



**ANALYSIS ON NETWORK PERFORMANCE BY
CONSIDERING DOPPLER SHIFT EFFECT FOR
CONNECTED CAR WIRELESS MOBILE
COMMUNICATION**

by

**AZARUL FAHMIN BIN AB HAMID
(1830612735)**

A thesis submitted in fulfillment of the requirements for the degree of
Master of Science (MECHATRONIC ENGINEERING)

**Faculty of Electrical Engineering Technology
UNIVERSITI MALAYSIA PERLIS**

2022

ACKNOWLEDGEMENT

First and foremost, I would like to express my deepest and sincere gratitude to my supervisor Ir. Ts. Dr. Md Tasyrif Bin Abdul Rahman and co-supervisor Asc. Prof. Dr Norasmadi Bin Abdul Rahim. They gave me plenty of advice, support and common knowledge through my research. Due to their willingness to motivate me contributed tremendously. I want to thank them for spare their time to keep track on my project progress from Master Degree of Science Mechatronic Engineering. Thanks to Dr. Anas Abdul Rahman also for guide and give me the knowledge regarding presentation preparation, thesis preparation and etc.

Furthermore, I would like to thanks to Muhammad Asmu'ie, Muhammad Muzzamil, Muhammad Afiq, Zairul Tan and many more that I had not stated direct or indirect for helping me through the spare some idea or creating my research more interesting.

Al-Fatihah to my mother Halimah Bt Saad that died last year. She is the person that encourage me to further this study even though I want to stop furthering study since my Diploma. Her sacrifices and support could not be repaid. Last but not least, I would like to honorable thank to my family for their encouragement and understanding on me to making this research.

TABLE OF CONTENTS

	PAGE
DECLARATION OF THESIS	i
ACKNOWLEDGEMENT	ii
TABLE OF CONTENTS	iii
LIST OF TABLES	vi
LIST OF FIGURES	vii
LIST OF ABBREVIATIONS	xi
LIST OF SYMBOLS	xiv
ABSTRAK	xvi
ABSTRACT	xvii
CHAPTER 1 : INTRODUCTION	1
1.1 Background	1
1.2 Research Problem	5
1.3 Research Question	6
1.4 Objective	6
1.5 Scope	7
CHAPTER 2 : LITERATURE REVIEW	8
2.1 Introduction	8
2.2 Existing Wireless Sensor Communication Technology	9
2.2.1 Overview of Wireless Communication	9

2.2.2	Cellular Communication	12
2.2.3	The Challenge in Wireless Communication for High Velocity Mobile Communication Node Movement.	14
2.2.3.1	Path loss measurement and analysis	18
2.2.3.2	Doppler shift effect measurement and analysis	22
2.2.3.3	Latency Measurement and Analysis	24
2.2.4	Long Range Low Power Wide Area Network (LoRaWAN)	27
2.2.4.1	LoRaWAN Limitation	29
2.2.4.2	LoRa and LoRaWAN Evaluation for The Wireless Sensor Network	29
2.2.5	Comparison between Wireless Sensor Communication Solutions	31
2.3	Vehicular Network Technology for Intelligent Transport Systems (ITS)	32
2.4	Past Implementation Studies	40
2.5	The Gap in Existing Knowledge	43
CHAPTER 3 : METHODODOLOGY		44
3.1	Introduction	44
3.2	Communication Node Development	45
3.3	Webserver Deployment	51
3.4	Cells Network System Development for LoRa	51
3.4.1	Fast Base Station Switching	54
3.4.1	Macro Diversity Handover	55
3.5	Data collection and Integration System Testing	56
3.5.1	Path Loss with Doppler Shift Effect Data Collection	59
3.5.2	Latency Data Collection	63
3.6	Analysis Design Flow	64
3.6.1	Latency analysis based on the type of environment and vehicle speed	66

