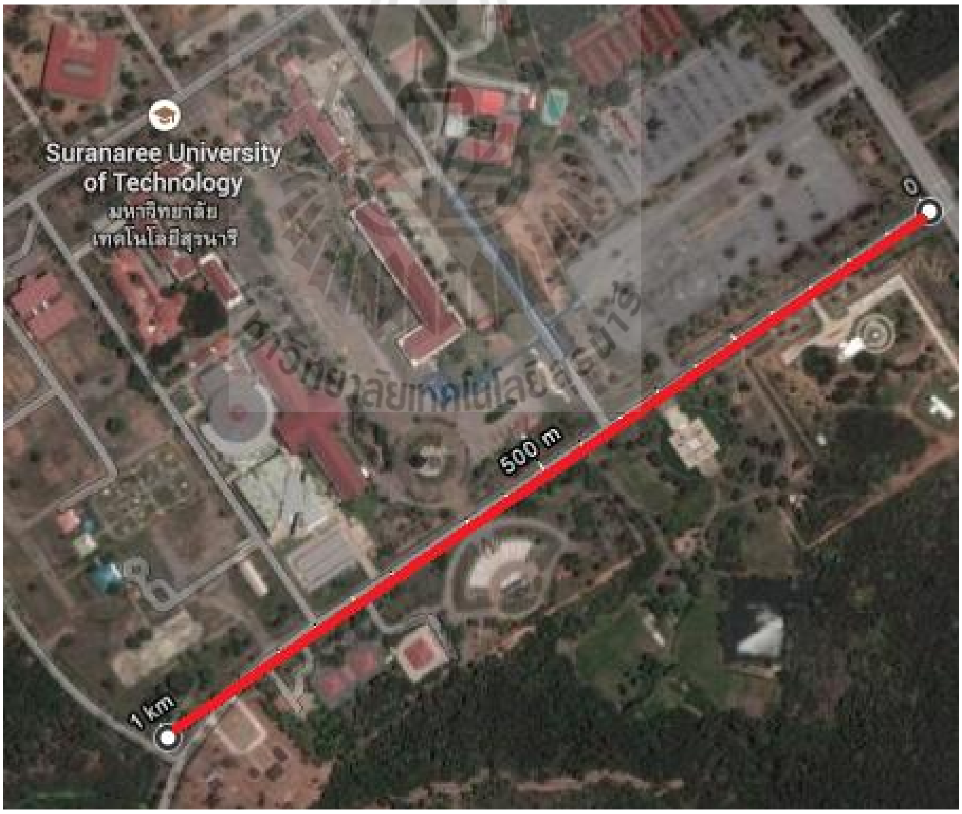


Figure 6.14 The experimental location

Also, four beam switched-beam system are applied due to the capability of corner reflector and USB-RF switch. The radiation pattern of the proposed system is presented in Fig 6.12. The optimum antenna HPBW are presented as following: 67, 113, 67 and 113. Next, the proposed system can produce the optimum antenna HPBW value then the applying into the experiment is more attractive. The next section will introduce the experimental setup and system configuration.

6.6 Measurement setup, OBU installation and Device Configuration

The measurement setup of the proposed system is explained in this section. First of all, the measurement setup and system configuration follow IEEE802.11p WAVE-DSRC standard. The operating frequency is 5.86 GHz in channel 172 for public V2V communication. Two OBUs from Arada Company are chosen. OBUs are installed inside transmitting and receiving vehicles. Transmitting vehicle is called Provider. Receiving vehicle is called User. An antenna having omi-directional radiation pattern is integrated to the Provider. Then, V2V messages are disseminated in all directions. Then, User equipping with an antenna having omni-directional radiation pattern can sometime receive undesired signal. As a result, V2V communication link performance is decreased such as low receiving power (RSSI), high BER and PER and other performances which degrade V2V communication. Also, the result from the user equipping with an antenna having omni-directional radiation pattern introduces the attractiveness for V2V communication link enhancement. Thus, four beam switched-beam system has been proposed for the solution. The proposed system is installed at the user. Locomate OBU is installed on the roof of receiving vehicle according to Fig.6.13. The experimental is only measurement in urban area road. Four beam switched-beam system is considered due to the limitation of USB-RF switch. The experimental is occurred at Suranaree Universisty of Technology, Nakornratchasima, Thailand. Focusing on the measurement parameters, the measurement of RSSI at the receiving vehicle are measured. The objective of the measurement is the experimentation of the proposed system which increases V2V communication link performance and reliability. In the first time, RSSI performance of the proposed system are measured. The experimental is separated into two scenarios: static and dynamic situations. The experimental setup configured as two vehicles following in the same lane according to static scenario. Forward vehicle is configured as receiving vehicle (User) which is equipped with the proposed system. Backward vehicle is configured as transmitting vehicle (Provider). V2V message size is configured as 512 bytes. Switched-beam antenna system steers the beam every 100ms from beam B1 to beam B4. This is because the switches time relates to channel switching time of DSRC standard. OBU connects with host computer which is hold the maximum RSSI. As a result, the receiving vehicle can also receiving a good signal quality due to the manner of SWB mechanism. However, when the vehicle moving out of the communication rage, the communication link between two vehicles discard. Finally, the SWB system start for a new process but using the same procedure. RSSI of the reeving signal have been collected 5 times per position. The results of experiments are presented in the next section.

6.7 Experimental Results

To confirm the successful of the proposed system then determination of best beam is investigated. The best beam produces a highest RSSI. The highest RSSI introduces for a high quality and high performance of V2V data dissemination. Focusing on Table 6.4, the best beam is occurred at Beam B1. The communication scenario is the forward vehicle equipping with switched-beam antenna. Beam B1 directly steers to the transmitting vehicle. Also, Beam B1 can receive for more RSSI comparing to other beams. The measurement result is present in Fig.6.15. The measurement result indicates that beam B1 introduces a highest average RSSI. When the distance between vehicles is increased then average RSSI decreased. However, beam B1 provides a highest average RSSI until the vehicle going out of the communication range. Also, when the communication link has been discard, the new operation of best beam determination is occurred.

Table 6.4 Best beam determination

Distance (m.)	Average RSSI (dBm)				
	Omni directional	***Beam B1***	**Beam B2**	**Beam B3**	**Beam B4**
200	-77.3	***-73.7***	-75.7	-74.9	-75.7
400	-79.3	***-75.7***	-76.9	-76.8	-76.8
600	-81.3	***-77.7***	-78.7	-78.7	-78.7
800	-83.3	***-78.7***	-79.8	-79.6	-79.2
1000	-85.3	***-81.7***	-85.7	-84.7	-82.7

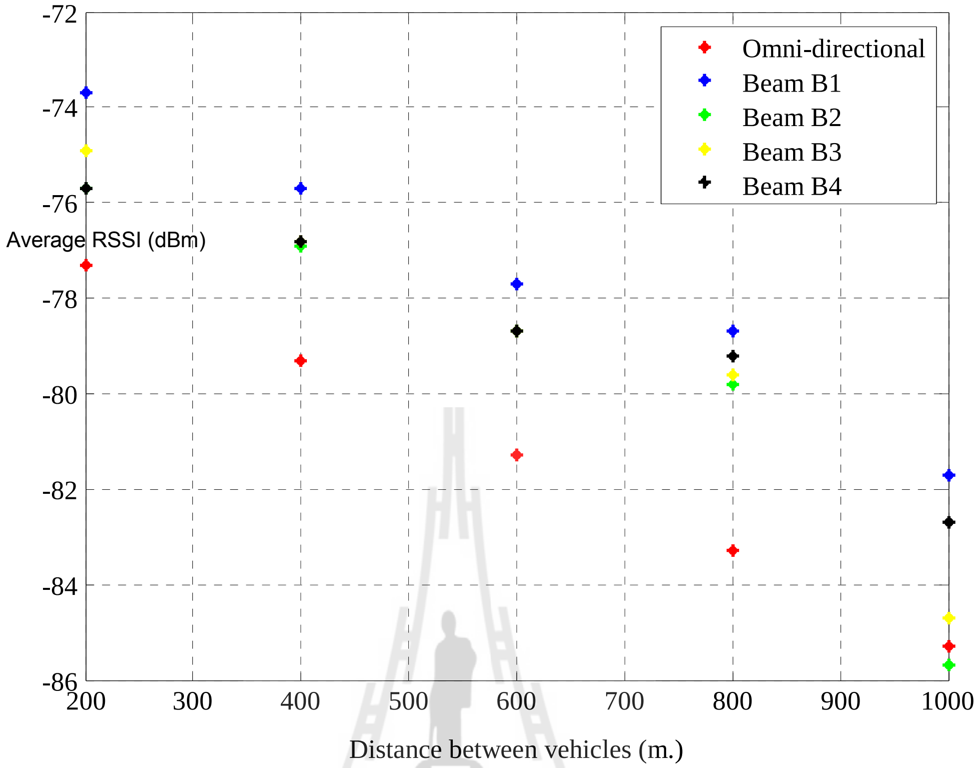


Figure 6.15 Best beam determination: Tx and Rx are in the same lane.

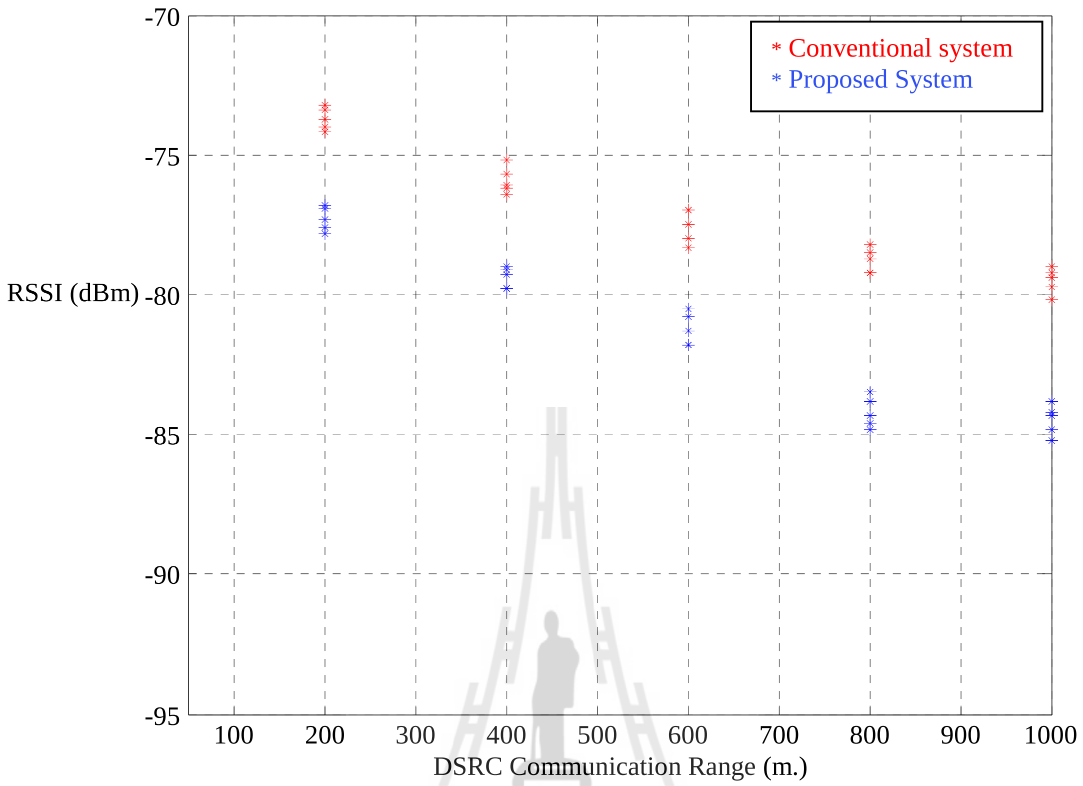


Figure 6.16 The comparison of RSSI between conventional system and the proposed system

Next, comparison of RSSI at the receiving vehicle between conventional system and the proposed system is presented in Fig.6.16. Switched-beam system with optimum antenna HPBW provide the highest RSSI comparing to conventional system. Focusing on the maximum communication range at 1000m., the proposed system with best beam received highest RSSI about -3.6 dB more than conventional system. The increasing of RSSI at receiving vehicle introduces the improvement of V2V communication link. Also, performance of V2V communication in terms of RSSI has been enhanced by the proposed system. Another significant performance metric is the average signal to noise ratio. The experiment is measured the noise power level. The average noise power level is about -95 dBm at the measurement location. Also, the average SNR can be determined. Moreover, the average SNR can be fed into the BER and PER calculation. The literature reviews introduced that BER and PER refer to V2V communication link reliability. The lowest BER and PER present a high performance V2V link. Also, BER is calculated by (4.18). In addition, PER is computed using (4.19). The performance in terms of BER is presented in Fig.6.17.

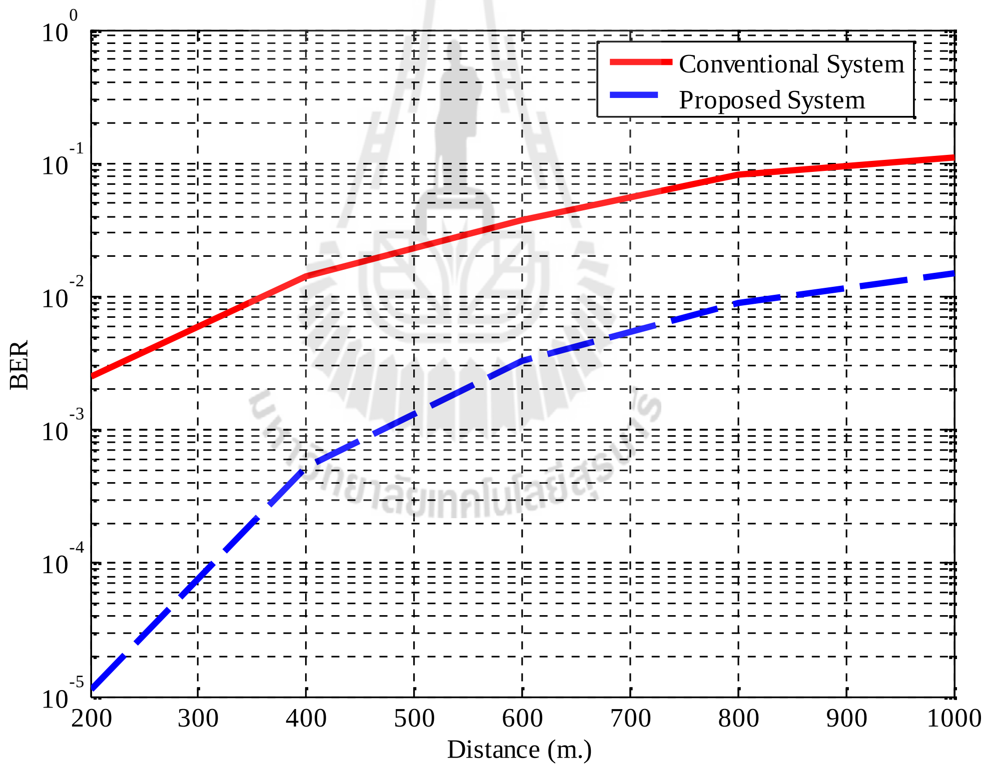


Figure 6.17 The comparison of BER performance between conventional V2V and the proposed system.

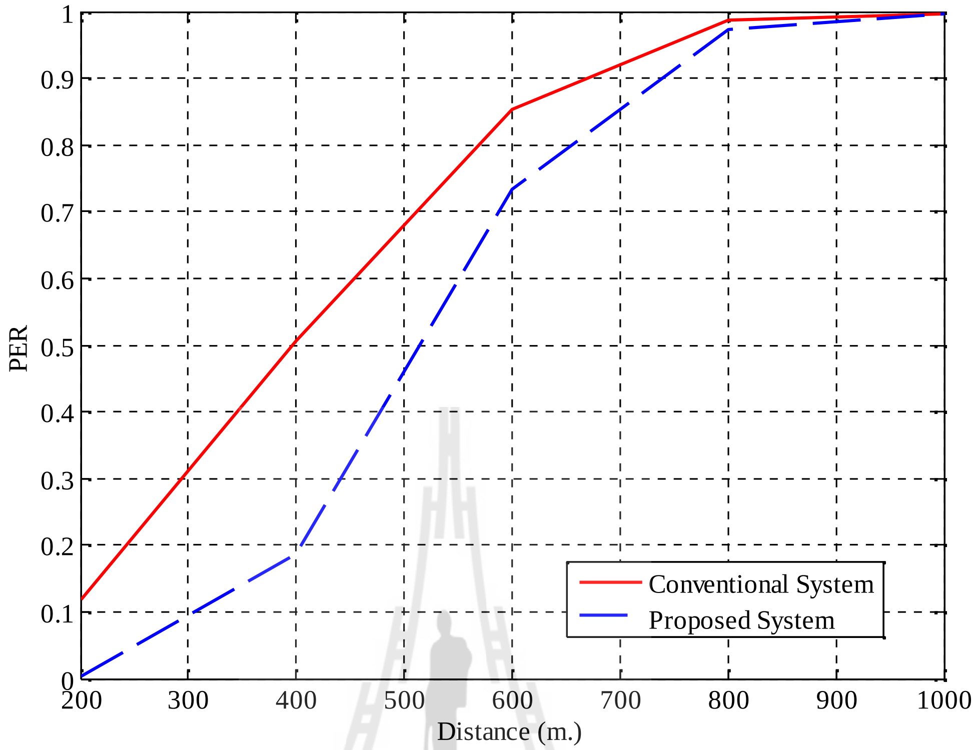


Figure 6.18 The comparison of PER performance between conventional system and the proposed system.

