Master's Thesis

The Effect of Radio Channel Modelling on the Network Performance in VANET

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By

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Abstract

Research in vehicle-to-vehicle communication and the Vehicular Ad Hoc Network (VANET) are two major fields of growing interest. The advent and recent development of these concepts foster evolution of the new paradigm of the transportation system, widely known as Intelligent Transport System (ITS). Among the numerous challenges in adopting VANET for ITS, modeling the radio channel is a vital one, because of the mobility of transmitters and receivers, low elevation of antennae, channel fading and statistically non-stationary of channels. A channel model has been proposed that agree with the above mentioned unique characteristics exist in VANET i.e. Lund model. In this work, we have focused on data delivery performance at the network layer of VANET under Lund propagation model and compared the performance with that of some of the existing models i.e. Three log distance model, Friis model and Nakagami model which are commonly used for analyzing conventional wireless communications. Average delay per packet and average packet loss ratio are the two parameters used for comparing the performance. Simulation results indicate that Lund Model yields mixed kind of results with all other propagation loss models in both highway and rural scenario in terms of average delay per packet and average packet loss ratio as a result of its more realistic nature.

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Md. Ashraful Islam and Nasimul Hyder Maruf Bhuyan.

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List of Acronyms

BER	Bit Error Rate
CCH	Control Channel
DI	Diffuse scatterer
DSRC	Dedicated Short Range for Communications
GSCM	Geometry Based Stochastic Channel Model
HVC	Hybrid vehicular communications
ITS	Intelligent Transportation Systems
IVC	Inter-Vehicle Communications
LOS	Line of Sight
MAC	Media Access Control
MD	Mobile scatterer
MIMO	Multiple Input – Multiple Output
OBU	Onboard Unit
PER	Packet Error Rate
RSU	Roadside Unit
V2I	Vehicle-to-Infrastructure Communications
V2V	Vehicle-to-Vehicle Communications
VANET	Vehicular Ad hoc Networks
WAVE	Wireless Access in Vehicular Environments
WSSUS	Wide Sense Stationary Uncorrelated Scatterer

CHAPTER 1

1 Introduction

The vehicle-to-vehicle communications or VANETs is currently an interesting and very popular research area for a variety of applications including those which have the potential to significantly improve road safety, convenience as well as comfort to both drivers and passengers, traffic efficiency and plays a crucial role in intelligent transportation system. The field of inter-vehicular communications (IVC), including vehicle-to-vehicle communications (V2V), vehicle-to-roadside communications (V2R) and hybrid vehicular communications (HVC) also known as VANET. IVC systems were developed by using on-board units (OBUs) which can communicate without any infrastructure. Within the transmission range or multi hop the packet distributed can be a single hop. Without the infrastructure of RVC can't cover a wide area, and this communication take place between the vehicles and roadside infrastructure. The extending range of RVC systems is also called the HVC systems using other vehicles as routers.

The development of Intelligent Transportation Systems (ITS) aims for improving of the road safety, security and efficiency of the transportation systems and in the vehicular communication. And remove the dependence on cellular networks by offering direct communication between cars or to and from the roadside with minimal latency.

VANET is a field of growing interest and importance. Especially since the US Federal Communications Commission (FCC) allocated 75 MHz between 5.850 - 5.925 GHz for Intelligent Transport Systems (ITS) in 1999, the start of the ISO Communication Access for Land Mobiles (CALM) standardization in 2001 and the work on IEEE 802.11p which has been finalized in 2010 [1]. The V2V communication which is working for the IEEE 802.11p/1609 WAVE (Wireless Access in Vehicular Environment) is specifically designed for ITS communication systems but still it has some social, technical and economic issues. Therefore, it has been the topic of continuous and vigorous research and discussion among academia and industry [3].

The SmartVANET architecture with the dedicated short-range communications (DSRC) plan which divides road into segments and assigns a service channel to each segment. This SmartVANET architecture proposed safety, traffic management and commercial application. It also combines a segment based clustering technique with a hybrid Medium Access Control (MAC) mechanism [5].

1.1 Overview of the VANET's project

Though the characteristics of metropolitan area network (MANET) are very similar to the one of VANET, the channel models and other protocols developed for MANET cannot be applied directly to the VANET. In addition, the channel parameters of a VANET is different from that of cellular mobile networks in many ways. For example, the antenna height (both of transmitter and receiver) in a VANET is much lower than that of a cellular network, the radio signal propagation environment is different, nodes are highly mobile and the impact of road side scatterers. Several projects on VANET have been carried out around the world, primarily focusing on vehicle safety channel modelling for the VANET. One of the earliest studies on IVC was started by *JSK* (Association of Electronic Technology for Automobile Traffic and Driving of Japan) in the early 1980s [4]. Later, California *PATH* and Chauffeur of EU demonstrated *DRIVE* to improve the traffic efficiency. Recently, the problems of vehicular safety and comfortable driving have been investigated in the *CarTALK2000* project [4]. Since 2002, much research have been conducted in both industry and academia for the development of VANET. The *Car2Car Communication Consortium* is a non-profit organization initiated by the European vehicle manufacturers in 2004 that wants to increase road security and efficiency using VANET technologies and guaranteeing inter-vehicle operability in all Europe [4].

1.2 Overview of the routing protocol for VANET

There are many routing protocols used for ad hoc networks [6, 7]. The main task of the routing protocol is moving the information from a source to a destination within minimal communication time with the minimum consumption of network resources. There are some routing protocols have been revealed for mobile ad hoc networks, and some of the routing protocols can be applied directly to VANET. In VANET, there are some difficulty to design a reliable routing protocol, because of the fast vehicles movements and the road scatterers, dynamic information exchange and relative high speed of mobile node movements. So finding and maintaining routes for vehicular communication is a very challenging task. In addition, a realistic mobility model is very important for both design and evaluation of routing protocols in VANETs.

According to the traffic density and mobility of the nodes there are some routing protocols are proposed for survey the routing protocols for VANETs. In [50] introduced some routing protocols for VANETs urban scenario, such as Anchor based street and traffic aware routing (ASTAR), Connectivity Aware Routing (CAR), Road based using vehicular traffic information (RBVT), Beacon less routing algorithm for vehicular environments (BRAVE), The Cross Layer Weighted Position based Routing (CLWPR), Mobility aware Ant Colony optimization Routing (MARDYMO) and Geographic Stateless VANET Routing protocol (GeoSVR). The dynamic source routing (DSR), ad hoc on demand distance vector (AODV) and destination sequenced distance vector (DSDV) are applied in vehicle to infrastructure (V2I) communication, but this protocol may reduce the network performance in vehicle to vehicle (V2V) communication [9]. For this reason a new protocol priority based dynamic adaptive routing (PDAR) used for priority scheduling adaptive routing mechanism which has lower delay and lower packet loss ratio to improve the network performance, but the author did not integrate the factor of node mobility into the transmission condition [9]. In this thesis, we survey the most recent research progress in mobility channel model and the routing protocols in VANETs. The next chapter we will describe some routing protocols of VANETs.

1.3 Goal of this thesis

The goal of this thesis is to investigate the impact of channel modeling on the network performance in VANET. To do this, different propagation pathloss models (Three Log Distance. Friis and Nakagami) were compared with Lund Propagation pathloss model in Highway and Rural scenarios. The Average Delay per Packet and Average Packet Loss Ratio were the measurement criteria. Simulation methodology is used in the investigation by NS-3. In this thesis the following research question is considered:

- What will be the effect of the Lund propagation pathloss model comparing with other propagation pathloss models on network performance in NS-3?

In particular, what effect average packet loss ratio and average delay per packet have on Lund model along with other propagation pathloss model in different scenarios (Highway and Rural for different road lengths?

1.4 Organization of the report

The rest of the report is structured as follows; In Chapter 2 overview of related background work along with the literature study is presented about the topics related to the thesis which includes ITS and routing protocols. In Chapter 3, simulation scenario is explained along the introduction of NS-3 simulator and discussed in detail with the system model of our simulation. The Chapter 4 deals with all the results of our simulations and their detailed analysis to find out the answers to our research questions. In Chapter 5 the conclusions and future work have been drawn on the basis of simulation results and the future work has been proposed.

CHAPTER 2

2 Literature Review

In the last decade, a lot of work has done in the field of vehicular ad hoc networks (VANETs), a subclass of mobile ad hoc networks (MANETs) and it has given birth to a new concept called intelligent transportation system (ITS). IEEE 802.11p supports the Intelligent Transportation Systems (ITS) applications such as traffic and accident control, cooperative safety, emergency warning and intersection collision avoidance. In the Intelligent Transportation System (ITS) environment, the IEEE 802.11p enhancements to the previous standards enable robust and reliable vehicle-to-vehicle and vehicle-to-infrastructure communications by addressing the challenges such as rapidly changing multipath conditions, doppler shifts and the need to quickly establish a link and exchange data in very short time (less than 100 ms). Further the enhancements are defined to support other higher layer protocols that are designed for the vehicle environment, such as the set of IEEE 1609 standards for Wireless Access in Vehicular Environment (WAVE). ITS is the combination of all the information of the road environment and vehicles. The important part of the wireless network simulation is to check the suitability of a proposed propagation pathloss model to set as an established channel model [11]. Now a days there are lot of research going on designing an efficient propagation loss model for VANET. In [12] VANET mobility and propagation are two main concern for a propagation pathloss model but there are very limited tools available in the world to simulate a new propagation pathloss model.

2.1 What is VANET?

The vehicle-to-vehicle communications or VANETs are currently a very popular research area and an interesting implementation platform for a variety of applications including those which have the potential to significantly improve road safety. The field of inter-vehicular communications (IVC), including vehicle-to-vehicle communications (V2V), vehicle-to-roadside communications (V2R) and hybrid vehicular communications (HVC) also known as VANET. IVC systems were developed by using on-board units (OBUs) which can communicate without any infrastructure. Within the transmission range or multi hop the packets are distributed can be a single hop. Without the infrastructure of RVC can’t cover a wide area and this communication take place between the vehicles and roadside infrastructure. The extending range of RVC systems is also called the HVC systems using other vehicles as routers. Intelligent Transportation System (ITS) has been developed to improve the safety, security and efficiency of the transportation system and vehicular communication remove the dependence on cellular networks by offering direct communication between cars or to and from the roadside with minimal latency [4].

Vehicle-to-vehicle communications or VANETs is a field of growing interest and importance. Especially since the US Federal Communications Commission (FCC) allocated 75 MHz between 5.850 - 5.925 GHz for Intelligent Transport Systems (ITS) in 1999, the start of the ISO Communication Access for Land Mobiles (CALM) standardization in 2001 and the work on IEEE 802.11p which has been finalized in 2010 [1].

The SmartVANET architecture with the DSRC channel plan which divides road into segments and assigns a service channel to each segment. This SmartVANET architecture proposed safety, traffic management and commercial application. It also combines a segment based clustering technique with a hybrid Medium Access Control (MAC) mechanism [5].

The main goal is provided by VANET systems is the security (reducing accidents and alleviating accident damages), ecology (reducing traffic congestion and pollution), comfort (driver assistance, entertainment, etc.) and efficiency (traffic monitoring) of daily road travel. In the wireless communications VANET is the unique area of the car industry, which has a large number of possible applications and resources [4].

2.2 VANET Application

In VANETs we can divide a large number of applications into three different groups.

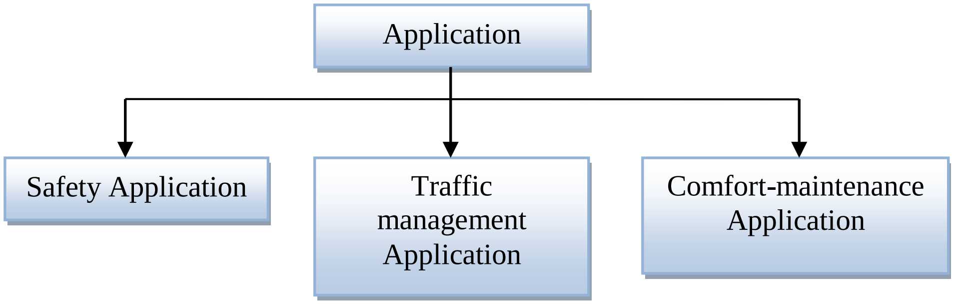

Figure 1: Application of the VANET.

2.2.1 Safety application

Each year there are less than 300 people dying in Sweden, around 43000 (one in every 12 minutes) in the USA with 6.2 million of police reported traffic accidents (one in every 5 seconds) and the economic impact of the traffic related road accident is 230 billion of dollars [4].

The technological improvement of the security measures in a car decreases the number of accidents and mortality on the street. VANETs systems can revolutionize the current driving concept with a radical improvement in safety, as Figure 2 depicts,

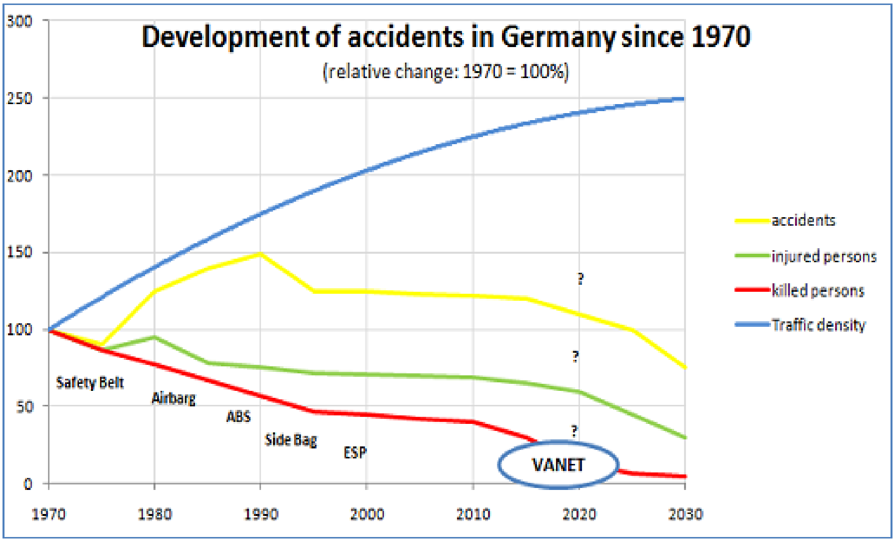

Figure 2: Drop of the accidents thanks to the technological improvement [4].

In a busy traffic when an initial collision occurs between the two vehicles and if the impossibility of breaking on that times for the driver then the chain of collision occur in the following vehicles. The operator of the vehicle was provided warning at least one-half second prior to a collision than 60% roadway collision could be avoided [27]. A system can propagate safety information for reaction of drivers quicker than a traditional chain of drivers reacting of their brake light between the cars [4]. The progressing of the security measures in a car decreases the number of road accidents. VANET keeps an important role in any uncertain situation on the highway. If any wheel of a vehicle puncture at night on the highway and the driver has to stop the vehicle without VANET technology, then he would not send any warning message to other vehicles to go out of the affected vehicles to fix it or asking for help (if the driver has no mobile or cannot find any emergency telephone booth on the highway). And it is a big risk for the other vehicles on the road. If the vehicle has a VANET system, other vehicles would detect the emergency message immediately, then the driver could repair the breakdown in safety conditions or send a message to the nearest garage to another driver asking for aid [4].

2.2.2 Traffic Management application

The vehicle-to-vehicle communication can share their information, quickly respond and the leading ability for the traffic management systems are more dynamic [28]. Everyday American people spend an average 2.5 hours with his/her own vehicles for traffic lights and mostly in traffic jam. In Madrid, people spend equivalent to seven resort days in traffic jams and they lost time almost double in Barcelona. According to the VANET we can improve the traffic system and reduce the accidents, traffic jams, travel time and $C0_2$ emissions [4]. For example, by using the RVC system the traffic light scheduling can be significantly improved which provides the information of the queue lengths at the traffic light or the number of expected vehicles to arrive in the future. The “Loading zone management” is one of the useful application that could be supported by the driver, road operator (allows the possibility to optimize the management of loading zones through better knowledge of the delivery time period and duration) and fleet manager (optimize the delivery time to its customer and reduce the cognition problem and driver stress), monitoring and management for the freight driver activities of the urban parking zone [4].

2.2.3 Comfort and Maintenance application

The comfort application used for making the travel more pleasant. The parking spot location, cooperative glare reduction, enhanced route guidance, GPS correction, instant message, mobile media services and mobile access to vehicle data [29].

Maintenance application is used to prevent an accident and avoid car problems. The safety recall notice, wireless diagnostics, time repair notification and software update [29].

2.3 Intelligent Transport Systems (ITS)

ITS is the one, which is used in an effort to enhance the efficiency, quality and reliability of different information and telecommunications and for reliable transport infrastructure. In [30] the ITS services also covers the area of better and optimized fuel consumption, because the energy requirements are increasing in today's world and the resources of energy are stretched to limits and new research efforts are in process to find the new and renewable energy sources, so in this environment of less and expensive energy resources ITS plays a vital role in better and optimum fuel consumption. The ITS system not only limited to the road transport, but also it depends on the other transportation domain including aviation, maritime and railway. In [31] the relay of the ITS is used in radio communication and wired technologies. In figure 3 we have shown the complete range of the ITS communication.

