A Feasibility Study of a Wi-Fi-Based Vehicular Ad Hoc Network in the Westfield Shopping Mall Parking Lot using Field Trial Measurements and Simulation

by

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Abstract

Vehicular Ad Hoc Networks (VANETs) play an important role in reducing car accidents on the road as well as in the parking lots of large shopping malls. Providing connectivity as well exchanging warning messages among the vehicles in the parking areas could potentially reduce car accidents. An empirical study using radio propagation measurements to get an insight into the performance of a VANET system in the shopping mall environment is required to assist the efficient design and deployment of such systems. In this thesis, an empirical investigation using field trial measurements (i.e. propagation measurements) to study the performance of an IEEE 802.11n-based VANET in the parking lot of the West City Auckland shopping mall is described and its results are reported. In the investigation, received signal strength, packet send/receipt and response times were measured between two experimental vehicles equipped with 802.11n cards. Received signal strengths were found to have ranged from -45 dBm to -92 dBm in the parking lot. The distance coverage between two experimental vehicles where warning messages were sent successfully were up to 57 m, 17.5 m, 9.4 m, and 68 m at parking levels 1, 2, 3, and the roadside, respectively. Simulations were performed to generalize the measurement results. This thesis also investigates a closest match between the propagation models and measurements. Finally, the thesis provides guidelines for network planners for the deployment of 802.11-based VANET in the parking lot of a large shopping mall.

Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person, nor material which to a substantial extent has been accepted for the qualification of any other degree of diploma or a University or other institution of higher learning, except where due acknowledgement is made in the acknowledgements.

Signature: ____________________________

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Contents

List of Abbreviations and Acronyms

AP	Access Point
AODV	Ad hoc On-demand Distance Vector
BSS	Basic Service Set
CA	Collision Avoidance
CICAS	Cooperative Intersection Collision Avoidance Systems Initiative
CPU	Central Processing Unit
CSMA	Carrier Sense Multiple Access
dB	Decibel
dBm	dB-milliwatts
DCF	Distributed Coordinated Function
DSSS	Driving Safety Support Systems
EDCA	Enhanced Distributed Channel Access
ESS	Extended Service Set
FHSS	Frequency-Hopping Spread Spectrum
FSPL	Free-space Path Loss
FTP	File Transfer Protocol
GPS	Global Positioning System
IBSS	Independent Basic Service Set
ISM	Information Systems Management
IR	Infrared
ITS	Intelligent Transportation Systems
IVC	Inter Vehicular Communications
IWF	Information Warning Function
LAN	Local-Area Network
LLC	Logical Link Control
MAC	Medium Access Control
MANET	Mobile ad-hoc Network
MH	Map Hack

MPDU	MAC Protocol Data Unit
mu	Microseconds
ms	Milliseconds
mW	Milliwatts
NLOS	Non Line of Sight
OPNET	Optimized Network Engineering Tool
P2P	Peer-to-Peer
PER	Packet Error Rate
PCF	Point Coordination Function
PLCP	Physical Layer Convergence Protocol
PMD	Physical Medium
PHY	Physical Layer
OSI	Open Systems Interconnection model
QoS	Quality of Service
RF	Radio Frequency
RSSI	Received Signal Strength Indicator
RSU	Road Side Equipment
RTS/CTS	Request to Send/Clear to Send
RWP	Random Way Point
SNR	Signal-to-Noise Ratio
SRD	Short Range Destination
SSID	Service Set Identifier
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
VANET	Vehicular Ad Hoc Network
VCWS	Vehicle Collision Warning Systems
V2I	Vehicle to Infrastructure
V2R	Vehicle-to-Roadside
V2V	Vehicle-to-Vehicle
WAVE	Wireless Access in Vehicular Environment
WDS	Wireless Distribution System
WLAN	Wireless Local-Area Network
WMN	Wireless Mash Network

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Chapter 1

Introduction

The number of automobiles on the road has been increasing rapidly over the last 10 years. Every year on U.S. highways there are about 43,000 accidents, 6.3 million police-reported traffic accidents and millions of people are injured. The economic effects are more than $230 billion caused by accidents and traffic delays resulting from vehicles leaving the road or travelling dangerously through intersections (Hassan 2009). At this time traffic congestion on the roads is a superior issue in crowded cities. The congestion and vehicle related problems such as bad traffic jams, slow or fast driving, not giving way to emergency vehicles and poor road conditions are accompanied by a constant threat of accidents. VANETs (Vehicular Ad-hoc Network) are a possibility for future vehicle applications (Raya and Hubaux 2007). VANET is, as the name implies, an ad-hoc network with digital communications vehicle to vehicle: a point-to-point wireless network (dedicated server) whose nodes are devices placed in vehicles. VANET is a subset of MANETs which is more advanced applications technology that offers ITS in wireless communication between V2V and RSU to vehicles according to IEEE 802.11p standard. Ad hoc networks are the category of wireless networks that uses multi hop radio relaying. Wi Fi technology is targeting to equip technology in vehicles to decrease these issues by sending messages to each other. Recently researchers have been focusing their efforts on improving road safety by new developments in latest vehicular technology and the evolution of wireless technology has allowed vehicles to participate in the communication network

The main objective of VANET is enhancing safety and efficiency in transportation systems, which communicate and provides a long list of applications varying from transportation protection to driver support and Internet access. Figure 1.1 shows sharing information V2V which provides collision detection, lane change warning, electronic brake warning, audio/ video exchanging, route guidance, weather information, electronic payment, internet access, post-crash notification, intersection violation warning, on-coming traffic warning, vehicle stability warning and traffic signal violation warning.

Figure 1.1 Sharing accident information from V2V communication

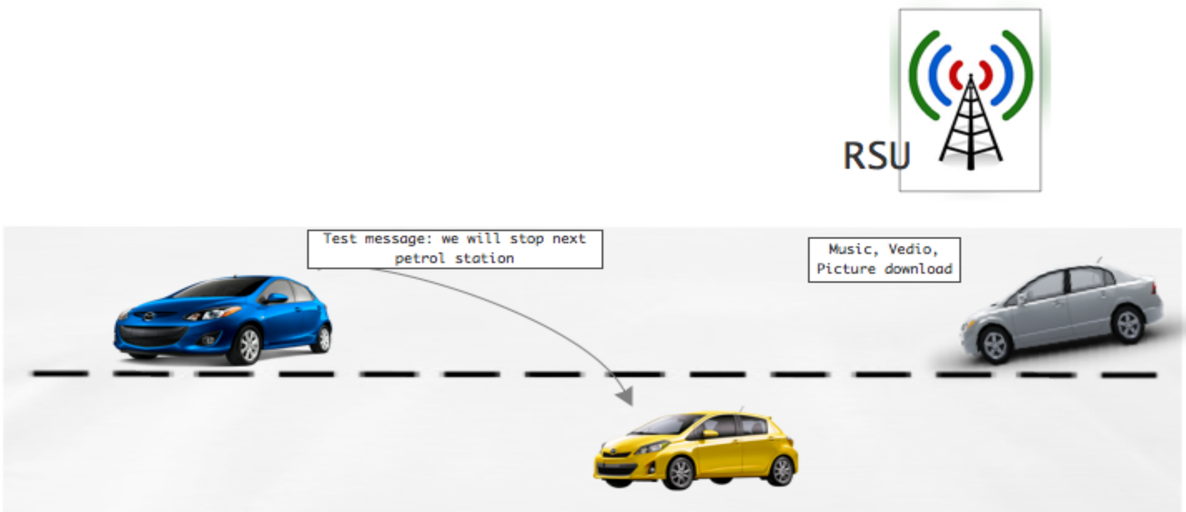

Figure 1.2 Sharing text and downloading multimedia from V2V and RSU communication

Sometimes driver behavior on the road is extremely complex as drivers react to challenging road conditions depending on their plans and behavior (Naumov, Baumann et al., 2006). Figure 1.2 shows V2V sending test messages and downloading multimedia from RSU. Applications can provide drivers additional information on traffic situations which will react timely and correctly assess possible risks. Adding an extra value in the operations services and vehicle industries, VANET might be considered as a future killer application. It is very confusing on motorways or highways to predict and monitor other drivers' speeds. However, with computer and wireless communication or sensor equipment, speeds could be monitored and the risk of potential accidents could be minimized by sending a warning message. This kind of network facility will generally be used to allocate safety message information such as traffic significant information, collision warnings and risk warnings.

To reduce accidents, Vehicular Ad-hoc Networks (Lagraa, Yagoubi et al., 2010) have been developed by network researchers to provide added safety for all vehicles on the road. To improve the safety, security and efficiency of transportation systems, ITS have been developing vehicle and transportation infrastructures that apply rapidly emerging information technology. Information Warning Function (IWF) would be used to warn the vehicle of the possibility of any danger on the road and inform the driver to take defensive action. The main challenges in VANET operation are the frequent changes in network topology due to the high mobility of the network nodes. IEEE 802.11 (Wi-Fi) based VANETs are becoming an attractive solution for road safety because of their low cost, widely used standards and mobility offered by the technology. In 802.11 transmissions the distance between the sender and receiver is an important factor causing decrease of performance for poor latency and throughput due to inefficiencies in implementation of the vehicular networking stack. Still there are some challenges and issues with VANET such as lack of online management, radio channel, high mobility, environmental conditions, security and privacy.

1.1 Objective of this study

The objective of this research was to conduct a feasibility study for the deployment of IEEE 802.11-based VANET in the parking lot of West City Auckland shopping mall. The idea is to set up a VANET in the parking lot to measure the system performance in terms of received signal strengths and response time. To fulfill this objective, a field trial propagation measurement was conducted using 802.11n cards. To generalize the measurement results, OPNET-based simulation was performed. In this thesis the following research questions have been addressed:

- What guidelines can be provided for network planners to implement an IEEE 802.11-based VANET in the parking lot of a large shopping mall?
- What propagation model would be the best-fit (closest match) with the measurement results?

1.2 Methodology Used for Study

"A methodology is a set of guidelines or principles that can be tailored and applied to a specific situation. In a project environment, these guidelines might be a list of things to do. A methodology could also be a specific approach, templates, forms, and even checklists used over the project life cycle" (Charvat, 2003). Selecting the appropriate methodology is the best justification for reducing risk, reducing cost, avoiding mistakes, identifying earlier errors and meeting project schedules. Case and Light (2011) specified there are three comprehensive types of methodology used to manage a research study: qualitative research, quantitative research and mixed method research. Quantitative research involves gathering numerical data and using mathematical-based techniques to clarify phenomena or research questions (Lindsay 2005). Quantitative methods also provide some strength including: suitable for studying huge numbers of people and experiments; quantitative research is subjective; quantitative method is comparatively fast for data collection; can generalized as research findings; testing and validating already constructed theory; data analysis is relatively less time consuming; provides quantitative, precise numerical data.

In quantitative research there are two main types of design: experimental design and non-experimental design. Experimental methods contain accurate experiments, which are a random assignment of subjects to treatment conditions. Zahn, O'Shea et al. (2009) established a V2V test bed experiment with emphasis on assessing the quantity of data that could be transferred among two moving vehicles and a fixed access point in urban and highway scenarios. However, similar experiences with other vehicle test beds have been presented by others but all have the same recurring problem: limited availability of equipment (Amoroso, Marfia et al., 2012). Moreover, experimental methods have their own drawbacks. They are normally expensive to implement and are not cooperative to extrapolation.

We used the quantitative approach and all data used in the analysis process were data collected from field trial measurements, OPNET simulations as well as simulation methods. The study adopted field trial measurements to get an insight into the performance of VANET in the shopping mall parking environment. Moreover, OPNET-based simulation is conducted to generalize the field trials measurement results. Simulations of VANETs often involve large and heterogeneous scenarios. There are two main components in a VANET network: a component that is capable of simulating the behavior of a wireless network, and a vehicular traffic component that is able to provide an accurate mobility model for the nodes of a VANET.

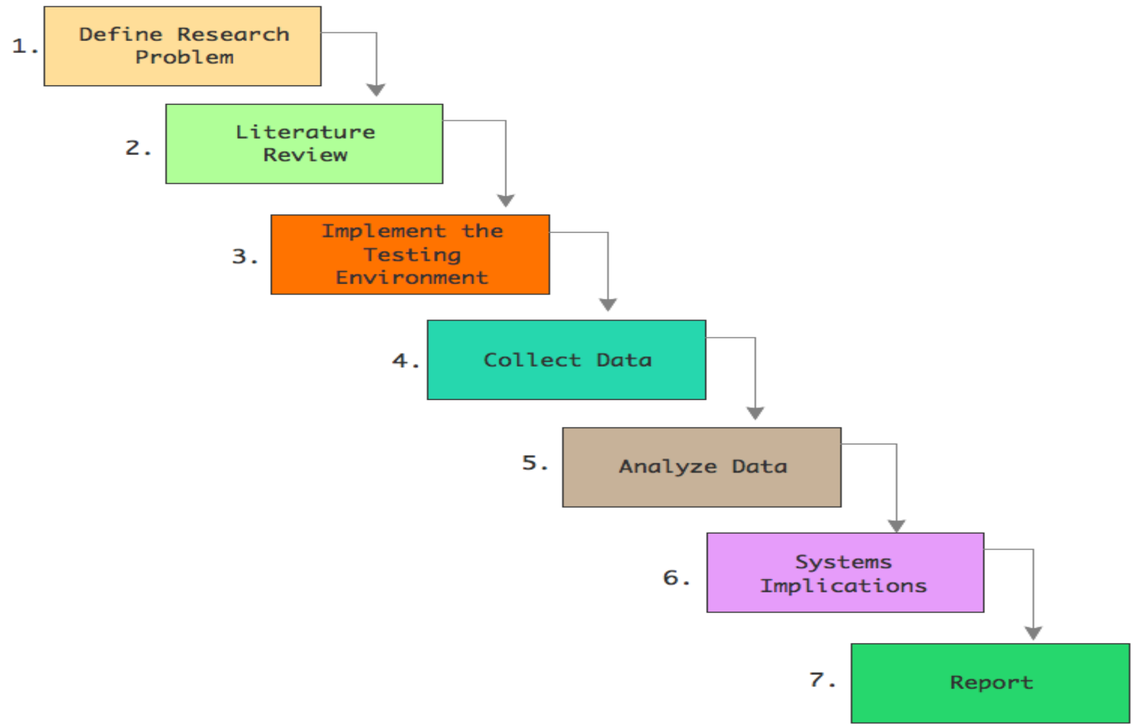

Figure 1.3: Steps involved in the study

Modified design science methodology was adapted in this study as the most appropriate model for this research. This model is based on sequential steps to carry out research and is a linear approach to software development which gathers and documents requirements, design and performance study. Also, this model is useful when the requirements are clear, well-known and fixed, short projects and there are no ambiguous requirements. This model contains certain advantages: it is very simple to implement, each stage produces documentation for development, easier to detect and diagnose faults at an early stage. Figure 1.3 shows all stages and steps involved in measurement /field trials.

Phase 1: This phase involves the express area of interest, outlines the existing problems and identifies goals to be achieved after the problem is solved. Supervisor guideline and discussion occurs in this phase.

Phase 2: This phase describes a review on past study with all relevant works to support this study.

Phase 3: This phase involves requirements for measurement, which includes hardware setup, software installation and design.

Phase 4: This phase provides quantitative data generated and various outputs captured, for example frequency, test scores, test result, number or percentages.

Phase 5: In this phase all data collected from earlier phases are analyzed and compared using suitable tools, for example Microsoft Excel.

Phase 6: This phase provides system implication based on earlier phases.

Phase 7: This is the final phase, based on all phase conclusions. The supervisor needs to provide feedback depending on this study.

1.2.1 Field Trial Measurements (Propagation Measurements)

Field trial testing generally focused on checking the feasibility of Wi Fi connections among vehicles in a shopping mall parking area. Field trial experimental measurement provides a difference to validate the results of analytical modeling and computer simulation to check the accuracy of the WLAN study. The most important aspects in this study that we considered while carrying out these tests are the hardware for Wi Fi communication and measuring distance of both vehicles using a correct method. On the test the driver must be aware of the positions where vehicles are parked and move into Wi Fi range.

Figure 1.4 illustrates the methodology used for this study. Each scenario of field trial design starts with defining the propagation measurements in the entire project. The next process consists of defining routes where V2V can communicate for propagation measurements. The following steps are route measurements with 1m distance making sure V2V is connected with the ad hoc network. The next process contains primary trials in order to recognize that the parking area can be measured. If the parking area consists of too much interference then we need to go to another parking area. Each scenario was designed with two trials to measure the accuracy of the Wi-Fi connection through a pair of nodes. The next procedure involving data collection and validation is compiled and performed. Finally a comparative analysis is done and conclusions discussed.

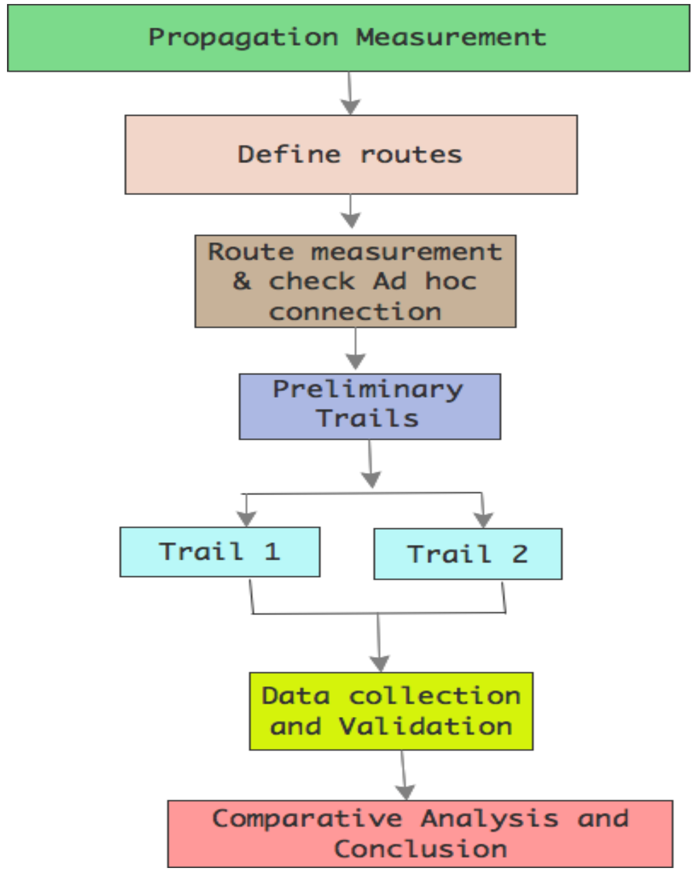

Figure 1.4: Field trial measurement approach for the study

1.2.2 Simulation

There are two types of simulators for smooth functioning in VANET: network simulators and traffic simulators. Network simulators are generally used to evaluate network applications and protocols in particular conditions. Traffic simulators are typically used for traffic engineering and transportation. Moreover, a VANET simulator is a combination of a network simulator and a large number of traffic simulators. However, most of the VANET simulators have a problem of proper 'interaction'. Mangharam, Weller et al. (2005) produced the first tools for assessment of VANET performance for forecasting and vehicular traffic flow. Numerous communicating network simulation tools already offer a platform to test and evaluate network protocols, for example NS-2 (Andr, Varga et al. 2008), OPNET (Weingartner, vom Lehn et al. 2009) to provide several models of switches, routers and servers based on vendor specifications. However, simulation tools are designed to deliver general simulation scenarios without being specifically adapted for applications in the transportation atmosphere. Advanced level simulation software has struggled to obtain detailed operational features of network protocols. Simulation tools are not enough for a comprehensive study of WLAN in numerous aspects and analytical modeling has a tough road in analysis of TCP over multiple-hop WLANs (Jin, Seung-Keun et al. 2003). OPNET can be used as a platform to develop models of a wide range of systems such as internetwork planning, LAN and WAN performance; mobile packets radio networks and satellite networks. It also provides a wide-ranging development atmosphere for modeling and performance evaluation of communication networks and distribution systems. Specification, data collection and simulation, and analysis phase modeling are major categories in OPNET and are performed in sequence. OPNET modeling efforts obtain measures of a system's performance or make observations concerning a system's behavior and admit realistic approximations of performance and behavior to be obtained by executing simulations. There are some advantages to using OPNET such as cost and time, efficiency and easy to reuse and modify scenarios. OPNET has increased significant acceptance in both academia and industry by providing a number of model networks that are commercially presented network mechanisms. However, there is no proper method for organizing VoIP or video conferencing into a current network in OPNET and it also requires high PC specifications and consumes big amounts of memory (Hussain and Habib 2011).

1.3 Data Collection Process

Data collection process was used in this section to obtain the data for this study. Quantitative methods contain the collection of data so the information can be counted and subjected to statistical analysis. The quantitative method also includes data collection in usually numeric and mathematical models, which researchers manage to use as the methodology of data analysis. There were two types of data collection methods used in this research: literature review and measurement data gathering process. The literature review process provides a knowledge base and information required for this study. In terms of field trial measurements all data gathering processes were carried out using multiple tests in the shopping mall parking center.

1.3.1 Literature Review Process

A literature review is the initial process of objective analysis, through a summary and critical analysis of others' relevant works. The main goal of the reader is to update with current literature on a chosen topic such as justification, limitations and future research area. A good literature review also provides the background of the study, knowledge base, clear search, selection strategy and information required for this study.

In this study, all literature was collected from different reliable resources, for example academic databases, books, library references and a proper reliable association website. Table 1.1 shows an example of reliable resources. After the literature is reviewed and critically analysed, the next process is measurement and data gathering.

Table 1.1: Credible Resources

Resources	From
Academic database	IEEEXplore, EBSCO HOST, ACM Digital Library, ScienceDirect Journal Database
Books	AUT library, Google Books
Web search engine	Google scholar

1.3.2 Field Trial Data Gathering Process

This section is the main resource for data gathering for this study. Data collection was done from WirelessMon software. To achieve this data gathering process, two computers with ad hoc networks were set up in the Henderson Westfield Shopping mall parking lot and numberous tests were run in order to get accurate results.

1.4 Thesis structure

Figure 1.5 shows the structure of the dissertation. This study consists of seven chapters. Chapter 1 and Chapter 2 present background material. Chapter 3 to 6 combine to make the main contribution and the final chapter presents concluding remarks.

- ***Chapter 1 – Introduction:*** This chapter provides an introduction to the thesis and motivation for undertaking the research. It also covers the methodology employed for this research with real measurement and analytical methodologies.
- ***Chapter 2 -*** **Vehicular Ad-Hoc Networks:** Reviews related work on Vehicular Ad-Hoc Network's challenges and issues in wireless propagation measurements. This chapter describes the IEEE 802.11 standard with the IEEE 802.11p physical layer and MAC layer.
- ***Chapter 3*** **– Research design:** Describes details of experiential design used for this study, which are hardware and software requirements. The propagation measurement environment and preliminary propagation field trial measurement scenarios are described.
- ***Chapter 4*** **– Results and discussion:** The findings from propagation measurements are presented.
- ***Chapter 5*** **– Propagation models versus measurements:** This chapter covers a comparison of the model implementation's results with measurement data.
- ***Chapter 6*** **– Implications and recommendations for future systems deployment:** This chapter discusses the practical implications in future VANET environments.
- ***Chapter 7 -*** **Conclusions and future research:** *S*ummarises each chapter and presents the overall findings made by the study.

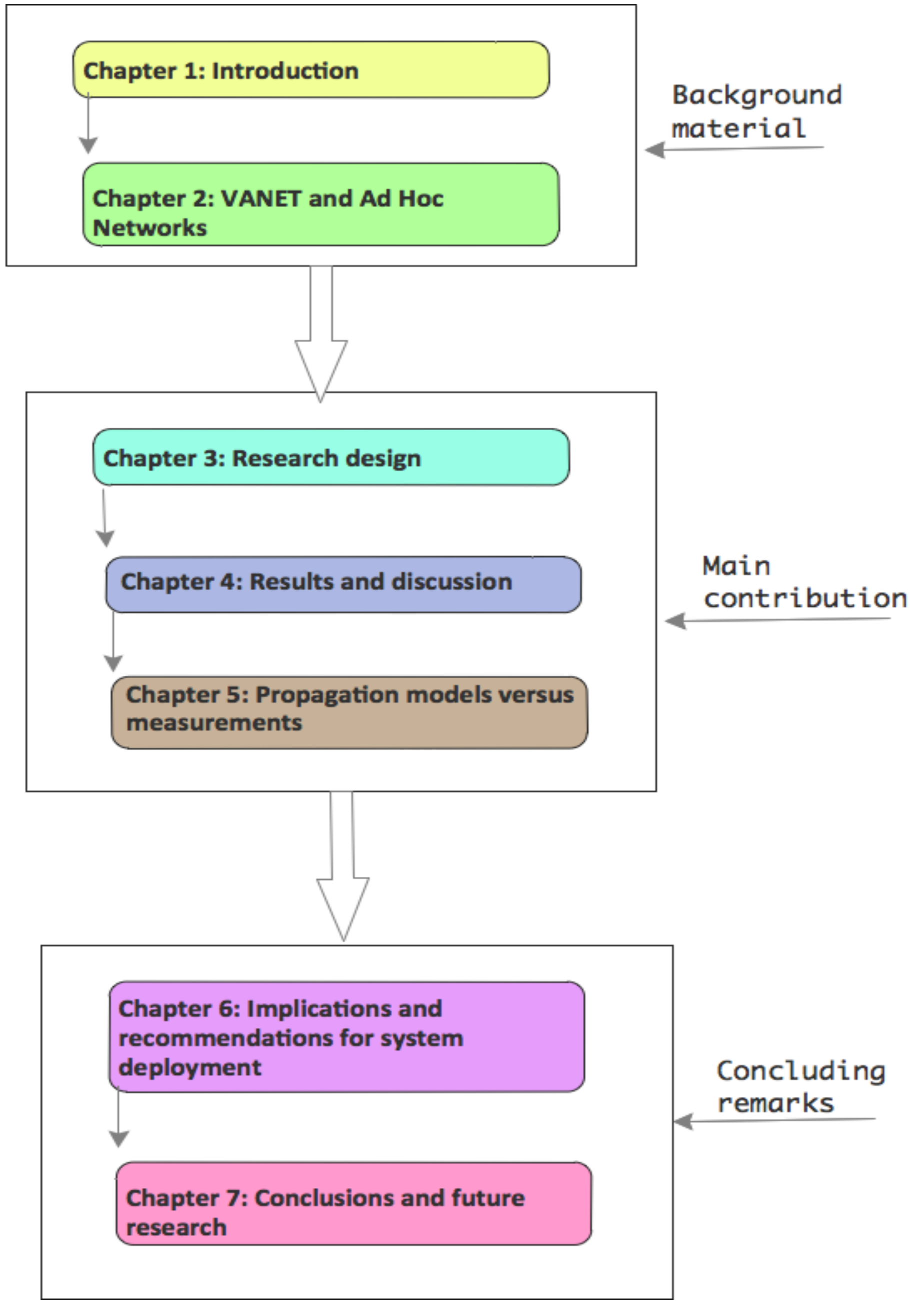

Figure 1.5: Dissertation structure

Chapter 2

VANET and Ad Hoc Networks

Chapter 1 outlined objectives of the thesis and thesis stature and presented the methodology used for study. The key network researchers and their main contributions to the design and fundamentals of VANET networks are identified and discussed in Chapter 2. Section 2.1 describes a vehicular Ad Hoc Network based on IEEE 802.11 wireless technology as well VANETs applications and classification and VANET's issues and challenges. Section 2.2 outlines the MANAT network where nodes represent vehicles moving at high steps and vehicle traffic persistent consistency. Section 2.3 outlines and compares the development and properties of the IEEE 802.11 b,a,g and n standards. This section also provides details of IEEE 802.11p protocols for vehicular Ad Hoc Network. Section 2.4 outlines wireless mesh clients and mesh routers. Section 2.5 explains wireless communications technology classified according their range and differentiates long range, medium range and short range. Section 2.6 outlines WLAN signal strength management with WLAN performance, IEEE 802.11 signal strength and indoor positioning systems. Section 2.7 outlines propagation measurement models.

2.1 Vehicular Ad Hoc Network (VANET)

2.1.1 Vehicular Ad-hoc Network Communications

Vehicular Ad Hoc Network (VANET) is accepted as an important constituent of Intelligent Transportation Systems. The key advantages of VANET communication are in active safety communications and the object of VANET is to increase safety of drivers and passengers by exchanging information between V2V. VANETs are an extreme case of MANETs. In MANETs, nodes connect with each other in an ad hoc mode, for example, without attached infrastructure. Nodes communicate in VANET in similar ways, however the network topology changes frequently with high speed and different mobility features such as all vehicles in VANET are moving within specific directions. Tufail, Fraser et al. (2008) tested the existing Wi-Fi protocol for Vehicle-to-Vehicle (V2V) communication particularly at high speed with several protocols (V2R and V2V). As a result they demonstrated with real-life measurements and logical justification that Wi-Fi is a successful way of communication between vehicles even at extremely high speeds and also suggested some useful applications. Moreover VANET provides massive chances and opportunities in online vehicle entertainment such as through the local ad hoc networks sharing pictures, video, files, gaming and chatting. Figure 2.1 shows this kind of technology used to communicate in vehicle roadside sensors, positions, intersection maps and both way wireless communications.

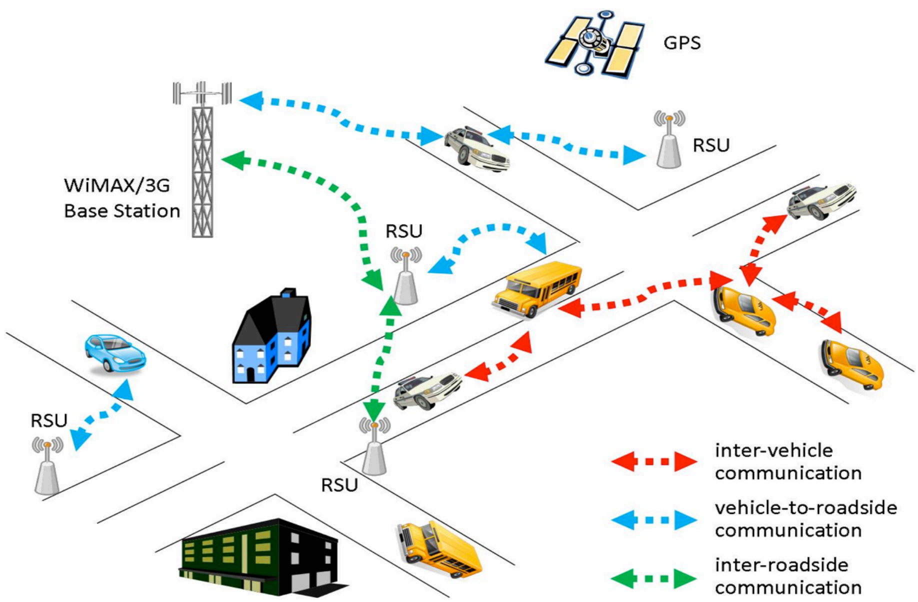

Figure 2.1: Illustration of a vehicular Ad Hoc network

This kind of network usage communication kit exchanges messages with each other in Vehicle-to-Vehicle (V2V) and it also exchanges messages with a Vehicle to Infrastructure (V2I) and roadside network infrastructure (Vehicle to Roadside Communication V2R). Figure 2.2 shows this network. A number of applications have already been proposed which are likely designed for some vehicles recently such as safety monitoring, map localization, parking lot localization, security distance warning, vehicle-to-vehicle communication, platooning, vehicle collision warning systems, cooperative intersection safety, internet access, driver assistance etc. (Boukerche, Oliveira et al. 2008)

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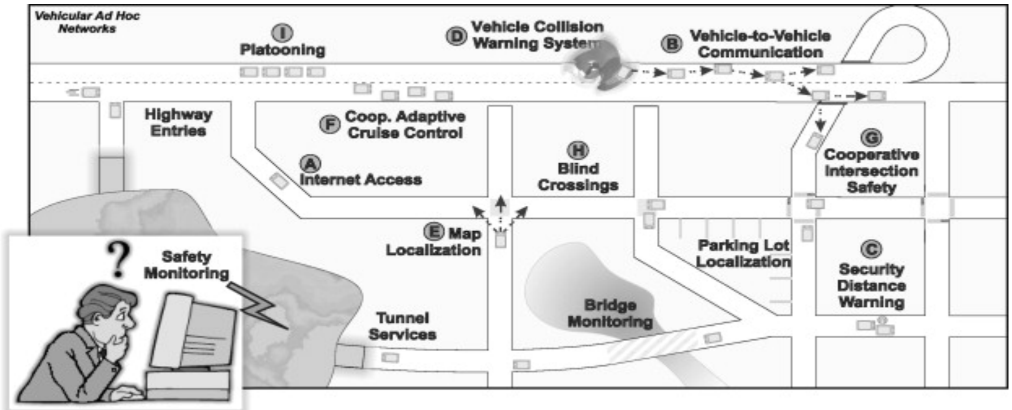

Figure 2.2: VANET applications (Boukerche, Oliveira et al. 2008)

VANET apply short-range communication based on IEEE 802.11 wireless technology, which is multi-hop communication using geographic positions enabling exchange information between network nodes. VANET's knowledge of the present position of nodes is an assumption made by most algorithms, protocols and applications, for example, since GPS receivers can be easily installed in any vehicle or be already built within the technology of the car. For an assumption, since GPS receivers can be installed easily in vehicles, a number already come with this technology. GPS has some undesired difficulties; for example, not continuously being available or losing signal or not being robust or sufficient for certain applications. Although VANETs progress is hooked on critical areas it is gradually becoming connected to local systems.

2.1.2 VANETs applications and classification

The principle determination of communication in vehicular networks, whether in vehicle-to-vehicle or vehicle-to-infrastructure, is to offer safety and/or non-safety assistance. VANET applications are categorised into two groups: message and file delivery (target receivers with acceptable performance, accident and road construction warning systems, priority over non-safety applications), and internet connectivity (vehicles can communicate to roadside Internet gateway via the ad hoc network Group (2010). Moreover, the safety application is given main priority in VANET. However, transmission collision may occur due to a transmission of other safety messages, for example, alternative safety messages that need to be sent with priority at the same time. A number of applications involving VANET can take some advantage of localization techniques. However, identifying their physical location is difficult among nodes such as longitude, latitude and altitude or virtual spatial distribution relative to each other. For example, map location is generally completed using GPS receivers with a Geographic Information System, although VCWS can be applied by comparing distances among nodes' locations combined with geographic information distribution. Driverless vehicles and VCWS advance toward more critical applications in VANET technology but they will require a robust and highly offered localization system. GPS accuracy range is up to 20 meters or 30 meters and not able to work indoors or city areas because they do not have direct visibility to satellites. Inappropriately, it is not the best solution for VANET applications. Although other applications such as particularly critical safety applications require more reliability and accuracy for localization systems with sub-meter accuracy. For security reasons GPS information is probable to be joined with other localization techniques, for example cellular localization, dead reckoning and image/video localization. VANET applications do not require localization to function. When the position of the vehicle is available then it can take advantage of localization for showing better performance (Table 2.1).

Table 2.1: VANET applications (Boukerche, Oliveira et al. 2008)

Technique	Localization Accuracy		
	Low	Medium	High
Routing	X	-	-
Data Dissemination	X	-	-
Map Localization	X	-	-
Coop. Adapt. Cruise Control Coop. Intersection Safety	-	X	-
Blind Crossing	-	X	-
Platooning	-	X	-
Vehicle Col. Warn. System Vision Enhancement	-	X	-
Automatic Parking	-	-	X
Vision enhancement	-	-	X
Automatic parking	-	-	X

These kinds of networks rely on the use of short range networks (about 100 meters) with IEEE 802.11 for vehicle communication and providing bandwidth in the range of MBPS. Drivers can send and receive information from nearby drivers using VANET. Drivers can exchange information with other drivers in communication networks such as when a possibly dangerous incident arises (emergency braking, accident, suddenly stopped vehicle, speeding) difficult traffic conditions. Specifically, some other networks have addressed the advertisement of available parking spaces and finding an available parking space is certainly stressful. Moreover, it indicates environment pollution and fuel consumption due to the release of gases. Caliskan, Graupner et al. (2006) presented the costs of searching for parking spaces and also expressed closely two cars on the move searching for a parking area. To find out advertised available parking space on a parking lot Xu, Ouksel et al. (2004) used the following significance function to characterise the relevance of a parking space.