BER performance of the proposed system is lower than conventional system. Focusing on 1000m distance between vehicles, the transmitting bit is 4096 bits. Then, conventional system produces 446 bits error comparing to the proposed system which produces 61 bits error. Thus, V2V message dissemination with low bits error introduces for high reliability of a commination link. The increasing of road safety due to vehicle receiving a high correct received packet introduces the road safety enhancement. Focusing on the PER performance, the conventional system

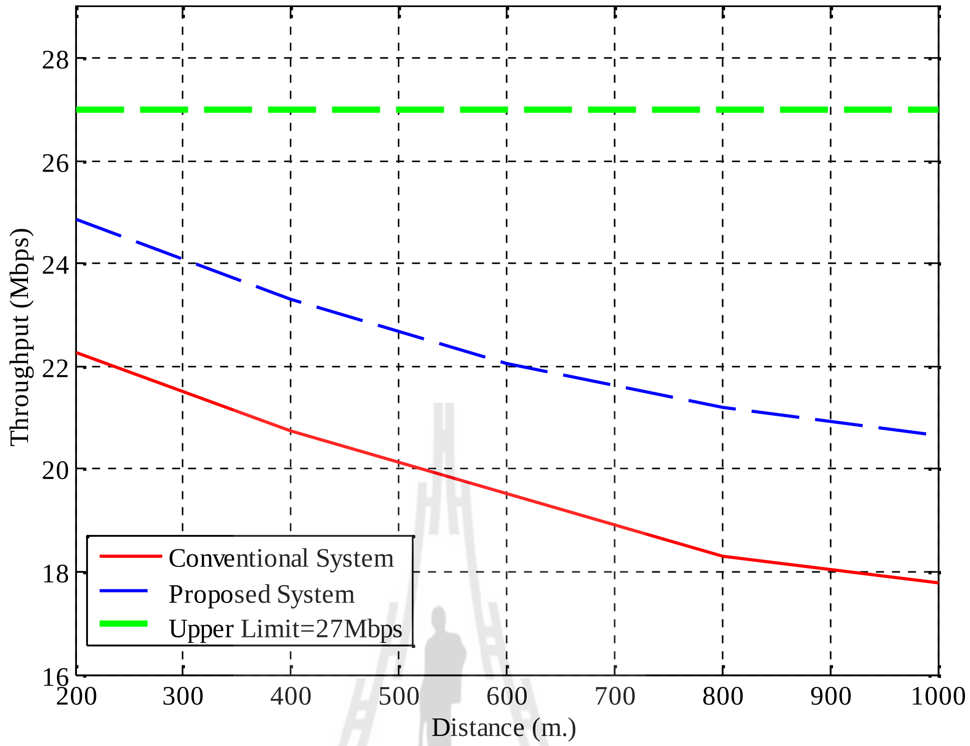


Figure 6.19 The comparison of DSRC throughput between conventional system and the proposed system .

provides a higher PER performance comparing to the proposed system. PER performance is presented in Fig.6.18. Assuming V2V transmit 100 packets, the conventional system produces 19 packets error at 400m of a distance between vehicles. As a result, receiving high packets error increases the chance of an accident. Because receiving vehicle sometime receives error information that effect to the decision making. Moreover, the throughput of the proposed system is higher than the conventional system. This result indicating a huge message can transmit in a fast period.

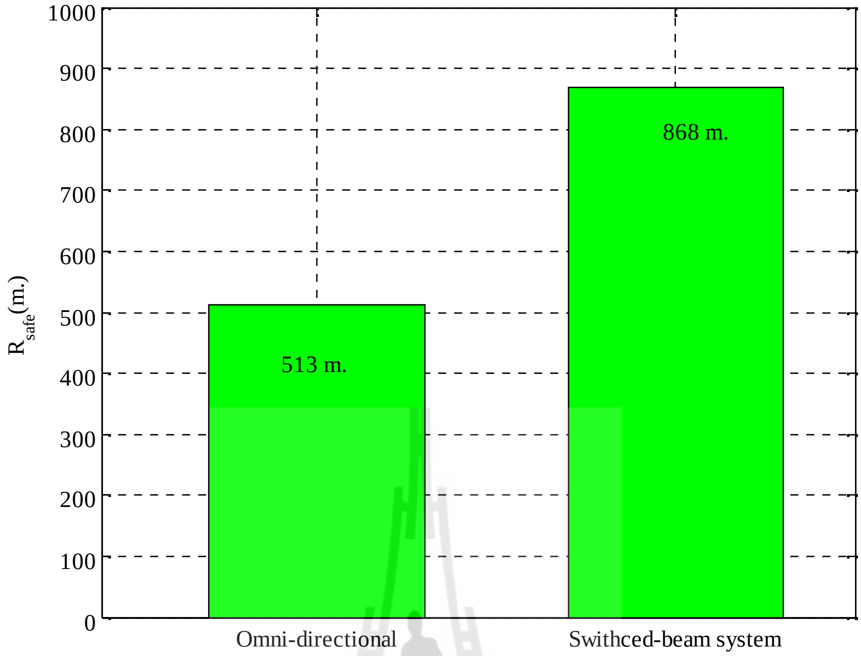


Figure 6.20 The comparison of R_{safe} between conventional and proposed system.

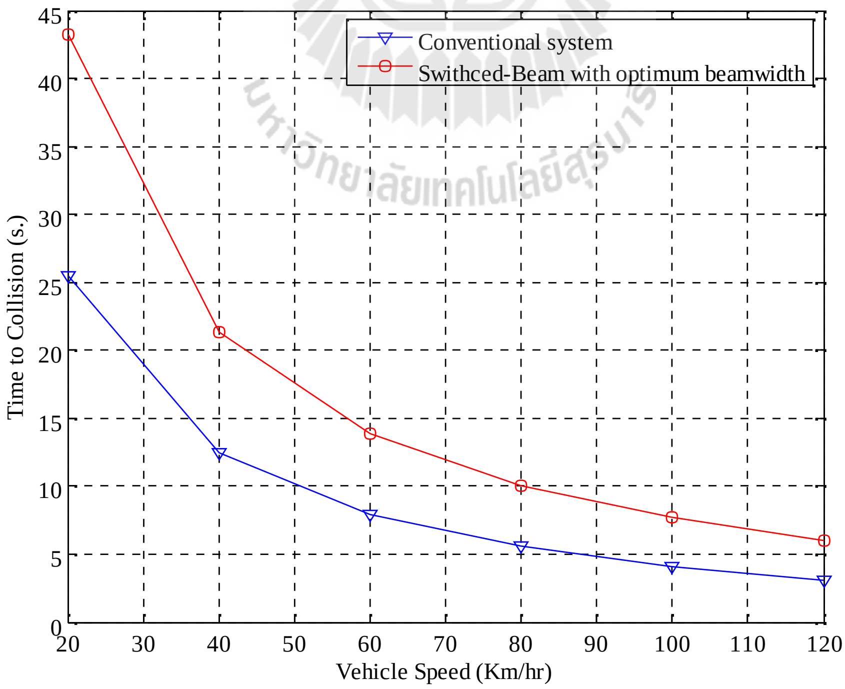


Figure 6.21 The comparison of T_{safe} between conventional and proposed system.

This result supports the major requirement of V2V communication under a low latency. However, the experimental results present in static environment. Transmitter vehicle is fixed position. Receiver vehicle varies position from 200 – 1000m. for collecting RSSI performance. Focusing in V2V communication, vehicles communicate to each other when moving with a high speed. Thus, dynamic environment is introduced.

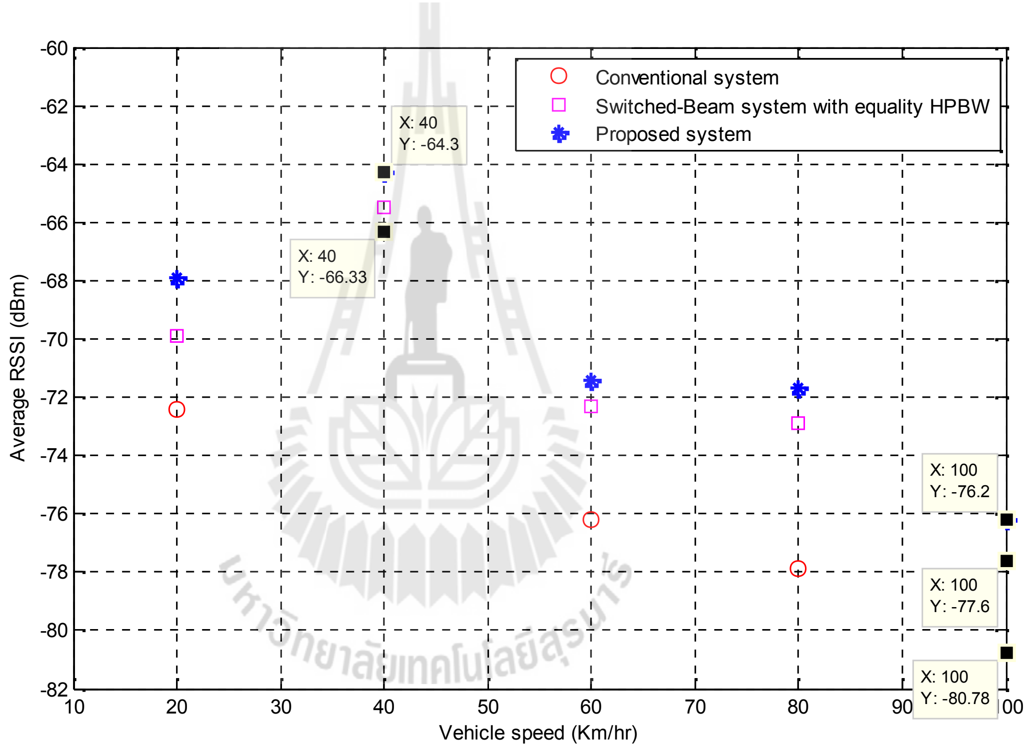


Figure 6.22 The comparison of average RSSI versus vehicle speed in dynamic environment.

The experimental in dynamic environment is presented in this section. Transmitter vehicle travels with 20 km/hr. The receiver vehicle varies speed from 20 km/hr to 100 km/hr. Then, RSSI performance are collected. The experimental of dynamic scenario is introduced. Two lanes road in urban area is the experimental location. Transmitter and receiver vehicles are in the same lane. Receiver vehicle speed varied from 20 km/hr to 100 km/hr. Maximum vehicle speed in urban are is not exceed 60 km/hr. However, to confirm the success of the proposed system, 100 km/hr is investigated to study performance of communication link when vehicle moving with high speed. In addition, performance metrics include with RSSI, BER, PER and communication delay time.

Focusing on average RSSI performance presenting in Fig. 6.22, maximum average RSSI appears at 40 km/hr vehicle speed. At 40 km/hr of receiver vehicle speed, receiver vehicle is near transmitter vehicle. Then, RSSI increases when two vehicles travelling closely. Then, other performance metrics including with BER, PER, Communication delay time are investigated in offline mode. A communication delay time is introduced in Fig.6.25. A result indicates the enhancement of V2V communication link. The proposed system produces a lowest communication delay time. Low communication delay time producing a huge warning message disseminate in a short period. Also, receiving warning message in a short period indicate that driver gains more preparation time before approaching the accident area. Moreover, correct warning message reception at the receiver vehicle is improved by the proposed system. Traffic safety increases with the successful of the proposed system.

Focusing on BER and PER performance introducing in Fig.6.23 and 6.24, BER of the proposed system is lowest when comparing to conventional and switched-beam system with equality HPBW. Assuming 1000 bytes of warning message size, conventional produces 5 bits error. Focusing on 5 bits error, if 5 bits error is significant bit in transmission packet then incorrect warning message reception at the receiver vehicle increase. Also, incorrect warning message reception introduces a wrong driver decision making. Then, a chance of accident increases. Traffic safety is reduced due to high BER. However, the proposed system produces a low bit error rate.

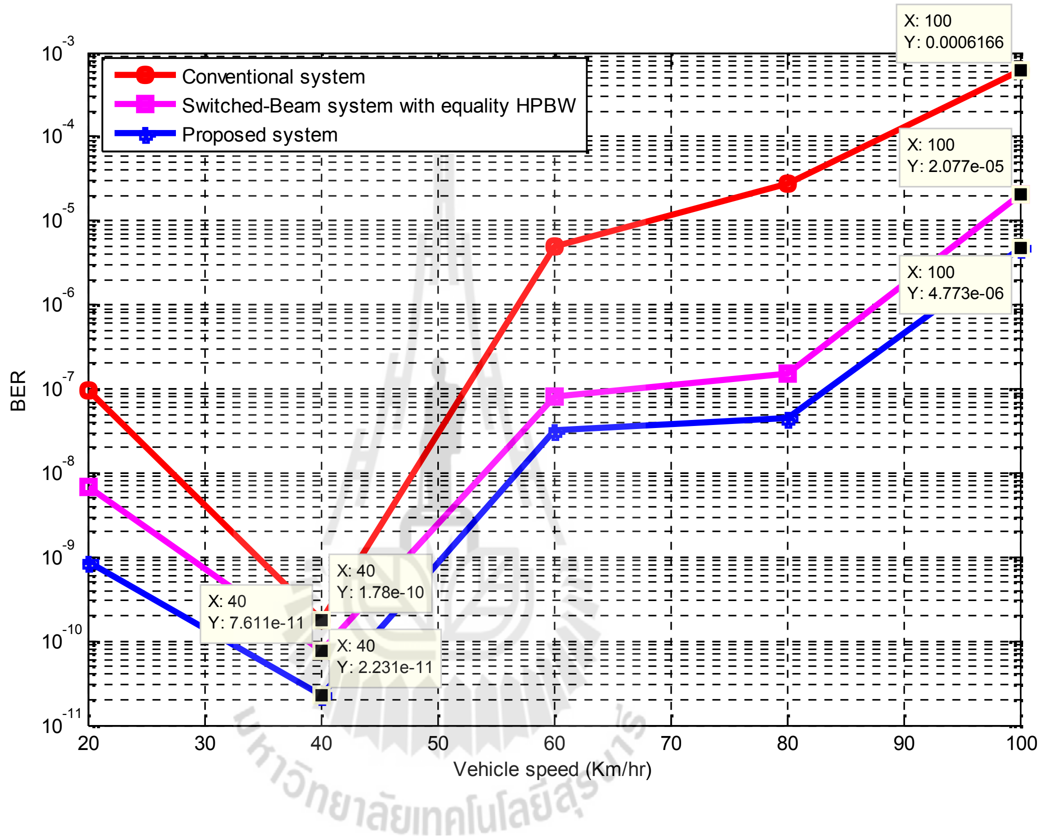


Figure 6.23 The comparison of BER versus vehicle speed in dynamic environment.

Focusing on V2V safety application, the proposed system increases correct warning message reception. Then, traffic safety improves due to the increasing of message reception with low BER. However, BER and PER are improved when using the proposed system. The experimental results indicate the enhancement of V2V performance metrics when using the proposed system. However, the comparison of the proposed system and switched-beam equality HPBW introduces tradeoff between two systems. Focusing on safety applications, the proposed system provides high performance of V2V communication link. Then, traffic safety increases due to a high correct warning message reception.

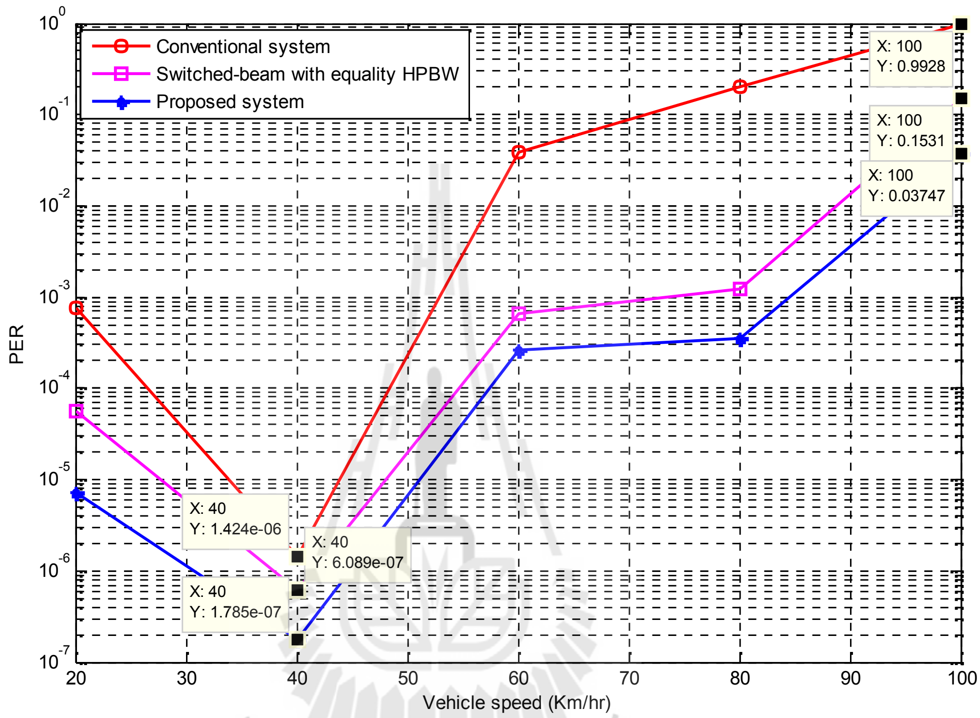


Figure 6.24 The comparison of PER versus vehicle speed in dynamic environment.

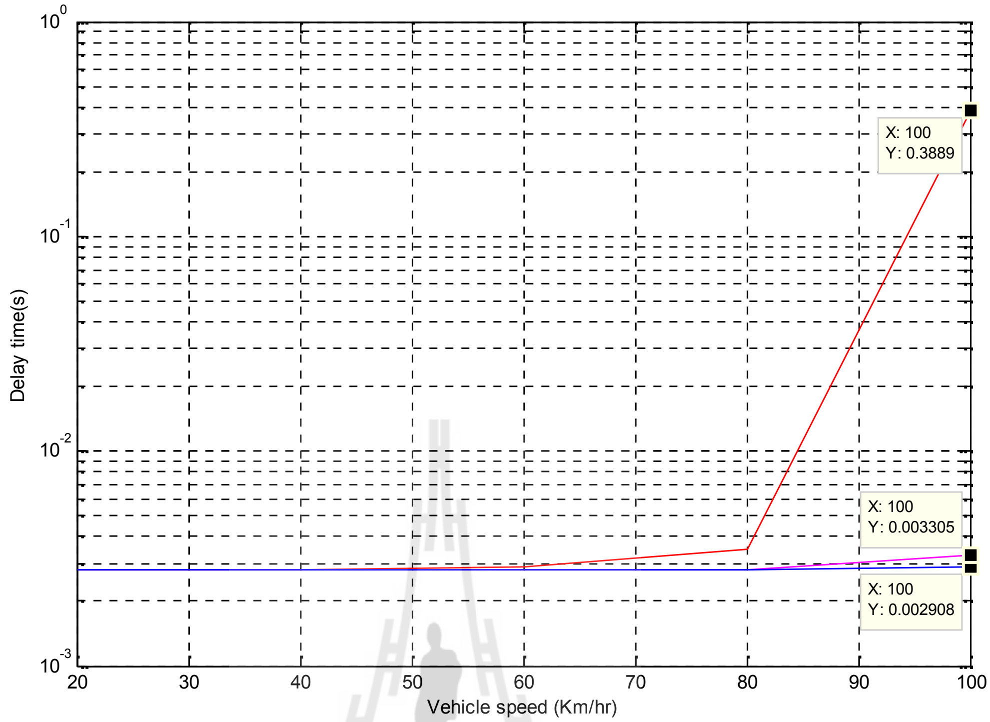


Figure 6.25 The comparison of Communication delay time versus vehicle speed in dynamic environment.

Focusing on a low distance between vehicles, Fig. 6.26-Fig.6.27 present the relationship of RSSI at the designing point and BER versus distance between vehicles. Low distance between vehicles at the designing point indicate a highest RSSI and lowest BER. Because the optimum value occurs in this point. Thus, using the proposed system at the mentioned points produce a highest V2V communication link performance.