ETSI is one of the respected and important standardization organization which is recognized by the European Union as a European standards organization. The domain of ITS also falls under the ETSI and it is the responsibility of ITS to support with comprehensive standardization activities [30]. The Technical Committee Intelligent Transport System (TC ITS) is the special committee of ETSI which takes care of all standardization of ITS [30]. Since the road accident is the main global issue for the ETSI, it cooperates closely with other international standard organizations such as International Organization for Standardization (ISO), European Committee for Standardization (CEN), Electrical and Electronics Engineers (IEEE) etc. [30, 31].

Figure 3: Scenario for Intelligent Transport Systems (ITS) [31].

According to the road traffic environment, there are two main message models.

1) Cooperative Awareness Message (CAM).
2) Decentralized Event Notification Message (DENM).

2.3.1 Cooperative Awareness Message (CAM)

The Cooperative Awareness Message (CAM) standard is one of the reference architecture defined by the European Telecommunications Standards Institute (ETSI) for geographically transmitting data and relevant information for every vehicle within its range of communication. Within a single hop distance the CAM message generally consists of message identifier, station type, speed, acceleration, curvature geographical location of the vehicles and the basic status of neighboring vehicles to communicating vehicles. They cannot contain destination address. The interval of CAMs transmission varies from 0.1 second to 1.0 second depending on the application, but generally mostly applications uses 0.1 second which are equal to 10 Hz frequency [30]. All the vehicles within the system must be able to transmit and receive these messages. It is the basic form of ITS message and it constitutes the overwhelming majority of messages that are transmitted and received in the network [32]. In the figure depicts the highway CAM scenario where all of the vehicles are simultaneously transmit and receive the CAM from each other too.

Figure 4: Cooperative Awareness Message (CAM) [17].

2.3.2 Decentralized Event Notification Message (DENM)

Decentralized event notification message (DENM) are generated when hazardous events (e.g. accidents) has taken place on the road and it is not routinely transmitted as CAM’s but it is dependent on the happenings of certain events. DENM does not have any fixed schedule of transmission and don’t have any destination address. The broadcasting message of DENM continues till event that triggered the generation of DENM is present, generally the DENM are generated with high frequency of 20 Hz and it has a very stringent time delay limits from source to destination [30]. In the following figure the red car has met an accident and transmitting the DENMs to other vehicles within the vicinity.

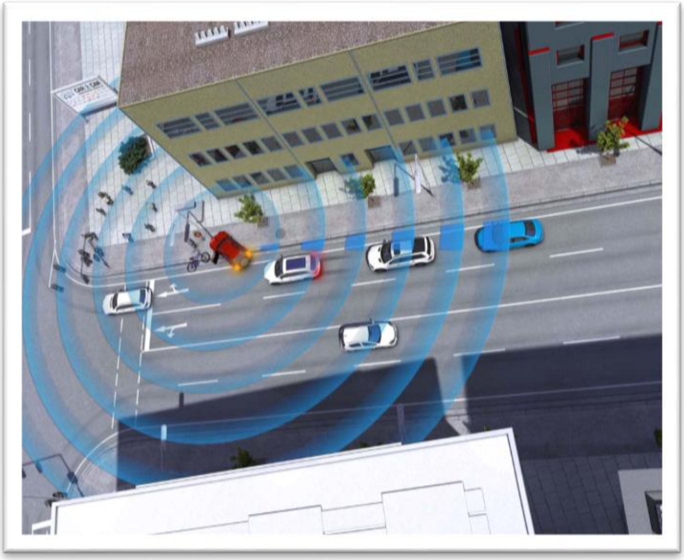

Figure 5: Decentralized Event Notification Message (DENM) [17].

2.4 VANET Projects

2.4.1 Projects in Europe

In [13] infrastructure deployment, frequency allocation and protocol definition are three top-priority challenges in Europe. *CARTALK* (started in August 2001) was funded IST Cluster support system based on vehicle-to-vehicle communication (V2V) technologies [4]. During 2001 to 2004 *CARTALK2000* was developed as a self-organizing ad hoc radio network and a cooperative driving assistance system based on the future standards [4]. In Germany from September 2000 to December 2003 another project *Fleetnet* was developed a wireless ad hoc network for inter-vehicle communications and the solutions of the *Fleetnet* was based on the UMTS-UTRA at the data link layer [14]. WILLWARN and INTERSAFE was the two subproject of VANET [15]. Another project integrated within the EU was *PreVENT* which was run until 2007 [4]. Network On Wheels (NOW) was follow-up project of *Fleetnet* (2004-2008) [4] and for the safety applications initial 30 MHz in the frequency band has been used for the European standard ETSI ITS-G5 [16]. The *Car2Car Communication Consortium* is one of the European non-profitable organization initiated by the European vehicle manufacturers in 2004 that wants to increase road security and efficiency using VANET technologies and guaranteeing inter-vehicle operability in all Europe [17]. There are some projects *are CVIS-*

Cooperative Vehicle to Infrastructure Systems [4], *COMeSafety*[18], *Safespot* [19], *SeveCom (Secure Vehicular Communications)* [20], *Coopers (CO-OPerative SystEms for Intelligent Road Safety)* [21], *Geonet* [22], *iTETRIS* [23], *Pre-Drive C2X* [24] and *Have-It* project integrates several advanced vehicle applications for comfort, safety and fuel efficiency [25].

2.4.2 Projects in USA

In USA the initial research and application development started in 2002 and finished in 2004 for Vehicle Safety Communication (VSC) organization worked for development the DSRC standard protocols and applications for vehicle-to-roadside communication and inter-vehicle communication. The VSC determined 5.9 GHz DSRC wireless technologies had been the requirement for the VANETs. VSC is some different project like Cooperative Intersection Collision Avoidance System-Violations (*CICAS-V*), Emergency Electrical Brake Light (*ERBL*), Vehicle Safety Communications-Applications (VSC-A) [4]. IntelliDrive is one of the major research project in the USA is the five years (2009-2013) research consisting in seven tracks to accelerate the development of the V2V communication system [4]. Different USA University doing significant research projects such as *PATH:* California Partners for Advanced Transit and Highways (administered by university of California, Berkeley), is currently working on more than 60 projects using the cutting edge technology in the area of Intelligent Transportation Systems [4].

2.4.3 Projects in Japan

The Advanced Safety Vehicles (*ASV*) and V2I based Advanced Highway Systems (*AHS*) are two main initiatives related vehicle cooperative systems. The ASV projects are now working in 4th phase. The *AHS* project is promoted by Advanced Cruise-Assist Highway Research Association (*ASHRA*) [4]. The *Smartway* project (*AVS* and *AHS*) consists of several communication systems between vehicles and the road, and the variety of sensors like infrared, cameras, radars, ultrasound, etc. [26]. The important thing is the transmission of an emergency message via the cross channel interference problem that cause a car is not receiving the emergency message. The channel management policies are one of the most efficient solutions, but it is not the IEEE standard. In IEEE 802.11p have improved the performance of the receiver requirements in adjacent channel rejections [4].

2.5 Routing protocol in VANET's

Routing is the process of moving the information across from a source to a destination. Routing protocol uses for the circuit-switching telephone network, electronic data networks (Internet) and the transportation network. In packet switching networks, the routing directs packet forwarding (packets from their source to the destination) by intermediate nodes. This intermediate nodes are typically network hardware devices such as routers, gateways, bridges, firewalls, or switches. General purpose in computers can also forward the packets and perform the routing, although they are not specialized hardware and may suffer from limited performance. The routing process normally directs forwarding on the basis of routing tables which maintain a record of the destination routes into the networks. Hence, constructing routing tables, which held in the router's memory, is very important for the efficient routing. Most routing algorithm uses only one network path at a time. Multipath routing techniques enable the uses of the multiple alternative paths.

In case of overlapping equal routes, the following elements are considered in order to choose which routes get installed into the routing table (sorted by priority):

1) *Prefix-Length:* Where longer subnet masks are preferred (independent if it is within a routing protocol or over different routing protocol).
2) *Administrative Distance*: where a lower distance is preferred (only valid between different routing protocols).
3) *Metric:* where a lower metric/cost is preferred (only valid within one and the same routing protocol).

Routing, in a more narrow sense of the term, is often contrasted with bridging in its assumption that network addresses are structured and that similar addresses imply proximity within the network. Structured addresses allow a single routing table entry to represent the route to a group of devices. In larger networks, structured addressing (routing, in the narrow sense) outperforms unstructured addressing (bridging). Routing has become the dominant form of addressing on the Internet. Bridging is still widely used within localized environments [34]. Major applications of VANET providing safety data, traffic management, toll services, location based services and documentary [45].

VANET routing is classified into unicast, multicast and broadcast communication. The characterized of VANET routing by dynamic topology, frequently disconnected network, mobility modeling (varies from highway of the city environment) and prediction, communication environment, delay constraints and location identification using sensor [46]. In VANET there are three types of routing protocols namely rural, highway and urban. The routing protocols on rural area have less network density and higher mobility. The communication in highway is relatively good communication in one direction only. In urban environment there are some challenges for routing protocols; these are node movement which is bidirectional, traffic density is high in city environment more specifically at junctions where the density is much higher and also follows any angle as described in a street map [46].

For the smart ITS system the routing protocols in VANET are an important and necessary issue because the main difference between VANETs and MANETs is the rapidly changeable topology and special mobility pattern [10]. It is not effectively applied the existing routing protocol of MANET into VANET [10]. Recently, VANET routing protocols are surveyed into three broad categories; they are unicast, multicast and broadcast routing protocol [10].

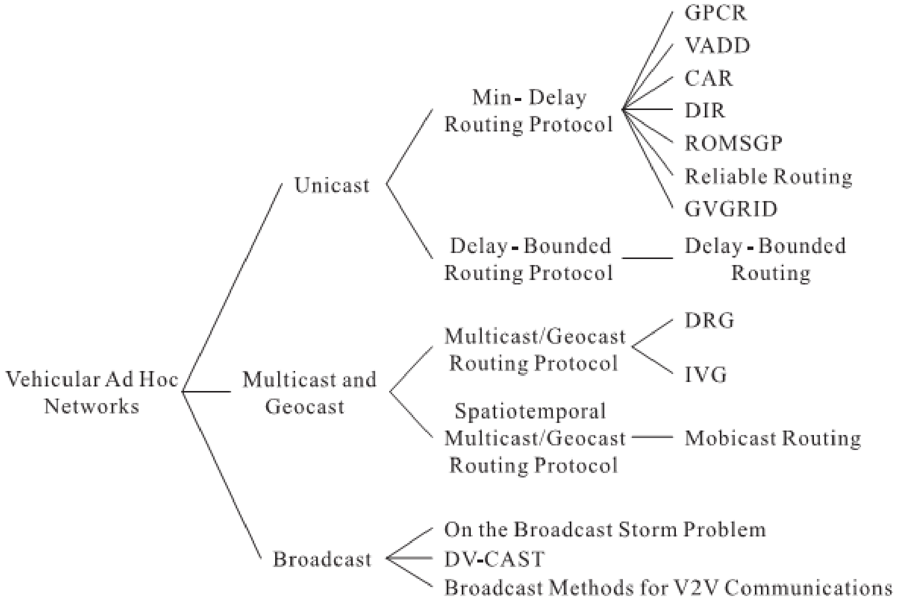

Figure 6: The taxonomy of the vehicular ad hoc networks [10].

Most of the recent papers suggest to use **DSR**, it is a reactive protocol for routing in MANET and it is also shown that these reactive protocols are not suitable for higher mobility scenario in VANET because the connectivity of the network is not known to any node [47]. Also, route repairs and failure notification overheads lead to low throughput and a high route rediscovery delay.

Zone based Hierarchical Routing Protocol (ZHLS) is a hierarchical proactive routing protocol designed for MANET environment that can be used in VANET in order to improve the performance over other routing protocols [48]. In this zone based routing protocol roads can be divided into different geographical segments called zones and the information about these road segments or zones can be distributed along with the road information [48]. The benefit of the ZHLS is to take GPS and road information database in order to improve its routing performance [48].

Anchor based street and traffic aware routing (ASTAR) proposed by B.C.Seet et al. follows street awareness for efficient routing and also follows traffic awareness for city environment consists of roads and junctions that can accommodate more vehicles [46]. As the density increases, connectivity also increases.

The Connectivity Aware Routing (CAR) protocol proposed by V.Naumov et al. has four segments namely: Destination location and path discovery, Data forwarding along the path, path maintenance with the help of guards and error recovery [49].

Road based using vehicular traffic information (RBVT) protocol proposed by J.Nzouonta et al. uses real time traffic information to create path either proactively or on demand and this protocol uses advanced flooding mechanism which will discard the packet whose address and sequence number matches that of a previously received packet [46].

Beacon less routing algorithm for vehicular environments (BRAVE) proposed by P.M.Ruiz et al. follows spatial awareness and opportunistic forwarding. A change from one street to another street is followed when the distance between the neighbour node of the current junction and the second junction is less than the actual distance between the two junctions [46].

Mobility aware Ant Colony optimization Routing (MARDYMO) protocol proposed by Correia et al. uses Ant colony optimization in the existing dynamic MANET On demand (DYMO) protocol which is a reactive protocol. In order to predict the mobility, position, speed, displacement and time stamp are added to the Hello message and are sent in a periodic manner using which the nodes will have updated information on their neighbors [46].

Geographic Stateless VANET Routing protocol (GeoSVR) proposed by Y.Xiang et al. routes data using node location and digital map. This protocol consists of two main algorithms namely, optimal forwarding path algorithm and restricted forwarding algorithm.

2.5.1 Optimized Link State Routing (OLSR)

In [35] Optimized Link State Routing is a proactive table driven link state routing protocol which is selecting multipoint relay (MPR) set, also known as the MPR set of its neighbors such that all its two hop neighbors are accessible through the MPR set. There are three fold as MPR set are: only broadcast messages are folded with MPR nodes, link state advertisements originate only from MPR nodes and MPR nodes can choose the link between itself and its MPR selector [35]. All of these optimizations serve to reduce the number of control packets in the network, thus substantially reducing the overhead compared to other link state protocols. OLSR uses HELLO and topology control (TC) messages to discover and broadcast link state information throughout the network [36]. HELLO messages are periodically sent by a node to its neighbors and contain information about its MPR selector set (nodes that have chosen it as an MPR node) and it is not flooded. The topology control messages are used to advertise the MPR selector set of a node to the entire network and are flooded using the multipoint relaying system [35]. The advantage of OLSR is the overhead does not increase with the number of routes required in a network and that a route is always available when needs [35]. The source code for the OLSR model it can be found in the directory “src/olsr” in NS-3 and the class hierarchy is shown in figure below,

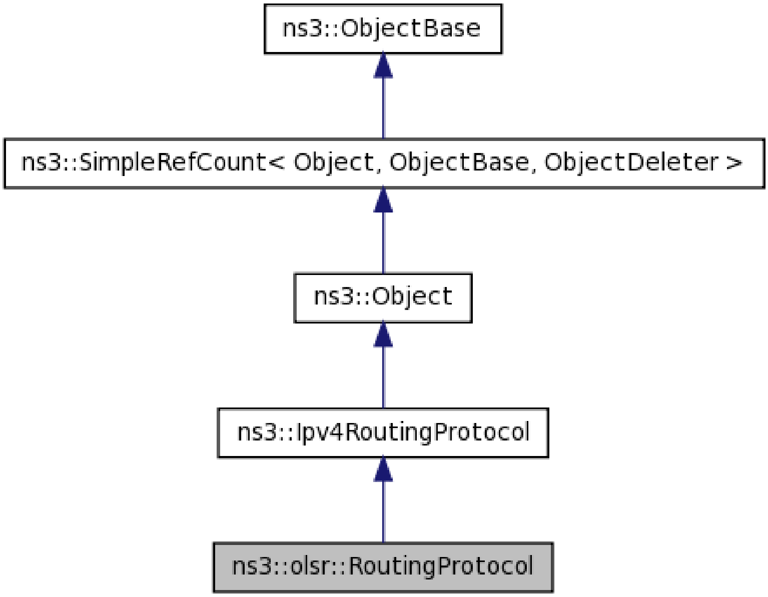

Figure 7: OLSR Hierarchy Diagram in NS3.

