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Simulation and Analysis of Vehicular Network Capacity

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Abstract

Communication is essential for Intelligent Transport Systems (ITS). Vehicular network have envisioned various applications that greatly improve traffic safety and efficiency along the roads and highways. Vehicular networks could use both short-range (e.g. Wi-Fi, DSCR) and long-range (e.g. 2G, 3G, 4G) communication technologies for sharing and distributing information among vehicles.

Despite it's promising; it is not fully deployed to benefit from it. One reason is the different challenges of vehicular network communication that should be answered and solved. Among the major challenging issue of vehicular network is capacity. Many information services and applications compete for the available network capacity, especially in urban areas i.e. high vehicles density. The guaranteed network capacity per each vehicle depends on vehicles density, different information source, and mobility, and used wireless technologies. It is a difficult task to estimate the individual vehicles' available network capacity.

This thesis examines different aspects that affect available network capacity. Then design a simulation model, which comprises all aspects that affect network capacity. And Using different simulation scenario, we analyzed the performance experienced by individual vehicles and also study the effect of different aspects that affects network capacity.

Problem Description

Name of student: Mohammed Seid, Ali

Simulation and Analysis of Vehicular Network Capacity

Intelligent Transport Systems (ITS) is the utilization of ICT in the transport sector for e.g. improved safety, efficiency and convenience. Many information services and applications compete for the available network capacity – especially in urban areas with a high vehicle density.
Vehicles may connect through both short-range (e.g. WiFi, DSCR) and long-range (e.g. 2G, 3G, 4G) communication technologies, making it hard to estimate the network capacity as seen from the individual vehicles.

The assignment is to design a simulation model and test it in a network simulator, before its effects are analysed. The simulation model should include the available wireless channels (both short-range and long-range), vehicle mobility and different information sources. The analysis must look at different aspects (e.g. mobility, vehicle density, data sources, etc.) that affect the aggregated network capacity (i.e. all available network connections), and the effects these aspects have on the vehicle's experienced network performance.

Assignment given: January 17,2013

Supervisor: Adjunct Associate Professor Tor K. Moseng, NTNU ITEM

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Acknowledgment

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Abbreviations

CCH	Control Channel
CSMA/CA	Carrier sense multiple access with collision avoidance
CTS	Clear to send
DSCR	Dedicated Short Range Communication
EDCA	Enhanced Distributed Channel Access
GPRS	General packet radio service
GSM	Global system for mobile communications
ICT	Information and communication technology
IDE	Integrated development environment
IEEE	Institute of Electrical and Electronics Engineers
ITS	Intelligent Transport Systems
I2I	Infrastructure to infrastructure
I2V	Infrastructure to vehicle
IVC	Inter-Vehicle communication
MANET	Mobile Ad-hoc Network
OBU	On-Board Unit
PDR	Packet Delivery Ratio
OFDM	Orthogonal Frequency-Division Multiplexing
QoS	Quality of service
RSU	Road-side Unit
RTS	Request to send
RTT	Round trip time
RT	Round trip
R2R	Road-side to Road-side
R2V	Road-side Unit to vehicle
SCH	Service Channel
SMS	Short message service
SNIR	Signal to noise plus interference ratio
TA	Trusted Authority
TCP	Transport control Protocol
UDP	User Datagram Protocol
UTC	Universal time coordinated

VANET	Vehicular Ad-hoc Network
V2I	Vehicle to Infrastructure
V2R	Vehicle to Road-side Unit
V2V	Vehicle to Vehicle
WAVE	Wireless Access in Vehicular environment
WiMAX	Worldwide Interoperability for Microwave Access
WSA	WAVE Service announcement
WSMP	WAVE short-message protocol

CHAPTER 1

INTRODUCTION

1.1. Overview

Road transportation is one of the vital areas that impact the development of any community. Though it benefits the community, there are several challenges related to it e.g. congestions and traffic safety problems, which creates huge anxiety to the society, especially in urban areas with high vehicles dense. Approximately 1.24 million people die each year on the world's roads. [14] The results show that road traffic injuries remain an important public health problem, particularly for low-income and middle-income countries. The report also emphasis that significantly more action is needed to make the world's roads safe.