2.1.3 VANET's design issues and challenges

Nzouonta, Rajgure et al. (2009) presented actual issues and challenges of VANET applications in V2V communication, for example, hidden and exposed mode problems, fake message send, stability, scalability, reliability and security. One of the main issues is high speed and frequent topology change when vehicles move very fast within the vehicular network. While, due to road geometry, vehicles guidelines can be predicted to a certain area, these issues might be treated very carefully by the MAC protocol; such as if the transmission ranges of two nodes communicate with each other. However, the system's performance can be degraded intensely due to high speed (when vehicles move 110km or 140km having frequent link disconnections arising) and high node density. Scalability is another issue, which is vehicle density, is almost the average, such as changes of network. While the vehicle density can quickly grow significantly and becomes very large in a road segment without suffering a noticeable detriment in performance or a complexity increment. Hidden and exposed node problems are one of the main issues in VANET. Because of the high speed mobility in vehicular networks, the hidden node problem is predicted to occur more frequently. Yihong and Nettles (2005) proposed this problem could be solved by using the request-to-send/clear-to-send (RTS/CTS) handshaking. Ho, Leung et al. (2012) classified VANET simulations as macroscopic or microscopic. They also explained network component and vehicular traffic component in a VANET simulator, which provides capability of wireless network behavior and presents an accuracy mobility model of nodes of VANET.

Liu, Khorashadi et al. (2010) conducted research about assessing VANETs under different traffic mobility, which is both one-way and highway free flow traffic. Firstly they examined city traffic with a Random Way Point (RWP) mobility model and finally they performed simulations based on real traffic trace. Karim (2008) proposed VANET would be the main comfort and safety related application for car and passenger safety. However security and privacy issues will occur with these applications, such as fake messages, private information etc. Also the author explained why VANET is better than 3G due to infestations. Many researchers have studied VANET to change the random directions – the random way where the nodes change the speed and direction randomly (Naumov, Baumann et al. 2006). The researchers compared ad-hoc Wi-Fi in VANET with real experience versus simulated where real-world communication was quite hard to simulate due to complexity of wireless transceivers. To improve the traffic efficiency requires traffic lights and vehicle communication. To set up VANET might require very expensive infrastructure however it will require low maintenance costs. Also, there is no associated cost for small-range wireless communication technologies except the communication devices.

However, VANETs can be vulnerable to attacks and threaten users' privacy. Hubaux, Capkun et al. (2004) address the security and privacy challenges in VANET. Others researchers have provided threat analysis and suggest security architecture based on public key cryptography. Yamamoto, Ohnishi et al. (2008) proposed the DSSS to prevent accidents by warning drivers about possible threats at intersections and their main target for DSSS was red light violations, crossing-path accidents, stop sign violations, turning accidents and collision with pedestrians. Intersection safety proposed in CICAS implements wonderful safety applications merging with different ITS technologies, such as decreased intersection accidents by directing real-time warnings together at the infrastructure and vehicle.

2.2 Mobile Ad Hoc Network

MANET is a wireless mobile node that accommodatingly forms a network without infrastructure. Ad hoc networks are the highest development of wireless networks and VANET has extensively reviewed this area of wireless communication at present. VANET is a subsection of MANET where nodes represent vehicles moving at high step and vehicle traffic persistent consistency. Mobile Ad Hoc Networks are constructed on wireless links and will remain of significantly inferior capability than wired counterparts. MANET networks physical security is limited due to the wireless transmission. VANET shares certain similar characteristics with common MANET. The movement and self-organization of the nodes characterize together MANET and VANET. MANET finally used a peer-to-peer network for the exchange of data or channel through speech.

However, MANET involves numerous nodes that cannot recharge their power and have un-controlled moving patterns but often VANET nodes can charge. MANET has several challenges such as resource issues, wireless communications issues and routing packets where the topology is often changing (Conti and Giordano 2014).

2.3 IEEE 802.11 Standard and background

In 1997 the IEEE 802.11 standard was first published. IEEE 802.11 consists of a low data rate of 1 Mbps to 2 Mbps and operates at 2.4 GHz ISM band. In 1999, the IEEE 802.11 committee approved IEEE 802.11a and 802.11b amendments. The standard employs frequency-hopping spread spectrum (FHSS) and direct-sequence spread spectrum (DSSS) techniques for radio transmission. IEEE 802.11 based wireless access technology has widely been used in WLAN. WLAN technology has two (managed and uncoordinated) possible development infrastructures in IEEE 802.11 networks. WLAN technology can deliver high-speed Internet connectivity up to 11 Mb/s (IEEE 802.11b) or 54 Mb/s (IEEE 802.11a/g). Woesner, Ebert et al. (1998) presented two wireless LAN standards, which are IEEE 802.11 and HiperLAN in simulations of power saving mechanisms. They also demonstrated various size beacon intervals in IEEE 802.11 have major impacts on throughput.

IEEE 802.11b supports a bandwidth of 5.5 to 11 Mbps and uses the same unregulated radio signaling 2.4 GHz frequencies and outdoors cover around 35 to 140 meters. Every channel requires the same 11-MHz bandwidth as an 802.11 DSSS channel. However, IEEE 802.11b speed is slow. IEEE 802.11a is a second extension and it is much faster than IEEE802.11a. Actually IEEE 802.11b and IEEE 802.11a were created at the same time. IEEE 802.11 supports a bandwidth of up to 54 Mbps and uses 5 Ghz frequency spectrums. However, possible data rates per channel for IEEE 802.11a are 6, 9, 12, 18, 24, 36, 48, and 54 Mbps. An IEEE802.11g supports a network bandwidth of 12 to 54 Mbps and uses 2.4 Ghz frequencies for a better range. Signal range is good and not easily obstructed; however appliances may delay on the unregulated signal frequency. IEEE 802.11n supports a network bandwidth up to 3000 Mbps. It also offers better signal range over earlier Wi-Fi standards. It supports multiple wireless signals and antennas and also is more resistant to signal interference from outside sources. Indoor coverage for IEEE802.11n is approximately 70 meters and outdoor ranges 250 meters. However, multiple signals interfere with nearby networks (Perahia 2008). IEEE 802.11ac supports a network bandwidth up to 450 Mbps on 2.4 GHz. It utilizes dual band wireless technology and its covered backward compatibility to 802.11b/g/n as shown table 2.2

Table 2.2: Common 802.11 standards (Perahia 2008).

Standard	Frequency band (GHz)	Bandwidth (GHz)	Approximate Range (m)	Maximum data rate (Mbps)	Number of channels	Ad-hoc ability
802.11b	2.4	20	140	11	3	Yes
802.11a	5	20	120	54	23	Yes
802.11g	2.4	20	140	54	3	Yes
802.11n	2.4, 5	20, 40	250	600	26	Yes

Ghahfarokhi (2015) mentioned IEEE 802.11 has a lack of proper channel assignment generally because of unawareness of users about its importance. The IEEE 802.11 standard has two types of scanning modes: passive and active. In the passive scan mode, MH listens to each channel of the physical medium consecutively and tries to locate the next AP and deliver the MH through timing and advertising information. So the passive scan mode experiences significant delay. The active scanning mode contains the transmissions of investigation request frames by the MH, which is collecting the information from all presented APs. IEEE 802.11 technology exploits unlicensed frequency bands of 2.4 GHz or 5 GHz where 2.4 GHz band is more popular. However 2.4 GHz band contains 1 to 14 channels but 3 channels (1, 6, and 11) are non-overlapping. Although 12 channels in the 5 GHz band are non-overlapping (Chieochan, Hossain et al. 2010), Bisdikian (2001) proposed a Bluetooth device with low-cost and low power in the wireless network, which is organized into Piconets and it consists of up to seven slave devices.

The IEEE 802.11 networks standard supports two common operation modes: ad-hoc mode and infrastructure mode. In infrastructure mode all clients communicate with each other wirelessly and wired through a wireless AP (as shown in figure 2.3). The stations need to be connected to an AP in the network in order to communicate to each other. A wireless AP which supports one or many wireless clients is recognized as BSS. When two or more wireless APs are connected to a similar wired network it is recognized as ESS.

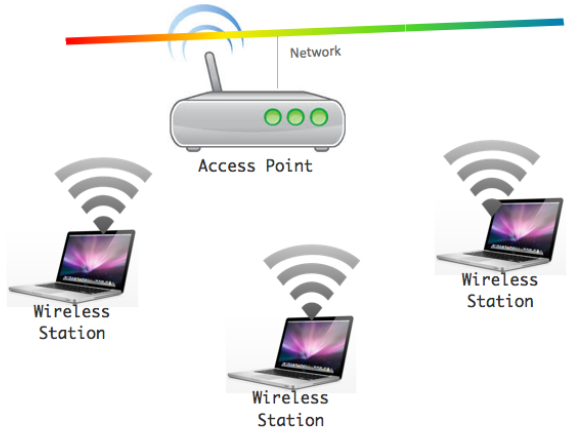

Figure 2.3: An infrastructure mode

Figure 2.4 shows an ad-hoc mode wirelessly communicating directly with each other without using an access point. The ad-hoc mode is able to connect or communicate wirelessly when there is no wireless AP present or the wireless client is obviously configured to use the ad hoc mode or AP discards a connotation due to failed authentication.

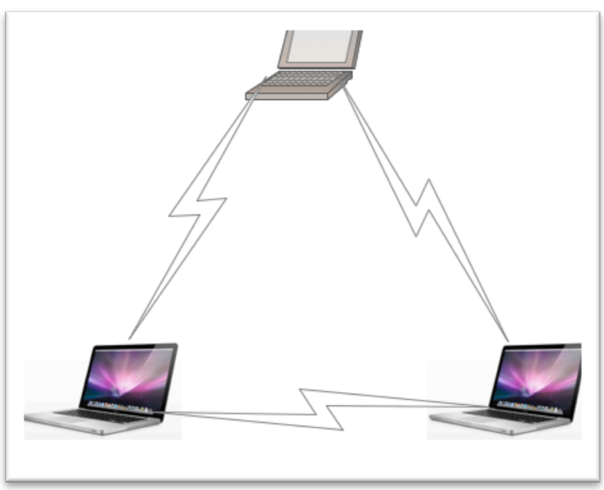

Figure 2.4: An ad-hoc network

IEEE 802.11 network architecture consists three different types of network: (Group) basic service set (BSS); (Group) independent BSS (IBSS); and extended service set (Dressler, Sommer et al.). BSS (as shown in figure 2.6) is a set of stations that communicate with each other and contains more than two wireless nodes. BSS does not usually indicate to a specific area due to the uncertainties of electromagnetic propagation and also BSS no longer communicates sprightly in all stations; consequently AP acts as a master to control the station. IBSS (as shown in figure 2.5) is IBSS is usually a short-lived network, with smallest number of service station units, which is created for a particular purpose in the IEEE 802.11 network. IBSS can enable communication with other wireless stations without AP. However, if a group of mobile terminals transfers data through wireless media then all nodes need to be within signal range of each other, and if any node is out of signal range they cannot communicate and are not able to share anything, therefore topology is referred to IBSS or also recognized as ad hoc (Mishra, Shin et al. 2003) .

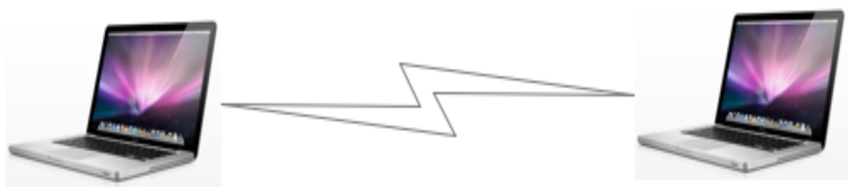

Figure 2.5: Independent Service Set (ISS)

Figure 2.6: Basic Service Set

An extended service set (as shown in figure 2.7) network appears similar to an LLC layer as an IBSS network. BSS to another transparently to LLC may move ESS stations to communicate. The SSID component specifies the identity of an ESS or IBSS. The ESS distribution system shares and communicates through wireless stations and APs from same LLC layer.

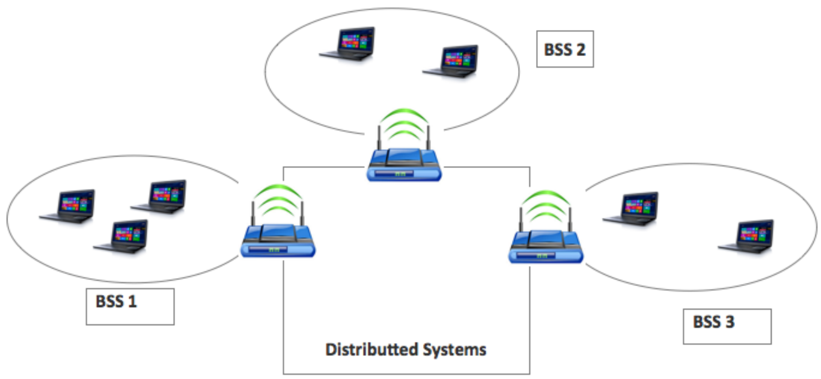

Figure 2.7: Extended Service Set

2.3.1 The IEEE 802.11 Protocols for Vehicular Ad Hoc Network

Protocol architecture 802.11 is a member of the IEEE 802 family. In IEEE 802.11p is one of the present approved amendments to the IEEE 802.11 standard to add in WAVE. Figure 2.8 shows the connection between different components of the IEEE 802.11 and IEEE 802 families and their position in the OSI model. The IEEE network has different types of layers, which is IEEE 802.11 standard specifications focused for the two bottom row made up levels in the OSI Model networking stack: the Physical Layer and the Medium Access Control. Also it introduces how IEEE 802.11 fits with existing IEEE 802 also IEEE 802 network has both PHY and MAC components. The LLC and MAC layer combination can be connected to the OSI model as the data link layer. While IEEE 802.11a, IEEE 802.11b, and IEEE802.11g adopt verities of physical layers for sharing common MAC and LLC through the same link layer address (48-bit).

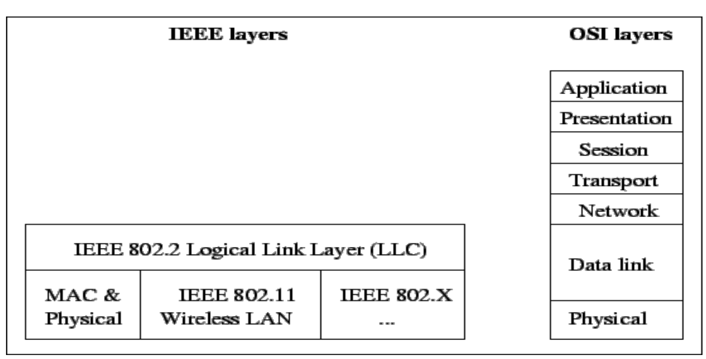

Figure 2.8: IEEE 802 Family of Protocol's

2.3.2 IEEE 802.11p Physical Layer

IEEE 802.11 PHY is the interface between the wireless and MAC layer where this layer frames the receive and transmit data frame. As shown in Figure 2.9 the physical layer of the OSI architecture is comprised of two separate sub layers which are (Group) physical layer convergence procedure (PLCP); and physical medium dependent (PMD). The physical medium dependent sub layer interfaces straight to where the wireless transmission medium frames occur of modulation and encoding/decoding of the transmission. The physical medium dependent key responsibility is to include bit-timing, signal coding and interacting with a physical medium. The MPDU framing system is appropriate for sending/receiving user data and management data among those linked with PMD system physical frame delivery. The IEEE 802.11 physical layer connects via transient data primitives between the PLCO and PMD sub layers. PLCP sub layer maps the MPDU framing system appropriately for sending or receiving management data and user data among related PMD systems for PHY frame delivery (Bing 1999).

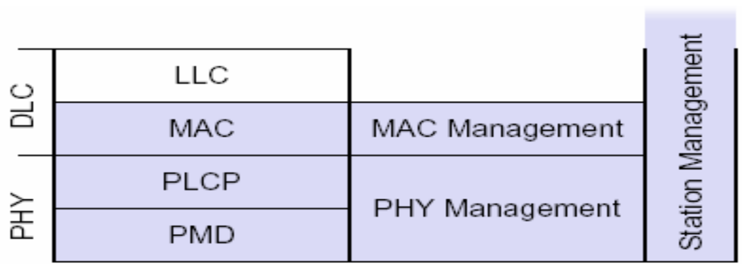

Figure 2.9: IEEE 802.11 Protocol Architecture

IEEE 802.11 standard assistance three physical layers are DSSS, FHSS and IR. The IR and FHSS physical layers support 1 Mbps but the DSSS physical layer supports together 1 Mbps and 2 Mbps. There are 52 sub-carriers, with 4 pilots and 48 data carriers in IEEE 802.11, OFDM techniques support various data rates in modulated techniques (IEEE 80211 Standard, 2003). IEEE 802.11b uses a new PHY layer and also IEEE 802.11 and IEEE 802.11g are based on OFDM which significantly increases the overall throughput of the AP. However IEEE 802.11n also uses an OFMD modulation technique joined with a MIMO mechanism. IEEE 802.11 uses overlapping channels with bandwidth 20 and 40 MHZ (Skordoulis, Qiang et al. 2008).

IEEE 802.11p is one of the latest appropriate amendments to the IEEE 80211 standard to add WAVE which supports applications of ITS. IEEE 802.11 contains data exchange between V2V and V2I with minimal modifications of the 802.11 PHY layer and also the audio frequency of the LAN systems is originally designed for 5.15 to 5.25, 5.25 to 5.35 GHz. IEEE 802.11p supports sending data at 6, 12, and 24 Mbit/s if required, however 9, 18, 36, 48, 54 Mbit/s are optional data rates (Abdelgader and Lenan 2014). The physical layer of the IEEE 802.11p operates at 5.9 GHz and IEEE 802.11a operates at 5 GHz, which is very close. Moreover the PHY layers 802.11p and 802.11a, both adopt an OFDM transmission technique but the bandwidth of a particular channel in 802.11p is scaled down to 10 MHz from 802.11a. However the authors mentioned using OFDM systems provides both V2V and V2I wireless communications over a distance of up to 1000m fast multipath fading and different scenarios. By using 10MHz channels it allows data payload communications capabilities of 3,4,5,6,9,12,18,24, and 27Mb/s (Menouar, Filali et al. 2006).

2.3.3 IEEE 802.11p MAC Layer

Figure 2.10 shows the IEEE 802.11 MAC layer defines two sub-layers which are distributed coordination function (DCF); and point coordination function (PCF), (Group 2010).

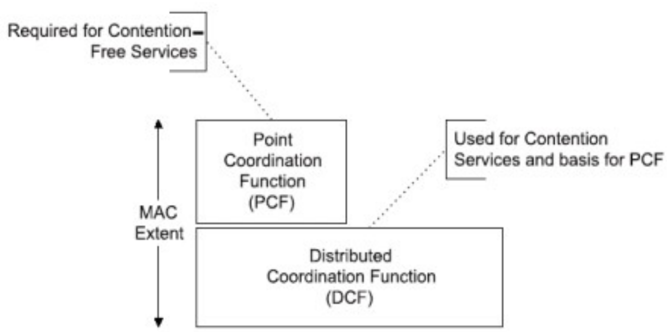

Figure 2.10: Wireless LAN MAC Architecture (2003)

In IEEE 802.11 DCF is a default medium access control; therefore DCF supports both infrastructure mode and ad-hoc mode. IEEE 802.11 uses a CSMA/CA to avoid collisions and also uses another MAC technique recognized as PCF (Akyildiz and Xudong 2005). This mechanism is divided in two parts and AP scans all its STA and connection based schemes the same as DCF. Furthermore, because of the polling mechanism in PCF the collective throughput of an IEEE 802.11 network diminishes. In IEEE 802.11 standard DCF is the default in MAC techniques. PCF is involved in the Wi-Fi grouping standard and is therefore not as popular as DCF (Hiertz, Denteneer et al. 2010).

IEEE 802.11p is intended to deliver reliable and effective MAC for the highest speed in the vehicular environment. MAC in IEEE 802.11p uses the EDCA mechanism originally provided by IEEE 802.11e (Wang, Ahmed et al. 2008). In the vehicular environment IEEE 802.11 MAC should make easier the BSS processes and decrease the quantity of the overhead needed to establish a communication link. It also offers prioritized channel access through the use of the EDCA by providing different access categories. IEEE 802.11p uses the basic mechanism of DCF, it does not operate efficiently for high mobility communication scenarios in VANETs, not considering the mobility impact at the medium access level and not providing required performance in terms of packet delivery ratio, throughput and fairness. In IEEE 802.11 MAC is meant for little mobility and has certain limitations particularly in a high-density scenario. The authors reviewed the saturated performance of 802.11 MAC in a single-hop network, which shows delay requirements (bellow 100ms), whilst the PDR decreases dramatically when the number of nodes increases. Also the authors propose the reason for the failure on achieving the desired PDR rate, which are high collisions due to the fixed short back-off window and hidden node problem (Chen, Refai et al., 2010). However, the authors assessed IEEE 802.11 MAC in simulation results in a highway scenario demonstration that certain nodes are forced drop over 80% of the time serious messages due to the long channel busy time, which could be achieved in scenario breakdown in delivering a safety message (Bilstrup, Uhlemann et al., 2009). Wang, Ahmed et al. (2008) also reflected that in IEEE 802.11p, fixation of the back of window size does not promise the desired throughput in vehicular networks and can cause a very long delay in transmission. However, to apply a vehicular network with a number of potential communication partners can increase the network size, while maintaining the traffic load, which leads to increased throughput. There are some other issues arising when IEEE 802.11p works efficiently which is caching for handoff, stateless channel access and opportunistic frame scheduling. The authors investigated IEEE 802.11p standard competences and provided a summary on both the competences and the limitations of this technology (Yi, Ahmed et al. 2008). Other authors also evaluated the maximum communication duration and potential communication associates for a vehicular ad hoc network using a highway scenario with a number of close vehicles is a significant contribution parameter for algorithms selecting the best following transmitter in a multi-hop communication scenario. However, they did not focus their present work on the MAC performance of IEEE 802.11p MAC protocol (Wang, Ahmed et al. 2008). IEEE 802.11p MAC sub layer performance analysis is an important and challenging issue that has been incompletely investigated in certain publications. The authors presented packet loss in usual vehicular environment results, which indicated the 802.11p outperforms the 802.11a, and also provides average delay, aggregate throughput and packet loss due to collision of particular specific simulation scenarios (Engelstad and Østerbo 2006).

2.4 Wireless mesh network

Wireless mesh networks are dynamically self-configured and self-organized through the nodes in the network automatically starting an ad-hoc network and maintaining the mesh connectivity. WMN has been envisioned as the economically feasible networking pattern to the concept of broadband and wide-ranging wireless commodity networks. (Baccarelli, Biagi et al. 2005). WMNs include two kinds of nodes: mesh clients and mesh routers. Mesh clients can work as a router for mesh networking; software and hardware platforms might be easier than mesh routers. The wireless mesh network operates just as a network of permanent routers expects, connected only by wireless links. WMNs achieve significant momentum as a low-cost technique to deliver last mile broadband Internet access (Raniwala and Tzi-cker 2005). WMN carries numerous advantages, for example easy network maintenance, low up-front cost, reliable service coverage, robustness, etc. Therefore, WMNs will significantly assist users to be always online anytime, anywhere. Therefore, instead any type of ad-hoc networking, WMN expands the capabilities of ad-hoc networks. WMN is an enterprise scale wireless backbone and it can efficiently remove the wired backbone and allow actual wireless enterprise, where access points connect using wireless links to form a connectivity mesh network. Though mobile ad-hoc networks are a similar idea of WMN there is particular variance between WMN and mobile ad-hoc networks as nodes in WMN are fixed, usually skewed and require proactive discovery of paths to reduce packet delays.

However, placement and maintenance of physical wires is the main cost factor in delivering high speed Internet access, but using WMN brings significantly overall low cost and proposes a beautiful alternative to the DSL/ cable modem. Mobile ad-hoc networks' reactive routing policies are usual as extra packet latency because on request route discovery is satisfactory. Akyildiz and Xudong (2005) presented that MAC and routing protocols are not scalable; throughput drops significantly as the amount of nodes or hops in WMNs grows. Therefore, present protocols need to be re-invented or improved for WMNs. WMN's lower and upper bounds for ad-hoc network capacity are derived where a node only should connect with close nodes (Gupta and Kumar 2000).

2.5 Wireless communications technology

Wireless technology communications are classified according to their range, for example long range, medium range and short range. Table 2.3 shows the standard, coverage, bit rate and long-range communication technology that could be used for data exchange between vehicles which locate out of the radio range (Dressler, Sommer et al. 2008). So, this technology is useful for VANET (V2V and fixed infrastructure V2I).

Table 2.3: Long range wireless technology V2V and V2I communications (Habib, Hannan et al. 2013)

Feature	Cellular technology	WiMax
Standard	Based on 3G, ETSI, 3GPP	IEEE 802.15
Coverage	Up to 15 KM	5 KM
Network	Full	Full
Modulation	FDD, TDD, CDMA	OFDMA, QAM-16, QAM-64
Advantage	Large coverage, high data rate	High Data rate, large coverage
Disadvantages	High development cost, scalability	High development cost, scalability
Bit rate	<2 to 100 Mbps	75 Mbps

Medium range is also referred to as "Wireless Local Area Network," or WLAN. Table 2.4 shows the standard coverage, bit rate, medium range communication technologies could be used within the radio range and is measured in tens or hundreds of feet where short range could only be use in line of sight. This range technology might be helpful for VANET (V2v and V2I) communications.

Table 2.4: medium range wireless technology V2V and V2I communications (Habib, Hannan et al. 2013)

Features	Wi-Fi (Wi-Fi a/b/g/n)	DSRC
Standard	IEEE 802.11	IEEE ASTM ISO
Coverage	100m to 1 km	100m to 305 m
Network	Point to point	Point to point
Modulation	OFDM, or DSSS with CCK	BPSK, QPSK, 16-QAM, 64-QAM
Advantage	Dominating WLAN tech	Low development cost
Disadvantages	High power, short to medium range interface	Low penetration rate
Bit rate	6000 Mbps using MIMO	IEEE 802.11p 3 to 27 Mbps IEEE 802.11p 6 to 27 Mbps

2.6 WLAN Signal Strength Measurement

WLAN Performance

Abulencia, Adelman et al. (2006) presented that IEEE 802.11 overheads are reasonably high and there is a huge gap between data rate and throughput. Nowadays numbers of users are using corporate applications, which will involve access to numerous server-based databases, voice and web browsing. Therefore, WLAN performance requires higher data rates and techniques to increase, such as, selecting the right IEEE 802.11 physical layer (IEEE 802.11a, IEEE 802.11b, IEEE 802.11g, IEEE 802.11n or 802.11ac. A previous standard (IEEE 802.11a, IEEE 802.11b, IEEE 802.11g) has some issues: limited capacity to three non-overlapping radio frequency channels. However, IEEE 802.11n offers the maximum capability, an extended set of channels to operate and is backward compatible with previous standards. Radio frequency (Amoroso, Marfia et al.) provides enough signal coverage. For example, the IEEE 802.11g access point may be operating at 54Mbps for the nearest user but more distant users may only get 6 Mbps capacity. Therefore to get the maximum WLAN performance, confirm those operators have RF coverage spread out to all users' areas. RTS/CTS protocol of the IEEE 802.11 standard requires a specific location to refrain from sending a data frame, as an example an access point. Figure 2.11 shows various overhead and effective throughput including RTS/CTS and Chebrolu, Raman et al. (2006) presented that overhead of RTS/CTS. WLAN performance may improve because RTS/CTS decrease collisions linked with hidden nodes. Though, (Chatzimisios, Boucouvalas et al. 2004) RTS/CTS handshake mechanism is not as predictable and functionality does not work appropriately while the distance from a receiver and to a transmitter is greater than 0.56 times transmission range.

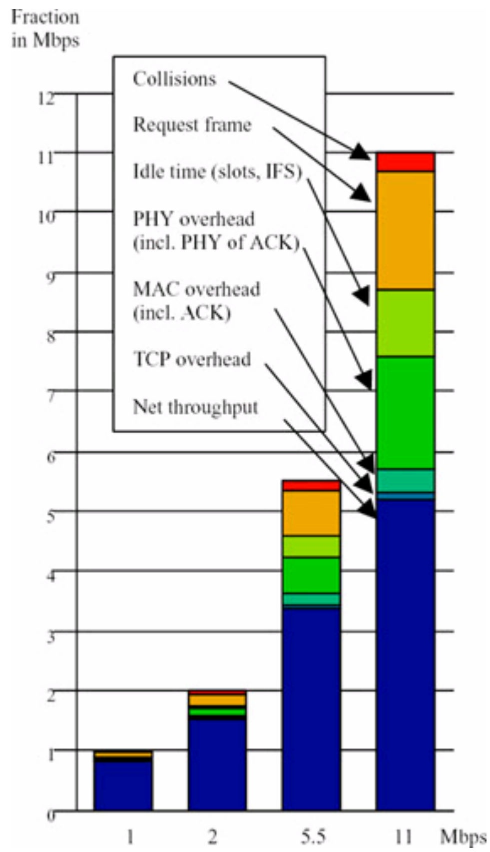

Figure 2. 11: Net throughput with 802.11b including RTS/CTS (Prasad and Prasad 2002)

Pelletta and Velayos (2005) presented numerous directions to improve accuracy of measurement results and recognized the use of a suitable packet size or file size for measuring AP throughput, turning off unnecessary services, using a short distance rather than long distances. There are some significant impacts on WLAN throughput, such as distance between receiver and transmitter, partitions and material of building, type of antenna (Boulmalf, El-Sayed et al. 2005).

IEEE 802.11 Signal Strength

RSS measurements units are mW, dBm, RSSI and percentage measurement. All these units are connected to each other, and are likely to change from one unit to another. Hadzi-Velkov and Spasenovski (2003) give an example, the relationship between dBm and mW

$$Power_{dBm} = 10\log_{10}\left(\frac{Power_{mW}}{1mW}\right) \tag{2.1}$$

Or

$$Power(mW) = 10^{Power(dBm/10)} \quad (2.2)$$

Although SNR measurements units are used to measure the relationship between noise power and signal (Sarkar and Lo 2008), Hadzi-Velkov and Spasenovski (2003) given by the SNR is typically measured in decibels (dB), and is given where S and N are the received signal and noise powers respectively.

$$SNR_{dB} = 10\log_{10}\left(\frac{S}{N}\right) \quad (2.3)$$

Zhu, Metzler et al. (2006) presented two latest adaptations developed where PER and RSS are two significant metrics in the adaptation algorithm. There are four different systems topologies for positioning systems which are remote positioned systems (signal transmitter is mobile and several fixed measuring units receive the transmitter's signal), self-positioned systems (receives the signals of several transmitters, and ability to calculate its site based on the measured signals), indirect remote positioned (wireless data link is provided in a positioning system) and indirect self-positioned (sent from a remote positioning side to a mobile unit via a wireless data link) (Liu, Darabi et al. 2007). Kaemarungsi and Krishnamurthy (2004) presented indoors positioning systems that use location fingerprints and current WLAN infrastructure has been established for indoor areas where GPS does not have a signal and does not work well. RSS is based on numerous indoor positioning systems; therefore, the reliability and accuracy of the positioning systems are prejudiced by the radio propagation environment. Zdruba, Huber et al. (2004) proposed two phases of making RSS base positioning systems to perform a field measurement to accumulate a position fingerprinting database as identified as a radio map and place calculation based on the measurement data. WLAN cards (D-Link, 3Com, SMC, BUFFLO, Hawking Technology, Intel and PROXIM) utilize field measurements in a busy floor for collecting RSS. There are many methods to improve signal strengths such as look for interface, switch channels, reposition router and upgrade with the latest version. However, a wireless adapter has a major effect on the accuracy of position systems (Youssef and Agrawala 2005). Key researchers'main contributions in Wi-Fi based VANET provide citations made by previous studies where they have investigated and analyzed the feasibility of Wi-Fi based networks, propagation measurements, VANETs simulations and an overview of IEEE802.11 standards. Study by previous researchers has provided different methods used to implement their technique as shown in table 2.6.

2.7 Propagation Models

Most of the studies on ad hoc networks are carried out in simulation because of logical and economic limitations. Earlier studies pointed out lots of models based on "too simplistic" assumptions (Pawlikowski, Jeong et al. 2002; Naicken, Livingston et al. 2007),and quantify the potential risks of such assumptions about radio propagation models or node mobility patterns (Naumov, Baumann et al. 2006). Sommer, Eckhoff et al. (2011) proposed that simulation is one of the main methodologies in the development procedure of protocols often involving large and heterogeneous scenarios for Inter-Vehicle Communication (IVC). In simulation environments VANETs appropriately model how vehicles move in a proper environment of ad hoc communication performance. Models apply different types of attenuation features on comparative heading nodes and positions proposed a suitable method to resolve these issues. Common understanding in wireless simulation expresses that transmissions are influenced by six main factors which are fading, shadowing, free-space path loss, Doppler shift/spread and reflection/absorption (Nagel and Eichler 2008). McKown and Hamilton (1991) proposed complex and realistic models which are limited to moderately tiny networks and not applied to evaluating typical large scale VANETs. Radio propagation modeling supplies an alternate to the empirical method for constructing search space for the algorithm. A deterministic model agrees to the computer received signal strength of any real environment, for example distance between a transmitter and receiver. "Free Space" models a single unobstructed communication path whose received power depends on transmitted power, antenna gain and distance between the sender and receiver. This model power decreases with the square of the distance when the radio wave travels from an antenna. The authors regard this model because from a topology point of view the nodes are floating in free space. Reflection occurs when an electromagnetic wave falls on an object, which has very large dimensions as compared to the wavelength of the propagating wave. For example, such objects can be the earth, buildings and walls. When a radio wave falls on another medium having different electrical properties, a part of it is transmitted into it, while some energy is reflected back (Van Eenennaam 2008). However the "Two-ray Ground" model gives more correct predictions at longer range than the "Free Space" model but does not specify decent results in a short distance because of oscillation caused by the constructive and discursive combination of two distinct paths. Although the "Two-ray Ground" model is a widely used propagation model for simulation of

VANETs at present (Ginige and Murugesan 2001), other authors presenting "Shadowing" models agree to lots of possible scenarios, which can affect radio signal power such as path loss value β in real building scenario communications (Singh and Lego 2011). "Hata" models appropriate bigger cell mobile systems however PCS does not fit in this mathematical model (Singh and Lego 2011). Table 2.5 shows a comparison between various channel models.