2.5.2 Ad hoc On-Demand Distance Vector (AODV)

Ad hoc On-Demand Distance Vector (AODV) routing protocol is the combination of both DSR and DSDV protocols because it has basic route discovery and route maintenance of DSR and uses the hop by hop routing, beacons and sequence numbers of DSDV [37]. When a route is required, then the route is discovered because if a route to a destination is not found in the routing table, the source generates a route request (RREQ) packet and broadcast it [37]. The RREQ packet contains the source IP address, broadcast id, current sequence number and most recent sequence number for the destination known to the source node [37]. The intermediate nodes update all information about the source node and sets a reverse route entry to the source [37]. If any intermediate node contains a route to the destination with a higher sequence number than the one in the RREQ packet, then it sends a route reply (RREP) to the source otherwise the packet is rebroadcast until it gets to the destination [37]. On receiving the packet, the destination sends a unicast RREP back to the source using the reverse route of the RREQ and each intermediate node sets a forward route entry to the destination. Each intermediate node also takes note of the RREQ's source IP address and the broadcast ID so that it does not rebroadcast a duplicate RREQ [37]. If there is a link breakage on an active route, the node upstream sends a route error packet (RERR) to the source to inform it that the route is invalid, thus the source can be initiated a route discovery [38]. The source code for the AODV model it can be found in the directory ”src/aodv” in NS-3 and the class hierarchy is showing into the figure below,

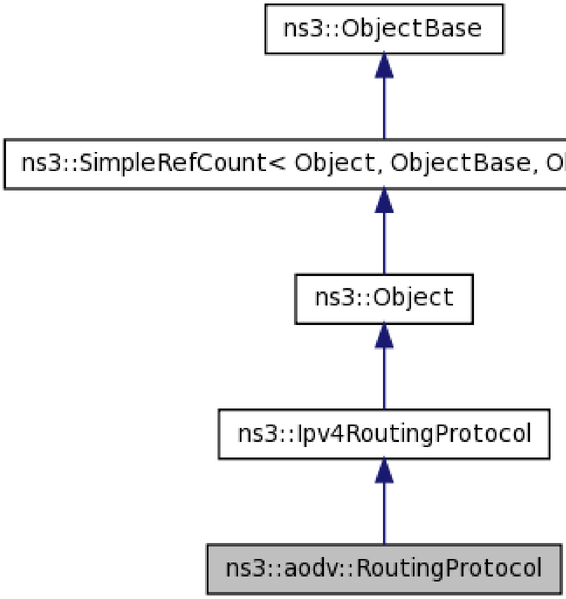

Figure 8: AODV Hierarchy Diagram in NS3.

2.5.3 Destination Sequenced Distance Vector (DSDV)

The Destination Sequenced Distance Vector (DSDV) protocol is a proactive routing table-driven protocol based on the Bellman Ford algorithm. The tables are periodically updated and the every node in the network has routing entries for all the nodes in the network [35]. The highest sequence number of routes is the freshest route and it is the one that is used [35]. If there are two entries with the same sequence number, the one with the better metric is used, DSDV uses hop count as its cost metric [36]. If a node wants to alert the other nodes of an invalid route it sends an update with an odd sequence number and they know to delete that route from their table. DSDV uses setting time to dampen route fluctuations [36]. Several protocols have been proposed addressing the challenges of a routing protocol for VANETs. The source code for the DSDV model it can be found in the directory “src/dsdv” in NS-3 and the class hierarchy is shown in figure below,

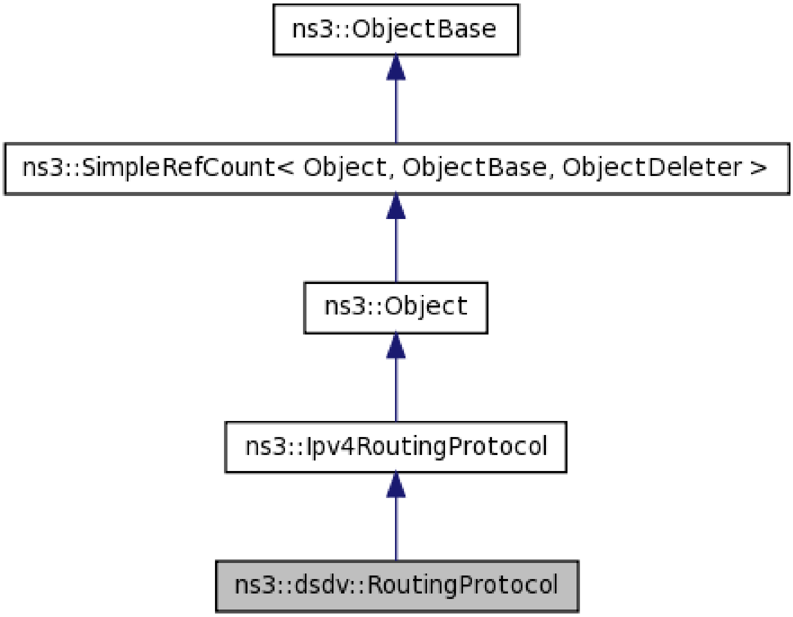

Figure 9: DSDV Hierarchy Diagram in NS3.

CHAPTER 3

3 System model and Simulation

In order to fulfill the goal of this thesis, we have to observe the effects of different radio channel models on the data delivery performance at the network layer of VANET. For this purpose, the previous work needs to be integrated into the upper layers of the network protocol stack in NS-3. In order to put the various alternatives to the test and to evaluate them under identical, realistic scenarios, computer simulations will be conducted in NS-3.16. One representative broadcast and unicast protocol were used on top of the existing (Three log distance Model, Friis Model and Nakagami Model) and newly integrated propagation loss models (Lund Model) in the scenario of Lund highway and rural to evaluate the effect of the various radio channels without routing protocols and with different routing protocols. This chapter showing a brief overview about the simulation we have used to model the system.

3.1 Problem Description

Relevant background papers about the routing protocols and propagation loss models for VANET needed to be studied to understand which kind of channel models are currently used and how the result from Kåredal et al [1] differs from the other models using different routing protocols. The first task was than to adjust the “Lund Model” implementation that was written for in NS-3.13, by Fabio Heer to the new structure of NS-3.16. The organization of the network simulator has been significantly changed in the later release, for example, new directories have been introduced to manage the growing number of models and names of some of the existing classes have been changed. The second task was to add flexibility to the “Lund Model”, so that it can interact well with the upper layers and to make the model as simple as possible according to the Lund highway and rural scenario.

The implementation of the “Lund Model” operates with the WiFi-stack and the mathematical model needs to be verified in NS-3 [1]. When one transmitter sends packets in a periodic interval to a receiver [1]. It supports an arbitrary number of receivers and in principle also any number of transmitters [1]. This can be easily realized with a simulation script based on *wifi-phy-test.cc* from the WiFi examples. For instance, as in *lund-model-broadcast.cc*. In the subsequent chapter, we have discussed more about the "Lund Model" and the other different propagation loss models implementations in NS-3.

In this work we have developed the upper layer of the new propagation loss model (Lund Model) and integrated with the physical layer. We have constructed the network layer for VANET in accordance with the newly propagation loss model and compared the performance with the other existing propagation pathloss models considering the parameters like average delay per packet and successful average packet loss ratio. The routing protocol accomplish with the minimal communication time with minimal consumption of network resources. We have conducted exhaustive simulations in NS-3 by incorporating various options and evaluated the performance in both highway and rural scenarios. In addition, we have used broadcast and unicast protocol on top of the existing propagation loss models (Friis model, Nakagami models, Three logs distance model) as well as the newly integrated propagation loss model (Lund propagation model). Some routing protocols used for MANET with MAC and PHY extension such as AODV, DSDV and OLSR are already available in NS-3.

3.2 Simulation Specification:

To implement our simulation, we have used the following specifications in our simulation.

Attribute Name	***Attribute Value***
WAVE operating frequency	5 GHz
WAVE Data Rate	6 Mbps
WAVE Bandwidth	10 MHz
Packet size	CAM (200 Bytes) DENM (100 Bytes)
Frequency of the packet	CAM (10 Hz) DENM (20 Hz)
Highway and Rural street length	500 m; 2 km
Routing Protocols	AODV; OLSR; DSDV

Table 1: Simulation Specification [12].

The basic scenario used in our simulation is based on the environment of "Lund Model". In to the figure below the diffuse scatterer points are shown in brown (cross), the static discrete are red (circle), the yellow car represent as a transmitter, red car represent as a receiver, blue car represent as a mdNodes and the symbols on the road denoted the starting positions of the cars. In the scenario the line extending from those positions show how far the vehicles drive during the simulation.

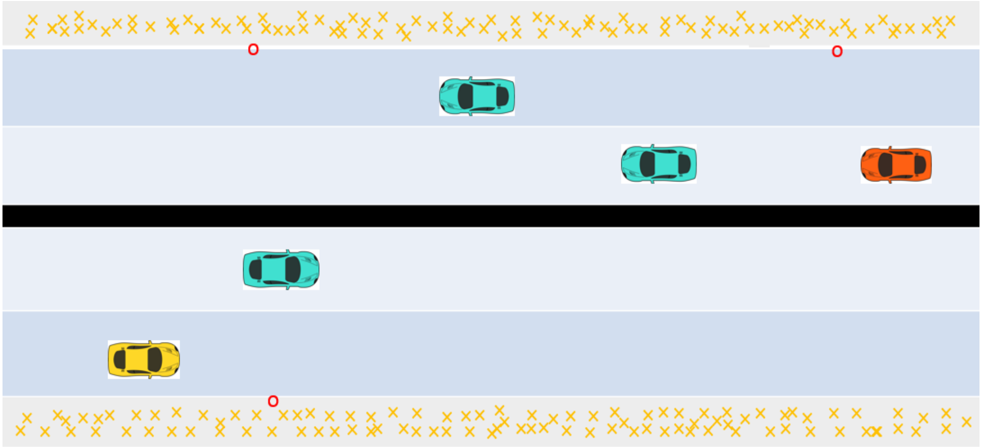

Figure 10: Road strip and scatterer distribution for Highway 500 m.

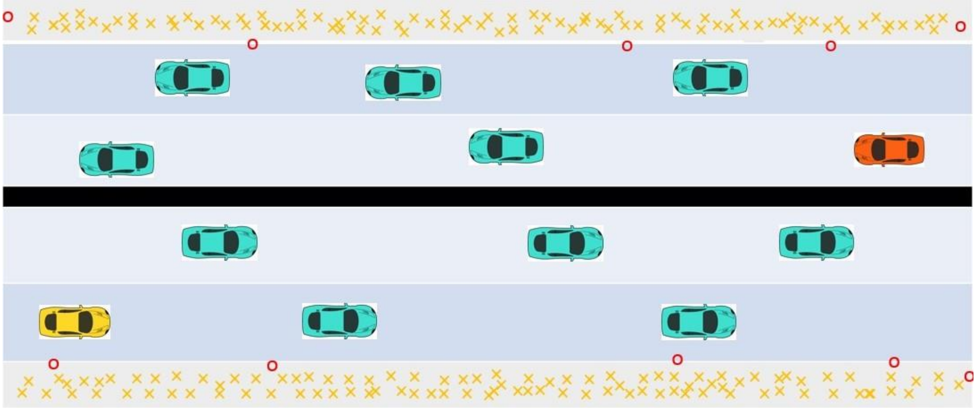

Figure 11: Road strip and scatterer distribution for Highway 2 km.

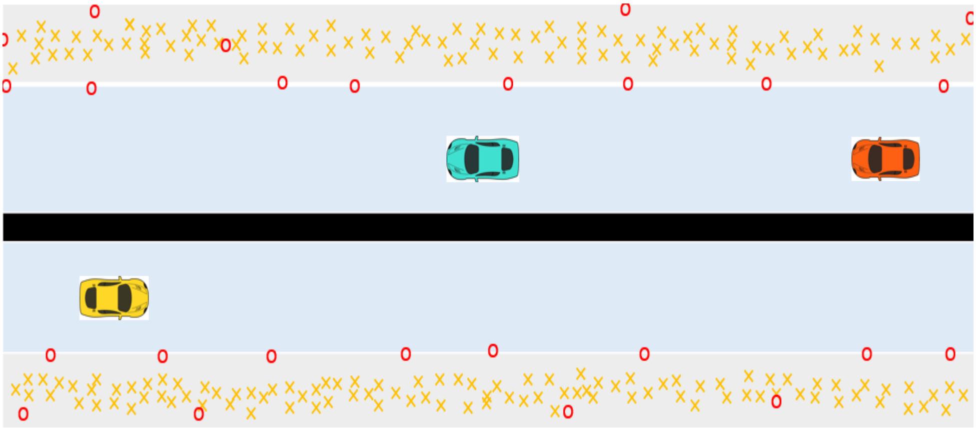

Figure 12: Road strip and scatterer distribution for Rural 500 m.

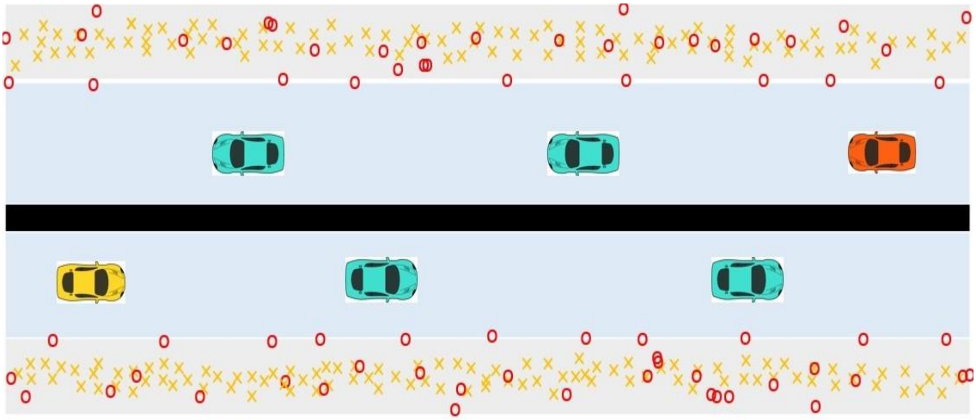

Figure 13: Road strip and scatterer distribution for Rural 2 km.

The “Lund Model” is based on the random number for the distribution (position) of scatters on a road strip, their pathloss exponent *n*, velocity *v*, variance σ_S^2 of the stochastic amplitude gain and their coherence distance $d_{c,rand}$. All of these values are generated in the class *LundModelGeometry*.

3.3 NS-3

NS-3 is a discrete-event network simulator, targeted primarily for research and educational use. NS-3 is free software, licensed under the GNU GPLv2 license, publicly available for development and research use. The goal of the NS-3 project is to open a simulation environment for networking research, it should be aligned with the simulation needs of modern networking research and should encourage community contribution, peer review, and validation of the software. NS-3 is supported by multiple operating systems, e.g. Microsoft Windows, Linux and Mac OS use Cygwin. The development of realistic simulation models with the help of NS-3 infrastructure allows it to be used as a real-time network emulator by allowing the reuse of many existing protocol implementations within NS-3 [30]. It provides the platform for both IP and non-IP based networks. However, much research work focuses on wireless/IP simulations involving WiFi, WiMAX or LTE model for layer 1, layer 2 and static or dynamic protocols, e.g. OSLR, DSDV and AODV for IP based network [30].

The scripting in NS-3 is mainly done in C++ and Python. Most of the API is available in Python, but the models are written in C++. We have used C++ as a programming language in our simulation. It includes rich environment, allowing users at several levels to customize the information that can be extracted from the simulations [30].

3.3.1 The “Lund Model”

Relevant background papers on vehicle-to-vehicle communications needed to be studied to understand, which kind of channel models are currently used and how the results from Kåredal et al. [2] differs from other models. At the same time, one had to get familiar with the C++ framework NS-3 through studying the NS-3 tutorial, the manual, the coding style guide and the API documentation. The final NS-3 implementation of Lund Model scenario is separated into three classes: *LundModel*, *LundModelGeometry* and *LundModelLsFading* [1]. The main one, *LundModel*, inherits the properties of a propagation loss model and thus integrates easily with the WiFi stack of NS-3. The class *LundModelGeometry* deals with the generation and distribution of static discrete and diffuse scatterers. It keeps track of the position and the individual parameters of each scatterer [1]. Finally, *LundModelLsFading* computes the stochastic amplitude gain for the large-scale fading for each pair of transmitter and receiver; in essence, it generates sequences of correlated Gaussian values for all paths. To make use of this class the GNU Scientific Library (GSL) needs to be installed on the system. Otherwise the model still works, but no large-scale fading is enabled (the stochastic amplitude gain G_S is 0 dB). *LundModelTypes* defines commonly used structs in the MD and SD scatters [1].

The user of the "Lund-Model" has complete control over the cars on the road strip (position and velocity). To simplify the positioning the implementation provides valid yet random positioning through *GetMobilityHelper*. It is the user's responsibility to keep the density of cars reasonable. Static discrete and diffuse scatterers can be created and passed on via *AddSDiscreteScattererers* and *AddDiffuseScattererers*, however, the "Lund-Model" automatically creates as many of these as required to fit the specified densities [1]. All that "Lund-Model" needs to know is passed on by the method Init, which requires a *NodeContainer* containing all TX nodes, another one for the RX nodes and a last one for cars that are just used as mobile discrete scatterers. This method also needs the communication duration and the interval in which packets are received to generate time correlated samples for the large-scale fading.

3.3.2 Propagation loss models in NS3

The important task in the wireless network simulation is the choice of the appropriate propagation loss model for the best performance of any wireless network channel or set of channels. In [11] variety of such models varying from abstract, fixed loss models, to a simple exponential decay proportional to the distance between a transmitter and receiver, accounting for the ground reflections to models accounting for fast fading. *Rappaport* [39] describing the mathematical formulae that can be used for the two points in a three dimensional space. The some of the NS-3 model equation are the basis of *Rappaport's equation* [11].