3.6.2	Latency Analysis Based on Handover Effect and Vehicle Speed	67
3.6.3	Path Loss Analysis Based on The Type of Environment and Vehicle Speed	68
3.6.4	Network throughput analysis based on vehicle speed	69
CHAPTER 4 : RESULTS & DISCUSSION		70
4.1	Introduction	70
4.2	DOE 1: Latency analysis based on the type of environment and vehicle speed.	70
4.3	DOE 2: Latency Analysis Based on Handover Effect and Vehicle Speed	76
4.4	DOE 3: Path Loss Analysis Based on The Type of Environment and Vehicle Speed.	84
4.5	DOE 4: Network Throughput Analysis Based on Vehicle Speed	94
4.6	Discussion Summary	102
CHAPTER 5 : CONCLUSION		103
5.1	Introduction	103
5.2	Conclusion	104
5.3	Recommendation	105
REFERENCES		106
LIST OF PUBLICATIONS		114
APPENDIX A: Code For Get Data From Device To Server		115
APPENDIX B: Gps Coding		121
APPENDIX C: Webserver PHP Code		123
APPENDIX D: Visualization Script		125

LIST OF TABLES

		PAGE
Table 2.1	IEEE 802.11 standards and technical specifications (Memon et al., 2021).	11
Table 2.2	Simulation parameters (Noh et al., 2016).	23
Table 2.3	LoRaWAN main characteristics (Rizzi et al., 2017).	28
Table 2.4	Comparison among LoRaWAN and others LPWAN technologies.	31
Table 2.5	Comparison of communication technologies used in smart environments (Ahmed et al., 2016).	39
Table 4.1	DOE 3 Summarize path loss data based on environment on each communication module.	91
Table 4.2	DOE 3 Summarize path loss data based on vehicle speed for each communication module.	92

LIST OF FIGURES

	PAGE
Figure 1.1	Three important domains of connected car. 1
Figure 1.2	Topology of CAN-bus In-Vehicle Network (Pohlmann et al., 2014). 2
Figure 2.1	Timeline of the Samuel Morse's activities (1832-1846) (van der Kooij, 2018). 10
Figure 2.2	Cellular communication system cell (Ur-Rehman & Zivic, 2018). 12
Figure 2.3	Cellular network architecture for a mobile distributed system (Bello et al., 2018). 13
Figure 2.4	Communication model (N. Cheng et al., 2014). 14
Figure 2.5	Vehicle moving within cellular area. 15
Figure 2.6	Cellular Network system. 17
Figure 2.7	Doppler shift effect model where velocity = V , distance = Δd , travel distance = Δt and LOS angle = θ . 18
Figure 2.8	Comparison of the path loss of the tuned Free-space model, Hata model in open area and the measurement (Wei et al., 2010). 22
Figure 2.9	Simulation scenarios : Two-way vehicle Environments (Vehicle to Infrastructure (V2I), Vehicle to Vehicle (V2V)) (Noh et al., 2016). 23
Figure 2.10	General network architecture. The end devices are connected to base stations or access points, which further communicate

	with one another through router switches mostly by wired networks (Jiang et al., 2019).	25
Figure 2.11	The latency formation of single-hop and multihop communication (Jiang et al., 2019).	26
Figure 2.12	Overview the connection interactions to vehicles (Lu et al., 2014).	32
Figure 2.13	The sensor features (Paier et al., 2007).	34
Figure 2.14	The connection between vehicle to vehicle for the safety awareness (Lu et al., 2014).	35
Figure 2.15	MEC system architecture (Zhdanenko et al., 2019).	41
Figure 2.16	MQTT-CV illustration (Chouali et al., 2020).	42
Figure 3.1	Research flow chart.	44
Figure 3.2	SIM900 Communication node.	46
Figure 3.3	SIM800L Communication node.	46
Figure 3.4	SIM5360E Communication node.	47
Figure 3.5	(a) LoRa Communication node for moving vehicle. (b) LoRa Communication node that will act as Base Station.	47
Figure 3.6	Actual hardware used on experiment (A) SIM800L gsm with GYNEO6MV2 (B) SIM5360E gsm module and (C) GYNEO6MV2 gps module .	48
Figure 3.7	Example of data collection table for communication node in PHP.	51
Figure 3.8	LoRaWAN cellular area.	53
Figure 3.9	Fast Base Station Switching network architecture.	54