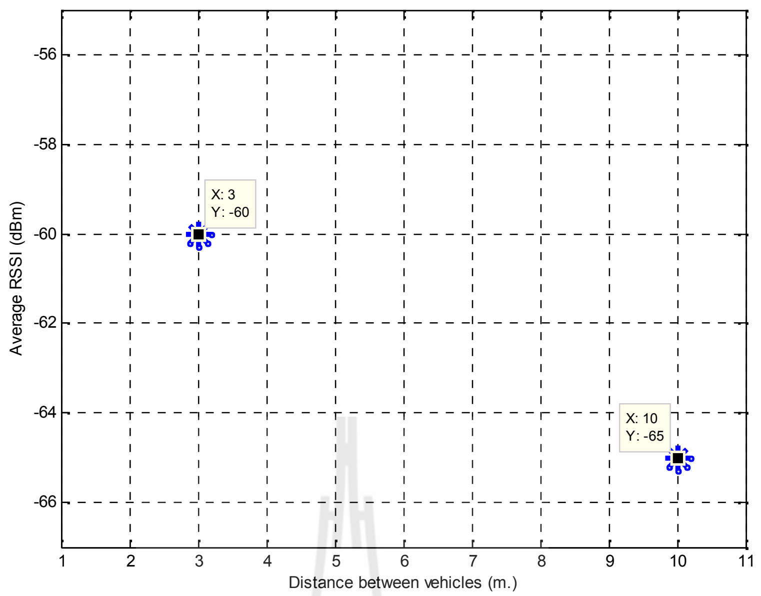


Figure 6.26 The comparison of RSSI versus distance between vehicles when using the proposed system at the designing point.

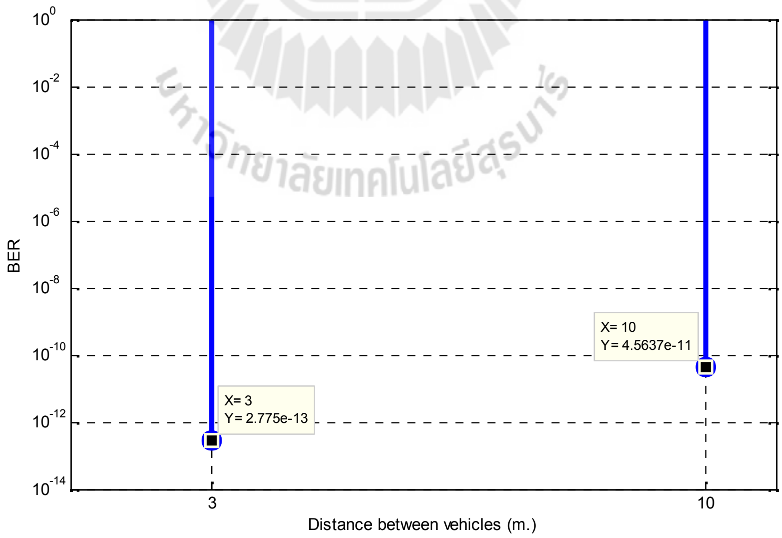


Figure 6.27 The comparison of BER versus distance between vehicles when using the proposed system at the designing point.

6.8 Contributions

The contributions of this work are described in this section. The powerful of switched-beam antenna system with optimum antenna HPBW increases road safety indirectly. Focusing on V2V applications, when vehicles receive a warning message with a high range then the drivers can prepare for a bad situation on the road. As a result, the increasing of safety duration introduces the increasing of traffic safety which corresponded to the main idea of ITS/DSRC.

Focusing on R_{safe} performance, safety distance introduces that the increasing of a communication range with following the main requirements such as PDR and PER performance metric enhancing road safety indirectly. Safety distance is the distance that provides 90% of PDR. IEEE802.11p standard defined PDR for a high reliability. Because V2V safety message dissemination affects to the human live. The safety distance is presented in Fig.6.20. Also, the proposed system can receive message longer than conventional system about 555m. Moreover, another performance metric is time to collision (T_{safe}). The time to collision is presented in Fig.6.21. The measurement is operated in urban road. Focusing on 60 km/hr, the proposed system has 13.87 seconds for the preparation of a bad situation. The drivers can break or change their positions to avoid the situation on the road. Also, the results indicate the success of applying optimum HPBW to switched-beam system in V2V communication. The road safety indirectly increase. Thus, the results indicate the proposed system enhancing V2V communication link performance and reliability.

6.9 Chapter Summary

The applying of the proposed system in real measurement is important. The measurement of RSSI introduces that the proposed system enhance the communication link in V2V environments. Arada Locomate OBU has been chosen for the experimental setup. Because the devices operate under IEEE802.11p DSRC standard. Corner reflector has been chosen for the production of antenna HPBW according to the optimum HPBW. USB-RF switch changed the input port and output port according to the time sequence adjustment. Then, the received signal is fed into Locomate OBU. The performance metrics of DSRC V2V link have been enhanced due to the benefit of the proposed system. The communication with the best beam introduces a good quality of V2V commination link. Finally, the measurement results indicate the success of applying optimum HPBW consideration for switched-beam antenna system in V2V communication.

CHAPTER VII

THESIS CONCLUSION

7.1 Conclusion

Optimum antenna HPBW determination has been proposed. The optimum antenna HPBW is gathered by the determination of maximum SNR which is produced by appropriate beam directly steering to vehicles on road. Then, proper antenna HPBW and correct beam introduce RSSI improvement. As a result, performance metrics inside receiving vehicle can be enhanced due to receiving only desired signal. Friis transmission equation is important for the determination of optimum antenna HPBW. The received power can be increased due to the improving of antenna gain. Focusing on transmitting side, transmitting antenna uses antenna having directional radiation pattern. Then, the antenna gain is constant. Receiving antenna can be many types but increasing receiving antenna gain. Due to drawbacks of conventional V2V system, an antenna having omni-directional radiation pattern installed and disseminating V2V safety message for all directions. Thus, signal power losing in undesired directions is occurred. Then, the received signal power at receiving vehicle is reduced. Also, signal quality is decreased. The simulation results and experimental results introduce the determination of V2V enhancing technology in terms of antenna technique. Thus, an antenna having directional radiation pattern is introduced. The main beam is concentrated to a certain object. Then, the signal power at receiving vehicle is increased. Then, other performances metrics are improved. However, an antenna having directional radiation pattern cannot be used in some application that is required for forward and backward beam communication simultaneously. Thus, other antenna technique is presented. The interested antenna technique is smart antenna. Smart antenna produces more benefits. Smart antenna steers the main beam to desired directions. The main beam producing maximum received signal power has been selected for data dissemination. Smart antenna system is separated into two major types: Adaptive Array and Switched beam system. Adaptive array system required for the intelligence processing unit this is because the adaptive array send a feedback bit from receiver to transmitter for the adjustment of transmitting signal. Also, the adaptive array system required for more processing time. Focusing on V2V communication, a small latency is the major requirement. V2V message disseminating to other vehicle in a short period increases driver reaction time. Also, the road safety is occurred due to V2V message dissemination in a short period. Thus, adaptive array is not proper for V2V communication. Thus, switched-beam system is another technique for the enhancement of V2V link quality. Switched-beam system does not transmit a feedback control bit to transmitter. Then, the system does not require more intelligent signal processing units. Thus, switched-beam system is appropriate for V2V data dissemination. Steering main beam to a desired direction and the determination of maximum RSSI are the benefits of switched-beam system. Then, signal quality at a receiving vehicle is improved. However, the literatures introducing that antenna HPBW is another significance parameter. The antenna gain depends on antenna HPBW. A wide HPBW provides a low antenna gain. As a result, the coverage range is reduced. In other words, a narrow HPBW provides high coverage range. Moreover, the consideration of antenna HPBW is separated into two main planes:

azimuth and elevation planes. However, this work focuses on azimuth plane. Because the distance between vehicle of V2V communication is short. Then, the adjustment of elevation antenna HPBW provides a small effect for V2V communication performance. Hence, this work focuses on azimuth antenna HPBW optimization. The average antenna gain has been determined. The antenna HPBW value appears in antenna gain function. Moreover, vehicle position on the road is fed into average antenna gain calculation. In addition, the average SNR is calculated. Then, optimization process is started. The antenna HPBW values providing a maximum average SNR present the optimum antenna HPBW. Thus, V2V communication link installing the proposed optimum antenna HPBW produce the enhancement of V2V communication link in terms of average antenna gain, average SNR, BER and other performance metrics. The simulation results introduce the successful of applying the proposed system to V2V communication. R_{safe} and T_{safe} introduce the road safety increase when RSSI at the receiving vehicle increase. Focusing on the real measurement, two lane road in urban scenario has been selected. BSM message has been transmitted according to IEEE802.11p (WAVE-DSRC). The antenna providing HPBW according to the simulation result can be many types which provide the optimum antenna HPBW. However, this work selected corner reflector method for antenna beam shaping. Thus, the comparison between conventional system with an antenna having omni-directional radiation pattern and the proposed system is introduced. The experimental results indicate the enhancement of BSM message dissemination using the proposed system. The installation of optimum antenna HPBW with switched beam system for V2V communication increases the performance metrics. Moreover, BER and PER introduce the reliability of V2V communication link. A low BER and PER introduce a high correctly received BSM message. Then, the proposed system indirectly increase the road safety. Moreover, R_{safe} and T_{safe} introduce road safety enhancement due to the driver getting more preparation time to accidents events on the road. Also, the proposed system answer the major requirements of DSRC V2V communication. The conclusion of this thesis can be summarized from the contributions as follows.

7.1.1 The reliability of V2V link is increased due to the proposed system. The enhancement of RSSI at the receiving side increasing the communication link reliability such as BER and Throughput. A Low BER indicates a high reliability of V2V communication link. Then, a receiving vehicle can receive the correct warning messages. Consequently, the chance of accident is indirectly reduced by the proposed system.

7.1.2 R_{safe} : The communication range is increased due to the RSSI enhancement. Then, the coverage range of V2V communication extension is improved. Also, the vehicles receive the message at a long range which means that the drivers have more time to aware for the accidents on the road. Then, the proposed system enhances the road safety for the drivers. As a result, the proposed system will support the requirements of V2V DSRC safety applications.

7.1.3 T_{safe} : Time to collision or T_{safe} indicates the preparing time for a bad situation on the road. In addition, this parameter refers to the collision time. The proposed system produces for more T_{safe} .Also, the road safety is improved due to the increasing T_{safe} .

7.1.4 Tradeoffs are the performance and system complexity between conventional switched-beam system and the proposed system. Focusing on system complexity, conventional switched-beam system presents a low system complexity. Because conventional system does not require the construction of an antenna having HPBW according to optimum value. However, low system performance such as high BER, PER are the limitations of conventional system. Focusing on the proposed system, the proposed system is more complex than the conventional system due to the construction of antenna HPBW corresponding to the optimum value. In contrast, the proposed system produces a high performance. Then, the road safety increases when using the proposed system. Thus, safety application should select the proposed system to increase the traffic safety.

For the future work, the applying of optimum antenna HPBW to other V2V safety application should be investigated. The integration of proposed system to a conventional safety applications will increase the communication reliability. In addition, the process of optimum antenna HPBW determination should be applied to other road environments. Moreover, the basic theory of optimum antenna HPBW determination should be applied to the related topics of DSRC transmission which enhanced the link quality. However, the experimental results and simulation results from this work can be used as a guide line for the performance of the DSRC V2V networks, where the benefit of the proposed system is better than the conventional V2V communication.

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APPENDIX

APPENDIX A

PUBLICATIONS

List of Publications

Poochaya, S. and Uthansakul, P. Beam Tracking in Switched-Beam Antenna System for V2V Communication. **International Journal of Antennas and Propagation Volume 2016**. Impact Factor 0.660

Settawt Poochaya., Peerapong Uthansakul, Monthippa Uthansakul and Ozan Tonguz (2014). **The Improvement Of A Vehicle To Infrastructure Communication Link For Its/Dsrc Using Sdr And Mimo Technology.** Suranaree Journal of Science & Technology (SJST).

Settawit Poochaya, Peerapong Uthansakul and Monthippa Uthansakul (2012). **Preliminary Study of DSRC using MIMO technique and Software Defined Radio for ITS.** International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI).

Settawit Poochaya, Peerapong Uthansakul and Monthippa Uthansakul (2012). **Performance Evaluation on Using IEEE802.11p for Indoor DSRC Approach.** IEEE Asia-Pacific Conference on Antennas and Propagation (APCAP).

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Research Article

Beam Tracking in Switched-Beam Antenna System for V2V Communication

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This paper presents the proposed switched beam antenna system for V2V communication including optimum antenna half power beamwidth determination in urban road environments. SQP optimization method is selected for the computation of optimum antenna half power beamwidth. In addition, beam tracking algorithm is applied to guarantee the best beam selection with maximum RSSI. The results present the success of the proposed system with the increasing of V2V performance metrics. Also, V2V data dissemination via the proposed system introduces the enhancement of V2V link in terms of RSSI, PER, BER, T_{safe}, and R_{safe}. The results indicate the improvement of V2V link reliability. Consequently, the road safety is improved.

1. Introduction and Related Works

The increasing of vehicles in the world promotes the traffic congestions and accidents on the road. The works in [1–3] have presented that the intelligence of conventional transportation system is made by Dedicated Short Range Communication (DSRC) technology which provides a fast data transmission and a high reliability of the communication link. ITS/DSRC communication regime operates under IEEE802.11p (WAVE-DSRC) standard at 5.9 GHz (7 channels) working for different manners. ITS improves the road safety by sending useful information to the drivers on the road for preparing for a bad situation. There are two differences of data dissemination procedures which are categorized into V2V (Vehicle to Vehicle) communication and V2I (Vehicle to Infrastructure) communication. The work in [4] has introduced that the equipment for ITS/DSRC is OBU (On Board Unit) and RSU (Road Side Unit). Both devices are equipped with omnidirectional antenna. The works presented in [5, 6] have introduced that ITS/DSRC applications are separated into two major types: safety applications and nonsafety applications. Safety applications require for more link reliability and lower latency. The work in [7, 8] has presented that the impacts of accident on expressways rely on the decision of drivers. There are 2194 accidents occurring on the expressways. Also, the human lives lost and the costs of damaging are the significant issues which motivate the governments in the world to search for better solutions. There are many well known safety applications in the world such as collision warning system, road side alert, and Road Hazard Warning. However, the works in [9, 10] have presented that the phenomenon of transmitting signal for all directions introduces the signal power losing in undesired directions. As a result, a signal quality at the receiving side is not good enough. Also, the signal quality drops at the receiving vehicles. The works in [11, 12] have presented that an antenna having directional pattern is the solution. This is because an antenna having directional pattern can radiate the signal to the desired directions. The signal quality such as RSSI performance is improved. However, there are some limitations of an antenna having directional pattern such as hidden node problem and sometime cannot be used in some applications. The works in [13–17] indicated the powerful antenna technology which provided the reduction of interference effect and increasing the signal quality at the receiving vehicle. Smart antenna has been proposed for a solution. There are two types of smart antenna technology including a switched-beam antenna and an adaptive array antenna. The adaptive array antenna requires more processing times due to feedback control bits for adjusting the phase and amplitude of the transmitting signal. Switched-beam system does not require complexity and intelligent methodology. Also, the processing time of switched-beam system is less than adaptive array system. However, the works presented in [18, 19] have introduced other significant factors to the performance of switched-beam system. One of these factors is the antenna half power beamwidth (HPBW). However, a conventional switched-beam system has an equal HPBW for each beam. The equal HPBW is determined without the consideration of vehicle positions on the road and the environments of the road so this causes the inefficiency of using conventional HPBW for V2V applications. Moreover, the improper HPBW indicate the chance of connection loss, low communication range, and low signal quality. The optimum HPBW will improve a signal quality at the receiving side. Moreover, to ensure that there is no connection loss until the data dissemination between vehicles, beam tracking algorithm has been proposed. In literatures, there are many methods of beam tracking algorithm. Focusing on the main idea of V2V communication, DSRC V2V requires fast and more reliability of the communication link. Then, the simplest beam tracking mechanism for V2V communication has been selected according to the works presented in [20–23]. Low connection loss and simplest procedures are the advantage of RSSI-based beam tracking mechanism. Focusing on V2V DSRC communication, beam tracking provides a seamless connection of the radio link between vehicles. The vehicles can travel from one position to other positions on the road if the connected beam is suitable for the position of the vehicle on the road. Then the signal quality can be improved. As a result, the high radio link reliability with low connection loss and seamless connection will promote the road safety. Because the vehicle connects to V2V network all the time, vehicles inside a communication zone can receive a warning message in order to prepare for a bad situation on the road.

This paper employs the corner reflector type for antennas according to [24] because it is the simplest way and less complexity of antenna HPBW beam shaping technique. The details to apply 4-beam SWB system with optimum HPBW for V2V communication have been given later. This paper presents the experiments of the proposed system for the real urban road. The performance matrices in this paper are the same as presented in [25, 26] including RSSI, ECR (R_{safe}), and TTC (T_{safe}). Note that the speed limit in urban road [27] following the law is 60 km/hr. The results confirm that applying switched-beam antenna with optimum HPBW and beam tracking can enhance V2V communication link. Moreover, the results indicate the improvement of traffic safety for 74% when comparing to the conventional V2V communication system. Moreover, the method to find the optimum HPBW is firstly introduced in this paper by using SQP optimization method. The consideration of antenna half power HPBW can be separated into two planes, elevation and azimuth planes. Focusing on urban road area, a distance between vehicles is short. Then, the effect from azimuth HPBW is more than elevation plane. Thus, this paper focuses on the determination of optimum HPBW on only azimuth plane. Also, the results in terms of RSSI, BER, PER, and R_{safe} and T_{safe} have been examined through simulations and experiment. The contributions of this work can be addressed in the following:

(1) V2V Communication link reliability is increased due to the proposed system. The increasing of RSSI presents the improving of communication link performance metrics and link reliability such as BER and throughput. Low BER introduces a high reliability of V2V communication link. As a result, a receiving vehicle can receive the correct warning messages. Then, the chance of accident is indirectly reduced by the proposed system.

(2) R_{safe}: RSSI enhancement introduces the increasing of coverage range of V2V message communication. The transmitting vehicle can communicate with receiving vehicle at a long distance. So, the vehicles receive the message at a long range which means that the drivers have more time to prepare for the bad situation on the road such as accidents and chain collisions. Thus, the outcome of the proposed system enhances the safety for the drivers. As a result, the proposed system will support the requirements of V2V DSRC safety applications.

(3) T_{safe}: this parameter indicates the preparing time for a bad situation on the road. In addition, T_{safe} refers to the collision time. The proposed system produces more T_{safe}. Also, the traffic safety has been improved due to the increasing of T_{safe}.

In summary, the road safety is indirectly increased by the enhancement of V2V communication link using the proposed system. The remainder of this papers is as follows: the mentioning about problem formulation is presented in Section 2 including optimal half power beamwidth determination. Beam tracking algorithm is also presented in this section. Next, the device configuration and experimental setup are presented in Section 3. The results and discussion are presented in Section 4. Finally, the conclusion is given in Section 5.