Aguayo [40] reports based on the result from a series of measurement studies based on the existing network in Cambridge (MA, USA) around MIT called *RoofNet*. In [11] the *RoofNet* consists of 38 IEEE 802.11b base stations mounted on or near rooftops at various points around their campus and the study uses an active probing technique to measure packet reception probability at each of the potential receivers for a continuous burst of packets from a single transmitter [11]. *Kotz* et. al [41] perform a set of active measurement experiments, but their approach was to deploy a temporary network with mobility to measure received signal strength and reception probability under controlled conditions. In [11] shows that the measured signal strength as a function of distance can in fact be used to create a stochastic pathloss model, and that the stochastic model can in fact produce simulated results that much reasonably well with the measured field experiments. Recently *Zheng* and *Nicol* described a detailed experiment using an *Anechoic Chamber*, which is a large room with the substantial radio signal shielding that essentially isolates the chamber from outside electromagnetic interference and using this chamber, they measure and report on the received signal strength for various distances and antenna characteristics [11].

In the NS-3.16 simulation tool has 11 different loss models include distribution and categorize those loss model into three groups are,

a) **Abstract propagation loss models.**
    1) Fixed Received Signal Strength.
    2) Matrix Loss Model.
    3) Maximal Range.
    4) Random Propagation Loss.

b) **Deterministic pathloss models.**
    1) COST-Hata Model.
    2) Friis Propagation Model.
    3) Log Distance Pathloss Model.
    4) Three log distance Model.
    5) Two Ray Ground Model.

c) **Stochastic fading models.**
    1) Jakes Model.
    2) Nakagami Model.

Each of the abstract models, as well as each of the pathloss models, are used in turn, configured with the NS-3 default parameters shown in the table1.

Propagation Model	**Default Parameters**
Fixed RSS	Receive Signal Strength: -150 dBm
Matrix	Loss: 1.8×10^{308} dB
Range	Maximum range: 250 m
Random	Loss: Constant (1 dB)
COST-Hata	Center Frequency: 2.3 GHz Base Station Antenna Height: 50 m Mobile Station Antenna Height: 3 m Minimum Distance: 0.5 m
Friis	Wave Length: 58.25 mm System loss: 1 Minimum Distance: 0.5 m
Log Distance	Exponent: 3 Reference Distance: 1 m

	Reference Loss: 46.67 dB
Three log distance	Distance: 1 m, 200 m, 500 m Exponents: 1.9, 3.8, 3.8 Reference Loss at 1 m: 46.67 dB
Two Ray Ground	Wave Length: 58.25 mm System Loss: 1 Minimum distance: 0.5 m Height above Z: 0 m
Jakes	Rays per Path: 1 Oscillators per Ray: 4 Doppler Frequency: 0 Hz Distribution: Constant (1)
Nakagami	Distances: 80 m, 200 m Exponents: 1.5, 0.75, 0.75

Table 2: Summary of NS-3 default parameters [11].

In our simulation we have used three propagation loss models (Friis, Nakagami, Three log distance) among the other propagation loss models in NS-3.16 with Lund *highway* and *rural* scenario.

Friis propagation loss model is valid for the free space far field region of the transmitter antenna. This model is used for the LOS pathloss incurred in the channel and it is based on the inverse square law of distance which states that the received power decays by a factor of square of the distance from the transmitter.

Nakagami channel model is similar to the Rayleigh model, but describes different fading equations for short-distance and long-distance transmission. The Rician and the Nakagami model behave approximately equivalently near their mean value.

Three log distance model is a variation of the log distance model. For different distance intervals it applies different factors to the logarithmic pathloss. It is used to predict the propagation loss for a wide range of environment.

3.4 Implementation of our scenario

We have used both *highway* and *rural* scenarios according to the Lund city environment in our simulation. The Lund model developed by Kåredal et al. based on the findings three types of scatterers mobile discrete (*MD*) scatterers represent other cars on the road, static discrete (*SD*) scatterers denote buildings, road signs and other prominent obstacles and finally, diffuse scatterers (*DI*) model the weak components that result mainly from the both sides of the $T_x - R_x$ path, and this diffuse scatterers are randomly distributed on a road strip in the $x - y$ plane [1]. We assumed that a straight road along the x-axis of width, W_{road}, all the scatterers x-coordinates are uniformly distributed over $[x_{min}, x_{max}]$. The y-coordinates of the *MD* scatterers follow a discrete uniform distribution, such that the possible y-values fall in the center of the of width, W_{lane}. The *SD* scatterers y-coordinates are Gaussian distributed, symmetrically around the road center. The *DI* scatterer points are placed in two uniform intervals with $\pm Y_{DI}$ and width, W_{DI} also symmetrically around the road center. The number of scatterers is dependent on the road length [1]. The scenarios of the other pathloss models were also based on the scenario of the Lund model's density of mdNodes.

Highway:

In our simulation the scenario of the *Highway* measurement were performed on 500 m and 2 km long four-lane and each lane was 4.25 m highway strip cutting through the city of Lund. The total street width was approximately 17 m. The travel direction separated by a low ($\approx 0.5\,m$) concrete wall, and the road side environment was characterized by fields or embankments, the letter constituting a noise barrier for residential areas, some road signs, few low-rise commercial buildings were located along the road side and street lamps.

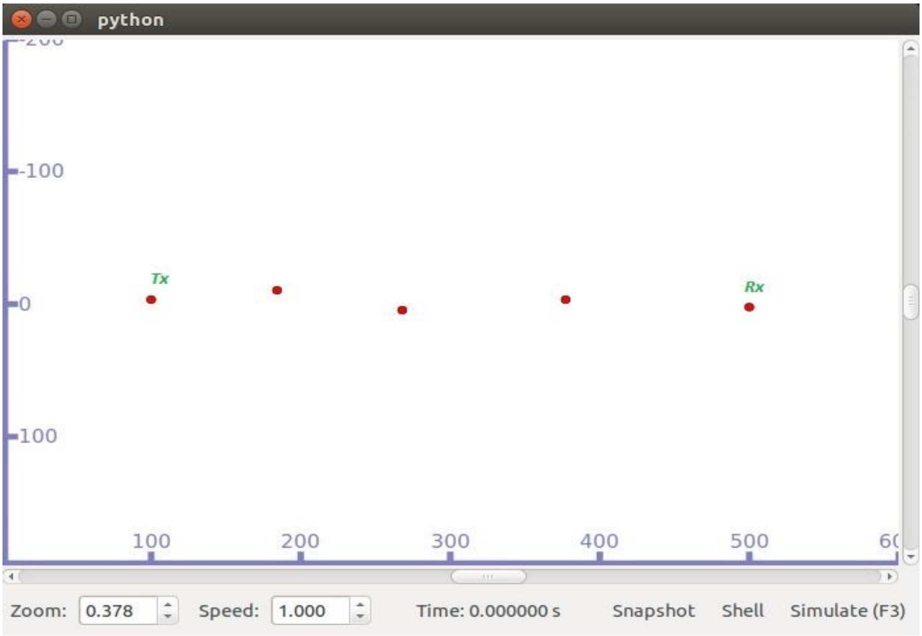

Figure 14: Position of the nodes in highway (500 m).

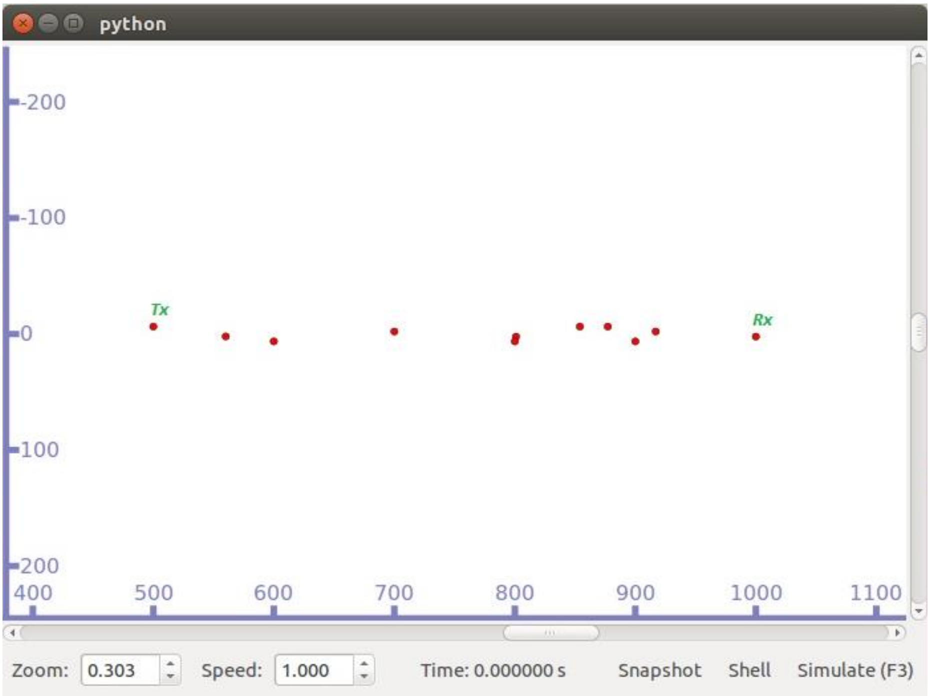

Figure 15: Position of the nodes in highway (2 km).

Rural:

Another scenario of our simulation of the *Rural* measurement were performed on 500 m and 2 km long two-lane strip cutting just outside Lund, where the road-side environment contains farm houses, road signs sparsely along the roadside and some residential house and almost there was no traffic during these measurements.

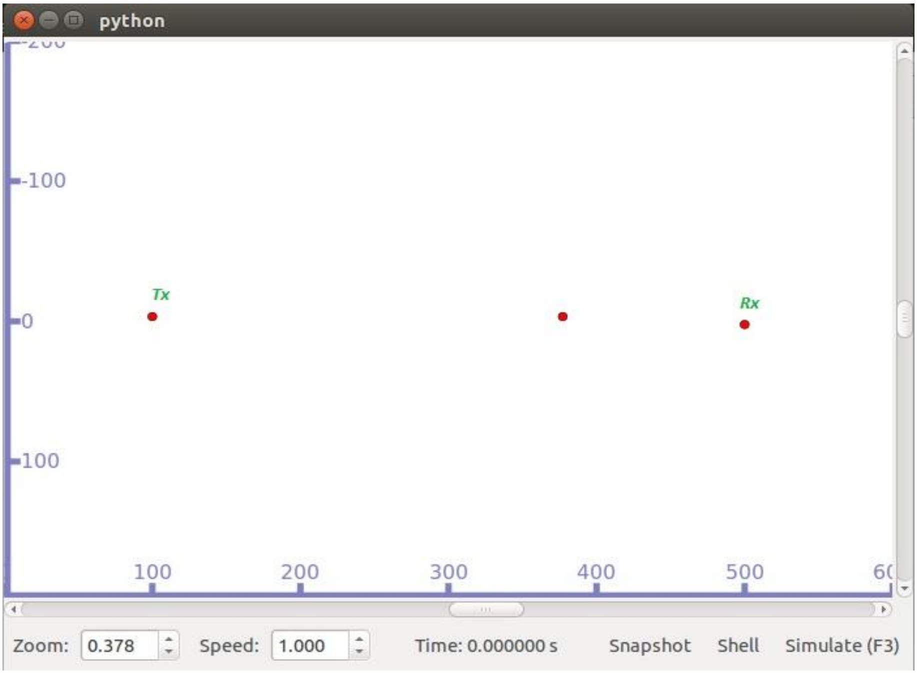

Figure 16: Position of the nodes in rural (500 m).

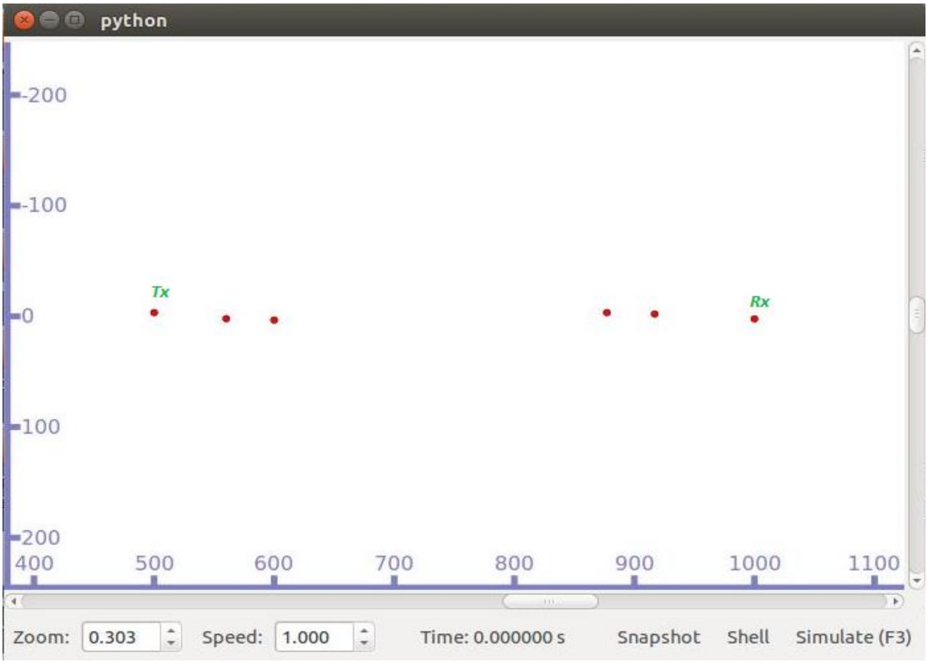

Figure 17: Position of the nodes in Rural (2 km).

In our simulation we have designed NS–3 scenario using a simple wireless *adhoc* network that allows us to perform a comparative analysis of the measured network performance (average delay per packet and average packet loss ratio). In NS-3, nodes contain multiple *NetDevice* objects; a simple example can be a computer with different interface cards, e.g. for *Ethernet*, *WiFi*, *Bluetooth*. When we add a *WifiNetDevice* to a node that create models of IEEE 802.11 based infrastructure and *adhoc* network [30]. As depicted in Figure 18 at the time of transmission *WifiNetDevice* converts the IP address to MAC address and add Logical Link Control (LLC) header to the packet and pass it to *AdhocWifiMac* which add *WiFi* Mac header and estimate the physical mode i.e. the data rate supported by the destination node.

After that Dynamic Channel Assignment (DCA) *DcaTxop* class insert the new packet in the queue and check for another packet transmission or reception along with a Distributed Coordination Function (DCF) class, if there is no packet pending, the packet is handed over to the *MacLow* class [30]. In case of a pending packet, *DcfManager* acknowledges the collision and starts the *backoff* procedure by selecting a random number and wait to access again. *DcaTxop* also checks whether the packet is multicast or it requires fragmentation or retransmission. When it reaches to the *MacLow* class of NS-3 it checks if the retransmission was required; it's called the procedure for retransmission of the packet, if not it sends the packet to the physical layer of NS-3 named as *YansWifiPhy*. Which informs the DCF about the start of transmission, after that the packet is handed over to the channel class named as *YansWifiChannel* which estimate the receive power and set the propagation delay.

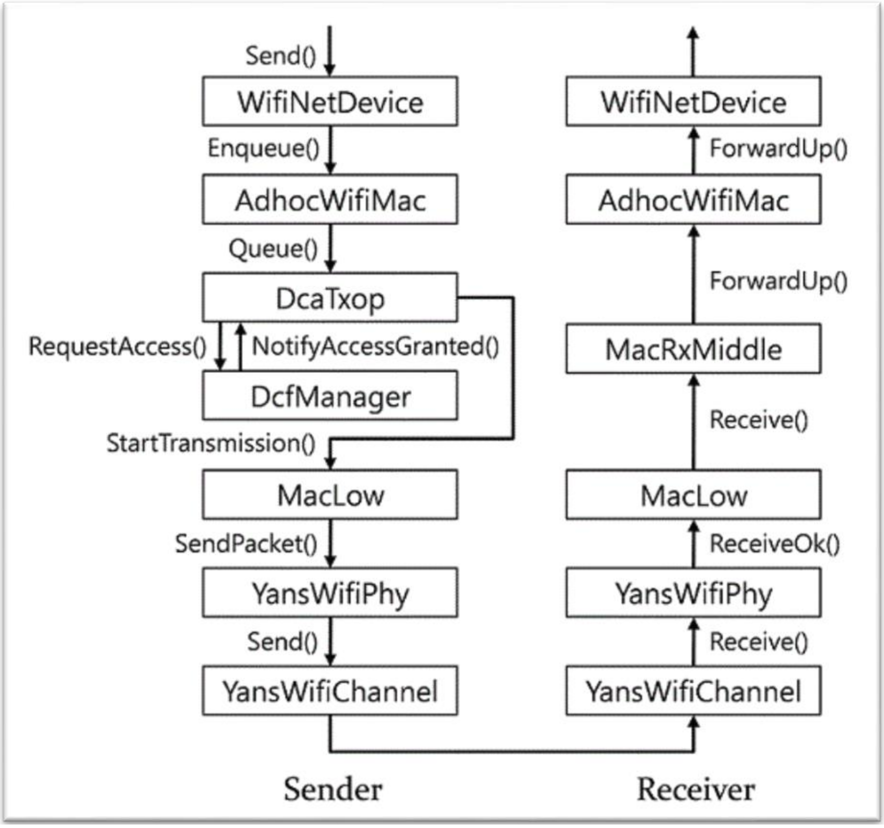

Figure 18: Wifi Data Flow in NS-3.

