TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

THESIS NO: 070/MSI/604

Adaptive Clustering Based Hybrid VANET Accommodating Adaptive Data Rate for Performance Enhancement

By

Krishna Kumar Jha

A THESIS

SUBMITTED TO THE DEPARTMENT OF ELECTRONICS AND COMPUTER ENGINEERING IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN INFORMATION AND COMMUNICATION ENGINEERING

DEPARTMENT OF ELECTRONICS AND COMPUTER ENGINEERING

Nov, 2015

Adaptive Clustering Based

Hybrid VANET Accommodating Adaptive Data Rate for Performance Enhancement

By

Krishna Kumar Jha

070/MSI/604

Thesis Supervisor

Daya Sagar Baral

A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Information and Communication Engineering

Department of Electronics and Computer Engineering

Institute of Engineering, Pulchowk Campus

Tribhuvan University

Lalitpur, Nepal

Nov, 2015

COPYRIGHT

TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

DEPARTMENT OF ELECTRONICS AND COMPUTER ENGINEERING

The undersigned certify that they have read and recommended to the Department of Electronics and Computer Engineering for acceptance, a thesis entitled "**Adaptive Clustering Based Hybrid VANET Accommodating Adaptive Data Rate for Performance Enhancement"**, submitted by **Krishna Kumar Jha** in partial fulfillment of the requirement for the award of the degree of "**Master of Science in Information and Communication Engineering**".

____

Supervisor: Daya Sagar Baral
Electronics and Computer Department
Institute of Engineering
Pulchowk campus

____

External Examiner: Er. Ananda Raj Khanal
Director
Nepal Telecommunication Authority

____

Committee Chairperson: Dr. Dibakar Raj Pant
Head
Electronics and Computer Department
Institute of Engineering
Pulchowk campus

____

Date:

DEPARTMENTAL ACCEPTANCE

The thesis entitled "**Adaptive Clustering Based Hybrid VANET Accommodating Adaptive Data Rate for Performance Enhancement**", submitted by **Krishna Kumar Jha** in partial fulfillment of the requirement for the award of the degree of "**Master of Science in Information and Communication Engineering**" has been accepted as a bonafide record of work independently carried out by him in the department.

____

Dr. Dibakar Raj Pant

Head of the Department

Department of Electronics and Computer Engineering

Pulchowk campus, Tribhuvan University, Nepal

ACKNOWLEDGEMENT

I am very much thankful to the Department of Electronics and Computer Engineering, IOE, Pulchowk campus for providing the opportunity for presenting this Thesis entitled "Adaptive Clustering Based Hybrid VANET Accommodating Adaptive Data Rate for Performance Enhancement".

I express my deepest appreciation to my thesis supervisor Daya Sagar Baral, who has the attitude and the substance of a genius. I am very thankful for his expert guidance, suggestions and coordination. Without his guidance and persistent help this dissertation would not have been possible.

I would like to express special thanks of gratitude to the Head of Department of Electronics and Computer Engineering, IOE, Pulchowk Campus, Dr. Dibakar Raj Pant,for his guidance and support.

I am very grateful to our Program Coordinator of Masters of Science in Electronics and Communication Engineering, Dr. Surendra Shrestha for his kind support and valuable coordination.

I would like to express my gratitude to all the Professors and Teachers of Institute of Engineering (IOE) who have helped and guided me directly or indirectly.

Finally, I would like to thank all my friends, colleagues and my family for their precious encouragement and support.

ABSTRACT

The Vehicular Ad-hoc Network (VANET) is the backbone of today's Intelligent Transportation System (ITS). The classes of applications for communication between vehicles range from time critical safety applications to delay tolerant Internet connectivity applications. The communication performance depends on how efficiently and timely the data delivery takes place in the network. Fast topology change and frequent disruptions due to highly mobile nodes of VANETs are the main challenges of VANETs. This thesis implements adaptive clustering of vehicles to improve the data delivery performance of the system. The design of cluster has significant impact on performance, which requires the analysis of physical layer channel condition and MAC operation at data link layer. This thesis analyzes the different propagation model along with the adaptive data rate on physical layer channel condition on real time traffic scenario. The 3G network is also deployed to send the sensitive packet without delay and to improve the system performance. The system performance is evaluated on the basis of throughput and packet delivery ratio. The throughput and packet delivery ratio are found to be better for Nakagami model than Rayleigh model. The clustering based VANET has been found to perform better than normal VANET in case of large number of nodes. The algorithm development and simulation are carried out in NS3 with real time traffic mobility scenario generated by Simulation of Urban Mobility (SUMO).

Keywords: VANET; 3G; NS3; SUMO; DMAC; MAC; Clustering

Table of Contents

List of Figures

List of Tables

List of abbreviations

3G	: 3rd Generation
3GPP	: 3rd Generation Partnership Project
3GSDD	: 3G assisted Sensitive Data Delivery
ADASE2	: Advance Driver Assistance Systems
AP	: Access Points
BSM	: Basic Safety Massage
CAMP	: Crash Avoidance Matrices Partnership
CPU	: Central Processing Unit
DSRC	: Dedicated Short Range Communication
ITS	: Intelligent Transportation System
MAC	: Media Access Control
MANET	: Mobile Ad-hoc Network
NS3	: Network Simulator version 3
PHY	: Physical Layer
RSU	: Road Side Unit
TTL	: Time to live
UTRAN	: Universal Terrestrial Radio Access Network
V2V	: Vehicle to Vehicle
V2R	: Vehicle to Roadside
VANET	: Vehicular Ad-hoc Network

WAVE	: Wireless Access in Vehicular Environments
WSMP	: WAVE short message protocol

1 Introduction

1.1 Background

In today's world, the growing need of data communication for information exchange and safety via wireless communication and the needs of new wireless devices have tend to research on self-organizing, self-healing networks without the interference of centralized or pre-established infrastructure/authority. The network does not rely on pre-centralized or pre-established infrastructure like router in wired networks or access points (AP) in managed wireless networks are called as Ad hoc networks. An ad hoc network typically refers to any set of networks where all devices have equal status on a network and are free to associate with any other ad hoc network device in link range. This enables the devices to create and join networks "on the fly". Ad hoc network often refers to a mode of operation of IEEE802.11 wireless networks.

1.2 Related Theory

1.1.1 Introduction to VANET

Vehicular ad hoc network (VANET) is a promising Intelligent Transportation System (ITS) technology, which enables vehicles to communicate with each other and roadside station. Both vehicle-to-vehicle (V2V) and vehicle-to-road-side-unit (V2R) communications are supported in VANETs to efficiently collect/report traffic updates from/to vehicles as well as road side units (RSUs). It can support critical vehicular safety applications such as emergency warning, collision avoidance, road condition broadcast, and lane-changing assistance [1]. The collected real-time traffic information can be utilized for freeway-traffic-flow managements, individualized vehicle path planning, and vehicle localization. VANET assists vehicle drivers to communicate and to coordinate among themselves in order to avoid any critical situation through Vehicle to Vehicle communication e.g road side accidents, traffic jams, speed control, free passage of emergency vehicles and unseen obstacles etc. The well-known application provided by VANET include, "Advance Driver Assistance Systems (ADASE2), Crash Avoidance Matrices Partnership (CAMP), CARTALK2000 and Fleet Net" that were developed under collaboration of various governments and major car manufacturers.

However, most of the related works assume that the incorporated VANETs have sufficiently small delivery delay for real-time information collection. Actually, as VANETs rely on short-range multi-hop communications, the end-to-end transmission delay can be non-neglectable in some scenarios. Therefore, evaluations should be conducted to study how the end-to-end transmission performance of vehicular communications impacts on the performance of path planning in different scenarios and how to design the transmission mechanisms to reduce the delay when delay is not neglectable. The VANET and hybrid VANET architecture is shown in figure 1.1 and 1.2 respectively.

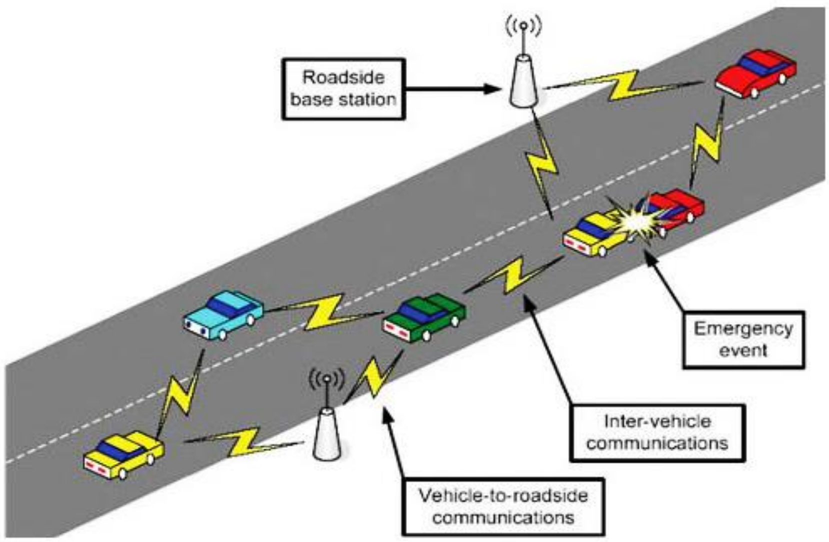

Figure 1.1 VANET Architecture [2]

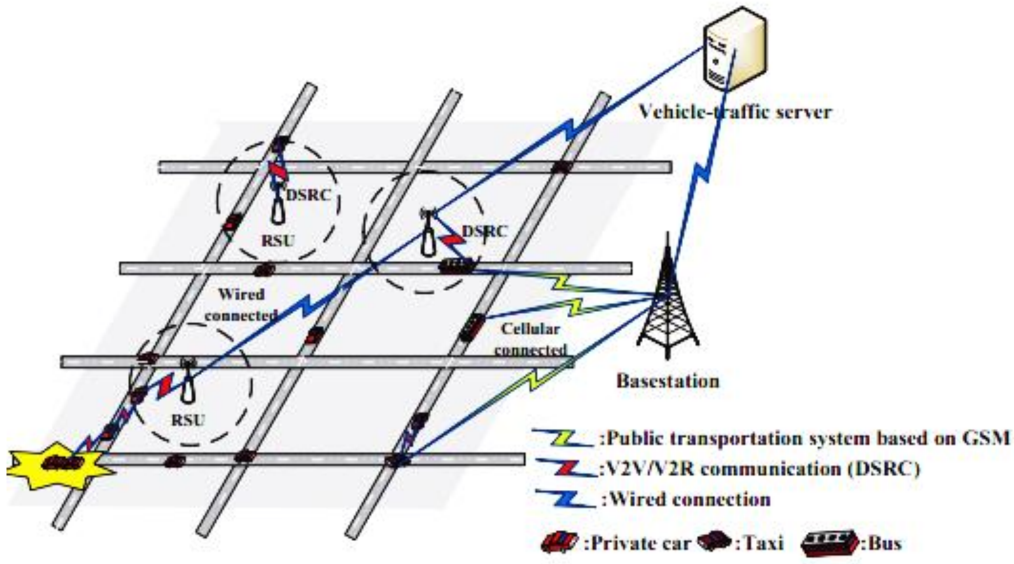

Figure 1.2 Hybrid VANET-enhanced network architecture [3]

Recently, VANETs experience rapid development due to these application, as well as emerging self-driving car technologies. An IEEE dedicated short range communication (DSRC) standard [4], also known as IEEE 802.11p, has been initialized to specify Media Access Control (MAC) protocols and Physical Layer (PHY) for VANETs.

IEEE 802.11p is an approved amendment to the IEEE 802.11 standard to add wireless access in vehicular environments (WAVE). It defines enhancements to 802.11 required to support Intelligent Transportation Systems (ITS) applications. This includes data exchange between high-speed vehicles and between the vehicles and the roadside infrastructure in the licensed ITS band of 5.9 GHz (5.850-5.925 GHz). Some applications of VANETs:

- Vehicle collision warning
- Driver assistance
- Dissemination of road information
- Automatic parking
- Electronic toll collection

Continuous mobility is a key feature of VANETs, which can result in rapid topology changes, unstable communications, and high overhead for exchanging new topology information. To alleviate these negative effects and improve communication quality, clusters can be formed by grouping nearby vehicles driving in the same direction. Vehicles moving in different directions should form different clusters, which is crucial for the stability and reliability of clusters. This can avoid the signaling overhead of repeatedly re-clustering vehicles.