A lot of efforts have been done in using ICT to address the challenges we face in transportation. Intelligent Transport Systems (ITS) is the utilization of ICT in the transport sector for e.g. improved safety, efficiency and convenience. A necessity in ITS is communication among the vehicles (vehicular networks), and between vehicles and the infrastructure. Through these communications, vehicles will share and communicate important information about road condition, which enhance traffic safety and efficiency. Beside the participating vehicles, roadside units also have an important role in this information dissemination.

Although the idea of ITS gave us a great expectation for the traffic safety improvement, vehicular network communication still has a lot of challenges to be addressed. High mobility of vehicles is an example among the challenges, which reasons highly dynamic nature of vehicular network. As a result, it confines connectivity to a short span of time that affects the delivery of essential information. Another serious challenge is guaranteed network capacity. The available network capacity changes through time as the number of participating vehicles changes depending on road traffic and number of active communications. Traffic congestion is common, which many vehicles concentrated at some point. This condition affects network capacity and performance experience of vehicles. Vehicles may connect through both short-range (e.g. Wi-Fi, DSCR) and long-range (e.g. 2G, 3G, 4G) communication technologies. Vehicles demand to use the available network capacity, But it may happen that the network capacity have reached its limit due network congestion. The network congestion may lead to other problems that affect the road traffic. The highly dynamic nature of the network makes it difficult to figure out the residual available network capacity. It is hard to estimate available capacity from each vehicle's perspective. Moreover it is also challenging to estimate optimal capacity for vehicular network deployment. These and other challenges have gained attention of researchers, whom working to find out optimal solutions.

1.2. Motivation

Vehicular network communication is significant for road safety and convenience. Guaranteed network capacity has great impact, in meeting its safety related target. Designing and planning infrastructures for vehicular communication needs a lot of struggle. Especially, estimating the optimal network capacity is challenging, as participating nodes depends on the road traffic. If there is no way to be aware of the required capacity, the promising benefit of vehicular networks will not be fully consumed. Vehicles' performance experience might help in estimation of available capacity, which assist designing decision and network deployment.

So observing vehicles' performance experience with respect to different capacity affecting factor might be helpful for better judgment. . Especially, the performance experience at the time of network congestion will significantly correlate to available capacity. The motive of this thesis is finding out different capacity affecting factor and study their impact on vehicles' performance experience and the available capacity.

1.3. Approach

In order to find reliable outcomes, the approach we followed is to divide the task in three parts: The first task was studying vehicular network in detail, and get familiar to different aspect and factors that affects available network capacity. In the second part, we designed a simulation model considering all relevant aspects and implement it using a simulation tool. In this specific task an agile approach is used i.e. after designing small portion of the simulation model, the implementation is done and tested. So, each stage of the simulation model will be workable, which helps to ensure bugs are caught and eliminated at each sub stages before going to next stage.

Finally, we conducted different simulation scenario. Then we collected results related to performance to show the effects of the different aspects on vehicles' performance experience and discuss the association with capacity.

1.4. Outline

This thesis report is organized as follows:

Chapter 2- Describes background information on vehicular networks and also includes communication modes, wireless communication technology, challenges in Vehicular Network.

Chapter 3- talks about network capacity in vehicular network, the different factor affecting available capacity.

Chapter 4- Simulation –presents the simulation model with the components used, the simulation tools used, and the different simulation scenario set-ups.

Chapter 5- Result and Discussion – presents the simulation results discussion and observation.

Chapter 6- Conclusion and future work- it summarizes the work done in this thesis and show future work areas.

CHAPTER 2

BACKGROUND ON VEHICULAR NETWORKS

2.1. Introduction

Vehicular network is an emerging network, which vehicles and roadside units are the communicating nodes. They provide each other different information, such as safety warnings and traffic information. As a cooperative approach, vehicular communication can be more effective in avoiding accidents and traffic congestions than if each vehicle tries to solve these problems individually. Vehicles, are equipped with wireless communication capability, are capable of communicating with each other and with roadside and infrastructures. Vehicular network is a special category of Mobile Ad-hoc Networks (MANETs). Even though all the characteristics and concerns apply for vehicular networks, some of the elements are different. In [42] Arzoo Dahiya and his colleague tries to list some of the unique characteristics comparing with MANETs. Potentially high number of nodes/vehicles, high mobility and frequent topology changes, high application requirement on data delivery, no confidentiality of safety information, privacy issue are the major unique characters. Resource is not limited, especially energy limitation.