At the receiver side *YansWifiChannel* hand over the packet to the *YansWifiPhy* which calculates the interference level, it drops the packet if the state of PHY is not idle or the receive power is below the threshold. It also estimates the packet error rate (PER) from signal to noise ratio. Then the packet is handed over to the *MacLow* which check its destination and send the acknowledgement if the destination is reached. *MacRxMiddle* checks whether the received packets is duplicated one with the correct sequence and passes the packet to the *AdhocWifiMac* and then to the

WifiNetDevice. The *AdhocWifiMac* was used in the MAC layer and add a QoS upper MAC.

3.4.1 Flow Monitor

To evaluate the network performance, we have used the *Flow Monitor* framework in NS-3 which can be easily used to store and collect network performance data and counting hop in a network from the NS-3 simulation. The architectural [44] view of *FlowMonitor* simulation will typically contain one *FlowMonitorHepler*, one *FlowMonitor*, one *Ipv4FlowClassifier* probe capture packets, then ask the classifier to assign identifiers to each packet, and report on the global the classifier to assign identifiers to each packet, and report on the global *FlowMonitor* abstract flow events, which are finally used for statistically data gathering and for evaluate the network performance by calculating the packet loss ratio and average delay per packet.

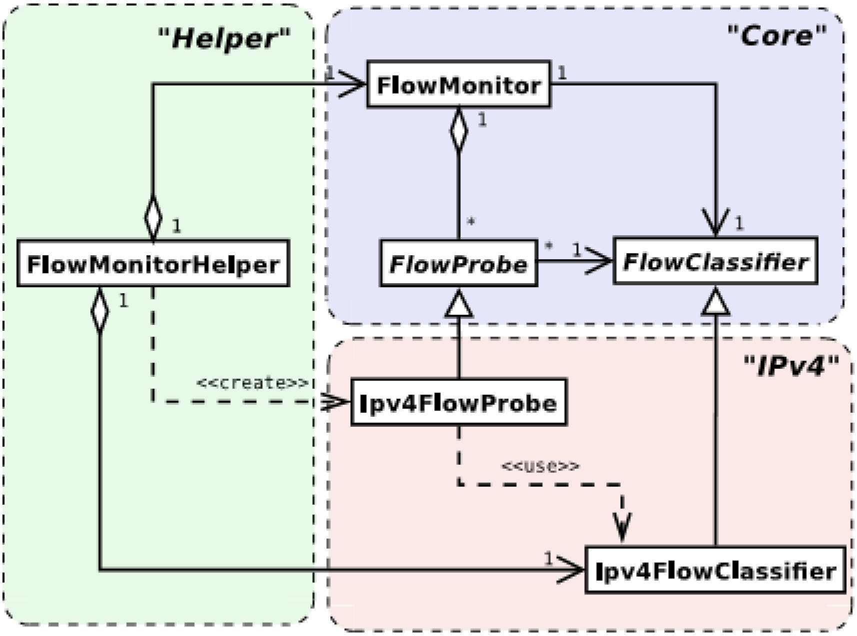

Figure 19: High Level view of Flow Monitor Architecture [44].

3.4.2 Mobility and Positioning

To make our system model realistic we have assigned the mobility of the *Tx* node, *Rx* node and other *mdNodes* in the highway and rural scenario at NS-

3. The *Tx* node send the packets towards *Rx* Node and all other *mdNodes* using broadcast and unicast protocol. The mobility module in NS-3 supports the sets of mobility models which are used to track and maintain the current position and speed of an object. The design includes position allocators, mobility models and helper functions. The initial position of the nodes is set with *PositionAllocator*. Using mobility helper classes most users interact with the mobility system and the *MobilityHelper* combines a mobility model and position allocator, and can be used with a node container to install mobility capability on a set of nodes [30]. The *ConstantVelocityMobilityModel* was used to give a constant velocity to all *mdNodes*, *Tx* and *Rx* in the scenario. Mobility of the *mdNodes*, *Tx* and *Rx* are bound to the minimum and maximum of X (0-500 m), X (0-2000 m) and Y coordinates (4.25 m for Highway and 4m for Rural). Individual car speeds (*mdNodes*) were randomly assigned according to a normal (Gaussian) distribution with the parameters of, Mean Speed = 25 m/s and Speed Variance = 4.0 m/s.

Generated traffic in our model from *Tx* to *Rx* has been implemented with the help of application module in NS-3. As according to Lund model the transmitter has the capability to generate packets to the receiver, in this context we have utilized two application models named *OnOff* application and *PacketSink* application from NS-3 for generation of packets and to sink them respectively.

Here, is an issue related to the installation of *OnOff* application that is due to the simultaneous installation of the application on vehicles that was limiting number of vehicles according to the vehicles density of the “Lund Model” [2]. We are using 10 Hz frequency for CAM and 20 Hz frequency for DENM in the *OnOff* application to send UDP datagrams of size 200 bytes and 100 bytes respectively [32]. To do this we have installed the *OnOff* application on each vehicle at different instance of time. The traffic generator follow the "On" and "Off" states alternate. The duration of each of these states is determined with the *onTime* and the *offTime* random variables. During the "*Off*" state, no traffic is generated. During the "*On*" state, packets are generated. This *OnOff* application is characterized by the specified "data rate" and "packet size". When an application is started, the first packet transmission occurs after a delay equal to (packet size/bit rate). Note also, when an application transitions into an off state in between packet transmissions, the remaining time until when the next transmission would have occurred is cached and is used when the application starts up again. In this context, we have utilized two application models named *OnOff* application and *PacketSink* application from NS-3 for generation of packets and to sink them respectively. In the application layer, *OnOff* application was used into the “Lund model”. We have created socket for UDP implementation by *UdpSocketFactory*. We have simulated CAM and DENM without routing and with three different routing protocols (AODV, DSDV, OLSR) in NS-3.

3.4.3 Simulation Time

The biggest difficulty during our simulations that we faced was the extraordinary time taken by NS-3 to process the simulations. To give an idea of how much time the simulations were taking for processing, the basic scenario of Lund Model will take longer time up to 2 hours of each simulation and this processing time, sometimes increases when we change the routing protocols and without routing. The time taken by each simulator for single run is about 2 hours, which implies after running the code we have to wait 2 hours for single run result and on the basis of those results the troubleshooting in the code is done and then run it again and wait for another 2 hours to get new results. The reason for this extraordinary delay in simulation processing is the detailed implementation of our simulation model and according to the NS-3 developers the performance optimization of the simulator is still in process.

3.5 A More Generic Scenario

In our simulation we have used one Tx, one Rx and some mdNodes (according to the Lund Propagation pathloss model). We ran our simulation 10 times for two scenarios (Lund highway and rural) to find the answer of our research question. To use the NS-3 Lund model with different random number generator we kept the distribution of scatterers and the properties assigned to them constant in every run and calculated the average of the result (average packet loss ratio and average delay per packet) [1].

If we want to make our simulation more generic i.e, multiple *Tx*, *Rx* are used randomly for sending and receiving packets by using different propagation loss models and routing protocols in NS-3. But in Lund propagation loss model *Tx*, *Rx* and *mdNodes* have different attributes [2] i.e. velocity, path-loss exponent, variance and coherence distance and those have given manually in the implementation of our simulation in NS-3. But if we want to send packets from a new *Tx* to a new *Rx,* then old *Tx* will become as a *mdNode* and the new *Tx*, *Rx* are constructed from the other *mdNodes*, as like as in the figure below,

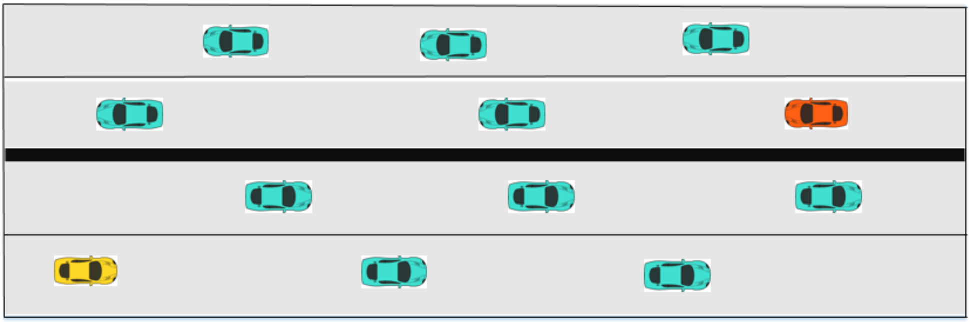

Figure 20: Transmitter (yellow car), receiver (orange car) and other mdNodes.

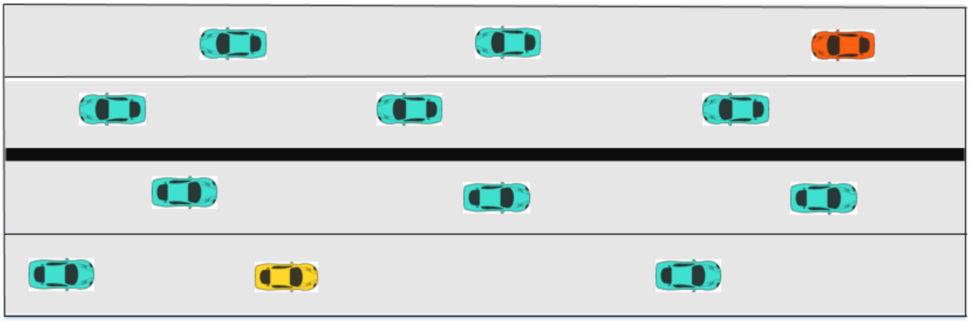

Figure 21: New transmitter (yellow car), receiver (orange car) and other mdNodes.

But into the Lund propagation path-loss model *Tx*, *Rx* and other *mdNodes* have different attributes [2] were given manually in the implementation of our simulation. When the *DocalcRxPower* is called by the *wifi* stack in NS-3, then the Lund model determines which node serve as *Tx*, *Rx* and *mdNodes*, select the consequent large-scale fading instances and calculates the path-loss [1]. But if we change *Tx* and *Rx* with an *mdNode*, then the new *Tx* and new *Rx* has to give the attributes like velocity, path-loss exponent, variance and coherence distance etc. and the other new *mdNodes* attributes (actually old *Tx*, *Rx*) needs to change it dynamically in the simulation and it is difficult to run 10 times and find the answer of the simulation.

This is only problem for the Lund Propagation path-loss model to implement in NS-3. But for the other propagation pathloss models in NS-3 like Three log distance path-loss model, Frii's model and Nakagami model they have also different attributes like Lund model are constant for *Tx*, *Rx* and *mdNodes* calculation and if we need to implement them, it is easy to implement in NS-3. Moreover, to evaluate the network performance, by using flow monitor it will be a harder task to fetch the result.

CHAPTER 4

4 Experiment Result

This chapter focuses on all the results of simulations findings. There were a number of simulations run to find the answer of our thesis research questions. The simulations were set up in such a way that, using CAM and DENM broadcast and with three different routing protocols specifically the AODV, DSDV and OLSR were working on different pathloss models. As the whole simulation scenario has already been defined in detail in the previous chapter, now the focus will be on its organization and how the simulations were executed. Before going into the details of simulation results, it is important to mention that the different pathloss models are implemented with the same Lund model scenario.

4.1 Performance Criteria

The main performance metrics are defined as follows,

1) *Average Delay per Packet:* The average time taken by each packet during its transmission from source to destination. Since ITS had defined a strict latency requirement for cooperative safety applications, it makes this parameter as the most important one in judging the capability of technology for cooperative safety applications in vehicular communication [30]. Hence the average delay per packet is basically the total delay of the packet from its transmitter to receiver.

$$Average\ Delay\ per\ packet\ = \frac{delay\ Sum}{Rx\ Packets} \tag{1}$$

2) *Average Packet Loss Ratio:* It is the ratio between the total number of packets lost to the total number of packets transmitted between transmitter and receiver.

$$Average\ packet\ loss\ ratio = \frac{lost\ packets}{Rx\ Packets + lost\ packets} \tag{2}$$

4.2 Simulation Setup

The performance of vehicular communication is evaluated on the basis of the metrics average delay per packet and average packet loss ratio. The simulations are divided in two different cases (broadcast and unicast). In the first case the frequency, packet size, propagation loss models and the number of *mdNodes* (500 m *3mdNodes* and for 2000 m *10mdNodes*) for *highway* and (500 m *1mdNodes* and for 2000 m *4mdNodes*) for *rural* in Lund city scenario of broadcast simulation and specified in table 3.

Parameter	**CAM**	**DENM**
Frequency	10 Hz	20 Hz
Packet Size	200 Bytes	100 Bytes
Propagation loss models	Lund model, Three log distance model, Friis model, Nakagami model	Lund model, Three log distance model, Friis model, Nakagami model
Scenario	Highway, Rural	Highway, Rural

Table 3: Broadcast simulation specification of CAM and DENM [12, 32].

In second case the frequency, packet size and propagation loss models and the number of *mdNodes* (500 m *3mdNodes* and for 2000m *10mdNodes*) for *highway* and (500m *1mdNodes* and for 2000m *4mdNodes*) for *rural* Lund city scenario with routing protocols. The outcome of all the phases of simulations is presented and discussed in the form of average packet loss ratio and average delay per packet. The main parameters that define the difference between the routing protocols are shown in the following Table 4.

Parameter	**Values**		
	Routing protocol 1	**Routing protocol 2**	**Routing protocol 3**
Routing protocols	AODV	DSDV	OLSR
Frequency	10Hz	10Hz	10Hz
Packet size	200 bytes	200 bytes	200 bytes
Propagation loss model	Lund model, Three log distance model, Friis model, Nakagami model	Lund model, Three log distance model, Friis model, Nakagami model	Lund model, Three log distance model, Friis model, Nakagami model
Scenario	Highway, Rural	Highway, Rural	Highway, Rural

Table 4: Simulation scenario specifications.

The network performance in VANET was evaluated with Lund propagation loss model along with some of the existing models, which are commonly used for analyzing conventional wireless communications. Average delay per packet and average packet loss ratio are the two parameters used for comparing the performance. We have used flow monitor for calculating the average delay per packet and average packet loss ratio. The Flow Monitor module's goal is to provide a flexible system to measure the performance of network protocols. The module uses probes, installed in network nodes, to track the packets exchanged by the nodes, and it will measure a number of parameters. Packets are divided according to the flow they belong to, where each flow is defined according to the probe's characteristics (e.g., for IP, a flow is defined as the packets with the same {protocol, source, destination} tuple). The average delay per packet is basically related with Rx packets and delay sum. The delay sum contains the sum of all delay for all received packets of the flows. And the average packet loss ratio is related with lost packet and Rx packet. For safety vehicular communication we set the WAVE requirement in our simulation for network performance is 1 ms for successful packet reception from *Tx* to *Rx* and the maximum delay of the packet at 100 ms [30, 32]. And over 100 ms delay packet, it is treated as a lost packet [32].

The experiment of the simulation showed a number of results regarding the overall effect of the chosen pathloss and fading models on the network performance in VANET. For simulation run, we set up the start time is 10 seconds and the stop time is 20 seconds for the received packet successfully. Then we run our simulation 10 times to find the answer to our research questions. This randomness is applied in the state of all the random variables used in the script, e.g. in our simulation to use the NS-3 Lund model with different random number generator while keeping the distribution of scatterers and the properties assigned to them constant in every run and calculated the average of the result (average packet loss ratio and average delay per packet) without routing protocols and with the different routing protocols (AODV, DSDV, OLSR) [1]. We have compared the newly integrated propagation loss model (Lund model) with other existing propagation loss model (Three log distance model, Friis model, Nakagami model) in Lund highway and rural scenario. Furthermore, we were able to show considerable variation in the computational complexity of the various models in NS-3.16. Now we are describing the results of Lund highway and rural scenario in detail below.

4.3 Results of Broadcast

In VANET we have used the packet size and frequency of CAM and DENM specification in our simulation. The total number of mobile discrete (mdNodes) has been tested for the ***rural*** and ***highway*** scenario.

4.3.1 Result with Highway scenario

In this case in our scenario we have used 200 bytes, 10 Hz frequency for CAM and 100 bytes, 20 Hz frequency for DENM [12]. The total number of mobile discrete (mdNodes) has been tested for the ***highway*** scenario (3 mdNodes for 500 m and 10 mdNodes for 2 km).

In our scenario the maximum average delay per packet for 2km in Lund model (around 80 ms) and the minimum average delay per packet in Three log distance model (around 15 ms). For 2 km the three log distance model, Friis model and Nakagami model have same (nearly 56 ms) average delay per packet and for 500 m the Friis model, Lund model and Nakagami model have same (20 ms) average delay per packet.