Clustering facilitates stable and scalable network structures and communications, where communications are coordinated/assisted by cluster heads (CHs) [5, 6]. A cluster is formed for data transmission among cluster members as well as to the outside through roadside gateways. In both cases, the cluster heads acts as the access point to facilitate data transmissions, as well as cluster formation and cluster membership management. Within a cluster, a CH manages media access, traffic control, QoS provision. Over the wide VANETs CHs can form dynamic virtual backbone to handle essential function, such as channel allocation and routing at higher layers. Specifically, communication between clusters moving in opposite directions can be implemented through their CHs, when they are passing each other. This help maintain stable clusters, and allow any safety critical message to propagate across the network in a reliable manner.

Under such VANET clustering architecture, the size and geographical span of a cluster are important design issues yet to be solved. Clustering performances, in terms of throughput and packet loss, are affected by several factors: like the MAC protocol operations, the PHY layer wireless channel conditions and the moving pattern of the vehicles.

In practice, all the above conditions influence the design of VANET clusters collectively. It is desirable to integrate them into a single model. Unfortunately, it is challenging to derive a comprehensive and mathematically tractable model to characterize practical VANET clustering processes, due to complicated interactions between the factors of mobility, fading and MAC operations.

Packet delivery ratio and throughput are the major performance factor for the VANET. Data delivery and throughput in VANETs is particularly challenging due to the unique characteristics of VANETs, especially under the circumstance of sparsely connected VANETs. A cluster based VANET along with the deployment of 3g using mobile gateway will improve the aforementioned parameters.

1.1.2 Comparison of VANET and MANET

VANETs have an advantage compared to traditional MANETs: they rarely have constraints related to the capacities of the devices. One important property that distinguishes MANET from VANET is that nodes move with higher average speed and the number of nodes is assumed to be very large.

Mobile Ad-hoc networks and Vehicular Ad-hoc networks are very much similar on various technical grounds but following are some parameters on the basis of which we can contrast both environments.

Table 1.1: Comparisons between MANET and VANET

Parameters	**MANET**	**VANET**
Cost of production	Low	Expensive
Mobility	Low	High
Node density	Sparse	Dense and frequently variable
Bandwidth	Hundred kps	Thousand kps
Range	Up to 100m	Up to 500m
Node lifetime	Depends on power resource	Depends on lifetime of vehicle
Multihop routing	Available	Weakly available
Reliability	Medium	High
Moving pattern of nodes	Random	Regular
Addressing scheme	Attribute based	Location based
Position acquisition	Using ultrasonic	Using GPS, RADAR

1.1.3 VANETS Specifications

Fully autonomous VANETS are still not a complete reality. The IEEE 802.11p amendment to the 802.11 standard is only a draft standard. Complementary with the IEEE 802.11p is the IEEE 1609. The latter outlines the specifications and implementation of the Upper layer protocol stack, while the former deals only with the physical layer and lower part of the MAC layer.

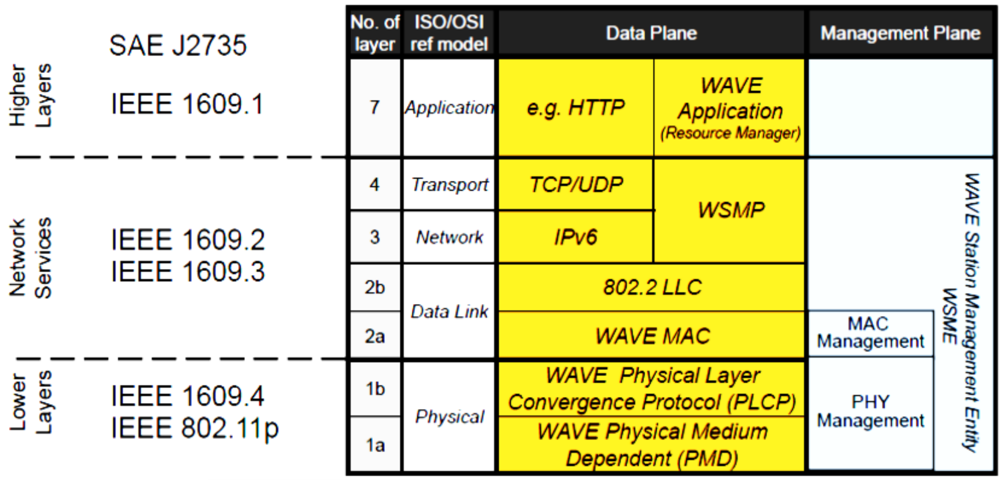

Figure 1.3 VANET communication protocol stack [7]

The figure 1.3 shows the communication protocol stack of VANET. This standard is also known as the dedicated short-range communication DSRC which also is the name for the frequency band 5.850-5.925 GHz. This band is further divided into 7 channels in which there is one control channel used for vehicle broadcasting.

1.2 Problem Statement

The main communication challenge of VANET lies in very poor connectivity caused by unbalanced traffic. Deploying more RSU's may relieve this problem, but it often requires a large amount of investment and elaborate design, especially at the city scale. To minimize the delay and to increase the efficiency of VANET with low cost, integration of the high data rates of IEEE 802.11p VANET with 3G networks will be done i.e. UMTS networks. Previous work and studies on VANET data delivery mostly focused on the infrastructure less VANET and infrastructure-based VANET. Very few studies have considered the integration of 3G in VANET. In this project I focus on the method that has the capability to make potential use of 3G along with improving the data delivery performance. The size of the cluster and the related geographical area have been a matter of interest which have not been properly resolved while designing clustering based VANETs. I ought to implement system measures that quantify the effects of cluster design criteria on VANET performance. The given thesis and analysis provides guidelines for the design and management of VANETs to maintain acceptable communication performance. The paper [1] considers a constant signal to noise ratio threshold for vehicle in order to design cluster sizes and its geographical span which is not the practical case. To significantly enhance the system performance for varying states of clustering in VANETs, I have worked to implement the adaptive data rates to the given cluster model to make it a complete hybrid VANET architecture incorporating the sensitivity issue for critical data as well as the design of adaptive clustered VANET to enhance the throughput and packet delivery ratio.

1.3 Objective

To implement the adaptive data rates to the given cluster model to make it a complete hybrid VANET architecture incorporating the sensitivity issue for critical data as well as the design of clustered VANET for better performance i.e. effect of cluster on throughput and packet delivery ratio.

1.4 Motivation

Vehicular Ad-hoc Networks have been the recent research trend in the field of scientific community of late. It is a very dynamic and complex trend with large practical usefulness especially for implementing Intelligent Transport System (ITS) which in course of time would avoid vehicle collision cases as well as equip the vehicle nodes to make important decision by itself. The practicality of this sector and the future scope it carries with regards to its implementation and useful consequences motivated me to take this sector as part of my thesis topic. Also the idea of bringing a useful enhancement to the IEEE transaction paper propelled me to take up this challenging topic with future prospect as my thesis.

2 Literature Review

In the area of vehicular communications, there has been a plethora of research work. The IEEE has specified 802.11p [4] as the MAC and PHY standard for data exchange between high-speed vehicles and between vehicles and roadside infrastructures in the licensed ITS band of 5.9 GHz (5.85–5.925 GHz). At MAC layer, data are transmitted using broadcast, which is a subset of the IEEE 802.11 standard distributed coordination function (DCF). As a result, most existing VANET Markov models are extensions from the general DCF models. [8] Proposed a Markov model for the throughput of the enhanced distributed channel access (EDCA) mechanism in the IEEE 802.11p MAC sublayer under saturated traffic conditions.

A one-dimensional Markov model for analyzing the performance of periodic broadcast in VANETs was used, where traffic conditions are unsaturated. This model was further extended for a two-dimensional Markov chain queueing model with finite buffer to characterize the broadcast performance of VANETs. These VANET Markov models assume ideal channel conditions, which are not always true in mobile vehicular environment. Empirical path loss models were developed in four different vehicle-to-vehicle environments, i.e., highway, rural, urban and suburban.

In [9] sensitive data handling by 3G in VANET was analyzed and performed. The sensitive data were transmitted with top priority without any conditions and also throughput and data delivery ratio were switched according to requirement. Some works have been done on the connectivity of information propagation focusing on packet loss rate, packet transmission distance and effective coverage range of road-side stations. Studies have also been carried out on the aspect of the moving patterns in VANETs.

In [10], connectivity in VANETs formed between vehicles that move on a typical highway has been investigated. The effects of the speed distribution, traffic flow and the transmission range of the vehicles are discussed. The above models separately characterized the MAC protocol operations, the PHY layer channel fading effects, and the vehicle moving patterns. These models are unable to provide a complete evaluation on VANETs, because in practice, all these factors affect the design of VANET clusters collectively.

In [11], the first attempt to explore the problem of 3G-assisted data delivery in VANETs has been made. They presented an approach called 3GDD which first allocates the 3G budget to each time slot by solving the ILP formulation of the original optimization problem, and then selects those packets that are most unlikely delivered via VANET for 3G transmissions.

A.Benslimane and T. Taleb [12] introduced a novel architecture that integrates 3G/UMTS networks with VANET networks. In the given architecture, a minimum number of gateways, per time instance, was selected to connect ordinary vehicles with the UMTS network. Route stability, mobility features, and signal strength of vehicles are all taken into consideration when clustering vehicles and selecting vehicle gateways. This paper envisions VANET-UMTS integrated network architecture. Coupling the high data rates of IEEE 802.11p-based VANETs and the wide coverage area of 3GPP networks (e.g., UMTS) improved the data delivery performance of VANET drastically. Vehicles are dynamically clustered according to different related metrics. A minimum number of vehicles, equipped with IEEE 802.11p and UTRAN interfaces, are selected as vehicular gateways to link VANET to UMTS. Vehicular gateway selection, gateway advertisement and discovery, service migration between gateways (i.e., when serving gateways lose their optimality) are all addressed and an adaptive mobile gateway management mechanism is proposed.

3 Methodology

In this thesis, the methodology is concerned with the physical layer condition, clustering and sensitive data handling via 3g for performance enhancement. So the methodology for this proposed system are divided into following parts and they are:

3.1 VANET-UMTS Integration

Through this mechanism, the sensitive data that is crucial for the entire system can be transmitted through 3G. This increases the delivery ratio and throughput. Also these sensitive data if allowed to hop through multiple hops might be requiring a lot of time before it reaches its intended destination. The very essence of sending this crucial information might fail. So sending these sensitive data through 3G as soon as identifying it to be sensitive would greatly minimize the end to end delay of the system. An architecture that integrates 3G/UMTS networks with VANET is introduced. The figure 3.1 shows the generation of sensitive packet.

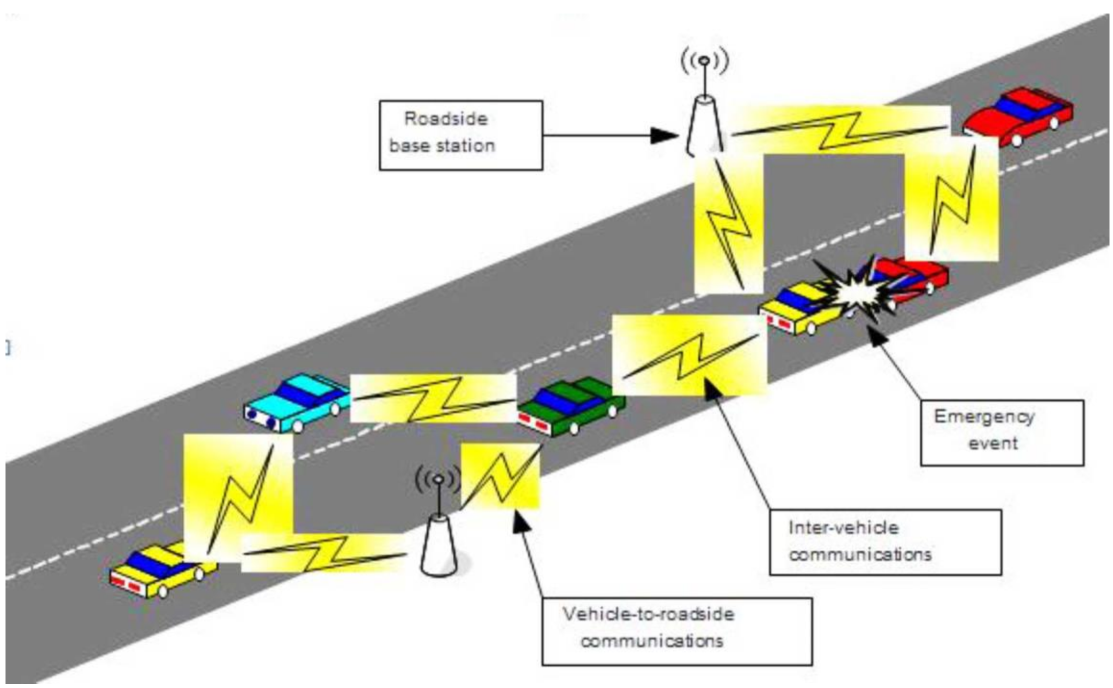

Figure 3.1 An instance of the origin of sensitive data [2]

The accidental data and the data concerning road blockage due to landslides and other such data will require immediate attention. Such data are termed as sensitive data in the thesis.