Table 2.5: Comparison between various channel models

Models	Applicable under conditions	Importance
"Free Space" Model	No obstacles nearby to cause reflection or diffraction	predicts the received power decays as negative square root of the distance.
"Free Space Path Loss" Model	line-of-sight path through free space	predicting radio signal strengths
"Hata" Model for urban	Applicable to radio propagation within urban areas; suited for point-to-point and broadcasting transmission	Frequency: 150-1500 MHZ; antenna height 1- to 200 m; distance 1-10km "Hata" model does not cover whole range requirement
"Hata" Model for suburban	Applicable rural areas or out of the city; suitable for where buildings exist; suited for point-to-point and broadcasting transmission	Frequency: 150 MHZ – 1.50 GHZ Hata" model uses the medium path loss from urban areas
"COST 231" Model	Applicable for urban areas; evaluate path loss	Frequency: 1500-2000 MHZ Antenna height – 200 m; link distance 1-20 KM
"Okumura" Model	Ideal for cities but not tall blocking structures	Height: 1 to 10 m; base station antenna height: 30 100 m; distance: 1 to 100 KM Not providing analytical expiation
"Egli" Model	Suitable for cellular communication, applicable for scenarios where antenna fixed. Though model does not travel through few vegetative obstructions.	Applied to VHF and spectrum transmissions Predicts path loss and subdivided loss into free space loss

Table 2.6: Key researcher and their main contributions in Wi-Fi based VANET

Researchers	Main contribution	Year	Key concepts/ description
(Tufail, Fraser et al., 2008)	Analyzes the feasibility of Wi-Fi based VANETs	2008	Communication testing involves two distances (GPS for long distance and Wi-Fi for short distance). The authors used IEEE 802.11 protocol for first moving vehicles connection and measuring the speed. However for critical issues or safety of passengers Wi-Fi can be use in communication.
(Lagraa, Yagoubi et al., 2010)	Localization techniques in VANET clustering	2010	Proposed a technique with full absence of GPS to determine positions of nodes in VANET and used localization in VANET clustering
(Liu, Khorashadi et al., 2010)	Assessing VANET's under different traffic mobility	2010	Analyze and formulate "storage capability" of VMesh (one-way and high-way). Proposed simulation tool with accuracy of vehicular freeway mobility
(Karim, 2008)	Superior systems vehicular applications	2008	VANET can be future killer application in the modern car, which will provide safety and comfort for the passengers and exchange message to the driver. IEEE 802.11p based technology which would communicate between roadside vehicles up to 200km/h
(Nzouonta, Rajgure et al., 2009)	VANET simulation	2009	Microscopic simulators demonstrated VANET applications design method, flexibility, scalability and increased performance tool. Explained more complex safety developments are GPS receivers, communication device, and radars.
(Perahia, 2008)	Vehicular Ad hoc Network model	2008	Details about propagation models used in VANET
(Grilli, 2010)	Data dissemination in vehicular networks	2010	Network requirement in VANET application such as mobility and permanent access. Preliminary concepts of 802.11g network, WiMAX, Bluetooth, ZigBee, WAVE, cellular network, satellite,
(Martelli, Elena Renda et al., 2012)	VoIP Performance in IEEE 802.11p VANET	2012	Mainly the authors focused the purpose of VoIP performance in IEEE 802.11p-based VANET through on-the-field measurements. Measure the software and hardware to implement VANET
(Ramteke and Krishna 2012)	VANET Using ZigBee Technology	2012	Used the simulations tools (AODV) to implementation and evaluate
(Ho, Leung et al., 2012)	VANET performance	2012	Introduced network model such as routing strategies, channel access protocols and interference. They also proposed a novel methodology to analyse protocol performance in VANET
(Buchenscheit, Schaub et al., 2009)	VANET-based Emergency Vehicle Warning System	2009	Implement the system as a prototype demonstrates the functionality and set up the communication with mechanisms, positioning mechanisms, security components an demo applications
(Qian and Moayeri, 2008)	Secure application in VANET	2008	Proposed secure and application-oriented network design framework for VANET

2.8 Summary

These studies provide robust guidelines to understand the usual features of VANET and the ad hoc networks background, and numerous literature of recently proposed VANET variants is reviewed and discussed. This chapter also provided a summary of a few of the existing examples of the VANET applications and software used for WLAN signal measurements. While the primary objective of this thesis is to investigate the impact of the signal strength in ad hoc networks and performance of VANET, a literature review of existing research is also essential in order to establish a measurement framework and choose result analysis methods. The literature review also proposed great insights into selection of WLAN cards to measure ad hoc networks. The research design is described in Chapter 3.

Chapter 3

Research Design

A review of literature on Wi-Fi based VANET and background materials was presented in Chapter 2. This chapter describes experimental design, which involves details of hardware and software equipment and description of the propagation environment and field trial measurements scenario. Section 3.1 describes details of performance metrics such as packet delivery ratio, end-to-end delay, packet loss and throughput. Section 3.2 provides detailed hardware and software specifications. Section 3.3 defines the propagation measurement environment. Sections 3.4 and 3.5 present detailed field trial measurement scenarios for each experiment and simulation environment. Finally section 3.6 discusses performance validation and measurement accuracy during conducting all experiments.

3.1 Performance Metric

Performance metrics of ad-hoc protocols are separate from external measurements (effectiveness of an ad-hoc protocol includes delay, debit, acquisition time, percentage segments received out sequence) and internal measurements (internal efficiency of the protocol which is average number of bits data transmitted / received, average number of control bits transmitted / received, and average packets and data transmitted / received) (Macker 1999). Packet delivery ratio, a most important factor to measure routing in any type of network, can be obtained from the total number of data packets arriving at destinations divided by the total data packets sent from sources. Mathematically it can be shown as the equation:

$$\sum \textit{Number of packets receive} \,/ \sum \textit{Number of packets sent} \qquad (3.1)$$

End-to-end delay is the time taken for a packet to be transmitted across a network from source to destination. Mathematically it can be shown as the equation:

$$d_{end\text{-}end} = N[\, d_{trans} + d_{prop} + d_{proc}]. \quad (3.2)$$

Where $d_{end\text{-}end}$= end-to-end delay, d_{trans}= transmission delay, d_{prop}= propagation delay, d_{proc}= processing delay, N= number of links (number of routers + 1). Packet loss occurs when one or more packets organized by source of data travelling across a computer network fail

to reach their destination. Mathematically it can be shown as equation:

$$PL = (nSentPackets - nReceivedPackets) / nSentPackets \quad (3.3)$$

Where nReceivedPackets = Number of received packets, nSentPackets = Number of sent packets. Throughput is the movement of inputs and outputs through a process – the amount of transactions produced over time during a test which indicates the number of transactions per second an application can handle. Throughput depends on various factors such as type of test, computer specifications, network card speed and software support. To calculate Wi Fi throughput, mathematically it can be shown as the equation:

$$Throughput\ (Mbps) = Data\ Size\ (MB) / Transmission\ Time\ (s) \quad (3.4)$$

To find the area of a rectangle, multiply the length by the width. The formula is: A = L x W, where A is the area, L is the length, W is the width, and · means multiply.

$$A\ (Area) = W\ (Width) \times L\ (Length) \quad (3.5)$$

3.2 Hardware and Software Requirements

Section 3.2.1 presents details of hardware equipment specifications and section 3.2.2 provides software requirements.

3.2.1 Hardware Equipment

In order to be consistent and produce correct data from this study, the hardware used in all of the measurements was kept identical. Hardware used in the field trial measurement consisted of two laptops, one wireless adapter, one external antenna and basic tools for recording and measuring the area and distance of the two laptops (i.e. measuring tape, pen paper and table chart). Details of following hardware specifications are as shown:

Laptop 1

- Vendor: Acer
- Model: Aspire E1-531
- Processor: Intel (R) Pentium (R)
- CPU: 2.2 GHz (2 CPUs)
- Memory: 8 GB
- Operating systems: Windows 8 64-bit

Laptop 2

- Vendor: Hewlett Packard
- Model: HP Elitebook 2570p
- Processor: Intel (R) core (TM) i5-3360M
- CPU: 2.8 GHz
- Memory: 8 GB
- Operating systems: Windows 7 professional 64-bit

IEEE 802.11n USB Wireless Adapter

- Vendor: OutLink
- Model: 0301SH300278
- Wireless Standards: IEEE 802.11n, IEEE 802.11g, IEEE 802.11bOutput Power: 300Mbps
- Frequency band: 2.4 GHz
- Channel: 1-14 channels
- Data Security: 16/128-bit WEP Encryption WPA, WPA-PSK, WPA2, WPA2-PSK, TKIP/AES
- Host Interface: High speed USB2.0/1.1 Interface

IEEE 802.11n 2.4 GHz Antenna

- Vendor: D-link
- Model: ANT24-0700
- Directivity: Omni-Directional Indoor Antenna
- Frequency Range: 2.4GHz to 2.5 GHz
- Power Level of Antenna: 7dbi
- HPBW/H-Plane (Horizontal): 360 degrees

3.2.2 Software

In terms of software specifications, two operating systems were involved in this study, which were Microsoft operating systems and some software was installed on the systems. In addition, the details of software are also explained in this section as below.

- **Colligo Workgroup Edition 3.2**

Colligo workshop edition software enables any wireless laptops at a client site, on the road or in the field instantly and securely which is used for transferring files, sharing folders and printers, chat, comparing calendars, collaborating on documents and much more.

http://windows.softwareweb.com/colligo-workgroup-edition-3.2-BE8.html

- **WirelessMon**

WirelessMon proposed wide-ranging graphing of signal levels and real time IP and 803.11 Wi Fi statics. This software allows users to monitor current connection information such as SSID, signal strength, channel in use, number of antennas, statistics information, IP information, IP counter information and so on.

http://wirelessmon.en.softonic.com/download

- **Windows OS 7 Professional**

Windows 7 is a Microsoft Windows operating system. Windows 7 Professional supports up to 192 GB of random access memory and operates as a remote desktop server, location aware printing, backup to network location, and has ability to install different types of software which also implements Windows file sharing between a pair of nodes.

- **OPNET**

OPNET stands for Optimized Network Engineering simulator that provides performance for any type of computer network and application. This software is significantly helpful when working with complex networks with a large number of devices and traffic flows.
http://www.opnet.com/university_program/itguru_academic_edition/

❖ **InSSIDer**

inSSIDer act as a Wi-Fi scanner that will identify the SSID, RSSI, Security and results are displayed by inSSIDer will give infomasi on the condition of wireless signals in the monitored network , and the information provided is easy to understand. Rawat, Yan et al. (2012) mentioned channel occupancy information along with the SSID, channel, RSSI, security, MAC address, vendor information, network type, etc. can be easily obtained using freely available tools such as inSSIDer.
http://www.inssider.com/downloads/

3.3 Propagation Measurement Environment

Propagation measurements for this study were performed in a set of scenarios considered with the aim of significant results under different test conditions in Henderson Westfield mall parking level 1, level 2, level 3 and level 4. The measurement scenarios were combined with different tests and each test was contained in constantly transferring data files. We used two different files for this measurement test. A TXT file 71 bytes (representing traffic notifications such as accidents, road conditions, sharing information etc.) and IMAGE file 1.05 MB (representing image file for example streaming to cars). To transfer or share files we used Colligo workshop software. We also used WirelessMon for collected data and information such as strength (dBM), bandwidth, data rate, received data rate, send data rate, time to transfer file. Figure 3.1 shows the measurement area in Henderson Westfield shopping center.

Figure 3.1: Photograph showing parking lot of Westfield Shopping Mall Auckland

There were two types of measurement at floor level 1 shown in Figure 3.2, 35m wide and 100m long. For level 2 and the rest of the levels, 35m wide and 50m long as shown in Figure 3.3. At Westfield mall the exterior flooring and walls of the entire building are made of concrete. Each level of parking has a concrete ramp for passing cars up and down. They also have two lifts and two stairs for human passing. There are approximate 4m distances between levels. Measurements were conducted in all parking levels.

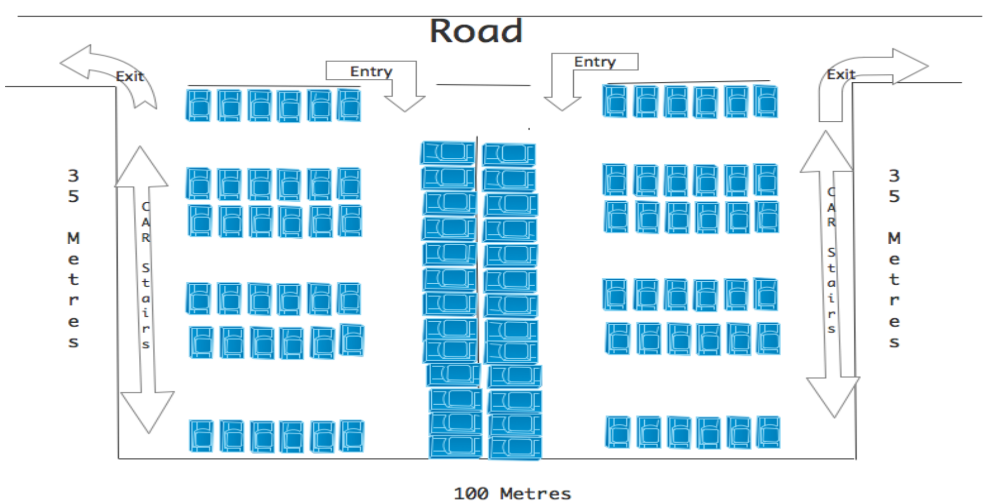

Figure 3.2: Westfield shopping mall parking layout (A)

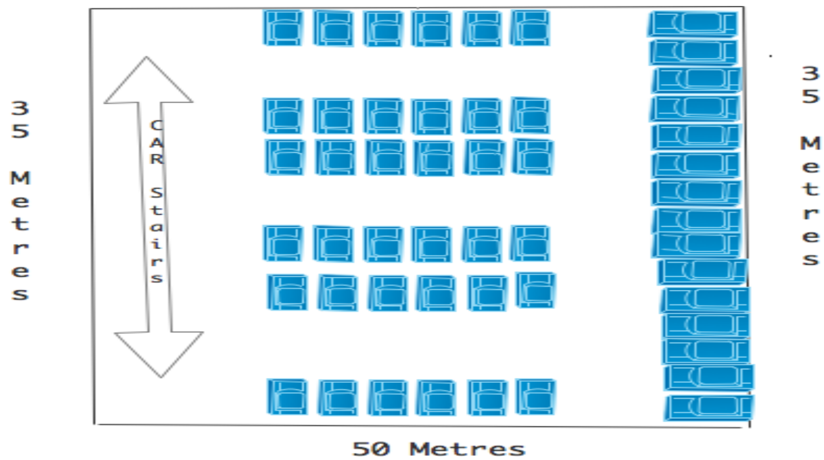

Figure 3.3: Westfield shopping mall parking layout (B)

To set up a field measurement scenario there are several planning steps required. Figure 3.4 shows primarily the intended route of each car is allocated into three segments: 1) start position, 2) start parking measurement to end parking measurements and 3) end position. The most important of this segment is parking measurement (start parking measurement to end parking measurement). Figure 3.5 shows the parking measurement is 1m from approach to departure while Figure 3.6 shows the measurement is continues from 1 to 100m.

Figure 3.4: Measurement planning sections (A)

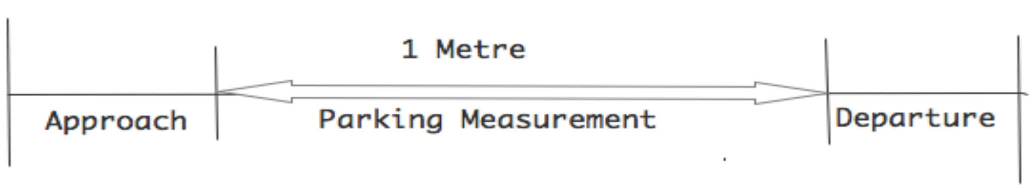

Figure 3.5: Measurement planning sections (B)

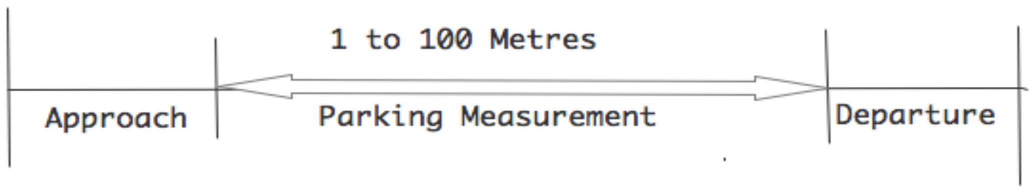

Figure 3. 6: Measurement planning sections (C)

Figure 3.7 illustrates the measurement flowchart. Starting with setting up required hardware then we installed all necessary software. Once we installed the software we needed to repeat for another computer the same procedure. Following the need to check both computers' Wi Fi connections and provide the IP address for both computers, they were able to communicate with each other. Following this we measured our required distance and marked the destination. Finally, we started measuring and collecting our required data. Once finished the first measurement then we started the next measurement.

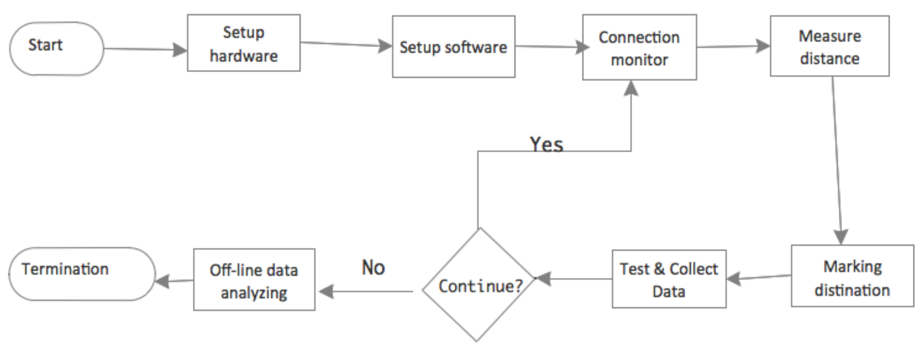

Figure 3.7: Flowchart field measurement

3.4 Measurement Scenarios

The main goal of the field trial measurement tests was confirming the accurate operation of rescue VANET in an integrated test and which allowed us to quantify the exact performance and provide insights on how to improve the implemented solutions in the future. Field trial measurements in parking area were conducted with two cars. Car A and Car B communicated with each other where

Car A was the transmitter (TX) and Car B the receiver (RX). Standard field trial measurement V2V scenarios are shown in Figure 3.8. Each test and scenario for VANET schematic demonstrations are as follows.

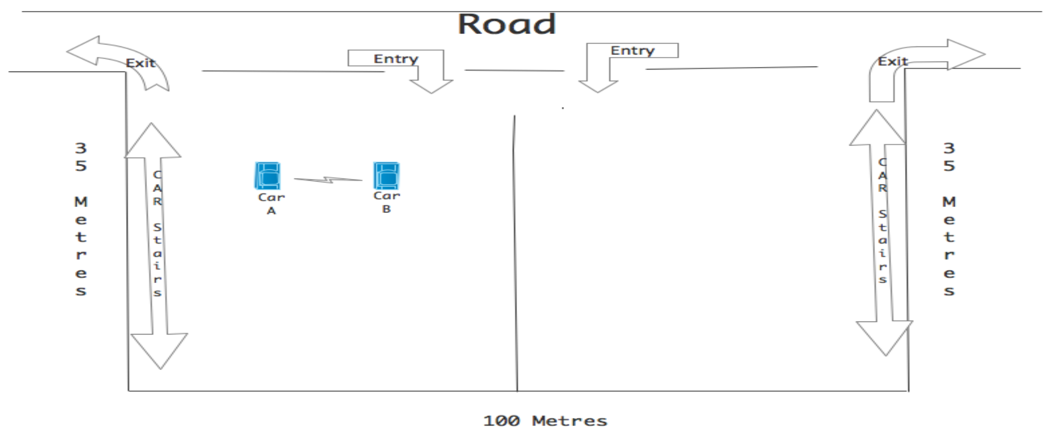

Figure 3.8: V2V communications

All scenarios were conducted with NLOS conditions applied when a wireless router was of fixed height of 1m and the transmitter was moved along the parking lot. Table 3.1 shows scenarios conducted in the parking lot under a controlled environment. Field trial measurements consisted of five scenarios.

Table 3.1: Wi-Fi-Based Vehicular Ad Hoc Network using Field Trial Measurement scenarios

Scenario	Description
1	In level 1, initially two cars (TX and RX) were placed 1m distances apart sharing a text and image file. This scenario is intended to study the impact of increasing the distance between the TX and RX step by step in little portions until getting maximum communication range between two vehicles. By conducting scenario 1, we gained a vision and collect signal strength, data rate and transmission time.
2	Scenario 2 started from 4m distances where TX was placed in level 1 and RX place in level 2. There is 4m distances from level 1 to level 2 to sharing a text file and image file. This scenario is intended to study the impact of increasing the distance between the TX and RX step by step in little portions until getting maximum communication range between two vehicles. By conducting scenario 2, we gained a vision and collect signal strength, data rate and transmission time.
3	Scenario 3 started from 8m distances where TX was placed in level 1 and RX placed in level 3. There is 8m distances from level 1 to level 3 to sharing a text file and image file. This scenario is intended to study the impact of increasing the distance between the TX and RX step by step in little portions until getting maximum communication range between two vehicles. By conducting scenario 3, we gained a

	vision and collect signal strength, data rate and transmission time.
4	Scenario 4 started from 12m distances where TX was placed in level 1 and RX placed in level 4. There is 12m distances from level 1 to level 4 to sharing a text file and image file. This scenario is intended to study the impact of increasing the distance between the TX and RX step by step in little portions until getting maximum communication range between two vehicles. By conducting scenario 4, we gained a vision and collect signal strength, data rate and transmission time.
5	Scenario 5 was conducted by parking on the road. There is 1m minimum distances from level 1 to the road to sharing a text file and image file. This scenario is intended to study the impact of increasing the distance between the TX and RX step by step in little portions until getting maximum communication range between two vehicles. By conducting scenario 5, we gained a vision and collect signal strength, data rate and transmission time.

3.5 Simulation Environment

The OPNET simulation tool was chosen for simulation purposes because of its availability and credibility. Figure 3.9 illustrates the OPNET simulation environment with a network size of 50 nodes. Table 3.2 lists the simulation parameters. Most of the parameters are default settings. Table 3.3 describes OPNET simulation scenarios with 2 nodes, 5 nodes, 10 nodes, 20 nodes, 30 nodes, 40 nodes and 50 nodes.

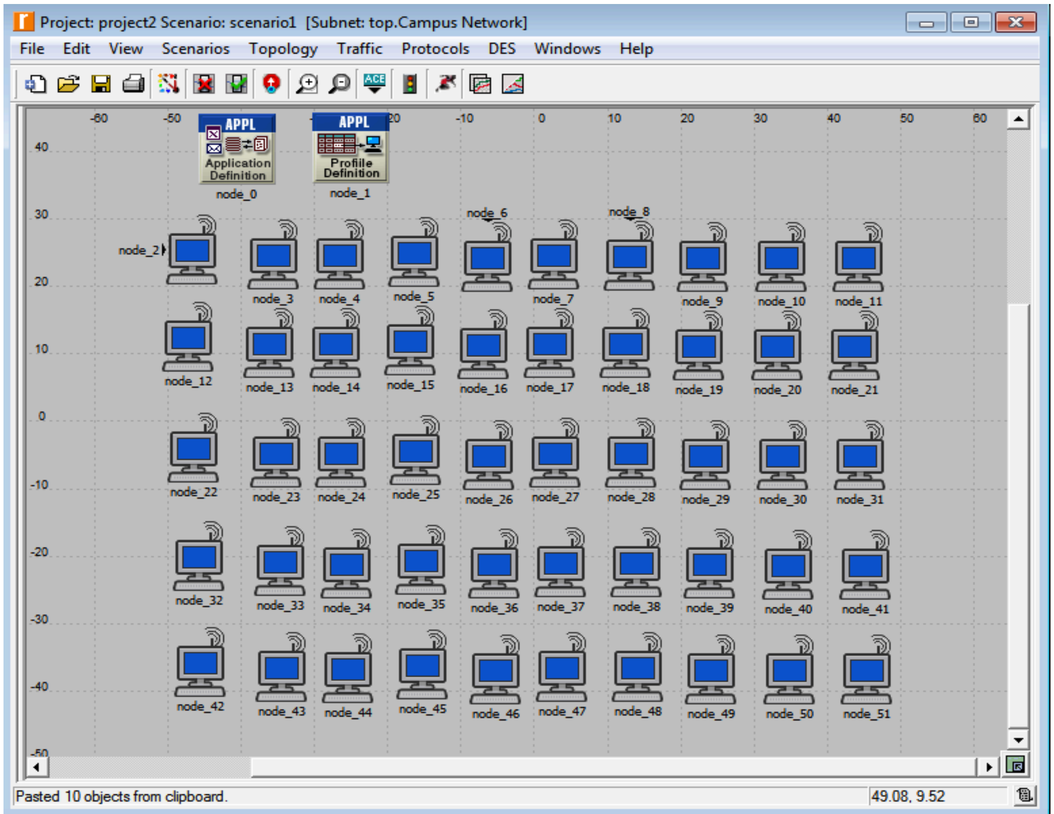

Figure 3.9: OPNET representation of 802.11n model (N = 50)

Table 3.2: General parameters used in simulations

Parameters	Value
Network scale	Office
Area	50 X 100 Square metres
Network Size (number of nodes)	Up to 50
Mobility model	Random way point

Data rate	26 Mbps (base / 240 Mbps (max)
Physical characteristics	HT PHY 2.4GHz (802.11n)
Transmit power (W)	0.005
Packet reception Power	-92 dBm
Channel	Auto assign
Buffer size (bits)	256000
Ftp	Low load (1000 bytes) Medium load (5000 bytes) High load (50,000 bytes)
P2P file sharing	Low traffic: Minimum outcome 10000 (bytes) Maximum outcome 100000 (bytes) High traffic: Minimum outcome 100000 (bytes) Maximum outcome 10000000 (bytes)
Simulation Time	300 seconds

Table 3.3: OPNET based Ad Hoc Network using multiples of nodes

Scenario	Description
OPNET based simulation	OPNET based scenario consists of six measurements (time average delay, throughput, traffic sent, traffic received, download file size and download response time). All measurements used the Ad Hoc Network environment and configuration illustrated in Figure 3.2, which is a common scenario in obstructed parking environments. According to two applications FTP and P2P, network size 2 nodes, 5, nodes 10 nodes, 20 nodes, 30 nodes, 40 nodes and 50 nodes. This scenario is intended to study the impact of Ad Hoc Network with multiple nodes.

3.6 Measurement Accuracy

Interference from human and car movement: The measurement-parking floor used for the propagation measurement is usually very busy during seven days in opening hours. Two people were involved to complete the field trial measurements. We performed the propagation measurements during the lunchtime to avoid too many people and cars moving around.

Systems Configurations: Firewall and anti-virus were disabled. Two ad-hoc computers were connected with the same wireless adapter.

Co-channel interference: During the tests there were large numbers of neighboring WLAN noticed.

Validation: The propagation measurement was repeated two times for each scenario to ensure accurate data were collected.

Measurement tools: The propagation measurement was conducted with measurement tape to get accurate distances.

3.7 Summary

This chapter outlined the intensity of the measurement design that was implemented for field trial measurements. For the field trial measurement hardware equipment and software requirements specifications are also presented. This chapter also provided propagation measurements and flowchart field measurement for this study. Five distinct scenarios are introduced. The measurement results for the performance metrics such as network strength (dBm), bandwidth, and time are provided in the following chapter along with evaluation and analysis of the findings. The experimental results in performance metrics such as Received Signal Strength Indicator (RSSI); data rate and transmission delay provided; and OPNET simulation results are also discussed in Chapter 4 together with evaluation and analysis of the findings.

Chapter 4

Results and Discussion

The research design and detail investigations for this study have been discussed in Chapter 3. This chapter outlines the research analysis and discussion. The preliminary trials are presented in section 4.1, which was done successfully in the West City Auckland shopping mall parking lot. It also covered the parking mall environment and measurement conducted between two cars with two laptops, which were transmitter (TX) and receiver (RX) placed at required distances and data collected for measurements. Appendix B provides all scenario outcomes in Service Set Identifier (SSID), Received Signal Strength Indicator (RSSI); data rate is numeric values. The impact of two different traffic types of applications (FTP and P2P) on the wireless network performance is discussed in section 4.2 and also the impact of node mobility (0, 5, 10, 30, 40 and 50). Appendix D provides numeric values for simulation results.

4.1 Field trial Measurement at West City Auckland shopping mall parking lot

All preliminary trials ran successfully in the West City Auckland shopping mall parking lot with a large number of surrounding networks and interfaces. West City Auckland shopping center is located in Henderson, a suburb of Waitakere, Auckland, New Zealand. Total retail floor area is about 36,921 m^2 (397,414 sq ft) with three floors. There are 130 stores and services located inside the mall and 1492 spaces for car parking inside and outside the shopping mall. The height of the parking lot is 4 m. The length of the parking lot is 50 m. The width of parking lot varies, from 50 m (level 2 to level 5) to100 m (level 1). All car parking is free for customers up to four hours as shown figure 4.1.

Figure 4. 1: West city Auckland shopping mall parking image

During the network assessment in the West City Auckland shopping mall parking lot, we experienced lots of network connectivity, which caused long delays and packet loss during packet transmission. Firstly we used a laptop which were network set-up by connected with an IEEE 802.11n USB Wireless Adapter and IEEE 802.11n 2.4 GHz Antenna. During the trials with a laptop we had found other interference. Before conducting any official measurements we tested with software inSSIDER a large number of SSID as Figure 4.2 shows; 19 to 36 of SSID were detected in all scenarios.

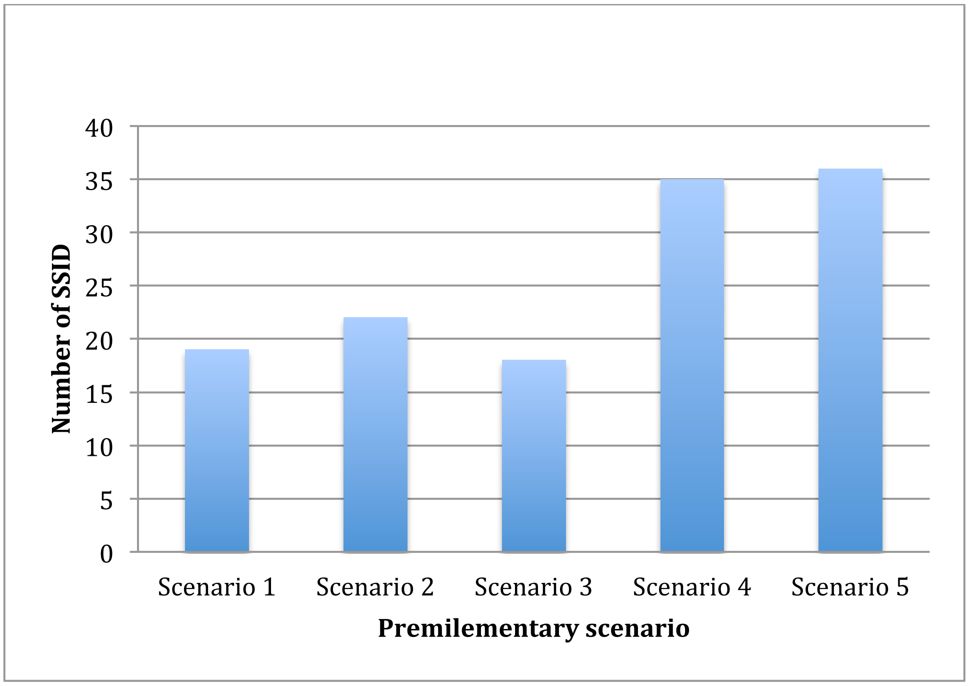

Figure 4.2: Number of SSID identified in the West city Auckland shopping mall parking lot

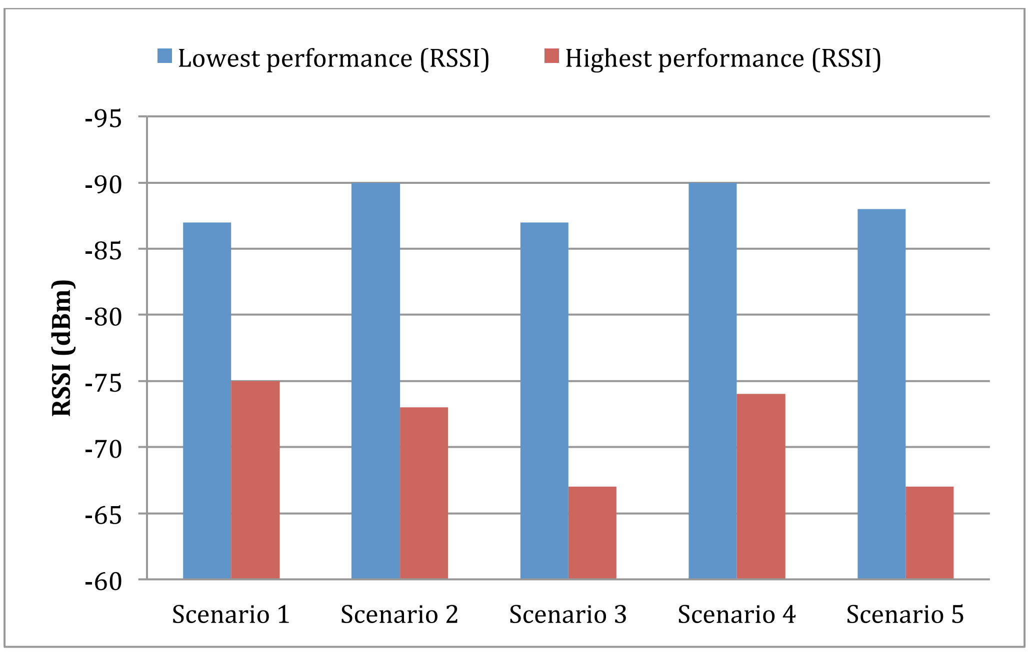

Figure 4.3: RSSI (dBm) in West city Auckland shopping mall parking lot

Figure 4.3 shows the network strength (high performance and low performance) of all scenarios. In scenario 1, 2, 3, 4, and 5 signal strength was between -75 to -87 dBm, -74 to -90 dBm, -67 to -87 dBm, -74 to -90 dBm, and -67 to -88 dBm respectively. This clearly shows in all scenarios that network strength quality was not reliable and provided lowest performance.

4.1.1 Study 1 (Level 1)

The measurements were carried out on the level 1 in the West City Auckland shopping mall parking lot with two cars and two laptops, which were transmitter (TX) and receiver (RX) placed at required distances and started sharing file to TX to RX. Measurements were completed by increasing the distance between the transmitter and receiver step by step in little portions until getting the ad-hoc signal or connection.

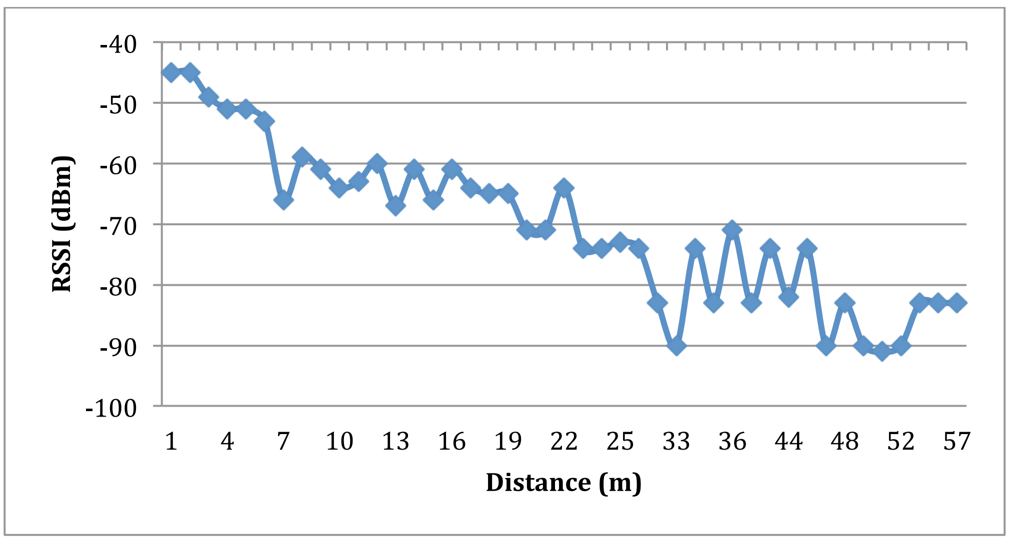

Figure 4.4: RSSI versus distance coverage

Figure 4.4 shows the relationship between strength (dBm) and distance starting from 1m to 57m including the wall barrier, car park and car moving and human moving. During the testing, no other devices were connected to the ad hoc networks. Therefore, no download /upload seed interference could have been caused by other devices. As the figure indicates, the RSSI gave best performance when its value was -45 dBm in about 1m to 2m distance, by which we determined that it gave best reliability. On the other hand we also saw that when its value was -90 dBm to -92 dBm it gave lowest performance in about 50m to 58m, which meant less reliability. The RSSI value change follows a nearly similar pattern, which is RSSI drops gradually when the distance increases. About -8 dBm drop occurs for each transmit power when the distance changes from 1 m to 6 m. From 1m to 31m the

RSSI value was about -45 dBm to -74 dBm, which is best reliability. This graph also shows RSSI value was -90 dBm when distances were only 32m from TX to RX but when the distance was 32m then RSSI was slightly increased and decreased till 57m. There was no signal identified when TX to RX distance was about 58m. The main reason for this RSSI dropping trend is because the distance gets longer from TX to RX.