Vehicles, in communicating with Roadside units different wireless technologies can be used. The wireless technologies used may be short range such as Wi-Fi and a long-range technology of cellular networks. If both technologies exist in together, they will have a collective overall capacity. The preference among the existing wireless channels depends on communication requirement of applications and the different available service i.e. applications use channel that fulfill their communication requirement. The final intention is to provision both safety applications and non-safety applications that enhance the driving experience of drivers with reliable communication.

As one of main component of ITS, vehicular network have different entities that makes network communication exists.
Major building blocks of a vehicular network are: Roadside unit (RSU), On board unit (OBU), Trusted Authority (TA), base stations

1. **Road Side Unit (RSU)**

RSU is a component that is located on side of road. It provides a lot of safety and convenience related information for vehicles such as information about traffic density, weather information etc. It mostly comprises short-range radio link like Wi-Fi. But it may use long-range radio link. It involves in traffic associated to Vehicle-to-Roadside or inter-roadside communication.

2. **On-Board Unit (OBU)**

OBU is a component that is putted in vehicles, to make them participate in the network. This unit can be installed during the manufacturing of the vehicle (actually can be installed later) or can be smart devices that the user uses inside a vehicle. This is the more interesting part of vehicular network.

3. **Trusted Authority (TA)**

TA is an entity in vehicular network, which covers different administrative issues and monitoring of the network. TA is responsible to solve any dispute that happens in the network.

4. **Base stations**

Vehicles may use long-technologies like cellular and WiMAX for communication and different ITS applications. Base stations are the one, which facilitate this kind of communication.

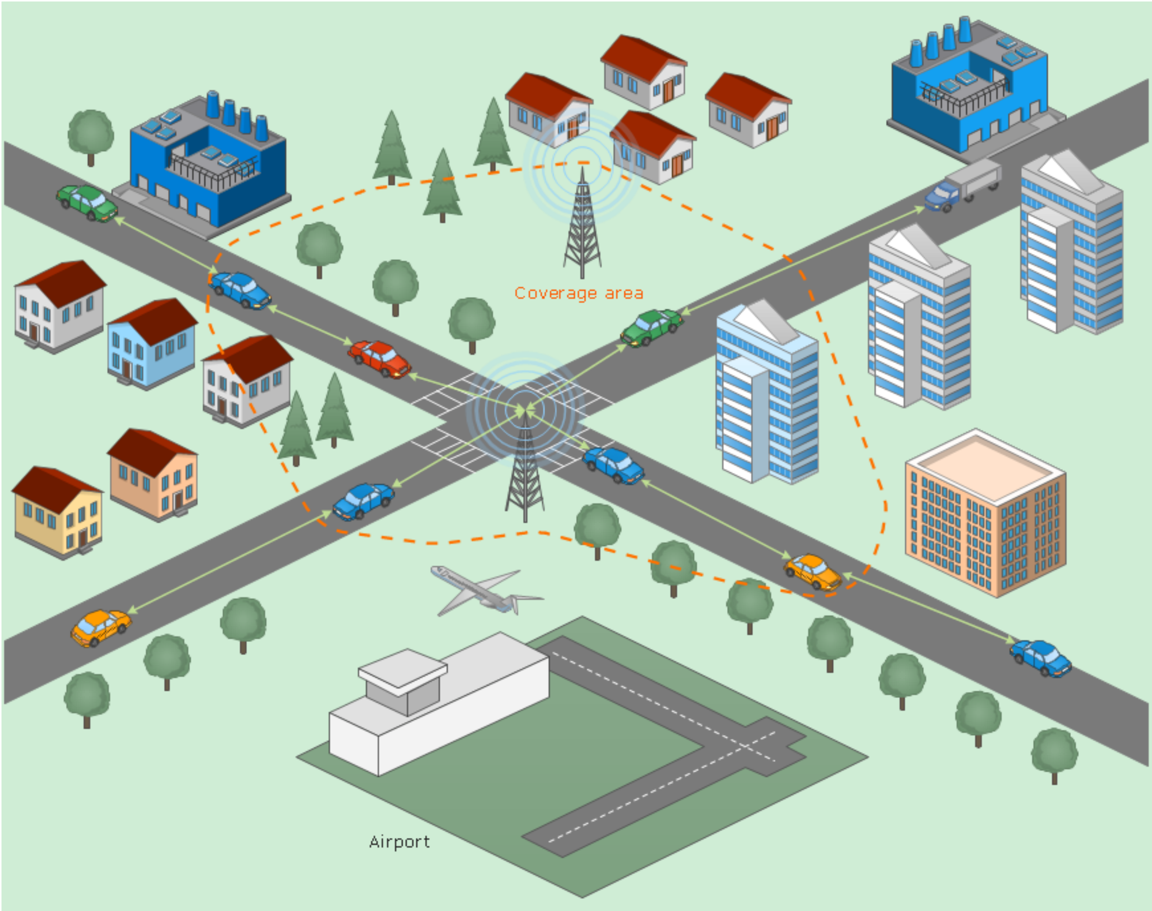

Figure 2.1: Vehicular networks architecture [5]