2. Problem Formulation

2.1. Optimal HPBW Determination. Focusing on optimal HPBW investigation, in this paper, the SQP optimization process has been selected to solve the optimization problem. First of all, the fundamental of proposed system is explained. The output of optimal HPBW investigation is the optimal HPBW values which can provide the maximum RSSI and SNR. As a result, the maximum SNR presents the best quality of V2V communication link. According to this, a better communication link refers to a higher RSSI at the receiving side. Thus, the higher RSSI improves system performance and system reliability. This paper proposes 4-switched-beam system with the optimum HPBW observation. Moreover, the comparison of two different systems is based on the same transmission power for an impartiality comparison between two cases. Thus, the gain comparator factor has been investigated for adjusting the antenna gain function of the two cases in a fairness comparison. The work presented in [28]

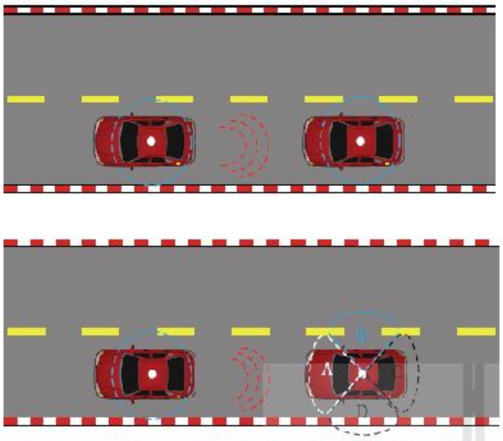


Figure 1: Traditional V2V communication when employing omnidirectional antenna.

has shown that the antenna gain function depends on main beam directions. The main beam directions are related to the antenna HPBW. Focusing on the performance metrics of V2V communication system, the work introduced in [29] has presented that the Effective Communication Range (ECR) or R_{safe} is configured according to BER threshold and PDR threshold related to IEEE802.11p standard. According to this, when vehicle is traveling inside communication area, this vehicle guarantees getting a high link reliability. Moreover, ECR (R_{safe}) can be related to time to collision or T_{safe} as shown in (1) and (2). The safety range (R_{safe}) is related to the speed of the vehicle (δ) and the PDR value: 0.9. Note that it can only be used in urban road with asphalt material. In addition, (R_{safe}) indicates the distance for the driver preparation to control vehicle into a bad situation on the road. Moreover, the relationship between the proposed system and time to collision or safety time (T_{safe}) is presented in (2). According to this, antenna technology is related with V2V communication link in terms of Effective Communication Range (R_{ECR}). Thus, (R_{safe}) and (T_{safe}) are important:

$$R = \frac{(\delta \cdot 3.6)^2}{100}, \tag{1}$$

$$T_{safe} = \frac{R_{safe} - R}{\delta}. \tag{2}$$

The proposed system includes omnidirectional antenna installing at the transmitting vehicle and the receiving vehicle equipped with switched-beam system following with Figure 1. Also, the relationship between transmitting and receiving signals is presented in

$$y = hx + n, \tag{3}$$

where y is a receiving signal, h is a wireless channel, and x is the transmitting signal. From (3), the average received power can be expressed as shown in

$$P_r = |x|^2 \overline{|h|^2} + \overline{|n|^2}, \tag{4}$$

where P_r is the average received power which combines the multiplication of transmitting signal power and propagation channel coefficient and the average noise power. The channel coefficient is expressed using Friss transmission equation. Then, (4) can be rewritten as shown in (5). Let N be the average noise power as $\overline{|n|^2} = N$. As a result, the signal to noise ratio (SNR) can be calculated in (6) and (7). However, there are more buildings and obstacles around the communication zone in an urban road. The scattering signal and interference signal from the nearby radio equipment get impact to the receiving vehicle. According to this, the probabilities of interference effect at the receiving side and the effect from the obstacles increase. This is because the receiving vehicle can receive signals from all directions. Also, the quality of V2V communication link decreased. Thus, V2V communication link in urban area needs the improvement of radio link quality. As a result, high performance link provides a high reliability data exchanging between vehicles. Focusing on the structure of the proposed system, Figure 2 presents the angle parameters (ϕ_r, ϕ_t). Assuming $N(\phi_r, \phi_t) = N$; $\forall(\phi_r, \phi_t)$ and SNR $= \gamma(\phi_r, \phi_t)$, then the average signal to noise ratio depends on the average antenna gain according to vehicle position probability and angle spread between beams as expressed in (6) and (7) as follows:

$$P_r(\phi_r, \phi_t) = P_t(\phi_r, \phi_t) G_t(\phi_r, \phi_t) G_r(\phi_r, \phi_t) \left(\frac{\lambda}{4\pi R}\right)^2 \overline{|h|^2}, \tag{5}$$

$$\gamma(\phi_r, \phi_t) = \frac{P_r(\phi_r, \phi_t)}{N(\phi_r, \phi_t)}, \tag{6}$$

$$\gamma(\phi_r, \phi_t) = \frac{P_t(\phi_r, \phi_t) G_t(\phi_r, \phi_t) G_r(\phi_r, \phi_t) (\lambda/4\pi R)^2 \overline{|h|^2}}{N}. \tag{7}$$

To find the average value over all directions, the average SNR can be calculated by

$$\overline{\gamma} = E\left\{\frac{P_r(\phi_r, \phi_t)}{N}\right\}. \tag{8}$$

Focusing on the average antenna gain determination, the antenna gain function $(G_i(\phi))$ consisted of the relationship between HPBW and main beam directions which is expressed in

$$G_i(\phi) = g_i \times 10^{0.1(G_{max} - 12[(\phi - \phi_{MB_i})/BW_i]^2)}, \tag{9}$$

where $(\phi_{MB_i} - BW_i/2) \le \phi \le (\phi_{MB_i} + BW_i/2)$. However, another important issue is a comparison of transmission power between three different systems. The comparison is based on equal transmission power. Then, the adjustment factor has been computed by gain comparator parameter (g_i) which will adjust the transmission power equally to an antenna having omnidirectional pattern. Next, the probability density function is expressed in (10) which includes

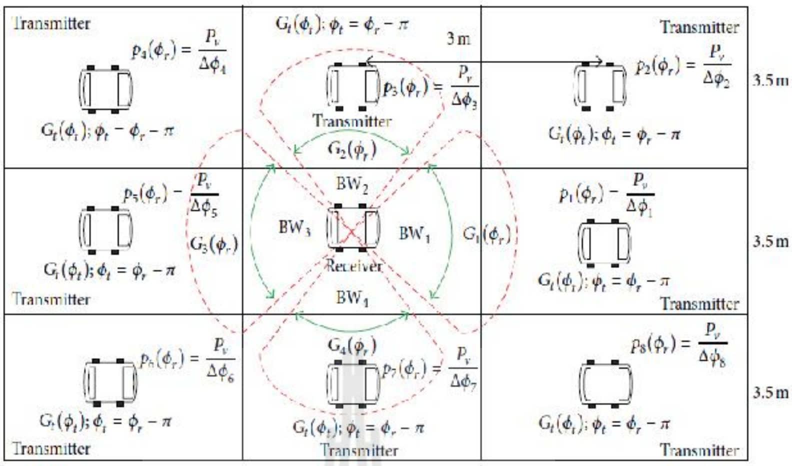


FIGURE 2: Proposed system when applying switched-beam antennas at receiver vehicle.

the vehicle position probability (P_v) and the angle spread between beams ($\Delta\phi$):

$$p_i(\phi) = \frac{P_v}{\Delta\phi}, \quad (10)$$

where ($\Delta\phi$) is determined by the road width (W_r) and distance between vehicles (D_v) according to the related works in a previous section. Then, a suitable antenna gain function consisted of HPBW (BW_i), main beam directions (MB_i), and probability density function of vehicle position ($p_i(\phi)$) which are expressed in (10). The angle spread between beams $\Delta\phi$ is expressed in

$$\Delta\phi = 2 \cdot \arctan \frac{(W_r)}{(D_v)}. \quad (11)$$

These parameters related to the road structure and the distance between vehicles. In addition, the computation of communication link performance is firstly initialized with Friis transmission equation which is expressed in (7). $G_t(\phi_r, \phi_t)$ and $G_r(\phi_r, \phi_t)$ are the function of transmitting and receiving antenna gain. The proposed system is considered at the receiving vehicle. Also, $G_r = (1/2\pi)\int_0^{2\pi} G_i(\phi)p_i(\phi)\mathrm{d}\phi$ changes to

$$\overline{G_r} = \frac{1}{2\pi}\int_0^{2\pi} G_r(\phi_r)\, p_r(\phi_r)\, \mathrm{d}\phi_r. \quad (12)$$

The transmitting vehicle is equipped with omnidirectional antenna. V2V safety message disseminates to the receiving vehicle. The receiving vehicle is installed with switched-beam antenna system. The distance between two vehicles is presented in terms of R. The related parameters are described as the following. Let $P_t(\phi_r, \phi_t) = P_t$, $G_t(\phi_r, \phi_t) = G_t(\phi_t)$, and $G_r(\phi_r, \phi_t) = G_r(\phi_r)$. When the relationship between ϕ_r and ϕ_t is $\phi_t = \phi_r - \pi$. Then, signal to noise ratio can be calculated using (8). The relationship between ϕ_r and ϕ_t is $\phi_t = \phi_r - \pi$. As a result, (5) is changed to (13) as follows:

$$P_r(\phi_r, \phi_t) = P_r(\phi_r) = P_t G_t(\phi_t)\overline{G_r(\phi_r)}\left(\frac{\lambda}{4\pi R}\right)^2 |h|^2, \quad (13)$$

$$P_r(\phi_r) = P_t G_t(\phi_r - \pi)\overline{G_r(\phi_r)}\left(\frac{\lambda}{4\pi R}\right)^2 \overline{|h|^2}, \quad (14)$$

$$\gamma = E\left\{\frac{P_t G_t(\phi_r - \pi)\overline{G_r(\phi_r)}(\lambda/4\pi R)^2}{N}\right\}\overline{|h|^2}, \quad (15)$$

$$\overline{\gamma} = \left(\frac{P_t}{N}\right)\overline{|h|^2}\left(\frac{\lambda}{4\pi R}\right)^2 \cdot \int_0^{2\pi} G_t(\phi_r - \pi)\overline{G_r(\phi_r)}p(\phi_r)\,\mathrm{d}\phi_r, \quad (16)$$

$$\overline{\gamma} = \left(\frac{P_t}{N}\right)\overline{|h|^2}\left(\frac{\lambda}{4\pi R}\right)^2 \int_0^{2\pi} G_r(\phi_r)\, p(\phi_r)\,\mathrm{d}\phi_r, \quad (17)$$

$$\mathrm{BER}_{\mathrm{BPSK}} = \frac{1}{2}\operatorname{erfc}\left(\sqrt{\frac{\overline{\gamma}}{2}}\right), \quad (18)$$

$$\mathrm{PER} = 1 - (1 - \mathrm{BER})^{8\times L}. \quad (19)$$

The noise power level N is gathered from the real measurements in urban road area. These values are collected from 5 times per point. The performance metrics indicate the Effective Communication Range (R_{safe}). The vehicles traveling inside a communication area maintains a stable link according to BER and PER threshold. Focusing on IEEE802.11p standard, PDR is configured at 90%. This value introduces more link reliability. The expression in (18) indicates the result of HPBW for V2V communication link. Also, the expression in (19) introduces the relationship between PER and BER, where L refers to the packet size. The work presented in [30] has introduced that the relationship between BER and PER relates with packet length. Moreover, PER causes a wrong decision of the driver when receiving high PER of safety message. Also, PER and BER are the performance metrics which indicate the performance of vehicular network.

The optimum HPBW determination process initiates with the constraint function which checks the condition of input values. Also, the average antenna gain and average SNR are calculated inside the objective function. The proposed systems can be categorized into nonlinear multivariable optimization. The works presented in [31, 32] have introduced Jacobian and Lagrange methods which are suitable for a single equality constraint. Focusing on the structure of the optimization problem, the proposed system requires a correction of antenna gain function corresponding to the vehicle position on the road. The selection of suitable antenna gain function, vehicle position probability, and the angle spread between beams introduce that the mentioning methods from above are improper for the proposed system. Moreover, the difficulty of the computation presents the unsuitableness for the proposed optimization problem. The work presented in [33] has expressed that the proper method for the similar objective function as the proposed system is SQP method. SQP method is the powerful method for the determination of the optimum value for the objective function which is related with quadratic equation. Moreover, SQP method requires low processing time. Also, SQP optimization method is selected for optimal HPBW determination. To apply SQP method for the determination of optimum HPBW for V2V communication, the objective function can be given in (20). This function consisted of input HPBW values, exact antenna gain function, and probability density function of vehicle position probability:

$$f(\mathrm{BW}_1, \ldots, \mathrm{BW}_M) = \left(\frac{P_t}{N}\right) \overline{|h|^2} \left(\frac{\lambda}{4\pi R}\right)^2 \int_0^{2\pi} G_r(\phi_r)\, p(\phi_r)\, d\phi_r, \tag{20}$$

where M is the number of beams. The solution can be obtained by applying SQP method on the optimization problem as presented in

$$\text{Maximize:} \quad f(\mathrm{BW}_1, \ldots, \mathrm{BW}_M) \tag{21}$$

$$\text{Subject to:} \quad \sum_{i=1}^{M} \mathrm{BW}_i = 2\pi. \tag{22}$$

A determination of the maximum average SNR is the main purpose of the objective function according to the constraint which is shown in (22). The summation of input HPBW values is equal to 360 degrees. The simulation program computes all cases according to the optimization constraint to guarantee the goal of objective function. Also, the maximum average SNR indicates the best solution of HPBW values. Then, the best solution of HPBW producing a maximum average SNR is selected to be the optimum HPBW. Moreover, the radiation pattern of the optimum HPBW is shown by Figure 3 including with 67, 113, 67, and 113 degrees of Beam 1, Beam 2, Beam 3, and Beam 4, respectively. Then, V2V communication link reliability can be computed. Moreover, the performance evaluations in terms of ECR (R_{safe}) and TTC (T_{safe}) corresponding to IEEE802.11p standard can be calculated via (19). Moreover, this paper introduces the measured radiation pattern of the optimal HPBW presented in Figure 4. The experiments introduced the improving of V2V communication link performance in terms of RSSI. However, the information of beam direction is another significant parameter to ensure that the receiving vehicle can receive DSRC message according to the proper beam. Also, beam tracking algorithm will be explained in next subsection.

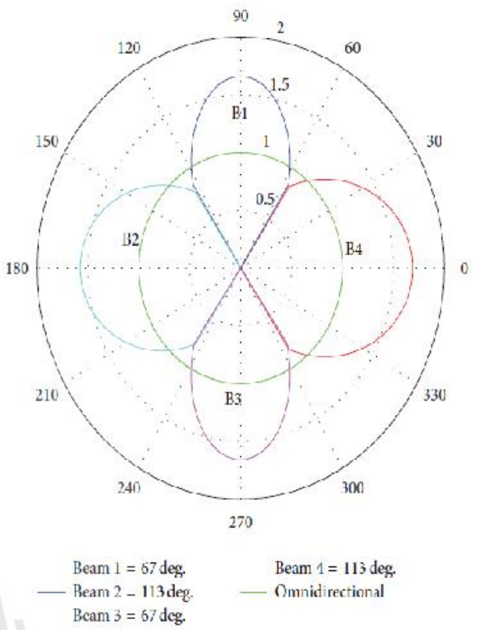
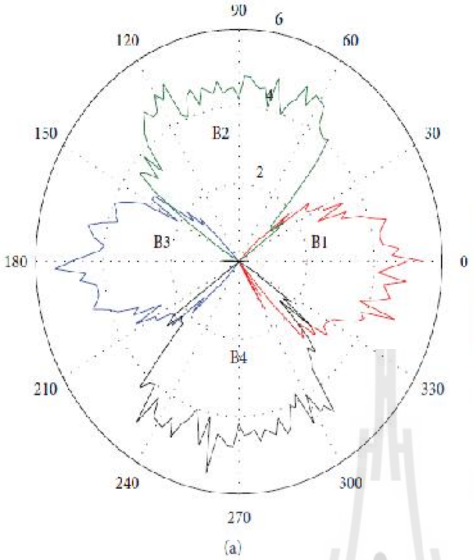
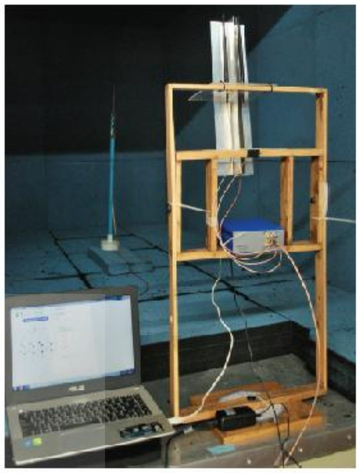


Figure 3: Radiation pattern of the proposed system (simulation).

2.2. Beam Tracking Algorithm. The determination of optimal HPBW has been presented in the previous section. Also, another important issue for V2V communication link is beam tracking. This section introduced beam tracking mechanism using RSSI decision-based algorithm. The work presented in [20–23, 34] has introduced that the signal strength of the receiving signal depends on path loss, shadowing fading, and multipath fading. Focusing on path loss issue, path loss is directly proper with the distance between vehicles. The increasing of distance between vehicles reduces the signal strength at the receiving vehicle. Focusing on urban road environments, many obstacles locate near the communication zone. Also, the effect from obstacles occurs at the receiving side. Many researchers try to improve the signal street at the receiving side under the mentioned conditions. Also, the abovementioned indicate the significance of improving





(b)

FIGURE 4: (a) Measured radiation pattern. (b) Devices and radiation pattern measurement.

V2V communication link. The previous section presented the powerful method of finding the optimum HPBW producing a good signal quality at the receiving side. However, to ensure that V2V communication link will connect all the time and that there is no connection loss in V2V communication link, beam tracking algorithm for V2V is important. The study cases can be separated into main scenarios: (1) Beam 1 changes to Beam 2 and (2) Beam 2 changes to Beam 3. The decision mechanism is based on (24).