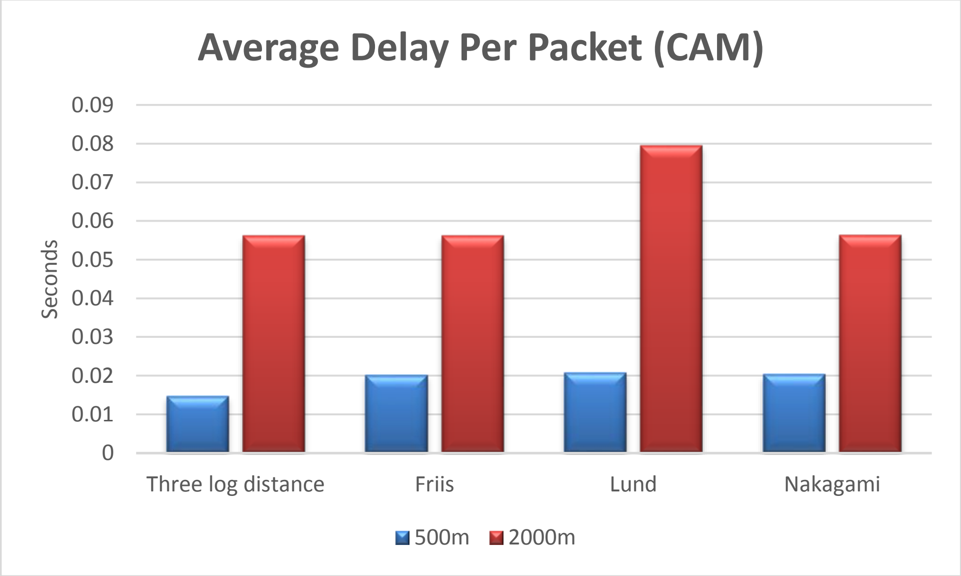

Figure 22: Average delay per packet in Highway (CAM).

In this scenario, the CAM has maximum average packet loss ratio 14% for 2 km in Lund model and other models (Three log distance model, Friis model, Nakagami) have same average packet loss ratio is around 6%. For 500 m Lund model showing the maximum average packet loss ratio is more than 6% and Friis model showing the minimum average packet loss ratio around 2%.

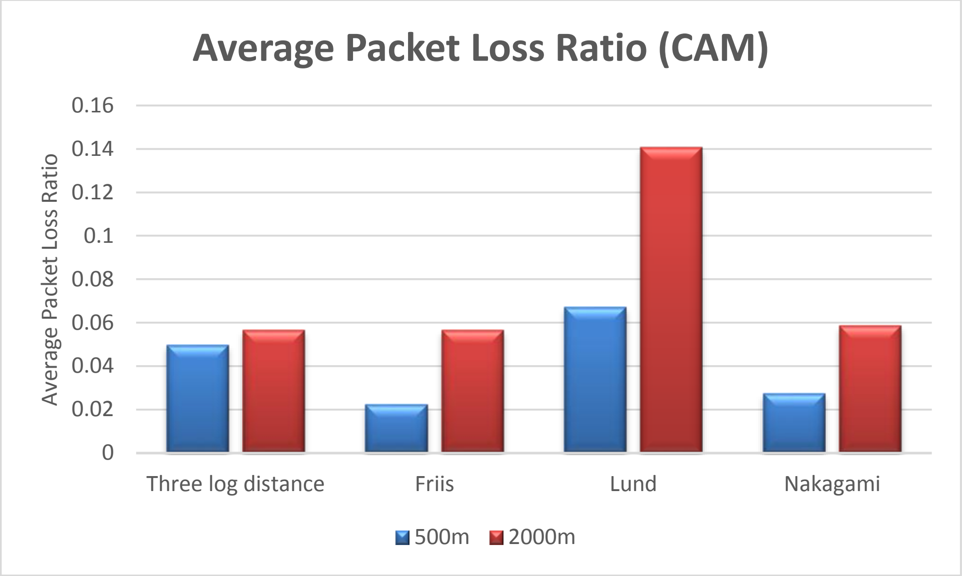

Figure 23: Average packet loss ratio in Highway (CAM).

For DENM broadcast the maximum average delay per packet is more than 80 ms in Lund model and the other models (Three log distance model, Friis model, Nakagami model) have almost same average delay per packet is around 65 ms for 2 km. and for the 500 m the minimum average delay per packet in Three log distance model is less than 20ms and Friis model and Nakagami model showing the maximum average delay per packet is more than 20 ms.

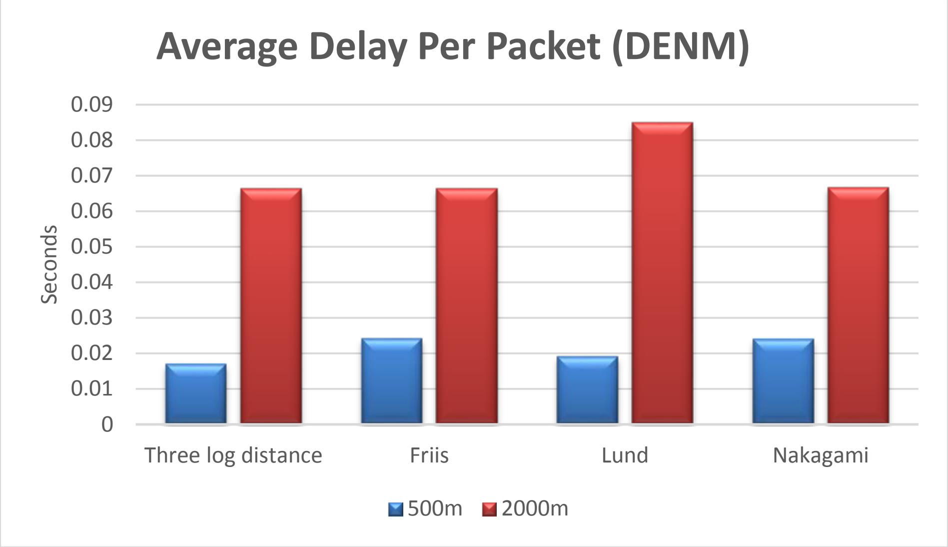

Figure 24: Average delay per packet in Highway (DENM).

The maximum average packet loss ratio of DENM broadcast is 9% in Lund model and the other models (Three log distance model, Friis model, Nakagami model) have same average packet loss ratio is around 7%. For 500 m Lund model showing the maximum average packet loss ratio is less than 8% in Lund model and Friis model showing the minimum average packet loss ratio is less than 5%.

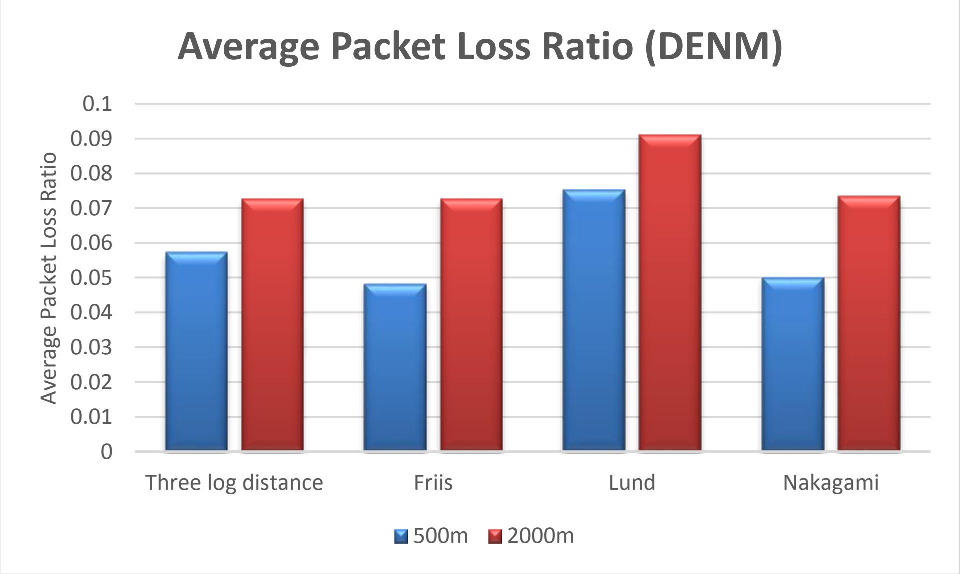

Figure 25: Average packet loss ratio in Highway (DENM).

If we compare the highway result of CAM to the result of DENM, we make some observations;

1) For 2 km distance Lund model showing the maximum average delay per packet and other models are almost same average delay per packet for both case CAM and DENM.
2) For 500 m distance Three log distance model showing the minimum average delay per packet in both cases.
3) The maximum average packet loss ratio in Lund model and others are same average packet loss ratio for 2 km.
4) For 500 m distance Lund model showing the maximum average packet loss ratio and Friis model showing the minimum average packet loss ratio.

4.3.2 Result with Rural scenario

In our scenario we have used 200 bytes, 10 Hz frequency for CAM and 100 bytes, 20 Hz frequency for DENM. The total number of mobile discrete (mdNodes) has been tested for the ***rural*** scenario (1 mdNodes for 500 m and 4 mdNodes for 2 km).

In this case, the broadcast rural scenario showing maximum average delay per packet for 2km in Lund model (around 65 ms) and the other models have same average delay per packet which is less than 30 ms. For 500 m all models have same average delay per packet for broadcast which is nearly 10 ms.

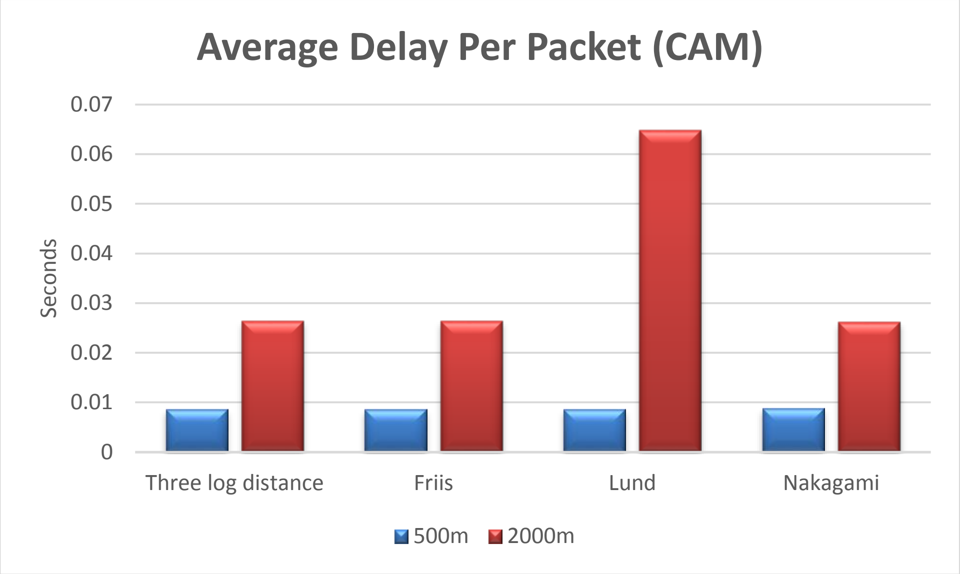

Figure 26: Average delay per packet in Rural (CAM).

The maximum average packet loss ratio of CAM in Lund model is around 13% for 2 km and other models (Three log distance model, Friis model, Nakagami model) have same average packet loss ratio is less than 4%. For 500 m the average packet loss ratio is almost same for all propagation loss models which is around 1%.

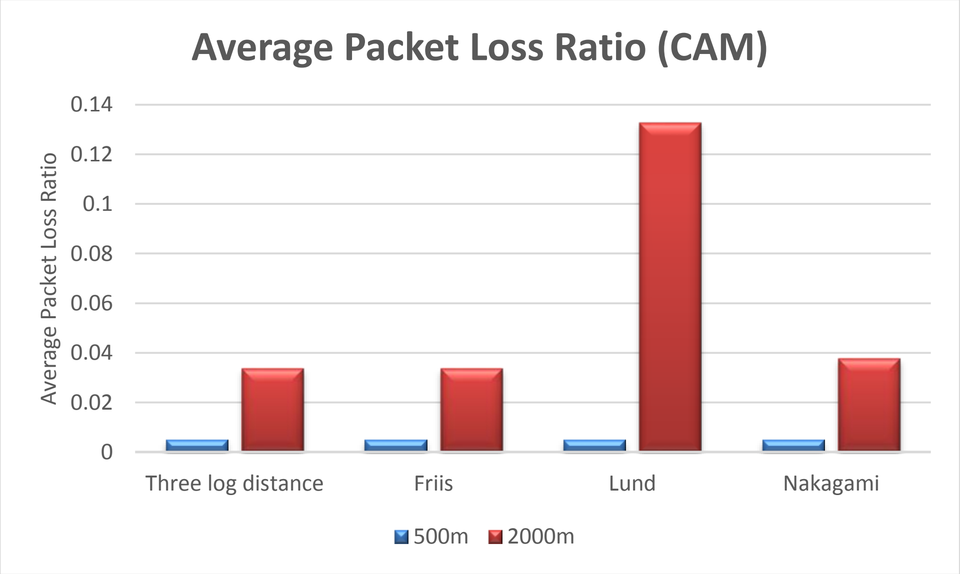

Figure 27: Average packet loss ratio in Rural (CAM).

The DENM average delay per packet in Lund model is maximum (more than 60 ms) for 2 km distance. There log distance model and Friis model showing the same (around 32 ms) average packet loss ratio and Nakagami model showing the minimum (20 ms) average packet loss ratio. For 500 m all propagation models showing almost same (10 ms) average delay per packet in rural scenario.

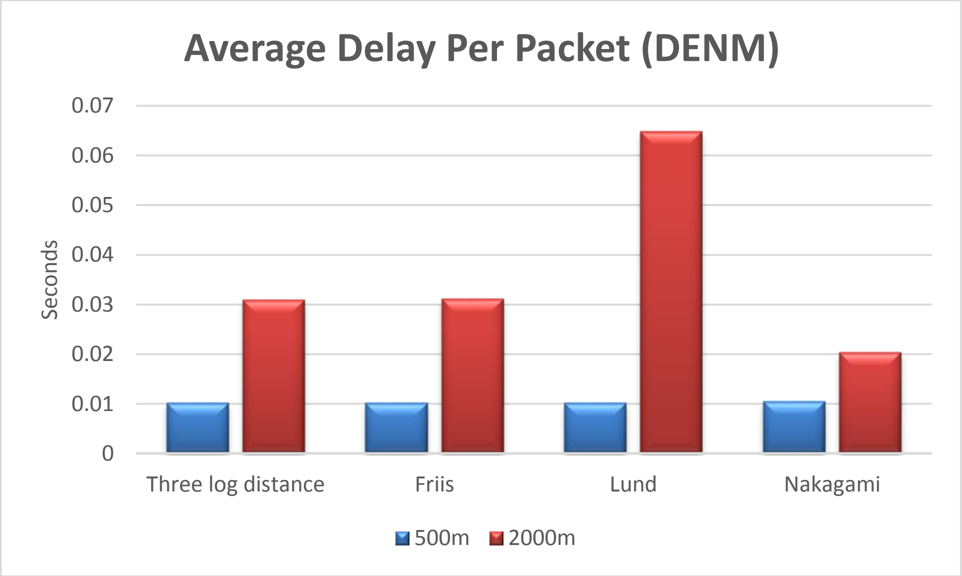

Figure 28: Average delay per packet in Rural (DENM).

In DENM, average packet loss ratio in Lund model showing the maximum (around 12%) average packet loss ratio and Nakagami model showing the minimum (2%) average packet loss ratio in 2 km rural scenario. Three log distance model and Friis model showing the same (nearly 6%) average packet loss ratio. For 500 m Nakagami model showing the minimum (less than 2%) average packet loss ratio and the other models (Three log distance model, Friis model, Lund model) showing same (2%) average packet loss ratio.

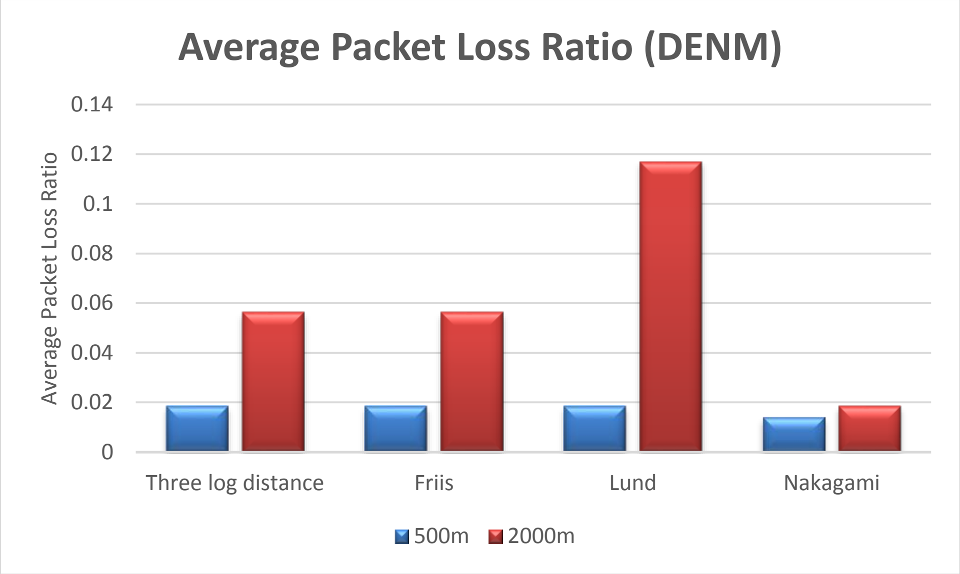

Figure 29: Average packet loss ratio in Rural (DENM).