2.2. Communication Mode in Vehicular Network

In Vehicular network, there are about three communication mode, which are used for different ITS applications:

2.2.1. ***Vehicle-to-Vehicle (V2V) communication*****:** Vehicle-to-vehicle communication, or V2V for short, allows vehicles to communicate with other vehicles in a given area. Each vehicle broadcasts its own speed and direction, making it easier to avoid potential collisions.

2.2.2. ***V2I/I2V communication*****:** is a type of communication that is between the roadside units infrastructures and vehicles. There are a lot of ITS application that use this kind of communication mode. It could use both short-range and long- range wireless technology, such as Wi-Fi, 3G etc. This communication is usually used to get in contact with other large networks like Internet.

2.2.3. ***I2I communication***: is a communication between roadside unit infrastructures, for a better efficiency. When there is a situation that vehicles at far wants to communicate though RSU this kind of communication may happen. There are applications that could make use of this communication mode. One example is when an ambulances is going in a road the first road side unit may inform to all road that the ambulances is going.

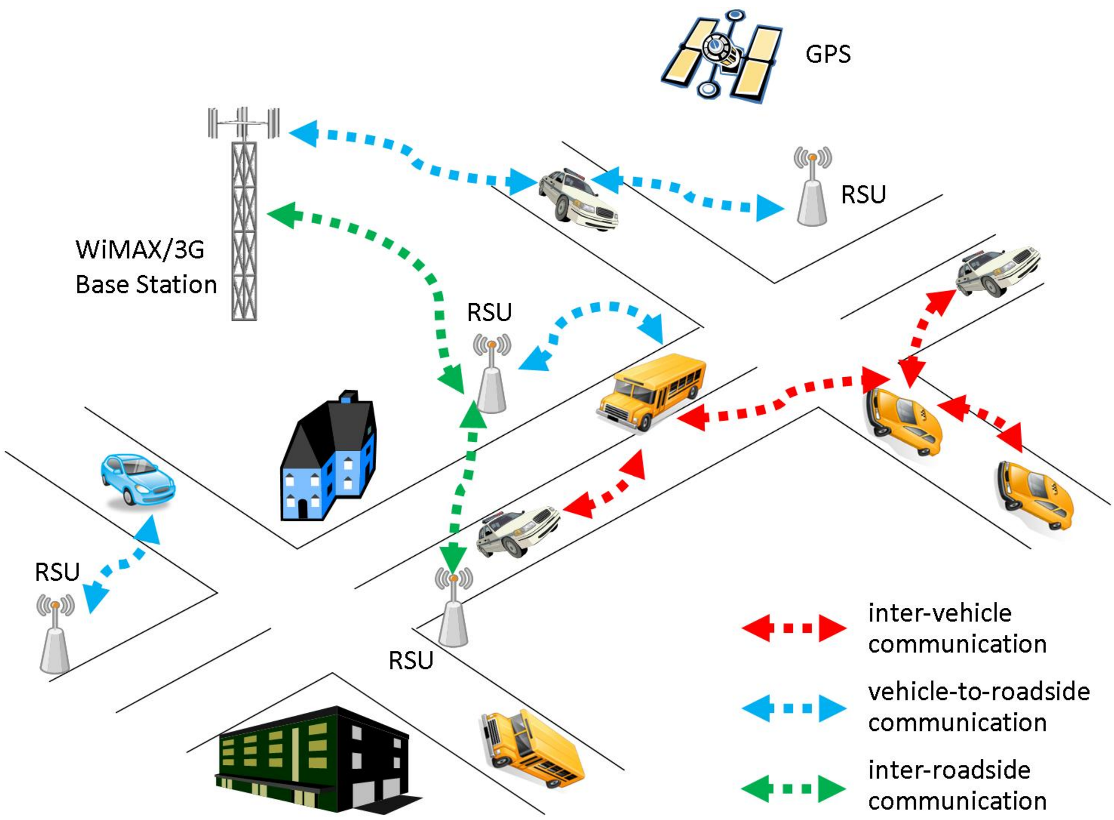

Figure 2.2: Vehicular network communication modes **[4]**

2.2. Wireless Communication technology

The concept of using wireless communication in vehicles has fascinated researcher since the 1980s [7]. In the last few years, a lot of efforts have been made to improve vehicular wireless communication. These all efforts are resulted from the promising significance of vehicular network communication, for safe and convenient road transportation. The study varies from investigating the suitability of available wireless technologies for vehicular communication to designing a new wireless standard specific to vehicular communication environment. Clearly these technologies should allow different communications by fulfilling the needs of different application requirements. These wireless technologies are categorized according to their range i.e., Long range and Short range.

2.3.1. Short range technology