Figure 3.10	Macro Diversity Switching network architecture.	55
Figure 3.11	Experiment locations on different environment condition. (a) Jalan Arau-Changlun rural area beside paddy field road. (b) Jalan Bukit Kayu Hitam-Changlun sub-urban area. (c) Jalan Kangar urban area.	57
Figure 3.12	OpenSignal Apps to determine base station location.	58
Figure 3.13	Doppler shift effect model.	60
Figure 3.14	Flow chart DOE 1	66
Figure 3.15	Flow chart DOE 2.	67
Figure 3.16	Flow chart DOE 3.	68
Figure 3.17	Flow chart DOE 4.	69
Figure 4.1	DOE 1 Rural result.	71
Figure 4.2	DOE 1 Suburban result.	72
Figure 4.3	DOE 1 Urban result.	73
Figure 4.4	DOE 1 summarize result based on area and communication module where average = X and standard deviation = σ .	74
Figure 4.5	DOE 2 Rural result.	77
Figure 4.6	DOE 2 Suburban result.	79
Figure 4.7	DOE 2 Urban result.	81
Figure 4.8	DOE 2 summarize result based on area and communication module where average = X and standard deviation = σ .	83
Figure 4.9	DOE 3 Rural result.	85
Figure 4.10	DOE 3 Suburban result.	87

Figure 4.11	DOE 3 Urban result.	89
Figure 4.12	DOE 3 summarize result based on area and communication module.	93
Figure 4.13	DOE 4 Rural result.	95
Figure 4.14	DOE 4 Suburban result.	97
Figure 4.15	DOE 4 Urban result.	99
Figure 4.16	DOE 4 summarize result based on area and communication module.	101

©This item is protected by original copyright

LIST OF ABBREVIATIONS

IoT	Internet of Things
EC	Edge Computing
LoRa	Long Range Low Power communication
ITS	Intelligent Transportation System
ECUs	Engine Control Unit
DTC	Diagnostic Trouble Code
BCM	Body Control Module
ECM	Engine Control Module
CAN	Control Area Network
UBI	Usage-Based Insurance
DMS	Distributed Measurement System
IoV	Internet of Vehicles
V2V	Vehicle to Vehicle
V2I	Vehicle to Infrastructure
V2R	Vehicle to Roadside
VANet	Vehicular Ad-hoc Network
V2G	Vehicle to Grid
V2X	Vehicle to Everything
LTE-M	LTE-Machine Type Communication
NB-IoT	Narrowband IoT
LoRaWAN	Long Range Low Power Wide Area Network
OFDM	Orthogonal Frequency-Division Multiplexing
GPRS	General Packet Radio Service
CSS	Chirp Spread Spectrum

MQTT	Message Query Telemetry Transport
MEC	Mobile Edge Computing
LTE	Long-Term Evolution
GPS	Global Positioning Service
GSM	Global System for Mobile Communication
RF	Radio Frequency
LAN	Local Area Network
MIMO	Multiple Input Multiple Output
DSSS	Direct-Sequence Spread Spectrum
FSSS	Frequency-Hopping Spread Spectrum
PCS	Personal Communication System
LPWA	Low Power Wide Area
LOS	Line-of-Sight
QoS	Quality-of-Service
M2M	Machine to Machine Communications
SF	Spreading Factors
ISM	Industrial, Scientific, and Medical
LPWAN	Low Power Wide Area Network
RFID	Radio Frequency Identifications
UWB	Ultra-Wideband
A.S.A.	Advanced Safety Assistant system
D2D	Device to Device Interactions
Wi-Fi	Wireless Fidelity
WSN	Wireless Sensor Network
PAN	Private Area Network

MEC	Mobile Edge Cloud
VNF	Virtual Network Function
AWS-IoT	Amazon Web Services Internet of Things
PHP	Hypertext Preprocessor
MySQL	My Structured Query Language
API	Application Programming Interface
GFSK	Gaussian Frequency-shift Keying Modulation
DBPSK	Differential Binary Phase-shift Keying
BPSK	Binary Phase-shift Keying
MQTT-CV	MQTT within Connected Vehicles
RSSI	Receive Signal Strength Indicator