If we compare the rural result of CAM to the result of DENM, we make some observations,

1) For 2 km distance in rural scenario, the maximum average delay per packet in Lund model and Nakagami model showing the minimum average delay per packet.
2) All propagation loss models showing almost the same average packet loss ratio in 500 m for both case CAM and DENM.
3) The average packet loss ratio in Lund model is maximum for 2 km.
4) For 500 m, the minimum average packet loss ratio is in Nakagami model.

4.4 Results of unicast Highway scenario

In VANET the packet size has been set to 200 bytes and the frequency is 10 Hz set in the simulation of vehiculer safety application. The total number of mobile discrete (mdNodes) has been tested for the ***highway*** scenario (3 mdNodes for 500 m and 10 mdNodes for 2 km).

4.4.1 Result with AODV

In this case, for AODV routing protocol in our scenario the maximum end-to-end average delay per packet for 500 m and 2 km in Lund model. For 500m the end-to-end average delay per packet is nearly 60 ms and for the 2 km it is around 90 ms. And the other pathloss models (Three log distance, Friis, Nakagami) the end-to-end average delay per packet was similar for 2 km (above 50 ms) and for the 500 m it was around 25 ms in AODV routing protocol.

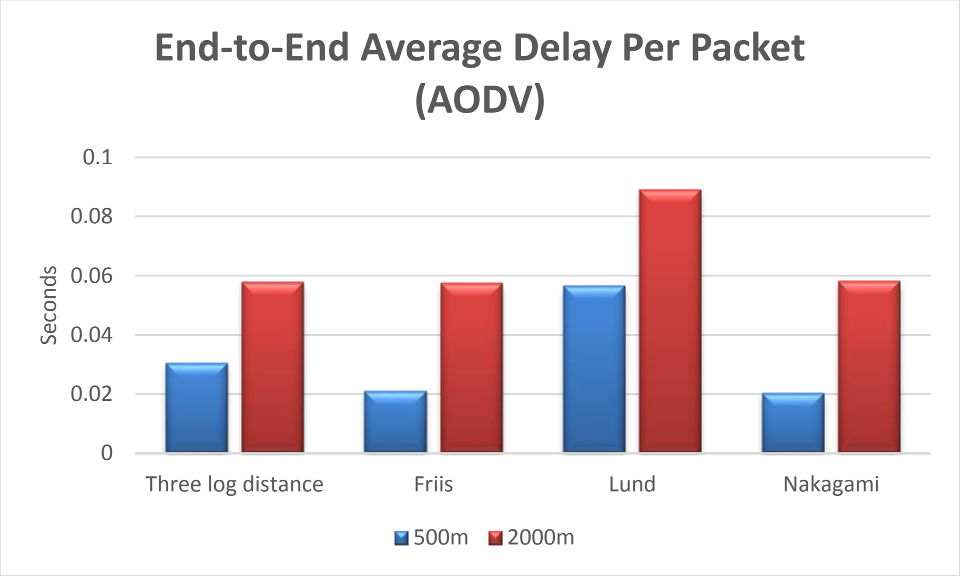

Figure 30: End-to-End Average delay per packet in Highway (AODV).

The end-to-end average packet loss ratio for Lund model in AODV routing protocol shows the significant difference among the other pathloss models (Three log distance, Friis, Nakagami) into the distance 500 m and 2 km. Friis model and Nakagami model showed quite similar average packet loss ratio (2% for 500 m and 5% for 2 km) and the Three log distance model was little bit higher than Friis model and Nakagami model in AODV routing protocol.

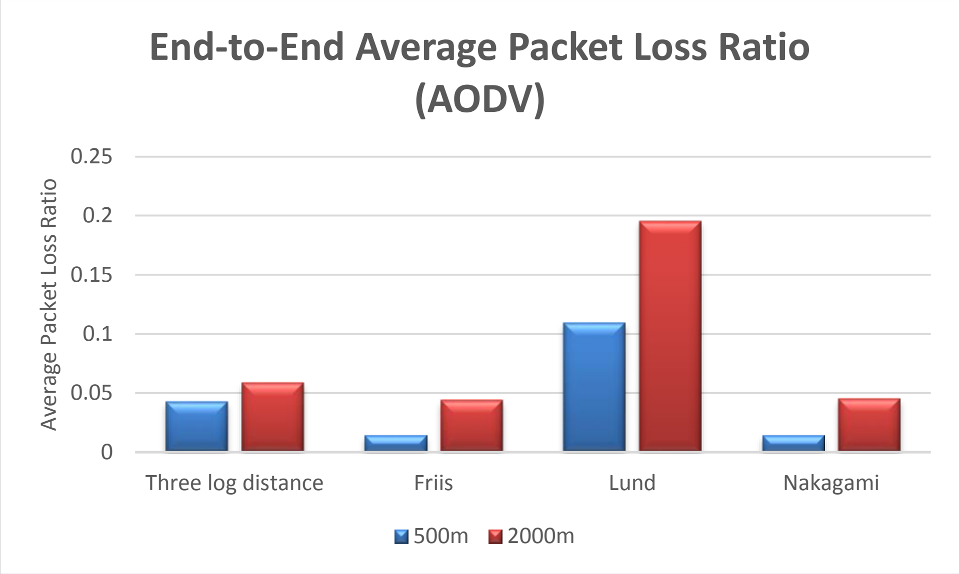

Figure 31: End-to-End Average packet loss ratio in Highway (AODV).

4.4.2 Results with DSDV

In this case, for DSDV routing protocol in VANET the packet size has been set to 200 bytes and the frequency is 10 Hz set in the simulation of vehicle safety application. The total number of mobile discrete (mdNodes) has been tested for the ***highway*** scenario (3 mdNodes for 500 m and 10 mdNodes for 2 km).

In our scenario the maximum end-to-end average delay per packet for 2 km in Lund model and for the 500 m it was Three log distance model. For 2 km the end-to-end average delay per packet Lund model showing the 80 ms, Three log distance model and Friis model is around 55 ms and Nakagami model is above 60 ms. and for the 500 m Lund model showing the lowest end-to-end average delay per packet and it is below 20 ms among the other pathloss models.

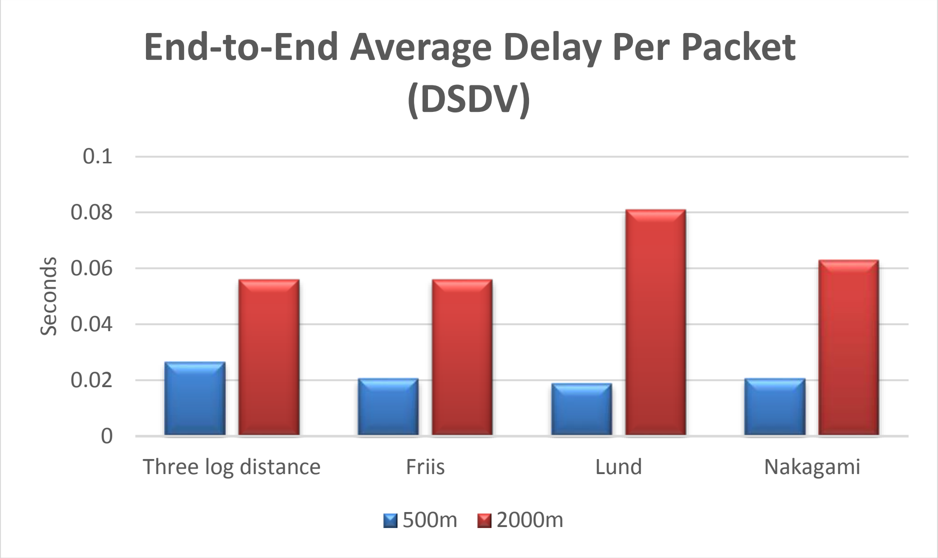

Figure 32: End-to-End Average delay per packet in Highway (DSDV).

In the DSDV routing protocol the end-to-end average packet loss ratio of Lund model is maximum (13% for 500 m and 22% for 2 km) than the other pathloss models (Three log distance, Friis, Nakagami) for 500 m and 2 km. The Three log distance model and Friis model are given nearly the same (1% for 500 m and 4% for 2 km) end-to-end average packet loss ratio for 500 m and 2 km. And Nakagami model are little bit higher than Three log distance model and Friis model for 2 km.

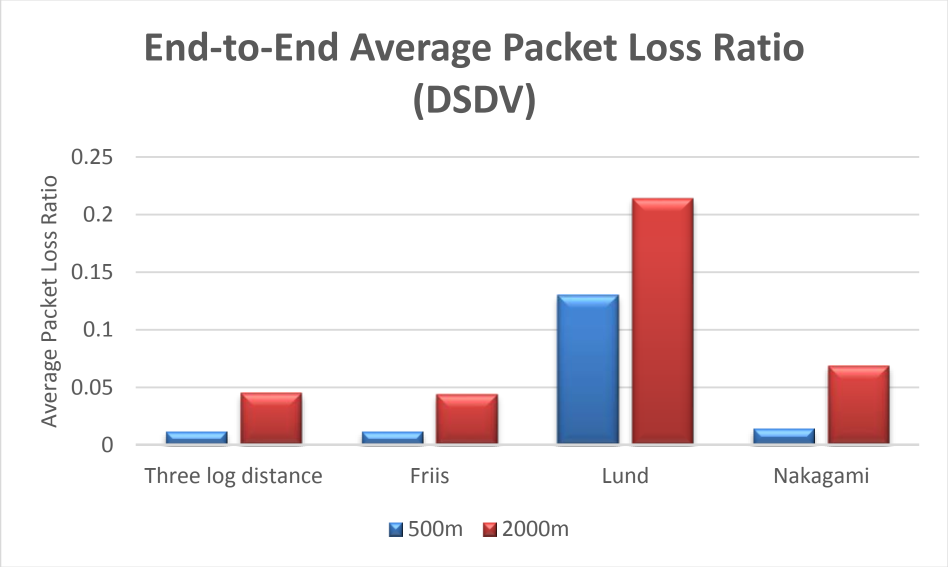

Figure 33: End-to-End Average packet loss ratio in Highway (DSDV).

4.4.3 Results with OLSR

In the routing protocol (OLSR) the frequency, packet size and the other parameter are not changed, we have just changed the routing protocol OLSR by replacing DSDV in our simulation. The total number of mobile discrete (mdNodes) has been tested for the ***highway*** scenario (3 mdNodes for 500 m and 10 mdNodes for 2 km).

In our scenario the maximum end-to-end average delay per packet for 2 km in Lund model and for the 500 m it was Three log distance model. For 2 km the end-to-end average delay per packet Lund model is above the 80 ms and the other pathloss (Three log distance, Friis and Nakagami) models are nearly same (below the 60 ms). And for the 500 m Lund model showing the lowest end-to-end average delay per packet and it is below 20 ms among the other pathloss models and there log distance model showing the higher end-to-end average delay per packet (nearly 25 ms).

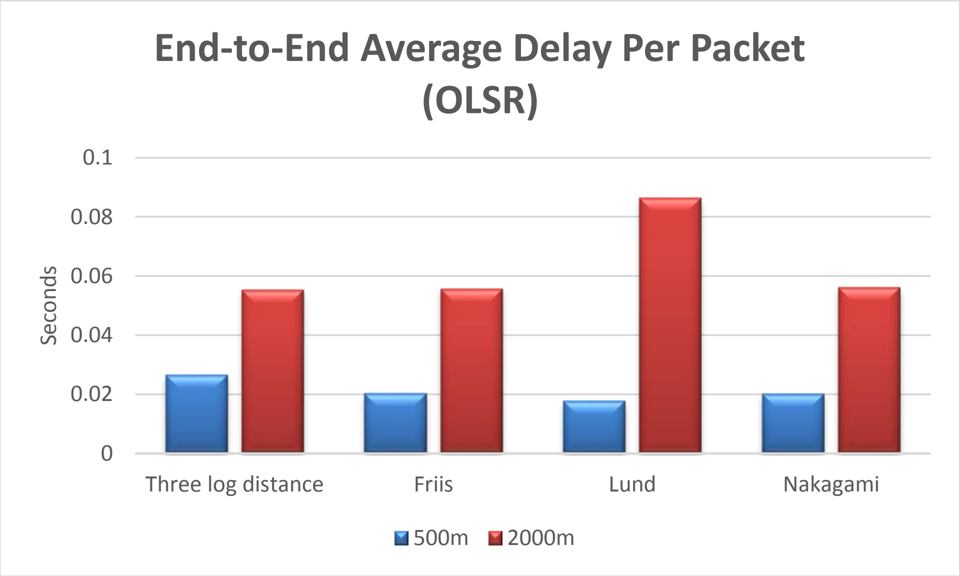

Figure 34: End-to-End Average delay per packet in Highway (OLSR).

In the OLSR routing protocol the end-to-end average packet loss ratio of Lund model is higher than the other pathloss models (Three log distance, Friis, Nakagami) for 500 m and 2 km. The Three log distance model, Friis model and Nakagami model are given nearly the same end-to-end average packet loss ratio for 2 km and for 500 m Three log distance model showing the lowest end-to-end average packet loss ratio.

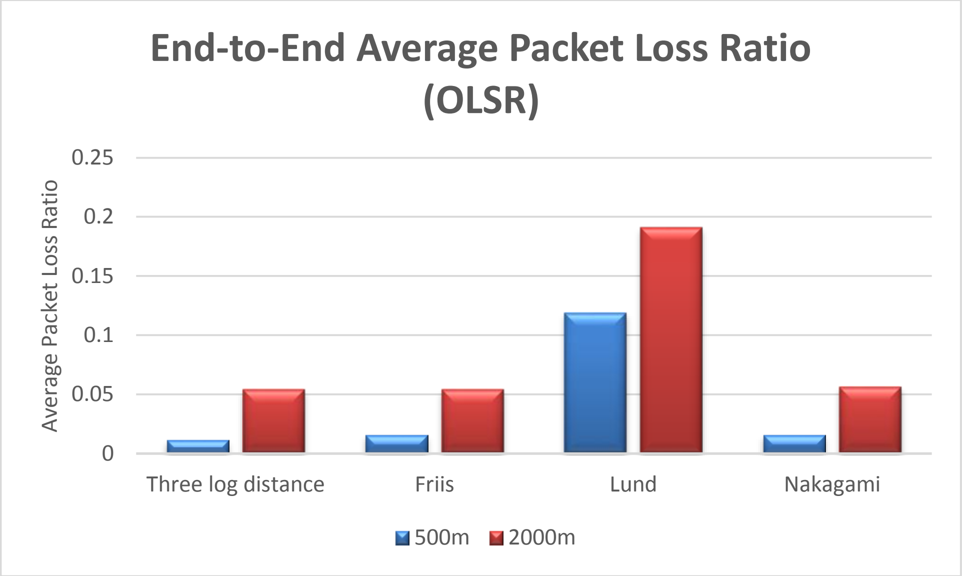

Figure 35: End-to-End Average packet loss ratio in Highway (OLSR).

If we compare the highway result of AODV routing protocol to the result of the other routing protocols DSDV and OLSR, we make some observations,

1) In AODV routing protocol the maximum end-to-end average delay per packet and the maximum end-to-end average packet loss ratio in Lund model among the other pathloss models for 500 m and 2 km.
2) For DSDV the maximum end-to-end average delay per packet is in Lund model for 2km and for the 500 m it is showing the minimum end-to-end average delay per packet. The maximum end-to-end average packet loss ratio in Lund model for 500 m and 2 km.
3) In OLSR the maximum end-to-end average delay per packet in Lund model for 2km and for the 500 m it is showing the minimum end-to-end average delay per packet. And the maximum end-to-end average packet loss ratio in Lund model for 500 m and 2 km.
4) Nakagami model showing the maximum end-to-end average packet loss ratio among the other pathloss models of different routing protocols.

4.5 Result of unicast Rural scenario

In VANET the packet size has been set to 200 bytes and the frequency is 10 Hz set in the simulation of vehicle safety application. The total number of mobile discrete (mdNodes) has been tested for the ***Rural*** scenario (1 mdNodes for 500 m and 4 mdNodes for 2 km).

4.5.1 Result with AODV

In this case, for AODV routing protocol in our scenario the minimum end-to-end average delay per packet for 500 m (below 5 ms) and 2 km (nearly 10 ms) in Lund model and the other pathloss models (Three log distance, Friis, Nakagami) for 500m the end-to-end average delay per packet is nearly 9 ms and for the 2 km it is above 25 ms.

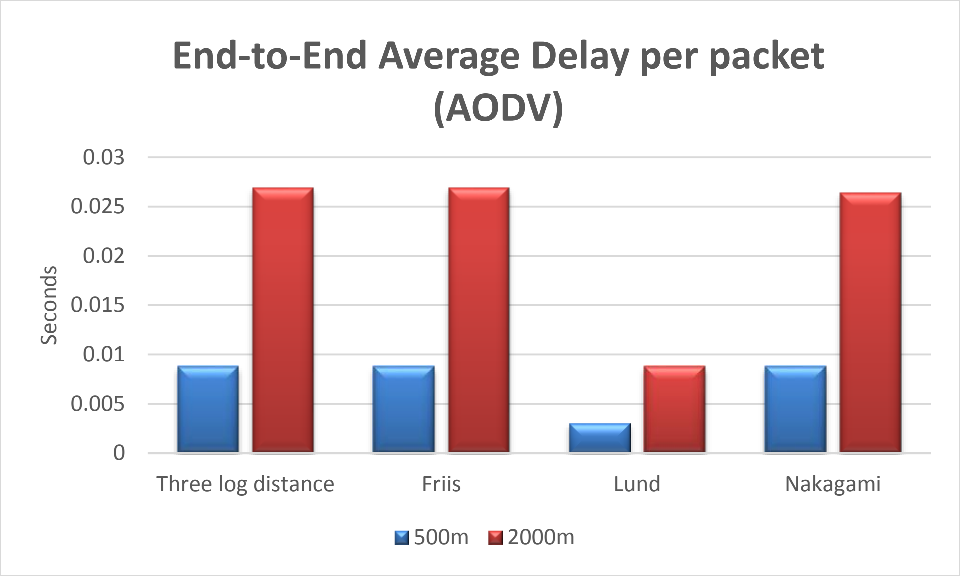

Figure 36: End-to-End Average delay per packet in Rural (AODV).