Short-range technologies can be used within shorter radio coverage range. Vehicular network mostly use a short-range wireless technologies to provision ITS applications. As vehicles are close to each other these type of technology is more relevant for delay sensitive safety applications. Even from the characteristics of short-range technologies they are the one most likely to fulfill requirement of most important ITS applications. The range of technologies may also be helpful for V2V and V2I communication.

Among IEEE scientific research development teams there is a team working on a variation of 802.11 standards so as to permit communications in the rapidly changing vehicular environment, which operates in the Dedicated Short Range Communication (DSRC) frequency band of 5.85-5.925GHz. The IEEE 802.11p PHY layer is an amended version of the 802.11a specifications, based on Orthogonal Frequency-Division Multiplexing (OFDM), but with 10MHz channels and data rates ranging from 3 Mbps to 27 Mbps. The IEEE 802.11pMAC layer has the same core mechanism of the Enhanced Distributed Channel Access (EDCA) specified in 802.11e [7],which is based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) scheme.

802.11p is intended to operate with the IEEE 1609 WAVE. The standard Document is known as IEEE 802.11p [8]. The work is done to make communication to happen in high speed Vehicle Movement with higher communication ranges. Another IEEE team (working group 1609) undertook the task of developing specifications to cover additional layers in the protocol suite. The IEEE 1609 standards set consisted of six documents: IEEE 1609.1 [9], IEEE 1609.2 [10], IEEE 1609.3 [11], and IEEE 1609.4 [12] and two unpublished IEEE 1609.0[13] and IEEE 1609.11[13] standard documents which describes whole architecture of wireless Access for vehicular environment.

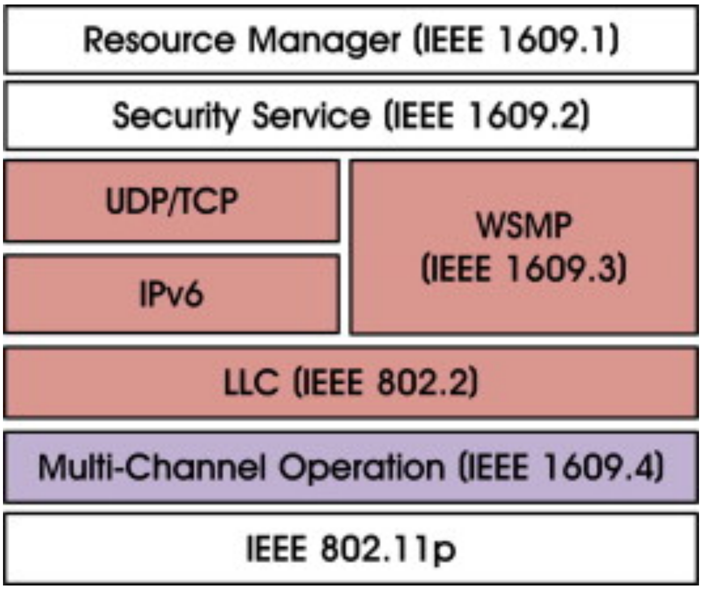

Figure 2.3: Protocol stack of IEEE 802.11p/1609 [2]

According to the specification standard, the overall stack relies on one CCH, which is reserved for transporting system control and safety messages, and four to six SCHs used to exchange non-safety data. The MAC layer is properly modified to work in the multi-channel WAVE environment, by implementing two separate EDCA functions, one for CCH and one for SCH, which handle different sets of queues for packets destined to be transmitted on different channels with different EDCA parameter sets.