3.2 VANET System Architecture

Here, a VANET system is proposed from the aspects of network structure, MAC Layer operations, PHY layer wireless fading and vehicle mobility. These aspects will be analytically characterized one by one in the next section, providing a new methodology of comprehensively modelling VANETs.

3.2.1 Channel Condition at PHY Layer

The channel condition at PHY layer has great influence on throughput and data loss. The different models used for propagation of signal has varying effect on data loss and throughput. Radio propagation is the behavior of radio waves when they are transmitted, or propagated from one point on the Earth to another, or into various parts of the atmosphere. Like light waves, radio waves are affected by the phenomena of reflection, refraction, diffraction, absorption, polarization and scattering [13].

The figure 3.2 represents the radio propagation models and the evolution of it's from free space to Nakagami radio propagation.

In this thesis, two propagation model i.e., Nakagmi and Rayleigh are analyzed.

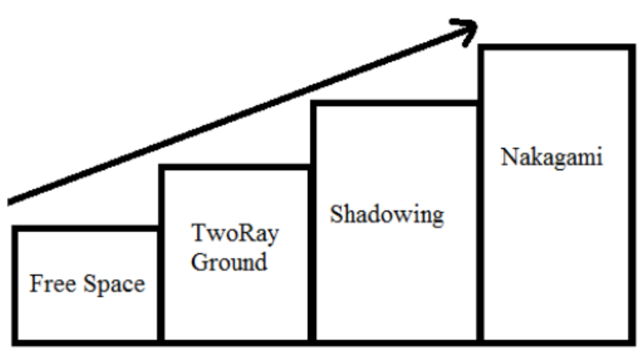

Figure 3.2 Radio Propagation Models Evolution for VANET

3.2.1.1 Nakagami Propagation Model

Nakagami is a mathematical general modeling of a radio channel with fading. Nakagami distribution is defined by the following probability density function:

$$f(x) = \frac{2m^m x^{2m-1}}{\Gamma(m)\Omega^m} exp\left[\frac{-mx^2}{\Omega}\right], x \geq 0, \Omega > 0, m \geq 1/2 \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (6.1)$$

The corresponding pdf (probability density function) of power (square of the signal amplitude) at the given distance can be obtained by a change of variables and is given by a gamma distribution of the following form:

$$p(x) = \left(\frac{m}{\Omega}\right)^m \frac{x^{m-1}}{\Gamma(m)} exp\left[\frac{-mx}{\Omega}\right], x \geq 0 \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (6.2)$$

Ωis the expected value of the distribution and can be interpreted as the average received power and m is the shape or fading parameter. The values of the parameters m and **Ω** are functions of distance. So the Nakagami model is defined by two functions: **Ω** (d) and m (d).

The Nakagami model is a general model, the Rayleigh distribution is a special case of Nakagami distribution where m (d) = 1 (for every d).

3.2.1.2 Rayleigh Fading/Propagation Model

Rayleigh fading is the name given to the form of fading that is often experienced in an environment where there is a large number of reflections present. The Rayleigh fading model uses a statistical approach to analyze the propagation, and can be used in a number of environments.

Rayleigh distribution is defined by the following probability density function:

$$f(x) = \frac{2x}{\Gamma(m)\Omega^m} exp\left[\frac{-x^2}{\Omega}\right], x \geq 0 \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (6.3)$$

3.2.1.3 Adaptive Data Rate

The energy of the received signal S(k, t) is assumed to be zero outside of the reception interval of packet k and is calculated from the transmission power with a path-loss propagation model mentioned above in the reception interval:

$$p_l(d) = p_l(d_0) + n10log_{10}\left(\frac{d}{d_0}\right) \quad \text{……………………………………………....... (6.4)}$$

where the path loss exponent, n, is chosen equal to 3, the reference distance, d0 is chosen equal to 1.0m, and the reference energy $p_l(d_0)$.

When the last bit of the packet upon which the PHY is synchronized is received, the probability that the packet is received with any error, Perr (k), is calculated to decide whether or not this packet could be successfully received or not. To evaluate Perr (k), the piecewise linear functions shown in figure 3.3is used and the Signal to Noise Interference Ratio function SNIR(k, t) is calculated with equation the equation (6.5).

$$SNIR(k,t) = \frac{S_k(t)}{N_i(k,t)+N_f} \quad \text{……………………………………………….............. (6.5)}$$

Where N_f represents the noise floor, which is a characteristic constant of the receiver circuitry, and $N_i(k,t)$represents the interference noise, that is, the sum of the energy of all the other signals received on the same channel:

$$N_i(k,t) = \sum_{m \neq k} s(m,t) \quad \text{……………………………………………….............. (6.6)}$$

From the SNIR(k, t) function, the BER(k, t)for BPSK is derived by

$$BER(k,t) = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_0}(k,t)}\right) \quad \text{………………………………………………….. (6.7)}$$

Where E_b is the energy per bit, N_0 the noise power density, and$\frac{E_b}{N_0}(k,t)$ is defined as:

$$\frac{E_b}{N_0}(k,t) = SNIR(k,t)\frac{B_t}{R_b(k,t)} \quad \text{………………………………………………....... (6.8)}$$

B_t is the unspread bandwidth of the signal and $R_b(k,t)$ is the bit rate of the transmission model used by signal k at time t. The SNR calculated above is compared with a random number generated and then the data rate is adapted according to that.

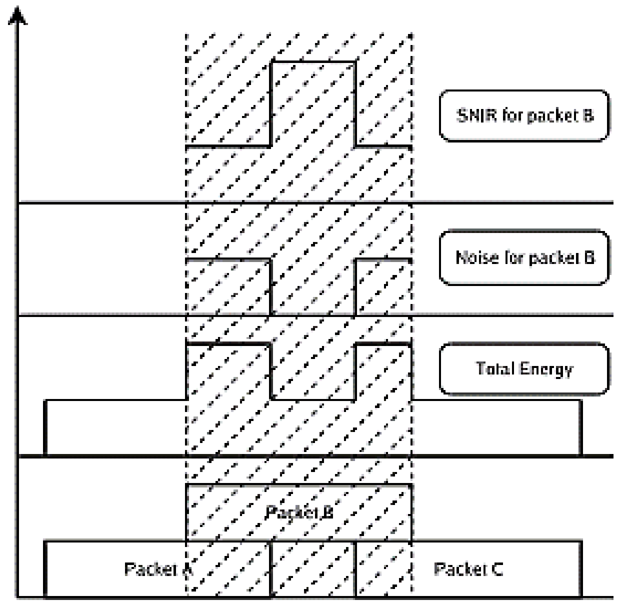

Figure 3.3 SNIR function over time

The Perr (k) is given by

$$p_{err}(k) = 1 - \prod(1 - p_e(k,l)) \quad (6.9)$$

Where $p_e(k,l)$ function represents an upper bound on the probability that an error is present in the chunk of bits located in interval l for packet k.

3.2.2 Clustering in VANET

Clustering is proposed to increase the performance of system. Here a cluster head is assigned to a cluster of n vehicles driving in the same direction along an uninterrupted highway. The focus is on the characteristics of stable clusters of vehicles. A CH is selected according to the scenario of cluster, and the other (n−1) vehicles are the cluster members. Let x_i and x_{ic} denote the positions of the i-th vehicle and the CH in the x-axis ($i \neq i_c$). s_i is the distance between the i-th vehicle and the CH, $s_i = |x_i - x_{ic}|$. The set of distances between the CH and the members is denoted by S={s1,s2,⋯,sn}. Communication within a cluster is assisted by the CH, which receives, processes and forwards messages from the other (n−1) vehicles. The reference time scale of the packet transmission we consider is of milliseconds. Assume the variation of the vehicles' speed is negligible within the reference time interval.

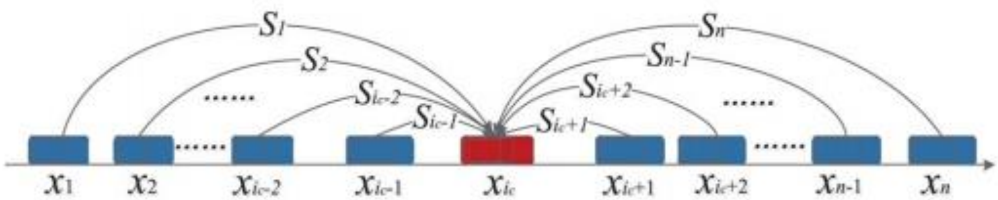

Figure 3.4Illustration of a linear cluster in VANETs [1]

3.2.2.1 Clustering Algorithm

Here DMAC mobility based clustering scheme is used.

Distributed and Mobility-Adaptive Clustering (DMAC) Algorithm

The algorithm is suitable for both the clustering set up and its maintenance. Adaptation to changes in the network topology is made possible by letting each node to properly react not only to the reception of a message from other nodes, but also to the failure of a link with another node (possibly caused by a node failure, or by nodes' movements) or to the presence of a new link.

The algorithm starts by making two common assumptions:

- ✓ a message sent by a node is received correctly within a finite time (a step) by all its neighbors
- ✓ each node knows its own ID, its weight, its role (if it has already decided to be a clusterhead or an ordinary node) and the ID, the weight and the role of all its neighbors (if they have already decided their role). When a node has not yet decided what its role is going to be, it is considered as an ordinary node.

  The algorithm is executed at each node in such a way that at a certain time a node v decides (to change) its role. This decision is entirely based on the decision (i.e. the role) of the nodes $u \in \Gamma(v)$ such that $w_u > w_v$.

- *Init:* At the clustering set up, or when a node v is added to the network, it executes the procedure Init in order to determine its own role. If among its neighbors there is at least a clusterhead with bigger weight, then v will join it. Otherwise it will be a clusterhead. Notice that a neighbor with a bigger weight that has not decided its role yet (this may happen at the clustering set up, or when two or more nodes are added to the network at the same time), will eventually send a message (every node executes the Init procedure). If this message is a C H message, then v will affiliate with the new clusterhead.