©This item is protected by original copyright

LIST OF SYMBOLS

$FSPL(db)$	Free Space Path Loss(db)
f_c	frequency
h_t	Height of Transmitter
h_r	Height of Receiver
d	distance
v	velocity
c_o	Speed of light
P_t	Transmitted power
G_t	Transmitter antennal gain
G_r	Receiver antenna gain
L	System loss factor
λ	Wavelength in meters
F_d	Doppler frequency
GHz	Gigahertz
MHz	Megahertz
T_x	Transmitter
R_x	Receiver
F_o	Carrier frequency
$kbps$	Kilo bit per second
$mbps$	Mega bit per second
$Gbps$	Giga bit per second
bps	bit per second
km	kilometer

km/h	kilometer per hour
lat	latitude
lon	longitude
r	radius
ms	millisecond
\bar{X}	average
σ	standard deviation

©This item is protected by original copyright

ANALISIS TERHADAP PRESTASI RANGKAIAN DENGAN MENGAMBIL KIRA KESAN ANJAKAN DOPPLER TERHADAP KOMUNIKASI MUDAH ALIH TANPA WAYAR UNTUK KENDERAAN TERHUBUNG

ABSTRAK

Teknologi kenderaan terhubung sepatutnya menjadi batu kunci untuk merevolusikan dalam bidang automotif. Konsep kenderaan terhubung ini muncul sebagai salah satu reka bentuk tersendiri bagi kereta generasi baharu, keupayaan untuk menyediakan pemandu dengan dimensi perkhidmatan baharu melalui komunikasi tanpa wayar. Daripada maklumat asas seperti lokasi, keselamatan dan kini prestasi enjin kenderaan kereta itu sendiri boleh dipantau. Teknologi kenderaan terhubung terdiri daripada beberapa komponen penting. Kenderaan itu sendiri, pautan komunikasi dan lapisan aplikasi. Penyelidikan ini memfokuskan kepada komponen komunikasi di mana kesan alam sekitar seperti anjakan doppler dan ketumpatan kawasan dianalisis. Terdapat beberapa masalah, telah dikenal pasti seperti kesan anjakan doppler ini akan menyebabkan kelewatan kepada komunikasi, pergerakan kelajuan tinggi akan menyebabkan kenderaan menukar kawasan selular dengan kerap dan masalah ini menghasilkan kelewatan semasa proses penyerahan. Kemudian kebanyakan pengangkutan halaju tinggi menggunakan rangkaian peribadinya sendiri untuk aplikasi pemantauan. Disebabkan masalah tersebut, penyelidikan ini menjalankan eksperimen pada rangkaian untuk modul komunikasi 2G, 3G dan LoRA dengan menggunakan SIM900, SIM800L dan SIM5360E untuk menganalisis kesan kehilangan laluan daripada anjakan doppler. Daripada eksperimen tersebut, kajian membuktikan terdapat kesan daripada anjakan doppler dan kesannya meningkat dengan ketara dengan perubahan persekitaran dari luar bandar ke bandar. Dalam kajian ini juga, eksperimen kelewatan penyerahan dijalankan pada setiap kelewatan komunikasi. Daripada eksperimen tersebut analisis telah dibuat ke atas keputusan dan membuktikan terdapat kesan daripada kesan anjakan doppler terhadap kelewatan penyerahan. Berdasarkan semua penemuan itu, penyelidikan menyimpulkan SIM5360E modul komunikasi dengan rangkaian 3G sebagai modul komunikasi terbaik dengan 10% hingga 20% lebih baik dalam prestasi komunikasi dan Pensuisan Stesen Pangkalan Cepat (FBSS) sebagai teknik penyerahan terbaik dengan 12% kelebihan dalam prestasi.