IEEE 1609.4 [12] says, the channel time is divided into synchronization intervals with a fixed length of 100ms (consisting of a CCH interval, during which all vehicular devices tune in the CCH frequency, and a SCH interval, during which vehicles (optionally) switch to one of the SCH frequencies. Channel coordination exploits a global time reference, such as the Coordinated Universal Time (UTC), which can be provided by a global navigation satellite system.

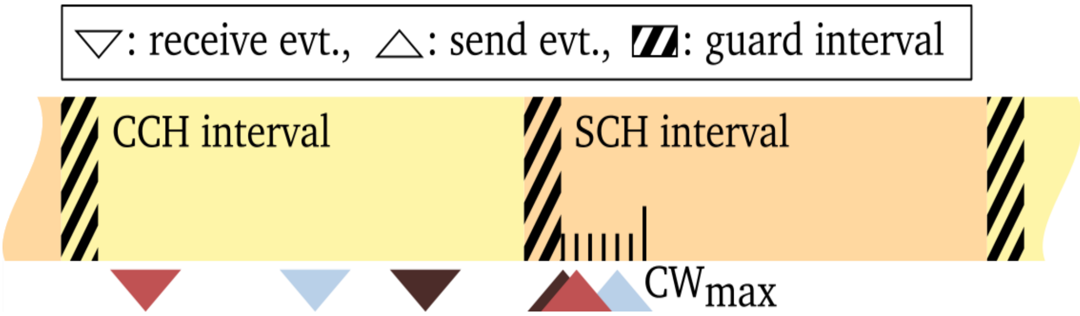

Figure 2.4: shows CCH interval and SCH interval

IEEE 1609.3 is the network management layer [11] that decides which SCH to tune into at the end of every CCH interval and the number of WSA (wave service announcement) repeats. The number of repeats defines the number of WSA messages that must be sent during the CCH interval. Since providers broadcast WSAs without any feedback on their successful reception, it is convenient that each provider sends multiple copies of WSAs for reliability purposes.

2.3.2. Long range technology

Long-range communication technologies can deliver data in miles distance. These technologies are preferred to expand coverage area of vehicular network. These technologies may be useful for Vehicles to communicate directly with each other (V2V) and with the fixed infrastructure (V2I) in the form of vehicular ad hoc network (VANET).

A lot of interest is give to use cellular network to avoid costs in deploying new infrastructure. Cellular networks provide mobility and infrastructure has already been constructed over the country. So Vehicles\passengers with capable of communicating using cellular network will the already deployed network infrastructure. In this case it will become cost effective, as it doesn't need a separate infrastructure to be built.

Cellular systems have been evolving rapidly to support the ever-increasing demands of mobile networking. The key role cellular technology is coverage and security, and 3G, slowly but steadily coming over 2/2,5G, provides enhanced and better capacity and bandwidth. [27] Several telematic and fleet management projects already use cellular technology (e.g. SMS reports). On the other hand it is more expensive, together with limited bandwidth and latency make it impossible to use as a main communication means. It is not convenient to use for safety messages, as safely message are sensitive to latency. Mostly it is convenient for convenient and entertainment applications.