PROCEDURE *Init;*

begin

    if $\{ z \in \Gamma(v): w_z > w_v \Lambda\, ch(z)\} \neq \emptyset$

        then begin

            x:=max $w_z > w_v\{z: ch(z)\}$;

            send Join(v,x);

            clusterhead:=x

            end

        end begin

            send CH(v);

            ch(v) := **true;**

            clusterhead := *v;*

            cluster (v) := {v}

            end

end;

- *Link failure:* Whenever made aware of the failure of the link with a node u, node v checks if its own role is clusterhead and if u used to belong to its cluster. If this is the case, v removes u from Cluster (v). If v is an ordinary node, and u was its own clusterhead, then it is necessary to determine a new role for v. To this aim, v checks if there exists at least a clusterhead $z \in \Gamma(v)$ such that $w_z > w_v$. If this is the case, then v joins the clusterhead with the bigger weight, otherwise it becomes a clusterhead.

```
PROCEDURE Link_failure(u);
begin
        if ch(v) and (u ∈ Cluster(v))
                then Cluster (v):= Cluster (v)\{u}
        else if Clusterhead=u then
                if { z ∈ Γ(v): w_z > w_v Λ ch(z)} ≠ ∅
                then begin
                        x:=max w_z > w_v{z: ch(z)};
                        send Join(v,x);
                        clusterhead:=x
                        end
                end begin
                        send CH(v);
                        ch(v) := true;
                        clusterhead := v;
                        cluster (v) := {v}
                        end
end;
```

- *New link:* When node v is made aware of the presence of a new neighbor u, it checks if u is a clusterhead. If this is the case, and if w_u is bigger than the weight of v's current clusterhead, than, independently of its own role, v affiliates with u.

```
PROCEDURE New_link(u);
begin
        if ch(u) then
                if (w_u > w_Clusterhead)
                then begin
                        send Join(v,u);
                        clusterhead:=u
                        if Ch(v) then Ch(v) := false
                        end
                end ;
```

- *On receiving CH(u):* When a neighbor u becomes a clusterhead, on receiving the corresponding CH message, node v checks if it has to affiliate with u, i.e., it checks whether w_u is bigger than the weight of v's clusterhead or not. In this case, independently of its current role, v joins u's cluster.

```
On receiving CH(u);
begin
        if (w_u > w_Clusterhead) then
                        send Join(v,u);
                        clusterhead:=u
                        if Ch(v) then Ch(v) := false
                        end
end ;
```

- *On receiving JOIN(u,z):* On receiving the message JOIN(u,z), the behavior of node v depends on whether it is a clusterhead or not. In the affirmative, v has to check if either u is joining its cluster (z =v: in this case, u is added to Cluster (v)) or if u belonged to its cluster and is now joining another cluster (z≠v: in this case, u is removed from Cluster (v)). If v is not a clusterhead, it has to check if u was its clusterhead. Only if this is the case, v has to decide its role: It will join the biggest clusterhead x in its neighborhood such that $w_x > w_v$ if such a node exists. Otherwise, it will be a clusterhead.

On receiving Join(u,z);

begin

    if *Ch(v)*

        then if z=v **then** Cluster(v) :=Cluster (v) ∪ {u}

            else if $u \in cluster\ (v)$ **then** cluster (v):= cluster (v)\{u}

        else if clusterhead = u **then**

            if $\{\ z \in \Gamma(v): w_z > w_v \Lambda\ ch(z)\} \neq \emptyset$

                then begin

                    x:=max $w_z > w_v\{z: ch(z)\}$;

                    send Join(v,x);

                    clusterhead:=x

                end

            end begin

                send CH(v);

                ch(v) := **true;**

                clusterhead := *v;*

                cluster (v) := {v}

            end

end;

3.3 Description of Proposed Work Flow

The figure3.5 shows the flowchart of proposed work in this thesis.

The algorithm considers the availability of digital map containing the information of road map and the RSUs locations and GPS in each vehicle which will give the position & speed. If a vehicle, say V1, wants to send data then its position in map is obtained from the GPS and then the nature of data is checked. If the data is a BSM packet then the data is broadcast using 802.11p WSMP (WAVE short message) protocol. If the data is non-BSM packet then it is again checked whether it is sensitive or not. The sensitive packet is sent through the 3G network to the destination. If the data is neither sensitive nor BSM then path from source to destination is searched through clusterhead using AODV protocol broadcast request query. The node broadcasts a request for connection. Other AODV nodes forward this message, and record the node that they heard it from, creating an explosion of temporary routes back to the needy node. When a node receives such a message and already has a route to the desired node, it sends a message backwards through a temporary route to the requesting node. After getting the message, the data rate is adapted according to the calculated SNR. The source node then transmits the data packet using the route that has the least number of hops through to the destination.

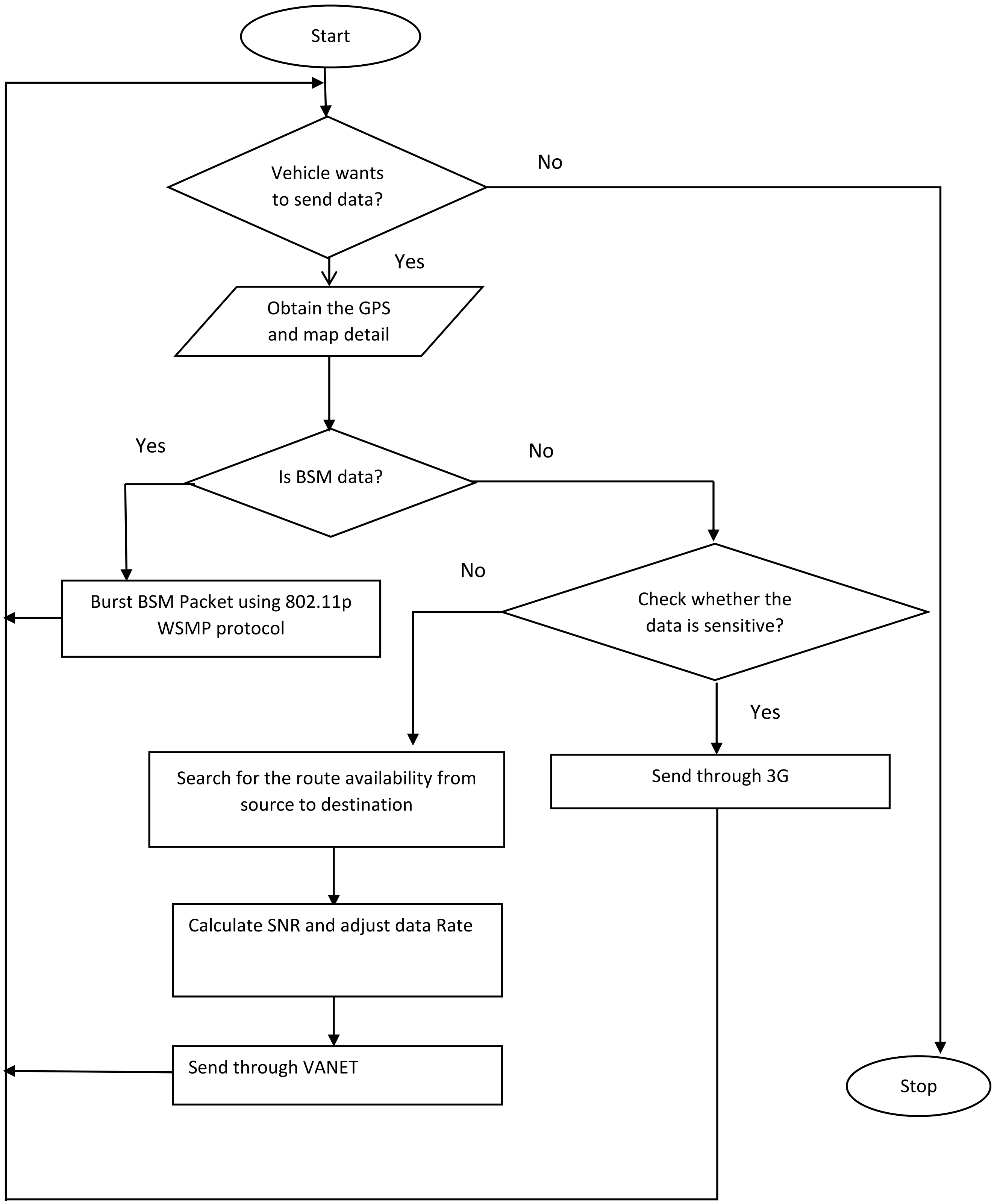

Figure 3.5 Flowchart of Working Step to Send a Packet

The given figure 3.6 shows the frame format. In the given approach, the reserved bit which is shown in the figure can be used to differentiate normal data from sensitive ones. For eg. 1 in that reserved bit position is used to indicate the start of sensitive information whereas a 0 would represent normal data.

Through this mechanism, the data that might be lost due to the expiry of TTL can be transmitted through 3G. This would increase the delivery ratio. Also these sensitive data if allowed to hop through multiple hops might be requiring a lot of time before it reaches its intended destination. The very essence of sending this crucial information might fail. So sending these sensitive data through 3G as soon as identifying it to be sensitive would greatly minimize the end to end delay of the system.

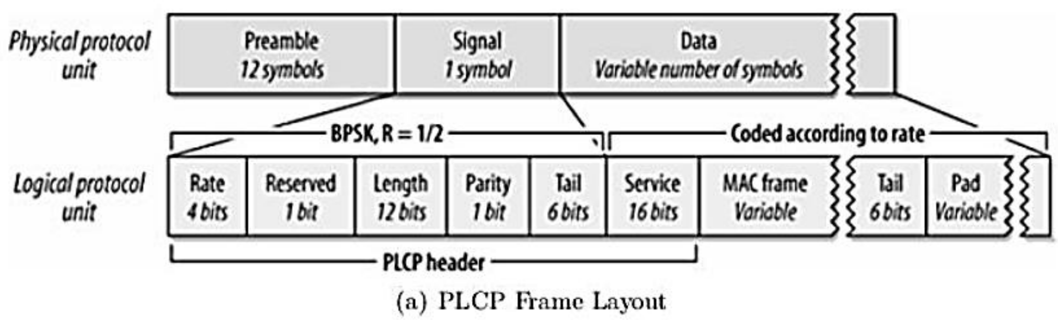

Figure 3.6 The basic Frame structure [14]

3.4 Project Breakdown

The whole work is broken down into two major parts:

i. Real Time Traffic Mobility generation using Traffic Simulator
ii. Network Simulation using Network Simulator

3.4.1 Traffic Simulator

Traffic simulation is Mathematical modeling of transportation system which is used for the application of computer software in order to help and provide a better way to effectively plan, design and operate transformation systems.

3.4.1.1 Simulation of Urban Mobility

Simulation of Urban Mobility (SUMO) is an open source traffic simulation package that includes net import and demand modeling components. SUMO helps to investigate several research topics e.g. route choice and traffic light algorithm or simulating vehicular communication. Therefore the framework is used in different projects to simulate automatic driving or traffic management strategies.

In this thesis the SUMO is used to generate real traffic on 4-way intersection junction and on the real map of Thapathali area, Kathmandu, Nepal.

Steps Generating Real Time Traffic on 4-way intersection Junction

The figure 3.7shows the steps involved in creating the real time traffic on 4-way intersection Junction.

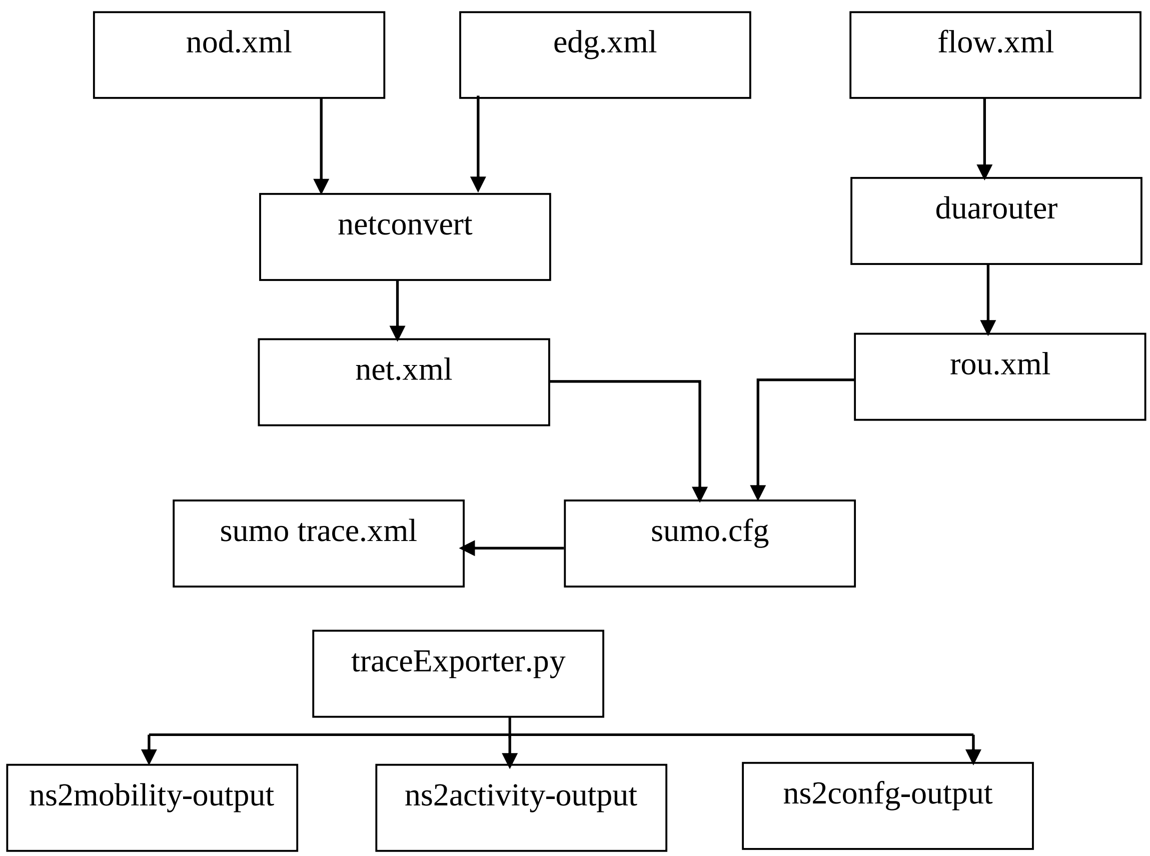

Figure 3.7 Steps involve in Generating Real Traffic Mobility

First a node file is created with a given number of nodes having node ID, position, type and other attributes. This node in real field represents the junction of the road network. The edge file is also created along with node file. The edge file joins the node, which has a unique ID, source node to destination node, type and other attributes. After that another file called connection file is defined, which describe how a node's incoming and outgoing edges are connected. We can specify connections on the edge level or you can declare in in detail which incoming lane shall be connected to which outgoing lanes. All together these three files are used to convert into network file with "netconvert command".