For V2V communication using Beam 2, Beam 1 changes to Beam 2:

$$P_{\text{rxb1}} < P_{\text{Th}}, \quad P_{\text{rxb2}} > P_{\text{rxmin}}. \tag{23}$$

For V2V communication using Beam 3, Beam 2 changes to Beam 3:

$$P_{\text{rxb2}} < P_{\text{Th}}, \quad P_{\text{rxb3}} > P_{\text{rxmin}}. \tag{24}$$

Beam 4 has been neglected due to the road structure. Only two-lane road is interesting in this paper. Since these events are statistically independent, P_{B1}, P_{B2}, and P_{B3} are presented as the following:

$$P_{B1} = Q\left(\frac{\mu_1 - P_{\text{Th}}}{\sigma}\right) Q\left(\frac{P_{\text{rxmin}} - \mu_2}{\sigma}\right),$$
$$P_{B2} = Q\left(\frac{\mu_2 - P_{\text{Th}}}{\sigma}\right) Q\left(\frac{P_{\text{rxmin}} - \mu_1}{\sigma}\right), \tag{25}$$
$$P_{B3} = Q\left(\frac{\mu_3 - P_{\text{Th}}}{\sigma}\right) Q\left(\frac{P_{\text{rxmin}} - \mu_2}{\sigma}\right),$$

where $P_{\text{Th}} = -88$ dBm and $P_{\text{rxmin}} = -95$ dBm refer to receiving power threshold and minimum receiving power at the receiving vehicle. In addition, $\mu_1 = K_1 - K_2$, $\mu_2 = K_1 - K_2 \times \log_{10}(R - d_1)$, and $\mu_3 = K_1 - K_2 \times \log_{10}(R - d_2)$ are mean of the receiving power presenting in Gaussian process. d_1, d_2 are the distance between vehicles. R is DSRC communication range which equals 1000 m. Moreover, σ introduces the standard deviation of shadowing effect according to IEEE802.11p (WAVE-DSRC) standard. σ has been varied for the simulation of beam selection probability. Also, K_1 and K_2 are path losses factor. The work in [20] has presented that K_1 and K_2 are equal to 0 dB and 30 dB, respectively. The probability of beam selection is presented in Figures 5 and 6. Due to the connection loss issue, also the "*Make before Break*" algorithm has been selected to ensure that there is no connection loss in V2V communication link. The simulation results in Figures 5 and 6 present the beam selection probability according to the proposed algorithm.

3. Devices Configuration and Experimental Setup

The experimental equipment is as the following: two vehicles with the same types, two Locomate OBU which are equipped with omnidirectional antenna. One Locomate device is installed at the transmitting vehicle which is configured as the Provider. Another one for receiving vehicle which is setup as User. These devices are installed at the center of the vehicle's roof. The transmitting vehicle installs the antenna having omnidirectional pattern. Focusing on the receiving vehicle, the proposed system is installed with corner reflector for producing HPBW according to optimal HPBW value. The main beam of each antenna steers to 0-, 90-, 180-, and 360-degree directions. The SWB system steers the beam every

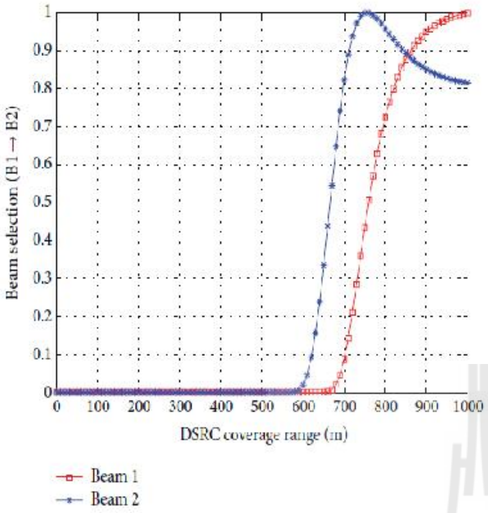


FIGURE 5: Beam selection probability Beam 1-Beam 2.

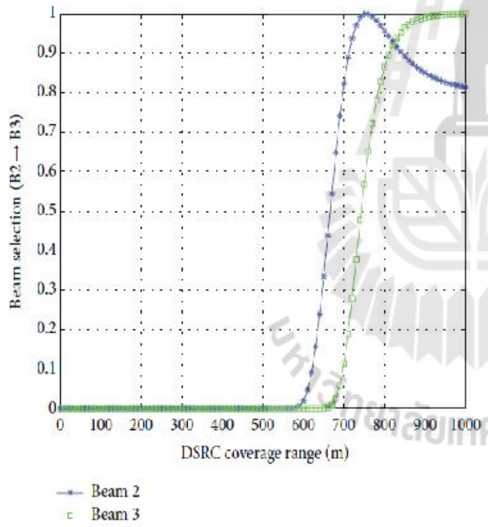


FIGURE 6: Beam selection probability Beam 2 Beam 3.

100 ms from Beam 1 to Beam 4. This is because the switches time relates to the channel switching time of DSRC standard. As a result, signal from antenna with corner reflector is fed into OBU. Also, OBU connect with host computer which holds the maximum RSSI. As a result, the receiving vehicle can also receive a good signal quality due to the manner of SWB mechanism. However, when the vehicle is moving out of the communication rage, the communication link between two vehicles is discarded. Finally, the SWB system starts for a new process but using the same procedure. The comparing between conventional V2V communication link performance and SWB system is the major purpose for next experiments. The road is made of asphalt which is related to the previous section that mentioned safety distance in an urban road. The experimental setup is configured as two vehicles travelling in the same lane. The vehicle in the front is configured as the receiving vehicle which is equipped with SWB system. The vehicle in the back is configured as the transmitting vehicle. The length of message size is configured as 512 bytes. The transmitting vehicle travels following the vehicle position (Point numbers 1 to 11) due to the test of beam tracking. RSSI of the reeving signal have been collected 5 times per position. The results of experiments are presented in the next section.

4. Experimental Results and Discussion

In Figure 7, the results present the relationship between vehicles positions and beam indices. Focusing on positions 1–4, Beam 1 has been selected for V2V data transmission. Moreover, the connected beam changed when the receiving power is relating to (23) and (24). Beam 1 changes to Beam 2 when the vehicle traveling passed positions 5–7. To choose the right beam index, the vehicle position should be accurately estimated. In our experiment, the estimation error is very little which does not affect the beam selection. However, vehicle position estimation error impacts on the performance metric when changing beam index. Vehicle position estimation error introduces incorrect beam selection. As a result, RSSI at the receiving vehicle reduces. Then, the communication between vehicles is reconnected. Also, new process of beam tracking is initiated. Then, the delay of the mentioned process occurs. The increasing of delay increases the latency of V2V data dissemination. After that, Beam 2 changes to Beam 3 when the vehicles traveling passed positions 8–11. The performance of receiving signal has been improved due to the information of beam tracking. Moreover, the proper connected beam introduces increasing of RSSI at the receiving side. In addition, the beam tracking provides a low connection loss to maintain a continuous V2V communication link. As a result, the reliability of information exchange between vehicle is increased. The result also shows that beam tracking provides a correct connected beam which provides a good signal quality at the receiving vehicle.

Figure 8 presents RSSI performance comparing between conventional system and the proposed system. Among antenna cases in the results, the optimum HPBW case indicates the best performance in terms of RSSI, R_{Safe}, and T_{Safe} performances. This is because the HPBW of the antenna is optimally allocated to the position of the vehicles on the road. Focusing on 600 m distance between vehicles, the proposed system increases RSSI performance 5 dB or three times from the conventional system. The result indicates the increasing of coverage range which is related to the cell planning for IEEE802.11p in [35]. The improvement of RSSI is benefit for coverage optimization planning which is significant for the deployment of WAVE-DSRC network.

R_{Safe} performance is presented in Figure 9. As a result, the optimum HPBW case provides more R_{Safe} in comparing to the conventional case. Moreover, the proposed case is better than conventional case for 35.5%. This result indicates that the vehicles using switched-beam with optimum HPBW system and beam tracking algorithm can receive the safety message

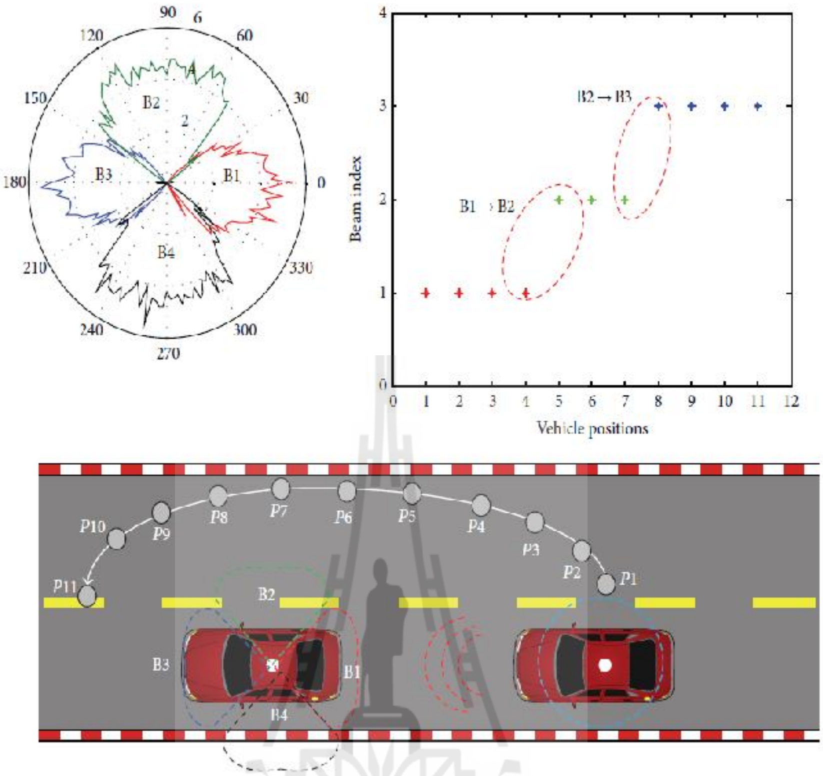


FIGURE 7: The comparison of beam index and vehicle positions on the road for beam tracking algorithm.

in a longer range when comparing to the conventional case. Also, the drivers inside the receiving vehicle can have a better chance to control a car in a bad situation. As a result, the proposed system increases the traffic safety by using switched-beam with optimum HPBW and beam tracking. Focusing on the vehicle speed at 60 km/hr, the optimum HPBW offers the best performance when comparing to the conventional system. Another performance metrics in terms of time to collision is presented by Figure 10. T_{safe} of the optimum HPBW is better than conventional case. This result confirms the effective usage of switched-beam system which can enhance the time to collision performance. Focusing on the real situation, the driver drives a vehicle at 60 km/hr and moves to the dangerous situation on the road. Preparing time for a bad situation increases 5 seconds when using proposed beamforming system. The result indicates the road safety increasing by the proposed beamforming and beam tracking approaches. Then V2V communication system with optimum HPBW disseminates the warning messages to the driver for a long communication range. As a result, the driver has more times for braking or preparing to the dangerous situation on the road. Also, the traffic safety has been increased when applying switched-beam antenna with the optimum HPBW and beam tracking to V2V application.

Another performance metric is packet error rate (PER) as presented in Figure 11. The result indicates that PER of the proposed system is less than 25% comparing to the conventional system at 300 m. Assume that 100 packets' transmission and 40 packets' error occur at the receiving side when using conventional system. But 15 packets' error occurs at the proposed system. The results indicate an indirect impact of the communication reliability. Focusing on safety message dissemination, the proposed system receives for more correct packet comparing to the conventional system. Also, safety message transmission with high reliability introduces the increasing of warning message accuracy. Thus, road safety increases due to the benefit of the proposed system. The comparative study in terms of PER performance metric indicates the successful beamforming and tracking approaches. Moreover, Bit Error Rate (BER) is the significant parameters of the communication link. The result shown in Figure 12 indicates the comparison of BER and distance between vehicles. The authors employ the approximation of BER introduced in [30]. Receiving powers of the proposed system are measured by the experiment on urban road environment. Two-lane road has been chosen. OBU with beamforming system is installed at the receiving vehicle. Another OBU with omnidirectional antenna is configured as transmitting vehicle. The receiving power was measured 5 times per points. Also, the average receiving power has been calculated with average noise power. Then, SNR has been translated to Eb/N0. Focusing at 300 m of distance between

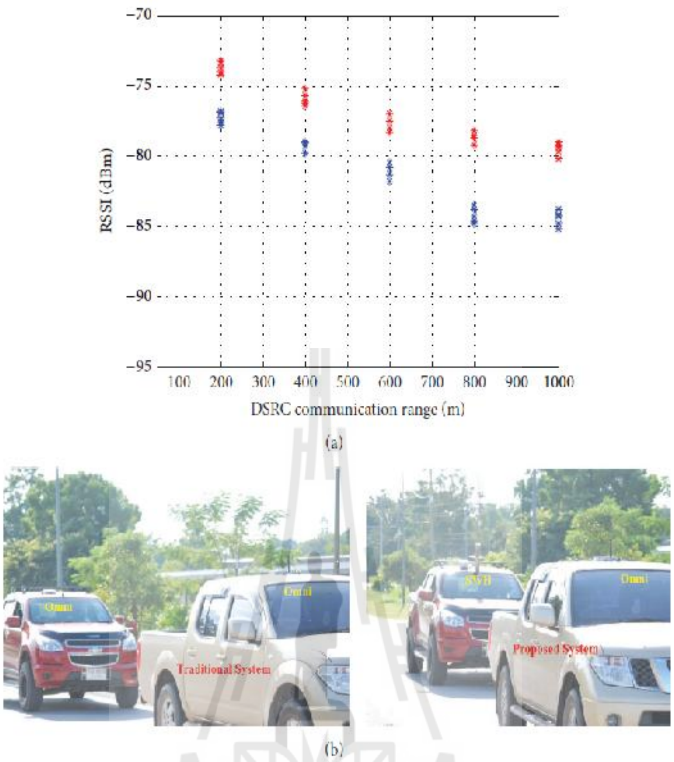


FIGURE 8: (a) RSSI performance when comparing between conventional system and SWB system. (b) The real experiment on the road.

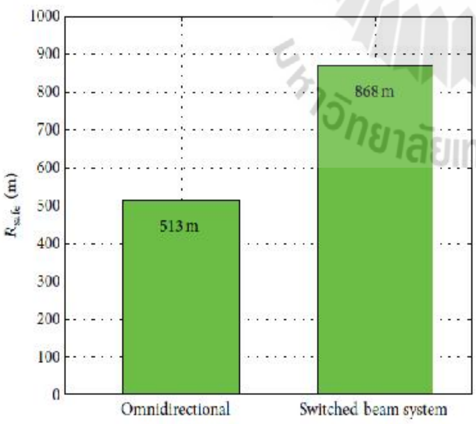


FIGURE 9: Effective Communication Range for DSRC V2V communication.

vehicles and 100 bytes of transmission packet size, BER of the conventional system is 4×10^{-2}. BER of the proposed system is 2×10^{-4}. As a result, the amount of bit error for the conventional system is 32 bits more than the proposed beamforming system. High BER indicates unreliable link. As a result, road safety is reduced due to the impact of incorrect warning message reception. Focusing on another QOS metrics, throughput can be estimated via the approximation method. The configuration is as follows: bandwidth: 10 MHz, data rate: 27 Mbps, modulation type: OFDM (BPSK), channel number: 172, frequency: 5.9 GHz, and devices: Locomate OBU devices. The result in Figure 13 indicates the improving of system throughput by using beamforming and tracking approaches. The throughput of proposed system provides 1 Mbps more than the conventional system. This means that the proposed system can transmit message faster than the conventional system. Focusing on the real life scenario, a huge message size such as short period video and high quality photo from car DVR (car Digital Video Recording) can transmit with higher speed than conventional system. The processing unit of those video and photo files can process and transmit the warning message faster than the conventional system. The impact of the proposed system increases the road safety indirectly.

5. Conclusion and Future Work

This paper presents the importance of applying optimum HPBW for V2V DSRC application. Switched-beam system with optimum HPBW enhances the communication link

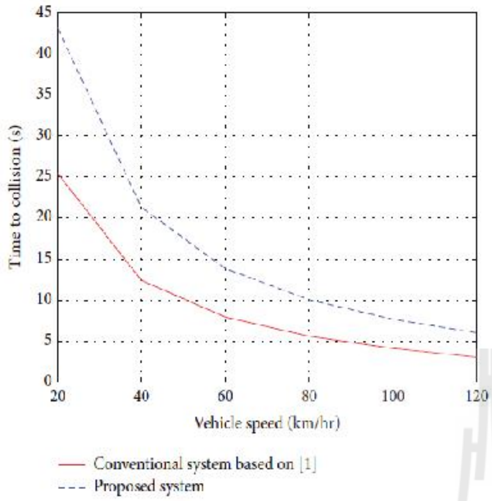


FIGURE 10: Time to collision performance when comparing between conventional system and SWB system.

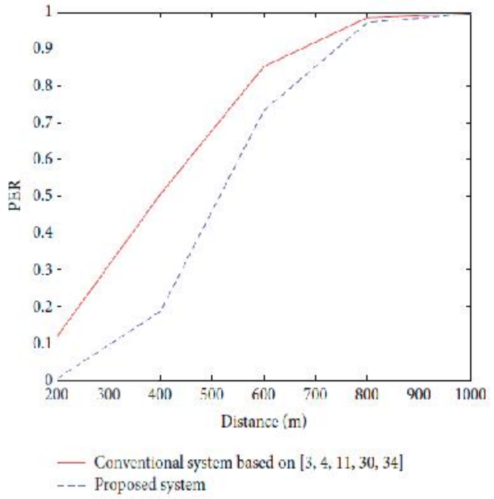


FIGURE 12: Bit Error Rate comparing to distance between vehicles.

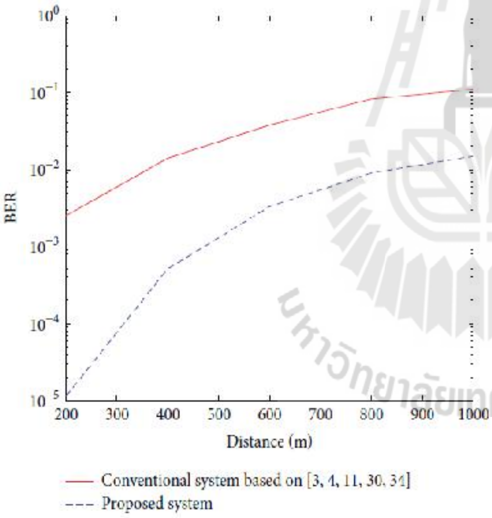


FIGURE 11: Packet error rate comparing to distance between vehicles.