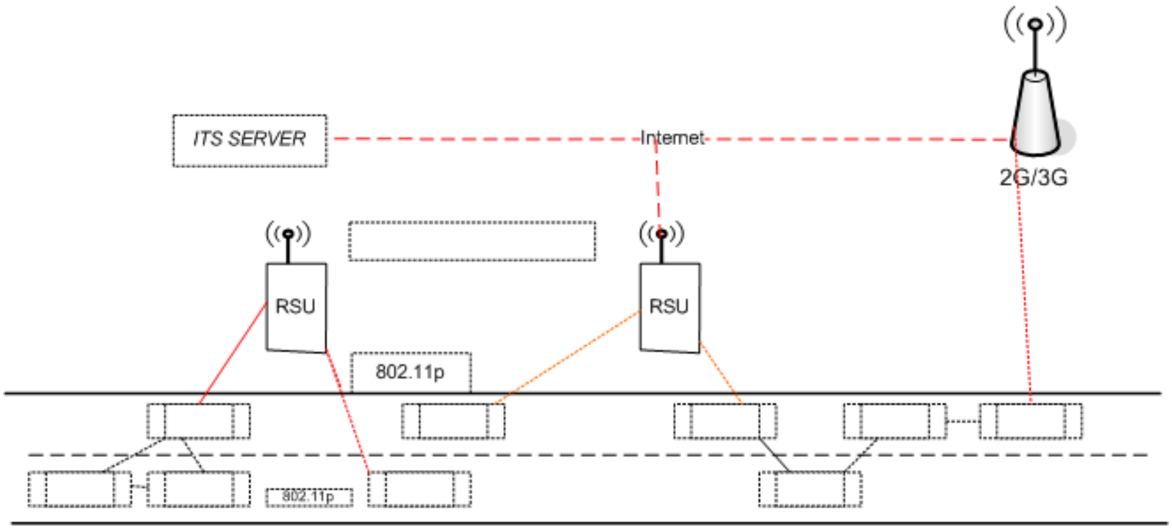

Figure 2.5: Vehicular network with both short-range and long-range wireless technologies

WiMAX (Worldwide Interoperability for Microwave Access) technology is also sometimes used in vehicular network communication. WiMAX aims at enabling the delivery of last mile wireless broadband access (<40Mbps) as an alternative to cable and xDSL, thus providing wireless data over long distances. So it allows vehicles to communicate in longer range and make use of different ITS applications specially infotainment applications.

It also supports several service levels including guaranteed QoS for delay sensitive applications, and an intermediate QoS level for delay tolerant application that requires a minimum guaranteed data rate. So it is another good candidate technology for vehicular network communications.

Table 2.1: Wireless communication technologies: characteristics and features. [6]

Communication Characteristics	Communication Technologies	
	GSM/GPRS	DSRC/ WAVE
Latency	1.5–3. 5sec	200 µs
Data rate	80–38 4 kb/s	~6 Mb/s
Range	10 km	~1 km
Transmission mode	1/2	1
Mobility	Yes	Yes
Operating band	0.8–1. 9 GHz	5.8–5.9 GHz

Vehicles may use both short-range and long Range wireless communication Technologies. Short range comprises V2V or V2R communication, while long range wireless technologies are mostly applied to take advantage of already deployed infrastructures and which mostly it comprises V2I communication. [6] The technology used depends on the availability of the technology around and the situation at hand. These communication technologies they have there own merit and demerit. So, Whether they are suitable or not for specific application depends based on the ITS application requirement. The major point here is to provide a set of protocols and parameters that are capable of handling the high-speed vehicular communication and fulfilling different application requirements so as to have a reliable communication.

2.4. Challenges of vehicular network communication

Vehicular network facilitates different important applications and services, ranging from active safety applications to traffic information, and comfort applications. Despite the benefits of a vehicular network communication, there are many challenges arises from it unique characteristics. More emphasis is given to challenges faced in ensuring of safe and reliable Communication between the vehicles.

Major challenges are listed below:

2.4.1. Security

Vehicular networks need an appropriate security architecture that will protect them from different types of security attacks. The problem at hand is to secure the operation of vehicular network communication. Especially, the safety of message content is a big issue that the content of a received message has to be verified within a short time to be able to use the information as soon as possible. There are a lot of security threat also that will affect normal function of the network communication. As it is a critical issue there have been a lot of work done to assure security balancing it with the privacy requirement. In [28], it lists some of issues that should be guaranteed in VANET as one of Vehicular Network. It says VANET communication should guarantee authentication, Integrity, reliability, confidentiality, and other Security related issues. A lot of researchers are doing their part to address these issues.

2.4.2. Quality of Service

Vehicular network communication requires fast association and low communication latency between communicating vehicles in order to guarantee: (1) service's reliability for safety-related applications while taking into consideration the time-sensitivity during messages transfer and (2) the quality and continuity of service for passenger's oriented applications [3].

Most Qos issues are result from the known major vehicular network challenges:

- **Mobility**: In vehicular network communication, vehicles are in high mobility with a predictable manner. In High-speed mobility of vehicles reduces connection time to short span, which results degradation of the overall network performance. There have been efforts to come-up with a solution to coup-up with these highly dynamic mobility nature of vehicles.

- **Network capacity**: when there is a lot of demand on the available network capacity or when congestions occur the network performance degrades rapidly. The performance experience of participating nodes is really affected by congestion. We will further explore this issue in our thesis to see different aspects that affect guaranteed network capacity of participating nodes/vehicles.