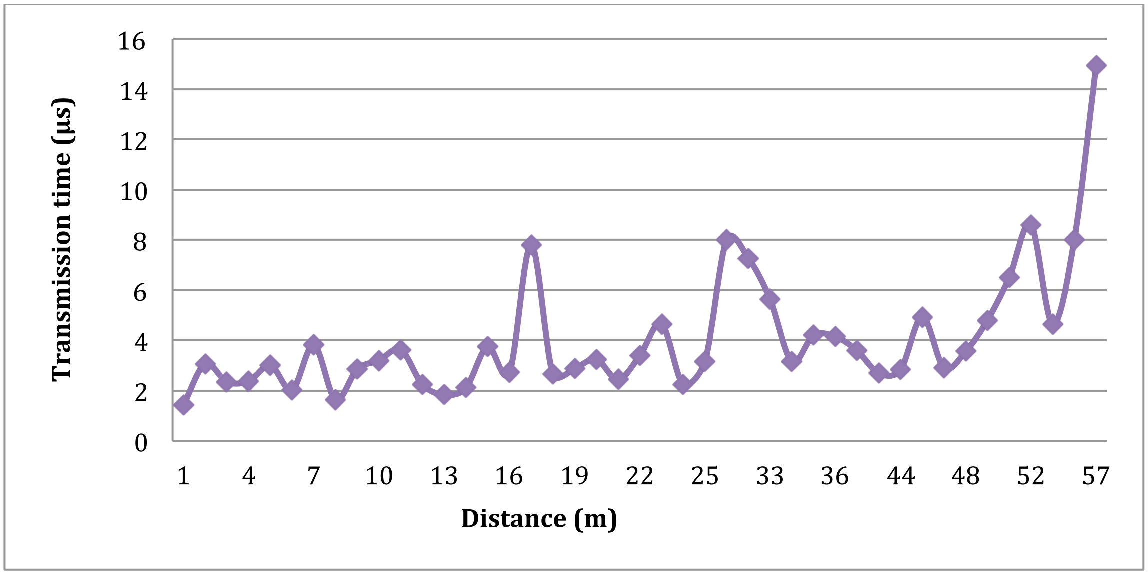

Figure 4.5: A text file transmission time from TX to RX

Figure 4.5 shows the relationship between transmission times and distance when TX is sending txt files (71 bytes) to RX. This figure also shows minimum and maximum time taken to send a text message between transmitter and receiver. The time value change follows a nearly similar pattern, which is time increased gradually when the distance increased. For example, it takes1.44 µs and 14.93 µs to send a text file within 1m and 57m distances where the transmission time increased about 13.49 µs between 1m to 57m distance which.

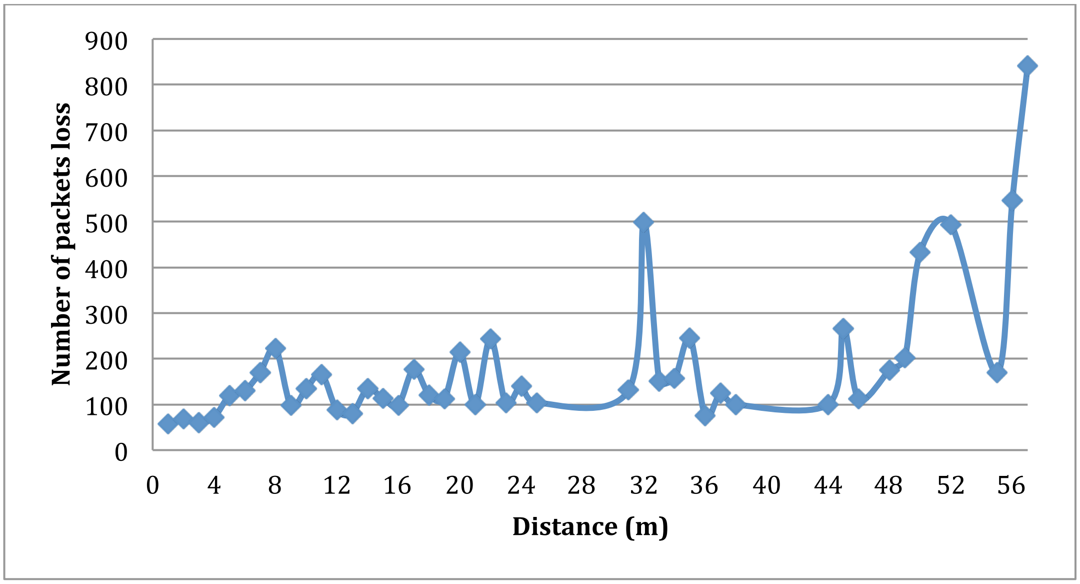

Figure 4.6: Packets loss in transmission a txt file over distance

Figure 4.6 shows packets missing when TX and RX transmission of a txt file with various distances. Moreover, packets sent 83, 228, 381 and 981; packets received 25, 58, 204 and 139; packets missing were 58, 170, 177 and 842; and when distance increased between TX to RX 1, 7, 17 and 57 m. However, when distance increase 1 m to 57 m the packets missing increased was 784. Packet loss is almost always bad when it occurs at the final destination. Packet loss happens when a packet doesn't make it there and back again. When a buffer is full and another packet comes in, the router or switch can only do one thing: "drop" the packet. Because TCP can't tell the difference between a packet lost because of a flipped bit or because of overflowing buffers in the network, it'll assume the latter and slow down.

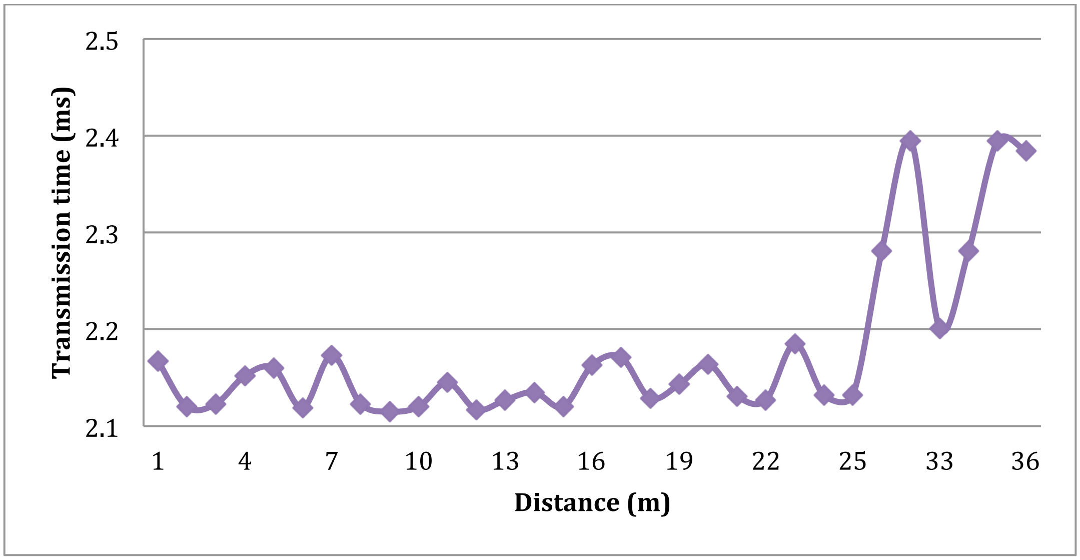

Figure 4.7: An image file transmission time between TX and RX

Figure 4.7 shows the relationship between transmission times and distance when TX is sending an image file (1.5 MB) to RX. In this case, an image file is only able to share between TX to RX about 26m. The time value change follows a nearly similar pattern, which is time increases gradually when the distance increases. This figure also shows minimum and maximum time taken to send an image message between transmitter and receiver. For example, 2.16 ms and 2.39 ms is taken within 1 m and 35m distances where the transmission time increased about 11.2 ms between 1m to 35m distance.

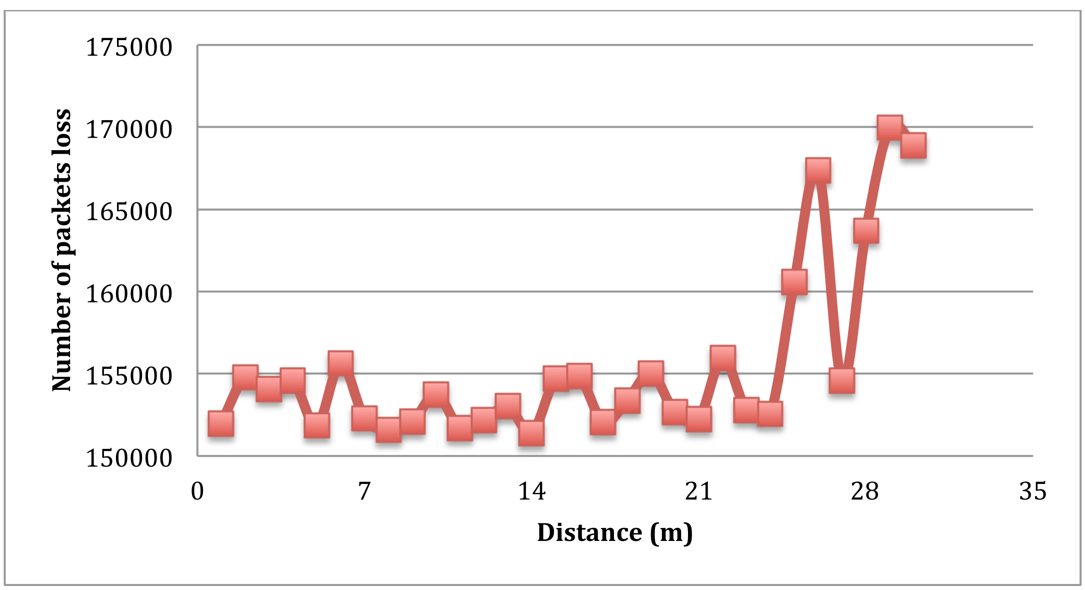

Figure 4.8: Packets loss in transmission an image file over distance

Figure 4.8 shows packets missing when TX and RX transmission of an image file with various distances. Moreover, packets sent 158840, 173490 and 173820; packets received 3610, 61300 and 49000; packet missing was 155230, 111190 and 167920; and when distance increased between TX to RX 1, 32 and 36 m. However, there were significant packets missing when distance was 1 m, which are about 155000. Packet loss is almost always bad when it occurs at the final destination. Packet loss happens when a packet doesn't make it there and back again

4.1.2 Study 2 (Level 1 to Level 2)

Measurements conducted in level 1 to level 2 in the West City Auckland shopping mall parking lot where two cars had two laptops, which were transmitter (TX) placed in level one and receiver (RX) placed in level two in the required distance and started sharing files to TX to RX. There are 4 m different between levels 1 to level 2. After finishing this measurement then it was extended until getting the ad-hoc signal or connection.

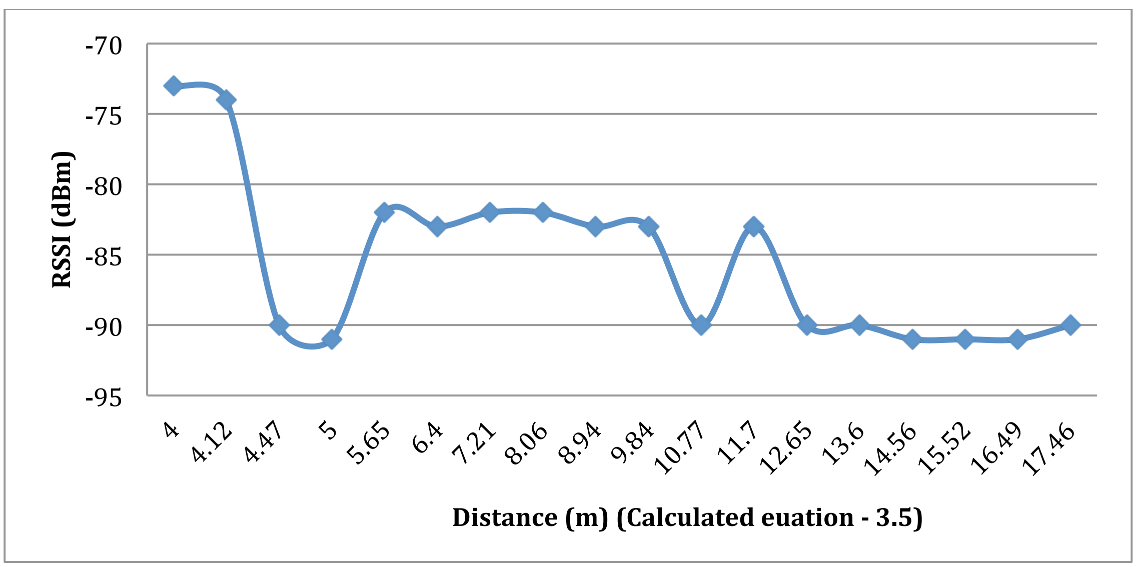

Figure 4.9: RSSI versus distance coverage

Figure 4.9 shows the relationship between strength (dBm) and distance starting from 4m to 17.46m included the wall barrier, car park and car moving and human moving. As the figure indicates, the RSSI gave best performance when its value was -73 dBm to -74 dBm in about 4m to 4.12m distance, by which we determine that it gives best reliability in scenario two. However, when the distance increased after 4.12m till 17.46m in level two then we found unsatisfactory results, which is -82 dBm to -91 dBm. We couldn't detect any signal when distance increased over 17.46 m. Because transmission delay is RSSI dropping trend when the distance increased from TX to RX with blocked of roofs and walls.

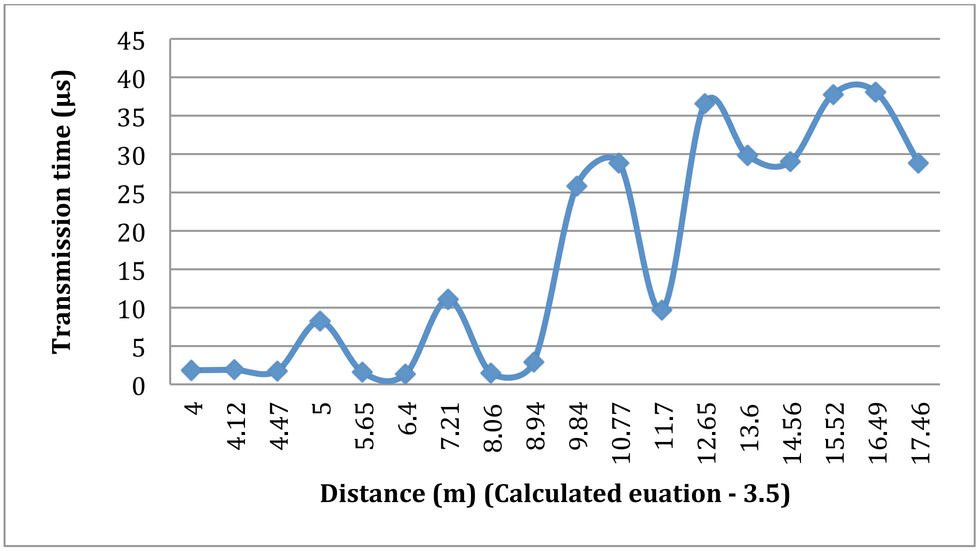

Figure 4.10: A text file transmission time from TX to RX

Figure 4.10 shows the relationship between transmission times and distance when TX is sending txt files (71 bytes) to RX. This figure also shows minimum and maximum time taken to send a txt message between transmitter and receiver. For example, it takes 1.8 µs and 1.9 µs to send a txt file within 4m and 8.94m distance where the transmission time increased about 0.1 µs. However there was 38.08 µs transmission time delay when the distance increased 16.49m. The main reason for transmission delay is RSSI dropping trend because when the distance gets from longer to longer from TX to RX with blocked of roofs and walls.

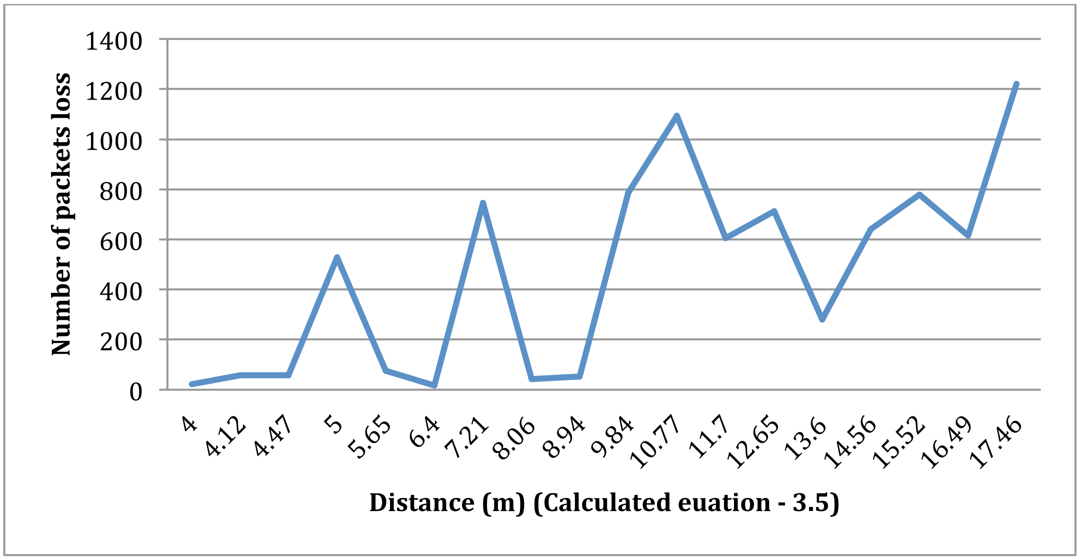

Figure 4.11: Packets loss in transmission a txt file over distance

Figure 4.11 shows packets missing when TX and RX transmission of a txt file with various distances. Moreover, packets sent 81, and 665; packets received 58, and 60; packet missing was 23, and 605; and when distance increased between TX to RX, in some respects. However, when distance increased 12.65 m to 17.46 m sending and received packets increased and missing packets increased 513 and 421. Packet loss is almost always bad when it occurs at the final destination. Packet loss happens when a packet doesn't make it there and back again

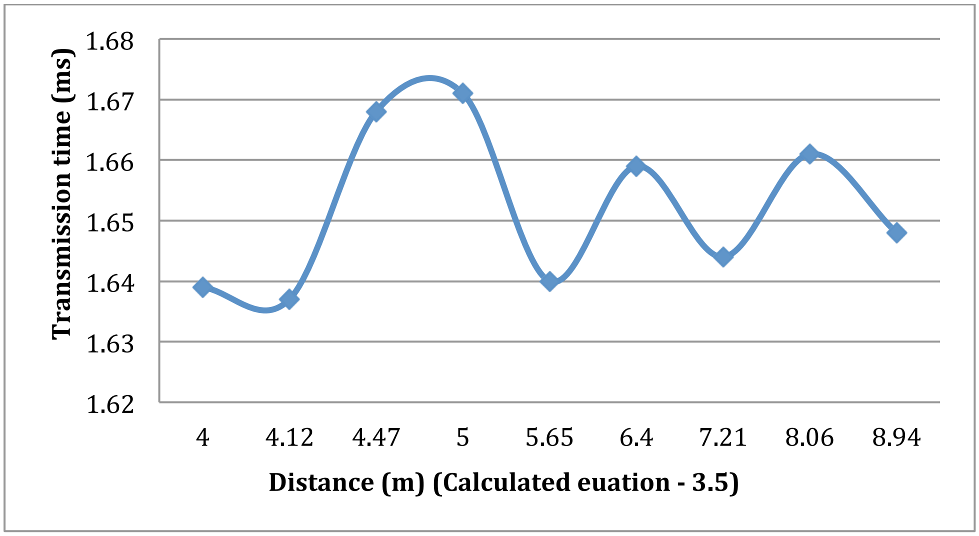

Figure 4.12: An image file transmission time from TX to RX

Figure 4.12 shows the relationship between transmission times and distance when TX is sending an image file (1.5 MB) to RX. In this case, image files were only able to share between TX to RX about 8.96 m increases. This figure also shows minimum and maximum time taken to send an image message between transmitter and receiver. For example, it takes 1.63 ms and 8.94 ms to send a txt file within 4 m and 8.94 m distances where the transmission time increased about 10.57 ms between 1 m to 35 m distances.

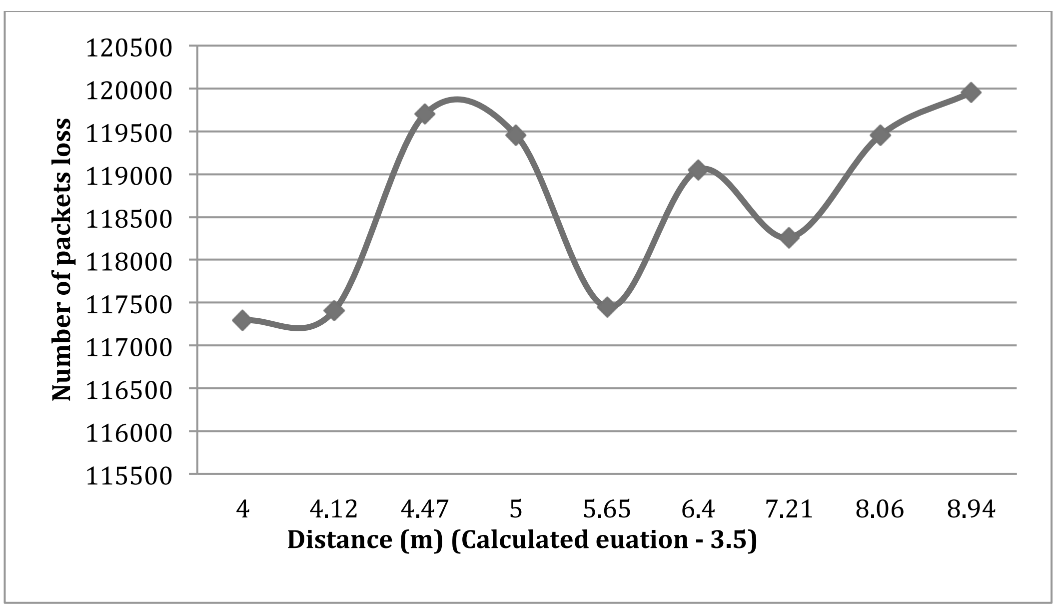

Figure 4.13: Packets loss in transmission an image file over distance

Figure 4.13 shows packets missing when TX and RX transmission of an image file with various distances. Moreover, packets sent 120100; packets received 28000; and 11300 packets missing; and when distance between TX to RX was 4 m, respectively. However, there is significant packet missing when distance was 4 m to 8.94 m.

4.1.3 Study 3 (Level 1 to Level 3)

Measurements conducted in level 1 to level 3 in the West City Auckland shopping mall parking lot where two cars with two laptops, which were transmitter (TX) placed in level 1 and receiver (RX) placed in level 3 at required distances and started sharing file to TX to RX. There are 8m difference between levels 1 to level 2.

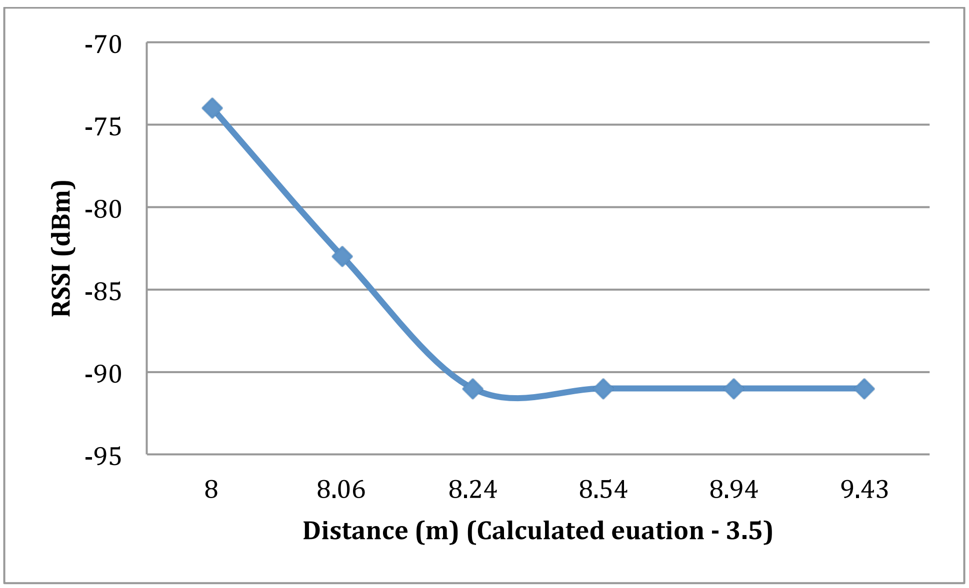

Figure 4.14: RSSI versus distance coverage

Figure 4.14 shows the relationship between strength (dBm) and distance starting from 8m to 9.43m including the wall barrier, car park and car moving and human moving. During the testing, no other devices were connected to the ad hoc networks. Therefore, no download /upload seed interference could have been caused by another devices. As the figure indicates, the RSSI gave best performance when its value was -74 dBm at about 8m distance, by which we determine that it gives best reliability in level 1 to level 3. The path loss directly increases with the distance, starting with -83 dBm at 8.24

m to -91 dBm at 9.43m, which means very poor reliability. The maximum measurement distance between transmitter and receiver with 802.11n wireless cards conducted about 9.43 m distance. After 9.43m distance we couldn't recognize any signal from transmitter to receiver.

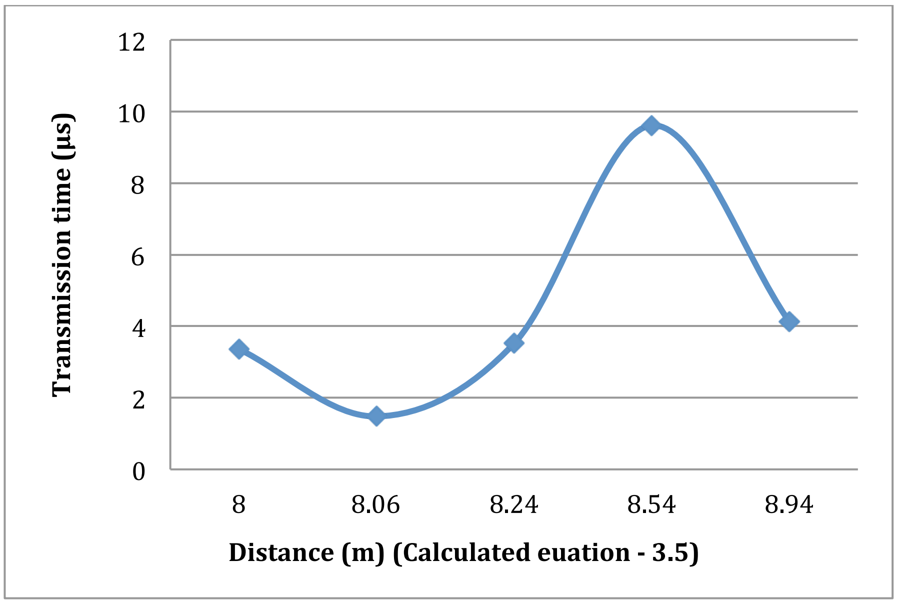

Figure 4.15: An image file transmission time from TX to RX

Figure 4.15 shows relationship between transmission times and distance when TX was sending txt files (71 bytes) to RX. This figure also shows minimum and maximum time taken to send a text message between transmitter and receiver. The time value change follows a nearly similar pattern, which is time, increased gradually when the distance increases. For example, it takes 3.36 µs and 8.54 µs to send a text file within 8m and 8.54m distances where the transmission time increased about 5.8 µs between 8m to 8.54m distances.

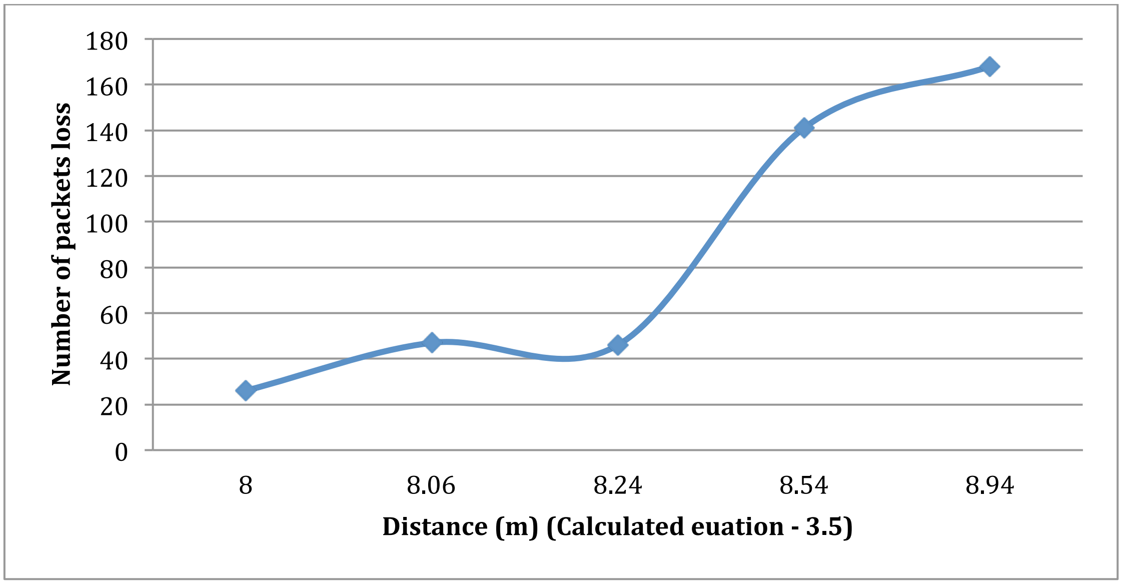

Figure 4.16: Packets loss in transmission a txt file over distance

Figure 4.16 shows packets missing when TX and RX transmission of a txt file with various distances. Moreover, packets 139, 79, 155, 431 and 239; packets received 113, 32, 109, 290 and 71; packet missing were 26, 47, 46, 141 and 168; and when distance increased between TX to RX 8, 8.06 m, 8.24, 8.54, 8.94 and 9.43 m. However, when distance increased 8m to 8,94m packets missing increased which is about 26 and 168.

Table 4.1: Packets sent and received versus distance for the transmission of an image file from TX and RX

Distance (m)	Packets sent (bps)	Packets received (kbps)	Transmission time (ms)
	File size 1.05 MB		
8	123.01	2.6	1.6
8.06	123.77	3.07	1.6
8.24	0	0	0
8.54	0	0	0

Table 4.1 shows TX and RX only able to share an image file 8m and 8.06m distance. When TX sends an image file (1.5 MB) to RX, they were only able to share files till 8.6m. After 8.6m was frequently disconnected to share a little file through ad hoc network and 1.6 ms transmission times between them.

4.1.4 Study 4 (Level 1 to Level 4)

Measurements conducted in level 1 to level 4 in the West City Auckland shopping mall parking lot where two cars with two laptops, which were transmitter (TX) placed in level 1 and receiver (RX) placed in level 4 at required distances and started sharing files TX to RX. There is 12m difference between levels 1 to level 4. After finishing this measurement then it was extended until getting the ad-hoc signal or connection.

Table 4.2: In Ad Hoc network TX and RX communicating between level 1 to level 4

Distance (m)	Strength (dBm)	Data Rat (bps)
12	0	0
12.04	0	0
12.17	0	0

Table 4.1 shows results where TX in level 1 and RX in level 4 were sharing information with ad hoc connections where 12m distance from level 1 to level 4. Unfortunately, we were unable to connect TX to RX or RX to TX, as there were no detected signals at 12m distances.

4.1.5 Study 5 (Level 1 to Road)

Measurements conducted in level one in West City Auckland shopping mall parking lot to Edsel Street where two cars with two laptops, which were transmitter (TX) placed in level one and receiver (RX) placed in Edsel Street at required distances and started sharing files TX to RX. There are 11m different between levels 1 and Edsel Street. After finishing this measurement it was extended until getting the ad-hoc signal or connection.

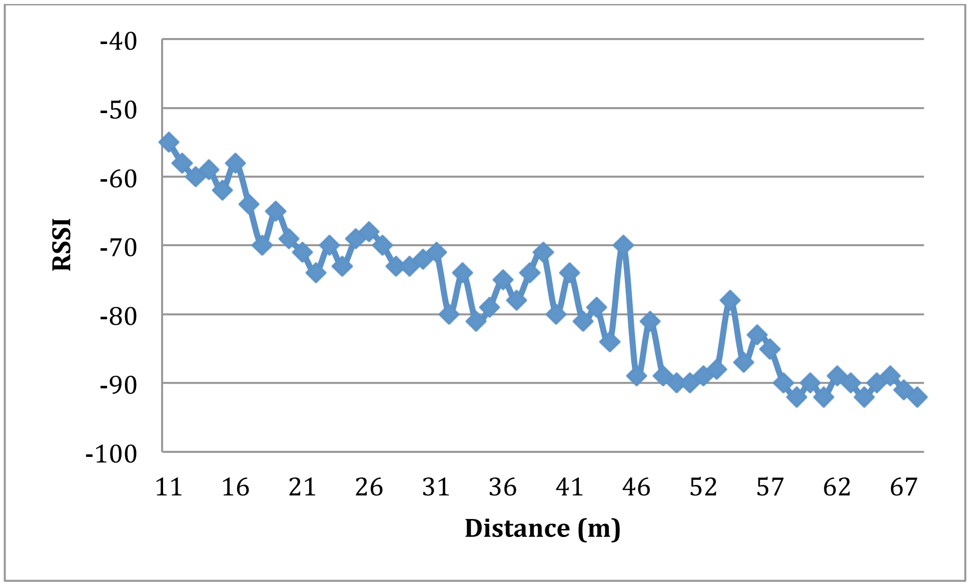

Figure 4.17: RSSI versus distance coverage

Figure 4.17 shows relationship between strength (dBm) and distance starting from 11m to 68m. This figure also calculated together receiving data rate and sent data rate depending on the distance from TX to RX. During the testing, no other devices were connected to the ad hoc networks. Therefore, no download /upload seed interference could have been caused by another devices. As the figure indicates, the RSSI gave best performance when its value was -55 dBm to -74 dBm in about 11m to 31m distance by which we determined that it gives best reliability. However, we also saw that when its value was-81 dBm to -92 dBm giving lowest performance in about 41m to 68m, which means poor reliability.