Traffic demand and route data is defined together with vehicle type data in a file with the extension name *.rou.xml*. The sample code used for creating route file having vehicle type data and vehicle is shown in figure 3.8.

```
<routes>
<vType id="type1" accel="0.8" decel="4.5" sigma="0.5" length="5"
maxSpeed="70"/>

<route id="route0" color="1,1,0" edges="beg middle end rend"/>

<vehicle id="0" type="type1" route="route0" depart="0"
color="1,0,0"/>
<vehicle id="1" type="type1" route="route0" depart="0"
color="0,1,0"/>

</routes>
```

Figure 3.8 route file creation example

And then sumo configuration file is written, which takes input as route file and network file and generate the trace file which is later used to convert into ns2mobility trace file using traceExporter.py command of sumo.

Steps Generating Real Time Traffic on 4-way Real Map

The map of Thapathali, Kathmandua is used to generate the real traffic scenario. The map of given area which is to be simulated is imported from OpenStreetMap (OSM). The map is saved as .osm file. The .osm file is then converted into sumo network file i.e .net.xml file using the steps mentioned in the figure 3.9.

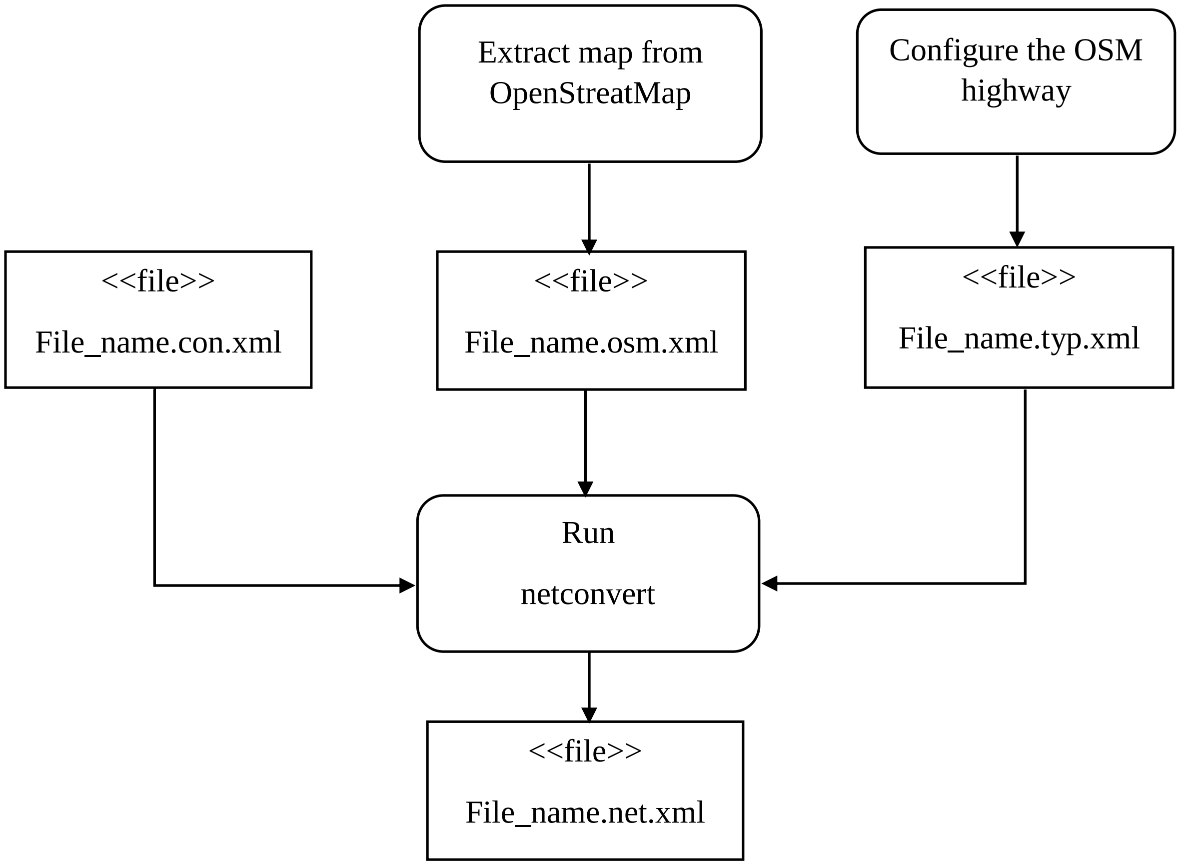

Figure 3.9 Steps of converting a Real World Map into SUMO network file [15]

The .net.xml file and route file which consists of the vehicle type and route from source node to destination node is then converted into sumo trace.xml file using the configuration file of SUMO.

After getting the sumo trace.xml, this file is converted into ns2 mobility file using the traceExporter.py of SUMO, which is then used for mobility model of nodes for network simulation of VANET. Here the map of Thapathali region of Nepal as shown in figure 3.10 is selected for the generation of mobility traffic for the analysis of VANET.

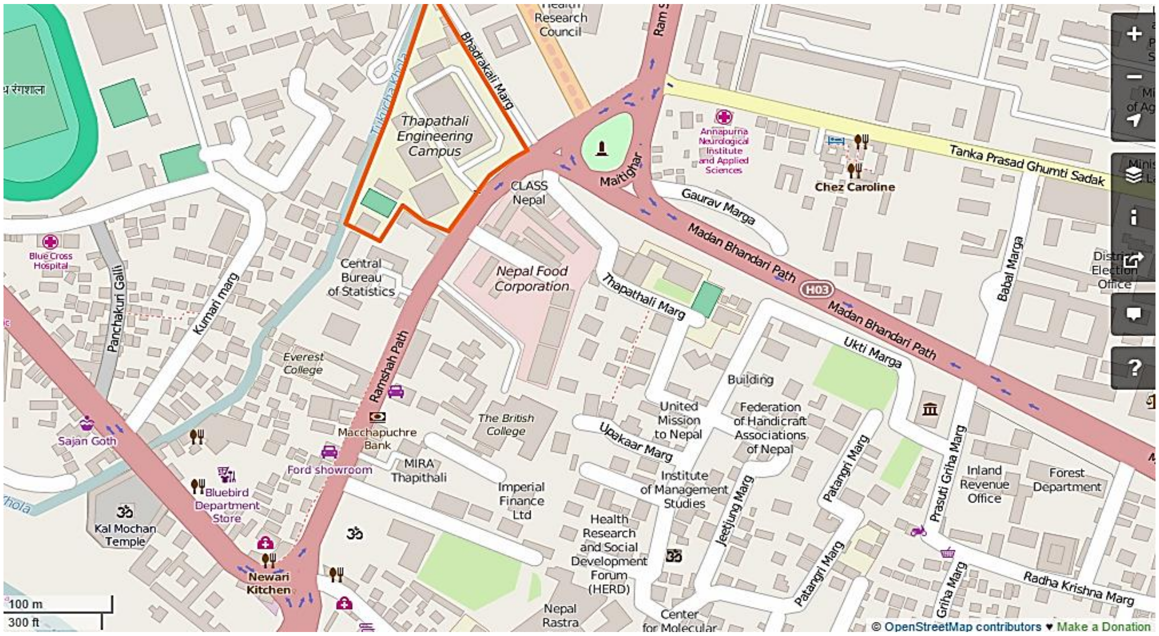

Figure 3.10 Map of Thapathali

3.4.2 Network Simulator

A network simulator consists of a wide range of networking technologies and protocols and help users to build complex networks from basic building blocks like clusters of nodes and links.

3.4.2.1 NS3

NS-3 is a discrete-event network simulator and a free software which succeeds popular network simulator NS-2, licensed under the GNU GPLv2license and is publicly available for research, development and use [16]. The goal of the NS-3 project is to develop a preferred, open simulation environment for networking research. NS-3 is available for Linux, Mac OS and MS Windows using cygwin.

Here C++ scripts is used for VANET simulation. Here different propagation module and wave as well as 802.11p modules have used for the performance analysis of VANET.

The figure 3.11 shows the snaps of data delivery under VANET animation. The animation creates the area of road structure in square for animation. The figure shows the communication via wirelessly by circle.

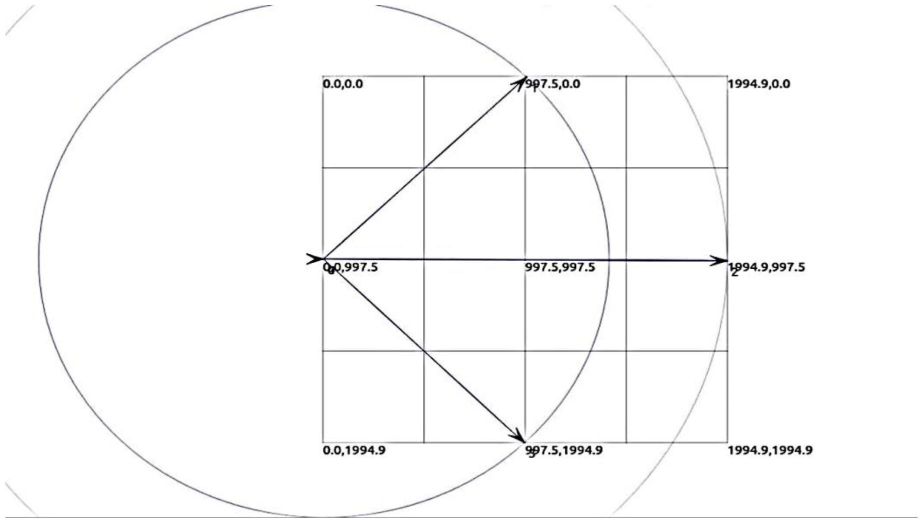

Figure 3.11 Snap of Data Delivery in VANET

4 Result and Analysis

4.1 Implementation

4.1.1 Simulation

Simulation is the technique of solving problems by the observation of the performance, over the time, of a dynamic model of the system. Simulation generally represents the relationship between the systems and models. A system is the collection of components that are interrelated and interacted in such a way that it distinguishes the system from its environment.

A model is a simplified representation of the system intended to predict what happens if certain actions are taken. Simulation development is iterative process in which the construction, execution and analysis of a model repeatedly perform in order to achieve desired level of understandings.

4.1.2 Traffic Mobility Simulation

Traffic mobility is simulated using SUMO by following the process mentioned in the methodology section.

The table 4.1 shows the traffic simulation parameter used in SUMO to simulate the vehicle and generate the mobility file.