ANALYSIS ON NETWORK PERFORMANCE BY CONSIDERING DOPPLER SHIFT EFFECT FOR CONNECTED CAR WIRELESS MOBILE COMMUNICATION

ABSTRACT

Connected car technology ought to be a keystone of revolutionizing the automotive area. The concept of a so-called connected car has recently emerged as one of the distinctive designs of new generation automobiles, with the ability to provide drivers with a new dimension of services through wireless communication. The performance of the car's engine can now be monitored from basic information like location and security. Connected cars consist of some important components, namely the vehicle itself, communication link and application layer. This research focuses on communication component, where the environmental effects such as doppler shift and area density are analyzed. A few problems have been identified including the doppler shift effect which will cause a communication delay, high speed movement which will cause the vehicle to frequently change cellular areas, consequently causing delays during handover process. The majority of high-speed transportation uses a private network of its own for monitoring purposes. This study conducted an experiment on a network for 2G, 3G, and LoRA communication modules by using SIM900, SIM800L and SIM5360E in order to study the impact of doppler shift on path loss. The experiment demonstrated that there is a doppler shift effect, and that the effect increases noticeably as one moves from a rural to an urban environment. The experiment on handover delay is run in this study on each communication delay as well. Analysis of the data from that experiment shows that the doppler shift effect has a negative impact on handover delay. The study concludes that SIM5360E, a communication module with a 3G network, is the best communication module with 10% to 20% better performance in each analysis and that Fast Base Station Switching (FBSS) is the best handover technique based on all of those findings with 12% better result.

CHAPTER 1 : INTRODUCTION

1.1 Background

Connected car technology nowadays has grown rapidly to becoming one of the important components in Intelligent Transportation System (ITS) (Hamid et al., 2017b). The concept of a so-called connected car has recently emerged as one of the distinctive designs of new generation automobiles, with its ability to provide drivers with a new dimension of services through wireless communication (Andrade et al., 2017). Basic information such as location and security enables owner to monitor the vehicle engine performance. Additionally, vehicles connected to network infrastructure have the ability to communicate with an organisation in charge of traffic control in order to receive information about potential hazards on the road or instructions for speed and route that will improve traffic flow (Berdigh & Yassini, 2017). Connected car consists of three important domains as depicted in Figure 1.1; the internal network and Electronic Control Units (ECUs), the application layer where the data from the vehicle will end up and the communication link which links both domains (Un-Noor et al., 2017).

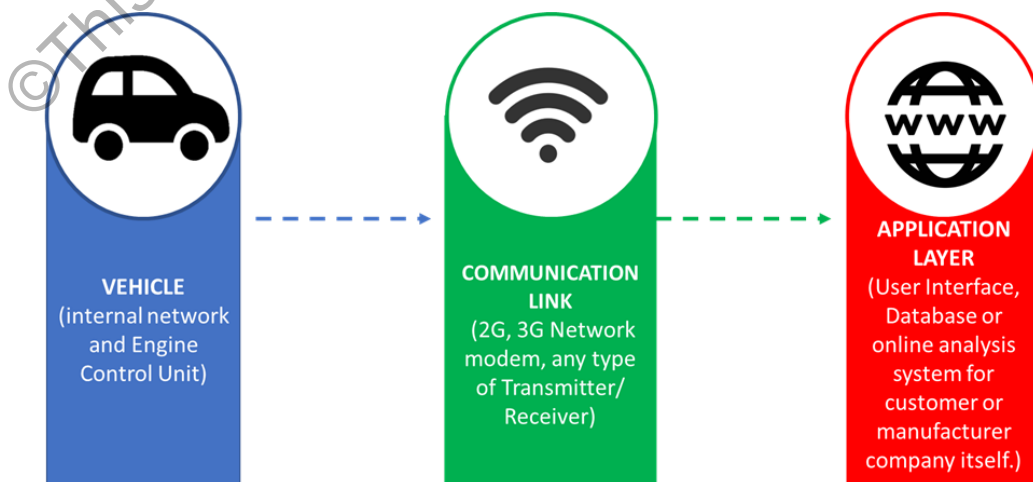


Figure 1.1 Three important domains of connected car.