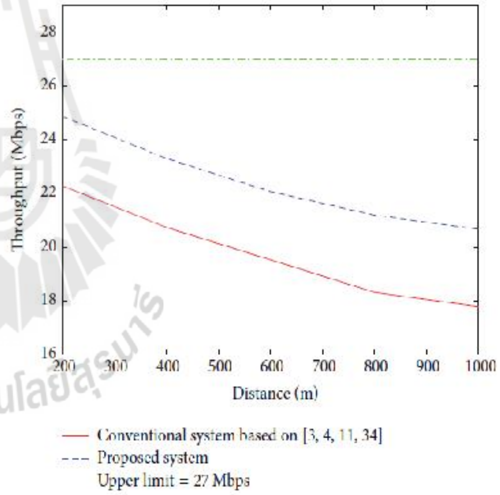


FIGURE 13: Throughput comparing to distance between vehicles.

between vehicles. The optimization problem is mathematically modeled by considering the probability of vehicle positions as well as road environments. SQP optimization method has been proposed for optimum HPBW determination. Moreover, beam tracking algorithm has been applied to ensure a seamless connection between vehicles. The results indicate that applying switched-beam antenna with optimum HPBW and beam tracking mechanism for V2V DSRC communication can increase the signal quality and system performances at the receiving vehicle in terms of RSSI, R_{Safe}, and T_{safe}. Particularly, the proposed system can improve the traffic safety 74% in comparing to the conventional DSRC V2V communication. This paper has addressed the simple method to save more lives by adjusting the optimum HPBW. Also, the proposed system can be practically implemented on existing V2V technology.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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THE IMPROVEMENT OF A VEHICLE TO INFRASTRUCTURE COMMUNICATION LINK FOR ITS/DSRC USING SDR AND MIMO TECHNOLOGY

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Abstract

The effect of multipath fading and the surroundings of the communication area cause errors in the V2I (Vehicle to Infrastructure) communication link. Traditional ITS/DSRC systems cannot read information when vehicles move at high speed. These reasons cause the unreliability of the conventional ITS/DSRC systems. Therefore, the authors propose using the MIMO technique and SDR technology to enhance the ITS/DSRC systems' performance. This article presents an implementation of the SDR technology for ITS/DSRC used with the MIMO technique. All experimentation has followed the IEEE 802.11p WAVE-DSRC standard. The USRP platform and GNU Radio software package have been used. The achievement of 2 USRP platforms can be configured easily as OBU and RSU. OBU are installed in the vehicles to perform measurements for V2I applications. The packet error rate, bit error rate, throughput, and average correct received packet ratio have been investigated by varying the distances between the RSU and OBU. The results show an improvement in the traditional ITS/DSRC system's performance. The proposed system increases the reliability for drivers when a small bit error rate occurred. The proposed system gains a high system throughput. Then, the ITS/DSRC communication system can transmit important information at a high data rate.

Keywords: **Software-defined radio, multiple antennas, multiple-input and multiple-output, Alamouti, V2I, electronic toll collection, Universal Software Radio Peripheral, GNU Radio**

Introduction

Recently, traffic problems have become one of the most important problems for governments around the world. Transportation systems are significant factors for human life such as for travel, medical purposes, and logistics. The number of vehicles increases in direct proportion to the numbers of the populations. This has an effect on traffic flows. If a government does

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not build roads to support the vehicles, it causes traffic problems and dangerous roads. The researchers suggest that telecommunication technology, called intelligent transportation systems (ITS), be used to improve the traditional transportation system. The ITS can solve traffic problems such as traffic congestion and accidents. The final goals of the ITS are to improve traffic efficiency and mobile safety without new road construction being required. Dedicated short range communications (DSRC) is an enabling technology that allows vehicles to communicate with each other and supports short to medium range communications and defines the infrastructure of the communication system. DSRC has provided high data rate services. The most popular application of the ITS and DSRC is electronic toll collection (ETC) using radio frequency identification (RFID) technology (Li *et al.*, 2011). The effect of vehicle mobility can degrade a system's performance because RFID cannot completely read all the data when there is high vehicle mobility (Kukshya and Krishnan, 2006). As a result, the performance of the communication link between the roadside units (RSU) and on board units (OBU) is very poor under such a condition. According to the literature (Mar *et al.*, 2008), many works have studied the effect on vehicle mobility of the performance of the communication system between the RSU and OBU. They introduce problems such as the effect of multipath fading by the surroundings of the communication area. A high bit error rate (BER) degrades the system's performance (Biswas *et al.*, 2006) and reduces the reliability of the communication system, thus providing a low system throughput which degrades the system's performance. In the case of the ETC system, the high BER decreases the user's payment reliability. An error occurs such as when the receiver cannot receive the overall packet, so that the receiver station at the toll gate cannot read the user's payment data. The low system throughput transmits the data packet slowly. Then the wooden barrier at the toll gate opens slowly because the data packets require more time. Also, Sibecas *et al.* (2002) concluded that vehicle mobility and multipath fading are the major problems directly affected by the ITS and DSRC system. The researchers determined the need for new technology for the conventional ITS/DSRC system. The use of orthogonal frequency-division multiplexing (OFDM) technology has been promoted. The researchers (Lin *et al.*, 2009) have found the feasibility of using the IEEE 802.11p wireless access for vehicular environments (WAVE) standard (IEEE, 2010). The advantages of the IEEE 802.11p standard are achieved by using the OFDM technique. It eliminates the effect of multipath fading or inter-symbol interference problems. IEEE802.11p introduces outdoor broadband communication such as DSRC and so protects against multipath fading as well as supporting a high mobility user while providing a high data rate transmission. Tarokh *et al.* (1999); Shan *et al.* (2004) introduced new technology that reduced the BER and provided a high system throughput. They found that the multiple-input multiple-output (MIMO) technique is one of the most promising technology developments that overcomes fading channels while maintaining the benefits of high data rate transmission as well as a low bit error rate. By using multiple antennas at both the transmitters and receivers, the system with space-time coding can provide more reliable transmission than a conventional system employing only 1 antenna at the transmitter and receiver. Also, the MIMO system can improve other system performances such as a high spectral efficiency, high system capacity, high coverage area, and high gain. In this light, this paper adapts the concept of the MIMO technique to apply it to the communication link between the RSU and OBU. This technique is able to be implemented for practical use comparatively more easily than the power control plus coding technique. Hence, it is believed that the MIMO technique can both defeat the effect of vehicle mobility and destroy the impediment between the RSU and OBU. The authors developed their own transmitter and receiver using the software defined radio (SDR) technology. The researcher can control the waveform with 2 host computers. Radio waveforms are controlled by the software corresponding to the parameters' configuration inside the host computer. The SDR technology changed the hardware problems to software problems. Marwanto *et al.* (2009), presented a basic concept in their study of GNU Radio and the Universal Software Radio Peripheral (USRP). The results showed that GNU Radio and the USRP is a rapid and low cost prototype suitable for any wireless technologies. Biddlestone and Redmill (2009) presented an implementation of the OFDM transmission by using the USRP and GNU Radio platform, but many parameters of the OFDM signals in the IEEE 802.11p standard such as modulation type, power level, fast Fourier transform bins, and frame format are totally different from IEEE 802.11a (IEEE, 1999). However, the implementation of the IEEE 802.11p standard is presented in Fuxjäger *et al.* (2010) with the offline experiments. Lan and Li (2010) transmitted the FM data over the air interface via GNU Radio and the USRP and collected the data and investigated the system performance. In this paper, the USRP and GNU Radio softwares are uses to measure the data in an offline situation according to the IEEE 802.11p standard. Many parameters such as the packet error rate (PER), BER, and throughput have been collected. Maier *et al.* (2012) investigated multiple antennas at the receiver for the ITS. They introduced selection combining, equal gain combining, and the maximum ratio combining algorithms. This work increased the frame success ratio by 25%. Agostini *et al.* (2013) introduced the SDR for the ITS which provided the flexibility for the next generation of vehicular networks. The work of Mata *et al.* (2013) presented the computer simulation of the MIMO-OFDM for the ITS. The system performance of the ITS/DSRC was done by computer simulation and the results showed the improvement of the traditional ITS. In the literature, there has never been presented the SDR technology with the MIMO system concept for the ITS. Thus, the authors also were interested in the enhancement of the ITS/DSRC by using the SDR technology and MIMO techniques.

This work introduces an implementation of the MIMO technique. The communication system integrates with the SDR technology to enhance the performance of the 5.9GHz IEEE 802.11p standard such as for the ETC communication between the RSU and OBU. All system configurations are based on the IEEE 802.11p standard. This is because the fading channel due to the effect of buildings around the roads and vehicular environments still performs the same as for any other standards. In experimentation, the BER, throughput, and PER performances have been investigated by varying the distances between the RSU OBU and the received power at the receiver. The comparisons between the proposed and conventional system indicate the benefits of the proposed technique.

The consequences of this paper are shown as follows:

For the ETC system, the good received signal power in the receiver promotes the lower BER and PER of the proposed system and is less than that of the ITS/DSRC conventional system. This refers to the improvement of the system's reliability for the user payment at the toll gate. The results will produce reliability for the drivers by ensuring that the proposed system can operate with more accurate data transmission and reception.

The average correct received packet of the proposed system promotes the enhancement of the conventional ITS/DSRC system. The proposed system received more packets.

Focusing on the ETC system, the proposed system can operate with more throughput than the conventional system. The vehicle can transmit the data at a high data rate to the toll gate, so that the wooden barrier opens quickly. This will reduce the waiting time in front of the toll gate, reduce the travelling time, and save fuel. The reduction of emissions in front of the toll gate is the most important consequence.

- For the collision avoidance system, the lower PER and BER promote an improvement in the accuracy of the warning message. This increases road or traffic safety and the MIMO system reduces the chance of an accident.

The remainder of this paper is arranged as follows: Materials and Methods present the system model, system configuration, experiments, and measurement setup. Results and Discussions have been explained. Finally, there is the conclusion to this article.

Materials and Methods

System Model

Conventional System

The ITS is an emerging technology between telecommunication technology and conventional transportation systems. It improves road convenience, and traffic safety for the driver and traffic congestion are its main purposes. The ITS operates DSRC technology which communicates with a short to medium communication range. The ITS's popular applications include traffic reports which send traffic information to the driver such as text, video, and audio. Next are intelligent traffic signs which present traffic signs to the driver. The information provided is about traffic congestion and suggests a good way for the driver to proceed. A Global Positioning System (GPS) tracking system is used for logistics management, using a GPS signal to manage a time table for logistics companies. The GPS signal navigates so that the truck driver can go faster to the destination. The managers manage the time table of the trucks. Parking guidance systems instruct the driver to drive a vehicle to pass over a parking gate and then park at an empty space. The most famous of the ITS services is the ETC system; this system improves the conventional toll collection system. For the traditional ETC system, drivers pay the toll to a human. The problems of the conventional toll collection system are that it is not fast because there are traffic jams at the toll gate and, because drivers accelerate and brake frequently, there

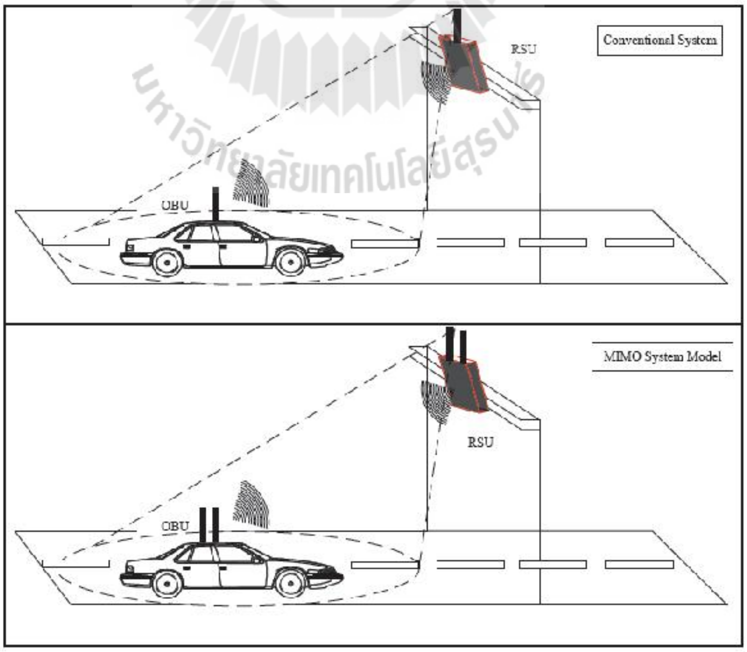

Figure 1. Conventional ITS/DSRC system versus integrated MIMO system: ETC (electric toll collection)

are high emissions at the toll gate from the exhausts of the vehicles.

The DSRC technology defines a standard of communication infrastructure for a short to medium communication range. It is categorized into 2 main communication procedures. The first is vehicle-to-infrastructure (V2I) which defines a standard of radio data transmission between a vehicle and a roadside unit. Secondly, vehicle-to-vehicle (V2V) defines the standard for data transmission between a vehicle and another vehicle. The components of the V2V and V2I systems are the RSU and OBU, as shown in Figure 1 in which the RSU is located beside the road or on the top of a tower that is positioned over the road. The OBU is placed on the dash board of a vehicle or located on the top of the vehicle's roof. The ITS/DSRC standard is the IEEE 802.11p standard for WAVE-DSRC. Table 1 shows the characteristics of the IEEE 802.11p standard which increased the duration of the symbol time from 4μs to 8μs. It protects from multi-path fading and provides strength against the effects of vehicular environments. The use of the OFDM modulation scheme is appropriate for the new technology that requires a high data rate according to the data size, such as a traffic report, caution sign, picture, and video between the RSU and OBU data transmission.

MIMO System

There are 2 main techniques for the MIMO encoder including spatial multiplexing and space-time coding. In this paper, the concept of space-time coding has been chosen. There is a tolerance to a fading channel that is caused by the road surroundings. In this paper, the Alamouti space time block code (STBC) is employed which is the simplest form of STBC and was invented by Alamouti (1998). This code is designed for a 2 transmit antennas system and operated on a block of input symbols. The columns of the coding matrix present the time and the rows show the antennas. The main feature of the STBC is a very simple decoding scheme and the code matrix is given as

$$x_{2x2} = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \quad (1)$$

for Nr, Nt = 2

At a given symbol period, 2 signals simultaneously transmit from the 2 antennas, namely S_1 from the first antenna and S_2 from the second antenna. In the next symbol period the $(t + T_S)$ signal $-S_2^*$ and S_1^* are transmitted from the first and the second antennas, where T_S denotes the symbol period. The columns of the matrix correspond to the antennas and a row corresponds to the time slot. This code matrix from equation (1) is orthogonal. At the receiver site, the space-time combiner combines the received signals as follows in equation (2):

Table 1. IEEE 802.11p specifications

Service	Specification
Modulation type	BPSK
Data rate	3 27 Mbps
Frequency band	5.850-5.925 GHz
Number of data subcarriers	48
Number of cyclic prefix	4
Total subcarrier	52
OFDM symbol duration	8 μs

$$\begin{pmatrix} \tilde{s}_1 \\ \tilde{s}_2 \end{pmatrix} = \frac{1}{\|H\|^2} \sum_{j=1:Nr}^{Nr} \begin{pmatrix} h^*_{1,j} r_{1,j} + h_{2,j} r^*_{2,j} \\ h^*_{2,j} r_{1,j} - h_{1,j} r^*_{2,j} \end{pmatrix} \quad (2)$$

for Nr, Nt = 2.

S_1 and S_2 present the estimated symbols in thecodeword matrix. The symbols $h_{i,j}$ present the estimated channel from the transmit antennas and $\|H\|^2$ receive antennas and presents the summation of the channel power per link.

System Block Diagram

Figure 2 shows the system block diagram consisting of the equipment as specified in Table 2. The system block diagram consists of 2 host computers which are used as 1 for the transmitter and 1 for the receiver. The host computers are connected with the USRP motherboard. The authors plugged an XCVR2450 daughterboard as the radio frequency (RF) front end inside the USRP motherboard. The VERT2450 transmit and receive antennas were connected with 2 XCVR2450 daughterboards. At the transmitter, signals flow from the software which was

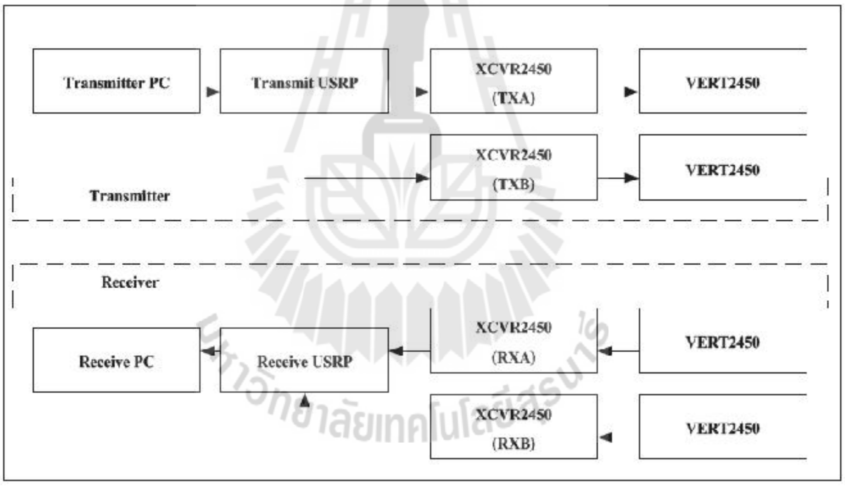

Figure 2. System block diagram for the setup of the MIMO implementation

Table 2. Equipment specifications

Devices	Quantity	Specification
Host Computer	2	Intel Core i5 DDR3-4GB Ram Ubuntu 10.04 Operating System with GNU Radio instal
USRP Daughterboard	2	USRP V.1
	4	XCVR2450 Frequency: 2.4 to 2.5GHz, and 4.9 to 5.9GHz 2 for Transmitter 2 for Receiver
Antenna	4	VERT2450 Frequency: 2.4 to 2.5GHz, and 4.9 to 5.9GHz Gain:3dBi

designed by the authors. Digital signals are generated via the USRP motherboard and sent through the XCVR2450 RF front end. The RF front end converted the digital signals to analog signals. Finally, an analog signal flowed to the VERT2450 transmit antennas sending analog signals over the air interface. At the receiver, the procedures of the signals flow were the inverse of those for the transmitter.

System Configuration

Hardware: USRP

Figure 3 presents the USRP platform. The USRP was developed by Ettus Research LLC of Mountain View, CA, USA. Inside the USRP, there are 2 main components. First, the motherboard field-programmable gate array (FPGA) is the main component of the USRP. The responsibilities of the FPGA are to calculate and process the signals at the transmitter and the receiver. At the transmitter, the USRP includes high speed digital to analog converters (DACs) which convert the digital signals to analog signals. After that, the signals have gone to the RF part. At the receiver, high speed analog to digital converters (ADCs) are installed to reverse the analog signal to a digital signal before sending the signal to the FPGA. The main idea of the FPGA is that all the high-speed general purpose operations like digital up and down conversion, decimation, and interpolation are done on it. Secondly, the daughterboards the duty of which is to hold the RF receiver interface or tuner and the RF transmitter. The daughterboards are plugged inside a USRP motherboard. The complete USRP and daughterboards equipment is for the convenience of the radio engineer. The authors created their own communication system. The inside of the motherboard contains an Altera Cyclone EP1C12 FPGA. This FPGA consists of 4 ADCs which run on 12 bits per sample with 64 Msamples/sec. The 4 DACs run on14 bits per sample with 128 Msamples/sec. With regard to the daughterboards' work in the field of the RF front end, this paper employs XCVR2450 daughterboards which respond to the RF in dual bands, 2.4 GHz and 5.9 GHz. All the components are assembled in 1 USRP box using a 3A 6V power supply. Finally, the USRP connects to the host PC via a Universal Serial Bus 2.0.