In AODV routing protocol for 2 km the end-to-end average packet loss ratio for Lund model is minimum (1%) and Nakagami model showing the higher end-to-end average packet loss ratio (2.5%). Three log distance model and Friis model are showing the same (2%) end-to-end average packet loss ratio into the AODV routing protocol for 2 km. and for the 500 m all pathloss models showing zero end-to-end average packet loss ratio.

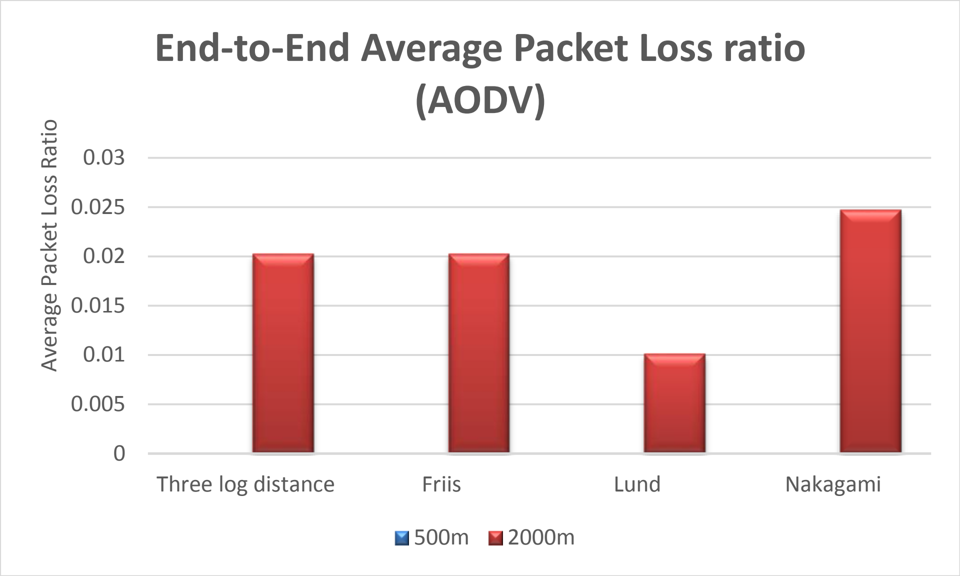

Figure 37: End-to-End Average packet loss ratio in Rural (AODV).

4.5.2 Result with DSDV

Into the DSDV routing protocol in VANET the packet size has been set to 200 bytes and the frequency is 10 Hz set in the simulation of vehicular safety application. The total number of mobile discrete (mdNodes) has been tested for the ***rural*** scenario (1 mdNodes for 500 m and 4 mdNodes for 2 km).

In DSDV routing protocol for 2 km the maximum end-to-end average delay per packet in Lund model (45 ms) and the other pathloss models (Three log distance, Friis, Nakagami) are showing the same (around 25 ms) end-to-end average delay per packet. For 500 m all pathloss model showing the same (nearly 10 ms) end-to-end average delay per packet.

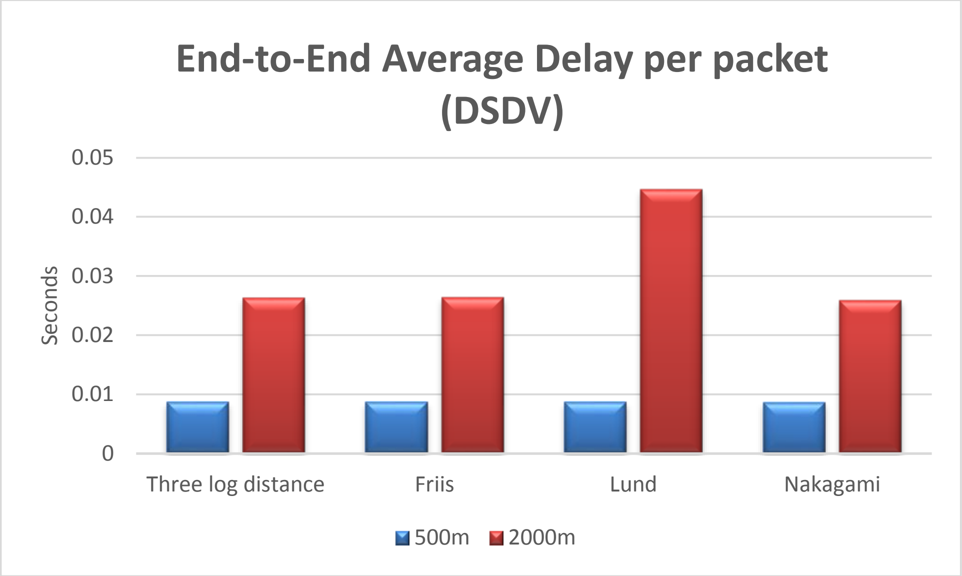

Figure 38: End-to-End Average delay per packet in Rural (DSDV).

In DSDV the end-to-end average packet loss ratio of Three log distance model, Friis model and Nakagami model are nearly same (1.8%) and the Lund model showing the maximum end-to-end average packet loss ratio is nearly 2% for 2 km. For the 500 m all pathloss models showing zero end-to-end average packet loss ratio.

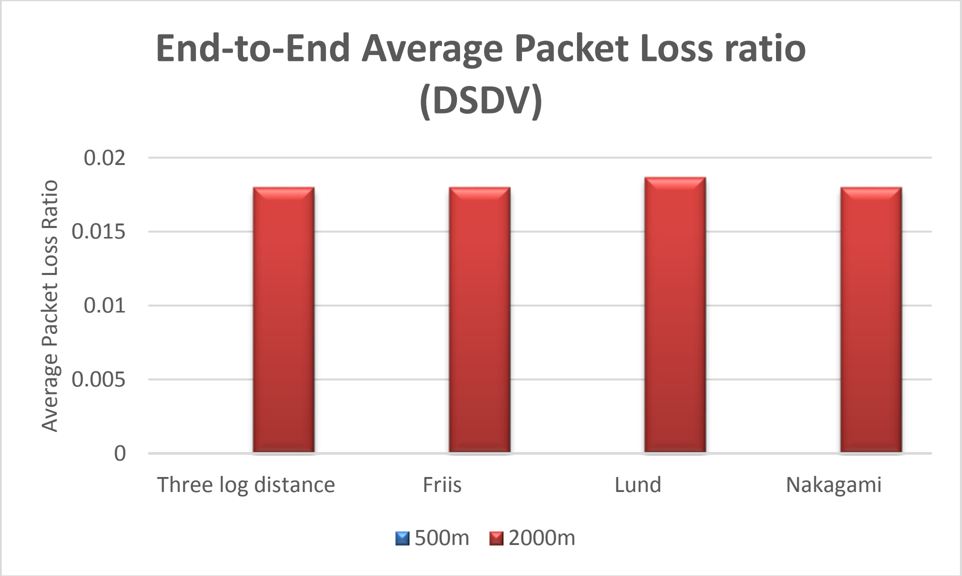

Figure 39: End-to-End Average packet loss ratio in Rural (DSDV).

4.5.3 Result with OLSR

Into the OLSR routing protocol in VANET, the packet size has been set to 200 bytes and the frequency is 10 Hz set in the simulation of vehicular safety application. The total number of mobile discrete scatterers (mdNodes) have been tested for the ***rural*** scenario (1 mdNodes for 500 m and 4 mdNodes for 2 km).

The end-to-end average delay per packet are nearly same for 2 km, that is above 25 ms and for the 500 m it is below 10 ms for all pathloss models.

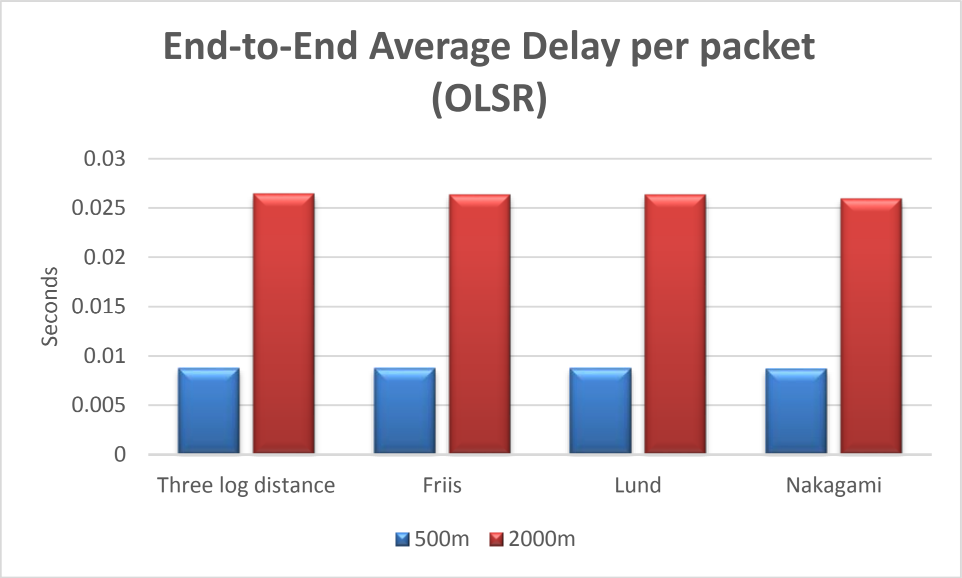

Figure 40: End-to-End Average delay per packet in Rural (OLSR).

The maximum end-to-end average packet loss ratio for 2 km is 2.5% in Nakagami and the other three pathloss models (Three log distance, Friis, Lund model) are nearly same (above 2%).

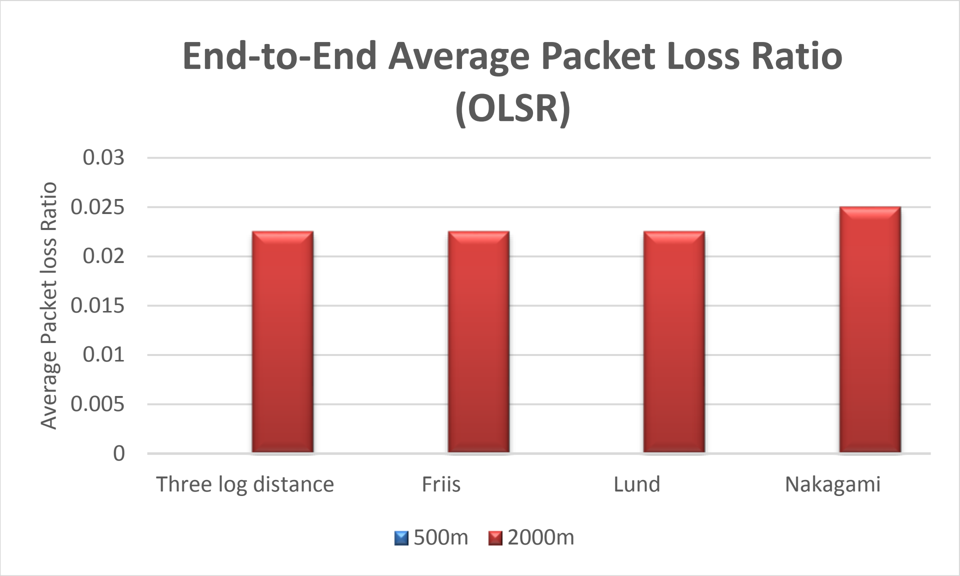

Figure 41: End-to-End Average packet loss ratio in Rural (OLSR).

If we compare the rural result of OLSR routing protocol to the result of the other routing protocols AODV and DSDV, we make some observations,

1) In AODV routing protocol the Lund model showing minimum end-to-end average delay per packet and end-to-end average packet loss ratio for 500 m and 2 km.
2) In DSDV routing protocol the Lund model showing maximum end-to-end average delay per packet for 2 km and for the 500 m it is nearly same end-to-end average delay per packet for all pathloss models and Lund model showing minimum end-to-end average packet loss ratio among the other pathloss models for 2 km.
3) In OLSR routing protocol the end-to-end average delay per packet is same for all pathloss models in 500 m and 2 km and the Nakagami model showing maximum end-to-end average packet loss ratio among the other pathloss models.
4) For 500 m the end-to-end average packet loss ratio is zero for one mdNode in rural scenario.

CHAPTER 5

5 Conclusion and future work

The different propagation loss models including Lund Propagation model were used to determine the average packet loss ratio and average delay per packet in a set of receivers; packets are being transmitted by a single transmitter. In this thesis, the effect of Radio Channel Modeling on the Network Performance for vehicular communications is solely based on the results of the simulations done in NS-3.16. On the basis of the simulation results presented in the Chapter 4 we tried to answer our research question. By analyzing the results in Chapter 4 we came to the conclusion that the effect of the different radio channel modeling without routing protocols and using different routing protocols in our simulation scenario (for highway and rural), in terms of the average delay per packet and average packet loss ratio for VANET in NS-3.16.

Highway:

a) Broadcast:

For broadcast Lund model showing maximum average delay per packet (>80 ms) and average packet loss ratio in both CAM and DENM for 2 km. For 500 m Lund model showing mixed results in average delay per packet. Regarding average packet loss ratio Lund model showing the maximum (>6%) in 500m for both CAM and DENM.

b) Unicast:

For 2 km Lund model showing the maximum end-to-end average delay per packet in all routing protocols and in AODV routing protocol showing the maximum end-to-end average delay per packet for 500 m. But in 500 m DSDV and OLSR routing protocols showing the minimum end-to-end average delay per packet in Lund model.

The maximum end-to-end average packet loss ratio in both 500 m and 2 km is Lund model among the other existing pathloss models in different routing protocols. For the Lund model the end-to-end average packet loss ratio is around 20% for 2 km and for 500 m it is above 10% in all routing protocols.

Rural:

a) Broadcast:

For broadcast scenario the average delay per packet showing nearly similar results for both CAM and DENM. Lund model showing the maximum average delay per packet (>60 ms) and average packet loss ratio in both CAM and DENM in 2 km. But for 500 m all propagation pathloss models are nearly same in CAM and DENM.

b) Unicast:

The end-to-end average delay per packet in rural scenario of Lund model is minimum for AODV routing protocol and all other pathloss models are same at 500 m scenario. For 2 km in DSDV, Lund model gives the maximum end-to-end average delay per packet and the minimum end-to-end average delay per packet in AODV routing protocol. But in OLSR showing the same end-to-end average delay per packet in 2 km for all pathloss models.

For 500 m the end-to-end average packet loss ratio is zero for all propagation loss model because for one mdNode. For 2 km the minimum end-to-end average packet loss ratio is 10% in AODV and above 16% in DSDV and above 20% in OLSR. But Nakagami model showing the maximum end-to-end average packet loss ratio among the all routing protocols in 2 km.

By above research we can find that Lund model has mixed kind of average packet loss ratio and average delay per packet among all propagation pathloss models. There are some findings of our research are given below,

1) In broadcast scenario Lund model showing the maximum average delay per packet and average packet loss ratio for 2 km in both rural and highway scenario in CAM and DENM.
2) Except AODV routing protocol of the rural scenario, the Lund model showing maximum end-to-end average delay per packet in unicast.
3) For the rural scenario in unicast, the average packet loss ratio of all pathloss models are nearly zero as there are number of mdNodes are very few.

4) For 500 m, Lund model showing in DSDV and in OLSR routing protocols minimum end-to-end average delay per packet in highway unicast.
5) The Diffuse scatterers, Static Discrete scatterers and mdNodes are major concern for average packet loss ratio and average delay per packet for 500 m and 2 km Lund highway and rural scenario.

Future Work

According to IEEE, the future of vehicular communication will be autonomous car which will drive by itself and it has also been predicted that by 2040 the driving license would be void [30]. There are some future work of our thesis are given below,

In NS-3, there are only four routing protocols (AODV, OLSR, DSDV and DSR). DSR is only suitable for MANET routing; so we didn't use DSR for our simulation.

Now a days, a lot of routing protocols were introduced like *BRAVE*, CAR etc. for VANET. These are especially for VANET but not available in NS-3.These could be more realistic routing protocols to implement.

It will be interesting if you we use WAVE module instead of wifi module in NS-3. NS-3 has realized the necessity to implement WAVE module and they are working on this. Hopefully, they will introduce it in coming versions.

Another interesting implementation will be to see the performance in IPV6.
We used only typical packet from NS-3 as CAM (200 bytes) and DENM (100 bytes).If NS-3 introduce new packet type for CAM or DENM in WAVE module, it will be nice to see the realistic result.

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