Table 4.1 Simulation Parameter for Traffic Mobility

Vhicle No.		108			
Vehicle Type		CAR			
Car-following Model		Krauß-model			
Sigma (Driver imperfection 0-1)		0.5			
Min Gap		3m			
Lane Type		Max. Speed in Km/hr			
	Lane 1	80			
	Lane 2	40			
	Lane 3	70			
Car Type		Max. Acceleration	Max. Decceleration	Length	Max. Speed in Km/hr
	A	3	6	2.5	180
	B	2	6	3.5	180
	C	1	5	2.5	144
	D	1	5	3.5	108

The figure 4.1 and figure 4.2 show the simulation snaps shot of vehicle mobility on 4-way intersection junction and on the real map of Thapathali area.

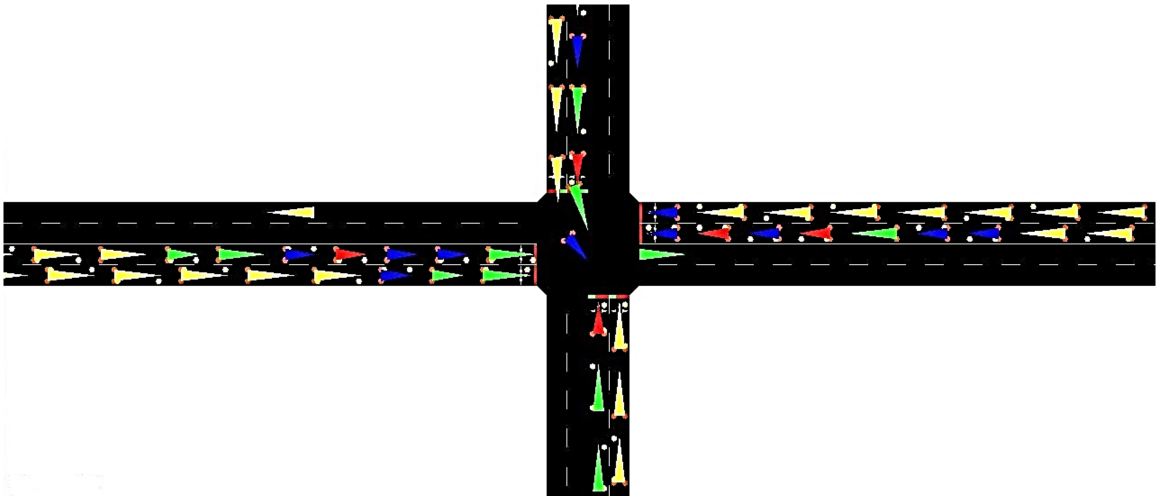

Figure 4.1 Snap of Simulation of Vehicle on 4-way Junction

Figure 4.2 Snap of Simulation of Vehicle on Thapathali Map

4.1.3 Network Simulation

The VANET network is simulated using Network Simulator NS version 3.23. NS-3 is a discrete-event network simulator and a free software which succeeds popular network simulator NS-2, licensed under the GNU GPLv2 license and is publicly available for research, development and use [16]. The goal of the NS-3 project is to develop a preferred, open simulation environment for networking research. NS-3 is available for Linux, Mac OS and MS Windows using cygwin.

The ns-3 project is committed to building a solid simulation core that is well documented, easy to use and debug, and that caters to the needs of the entire simulation workflow, from simulation configuration to trace collection and analysis.

Furthermore, the ns-3 software infrastructure encourages the development of simulation models which are sufficiently realistic to allow ns-3 to be used as a real time network emulator, interconnected with the real world and which allows many existing real-world protocol implementations to be reused within ns-3.

The ns-3 simulation core supports research on both IP and non-IP based networks. ns-3 also supports a real-time scheduler that facilitates a number of "simulation-in-the-loop" use cases for interacting with real systems. For instance, users can emit and receive ns-3-generated packets on real network devices, and ns-3 can serve as an interconnection framework to add link effects between virtual machines.

A simple NS-3 script can be written in either C++ or Python language. NS-3 is built on both-C++ and Python bindings.

Here C++ scripts is used in simulation. Here different propagation module and wave as well as 802.11p modules have used for the performance analysis of VANET.

4.1.3.1 Network participants and deployment

Network design consists of wireless ad hoc network for the generation of simulation results. The network consists of road map, mobile nodes (vehicles), static nodes (RSU and 3G) and GPS enabling in vehicles. In this section these network participants and its configuration and deployment for simulation setup are discussed briefly.

Road network construction

Road map construction plays an important role to study vehicles behavior in specific area. To observe a vehicle behavior road construction should be more realistic. Vehicles speed, movement and braking etc. are proportional to road conditions, inter-vehicular distance and vehicles distance from the traffic signals. For this simulation roads and vehicle types and their mobility is generated using SUMO as mentioned above. A total of 108 vehicles are used to generate the mobility.

The generated mobility file is used in NS3 for the vehicle mobility in real field scenario.

Mobile Nodes (Vehicles)

Vehicles are the network participants that are used to communicate among themselves on the roads. The request from a source to destination is sent by gathering the geographical data with help of other intermediate nodes. Each vehicle is assigned a unique node number. Vehicles will move in a particular lane only.

Static Nodes (RSU and 3G)

Road Side Units (RSUs) and 3G BTS (Node B) are static nodes. One 3G BTS and 5 RSUs are deployed. To know the position and speed of each vehicle, GPS is enabled for each vehicle. Position and speed is updated continuously to achieve good accuracy.

The Network simulation parameter used here is given in the table 4.2.

Table 4.2 Simulation Parameter for NS3

Area	2KM * 2KM or Map of Thapathali Area
Channel	Channel/ Wireless Channel
Propagation Model	Nakagami or Rayleigh
Network Interface	Phy/WirelessPhy
MAC Interface	MAC/802.11p
Antenna Type	Omni Antenna
Total No of VANET Vehicle	5-80
Transport Layer Protocol	UDP
Data Packet Size	64B
BSM Packet Size	200B
Transmit Power	20dBm

Antenna gains of transmitter and receiver 1	1dB

The figure 4.3 shows the animation of simulation of VANET used in this scenario. The NetAnim, which is an offline animator based on the Qt toolkit is used to animate the simulation using an XML trace file collected during simulation.

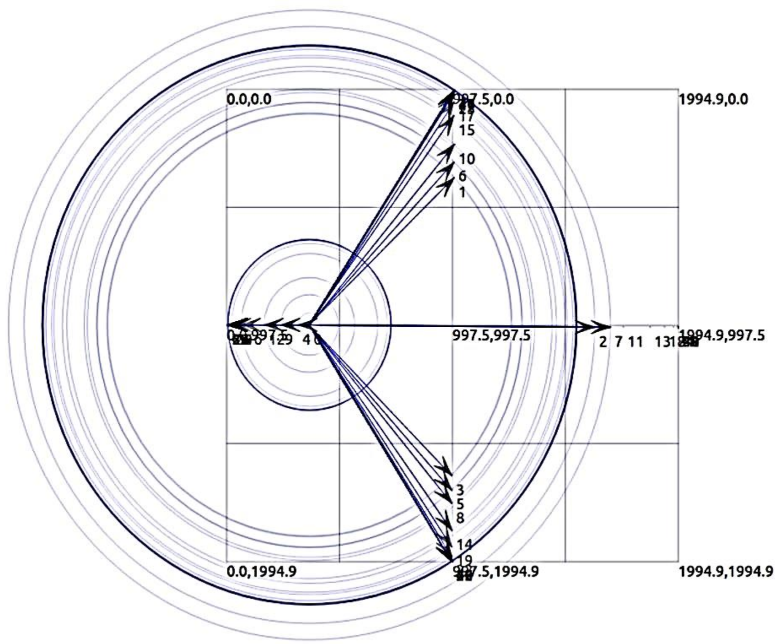

Figure 4.3 Animation Snap of VANET

4.2 Analysis

In this section the simulation results are discussed and analyze. Many situations can be considered and many possibilities can be simulated in order to perform VANET simulation. In this thesis, the performance of different propagation model with adaptive data rate and 3g in real time traffic is analyzed for achieving better throughput and packet delivery ratio.

4.2.1 Throughput Analysis

The figure 4.4 below shows the throughput of BSM and non-BSM packets under different conditions.

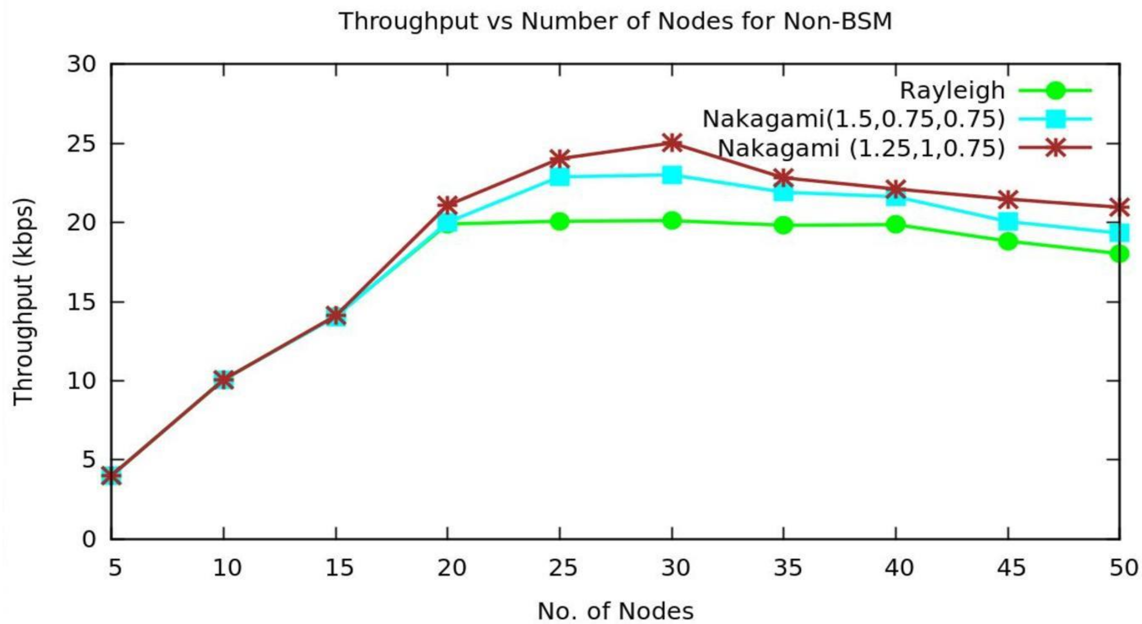

Figure 4.4 Throughput vs Number of node Non-BSM packet

The figure 4.4 gives the variation of throughput with the number of nodes for Rayleigh and Nakagami model accommodating adaptive data rate. For number of nodes less than 15, there is no major difference in the throughput. However as the number of nodes increase, the chances of packet loss due to interference of noise and channel congestion increase more in case of Rayleigh than the Nakagami model. So the Nakagami model gives better response compared to Rayleigh as shown in figure 4.4. The value attains peak at 30 nodes and then again starts to decrease gradually.

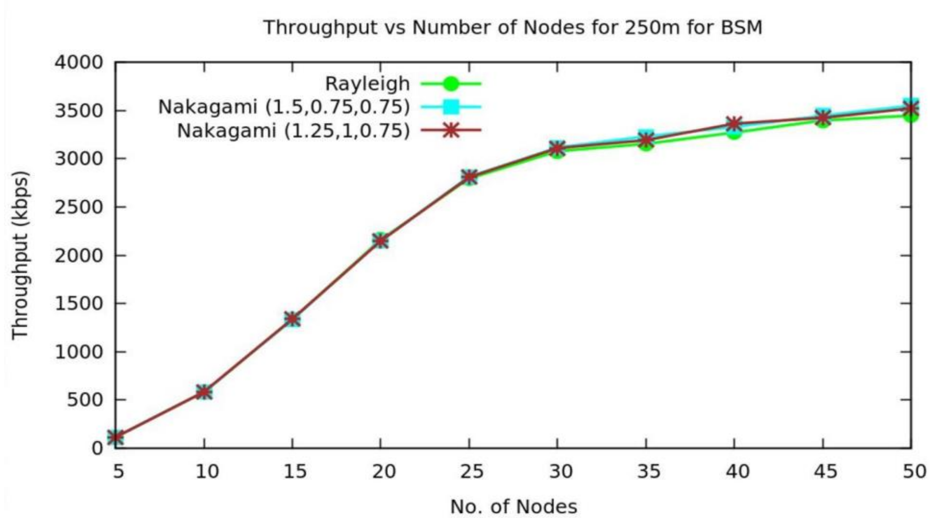

Figure 4.5 Throughput vs Number of node for BSM packet for 250m distance

As the number of nodes increase within the same area the interference also increase so the throughput gets affected but the rate of decrement is slow.