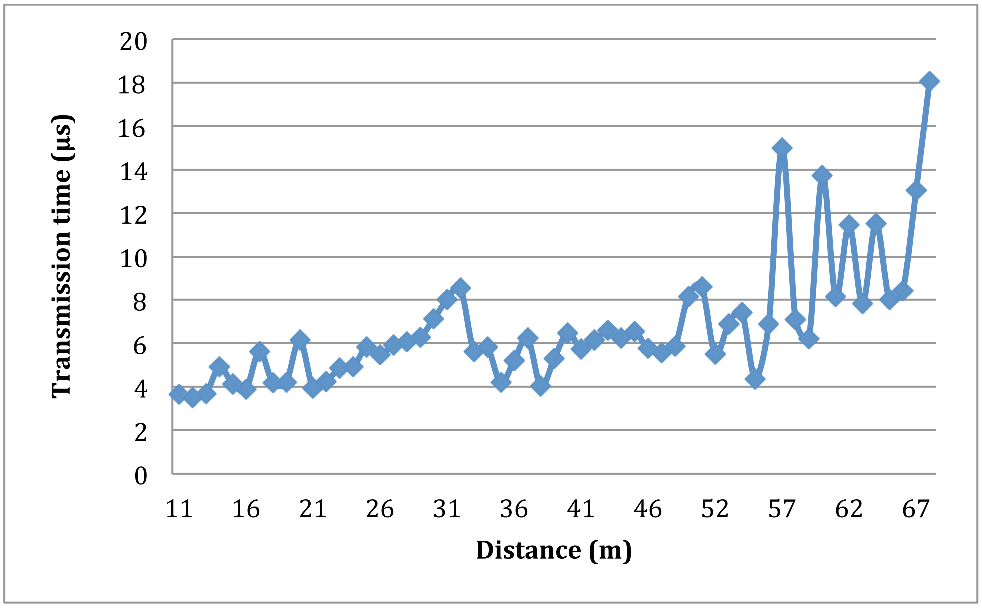

Figure 4.18: A text file transmission time from TX to RX

Figure 4.18 shows relationship between transmission times and distance when TX is sending txt file (71 bytes) to RX. This figure also shows minimum and maximum time taken to send a txt message between transmitter and receiver. It takes 3.66 µs to send a txt file within 11m to 13m distance and 18.07 µs take to send 71 bytes file to 68m distance. However when distance was increased to 68m then then TX was unable to send any txt to RX because time increased gradually when the distance increases.

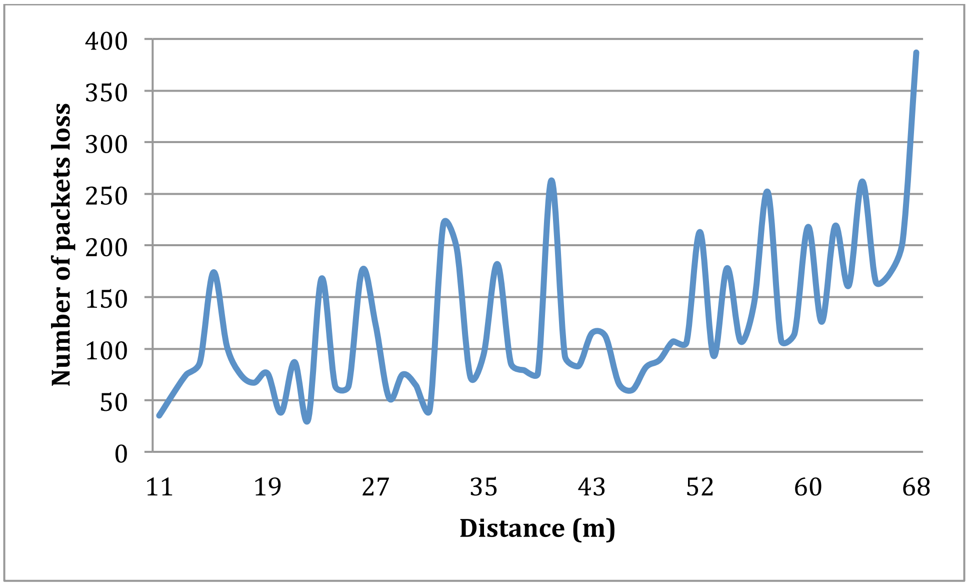

Figure 4.19: Packets loss in transmission a txt file over distance

Figure 4.19 shows packets missing when TX and RX transmission of a txt file with various distances. Moreover, packets sent 215, 369, 760 and 871; packets 60, 43, 365 and 284; packet missing were 275, 412, 1125 and 1155 when distance increased between TX to RX 11, 26, 57 and 68 m, respectively.

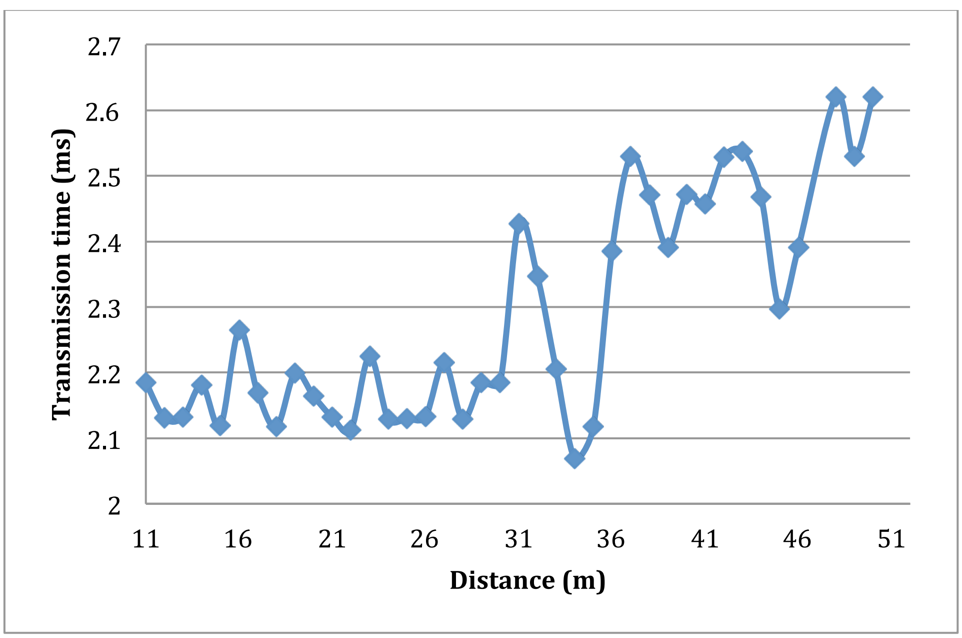

Figure 4.20: An image file transmission time from TX to RX

Figure 4.20 shows relationship between transmission times and distance when TX is sending an image file (1.5 MB) to RX. In this case, an image file was only able to share between TX to RX about 50m. The time value change follows a nearly similar pattern, which is time increased gradually when the distance increases. This figure also shows minimum and maximum time taken to send an image message between transmitter and receiver. It takes 2.18 to 2.6 ms to share a file between distances 11m to 50m where the transmission time increased about 0.42 ms.

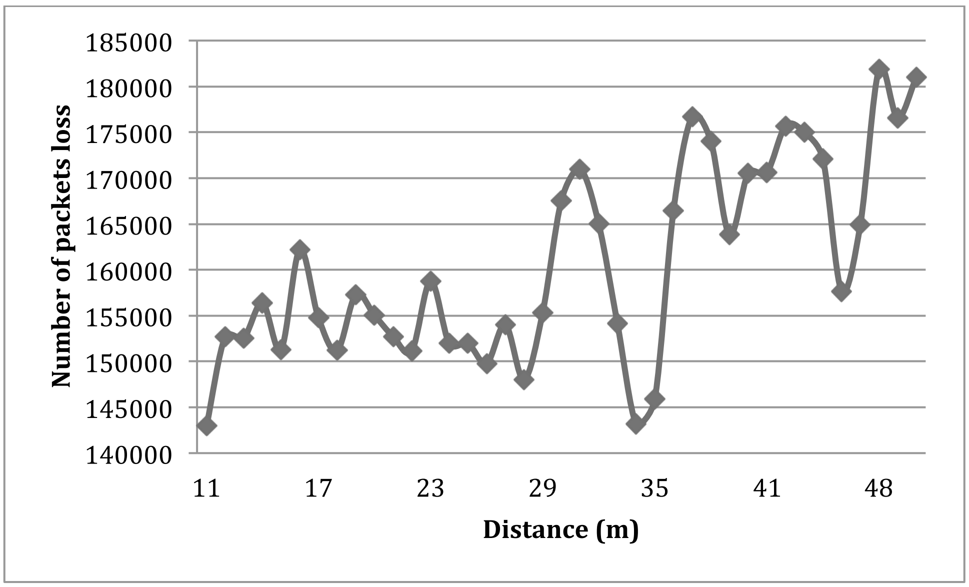

Figure 4.21: Packets loss in transmission an image file over distance

Figure 4.21 shows packets missing when TX and RX transmission of an image file with various distances. Moreover, packets sent 160370, 176510 and 188760; packets received 3500, 5520 and 7760; packet missing were 156870, 170990 and 181000; and when distance increased between TX to RX 11, 31 and 50 m, respectively. However, there is significant packet missing when distance was increased.

Wi-Fi signal strength is represented either as quality in percentage which is high quality: 90% ~= -55db; medium quality: 50% ~= -75db; low quality: 30% ~= -85db; unusable quality: 8% ~= -96db. However an RSSI level less than -80db may not be usable, depending on noise. To get the vehicular ad-hoc signal, requires one or more access points to increase the signal. The authors performed an experiment with V2V with 2.4 GHz band in an open road environment and they found significantly worse signal reception during the heavy traffic (Otto, Bustamante et al. 2009). A similar study presented which analysed the signal propagation in “crowded” and “uncrowded” highway scenarios with a 60 GHz frequency band and numbers of cars and found significantly higher path loss for the crowded scenarios (Takahashi, Kato et al. 2003). Past studies on VANET have emphasised more on improving the performance of PHY and MAC, transmission power control, and channel assignment than access point placement. According to our field trial measurements, examination and propagation measurements, appropriate access point placement might improve VANET performance significantly.

4.2 Simulation results

4.2.1 OPNET-based Simulation study

This section investigates the impact of two traffic types (FTP and P2P) on the performance of wireless networks of multiples of nodes. The OPNET modeler was selected not only for its easy to use GUI interface but also it has a complete collection of commercially obtainable network mechanisms which allow network researchers to improve and validate network models further. Simulation results are classified into varying node sizes with P2P file sharing and ftp. The effects of increasing the number of wireless stations for N = 2, 5, 10, 20, 30, 40 and 50 stations on both the network mean delay and throughput performance of the IEEE 802.11n infrastructure network. Average outcomes are presented for a simulation time of 300 seconds. The time a node is detecting an event is referred to as a session and their duration is modeled with an exponential distribution of mean 300 seconds. All simulations consists number of nodes was run for 300 seconds and the following results were generated.

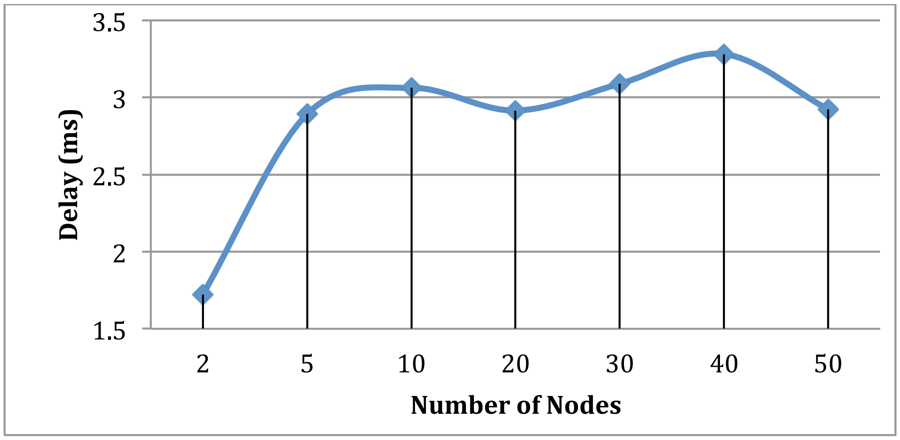

Figure 4.22: The effect of increasing wireless nods on 802.11 packet delays

As shown in Figure 4.22, the network mean throughput of IEEE 802.11n infrastructure network increased as the number of N increases. For example, the network mean throughputs are 5.6, 10.3, 17.5, 32.8, 55.63, 70.01 and 69.9 kbps for N = 2, 5, 10, 20, 30, 40 and 50, respectively. However, the throughput increased as the node increased more significantly for N > 30.

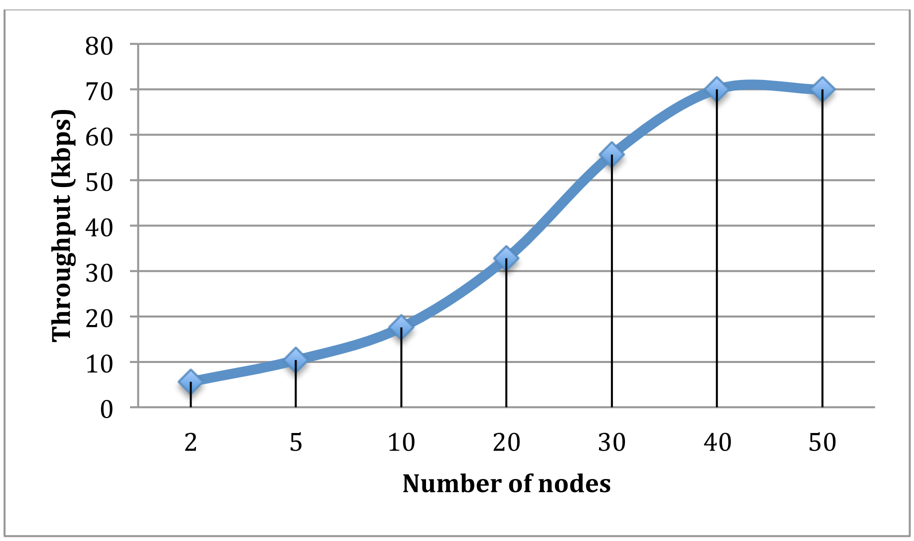

Figure 4.23: The effect of increasing wireless nods on 802.11n throughput

As shown Figure 4.23 represents the end-to-end delay of all the data packets, collected separately for each 802.11n successfully received by all the 802.11n capable WLAN MACs in the network and forwarded to a higher layer. The mean packet delay increases with the number of nodes. For example, the network mean packet delays are 1.72, 2.89, 3.06, 2.91, 3.08, 3.2 and 2.9 ms for N = 2, 5, 10, 20, 30, 40 and 50, respectively. The rise in mean packet delay for N > 2 positions are generally because of number of nodes increased and back off delays.

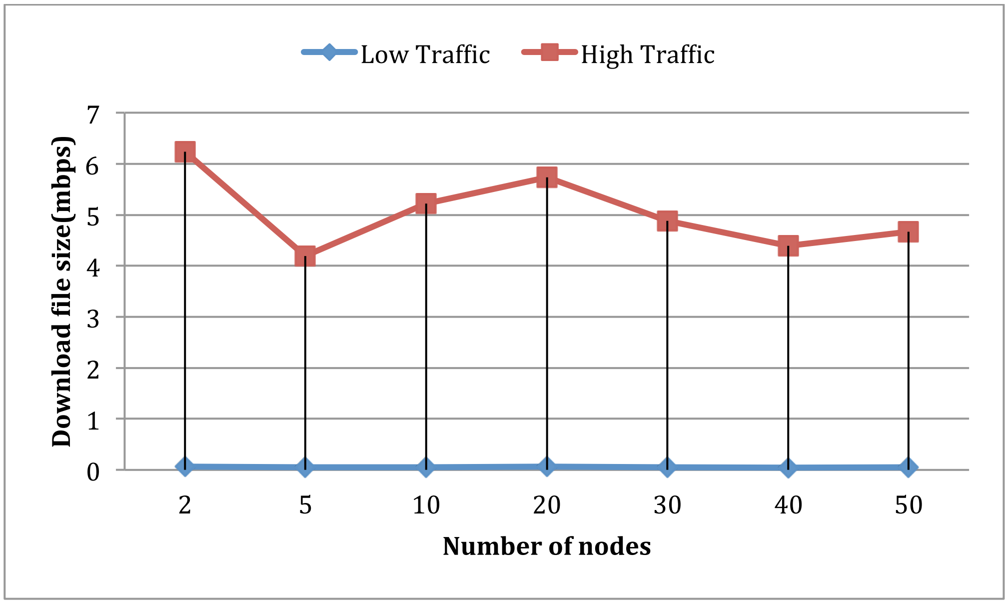

Figure 4.24: P2P file sharing download file size versus number of nodes

Figure 4.24 and 4.25 show the results for P2P file sharing download file size and download response time respectively when the nodes increase. There are two traffic loads used for P2P file sharing which are low traffic: minimum outcome 10 (KB) and maximum outcome 100 (KB); and high traffic: minimum outcome 100 (KB) and maximum outcome 10 (MB) with 300 sec for simulation times. As shown in Figure 4.24 there was a noticeable difference between low traffic and high traffic when the number of nodes increased. Moreover, the mean download file size for low traffic 0.06, 0.05, 0.05, 0.06, 0.05, 0.04 and 0.05 mbps and high traffic 6.16, 4.13, 5.17, 4.83, 4.3 and 4.6 mbps, for N = 2, 5, 10, 20, 30, 40 and 50, respectively. In Figure 4.25, the mean download response time with low traffic and high traffic increases when the nodes are increased. For example, download response time with low traffic 1.26 sec and high traffic 55.84 sec when there are two nodes, but when the nodes increase to 40 nodes then low traffic download response time is 0.22 sec and high traffic download response time is 71.34 sec which is a 25.5% increase with high traffic.

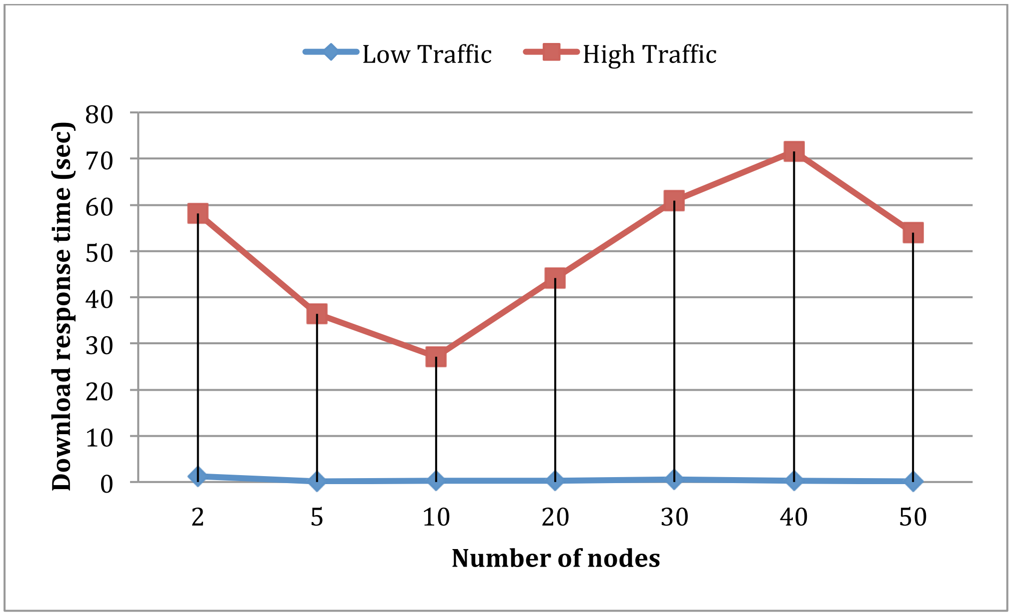

Figure 4.25: P2P file sharing download response time versus number of nodes

Figures 4.26 and 4.27 show the results for traffic sent and traffic received respectively for the different P2P files sharing traffic (low and high) when the nodes increase. As shown in Figure 4.26, there was a noticeable difference between low traffic and high traffic. P2P file sharing traffic sent rapidly increased when the number of nodes increased although there is no significant relationship between traffic sent and the number of nodes. For example traffic sent for low traffic 0.67, 1.22, 1.74, 3.55, 5.82, 6.99 and 9.23 kbps and high traffic 41.09, 71.34, 168,97, 367.03, 580.39, 750.28 and 3195.58 kbps, for N 2, 5, 10, 20, 30, 40, and 50, respectively. When the nodes increase from 2 nodes to 40 nodes low traffic increases 6.32 kbps and high traffic increases 709.20 kbps. But when the nodes increase 40 to 50 then low traffic increases to 2.23 kbps and high traffic increases to 2445.3 kbps. Figure 4.27 shows there was a noticeable difference between low traffic and high traffic when the number of nodes increased although there was no significant relationship between traffic received and the number of nodes. The mean traffic received increases with number of nodes. For example, traffic received for low load 0.67, 1.22, 1.74, 3.55, 5.82, 6.99 and 9.23 kbps, high load 41.09, 71.34, 168.29, 525,00, 611.82 and 618.36 kbps for N = 2, 5, 10, 20, 30, 40 and 50, respectively. When the nodes increase from 2 nodes to 20 nodes low traffic increased 2.87 kbps and high traffic increased 315.20 kbps.

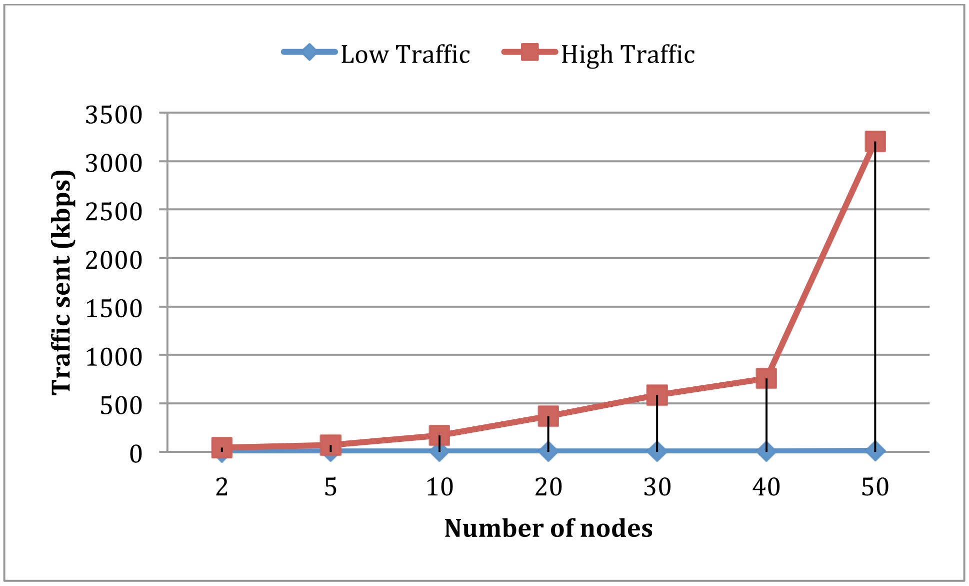

Figure 4.26: P2P file sharing traffic sent versus number of nodes

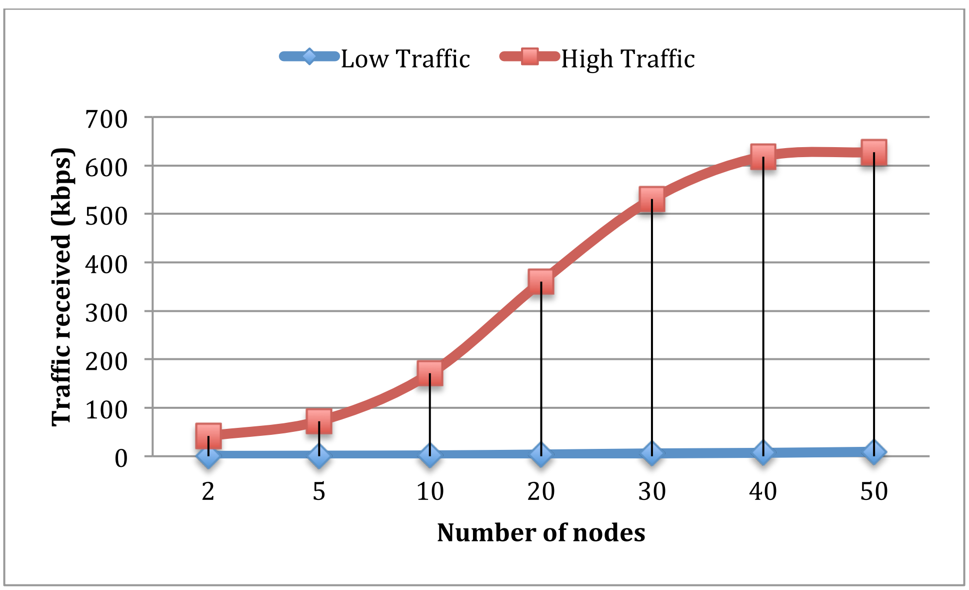

Figure 4.27: P2P file sharing traffic received versus number of nodes

Figures 4.28 and 4.29 show the results for download and upload response time respectively for the different FTP traffic loads (low load (1000 bytes), medium load (5000 bytes) and high load (50,000 bytes) with 300 sec simulation time) when the nodes increase. As shown in Figure 4.28 there was a noticeable difference between low load, medium load and high load. FTP download response times rapidly increased when the number of nodes increased. Moreover FTP download response times from low load and medium load increased in almost same way when the number of nodes increased. although there was no significant relationship between download response time and the number of nodes. The mean download response time increases with number of nodes. For example, download response time for low load 0.13, 0.01, 0.08, 0.12, 0.10, 0.11 and 0.08 sec, high load 0.07, 1.63, 1.61, .08, 1.41, 0.83 and 0.62 sec, for N = 2, 5, 10, 20, 30, 40 and 50, respectively. Figure 4.29 also shows that the FTP traffic upload response times increase and decrease with the increase in the number of nodes. Low load, medium load and high load FTP traffic upload response times increased by 0.08, 0.12 and 3.45 sec respectively when the number of nodes increased from 2 to 5.

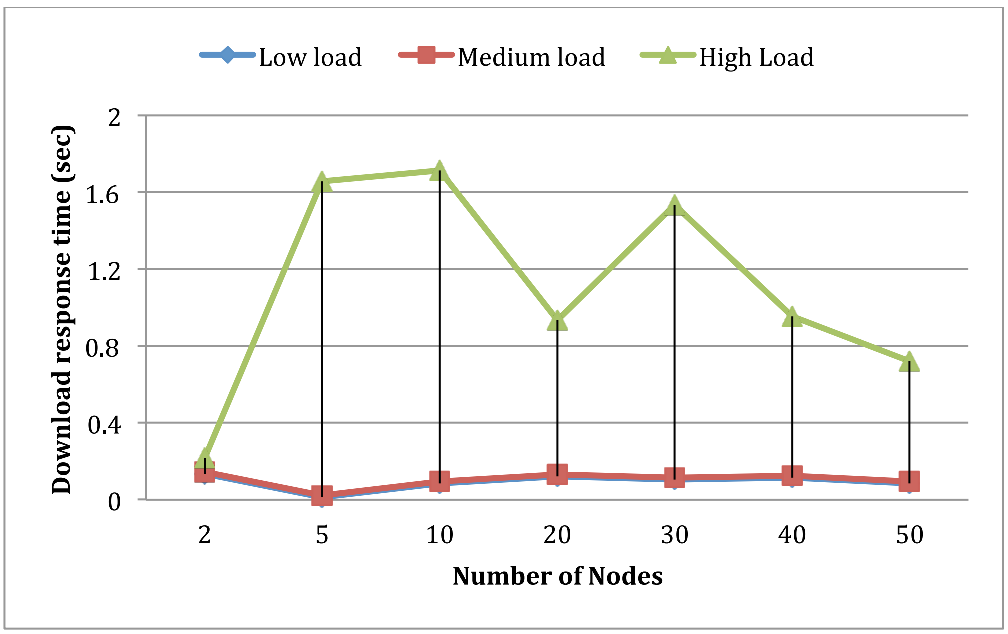

Figure 4.28: FTP file sharing download response time versus number of nodes

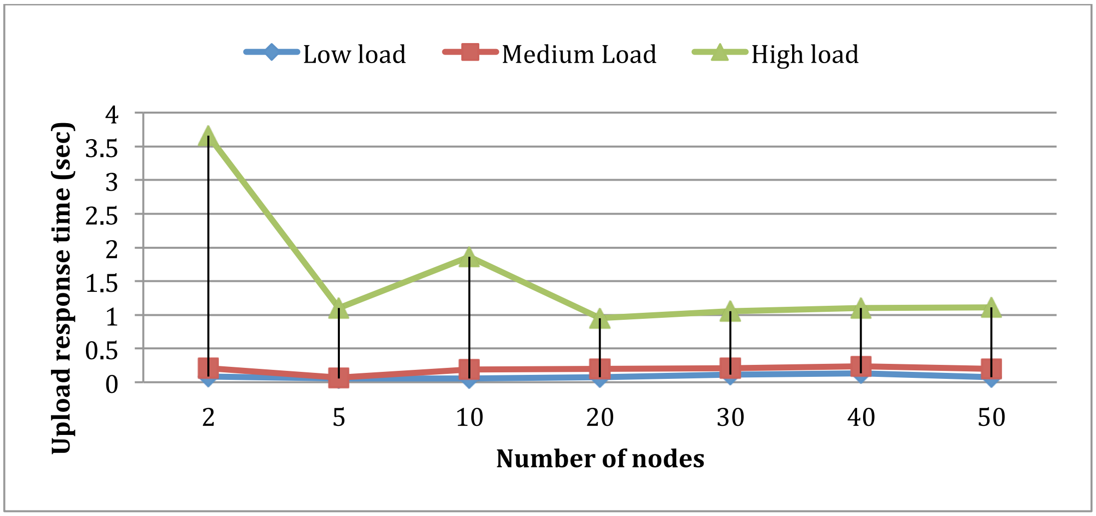

Figure 4.29: FTP file sharing upload response time versus number of nodes

Figures 4.30 and 4.31 show the results for traffic sent and traffic received respectively for the different FTP application (low load, medium load and high load) when the nodes increase. As shown in Figure 4.30, there was a noticeable difference between low load, medium load and high load. FTP sent rapidly increased when the number of nodes increased although there was no significant relationship between traffic sent and the number of nodes. For example traffic sent for low load 0.01, 0.02, 0.05, 0.10, 0.16, 0.22 and 0.26 kbps; medium load 0.09, 0.09, 0.25, 0.57, 0.55, 0.17, 1.02 and 1.30 kbps and high load 0.84, 1.34, 3.36, 5.72, 8.58, 14.31 and 13.97 kbps, for N 2, 5, 10, 20, 30, 40, and 50, respectively. When the nodes increase from 2 nodes to 30 nodes the low load increase was 0.14 kbps, medium load increase 0.62 kbps and high load increase 7.74 kbps. But when the nodes increased 30 to 40 then the low load increase was 0.06 kbps, medium load increase 0.31 kbps and high load increase 5.72 kbps. Figure 4.31 shows there is not much difference between traffic received and traffic sent (Figure 4.31) although there is no significant relationship between traffic received and the number of nodes. The mean traffic received increases with number of nodes. For example, traffic received for low load 0.01, 0.02, 0.05, 0.1, 0.16, 0.22 and 0.26 kbps, medium load 0.09, 0.09, 0.25, 0.53, 0.72, 1.03, and 1.31 kbps; and high load 0.85, 1.36, 3.23, 5.78, 8.67, 14.45 and 13.94 kbps for N = 2, 5, 10, 20, 30, 40 and 50, respectively. When the nodes increase from 2 nodes to 40 nodes the low load increase was 0.21 kbps, medium load increase 0.94 kbps and high load increase 13.65 kbps.

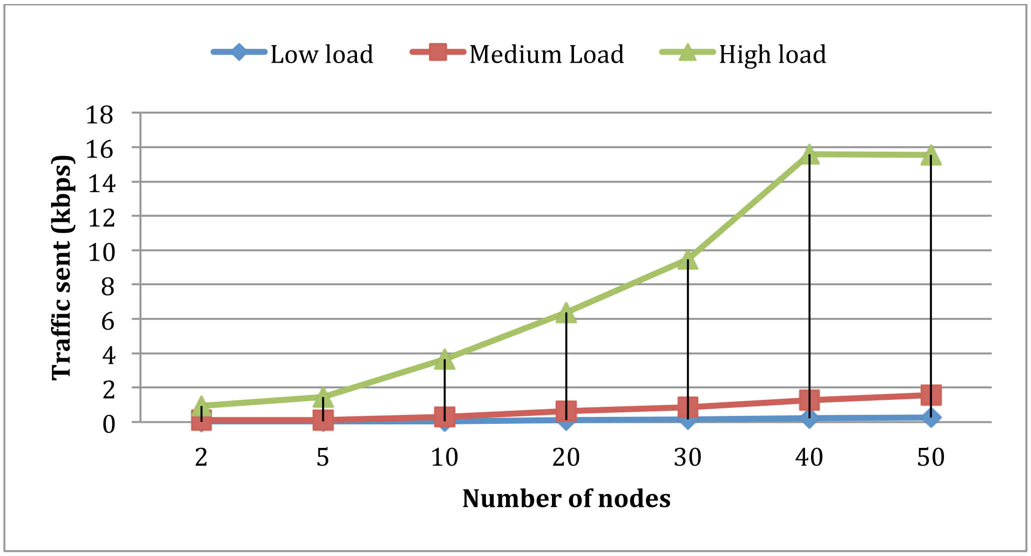

Figure 4.30: FTP file sharing traffic sent versus number of nodes

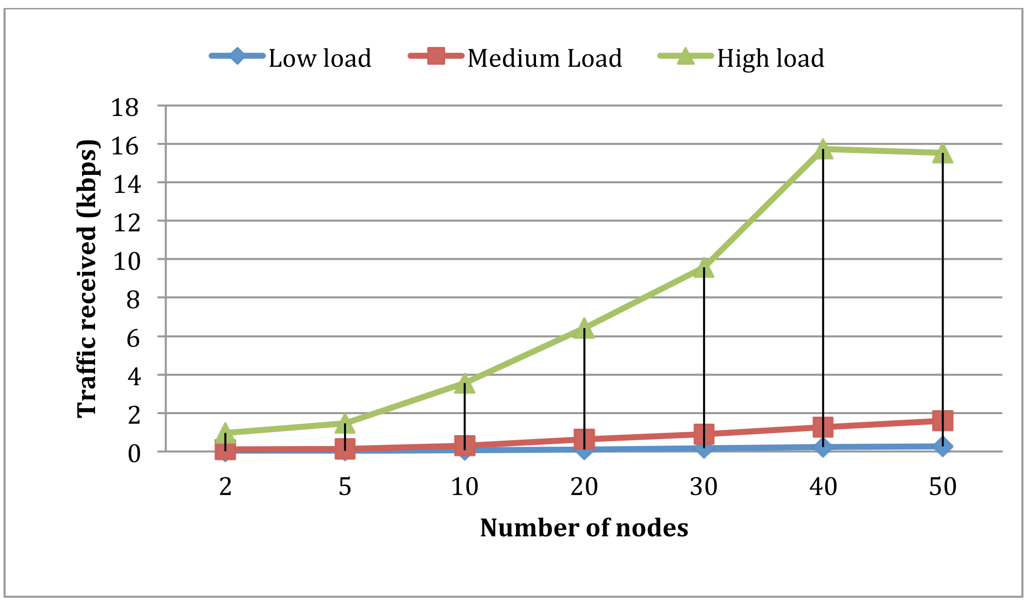

Figure 4.31: FTP file sharing traffic received versus number of nodes

The OPNET-based VANET simulators are integrated frameworks of networking and traffic simulators. This study has presented a comprehensive analysis of FTP and P2P in VANET simulators. Traffic simulators generate realistic traffic traces for use as input to a network simulator. This can help as a rapid reference for researchers or developers who want to deploy on VANETs with a number of nodes, which is a rapidly developing area of research. All OPNET-based VANET simulators are open sources but they still need further modifications to be widely used.

4.3 Summary

This chapter presented and analyzed data collected from field trial measurements. Our measurement results are shown in Appendix A, which include Wi-Fi based VANETs. Preliminary trials presented in VANET environments signal coverage in all measurements were decent except scenario 4 as ad-hoc mode cannot provide sufficient signal coverage in the entire West City Auckland shopping mall parking lot environment. Scenario 1 presented the relationship between strength (dBm) and distance starting from 1m to 57m including the wall barrier, car park and car moving and human moving as well RSSI gave best performance till 31m which is -74 dBm and scenario 5 presented the relationship between strength (dBm) and distance starting from 11m to 68m and RSSI gave best performance till 31m which is dBm -74. In scenario 4, TX in level 1 and RX in level 4 were sharing information with the ad hoc connection where 12m was the distance from level 1 to level 4, and at 12m distance we were unable to connect (no signal detected) TX to RX or RX to TX. Finally, OPNET-based simulation outcomes presented that the number of active stations has a significant impact on the mean throughput and packet delays of 802.11n. The propagation models results versus measurement in performance metrics such as RSSI are provided in Chapter 5.