Software: GNU Radio and MIMO Implementation

GNU Radio is an open source software package which controls and processes the signals. GNU Radio is written in both the Python and C++ programming languages as shown in Figure 4. The C++ programming language was created for the signal processing block. The main role of the Python programming

Figure 3. Universal Software Radio Peripheral

language is to connect and glue the entire signal processing blocks. GNU Radio provided the frequently used blocks for the researchers. They created the communication system such as the modulator, demodulator, filter, and the many signals processing blocks inside this package. GNU Radio worked with the USRP hardware and the authors developed and applied their own codes for the configuration of the radio communication system.

Figure 5 and Figure 6 have shown the transmitter and receiver structures, respectively. The directions to create the MIMO system were set out in Wee *et al*. (2009a, 2009b). The authors applied the source codes from the GNU Radio software package and they used the C++ language for the digital signal processing program. The Python programming language glued all of the signals processing blocks. The authors defined the pilot signals x_1 and x_2 for estimating the channel coefficient at the receiver, and the data streams as the payloads S_1 and S_2 for the transmission in the first period. For the second period, the authors sent $-S_2^*$ for payload1 and S_1^* for payload 2. After that, payload 1 was transmitted to antenna 1 and payload 2 was sent to the transmit antenna 2, respectively. Finally, our program checked the status of any more data to be sent and the end of program. The signals' flow at the receiver is shown in Figure 6. The authors received the pilot signals from both symbol periods and obtained the channel coefficient by estimating from the pilot signals x_1 and x_2. The authors extracted the receiver payload at the first symbol period and the second symbol period and then the program processed the signals. The codes applied a decision rule for the raw data. After that, the program stopped and the authors extracted the raw data which consists of pktno (packet number), n_rcvd (number of received packets), and n_right (number of correct received packets). Finally, the authors calculated the system performances such as the PER, BER, and throughput by varying the distances between the RSU and OBU.

Experiments and Measurements Setup

The experimentation contained the transmitter or RSU and the receiver or OBU. The transmitter consisted of the USRP motherboard and XCVR 2450 daughterboards. The software was developed and installed on the motherboard. The authors configured the data packets as the IEEE 802.11p (WAVE DSRC) standard. Also, the authors transmitted the signals over the air interface. At the receiver, all parameters were configured similar to the transmitter based on the same standard.

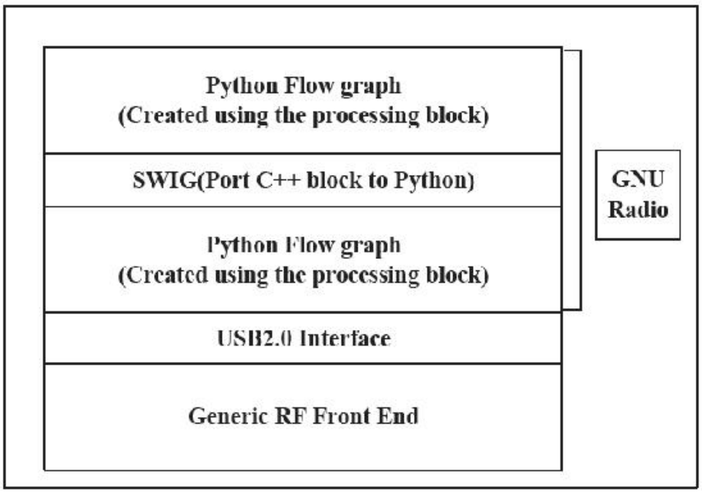

Figure 4. GNU Radio structure

The authors configured the decimation rate, interpolate rate, and number of samples per symbols at the receiver and receiver, respectively. Also the signals were tested in the laboratory before real experimentation, so that the authors could check the validation of using our software.

At the OBU, the USRP was connected to the laptop. The authors connected the USRP RSU to a personal computer (PC). Both

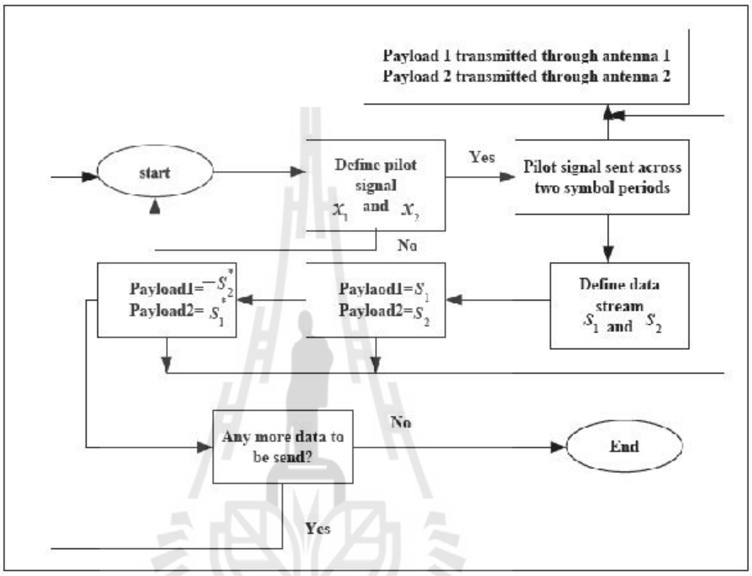

Figure 5. Signals flow diagram at the transmitter (Wee *et al.*, 2009a)

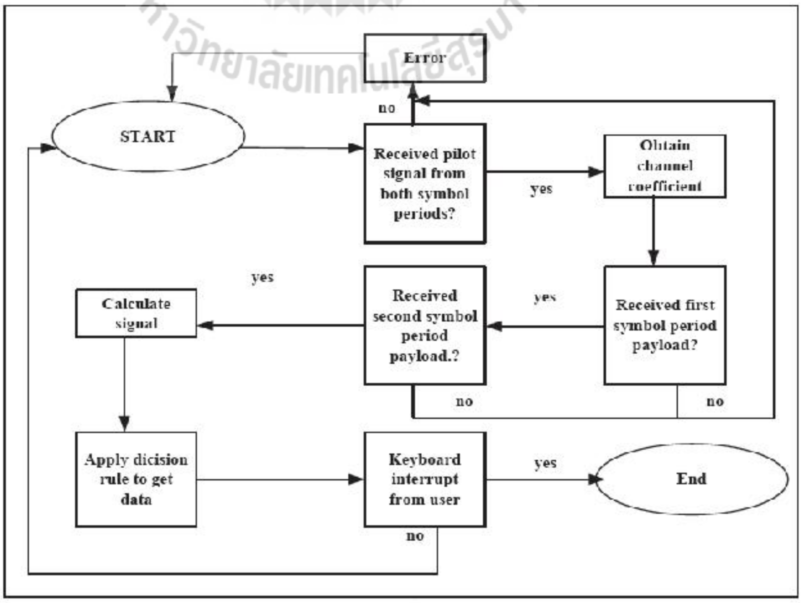

Figure 6. Signals flow diagram at the receiver (Wee *et al.*, 2009b)

the laptop and PC generated and collected the data packets. The XCVR2450 daughterboards were used for these experiments at both the OBU and RSU. The authors configured the transmitter and the receiver as the MIMO-Alamouti encoded and decoded operation with 2×2 antennas. The single-input single-output (SISO) system consists of 2 antennas, 1 at the transmitter side and 1 at the receiver side. The differences in the systems' configurations are the number of transmit antennas and the STBC code for the MIMO system. The frequency band for this experimentation is the 5.9 GHz band. The USRP A was configured as the OBU and was located on the roof of a car, as shown in Figure 7. The USRP B in Figure 8 was configured as the RSU and located beside the road. The experimentation was conducted in an outdoor environment. The maximum distance between the RSU and OBU is 5 m, because of the USRP's limited specification. The authors measured for a vehicular environment which was a 2 lane road. All of the system specifications were configured as the IEEE 802.11p (WAVE-DSRC) standard (IEEE, 2010; IEEE 1609.3, 2006; IEEE 802.11p: Part11, 2010). For each of the measurement locations, 10 times of data collection were performed. The measurement methodology was categorized into 2 procedures per point. First, the authors investigated the SISO system in Figure 9(a), and then the MIMO measurement in Figure 9(b). Every point varied the distance between the RSU and OBU. The authors collected the

Figure 7. On-Board unit (located on the roof of a car)

Figure 8. Roadside unit

(a) **(b)**

Figure 9. Experiment and measurement setup a) SISO b) MIMO

received power in each position, and the off-line data, and extracted all the data. The authors computed the system performances such as the PER, BER, and throughput. The aims of these experiments determined the relationship between the PER, BER, and throughput versus a distance between the RSU and OBU and the received power with the binary phase-shift keying (BPSK) modulation type. The authors got the raw offline data from the experimentation. The experimentation measured 10 times/points and varied the distances between the RSU and OBU. The authors extracted the raw data and determined the average values of pktno, n_right, n_rcvd, and received power. After that, the authors used equation (3) in order to calculate the PER performance and computed the BER by equation (4).

$$PER = (1 - \left(\frac{n\_right}{pktno}\right)) x100\% \quad (3)$$

$$1 - PER = (1 - BER)^{L} \quad (4)$$

n_right is the number of correct receive packets
pktno is the packet number
L is the packet length

Results and Discussions

The experimentation investigates the system performance. There are the PER, BER, and throughput. The authors varied only the distances between the RSU and OBU. Table 3 presents the results. The PER of the MIMO 2×2 versus the distance between the RSU and OBU is less than the conventional SISO system. For the BER performance, the BER increased when the distance between the RSU and OBU increased. The BER performance of the proposed system is less than that of the SISO system. For example, in the ETC system, these results increase the reliability

Table 3. Experimentation results for the PER, BER, and throughput vs. distance (m.) and average received power (dBm)

Variable	Average received power (dBm)	Distance between RSU and OBU (m)	Conventional system	MIMO 2×2
PER	-61.3	1	39.42%	39.04%
	70.1	2	60.40%	59.10%
	-74.8	3	84.02%	83.41%
	-77.7	4	97.04%	96.44%
	-81.2	5	98.73%	98.40%
BER	-61.3	1	1.25×10^{-3}	1.19×10^{-3}
	-70.1	2	2.31×10^{-3}	2.23×10^{-3}
	-74.8	3	4.57×10^{-3}	4.48×10^{-3}
	-77.7	4	8.76×10^{-3}	8.30×10^{-3}
	-81.2	5	1.10×10^{-2}	1.00×10^{-2}
Throughput	-61.3	1	1.81×10^{6}	1.90×10^{6}
	-70.1	2	1.18×10^{6}	1.23×10^{6}
	74.8	3	4.80×10^{5}	4.97×10^{5}
	77.7	4	8.88×10^{4}	1.07×10^{5}
	-81.2	5	3.81×10^{4}	5.37×10^{4}

for drivers by ensuring that the proposed system can operate with more accuracy. Our results promote the reliability for user payment at the toll gate. The reliability of the communication system in the ITS is affected by the multipath fading channel (Ma *et al.*, 2012). The PER in this work is measured under the fading channel. The PER threshold, based on the ASTM E2213-03 standard (ASTM, 2010) for data transmission in the ITS is 10% at 1000 bytes packet length. The PER and BER relationship is presented in Equation (4). Moreover, the PER refers to the probability of the correct received packet at the receiver side. The PER indicates a low reliability of the communication system when high PER. Also, the reliability of the communication in the ITS is indicated by the PER and BER. Focusing on the system's accuracy, both the PER and BER indicate the accuracy of the information received at the receiver. The packet lengths of 400 bytes are transmitted by the transmitter. As to the measurement of the results, the receiver can receive 1248 bits at a distance between the RSU and OBU of 1 m. Also, this situation promotes the accuracy of the receiver side in a communication system in the ITS.

Therefore, the proposed system can confirm that the MIMO technique and SDR technology improved the traditional system's performance. The SDR technology promotes convenience for engineers to configure communication systems. Furthermore, the throughput of the proposed system is more than that of the conventional system. The results show that the proposed system is able to operate for high speed data communication. From the reasons above, it allows the user to transmit huge data packets such as audio, image, and video. Table 3 shows the investigation of the average received power. When a vehicle moves far from the RSU, the average received power at the receiver decreases. The overall results demonstrate the improvement of the proposed system which improves the link quality of the ITS/DSRC system. As to the ETC systems, the use of the MIMO system improves the system's performance. Furthermore, when considering the collision avoidance system, the use of the proposed system can improve the accuracy of the warning message. The effect of this has increased road or traffic safety and the MIMO system has decreased the chance of an accident. Finally, the authors investigated the system's performance of the average correct received packet ratio. The result is the comparison between the distances of the RSU and OBU versus the average received power. Figure 10 presents the relationship of the average correct received packet ratio versus the distance between the RSU and OBU. The average correct received packets are counted under the same total number of transmitted packets. At 3 m, the results reveal that the proposed system received 415 packets more than the conventional system which received 390 packets. Our result confirms that the MIMO system received more packets than the traditional system. Figure 11 compares the average correct received packet versus the average received power. For example, at -80 dBm, the value shows the system's sensitivity and confirms that the receiver can receive packets from the transmitter. For -80 dBm, the transmitter is about 5 m from the receiver. The results indicate that the MIMO system can receive 70 packets and the conventional system can receive 45 packets. All our results promote the proposed system as being able to be operated with more efficiency than the conventional SISO system. The proposed system's use as an ETC system improves reliability for drivers, because when they are in front of the toll gate they are sure of the reliability of the payment data. In front of the toll gate, the proposed system reduces the waiting time because of a high system throughput that can send the data packet with a fast data stream. The effect is to reduce the waiting time in front of the toll gate, reduce the travelling time, save fuel, and most importantly reduce exhaust emissions in front of the toll gate. The average correct received packets ratio of the MIMO system is more than that of the conventional system. This

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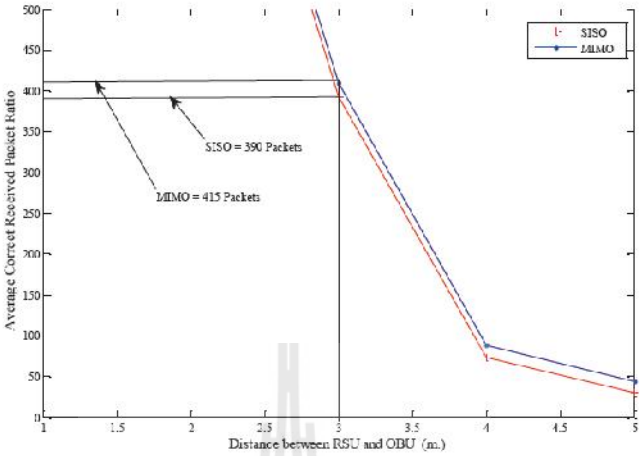

Figure 10. Average correct received packet ratio versus distance between the RSU and OBU

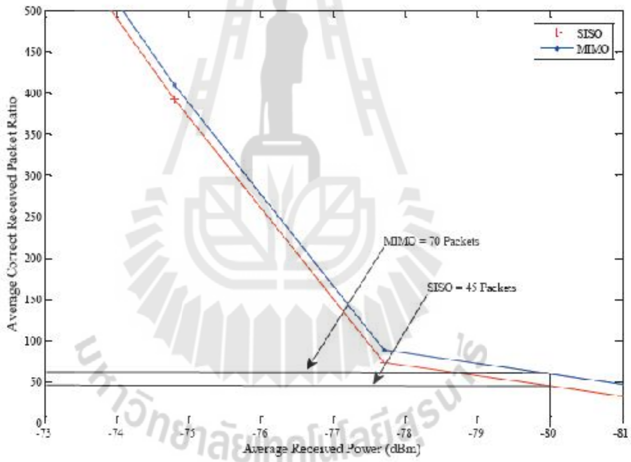

Figure 11. Average correct received packet ratio versus average received power (dBm)

MIMO system can receive more packets in the same time than the traditional system. Because of the limitations of the equipment with a low transmission power and a small gain from the antennas, this system cannot be implemented providing a coverage range of more than 5 m. In the future the authors will improve this limitation and experiment with vehicle movement at varying speeds of the vehicle. We have investigated the system's performance and compared it with the ITS/DSRC communication system.

Conclusions

This paper introduces an implementation of the SDR technology using the MIMO technique. The proposed system improves the ITS/DSRC conventional services. The authors apply the GNU Radio and USRP platforms to the IEEE 802.11p (WAVE-DSRC) standard. The PER, BER, average correct received packets, and throughput have been investigated by varying the distances between the RSU and OBU. The results will provide reliability for drivers to ensure that the proposed system can operate with more accuracy. In the future, the authors will improve and develop the system to support a moving vehicle.

Acknowledgement

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Preliminary Study of DSRC using MIMO technique and Software Defined Radio for ITS

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***Abstract*— The development of DSRC (Dedicate Short Range Communication) for ITS (Intelligence Transportation System) has been recently concerned for high speed data transmission. However, the existing DSRC technique provides a low speed data transmission. The searching for new techniques to support transmission requirement is still on focus. This paper introduces to apply MIMO (Multiple Input Multiple Output) technique and SDR technology to study the performance of 5.9GHz DSRC based on IEEE802.11p (WAVE-DSRC) standard. The experiment results show that both BER and throughput performances are improved by using the proposed system.**

Keywords- DSRC; ITS; SDR;MIMO

I. Introduction

ITS (Intelligence Transportation System) has been developed to solve the traffic problems such as traffic congestion, accidents and reduce the overall congestion cost. The final goal of ITS will improve the traffic efficiency and mobile safety without a new road construction required. IEEE802.11p is a standard used for DSRC (Dedicated Short Range Communication) communication system between RSU (Road Side Unit) and OBU (On Board Unit). DSRC is a short to medium range communication system and it is established for telecommunication exchanges between RSU and OBU system. DSRC provides a high speed radio link between RSU and OBU within a narrowband communication area. The most application of ITS is ETC or Electric Toll Collection system. ETC consist RSU locate on the road and OBU place on dash board or the roof of a car.

IEEE802.11p (WAVE-Wireless Access for Vehicular Environments) is a standard to be used in an outdoor propagation. An advantage of IEEE 802.11p [1] is achieved by using OFDM (Orthogonal frequency-division multiplexing) technique so it can eliminate the effect of multipath fading or ISI (Inter symbol Interference) problem. This standard is benefit for outdoor broadband communication such as DSRC (Dedicated Short Range Communication)[2], ITS (Intelligence Transportation System) [3] because of its endurance for multipath fading as well as supporting a high mobility user while providing a high data rate transmission.