The figure 4.5 shows the variation of the throughput vs number of nodes for 250m safety ranges for BSM packet. Nakagami model fares better as compared to the Rayleigh model.

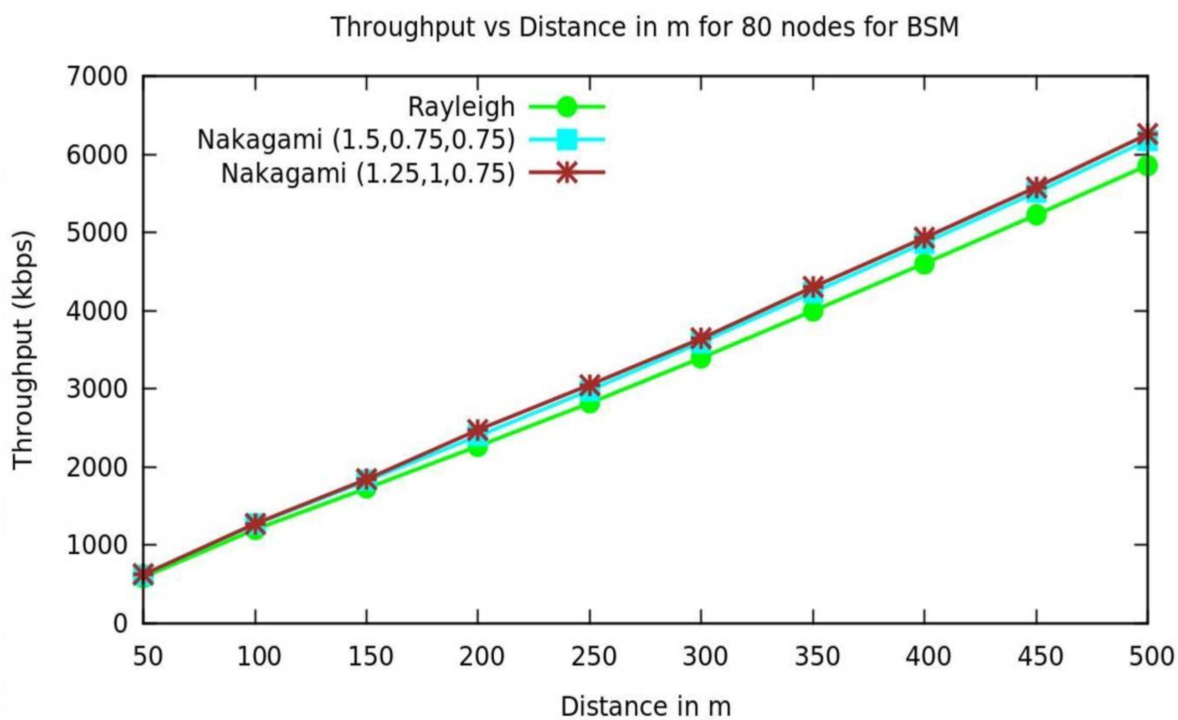

Figure 4.6 Throughput vs Distance in m for 80 nodes for BSM packet

The figure 4.6 shows the variation of the throughput versus distance at constant node number 80. The graph shows that, the throughput increases with increase in safety range distance for all case. However the values in all case is greater for Nakagami model having m value 1.25,1 and 0.75 for distances less than 80m, between 80 to 200m and greater than 200m respectively.

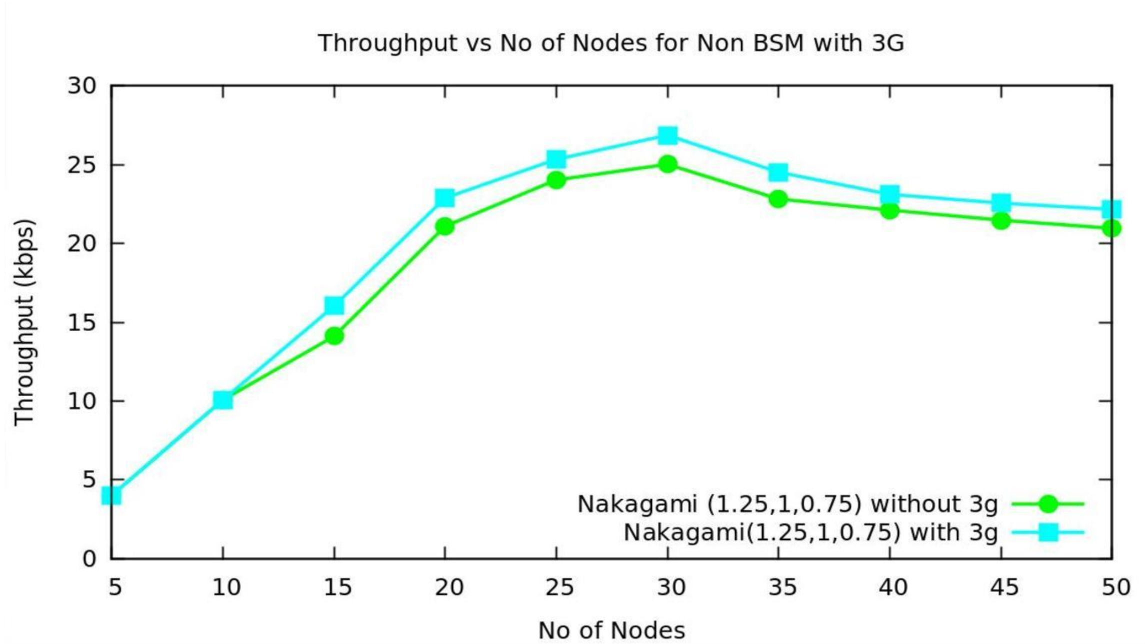

Figure 4.7 Throughput vs No of Nodes for Non-BSM with 3G

Since the throughput versus number of nodes is better for Nakagami model as verified from the given analysis, so 3G is analyzed only with Nakagami model in this thesis. The figure 4.7 depicts that for the lower number of nodes the sensitive packet generated by nodes are less so they have same throughput. But as the number of nodes increase, the chance of increase of sensitive packet also increases, which are directly routed through the 3G network, so the throughput gets increased. And the sensitive packet is routed to destination without being delayed.

The figure 4.8 shows the variation of throughput with number of nodes for clustering of vehicles and without clustering it. The analysis has been done for Nakagami model only. It depicts similar throughput for the lower number of nodes in both the clustering based VANET and normal VANET. But as the number of nodes increase, the clustering based VANET have better throughput. As the number of nodes goes on increasing, the throughput for clustered vehicles also increases with respect to normal VANET. So it can be said from the given graph that the effect of clustering of vehicles become more logical as the number of nodes increase.

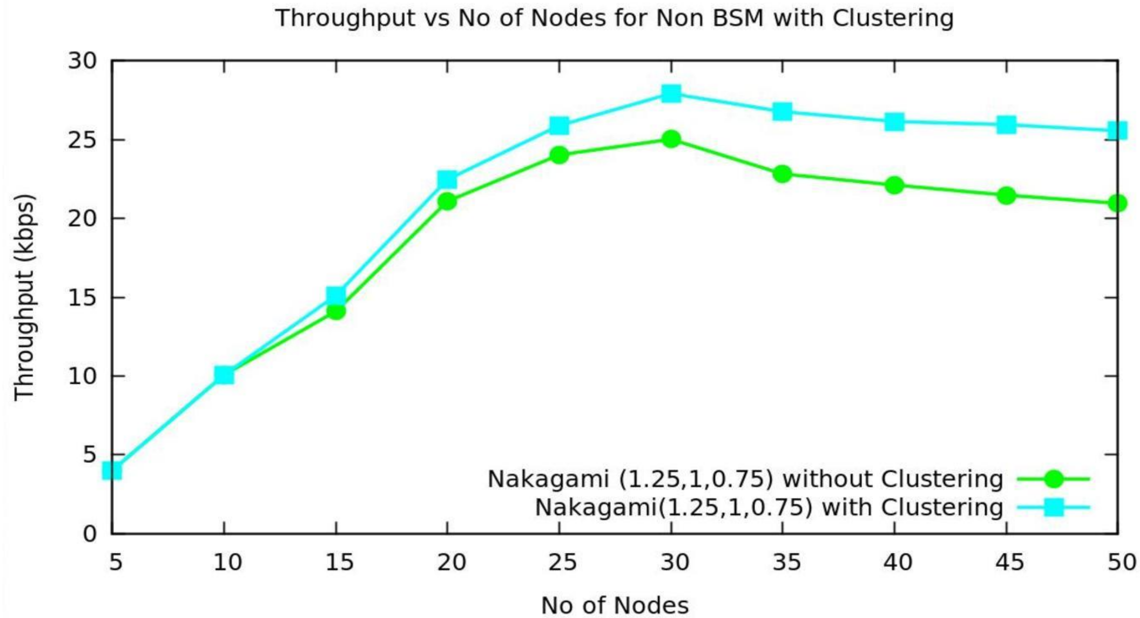

Figure 4.8Throughput vs No. of Nodes for Non-BSM data with Clustering

4.2.2 Packet Delivery Ratio

The packet delivery ratio is the measure of how many packets are successfully received out of total transmitted packets.

The figure 4.8 and 4.9 show the variation of Packet delivery ratio for BSM packet versus distance of safety ranges for number of nodes 40 and 80 respectively. These figures depict that in both the cases, the packet delivery ratio increases up to 100m and then it starts to fall for both the Rayleigh and Nakagami model. But here also the Packet delivery ratio for Nakagami model is greater than the Rayleigh model. Initially the PDR increases in all three cases for up to 100m safety ranges, since the number of packet received increases as the range of distance increases, but after 100m the effect of interference due to noise is so intense, that it decreases the packet delivery ratio.