Chapter 5

Propagation Models versus Measurements

Chapter 4 presented analysis of the findings for experimental results of OPNET-based simulations. This chapter overviews five selected radio propagation "Free space" models: "Shadowing Path Loss" model, "Egli" model, "Hata" model, and "COST 231" model. Section 5.2 presents data analysis and comparisons with each selected model and experimental data.

5.1 Model Overview

Radio propagation models were recommended to assist in computation of signal strength in the area of wireless communication environments. Path loss calculation is taken from the power productivity point of the transmitter to the signal contribution of the receiver and contains all points like cables, antennas, free space loss and any further losses. The selected models of radio propagation are: "Free space" model, "Shadowing Path Loss" model, "Egli" model, "Hata" model and "COST 231" model. All of these models is appropriate in their function, but for all models a common condition applies – they work in the "Far field region". Table 5.1 shows parameters used for 5 empirical propagations.

Table 5.1: Parameters used for models

Parameters Name	Value
Frequency (f)	$f = 2.4$ GHz $= 2.4 \cdot 10^9$ Hz
Speed of light ©	$c = 300000$ km/s $= 3 \cdot 10^8$ m/s
Wavelength (λ)	$\lambda = c / f = 0.125$ m.
Linear size of the antenna (D)	$D = 2 \cdot \lambda = 0.25$ m.
Reference distance (d_0)	$d_0 = 2D^2 / \lambda = 1$ m
Power of radio wave on the transmitting antenna (P_t)	$P_t = 15$ dBm $= 1$ mW $\cdot 10^{(15 \text{ dBm} / 10)} = 0.03162$ W
Power of radio wave on the reference distance (d_0)	$P_r(d_0) = P_t \cdot \lambda^2 / (4\pi d_0^2) = 3.93 \cdot 10^{-5}$ W.

5.1.1 "Free Space" model

The Free Space propagation model has the ability to propagate without obstruction and atmospheric effects and without loss over the surface of a sphere surrounding the antenna. It predicts received power decays as negative roots of the distance between transmitter and receiver. In this scenario, this model is applicable of microwave in line of sight and satellite communication. Free Space radio propagation model is appropriate for parking lots. The technology is useful where the physical connections are impractical due to high costs or other considerations. Free-space path loss is proportional to the square of the distance between the transmitter and receiver, and also proportional to the square of the frequency of the radio signal. Free space model predicts that the received power decays as negative square root of the distance. The Friis Transmission Formula is presented by the following equation to calculate the received signal power which describes this wave behaviour as "Free Space" (Friis 1946)

$$P_r(d) = P_t \cdot \lambda^2 \cdot G_t \cdot G_r / (4\pi d^2 L) \tag{5.1}$$

Where, d = distance between the antennas (transmitter and receiver), $\lambda = c / f$ - wavelength (f - frequency), Pr = power received, Pt = transmitted signal power, G_t = gain of transmit antenna, G_r = gain of receive antenna and L = system loss. It is common $G_t = G_r = 1$ and $L = 1$ in ns simulations. Generally the "Free Space" propagation model uses the following formula:

$$P_r(d) = P_r(d_0) \cdot (d / d_0)^{-n} \tag{5.2}$$

$$d_0 = 2D^2 / \lambda \tag{5.3}$$

Where, λ - wavelength, D = maximum linear dimension of the antenna and n = exponent for environment conditions (n = 2 defines "Free Space") (Laasonen 2003).

5.1.2 "Shadowing Path Loss" model

Shadowing Path Loss (FSPL) is the loss in signal strength of an electromagnetic wave, which results from line-of-sight path through free space without obstacles nearby to cause reflection or diffraction.

FSPL is used in many areas for predicting radio signal strength which might be expected in radio systems. While FSPL does not control most earthly circumstances because of object path and effects from the ground, the FSPL model is very beneficial for simple thoughtful numerous real life radio propagation situations and it can be approximately used for calculations for short distances or numbers of areas where there are few obstructions The FSPL is rarely used separately but as part of the Friis transmission equation, which contains the gain of antennas (Sommer, Joerer et al. 2012).

$$\begin{aligned} \mathrm{FSPL} &= \left(\frac{4\pi d}{\lambda}\right)^2 \\ &= \left(\frac{4\pi d f}{c}\right)^2 \end{aligned} \tag{5.4}$$

Where, λ - wavelength, d = distance between the antennas (transmitter and receiver), c = speed of light in a vacuum and f = the signal frequency.

5.1.3 “Egli” model

The Egli model is a terrain model for radio frequency propagation. Egli model calculations are used to mathematically calculate propagation loss, which is the distance between transmitter and receiver. The Egli model is simplified as "gently rolling terrain with average hill heights of approximately 50 feet (15 m)" (Roslee and Kwan 2010). The Egli model is mathematically expressed as:

$$P_R = G_B G_M \left[\frac{h_B h_M}{d^2}\right]^2 \left[\frac{40}{f}\right]^2 P_T \tag{5.5}$$

Where, Pr = receive power, Pt= Transmit power, Gb= Gain the base station antenna, Gm=Gain of the mobile station antenna, hB= Height of the base station antenna, hM= Height of the mobile station antenna, d = Distance from base station antenna and f = Frequency of transmission.

5.1.4 “Hata” model

The Hata model creates an experimental mathematical link to define the graphical information specified by Okumura. This model is mostly used for radio frequency propagation models for predicting the behaviour of cellular transmissions in built up areas. This model includes the graphical information from the Okumura model and improves it to understand the effects of reflection, diffraction and scattering caused by city structures. The Hata model creates a number of representative path losses for each urban, suburban and country environment (Nadir and Ahmad 2010).The Hata model is mathematically expressed below:

For urban areas,

$$L_U = 69.55 + 26.16 \log_{10} f - 13.82 \log_{10} h_B - C_H + [44.9 - 6.55 \log_{10} h_B] \log_{10} d \quad (5.6)$$

For small or medium-size city

$$C_H = 0.8 + (1.1 \log_{10} f - 0.7) h_M - 1.56 \log_{10} f \quad (5.7)$$

For larger cities,

$$C_H = \begin{cases} 8.29 (\log_{10}(1.54 h_M))^2 - 1.1 & , \text{if } 150 \leq f \leq 200 \\ 3.2 (\log_{10}(11.75 h_M))^2 - 4.97 & , \text{if } 200 < f \leq 1500 \end{cases} \quad (5.8)$$

Where, Lu= Path loss in urban areas, hB= Height of base station antenna, hM= Height of mobile station antenna, f= Frequency of transmission, CH= Antenna height correction factor, d= Distance between the base and mobile stations.

5.1.5 "COST 231" model

The European COST 231 recommended a model for indoor office propagation where attenuation linearly produces the amount of walls traversed and the result of floors is non-linear. The COST 231 model covers modifications for urban, suburban and urban environments, which is proposed to extend the Hata model. This model is limited to cases where the base station antenna is positioned higher than nearby buildings (Dalela, Prasad et al. 2012). The COST 231 model is mathematically expressed as:

$$L = L_{fs} + 37 + 3.4\, kw1 + 6.9\, kw2 + 18.3\, n^{((n+2)/(n+1)-0.46)} \quad (5.9)$$

Where, L = attenuation, L_{fs} = free space loss and number of traversed floors, k_{w1} = number of light internal walls, k_{w2} = number of concrete or brick internal walls

5.2 Model versus measurement: Comparative study

The following presents measured data, along with modeled data generated by the “Free Space”, “Shadowing Path Loss”, “Egli”, “Hata” and “COST 231” models. The paths selected for this study were chosen because they were considered to provide results illustrative of the models’ overall performance features for short-range propagation paths. Estimated received signal power obtained based on the corrected propagation models are more fitting to the measurement data. The measured received signal power and that estimated using each of the corrected propagation models were calculated using equations 5.1, 5.4, 5.5, 5.6, and 5.9 for “Free Space”, “Shadowing”, Egli, Hata and “COST 231” models. The accumulated path losses for the 5 models are shown in Figures 5.1, 5.2, 5.3, 5.4, and 5.5, and all 5 models’ numeric results are shown in Appendix E. The result of received signal strength vs. distance plot deploying the 5 models is as shown in the graph. After determining the path loss of the practical measurements for each distance, the study was agreed on in order to create a difference among the experimental and theoretical models values and the result. It is only theoretical data and it may vary from the data obtained in real applications due to the environment or operating circumstances though bigger loss at higher frequencies can be seen clearly.

Figure 5.1 shows (scenario 1) the comparison of path loss of different propagation models with measured path loss results obtained for each propagation model are presented in the form of a plot. It can be seen from the figure that the “Free Space” and “Hata” models have the lowest path losses prediction -40.04 dBm to -75.46 dBm and -24.73 dBm to -104.24 dBm for 1m to 59m. The RSSI value change follows a nearly similar pattern, which is RSSI drops gradually when the distance increases. The “Free Space” model gave the highest prediction when it was -40.4 dBm to -73.11 dBm in about 1m to 45m distance. Under non-LoS conditions “Free Space” and “Hata” models marginally distorted the nature of the curve of the dependency of the received signal power from a distance, but had a very good agreement with the level of the measurement data. As well it can be seen from the figure that the “COST 231” “Egli”, and “Shadowing Path Loss” models had the highest path loss prediction -77.04 dBm to 112.46 dBm, -40.04 dBm to -106.39 dBm and -33dBm to -68.5 dBm for 1m to 59m. Under non-LoS conditions “COST 231”, “Egli” and “Shadowing Path Loss” models basically do not work with the presented dependence of power received from a distance. That is something which is unrealistic. Hence, its values can be ignored. However, based upon the measured and models’ results presented in this study, it is clear that the “Hata” and “Free Space” models are a closer match and have a very good agreement with the level of the measurement data. Other models overestimated the path loss for the indoor propagation environment. According to these results for scenario 1, the "Free Space" is recommended for the evaluation of comparable partition inspiration on the signal propagation under NLOS conditions. The "Free Space" model, which is capable of providing path loss, estimates significantly closer to actual values than other models.

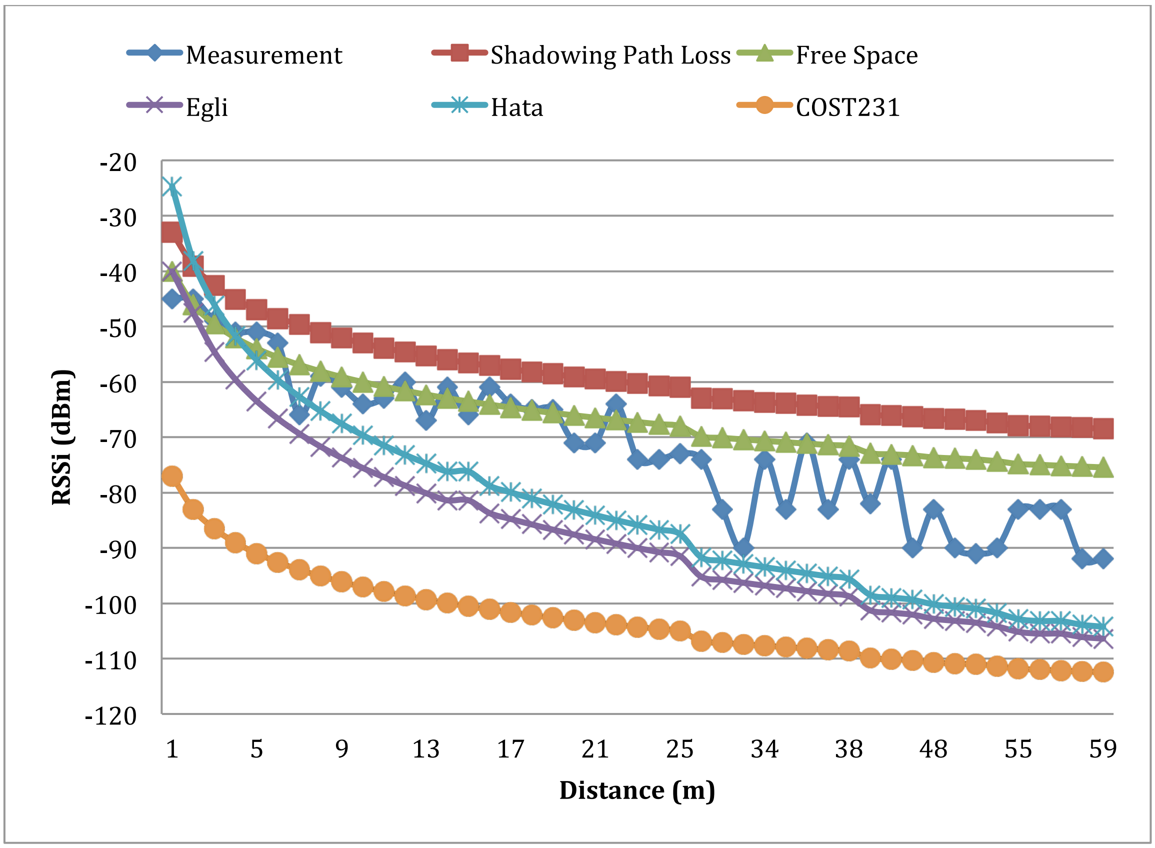

Figure 5.1: RSSI versus distance for NLOS condition: Comparison of measurement and five models

Figure 5.2 shows (scenario 2) the comparison of path loss of different propagation models with measured path loss results obtained for each propagation models presented in the form of a plot . It can be seen from the figure that the "Egli" model has the lowest path loss prediction –59.64 dBm to –85.24 dBm for 4 m to 17.46 m. The RSSI value change follows a nearly similar pattern, which is RSSI drops gradually when the distance increases. The "Hata" model gave the highest prediction. Under non-LoS conditions the "Hata" model marginally distorted the nature of the curve of the dependency of the received signal power from a distance, but had a good agreement with the level of the measurement data. As well it can be seen from the figure that the "Shadowing Path Loss", "Free

Space", "Egli", and "COST 231" models have the highest path loss prediction -45.1 dBm to -57.4 dBm, -52.08 dBm to -64.88 dBm and -59.64 dBm to -85.24 dBm, and -134.94 dBm to -147.78 dBm for 4m to 17.46m. Under non-LoS conditions "Shadowing Path Loss", "Free Space", "Egli", and "COST 231" models, did not work with basically the presented dependence of power received from a distance. That is something which is unrealistic. Hence, its values can be ignored. However, based upon the measured and models results presented in this study, it is clear that the "Hata" model is a closer match and has a very good agreement with the level of the measurement data. Other models overestimate the path loss for the indoor propagation environment. According to these results for scenario 2, the "Hata" model provides maximum accuracy and flexibility with signal propagation modes and is recommended for the evaluation of comparable partition inspiration on the signal propagation under NLOS conditions. The "Hata" model, which is capable of providing path loss, estimates significantly closer to actual values than other models.

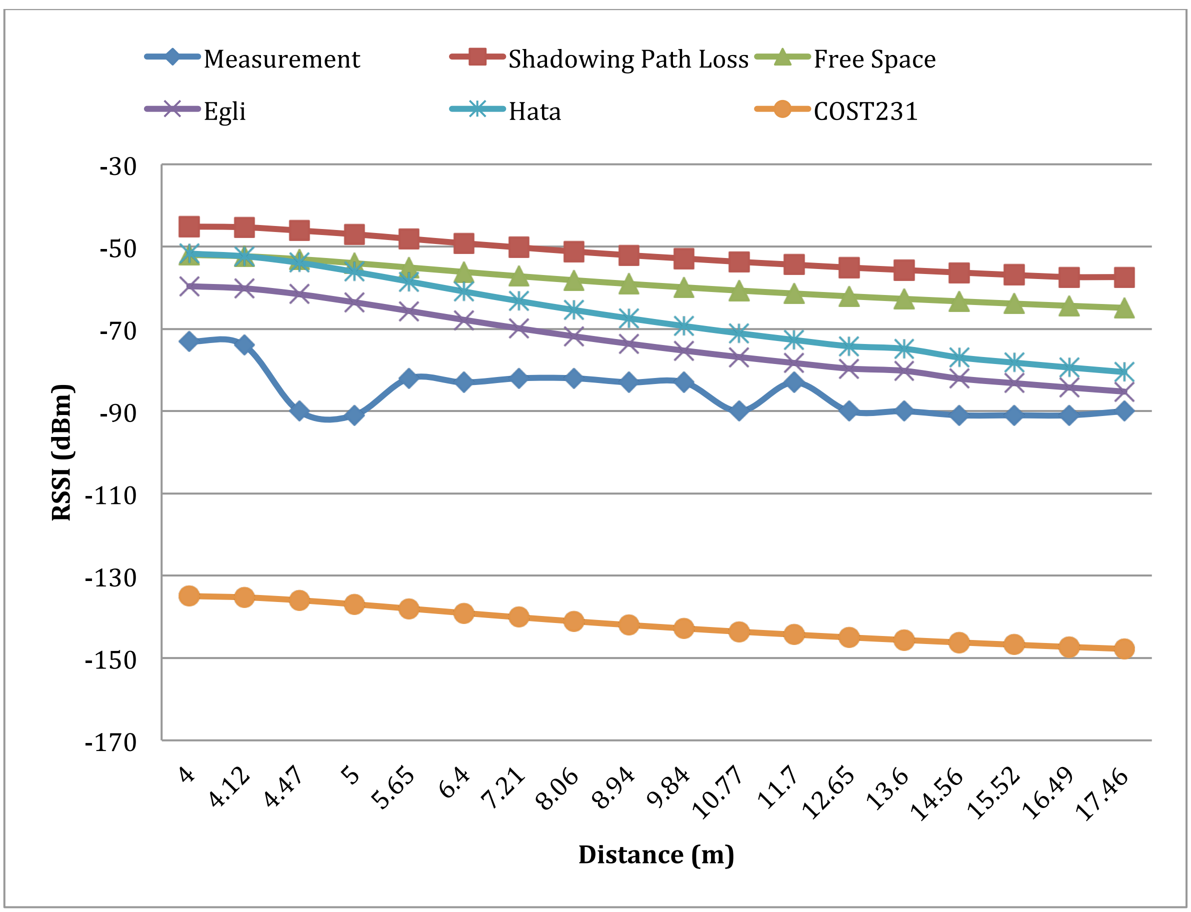

Figure 5.2: RSSI versus distance for NLOS condition: Comparison of measurement and five models

Figure 5.3 shows (scenario 3) the comparison of path loss of different propagation models with measured path loss results obtained for each propagation model presented in the form of a plot. It can be seen from the figure that the "Egli" model has the lowest path loss prediction, –71.64 dBm to -74.54 dBm for 8m to 9.43m. The RSSI value change follows a nearly similar pattern, which is RSSI drops gradually when the distance increases. The "Egli" model gave the highest prediction when it was -71.64 dBm in about 8m distance. Under non-LoS conditions the "Egli" model marginally distorted the nature of the curve of the dependency of the received signal power from a distance, but had a very good agreement with the level of the measurement data. As well it can be seen from the figure that the "Shadowing Path Loss", "Free Space", "Hata", and "COST 231" models have the highest path loss prediction –51.1 dBm to 52.5 dBm, --58.1 dBm to -59.53 dBm, -65.27 dBm to -68.28 dBm and -156.23 dBm to -157.65 dBm for 8m to 9.43m. Under non-LoS conditions the "Shadowing Path Loss", "Free Space", "Hata", and "COST 231" models, basically do not work with the presented dependence of power received from a distance. That is something which is unrealistic. Hence, its values can be ignored. However, based upon the measured and models results presented in this study, it is clear that the "Egli" model is a closer match and has a very good agreement with the level of the measurement data. Other models are overestimate the path loss for the indoor propagation environment. According to these results for scenario 3, the "Egli" model provides maximum accuracy and flexibility with signal propagation modes and is recommended for the evaluation of comparable partition inspiration on the signal propagation under NLOS conditions. The "Egli" model, is capable of providing path loss estimates significantly closer to actual values than other models.

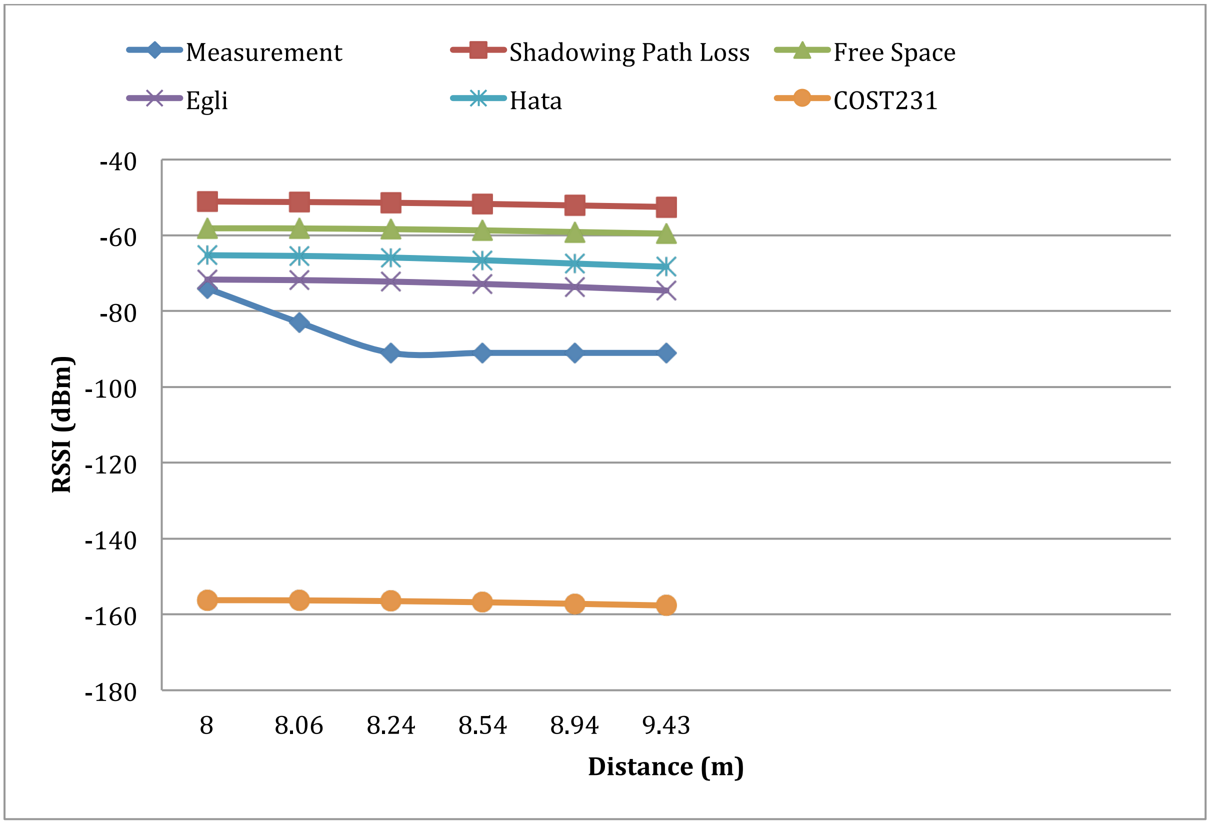

Figure 5.3: RSSI versus distance for NLOS condition: Comparison of measurement and five models

Figure 5.4 shows (scenario 5) the comparison of path loss of different propagation models with measured path loss results obtained for each propagation models are presented in the form of a plot . It can be seen from the figure that the "Free Space" and "Shadowing Path Loss" models have the lowest path losses prediction -60.87 dBm to -76.69 dBm and -53.9 dBm to -69.7 dBm for 11m to 68m. The RSSI value change follows a nearly similar pattern, which is RSSI drops gradually when the distance increases. The "Free Space" model gave the highest prediction when it was -60.87 dBm to -72.3 dBm in about 11m to 41m distance, as well, the "Shadowing Path Loss" model gave close prediction when it was -53.9 dBm to -57.1 dBm in about 11m to 16m distance. Under non-LoS conditions the "Free Space" and "Shadowing Path Loss" models marginally distorted the nature of the curve of the dependency of the received signal power from a distance, but had a very good agreement with the level of the measurement data. As well it can be seen from the figure that "Egli", "Hata", and "COST 231" models had the highest path loss prediction -77.21 dBm to 108.86 dBm, -71.48 dBm to -107.01 dBm and -125.47 dBm to -140.76 dBm for 11m to 68m. Under non-LoS conditions the "Egli", "Hata", and "COST 231" models, basically do not work with the presented dependence of power received from a distance. That is something which is unrealistic. Hence, its values can be ignored. However, based upon the measured and models results presented in this study, it is clear that the "Shadowing Path Loss" and "Free Space" models are a closer match and have a very good agreement with the level of the measurement data. Other models overestimate the path loss for the indoor propagation environment. According to these results for the scenario 5, the "Free Space" model provides maximum accuracy and flexibility with signal propagation modes and is recommended for the evaluation of comparable partition inspiration on the signal propagation under NLOS conditions. The "Free Space" model, is capable of providing path loss estimates significantly closer to actual values than others models.

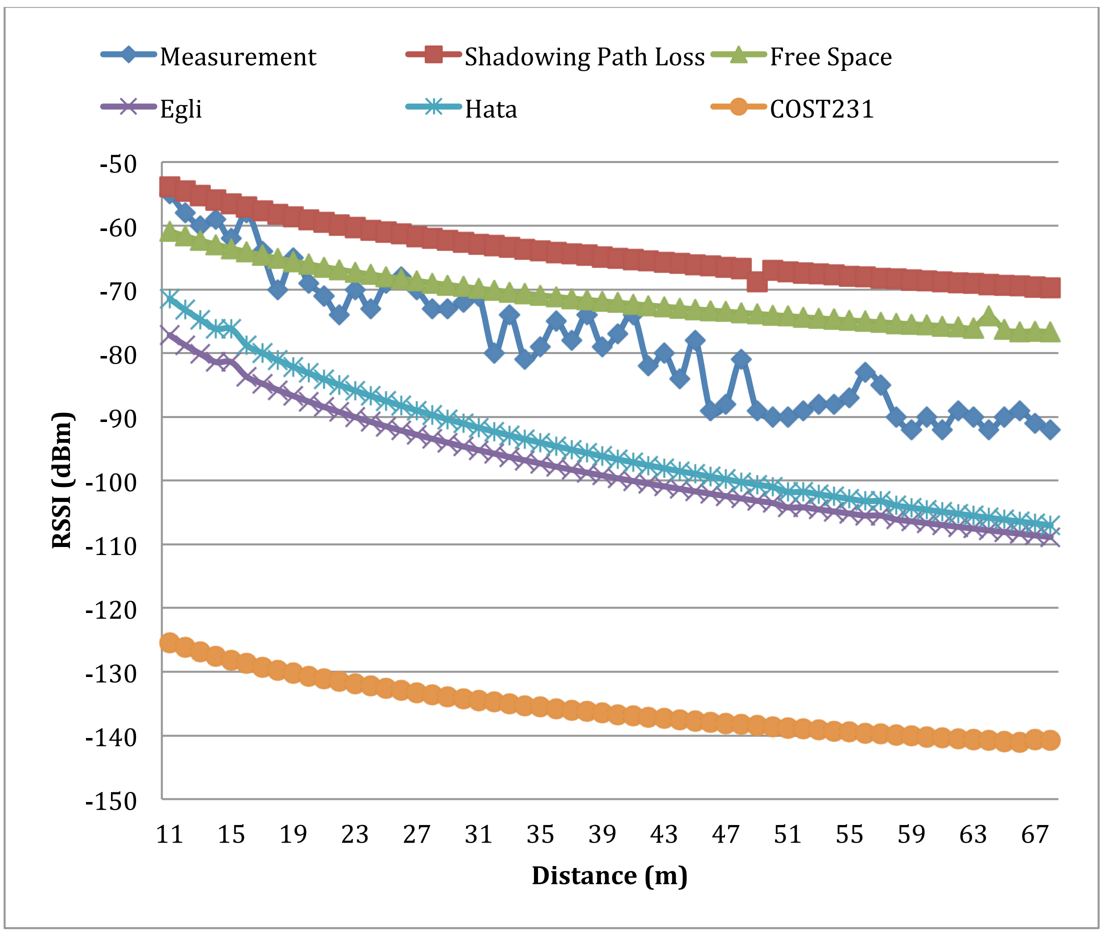

Figure 5.4: RSSI versus distance for NLOS condition: Comparison of measurement and five models

In our comparisons of different indoor propagation models on the basis of theoretical path loss with field measurement data it was revealed during the comparative study of different models along with interpolated measured field data values that out of the different models studied only five specific models closely approximate the actual measurement characteristics, namely: “Free Space”, “Shadowing Path Loss”, “Egli”, “Hata” and “COST 231” models.

All other models showed huge deviation from the measured field data value, which clearly indicates inefficiency of all other models to be deployed for network planning in this region; however, it can be seen from Figures 5.1 and 5.4, that the received signal power estimated using the corrected “Free Space” propagation model shows a good fit with measured received signal power for the required distance.

5.3 Summary

This chapter presented radio propagation models, which are “Free Space”, “Shadowing Path Loss”, “Egli”, “Hata” and “COST 231” models that can be used to predict signal strength of planning VANETs based on measurement results. By conducting all measurements, all possible procedures to adjust or modify existing models can be chosen. It is clear that the received signal power in scenario 1, “Free Space” model and Hata model are better than other models. In scenario 2, the Egli model is closer and has very good agreement with the level of measurement data. In scenario 3, the Egli model is a bit closer than other models. In scenario 5, the “Free Space” propagation model is closer and has a very good agreement with the level of the measurement data. Implications and recommendations for deployment of VANET in a large shopping mall are presented in Chapter 6,

Chapter 6

Implications and Recommendations for System Deployment

Chapter 5 discussed the comparative study of models versus measurement. This chapter presents implications which provide significantly well-organized choosing of appropriate positions in similar environments in section 6.1, and section 6.2 discusses recommendations for VANET development such as wireless access points, smart antenna for wireless, indoor radio WLAN performance, ad hoc localized position systems, cross-layer design of ad hoc networks and trust and reputation management framework.

6.1 Implications

By conducting numerous preliminary field-trial measurements in the West City Auckland shopping mall parking lot and propagation models, we expanded an understanding into the radio propagation performance of an IEEE 802.11n network. The initial measurements support us to understand IEEE 802.11n configuration and practical deployment as well provide reference for our data used for analysis. The features of the wireless adapter would differ with special models and vendors.

Our study findings stated the contribution of a particular purpose, which is to provide significant implications and be well-organized in choosing appropriate positions in a similar environment. Firstly, our findings, as described in this paper, might be beneficial for administrators to deploy informed assessments about the expansion of IEEE 802.11n in locations similar to the West City Auckland shopping mall parking buildings. Secondly, this study demonstrates, by measurement, the straight influence West City Auckland shopping mall parking lot separation and RSS on system performance, which is genuine hardware to measure performance, escaped the difficulty of theoretical modeling of radio signal propagation and system implementation. Thirdly, our study measurement results specify that RSS was not sufficient to represent the actual performance of WLANs. So a wide measurement study is primarily required to develop further accurate results before any practical VANET as table 6.1 shows. Wireless access in vehicular environment forces a set of the latest requirements on the communications system that controlled to the indication of the WAVE functional mode and of the WAVE BSS in IEEE 802.11p, which theatrically decreases the connection setup transparency and suits vehicular safety applications well.

Table 6.1: VANET features and implications

Features	**Implications**
Wireless Access Point	Strength range in VANET environment
Wireless Communication and radio signal propagation	Restricted bandwidth and error-prone wireless communication.
High Mobility	Short communication periods
Beaconing	Further network capacity, but protocols can advantage from information exchanged by this basic service.
Dissemination delay	Safety applications require instant relaying of information
Delay Constraints	Any messages must need to be broadcast instantly, without introducing any delay.

Fourthly, video and audio conferencing in inter-vehicle communications in VANET need to be sophisticated implications because faster data transfer needs longer connection lifetime. VANET vehicles (nodes) are expected to be equipped with calculations encryption and others vehicles positions, vehicle track location with GPS receiver enabling, communication devices to propagate /receive information, set a sensors to report such as weather conditions, safety for crashes require to deliver of emergency warning messages, vehicle statistics etc., dedicated and secured memory to strong log files. Multi-hop data dissemination without aggregation concept every vehicle would need to broadcast for position and speed information which in turn disseminates to support approaching vehicles to avoid traffic jams. Finally, identifying misbehavior in VANET's significant issues in extensive range of implications with safety related and congestion avoidance applications.

6.2 Recommendations for system Deployment

Based on the study in the previous section, we have designed a parking environment with Vehicular Ad Hoc Networks as shown in Figure 6.1. A wireless access point is a device that allows wireless devices to connect to a wired network using Wi Fi. Internet-enabled nodes access points have a robust benefit, with the possibility of having numerous access points connected by a WLAN.

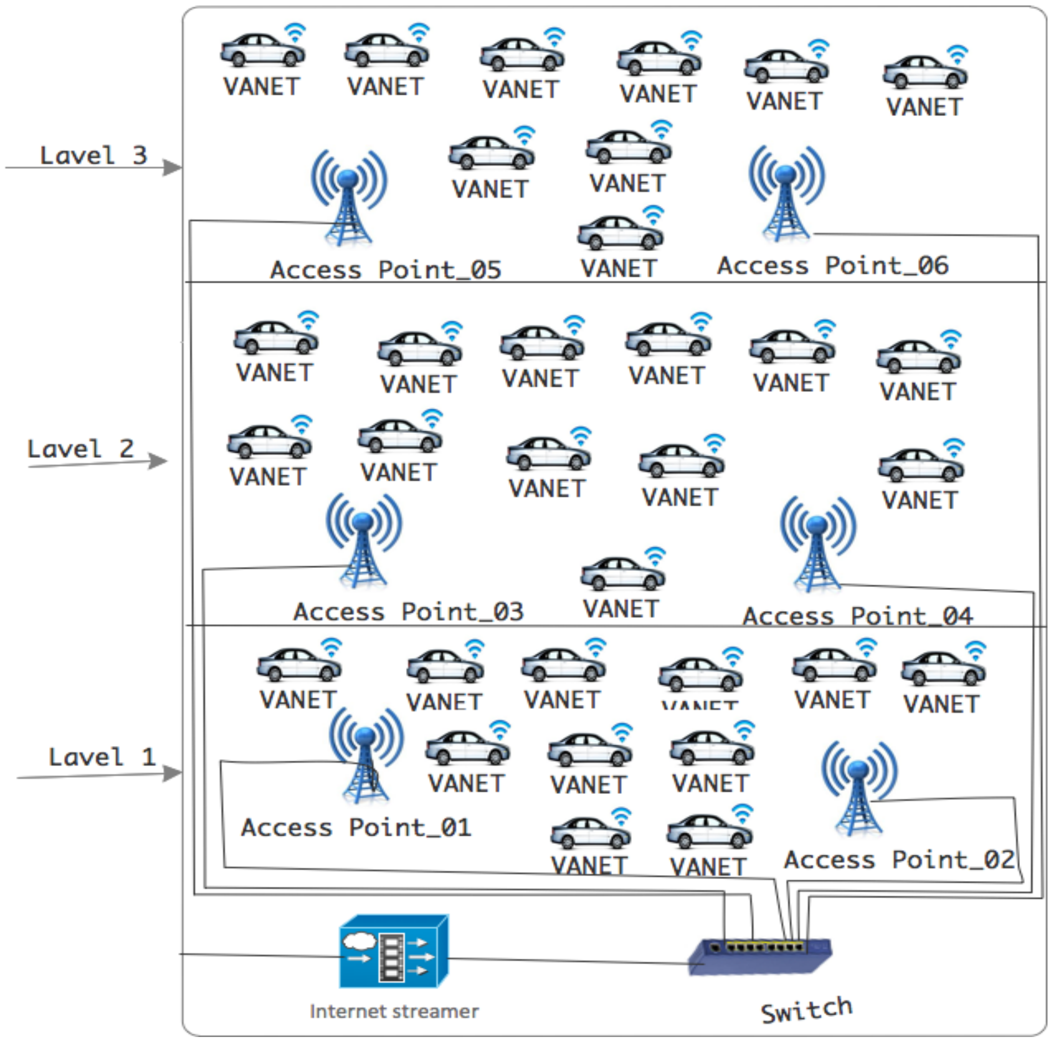

Figure 6.1: Deployment Scenario - a VANET in the parking lot

Recommendations for system deployment

The following are guidelines to be recommended for system development in the future:

1. Analyzing inter-floor signal propagation. Because every building is different it is a good idea to do some testing and determine how much the floors actually attenuate the radio signal. The following are steps that should be completed when analyzing inter-floor signal propagation:

Identify Primary Requirements:

- Type of facility (Access the construction of the facility which includes ceiling tiles, wood, concrete, steel etc.)
- Type of client devices
- Industry vertical

Identify Customer Facility Requirements

- Single-floor
- Multi-floor
- Campus (indoor and outdoor)

Identify Requirements for Type of Client Devices

- Minimum Received Signal Strength Indicator
- Minimum Signal-to-Noise Ratio
- Delay and Jitter tolerance
- Maximum transmit (Tx) power

Wireless access points are exceptional for the purpose of communication devices on wireless local area networks, which are a central transmitter and receiver of the wireless radio signal. Each access point has its own radio range for communication with a network adapter, which is 20m to more than 300m depending on product specification and antenna and operation environment. Multiple access procedure affects share the wireless network connection to end-user because the transmitter-to-receiver frequency spacing has to be carefully controlled in order to avoid unaccountably complex filters. In an environment multiple access technology concept is the best possible way for combing, instance, multiple coverage with high bandwidth WLAN hot spots. Panko (2002) presented 15% radio signal overlaps when placing multiples. Vehicular Ad Hoc Network extension is one of the recommendations. The access network operates in the infrastructure mode and can be retrieved by normal users with no specific software. The following are steps which should be completed for analyzing inter-floor signal propagation:

- Measure inter-floor signal propagation
- Characterise the inter-floor propagation
- Determine access point placement
- Avoid placing access points near structures
- Use power to deploy wireless access points
- Avoid overlapping DHCP scopes
- Use meaningful SSID

2. Apply smart antenna technology, which consists of multiple antenna elements for wireless environments to systems which can provide better performance for radio propagation signals where wireless communications are limited in performance and capacity. Multiple transmit and multiple receive antennas can provide multiple independent channels to increase data rate smart antennas which can significantly improve the performance of wireless systems. Fixed antenna can increase gain for better coverage and can be used for downlink or uplink. The researchers' measurement with 4 antennas at access point in IEEE 802.11a for real-time implementation where the result shows 6 db gain rise for 40% better range and process with an equivalent power interferer with possible to more than double with rapid fading and provides up to 216 Mpbs in 20 MHz bandwidth (Winters 1998). In indoor environments propagated electromagnetic signals can undergo three main physical modes, which are reflection, diffraction, and scattering. Moreover, a Toroidial Helical Antenna provides up to 300 percent performance improvement because antenna fading is not an issue and nearly isotropic direction. The radio spectrum is a limited resource and solutions need to maximize that can get better radio signal. Installing metal shielding can be effective.