In recent decades, modern cars have become no more than mechanical instruments through extensive use of electronic components. A large number of ECUs is used to control and monitor the status of vehicles connected to various kinds of buses (Bhosekar & Khatavkar, 2018). The in-vehicle network of buses and electrical equipment reduces the challenges of designing, repairing and refitting vehicles. Those with little understanding of vehicles can diagnose their vehicle through a Diagnostic Trouble Code (DTC) or corresponding firmware reprogramming can be used to improve the vehicle's performance (Vrachkov & Todorov, 2018). Therefore, the in-vehicle network benefits manufacturers, drivers, and after-sales support. Additionally, the in-vehicle network made it simpler to connect the large number of sensors and actuators in contemporary vehicles to the electrical system. Every control part in the vehicle will have its own ECUs as illustrated in Figure 1.2, for example, Body Control Module (BCM) for controlling body part in vehicles like power windows, interior light and radio and Engine Control Module (ECM) for controlling fuel injector and ignition spark plug. All ECUs will communicate with each other through Control Area Network (CAN) busses (Bachihal & Yashwanth, 2020).

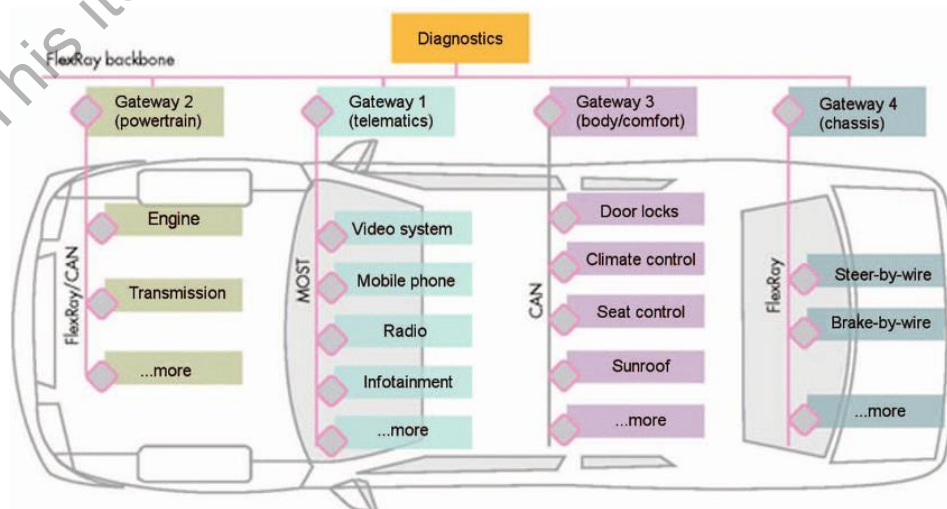


Figure 1.2 Topology of CAN-bus In-Vehicle Network (Pohlmann et al., 2014).

The data from the vehicle will be useful at the application layer. Through a communication link, the cloud will receive the data from in-vehicle networks. Vehicle owners, manufacturers, and after-sales service providers can analyse and use this data (Pillmann et al., 2017). There are many advantages of using the analysed data for real-time vehicle data collection, including data on frequency of hard acceleration or braking, distance travelled, travel time, harsh cornering, and speed. These data are collected with the help of in-car sensors or mobile apps and are used by insurers to offer individualized premium plans to their users based on their specific driving behaviour known as Usage-Based Insurance (UBI) (Zhuo & Huang, 2019). Data can also be used by insurers including offering preventive maintenance and other value-added suggestions to users, better detection of fraudulent claims, better customer selection (focus on less risky, more loyal customers) and segmentation, creating products with improved risk-pricing and rating capabilities, creating more effective marketing campaigns and improving up/cross selling. Analysis of telematics data can even help insurers in easier car crash liability detection, as such data can be helpful in understanding all aspects of car crash better, including impact force, whiplash, soft tissue injury and broken bones (Händel et al., 2014).

A communication link, also known as a "application layer," is an external wireless communication path that connects a vehicle to the internet. Unlike in-vehicle network, communication link needs to be wireless because of the vehicle mobility. Wireless communication generally works through electromagnetic signals that are broadcasted by an enabled device within the air, physical environment or atmosphere (Elkhouly & Mohajer, 2020). The sending device can be a sender or an intermediate device with the ability to propagate wireless signals. The communication between two devices occurs