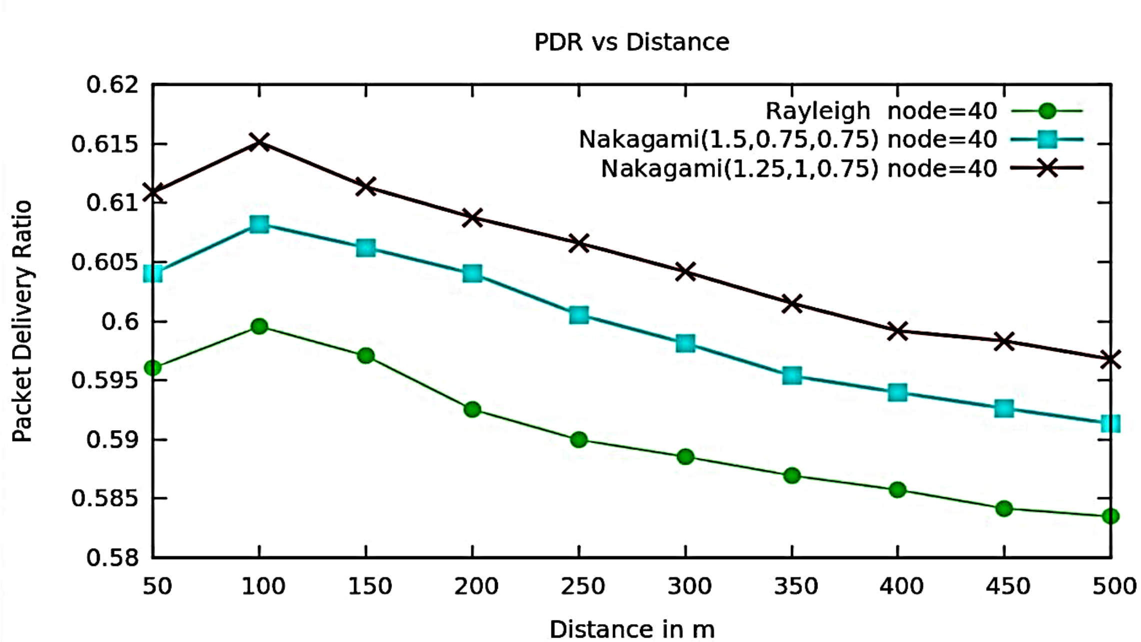

Figure 4.9 PDR vs Distance for BSM at No. of nodes 40

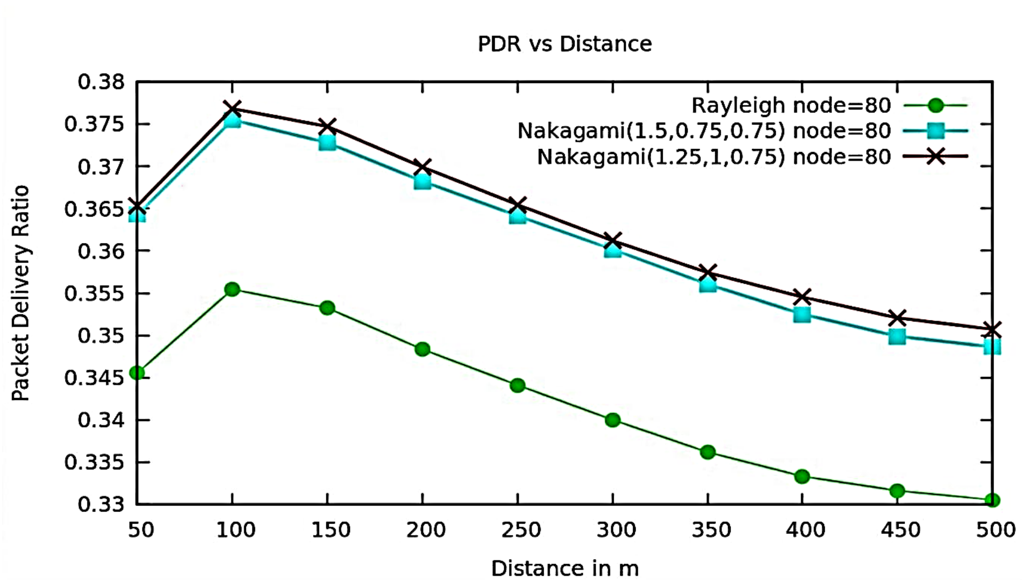

Figure 4.10 PDR vs Distance for BSM at No. of nodes 80

The figure 4.11 shows the variation of packet delivery ratio vs number of nodes. The variation shows that as the number of nodes increase, the PDR gets decreased. As the number of nodes is less, there is no congestion problem which causes less packet drop due to expiry of TTL. But as the number of nodes gets increased, the congestion problem becomes prominent and the TTL expiry problem also arises which results in the decrease of packet delivery ratio.

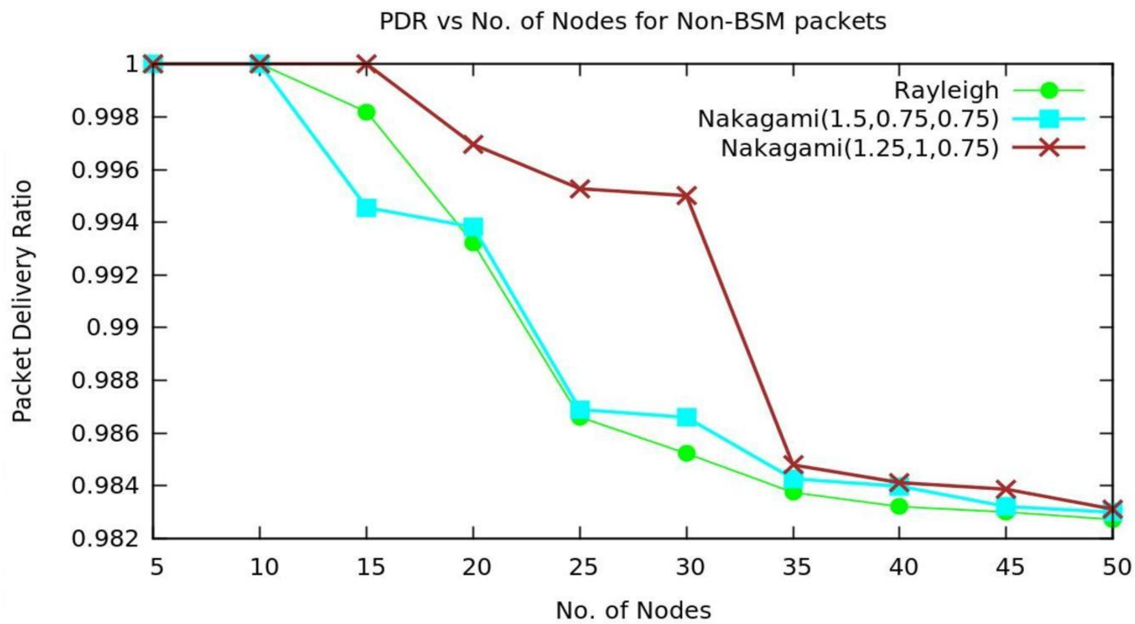

Figure 4.11PDR vs No. of Nodes for non-BSM

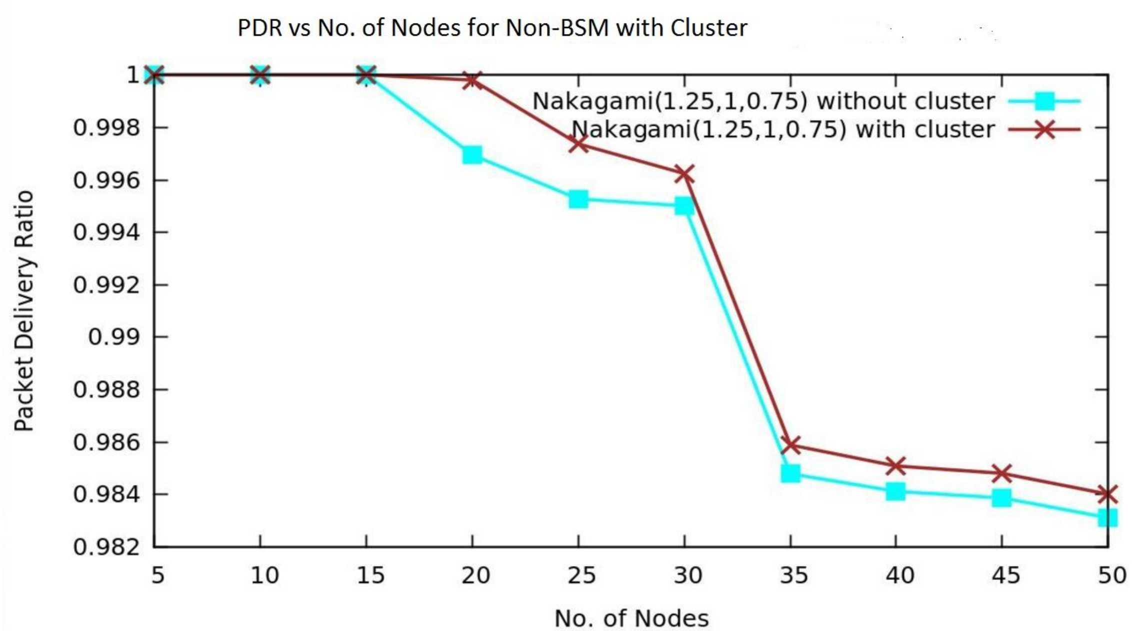

Figure 4.12 PDR vs No. of Nodes for Non-BSM with cluster

The figure 4.12 shows the variation of PDR vs number of nodes for non-BSM packet with clustering effect. The PDR is same in both cases for lower number of nodes, whereas it gets increased in the case of clustering as the number of nodes goes on increasing. The cluster plays a vital role as the number of nodes becomes larger, since this minimizes the loss of packet which would be lost due to congestion problem, which arises when a large number of vehicles try to initiate data transfer in the absence of cluster.

5 Conclusion

The main aim of the thesis is to analyze the VANET for performance enhancement i.e. to analyze throughput and packet delivery ratio on the basis of clustering for different propagation models along with the feature of handling of sensitive data with 3G. The different propagation models are Rayleigh and Nakagami. The Nakagami model performance in terms of throughput and packet delivery ratio for both BSM and non-BSM packets is found to be better than Rayleigh model. For thirty number of nodes a peak throughput is obtained in the case of non-BSM packets. For BSM packets the throughput increased with the increase in safety ranges of nodes and Nakagami model fared better than the Rayleigh model for all the cases.

For the handling of sensitive data, the 3G assisted mechanism is used, which increased the throughput and the end to end delay also decreases as the sensitive data is sent without any delay to the intended destination with top priority.

Clustering based VANET plays a great role when the number of nodes is larger. If there is less number of nodes, then it is better to choose the normal VANET, which is less complex than former one, as the performance i.e. throughput and packet delivery ratio are similar in both the cases. Whereas as the number of nodes get increased, clustering based VANET has been found to obtain better performance in terms of throughput and packet delivery ratio.

It can be suggested that for better throughput and packet delivery ratio clustering based VANET with Nakagami propagation model should be used if the number of nodes are large.

This following things can be considered as future works:

- Multiple clustering technique can be considered to analyze the performance.
- Certain vehicles such as ambulance, fire service vans, and police patrols need to be given a high priority. Hence, enabling QoS for differentiating the services according to vehicular priorities in an effective real-time application may be done.

- The clustering design based on more parameter like power of nodes, Route Expiration Time and Link Expiration Time can be considered.

References

[1] Huixian Wang et al., " VANET Modelling and Clustering Design Under Practical Traffic, Channel and Mobility Conditions", IEEE Transactions on Communication , March 2015

[2] http://vehicularcommunication.blogspot.com/ 23 September, 2015

[3] Miao Wang et al., " Real- Time Path Planning Based on Hybrid-VANET-Enhanced Transportation System", IEEE Transactions on Vehicular Technology, July 2014

[4] Amendment 6: Wireless Access in Vehicular Environment (Part 11: Wireless LAN medium access control (MAC) and physical layer (PHY) speci-fications), IEEE Std 802.11p TM-2010, Jun. 17, 2010.

[5] H. Su and X. Zhang, "Clustering-based multichannel MAC protocols for QoS provisionings over vehicular Ad Hoc networks", IEEE Trans. Veh. Technol., vol. 56, no. 6, pp. 3309–3323, Nov. 2007.

[6] A.Benslimane, T. Taleb, R. Sivaraj, "Dynamic Clustering-Based Adaptive Mobile Gateway Management in Integrated VANET-3G Heterogenous Wireless Networks", IEEE Journal, vol. 29, no. 3, March 2011.

[7] A Study of VANET Networks ENSC 427, Spring 2012

[8] C. Han, M. Dianati, R. Tafazolli, R. Kernchen, and X. (S.) Shen, "Analytical study of the IEEE 802.11p MAC sublayer in vehicular networks", IEEE Trans. Intell. Transp. Syst., vol. 13, no. 2, pp. 873–886, Jun. 2012.

[9] M. Mallick, "Sensitive Data Handing by Using 3G in VANET", Master Thesis IOE, 2014

[10] S. Yousefi, E. Altman, R. El-Azouzi, and M. Fathy, "Analytical model for connectivity in vehicular Ad Hoc networks", IEEE Trans. Veh. Technol., vol. 57, no. 6, pp. 3341–3356, Nov. 2008. 8

[11] Qingwen Zhao et al., "When 3G Meets VANET: 3G-Assisted Data Delivery in VANETs", IEEE Journal, October 2013.

[12] Abderrahim Benslimane and Tarik Taleb, "Dynamic Clustering-Based Adaptive Mobile Gateway Management in Integrated VANET – 3G Heterogeneous Wireless Networks", IEEE Journal, March 2011.

[13] Pranav Kumar Singh, Kapang Lego “Comparative Study of Radio Propagation and Mobility Models in Vehicular Adhoc Network”, International Journal of Computer Application, Volume 16–No.8, February 2011.

[14] Diane Barlow Close, Arnold D. Robbins, Paul H. Rubin, Richard Stallman and Piet van Oostrum, The AWK Manual, 1st edition, December 1995.

[15] http://sumo.dlr.de/wiki/Tutorials/Import_from_OpenStreetMap/20 August 2015

[16] Christos Profentzas, “Studying Routing Issues in VANETs by Using NS-3”, Thesis, Alexander Technological Educational Institute of Thessaloniki, Department of Informatics, November 2012.