Table 6.2: Smart Antenna technology

High Efficiency	Very Low Cost	Compact Size
Frequency range from 450MHz to 6GHz	One antenna replaces all others	Size reductions up to 75x
Wide bandwidth	One antenna replaces all others	Flexible
High port isolation	Flexible implementation in foil or copper	Occupies very little space

3. Co-channel users on the similar channel are factually protected from another decreasing the chance of interface. The authors were using RSSI readings to evolution the channel simulation

and to recreate interface. Moreover, channel modeling could decrease the received signal by obstructing LOS signal propagation (Boban, Vinhoza et al. 2011).

4. Assigning Radio Frequency (RF) channels and wireless network deployment, should be an alternative to the use of RF channels in a manner that minimizes inter-access-point interference. The weakness of non-overlapping channels in the 2.4GHz band makes it extremely problematic and sometimes difficult to sustain inter-access-point interference down to satisfactory levels in multi-floor buildings, particularly when supporting high-capacity voice systems. Consequently, it is advisable to migrate to 5GHz 802.11n. The 5GHz spectrum contains a comparatively big number of non-overlapping channels, which significantly reduces channel reuse problems and improves the performance of the network.
5. Wi-Fi extenders simply piggyback on existing Wi-Fi connections and rebroadcast and it is a good way to extend coverage. Wi-Fi extenders are placed in between a base router or access point and users that are not close enough to receive acceptable services or one that is on the other side of a barrier. They connect wirelessly to the router or access points, pick up the signal and retransmit it to the users.

6.3 Summary

This chapter discussed implications and recommended solutions provided to show that these proposed solutions actually work and can improve network performance in future VANET development. The performances can be developed to deploy a number of access points in an indoor parking environment. In Chapter 7, will be discussed research conclusions and possibilities for future research.

Chapter 7

Conclusions and Future research

Chapter 6 outlined system implications and recommendations for VANET deployment in a large shopping mall. In this chapter, section 7.1 discusses the summary and conclusions for each chapter. Section 7.2 presents for future research emphasis on the investigation of the impact of security mechanisms on Wi-Fi throughput, which would provide suggestions for significant vision vehicle safety, and information services into choosing security mechanisms for VANET deployment.

7.1 Summary and Conclusions

The main objective of this thesis was to provide for network planners to implement an IEEE 802.11-based VANET in the parking lot of a large shopping mall and a best-fit propagation model in measurement scenario. This study also illustrated a field trial measurement approach in IEEE 802.11n to implement the testing environment, collect data and analyze data with propagation models to achieve an accurate and realistic RSSI and transmission time of WLAN in the obstructed West City Auckland shopping mall parking lot environment. Recently researchers have proposed studies about VANETs environments. However, very few studies have proposed for network planners to implement an IEEE 802.11-based VANET in a large parking shopping mall. A deeper understanding of the impact RSSI in VANET's performance has been obtained by conducting various measurements and simulation experiments in this study. The preliminary results gave a clear indication of which VANET's parking lot scenarios perform best in a given situation. These results not only help by doing a virtual analysis but also give an insight into the variables that are VANET's performances and a better judgment of which IEEE 802.11-based VANET is to be used in a similar situation in the future.

Chapter 1 introduced the basis of this research, outlined the motives, aims and organizational structure of this research.

Chapter 2, reviewed vehicular ad-hoc communications with VANET applications and classifications, VANET issues and challenges, which provided us with a better understanding of VANET implications. Moreover VANET provides massive chances and opportunities in online vehicle entertainments such as through the local ad hoc networks sharing pictures, video, files, gaming and chatting. In order to use 802.11 standards technology, a fundamental understanding is required for designing, deploying and testing for best performance. However IEEE 802.11n have been designed for better signal strength and data rates for VANET communications. This kind of network relies on the use of short range networks (about 100 meters) with IEEE 802.11 for vehicle communication and providing bandwidth in the range of MBPS. Radio propagation was also addressed in this study, which can affect RSSI and throughput on the wireless network. In simulation environments, VANETs can appropriately model how vehicles move in a proper environment of ad hoc communication performance. Models that apply different types of attenuation features on the comparative heading nodes and positions proposed a suitable method to resolve these issues. A good understanding of how VANETs behave, the influential factors and performance issues that stimulate or cause a drawback is required to identify areas of improvement in VANETs deployment. The flow charts and contributions by researchers helped to isolate the gap where improvement is required.

In Chapter 3, the detailed experimental design and planning of propagation in the West City Auckland shopping mall parking lot environment are presented. Table 3.1 in Chapter 3 presented details of Wi-Fi-Based Vehicular Ad Hoc Networks using field trial measurement scenarios. As well, tables 3.2 and 3.3 in Chapter 3 describe clearly the OPNET parameters used in the configuration of the experiments and the numbers of experiments conducted in a particular scenario.

Chapter 4 generated experimental results on the performance of VANETs. The performance measurement of a VANET is considered by the four performance metrics RSSI, transmission time, sent data rate and received data rate. The results are classified into 5 scenarios for measurement. In scenario 1 and 5, we found RSSI gave best performance till 31m, which is -74 dBm. However the rest of the scenarios got poor signal coverage due to the concrete roof and wall barriers. Finally, the OPNET based scenario consisted of six experiments (time average delay, throughput, traffic sent, traffic received, download file size and download response time) according to two applications FTP and P2P, and network sizes 2, 5, 10, 20, 30, 40 and 50 nodes. OPNET simulations represent the end-to-end delay of all the data packets, collected separately for each 802.11n and successfully received by all the 802.11n capable WLAN MACs in the network and forwarded to a higher layer. Network mean packet delays are 1.72, 2.89, 3.06, 2.91, 3.08, 3.2 and 2.9 ms for N = 2, 5, 10, 20, 30, 40 and 50, respectively, and network mean throughput are 5.6, 10.3, 17.5, 32.8, 55.63, 70.01 and 69.9 kbps for N = 2, 5, 10, 20, 30, 40 and 50, respectively.

Chapter 5, presented radio propagation models, which are “Free space”, “Shadowing Path Loss”, “Egli”, “Hata” and “COST 231” models that can be used to predict the signal strength of planning VANETs based on measurement results. It is clear from the received signal power in scenario 1, the “Free Space” model and Hata model is better than other models. In scenario 2, the Egli model was closer and has very good agreement with level of measurement data. In scenario 3, the Egli model was bit closer than any other model. In scenario 5, the “Free Space” propagation model was closer and had a very good agreement with the level of the measurement data because there was no obstacle or reflected area effect between transmitter and receiver.

The models can be used in all kinds of indoor radio wave propagation to approximate signal attenuation for signal and multi floor wireless links using such building nature. We consider that the outcomes of our measurement result could save researchers time through discarding unnecessary issues when accomplishing simulations for VANET-related research or implementing VANET in any indoor parking environment. This approach can be a beneficial tool to help in approximating the signal power any place in the building, and wireless indoor communication coverage so this approach could be useful for all types of VANET indoor radio communications environments. The data measured in the simulation network illustrates the outcome of measurement conducted in real VANET scenarios. The performances can be developed to deploy a number of access points in indoor parking environments. The recommended solution might provide simulations to show that these proposed solutions actually work and can improve network performance in future VANET development.

7.2 Future Reserch

In this thesis significant numbers of issues arise which can affect radio propagation signal power. This section outlines a number of possible extensions to this research that could help further understanding of the problem.

- We only considered an ad hoc network in the study. An infrastructure network using wireless access points to carry out the field trial measurements would be a logical extension to the work presented in this thesis. Wireless Access Point especially supports public hotspots Wi

Fi network in a large building where space is required for wireless coverage. The work can be further extended by considering vehicle mobility

- Deploy some sensor networks around the parking lot to collect data regarding moving vehicles (cars) and then repeat field trial measurements by considering both ad hoc and infrastructure network. Sensor networks agree a system to be extended from one with simple functions to one that can receive and act on data about the environment it operates in.

Appendix A: Wi-Fi around West City shopping mall parking lot

Table A1: Level 1 in West city shopping mall parking lot

SSID	RSSI (dBm)	Channel
Spark Westcity	-80	7
Shing	-78	11
Colubris Network	-86	3
Koffee Bar Free Wifi	-75	11
DSE	-88	2
Smart Service Westcity	-83	5
DSE-Internal	-82	4
Smart Service Westcity	-85	5
ASB Customer WiFi	-83	13
SS	-86	11
DSE	-87	4
Smart Service Westcity	-85	5
Magstar	-87	9
No1ShoesWiFi	-84	6
TNZ-4279	-87	13
Spark-BPTA5W	-86	8
TPM Training	-87	11
ANZ Public Hotspot	-87	8
ANZ WTR Hotspot	-86	8

Table A2: Level 2 West city shopping mall parking lot

SSID	RSSI (dBm)	Channel
Spark Westcity	-78	7
Guest WaiFi	-87	11
Colubris Networks	-73	3
ANZ WTB Hotspot	-86	8
ANZ Public Hotspot	-88	8
ASB Customer WiFi	-87	13
SmartServiceWestcity	-87	5
Koffee Bar Free Wifi	-79	11

SmartServiceWestcity	-87	5
SS	-86	11
Shing	-74	11
No1ShoesWiFi	-84	6
Magstar	-85	9
Spark- BPTA5W	-87	8
CE Only	-85	11
TPM Training	-89	11
Test	-87	11
SmartServiceWestcity	-85	5
DSE	-90	2
DSE-Internal	-84	4
TNZ-4279	-87	13
DSE	-84	4

Table A3: Level 3 West city shopping mall parking lot

SSID	RSSI (dBm)	Channel
Staff WaiFi	-86	11
Thomson2959DF	-67	16
Staff WaiFi	-83	6
Test	-83	11
Guest WaiFi	-82	11
Koffee Bar Free WiFi	-79	11
TPM Training	-84	11
HP-Print-24-Officejet	-87	1
Shing	-80	11
Tomizone@Westfield	-87	1
WiFi2	-86	1
Guest WaiFi	-86	6
Test	-84	6
No1ShoesWiFi	-84	6
CE Onlt	-86	6
CE Only	-83	11
WiFi1	-87	1
Tomizone@Westfield	-87	1

Table A4: Level 4 West city shopping mall parking lot

SSID	RSSI (dBm)	Channel
Staff Wifi	-81	11
Thomoson2959DF	-74	6
Staff WaiFi	-82	6
Test	-78	11
Guest WaiFi	-77	11
Koffee Bar Free WiFi	-77	11
TPM Training	-77	11
HP-Print-24Officejet	-85	1
Shing	-77	11
Tomizone@Westfield	-87	1
Wifi2	-84	1
GuestWifi	-81	6
Test	-83	6
No1ShoesWifi	-87	6
CE Only	-80	6
CE Only	-73	11
WiFi1	-88	1
Tomizone@Westfield	-90	1
Guest WaiFi	-88	1
Ovl-chwap1	-88	9
WiFi1	-86	1
WiFi2	-87	1
Bbw	-88	7
Vodafone37CB	-87	11
TNCAPD24173	-88	6
Guest WaiFi	80	6
Fhlwpa2ccmp	-87	1
StaffWiFi	-86	1
StaffWiFi	-80	6
Test	-86	1
CR Only	-82	6
DSE-Internal	-85	4
CR Only	-88	1
DSE	-86	4

Test	-82	6

Table A5: Edsel Street in West city shopping mall parking lot

SSID	RSSI (dBm)	Channel
Staff WaiFi	-67	6
Test	-72	6
CE Only	-68	6
Koffee Bar Free WiFi	-87	11
Staff WaiFi	-74	11
Guest WaiFi	-74	11
CE Only	-74	11
Megatel-00286	-83	1
No1ShoesWiFi	-79	6
Test	-76	6
Test	-75	11
shing	-85	11
TPM Training	-73	11
CE Only	-80	1
ASB Customer WiFi	-84	13
Dlink	-84	11
Hp-Print-24-Officejet	-82	1
Guest WaiFi	-71	6
Staff WaiFi	-85	1
AndroidAP	-84	1
WTDEMO	-83	16
Test	-86	1
CE Only	-80	6
VodafoneX5WU	-78	1
BBw	-88	7
Unknown	-86	1
Staff WaiFi	-84	6
Guest WaiFi	-85	1

Lighting Direct	-76	1
Guest WaiFi	-79	6
VodafoneQ58F	-88	1
Telecom-0482	-88	1
CE Only	-87	11
TNZ-6060	-85	8
Elsha George	-75	1
Net Com wireless	-88	5

Appendix B: Preliminary Field trials results

Table B1: Measurement al results Scenario 1 (802.11n)

Distance (m)	RSSI (dBm)	Data Rate (Bytes /sec)	Transmission time (µs)	Data Rate (Bytes / sec)	Transmission time (ms)
		File size 71 bytes		File size 1.05 MB	
1	-45	108	1.44	162454	2.167
2	-45	229	3.053	158988	2.12
3	-49	176	2.347	159182	2.123
4	-51	178	2.373	161420	2.152
5	-51	225	3	161994	2.16
6	-53	152	2.027	158925	2.119
7	-66	286	3.813	163001	2.173
8	-59	123	1.64	159182	2.123
9	-61	214	2.853	158564	2.115
10	-64	240	3.2	158981	2.12
11	-63	272	3.627	160876	2.145
12	-60	168	2.24	158786	2.117
13	-67	138	1.84	159548	2.127
14	-61	158	2.107	160138	2.135
15	-66	281	3.747	158958	2.12
16	-61	204	2.72	162151	2.163
17	-64	585	7.8	162766	2.171
18	-65	199	2.653	159690	2.129
19	-65	216	2.88	160674	2.143
20	-71	243	3.24	162340	2.164
21	-71	183	2.44	159845	2.131
22	-64	254	3.387	159536	2.127
23	-74	349	4.653	163859	2.185
24	-74	168	2.24	159880	2.132
25	-73	238	3.173	159913	2.132
31	-74	601	8.013	171138	2.281
32	-83	545	7.267	179631	2.395
33	-90	422	5.627	165105	2.201
34	-74	237	3.16	171138	2.281
35	-83	315	4.2	179631	2.395

36	-71	311	4.147	178751	2.384
37	-83	269	3.587		
38	-74	202	2.693		
44	-82	212	2.827		
45	-74	370	4.933		
46	-90	218	2.907		
48	-83	267	3.56		
49	-90	360	4.8		
50	-91	487	6.493		
52	-90	654	8.6		
55	-83	349	4.653		
56	-83	601	8.013		
57	-83	1120	14.93		

Table B2: Measurement results Scenario 2 (802.11n)

Distance (m)	RSSI (dBM)	Data Rate (Bytes / sec)	Transmission time (µs)	Data Rate (Bytes / sec)	Transmission time (ms)
		File size 71 bytes		File size 1.05 MB	
4	-73	139	1.853	122924	1.639
4.12	-74	141	1.88	122804	1.637
4.47	-90	132	1.76	125105	1.668
5	-91	615	8.2	125322	1.671
5.65	-82	118	1.573	122976	1.64
6.4	-83	100	1.333	124388	1.659
7.21	-82	828	11.04	123349	1.644
8.06	-82	112	1.493	124573	1.661
8.94	-83	218	2.907	123641	1.648
9.84	-83	1935	25.8		
10.77	-90	2165	28.87		
11.7	-83	725	9.667		
12.65	-90	2745	36.6		
13.6	-90	2237	29.83		
14.56	-91	2175	29		
15.52	-91	2835	37.8		
16.49	-91	2856	38.08		
17.46	-90	2165	28.87		

Table B3: Measurement results Scenario 3 (802.11n)

Distance (m)	RSSI (dBm)	Transmission time (µs)	Data Rate (Bytes / sec)	Data Rate (Bytes / sec)	Transmission time (ms))
		File size 71 bytes		File size 1.05 MB	
8	-74	3.36	252	125619	1.691
8.06	-83	1.48	111	126837	1.691
8.24	-91	3.52	264		
8.54	-91	9.613	721		

Table B4: Measurement results Scenario 4 (802.11n)

Distance (m)	RSSI (dBm)	Transmission time (µs)	Data Rate (Bytes / sec)	Data Rate (Bytes / sec)	Transmission time (ms)
		File size 71 bytes		File size 1.05 MB	
12	-0	0	0	0	0
12.04	0	0	0	0	0
12.17	0	0	0	0	0

Table B5: Measurement results Scenario 5 (802.11n)

Distance (m)	RSSI (dBm)	Data Rate (Bytes / sec)	Transmission time (µs)	Data Rate (Bytes / sec)	Transmission time (ms)
		File size 71 bytes		File size 1.05 MB	
11	-55	275	3.667	163876	2.185
12	-58	264	3.52	159786	2.131
13	-60	276	3.68	159948	2.132
14	-59	368	4.907	163568	2.181
15	-62	310	4.133	158858	2.119
16	-58	292	3.893	169851	2.265
17	-64	423	5.64	162706	2.169
18	-70	313	4.173	158790	2.117
19	-65	316	4.213	164874	2.199
20	-69	462	6.16	162340	2.164
21	-71	296	3.947	159885	2.132
22	-74	319	4.253	158536	2.113
23	-70	364	4.853	166859	2.225
24	-73	370	4.933	159680	2.129
25	-69	438	5.84	159726	2.13
26	-68	412	5.493	160033	2.133
27	-70	443	5.907	166072	2.215
28	-73	456	6.08	159720	2.129

29	-73	471	6.28	163929	2.185
30	-72	534	7.12	177288	2.185
31	-71	601	8.013	182045	2.427
32	-80	640	8.533	176016	2.347
33	-74	422	5.627	165405	2.205
34	-81	437	5.827	155181	2.069
35	-79	315	4.2	158751	2.117
36	-75	390	5.2	178901	2.385
37	-78	469	6.253	189721	2.529
38	-74	475	4.027	185312	2.471
39	-71	398	5.307	179260	2.391
40	-80	487	6.493	185371	2.472
41	-74	431	5.747	184276	2.457
42	-81	461	6.147	189572	2.528
43	-79	495	6.6	190254	2.537
44	-84	468	6.24	185129	2.468
45	-70	490	6.533	172316	2.297
46	-89	432	5.76	179321	2.391
48	-81	418	5.573	196541	2.62
49	-89	439	5.853	189654	2.529
50	-90	613	8.173	196521	2.62
51	-90	646	8.613		
52	-89	413	5.507		
53	-88	517	6.893		
54	-78	556	7.413		
55	-87	527	4.36		
56	-83	518	6.907		
57	-85	1125	15		
58	-90	532	7.093		
59	-92	467	6.227		
60	-90	1029	13.72		
61	-92	612	8.16		
62	-89	859	11.45		
63	-90	587	7.827		
64	-92	864	11.52		
65	-90	601	8.013		
66	-89	632	8.427		
67	-91	979	13.05		
68	-92	1355	18.07		

Appendix C: OPNET Simulations Configurations

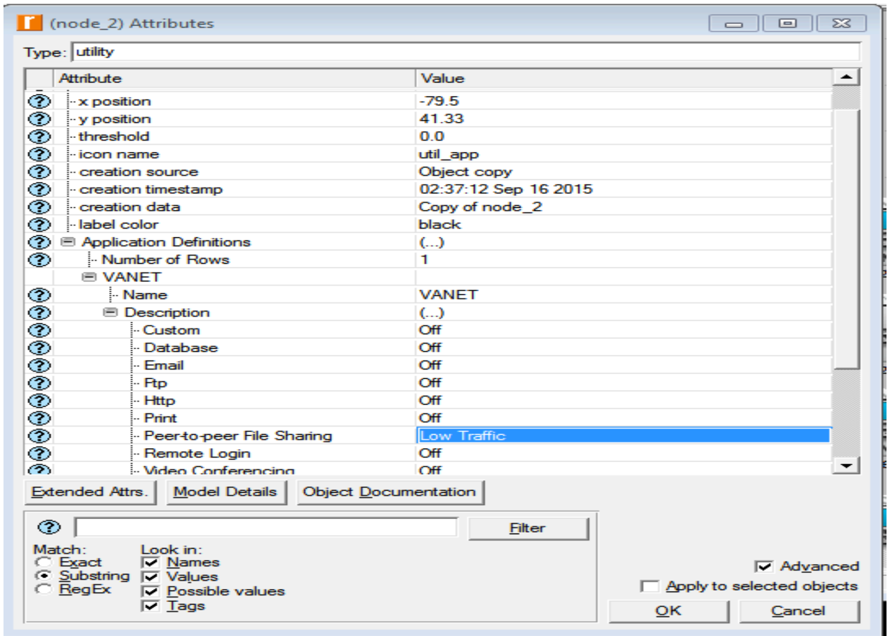

Figure C1: Application configuration

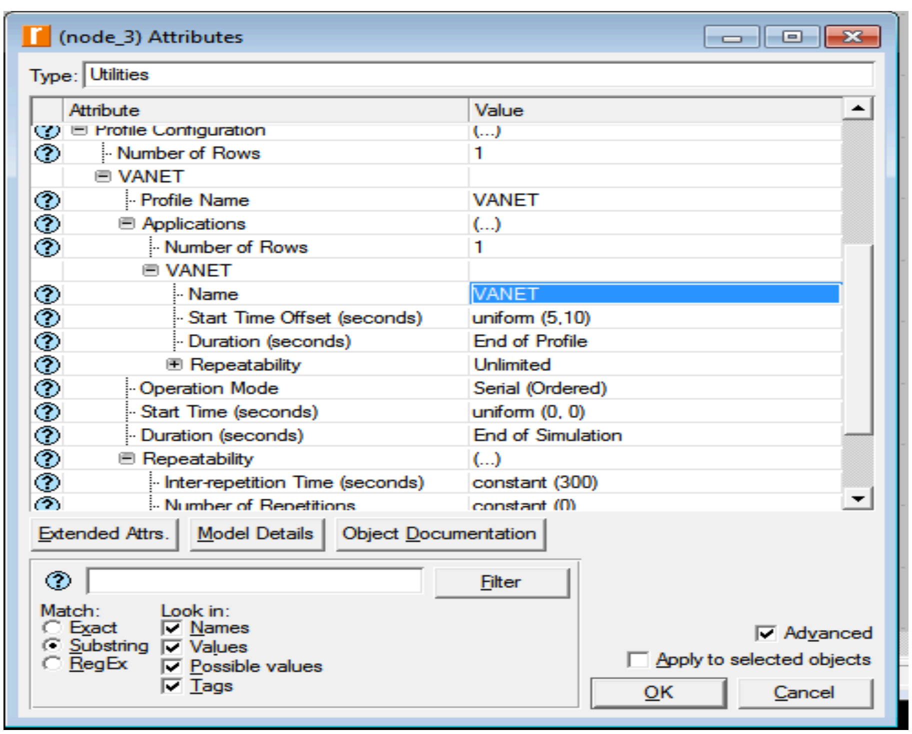

Figure C2: Profile Configuration

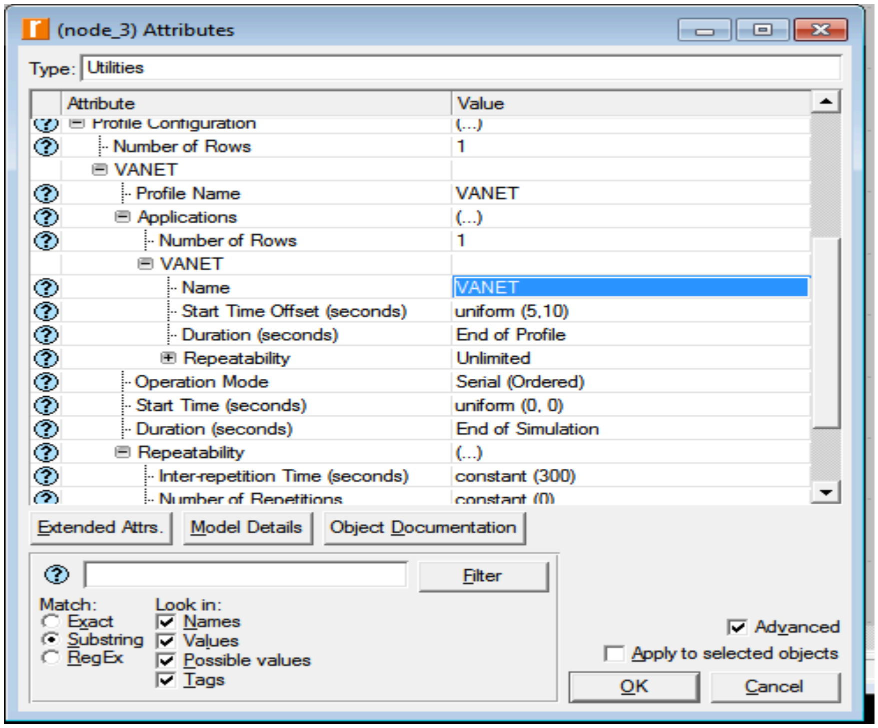

Figure C3: WLAN configuration

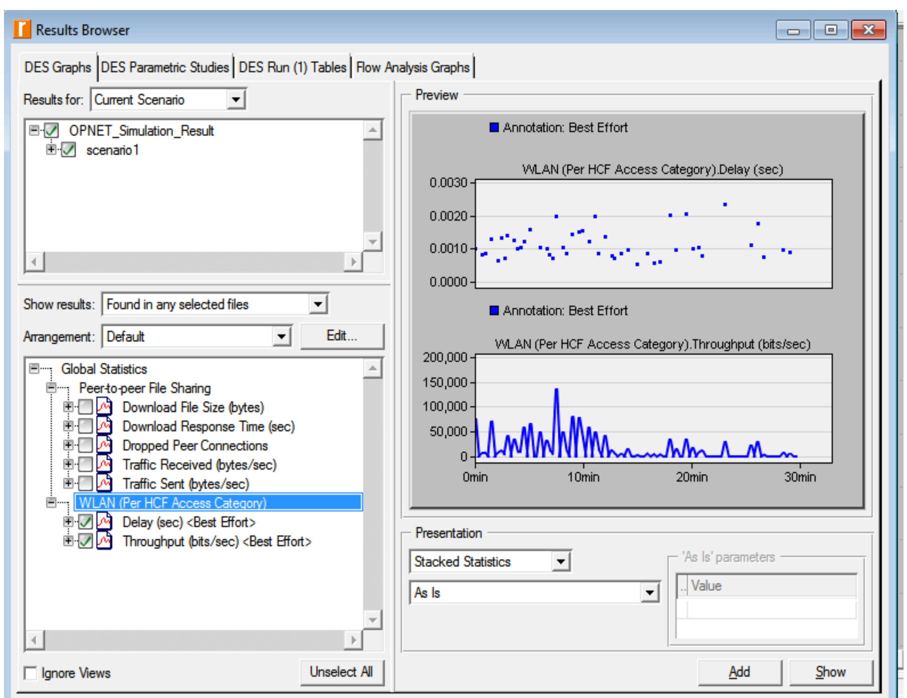

Figure C4: Simulation result browser

Appendix D: OPNET-based Simulation Scenario Results

Table D1: Peer-to-Peer File sharing packet delay (ms)

2 Nodes	5 Nodes	10 Nodes	20 Nodes	30 Nodes	40 Nodes	50 Nodes
1.72	2.89	3.062	2.91	3.08	3.28	2.92

Table D2: Peer-to-Peer File sharing Throughput (kbps)

2 Nodes	5 Nodes	10 Nodes	20 Nodes	30 Nodes	40 Nodes	50 Nodes
5.63	10.35	17.54	32.81	55.63	70.01	69.96

Table D3: Peer-to-Peer File sharing traffic received (kbps)

	2 **Nodes**	5 **Nodes**	10 **Nodes**	20 **Nodes**	30 **Nodes**	40 **Nodes**	50 **Nodes**
Low Traffic	0.67	1.22	1.74	3.55	5.82	6.99	9.23
High Traffic	41.09	71.34	168.97	356.29	525.00	611.82	618.36

Table D4: Peer-to-Peer File sharing traffic sent (kbps)

	2 **Nodes**	5 **Nodes**	10 **Nodes**	20 **Nodes**	30 **Nodes**	40 **Nodes**	50 **Nodes**
Low Traffic	0.67	1.22941	1.74	3.55	5.82	6.99	9.23
High Traffic	41.09	71.34	168.97	367.03	580.39	750.28	3195.584

Table D5: Peer-to-Peer File download file size (mbps)

	2 **Nodes**	5 **Nodes**	10 **Nodes**	20 **Nodes**	30 **Nodes**	40 **Nodes**	50 **Nodes**
Low Traffic	0.06	0.05	0.053	0.06	0.05	0.04	0.05
High Traffic	6.16	4.13	5.17	5.66	4.83	4.35	4.61

Table D6: Peer-to-Peer File download response time (sec)

	2 Nodes	5 Nodes	10 Nodes	20 Nodes	30 Nodes	40 Nodes	50 Nodes
Low	1.26	0.10	0.27	0.23	0.60	0.22	0.11
High	56.84	36.35	26.80	43.90	60.24	71.34	53.83

Table D7: Ftp download response time (sec)

	2 **Nodes**	5 **Nodes**	10 **Nodes**	20 **Nodes**	30 **Nodes**	40 **Nodes**	50 **Nodes**
Low load	0.13	0.01	0.08	0.12	0.10	0.11	0.08
Medium load	0.0098	0.0095	0.0098	0.0099	0.0097	0.0099	0.0099
High Load	0.072	1.63	1.61	0.80	1.41	0.83	0.62

Table D8: Ftp upload response time (sec)

	2 **Nodes**	5 **Nodes**	10 **Nodes**	20 **Nodes**	30 **Nodes**	40 **Nodes**	50 **Nodes**
Low load	0.08	0.05	0.05	0.07	0.11	0.13	0.07
Medium Load	0.12	0.017	0.13	0.12	0.09	0.10	0.12
High load	3.45	1.02	1.67	0.75	0.84	0.86	0.90

Table D9: Ftp traffic received (kbps)

	2 **Nodes**	5	10 **Nodes**	20 **Nodes**	30 **Nodes**	40 **Nodes**	50 **Nodes**
Low load	0.01	0.02	0.05	0.10	0.16	0.22	0.26
Medium Load	0.09	0.09	0.25	0.53	0.72	1.03	1.31
High load	0.85	1.36	3.23	5.78	8.67	14.45	13.94

Table D10: Ftp traffic sent (kbps)

	2 **Nodes**	5 **Nodes**	10 **Nodes**	20 **Nodes**	30 **Nodes**	40 **Nodes**	50 **Nodes**
Low load	0.01	0.02	0.05	0.10	0.16	0.22	0.26
Medium Load	0.09	0.09	0.25	0.55	0.71	1.02	1.30
High load	0.84	1.34	3.36	5.72	8.58	14.31	13.97

Appendix E: Model Propagation results

Table E1: Scenario 1. Measurement data under Non-LOS Conditions

Distance (m)	Measurement	“Shadowing Path Loss” Model, dB	“Free Space” model, dB	“Egli” Model, dB	“Hata” Model, dB	“COST231” Model, dB
1	-45	-33	-40.04	-40.04	-24.73	-77.04
2	-45	-39.1	-46.06	-47.6	-38.24	-83.06
3	-49	-42.6	-49.58	-54.64	-46.15	-86.58
4	-51	-45.1	-52.08	-59.64	-51.74	-89.08
5	-51	-47	-54.02	-63.52	-56.11	-91.02
6	-53	-48.6	-55.6	-66.68	-59.67	-92.6
7	-66	-49.6	-56.94	-69.36	-62.67	-93.94
8	-59	-51.1	-58.1	-71.68	-65.27	-95.1
9	-61	-52.1	-59.13	-73.73	-67.57	-96.13
10	-64	-53	-60.04	-75.56	-69.63	-97.04
11	-63	-53.9	-60.87	-77.21	-71.48	-97.87
12	-60	-54.6	-61.62	-78.73	-73.18	-98.62
13	-67	-55.3	-62.32	-80.12	-74.74	-99.32
14	-61	-56	-62.96	-81.4	-76.19	-99.96
15	-66	-56.6	-63.56	-81.4	-76.19	-100.56
16	-61	-57.1	-64.12	-83.72	-78.79	-101.12
17	-64	-57.7	-64.65	-84.78	-79.97	-101.65
18	-65	-58.2	-65.15	-85.77	-81.09	-102.15
19	-65	-58.6	-65.62	-86.71	-82.14	-102.62
20	-71	-59.1	-66.06	-87.6	-83.14	-103.06
21	-71	-59.5	-66.49	-88.45	-84.09	-103.49
22	-64	-59.9	-66.89	-89.25	-85	-103.89
23	-74	-60.3	-67.28	-90.03	-85.87	-104.28
24	-74	-60.7	-67.65	-90.77	-86.7	-104.65
25	-73	-61	-68	-91.48	-87.49	-105
31	-74	-62.9	-69.87	-95.21	-91.69	-106.87
32	-83	-63.1	-70.14	-95.76	-92.31	-107.14
33	-90	-63.4	-70.41	-96.3	-92.91	-107.41
34	-74	-63.7	-70.67	-96.82	-93.49	-107.67