For measuring equipments, the authors develop our own transmitter and receiver using SDR (Software Defined Radio) technology. Researcher can control waveform by 2 host computers and SDR change hardware problems to software problems. In [4], the researcher presented a basic concept to study GNU Radio and USRP (Universal Software Radio Peripheral). The results showed that GNU Radio and USRP is the rapid and low cost prototype suitable for any wireless technologies. The works in [5-6] presented an implementation of OFDM transmission by using USRP and GNU radio platform but many parameters of OFDM signals in IEEE 802.11p standard such as modulation type, power level, FFT bins and frame format are totally different from IEEE 802.11a. Although the implementation of IEEE802.11p standard was presented in [7] but it was an offline experiments. In this paper, USRPs and GNU Radio software are used to measure data in offline situation according to IEEE 802.11p standard. Many parameters such as packet error rate, bit error rate and throughput are collected.

MIMO (Multiple Input Multiple Output) technique is one of the most promising technology that overcomes fading channels while maintain the benefits of high data rate transmission as well as low bit error rate [8-9]. By using multiple antennas at both transmitter and receivers, the system with space-time coding can provide more reliable transmission than conventional system employing only one antenna at transmitter and receiver. Also MIMO system can improve other system performances such as high spectral efficiency, high system capacity, high coverage area and high gain. In this light, this paper adopts the concept of MIMO technique to apply on communication link between RSU and OBU with SDR technology. Also this technique is able to be implemented for practical use and comparatively easier than power control plus coding technique. Hence, it is believed that MIMO technique can defeat the effect of fading channel and be able to destroy impediment between RSU and OBU. However, so far in literatures, there has never been any report concerning this issue before.

This paper introduces an implementation of MIMO technique apply with SDR technology to enhance the performance of 5.9GHz IEEE802.11p for ITS purposes such as ETC communication between RSU and OBU. All system configurations are based on IEEE802.11p standard [10] which is one of the most recent standards for DSRC system. This is because the fading channel due to buildings effect around the road still performs the same for any other standards. In experimentation, both BER (Bit Error Rate) and throughput performances are investigated via observing the distance between RSU and OBU. The comparisons between proposed

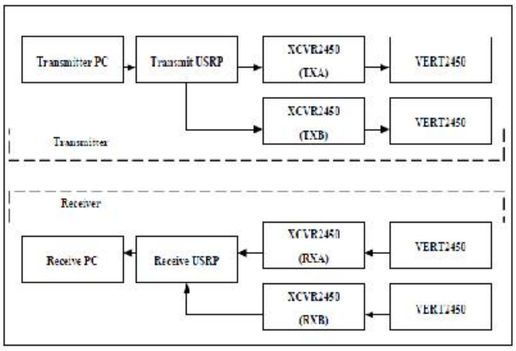

Figure1. Block Diagram of a system.

and conventional systems are also given in order to indicate a good of proposed technique. The remainders of paper are described as followed. The conventional DSRC, ITS system, MIMO technique, SDR technology and GNU Radio in section II. Then the system configuration used for experimentations are explained in section III including a system block diagram and equipment. In section IV, experiment setup and all results are discussions. Finally, the conclusion of this paper is given in section V.

TABLE I. IEEE.11P SPECIFICATIONS.

Service	Specification
Modulation type	QPSK,BPSK
Data rate	3-27 Mbps
Frequency band	5.8GHz
Number of data subcarriers	48
Number of cyclic prefix	4
Total subcarrier	52
OFDM symbol duration	$8\mu s$

II. ITS, IEEE802.11P (WAVE-DSRC), MIMO, SOFTWARE DEFINED RADIO TECHNOLOGY

A. ITS

Intelligent Transportation System is a new technology that occurs to improve traditional transport system. Main goal of ITS is improve traffic safety and solve the traffic problem without new road construction. Traffic problem is the main problem in many countries the government find solution to solve this problem. Many ITS system such as parking guidance system, intelligent traffic sign, traffic report and electric toll collection system. All of these, ETC is the most favorite system in the world. Because people can cash the tolls automatically by place the OBU on the dashboard or the top of a car. RSU located above the road and communicate with OBU. Then a wooden block is opening and a car can pass a toll gate. This method decrease travel time. But a surroundings around the toll gate cause an error to a communicate link between RSU and OBU. Because multi-path fading is occurs its affect to a communication channel. This paper represents an implement of

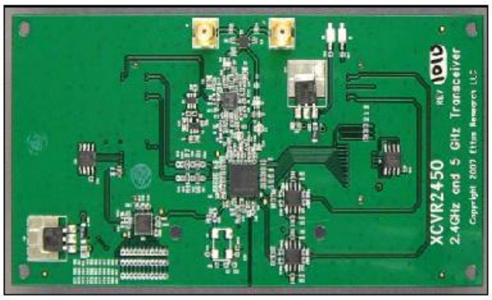

Figure2. XCVR2450 Daughter Board.

SDR and MIMO technology to study an improvement of conventional ITS system on ETC communication link between RSU and OBU.

B. IEEE802.11p (WAVE-DSRC) Standard

IEEE802.11p (WAVE) was developed from IEEE 1609 WAVE project and it was extended from IEEE802.11a by using OFDM technology. The IEEE802.11p standard operates in 5.85-5.925GHz bands. It differs from the old version with an increase of frame duration from 4 µs to 8 µs. The effect after applying OFDM symbol duration is that it can support higher user mobility and also decrease more inter-symbol-interference. This is because doubled OFDM symbol times also mean the extension of the cyclic-prefix duration. The parameters for IEEE 802.11p WAVE are described in Table I.

C. MIMO

There are two main techniques for MIMO encoder including spatial multiplexing and space-time coding. In this paper, the concept of space-time coding is chosen because its tolerance to fading channel caused by road surroundings is better than the other. The special case named as Alamouti STBC (Space Time Block Code) [8] is employed. The simplest form of Space Time Block Codes was invented by Alamouti in 1998. This code is designed for two-transmit antenna system. STBC operates on a block of input symbols, columns of the coding matrix represent time and rows represent antennas. Main feature of STBC is a very simple decoding scheme and the code matrix is given as

$$X_{n,t} = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \quad (1)$$

for Nr,Nt=2

At a given symbol period, two signals are simultaneously transmitted from the two antennas, namely from the first antenna and from the second antenna. In the next symbol period (t +), signal and are transmitted from the first and the second antenna, where denotes symbol period.

Columns of the matrix correspond to the antennas and a row corresponds to the time slots. This code matrix from (1) is orthogonal. At the receiver site, the space-time combiner

Figure3. Universal Software Radio Peripheral 1.

the received signals as follows (2):

$$\begin{pmatrix}\tilde{s}_1 \\ \vdots \\ \tilde{s}_2\end{pmatrix} = \frac{1}{\|H\|^2}\sum_{j=1}^{N_r}\begin{pmatrix} h^*_{1,j} r_{1,j} + h_{2,j} r^*_{2,j} \\ h^*_{2,j} r_{1,j} - h_{1,j} r^*_{2,j}\end{pmatrix} \quad (2)$$

for Nr,Nt=2.

and represents the estimated symbol in the codeword matrix. Represents the estimated channel from the transmit antennas and receive antenna and represents the summation of channel power per link.

D. SDR:Software Defined Radio and GNU Radio

SDR (Software Defined Radio) is a technology to decrease the complexity of radio transmission system by using software done the radio signal manipulate and processing. All of signal processing is done by using microcomputer. At the transmitter path before sending a signal on the air its must be convert a digital signal to analog signal by using DAC (Digital to Analog Converters) and then an analog signal go straight to a transmit antenna. At the receiver path a signal from receive antenna is an analog signal . To do a signal processing a signal must be converting to digital signal by using ADC (Analog to Digital Converter).

GNU radio is an open source software that control and processing a signal. GNU radio is a software package which creates by Python programming language and C++ programming language. Block and flow graph are create by Python and Signal processing are create by C++.GNU radio are working with USRP and user can develop their own code much the same as a radio engineer connects a sub device to make a radio communication system.

III. System Configuration

A. System Block Diagram

Fig.1 represents a transmitter and receiver. At the transmitter consists 1 host computer, 1 USRP, 2 XCVR2450 daughter board and 2 VERT2450 transmit antenna. At the transmitter a host computer connected with USRP to control transmit waveform and control all of parameter such as

Figure4. Experiment Setup.

modulation type, number of subcarriers, number of antenna , number of cyclic prefix and transmit frequency. Equipments at the receiver are the same as the transmitter but it work reversely.

B. Equipment

USRP (Universal Software Radio Peripheral) in fig.3 is a platform which developed by Ettus Research LLC. Inside the USRP have 2 main components to create a radio communication system. First is mother board. Mother board contains an Altera Cyclone EP1C12 Field Programmable Gate Array (FPGA. It has 4 ADCs which each running 12 bits per sample with 64 Msamples/sec and 4 DACs which running 14 bits per sample with 128 Msamples/sec. Second is daughter board that working in a field of RF-Front End. Fig.2 represents XCVR2450 daughter board it's providing radio frequency in dual band such as 2.4 GHz and 5.9 GHz. All components are assembly in one USRP box using 3A 6V power supply. Finally, USRP is connecting to the host PC with USB 2.0(Universal Serial Bus 2.0).

IV. Experiment Setup ,Result and Discussion

A. Experiment Setup

Fig.4 showed the experiment setup. The author setup OBU and RSU parameter follows IEEE802.11p (WAVE-DSRC) standard and assume situation relate to ETC operation. RSU place on a tower located beside the road high 1.5 m. OBU place the top of a car. Because of hardware limitation such as transmit/receive antenna VERT2450 gain is 3dBi cause the communication range between RSU and OBU is 5m and measure 10 times/point. An experiment parameters are: modulation type qpsk, data rate 1Mbps and packet length is 400. The authors marking 5 points from RSU to OBU. After that we measured the data in offline method then we get packet number, number of correct receive packet and number of receive packet. The authors use (3) to calculated Packet Error Rate (PER), and (4) for (BER) observing with a distance between RSU and OBU.

TABLE II. EXPERIMENTATION RESULTS BER, THROUGHPUT VS. DISTANCE (M.)

Variable	Distance (m.)	Conventional System	MIMO 2x2
BER	1 2 3 4 5	$1.25x10^{-3}$ $2.31x10^{-3}$ $4.57x10^{-3}$ $8.76x10^{-3}$ $1.10x10^{-2}$	$1.19x10^{-3}$ $2.23x10^{-3}$ $4.48x10^{-3}$ $8.30x10^{-3}$ $1.00x10^{-2}$
Throughput	1 2 3 4 5	$1.81x10^{6}$ $1.18x10^{6}$ $4.80x10^{5}$ $8.88x10^{4}$ $3.81x10^{4}$	$1.90x10^{6}$ $1.23x10^{6}$ $4.97x10^{5}$ $1.07x10^{5}$ $5.37x10^{4}$

$$PER = (1 - \left(\frac{n\_right}{pktno} \right)) x100\% \quad (3)$$

$$1 - PER = (1 - BER)^{L} \quad (4)$$

n_right is a number of correct receive packet

$pktno$ is packet number

L is Packet length

First, the authors extracted an offline data to compute average PER after that calculate BER compare with how long from RSU to OBU. Then compute throughput and keep the result to analysis and discussions.

B. Result and Discussions

Table II.represents a compare of conventional system and MIMO 2x2 systems at a distance from OBU and RSU equal 5 m. that show a different value. The result showed that BER of multiple antenna system less than conventional system related to improve system performance because it increases reliability of the ETC system and improve credibility of user. This result can improve authenticity of ETC system and attractive many people turn to use ETC system. From above a reason ETC is reduction in the man-hour required as the system does not require any human to work at the toll gate. Then reduction traffic jams because a car can pass the toll gate more quickly. When a car can pass toll gate quickly, time saving occur and fuel save is occur. And the most important reason is reduce an emission around toll gate. Focus on throughput vs. distance between RSU and OBU this results show that a throughput of MIMO system more than conventional system can indicate a good of the purpose system and improved system performance. These results showed that we can transmit the data rapidly. As a result a wooden block is opening speedy. Then drivers cannot stop and accelerate forward the toll gate it could be save the fuel and save the energy of a car.

V. CONCLUSION

This paper represents a preliminary study of implementation SDR technology and applies MIMO technique to improve ITS/DSRC system such as ETC system. The results can lead a good way to develop and increase ITS and DSRC system performance by apply MIMO technique. Which an advantages of SDR such as translate hardware problems to software problems and cheap components are leading researchers to building a communication system by themselves. Next work the author planning to improve a system that supports vehicle mobility and develop the software to be stability.

ACKNOWLEDGMENT

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Performance Evaluation on Using IEEE802.11p for Indoor DSRC Approach

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Abstract **IEEE 802.11p has recently proposed for Dedicated Short Range Communication (DSRC) which supports the high speed data transmission for Intelligent Transportation System (ITS). Most aspects for this standard depict the link between roadside equipments to vehicles under outdoor scenarios. However, when vehicles move to undercover car parking or indoor constructions, the transmission link is automatically detached from roadside equipments. Therefore, it is a better approach if vehicles can extend their services under indoor scenarios via IEEE 802.11p. In this light, this paper presents an investigation on using this standard for indoor approach. The real prototype using GNU Radio and USRP (Universal Software Radio Peripheral) has been implemented for data measurements. The results reveal the possibility of using this standard for indoor communication.**

Keywords-component; GNU Radio; USRP; DSRC; ITS

I. Introduction

IEEE802.11p (WAVE-Wireless Access for Vehicular Environments) is a standard to be used in an outdoor propagation. An advantage of IEEE 802.11p [1] is achieved by using OFDM (Orthogonal frequency-division multiplexing) technique so it can eliminate the effect of multipath fading or ISI (Inter symbol Interference) problem. This standard is benefit for outdoor broadband communication such as DSRC (Dedicated Short Range Communication)[2], ITS (Intelligence Transportation System) [3] because of its endurance for multipath fading as well as supporting a high mobility user while providing a high data rate transmission.

In general, the vehicles having OBU (On Board Unit) exchange outside information by communicating with RSU (Road Side Unit) which is located along the traffic road. This communication is no longer available when vehicles move to undercover car parkings or indoor constructions. The possible transmission for indoor scenarios can be achieved by other communication standards. However, it is a better approach if vehicles can still use their services via the same standard available for both outdoor and indoor. In this light, this paper presents the feasibility study on using IEEE 802.11p for indoor DSRC approach. So far in literatures, there has never been any report on using this standard for an indoor communication.

For measuring equipments, the authors develop our own transmitter and receiver using SDR (Software Define Radio) technology. In [4], the researcher presented a basic concept to study GNU Radio and USRP (Universal Software Radio Peripheral). The results showed that GNU Radio and USRP is the rapid and low cost prototype suitable for any wireless technologies. The works in [5-6] presented an implementation of OFDM transmission by using USRP and GNU radio platform but many parameters of OFDM signals in IEEE 802.11p standard such as modulation type, power level, FFT bins and frame format are totally different from IEEE 802.11p. Although the implementation of IEEE802.11p standard was presented in [7] but it was an offline experiments. In this paper, USRPs and GNU Radio software are used to measure data in real time according to IEEE 802.11p standard. Many parameters such as packet error rate, packet loss, throughput and channel power are collected.

II. Measurement Setup and Results

This paper has presented the measured data to investigate the use of IEEE 802.11p for indoor DSRC approach. From all results, it concludes the possibility of using this standard for indoor with the same quality as outdoor only if the transmit power is high enough and there is no obstruction between transmitter and receiver. For the future work, the other technique such as MIMO will be applied to improve the performance of using this standard for indoor approach.

Figure 1. USRP (Universal Software Radio Peripheral)

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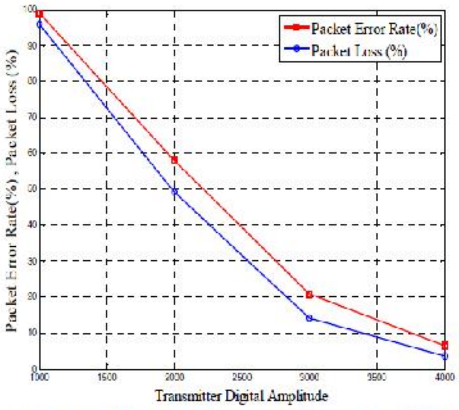

FIGURE 2. PACKET ERROR RATE AND PACKET LOSS VS TRANSMITTER Digital Amplitude for BPSK Modulation

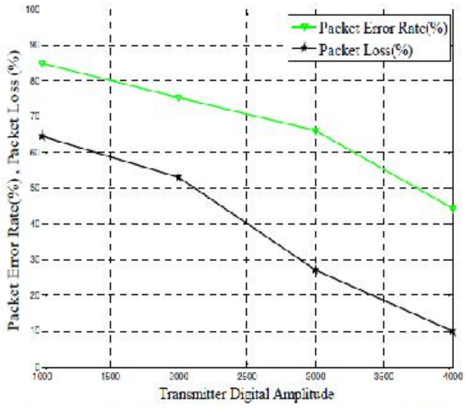

Figure 5. Packet Error Rate and Packet Loss Vs Transmitter Digital Amplitude for QPSK Modulation

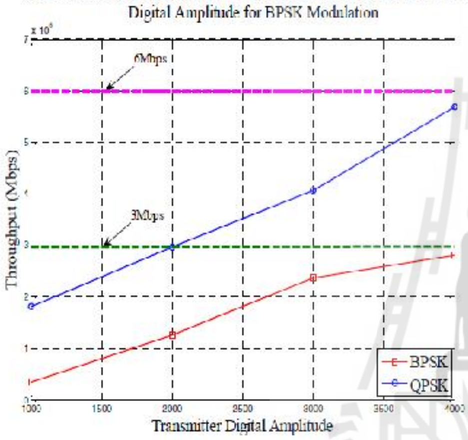

Figure 3. Throughput Vs Transmitter Digital Amplitude for BPSK and QPSK Modulations

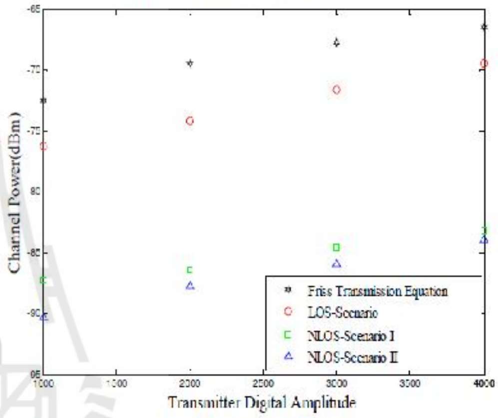

Figure 6. Average Channel Power Vs Transmitter Digital Amplitude

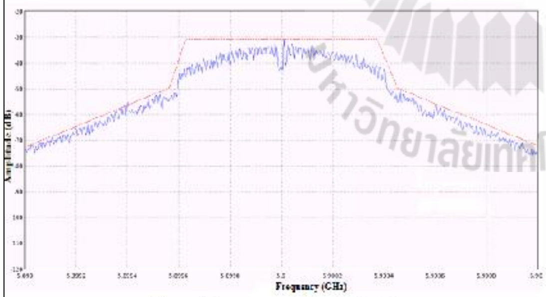

Figure 4. Spectrum mask of IEEE802.11p

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BIOGRAPHY

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