when the destination or receiving intermediate device captures these signals, creating a wireless communication bridge between the sender and receiver device. Wireless communication has various forms, technology and delivery methods including: Satellite communication, Mobile communication, Wireless Network communication, Infrared communication, and Bluetooth communication (Ur-Rehman & Zivic, 2018). However, the principal design problem encountered in wireless or mobile radio has been how to overcome the distortion of received signals by a time-varying and frequency-selective propagation path. Radio waves near the ground do not travel over a single well-defined radio path as in free space; they are scattered against reflecting obstacles in the vicinity of the mobile antenna. Reflected waves may add destructive interference, causing the received signal to disappear or become heavily attenuated at certain locations (Kagawa et al., 2018). A moving device, receives a resulting signal that is rapidly varying in time (Goswami & Kumar, 2018). This effect is called fading because of doppler shift (C. Zhu et al., 2019). Without improvement of the quality of communication links, connected car system will lack of vehicle information sharing communication performance due to the increase in vehicle speed and data packet size. To solve this problem, recently, the latest technologies development in ITS is Internet of things (IoT) for car, actively being pursued by researchers around the world that can be implemented in the automotive areas, specifically vehicle connectivity communication (F. Zhu et al., 2020). The use of mobile technology especially for cloud connectivity access through mobile devices such as laptops and smartphones is essential in this field. It is expected that the connectivity between car and internet will be massive towards the development of autonomous car. Through the process of the system, one of the commonly used methods for networking or connectivity purposes is cellular network or mobile network communication in term of IoT technology.

1.2 Research Problem

In a mobile communication cellular system, electronic switching from one cell frequency to another cell frequency is carried out without interruption and without a base station operator or manual switching as the distributed mobile transceivers move from cell to cell during ongoing continuous connectivity. This is known as handover or handoff. Typically, the new base station that should serve it will automatically select a new channel for the mobile device. The mobile device then switches automatically from the current channel to the new channel and continues communication (Abboud et al., 2015). Due to the decision-making and execution process time, this process will cause data transmission delays during communication sessions.

Furthermore, because most cell area networks range between one and five kilometres, high velocity of mobile communication device movement changes the area of the cell network rapidly (Chen et al., 2021; Jingyu, 2021; Ke et al., 2019).

Moreover, high velocity of mobile communication module movement can cause Doppler Shift Effect on communication frequency (L. Wang et al., 2019; Yi et al., 2020). Doppler shift is a frequency distortion effect that affects the transmitter's carrier frequency.

Lastly, with poor network performance on communication module that effected by the latency and doppler shift issue it could affect the data integrity between sender and receiver.

1.3 Research Question

In a few years to come, connected car system will become an important technology. Therefore, to overcome the poor communication link during vehicle moving in urban area road, experiment on path loss and handover delay of cellular communication should be conducted. The research questions are as follows:

- i. What is the best handover technique?
- ii. What is the best frequency range to reduce the doppler effect on communication link?
- iii. What is the best communication technology for a connected car system?

1.4 Objective

The research is in various environments, specifically, rural, sub-urban and urban areas. Hence, the objectives of this study that need to be accomplished are as follows:

- i. To analyze path loss effect on network for 2G, 3G and LoRA communication modules by considering doppler shift effect.
- ii. To determine handover delay effect on the network for selected communication modules.
- iii. To propose the best modem based on the network performance for wireless mobile communication.

1.5 Scope

The scope of this study is to analyze cellular network performance for vehicle wireless mobile communication. The Global System for Mobile Communication (GSM) modem cellular network for 2G and 3G has been chosen as the wireless mobile communication to obtain results for the parameters of latency, path loss of the mobile communication, and doppler shift effect toward the car speed. The GSM modem uses three different frequency bands, 900MHz for 2G, 1800MHz and 2100MHz for 3G. The data on the factors namely distance of the environment (rural, urban and sub-urban) and specific speed of the vehicle are analyzed from the base station. Furthermore, for non-cellular networks, the Long-Range Wide Area Network (LoRaWAN) will be selected with frequency between 866MHz ~ 915MHz. The LoRaWAN system will be tested using the same analysis and an additional handover system is implemented to enable LoRa to providing a cellular style low data rate communication network system. Vehicle speed that will be experiment in this research is from 40 KM/H to 70 KM/H. The Perlis region has been chosen as the site for the experiment.