35	-83	-63.9	-70.92	-97.32	-94.05	-107.92
36	-71	-64.2	-71.17	-97.81	-94.6	-108.17
37	-83	-64.4	-71.41	-98.29	-95.14	-108.41
38	-74	-64.6	-71.64	-98.75	-95.66	-108.64
44	-82	-65.9	-72.91	-101.3	-98.52	-109.91
45	-74	-66.1	-73.11	-101.69	-98.96	-110.1
46	-90	-66.3	-73.3	-102.07	-99.38	-110.3
48	-83	-66.7	-73.67	-102.81	-100.21	-110.67
49	-90	-66.8	-73.84	-103.17	-100.62	-110.89
50	-91	-67	-74.02	-103.52	-101.01	-111.02
52	-90	-67.4	-74.36	-104.2	-101.77	-111.36
55	-83	-67.9	-74.85	-105.17	-102.87	-111.85
56	-83	-68	-75	-105.49	-103.22	-112
57	-83	-68.2	-75.16	-105.49	-103.22	-112.16
58	-91	-68.3	-75.31	-106.1	-103.9	-112.31
59	-92	-68.5	-75.46	-106.39	-104.24	-112.46

Table E2: Scenario 2. Measurement data under Non-Los Conditions

Distance (m)	Measurement	“Shadowing Path Loss” Model, dB	“Free Space” model, dB	“Egli” Model, dB	“Hata” Model, dB	“COST231” Model, dB
4	-73	-45.1	-52.08	-59.64	-51.76	-134.98
4.12	-74	-45.3	-52.34	-60.15	-52.34	-135.24
4.47	-90	-46.1	-53.05	-61.57	-53.93	-135.95
5	-91	-47	-54.02	-63.52	-56.11	-136.92
5.65	-82	-48.1	-55.08	-65.64	-58.49	-137.98
6.4	-83	-49.2	-56.16	-67.81	-60.92	-139.06
7.21	-82	-50.2	-57.2	-69.88	-63.25	-140.1
8.06	-82	-51.2	-58.17	-71.81	-65.42	-141.07
8.94	-83	-52.1	-59.07	-73.61	-67.44	-141.97
9.84	-83	-52.9	-59.9	-75.28	-69.31	-142.80
10.77	-90	-53.7	-60.69	-76.85	-71.07	-143.59
11.7	-83	-54.4	-61.4	-78.29	-72.69	-144.3
12.65	-90	-55.1	-62.08	-79.64	-74.21	-144.98
13.6	-90	-55.7	-62.71	-80.2	-74.83	-145.61
14.56	-91	-56.3	-63.3	-82.08	-76.95	-146.2

15.52	-91	-56.9	-63.86	-83.19	-78.2	-146.76
16.49	-91	-57.4	-64.39	-84.25	-79.38	-147.29
17.46	-90	-57.4	-64.88	-85.24	-80.49	-147.78

Table E3: Scenario 3. Measurement data under Non-Los Conditions

Distance (m)	Measurement	"Shadowing Path Loss" Model, dB	"Free Space" model, dB	"Egli" Model, dB	"Hata" Model, dB	"COST231" Model, dB
8	-74	-51.1	-58.1	-71.68	-65.27	-156.23
8.06	-83	-51.2	-58.17	-71.81	-65.42	-156.29
8.24	-91	-51.4	-58.36	-72.2	-65.85	-156.48
8.54	-91	-51.7	-58.67	-72.82	-66.55	-156.79
8.94	-91	-52.1	-59.11	-73.61	-67.44	-157.19
9.43	-91	-52.5	-59.53	-74.54	-68.28	-157.65

Table E4: Scenario 4. Measurement data under Non-Los Conditions

Distance (m)	Measurement	"Shadowing Path Loss" Model, dB	"Free Space" model, dB	"Egli" Model, dB	"Hata" Model, dB	"COST231" Model, dB
12	0	-54.6	-61.62	-78.73	-73.18	-169.81
12.04	0	-54.7	-61.65	-78.78	-73.25	-169.84
12.17	0	-54.8	-61.75	-78.97	-73.46	-169.94

Table E5: Scenario 5. Measurement data under Non-Los Conditions

Distance (m)	Measurement	"Shadowing Path Loss" Model, dB	"Free Space" model, dB	"Egli" Model, dB	"Hata" Model, dB	"COST231" Model, dB
11	-55	-53.9	-60.87	-77.21	-71.48	-125.47
12	-58	-54.6	-61.62	-78.73	-73.18	-126.22
13	-60	-55.3	-62.32	-80.12	-74.74	-126.92
14	-59	-56	-62.96	-81.4	-76.19	-127.56
15	-62	-56.6	-63.56	-81.4	-76.19	-128.16
16	-58	-57.1	-64.12	-83.72	-78.79	-128.72
17	-64	-57.7	-64.65	-84.78	-79.97	-129.25
18	-70	-58.2	-65.15	-85.77	-81.09	-129.75
19	-65	-58.6	-65.62	-86.71	-82.14	-130.22
20	-69	-59.1	-66.06	-87.6	-83.14	-130.66

21	-71	-59.5	-66.49	-88.45	-84.09	-131.09
22	-74	-59.9	-66.89	-89.25	-85	-131.49
23	-70	-60.3	-67.28	-90.03	-85.87	-131.88
24	-73	-60.7	-67.65	-90.77	-86.7	-132.25
25	-69	-61	-68	-91.48	-87.49	-132.6
26	-68	-61.3	-68.34	-92.16	-88.26	-132.94
27	-70	-61.7	-68.67	-92.81	-88.99	-133.27
28	-73	-62	-68.98	-93.44	-89.7	-133.58
29	-73	-62.3	-69.29	-94.05	-90.39	-133.89
30	-72	-62.6	-69.58	-94.64	-91.05	-134.18
31	-71	-62.9	-69.87	-95.21	-91.69	-134.47
32	-80	-63.1	-70.14	-95.76	-92.31	-134.74
33	-74	-63.4	-70.41	-96.3	-92.91	-135.01
34	-81	-63.7	-70.67	-96.82	-93.49	-135.27
35	-79	-63.9	-70.92	-97.32	-94.05	-135.52
36	-75	-64.2	-71.17	-97.81	-94.6	-135.77
37	-78	-64.4	-71.41	-98.29	-95.14	-136.01
38	-74	-64.6	-71.64	-98.75	-95.66	-136.24
39	-79	-64.9	-71.86	-99.2	-96.17	-136.46
40	-77	-65.1	-72.08	-99.64	-96.66	-136.68
41	-74	-65.3	-72.3	-100.07	-97.14	-136.9
42	-82	-65.5	-72.51	-100.49	-97.61	-137.11
43	-80	-65.7	-72.71	-100.9	-98.07	-137.31
44	-84	-65.9	-72.91	-101.3	-98.52	-137.51
45	-78	-66.1	-73.11	-101.69	-98.96	-137.71
46	-89	-66.3	-73.3	-102.07	-99.38	-137.9
47	-88	-66.5	-73.48	-102.44	-99.8	-138.08
48	-81	-66.7	-73.67	-102.81	-100.218	-138.27
49	-89	-68.8	-73.84	-103.17	-100.62	-138.44
50	-90	-67	-74.02	-103.52	-101.01	-138.62
51	-90	-67.2	-74.19	-104.2	-101.77	-138.79
52	-89	-67.4	-74.36	-104.2	-101.77	-138.96
53	-88	-67.5	-74.53	-104.53	-102.15	-139.13
54	-88	-67.7	-74.69	-104.85	-102.51	-139.29
55	-87	-67.9	-74.85	-105.17	-102.87	-139.45
56	-83	-68	-75	-105.49	-103.22	-139.6

57	-85	-68.2	-75.16	-105.49	-103.22	-139.76
58	-90	-68.3	-75.31	-106.1	-103.9	-139.91
59	-92	-68.5	-75.46	-106.39	-104.24	-140.06
60	-90	-68.6	-75.6	-106.68	-104.57	-140.2
61	-92	-68.8	-75.75	-106.97	-104.89	-140.35
62	-89	-68.9	-75.89	-107.25	-105.2	-140.49
63	-90	-69	-76.03	-107.53	-105.52	-140.63
64	-92	-69.2	-74.16	-107.81	-105.82	-140.76
65	-90	-69.3	-76.3	-108.07	-106.13	-140.9
66	-89	-69.4	-76.63	-108.34	-106.42	-141.03
67	-91	-69.6	-76.56	-108.6	-106.72	-140.63
68	-92	-69.7	-76.69	-108.86	-107.01	-140.76

Appendix F: VANET in the West City Auckland shopping mall parking lot

Figure F1: VANET vehicle with wireless adapter, antenna and laptop

Figure F2: West City Auckland shopping mall outside parking image

Figure F3 : West city Auckland shopping mall parking image

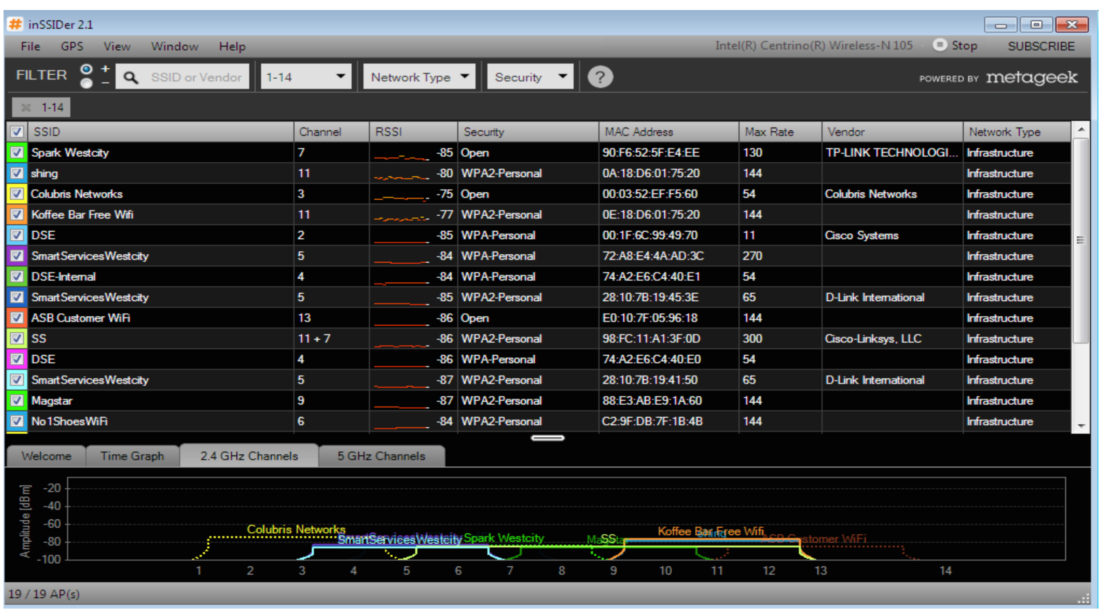

Figure F4: Frequency range 2.4 GHz in the West City Auckland shopping mall parking lot

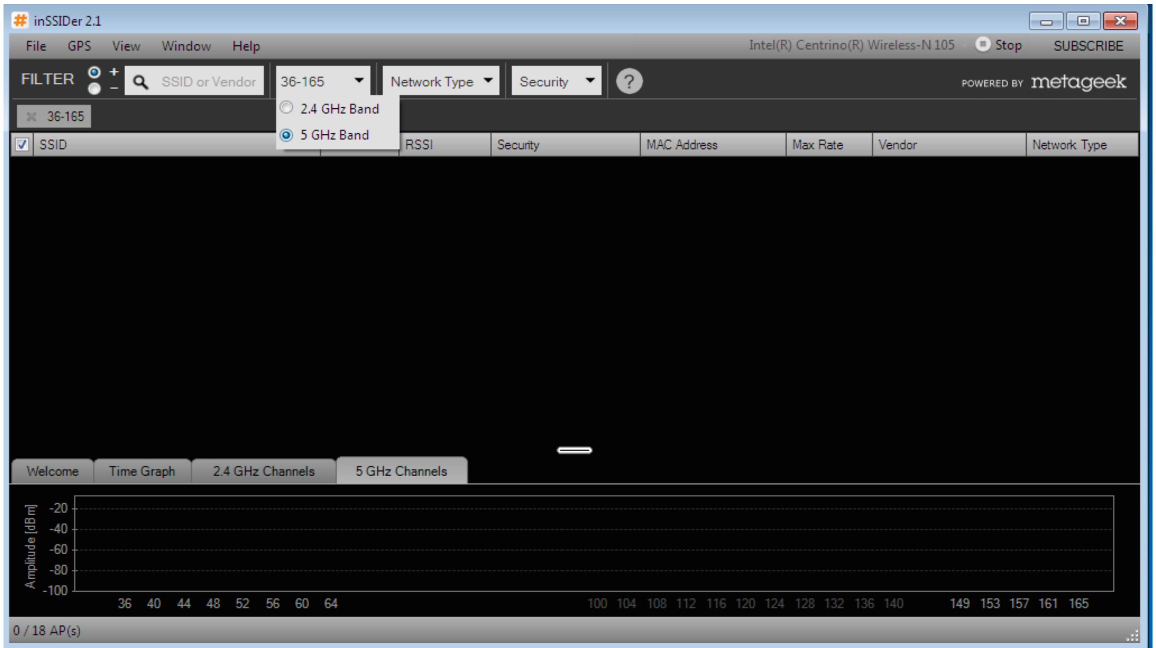

Figure F5: Frequency range 5 GHz in the West City Auckland shopping mall parking lot

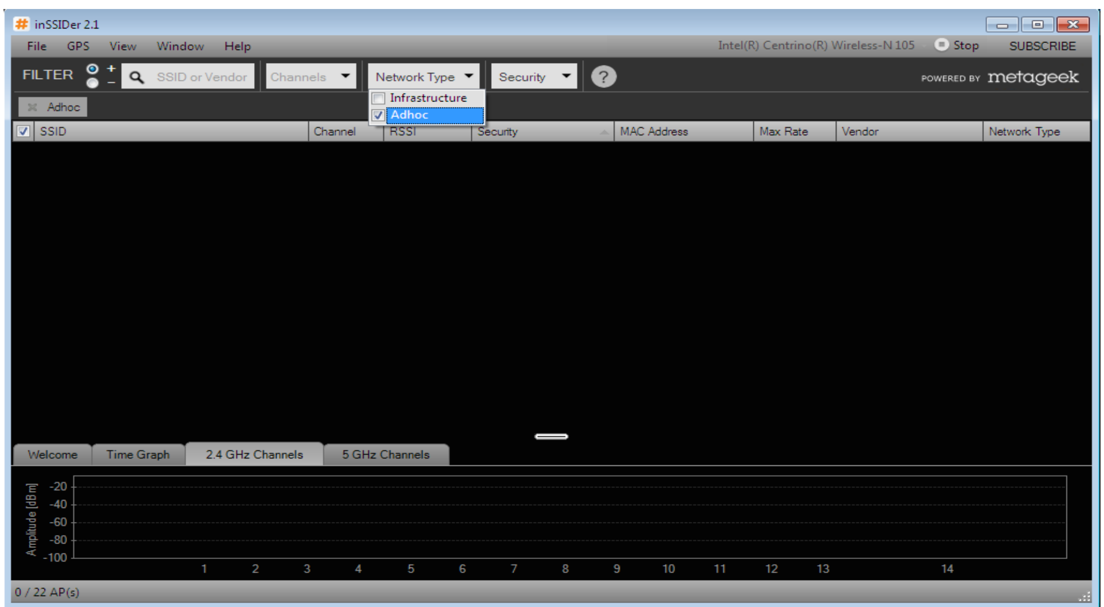

Figure F6: Ad Hoc network in the West City Auckland shopping mall parking lot

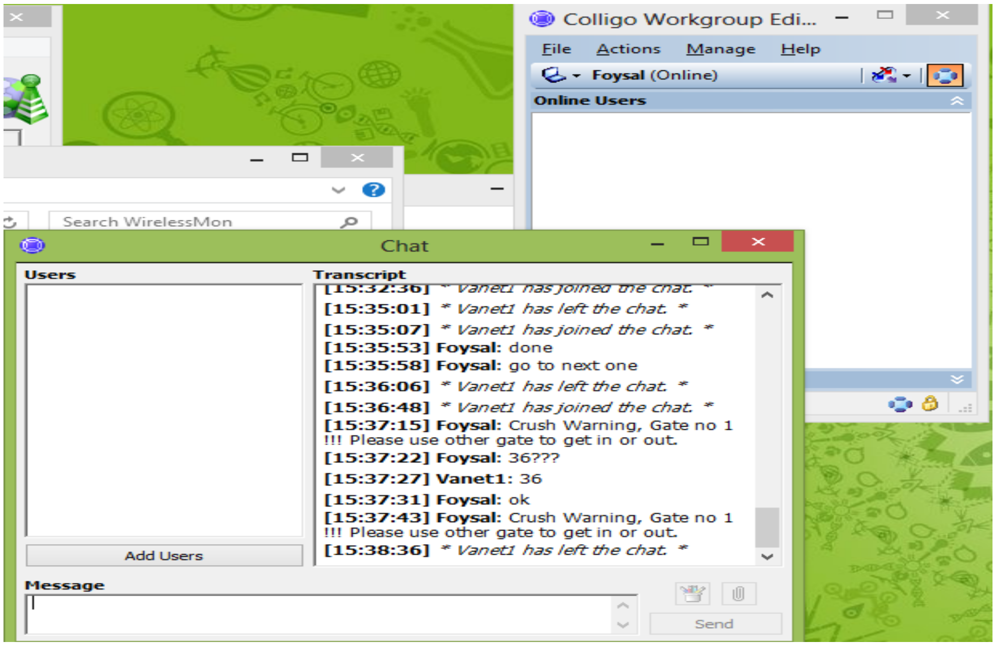

Figure F7: File sharing, chat through Colligo Workgroup Edition

References

Abdelgader, A. M. and W. Lenan (2014). The Physical Layer of the IEEE 802.11 p WAVE Communication Standard: The Specifications and Challenges. Proceedings of the World Congress on Engineering and Computer Science: 1 - 8.

Abulencia, A., et al. (2006). "Measurement of the t t¯ production cross section in p p¯ collisions at s= 1.96 TeV in the all hadronic decay mode." Physical Review D 74(7): 072005.

Akyildiz, I. F. and W. Xudong (2005). "A survey on wireless mesh networks." IEEE Communications Magazine, 43(9): S23-S30.

Alexiou, A. and M. Haardt (2004). "Smart antenna technologies for future wireless systems: trends and challenges." IEEE Communications Magazine, 42(9): 90-97.

Amoroso, A., et al. (2012). Creative testbeds for VANET research: IEEE A new methodology. Consumer Communications and Networking Conference (CCNC), 477 - 481.

Andr, et al. (2008). An overview of the OMNeT++ simulation environment. Proceedings of the 1st international conference on Simulation tools and techniques for communications, networks and systems & workshops. Marseille, France, ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering): 1-10.

Baccarelli, E., et al. (2005). Broadband wireless access networks: a roadmap on emerging trends and standards, Wiley.

Bilstrup, K., et al. (2009). "On the ability of the 802.11 p MAC method and STDMA to support real-time vehicle-to-vehicle communication." EURASIP Journal on Wireless Communications and Networking 2009: 5.

Bing, B. (1999). Measured performance of the IEEE 802.11 wireless LAN. Local Computer Networks, 1999. LCN '99. Conference: 34-42.

Bisdikian, C. (2001). "An overview of the Bluetooth wireless technology." IEEE Communications Magazine, 39(12): 86-94.

Boban, M., et al. (2011). "Impact of vehicles as obstacles in vehicular ad hoc networks." IEEE Journal on Selected Areas in Communications, 29(1): 15-28.

Boukerche, A., et al. (2008). "Vehicular Ad Hoc Networks: A New Challenge for Localization-Based Systems." Computer Communications 31(12): 2838-2849.

Boulmalf, M., et al. (2005). Measured Throughput and SNR of IEEE 802.11 g in a Small Enterprise Environment. The 61st, IEEE Vehicular Technology Conference, 2005. VTC 2005-Spring.: 1333 - 1337.

Boulmalf, M., et al. (2005). Measured throughput and SNR of IEEE 802.11g in a small enterprise environment. The 61st IEEE Vehicular Technology Conference, 2005. VTC 2005-Spring.

Bromage, S., et al. (2009). "SCORPION: a heterogeneous wireless networking testbed." SIGMOBILE Mob. Comput. Commun. Rev. 13(1): 65-68.

Buchenscheit, A., et al. (2009). A VANET-based emergency vehicle warning system. IEEE Vehicular Networking Conference (VNC): 1-8.

Caliskan, M., et al. (2006). Decentralized discovery of free parking places. Proceedings of the 3rd international workshop on Vehicular ad hoc networks. Los Angeles, CA, USA, ACM: 30-39.

Case, J. M. and G. Light (2011). "Emerging Research Methodologies in Engineering Education Research." Journal of Engineering Education 100(1): 186-210.

Chang, D.-C. and C.-N. Hu (2012). "Smart antennas for advanced communication systems." IEEE Proceedings of the 100(7): 2233-2249.

Charvat, J. (2003). "Project management methodologies: selecting, implementing, and supporting methodologies and processes for projects." New Jersey:John Wiley & Sons, Inc: 1 - 264.

Chatzimisios, P., et al. (2004). Optimisation of RTS/CTS handshake in IEEE 802.11 Wireless LANs for maximum performance. IEEE Global Telecommunications Conference Workshops, 2004. GlobeCom Workshops 2004. pp 270- 275.

Chebrolu, K., et al. (2006). Long-distance 802.11 b links: performance measurements and experience. ACM. Proceedings of the 12th annual international conference on Mobile computing and networking: 74 - 85.

Chen, X., et al. (2010). "On the enhancements to IEEE 802.11 MAC and their suitability for safety-critical applications in VANET." Wireless Communications and Mobile Computing 10(9): 1253-126

Chieochan, S., et al. (2010). "Channel assignment schemes for infrastructure-based 802.11 WLANs: A survey." IEEE Communications Surveys & Tutorials,12(1): 124-136.

Committee, I. L. M. S. (2003). "ANSI/IEEE Std. 802.11, 1999 Edition (2003)." Information Technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific Requirements. Part II.

Conti, M. and S. Giordano (2014). "Mobile ad hoc networking: milestones, challenges, and new research directions." IEEE Communications Magazine, 52(1): 85-96.

Dai, H. N., et al. (2013). "An overview of using directional antennas in wireless networks." International Journal of Communication Systems 26(4): 413-448.

Dalela, C., et al. (2012). "Tuning of COST-231 Hata model for radio wave propagation predictions." Computer Science and Information Technology (CS & IT), DOI 10: 255-267.

Dressler, F., et al. (2008). Requirements and objectives for secure traffic information systems. Mobile Ad Hoc and Sensor Systems, 2008. MASS 2008. 5th IEEE International Conference on: 808 814.

Engelstad, P. E. and O. N. Østerbo (2006). Queueing delay analysis of IEEE 802.11 e EDCA. WONS 2006: Third Annual Conference on Wireless On-demand Network Systems and Services: 123 - 133.

Fogue, M., et al. (2011). Analysis of the most representative factors affecting Warning Message Dissemination in VANETs under real roadmaps. Modeling, Analysis & Simulation of Computer and Telecommunication Systems (MASCOTS), IEEE 19th International Symposium: 197-204.

Friis, H. T. (1946). "A note on a simple transmission formula." proc. IRE 34(5): 254-256.

Ghahfarokhi, B. (2015). "Distributed QoE-aware channel assignment algorithms for IEEE 802.11 WLANs." Wireless Networks 21(1): 21-34.

Ginige, A. and S. Murugesan (2001). "Web engineering: An introduction." IEEE MultiMedia, 8(1): 14-18.

Goldsmith, A., et al. (2004). "Cross-Layer Design of Ad-Hoc Wireless Networks for Real-Time Media." online],[retrieved on Sep. 5, 2009], http://www. stanford. edu/˜ zhuxq/adhoc—project/adhoc—project. html.

Gopal, S. and D. Raychaudhuri (2005). Experimental evaluation of the TCP simultaneous-send problem in 802.11 wireless local area networks. ACM Proceedings of the 2005 ACM SIGCOMM workshop on Experimental approaches to wireless network design and analysis. Philadelphia, Pennsylvania, USA,: 23-29

Grilli, G. (2010). "Data dissemination in vehicular networks." PhilosophiDoctor (PhD) dissertation in Computer Science and Automation Engineering: 181-190.

Group, I. W. (2010). "IEEE Standard for Information Technology–Telecommunications and information exchange between systems–Local and metropolitan area networks–Specific requirements–Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications Amendment 6: Wireless Access in Vehicular Environments." IEEE Std 802: 11p.

Gupta, P. and P. R. Kumar (2000). "The capacity of wireless networks." IEEE Transactions on Information Theory, 46(2): 388-40

Habib, S., et al. (2013). "Inter-Vehicle Wireless Communications Technologies, Issues and Challenges." Information Technology Journal 12(4): 558-568.

Hadzi-Velkov, Z. and B. Spasenovski (2003). Capture effect with diversity in IEEE 802.11 b DCF. IEEE Computers and Communication, 2003.(ISCC 2003). Proceedings. Eighth IEEE International Symposium .

Hiertz, G. R., et al. (2010). "The IEEE 802.11 universe."IEEE Communications Magazine, 48(1): 62-70.

Hills, A. (2001). "Large-scale wireless LAN design." IEEE Communications Magazine, 39(11): 98-107.

Ho, I. W.-H., et al. (2012). "A methodology for studying vanet performance with practical vehicle distribution in urban environment." arXiv preprint arXiv:1211.6251.

Hubaux, J.-P., et al. (2004). "The security and privacy of smart vehicles." IEEE Security & Privacy Magazine 2(LCA-ARTICLE-2004-007): 49--55.

Hussain, T. and S. Habib (2011). "Assessing and Redesigning Enterprise Networks through NS-2 to Support VoIP." Procedia Computer Science 5(0): 742-748.

Jin, A. P., et al. (2003). Experiments on radio interference between wireless LAN and other radio devices on a 2.4 GHz ISM band. IEEE Vehicular Technology Conference, 2003. VTC 2003-Spring. The 57th IEEE Semiannual: 1798 -1801.

Jindal, N., et al. (2011). "Multi-antenna communication in ad hoc networks: Achieving MIMO gains with SIMO transmission." IEEE Communications, IEEE Transactions on 59(2): 529-540.

Kaemarungsi, K. and P. Krishnamurthy (2004). Properties of indoor received signal strength for WLAN location fingerprinting. Mobile and Ubiquitous Systems: Networking and Services. IEEE MOBIQUITOUS 2004. The First Annual International Conference on:14 - 23.

Karim, R. (2008). "VANET: Superior system for content distribution in vehicular network applications." Rutgers University, Department of Computer Science, Tech. Rep: 364-370.

Laasonen, K. (2003). "Radio propagation modeling." University of Helsinki, Tech. Re: 1 - 4.

Lagraa, N., et al. (2010). "Localization technique in VANets using Clustering (LVC)." IJCSI: 10-16.

Lindsay, R. (2005). "Doing quantitative research in education with SPSS." British Journal of Educational Technology 36(2): 353-354.

Liu, B., et al. (2010). Assessing the VANET's local information storage capability under different traffic mobility. IEEE INFOCOM, 2010 Proceedings IEEE: 116 - 120.

Liu, H., et al. (2007). "Survey of wireless indoor positioning techniques and systems." IEEE Transactions on 37(6). Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE: 1067-1080.

Macker, J. (1999). "Mobile ad hoc networking (MANET): Routing protocol performance issues and evaluation considerations."

Mangharam, R., et al. (2005). GrooveSim: a topography-accurate simulator for geographic routing in vehicular networks. Proceedings of the 2nd ACM international workshop on Vehicular ad hoc networks. Cologne, Germany, ACM: 59-68.

Martelli, F., et al. (2012). Measuring VoIP Performance in IEEE 802.11 p Vehicular Networks. IEEE Vehicular Technology Conference (VTC Spring), 2012 IEEE 75th: 1 5.

McKown, J. W. and R. L. Hamilton (1991). "Ray tracing as a design tool for radio networks." Network, IEEE 5(6): 27-30.

Menouar, H., et al. (2006). "A survey and qualitative analysis of MAC protocols for vehicular ad hoc networks." IEEE Wireless Communications, IEEE 13(5): 30-35.

Mishra, A., et al. (2003). "An empirical analysis of the IEEE 802.11 MAC layer handoff process." SIGCOMM Comput. Commun. Rev. 33(2): 93-102.

Nadir, Z. and M. I. Ahmad (2010). Pathloss Determination Using Okumura-Hata Model And Cubic Regression For Missing Data For Oman. International Multiconference of Engineers and Computer Scientistic, Hong Kong, China: 17 - 19.

Nagel, R. and S. Eichler (2008). Efficient and realistic mobility and channel modeling for VANET scenarios using OMNeT++ and INET-framework. Proceedings of the 1st international conference on Simulation tools and techniques for communications, networks and systems & workshops, ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering).

Naicken, S., et al. (2007). "The state of peer-to-peer simulators and simulations." ACM SIGCOMM Computer Communication Review 37(2): 95-98.

Naumov, V., et al. (2006). An evaluation of inter-vehicle ad hoc networks based on realistic vehicular traces. ACM, Proceedings of the 7th ACM international symposium on Mobile ad hoc networking and computing: 108 -119

Nzouonta, J., et al. (2009). "VANET routing on city roads using real-time vehicular traffic information." Vehicular Technology, IEEE Transactions on 58(7): 3609-3626.

Otto, J. S., et al. (2009). Down the block and around the corner the impact of radio propagation on inter-vehicle wireless communication. The 29th IEEE Distributed Computing Systems, 2009. ICDCS'09. International Conference on, IEEE: 605 - 614.

Panko, R. R. (2002). Business data communications and networking, Prentice Hall PTR.

Pawlikowski, K., et al. (2002). "On credibility of simulation studies of telecommunication networks." IEEE Communications Magazine, IEEE 40(1): 132-139.

Pelletta, E. and H. Velayos (2005). Performance measurements of the saturation throughput in IEEE 802.11 access points. Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks, 2005. WIOPT 2005. IEEE Third International Symposium on: 129- 138.

Perahia, E. (2008). "IEEE 802.11n Development: History, Process, and Technology." IEEE Communications Magazine, 46(7): 48-55.

Prasad, N. and A. Prasad (2002). WLAN systems and wireless IP for next generation communications, Artech House, Inc.

Qian, Y. and N. Moayeri (2008). Design of secure and application-oriented VANETs. IEEE Vehicular Technology Conference, 2008. VTC Spring : 2794 -2799.

Ramteke, M. A. and M. R. Krishna (2012). Realistic Simulation for Vehicular Ad-hoc Network Using ZigBee Technology. International Journal of Engineering Research and Technology, ESRSA Publications: 1- 5.

Raniwala, A. and C. Tzi-cker (2005). Architecture and algorithms for an IEEE 802.11-based multi-channel wireless mesh network. IEEE INFOCOM 2005. 24th Annual Joint Conference of the IEEE Computer and Communications Societies: 1 -12.

Rawat, D. B., et al. (2012). "wireless network Security: an overview." Building Next-Generation Converged Networks: Theory and Practice: 199 - 120.

Raya, M. and J.-P. Hubaux (2007). "Securing vehicular ad hoc networks." Journal of Computer Security 15(1): 39-68.

Roslee, M. B. and K. F. Kwan (2010). "Optimization of Hata propagation prediction model in suburban area in Malaysia." Progress In Electromagnetics Research C 13: 91-106.

Sarkar, N. I. and E. Lo (2008). Indoor propagation measurements for performance evaluation of IEEE 802.11 g. IEEE Telecommunication Networks and Applications Conference, 2008. ATNAC 2008. Australasian: 163- 168.

Satyanarayanan, M. (2001). "Pervasive computing: Vision and challenges." IEEE Personal Communications, 8(4): 10-17.

Setton, E., et al. (2005). "Cross-layer design of ad hoc networks for real-time video streaming." IEEE Wireless Communications, 12(4): 59-65.

Singh, P. K. and K. Lego (2011). "Comparative study of radio propagation and mobility models in vehicular adhoc network." International Journal of Computer Applications (0975-8887) 16(8).

Skordoulis, D., et al. (2008). "IEEE 802.11n MAC frame aggregation mechanisms for next-generation high-throughput WLANs." IEEE Wireless Communications, 15(1): 40-47.

Sommer, C., et al. (2011). A computationally inexpensive empirical model of IEEE 802.11 p radio shadowing in urban environments. IEEE Wireless On-Demand Network Systems and Services (WONS), 2011 Eighth International Conference on IEEE: 84 - 90.

Sommer, C., et al. (2012). On the applicability of two-ray path loss models for vehicular network simulation. IEEE Vehicular Networking Conference (VNC), 2012 IEEE, 344 - 347.

Syarif, A. and R. F. Sari (2011). "Performance analysis of AODV-UI routing protocol with energy consumption improvement under mobility models in hybrid ad hoc network." International Journal on Computer Science and Engineering 3(7): 2904-2918.

Takahashi, S., et al. (2003). Distance dependence of path loss for millimeter wave inter-vehicle communications. IEEE Vehicular Technology Conference, 2003. VTC 2003-Fall. 2003 IEEE 58th: 26 - 30.

Tufail, A., et al. (2008). An empirical study to analyze the feasibility of WIFI for VANETs. IEEE Computer Supported Cooperative Work in Design, 2008. CSCWD 2008. 12th International Conference

Valek, M., et al. (2002). "Indoor Propagation Measurement for Wireless Systems Operating in 2.45 GHz ISM Band." Radioengineering 11(4): 48-52.

Van Eenennaam, E. (2008). "A survey of propagation models used in vehicular ad hoc network (vanet) research." Paper written for course Mobile Radio Communication, University of Twente: 1 - 7.

Wang, Y., et al. (2008). IEEE 802.11 p performance evaluation and protocol enhancement. IEEE Vehicular Electronics and Safety, 2008. ICVES 2008. IEEE International Conference: 317- 322.

Weingartner, E., et al. (2009). A Performance Comparison of Recent Network Simulators. IEEE Communications, 2009. ICC '09. IEEE International Conference : 1 -5.

Winters, J. H. (1998). "Smart antennas for wireless systems." IEEE Personal Communications, 5(1): 23-27.

Woesner, H., et al. (1998). "Power-saving mechanisms in emerging standards for wireless LANs: the MAC level perspective." Personal Communications, IEEE 5(3): 40-48.

Xu, B., et al. (2004). Opportunistic resource exchange in inter-vehicle ad-hoc networks. IEEE Mobile Data Management, 2004. Proceedings. 2004 IEEE International Conference: 4 -12.

Yamamoto, M., et al. (2008). Development of vehicle-infrastructure cooperative systems—Field operational test of hiroshima DSSS. ITS World Congress.

Yi, W., et al. (2008). IEEE 802.11p performance evaluation and protocol enhancement. IEEE Vehicular Electronics and Safety, 2008. ICVES 2008: 317 - 322.

Yihong, Z. and S. M. Nettles (2005). Balancing the hidden and exposed node problems with power control in CSMA/CA-based wireless networks. IEEE Wireless Communications and Networking Conference: 683 - 688.

Yousefi, S., et al. (2006). Vehicular ad hoc networks (VANETs): challenges and perspectives. IEEE ITS Telecommunications Proceedings, 2006 6th International Conference : 761 -765.

Youssef, M. and A. Agrawala (2005). The Horus WLAN location determination system. ACM Proceedings of the 3rd international conference on Mobile systems, applications, and services: 205 - 218.

Zahn, T., et al. (2009). Feasibility of content dissemination between devices in moving vehicles. ACM Proceedings of the 5th international conference on Emerging networking experiments and technologies. Rome, Italy: 97-108.

Zdruba, G., et al. (2004). Monte Carlo sampling based in-home location tracking with minimal RF infrastructure requirements. IEEE Global Telecommunications Conference: 3624 -3629.

Zhu, J., et al. (2006). Adaptive CSMA for Scalable Network Capacity in High-Density WLAN: A Hardware Prototyping Approach. INFOCOM: 1 - 10.