2.5. Applications in Vehicular Network

Potential applications in a vehicular environment can be divided into three main categories [15,16], namely,

(1) Infotainment delivery, (2) road safety, and (3) traffic monitoring and management:

2.5.1. Infotainment delivery/comfort:
The aim of infotainment applications is to offer convenience and comfort to drivers and/or passengers. For example, Fleet net [17] provides a platform for peer-to-peer file transfer and gaming on the road. A real- time parking navigation system is proposed in [18] to inform drivers of any available parking space.

Digital billboards for vehicular networks are proposed in [19] for advertisement. Internet access can be provided through V2Icommunications; Therefore, business activities can be performed as usual in a vehicular environment, realizing the notion of mobile office [20] On-the-road media streaming between vehicles also can be available [21,22], making long travel more pleasant.

2.5.2. Road safety: Safety applications are always dominant to significantly reduce the number of accidents, the main focus of which is to avoid accidents from happening in the first place. They also have their own influence in reducing congestion. For example, Traffic View [24] and Street Smart [25] Inform drivers through vehicular communications of the traffic conditions in there close proximity and farther down the road. Vehicle platooning is another way to improve road safety. By eliminating the hassle of changing lane and/or adjusting Speed, platooning allows vehicles to travel closely yet safely together [1].

2.5.3. Traffic monitoring and management/Efficiency: Traffic monitoring and management are essential in proper utilization of road infrastructure and are essential to avoid traffic congestion. Intersections in city streets can be dangerous at times. Traffic light scheduling can facilitate drivers to cross intersections. Allowing a smooth flow of traffic can greatly increase vehicle throughput and reduce travel time [27]

On the other hand, with knowledge of traffic conditions, drivers can optimize their driving routes, whereby the problem of (highway) traffic congestion can be lessened [29]. The recommended wireless technology for these ITS application Functionalities may be as below:

Table 2.2: Technology category vs. vehicular ITS applications

Functionality	Category	Example
Safety	Short-range	Wi-Fi, DSRC, WAVE
Efficiency	Short-range and partially Long range	DSRC, WAVE, Cellular Network etc
Comfort	Short-range and Long range	DSRC, WAVE, Cellular Network etc

CHAPTER 3

CAPACITY IN VEHCULAR NETWORK

Communication systems upon deployed needs rapid response times, high availability, and adequate bandwidth. These are the demands placed on implemented networks that are used for any purpose. A lot of fascinating systems are emerging, which indeed depends on the performance of the network. Even though there are a lot of different reason that affects performance of a network one and the interesting reason is network capacity.

3.1. Network capacity

Network capacity expresses overall ability of a network, in serving the participating nodes. Upon deployed a network have potential capacity for serving different applications. More attention is given to guaranteed capacity, rather than the potential capacity. Due to different reasons, the whole potential capacity is not consumed. The available network capacity varies with different reasons, which affects performance experience of users. In other word, the performance experience of nodes depends on different conditions, which determine the available capacity.

Throughout the existence of networks, the issue of capacity is related to proper functioning the network. So big attention is given to network capacity planning, during the design phase of any network. In the design phase, network engineers need to anticipate the impact of different factors that may affects network capacity. There is a trend of following an adequate capacity planning process, for better outcome. Though some aspects that affect capacity may be identified, in some cases, it may be difficult to foresee all issues related to capacity. To clarify this point let us see an example, in road design, we can’t exactly say how much cars will pass a road as it is beyond the designer. The same is true for network capacity, which depends on different situations.

The technology used determines network capacity issues. It is obvious issues in wired and wireless networks will not be same. Sometimes the issue of network capacity becomes critical to a level of questioning the survivability and importance of the deployed network. So a lot of pre or post caution related to capacity is performed. However, the problem still exists and continues affecting the overall network performance experience.

3.2. Capacity in Wireless Network

Wireless networks refer to type of network that uses wireless medium (usually, but not always radio waves) for network connections. Some wireless networks have a wired backbone with only the last hop being wireless. There are different wireless networks categories. Among these known wireless networks, the most fascinating and a more related to our focus are wireless ad-hoc networks.

Wireless ad hoc networks are a decentralized type of wireless networks. The network is ad hoc, because it does not rely on a preexisting infrastructure, such as routers in wired networks or access points in managed (infrastructure) wireless networks. Instead, each node participates in routing by forwarding data for other nodes. This cooperation of nodes and factors such as, network size (depends on coverage), traffic patterns and others factors, affects the achievable network capacity. As we mention above network capacity issue is such a big issues capable of determining the successful implementation of a network.

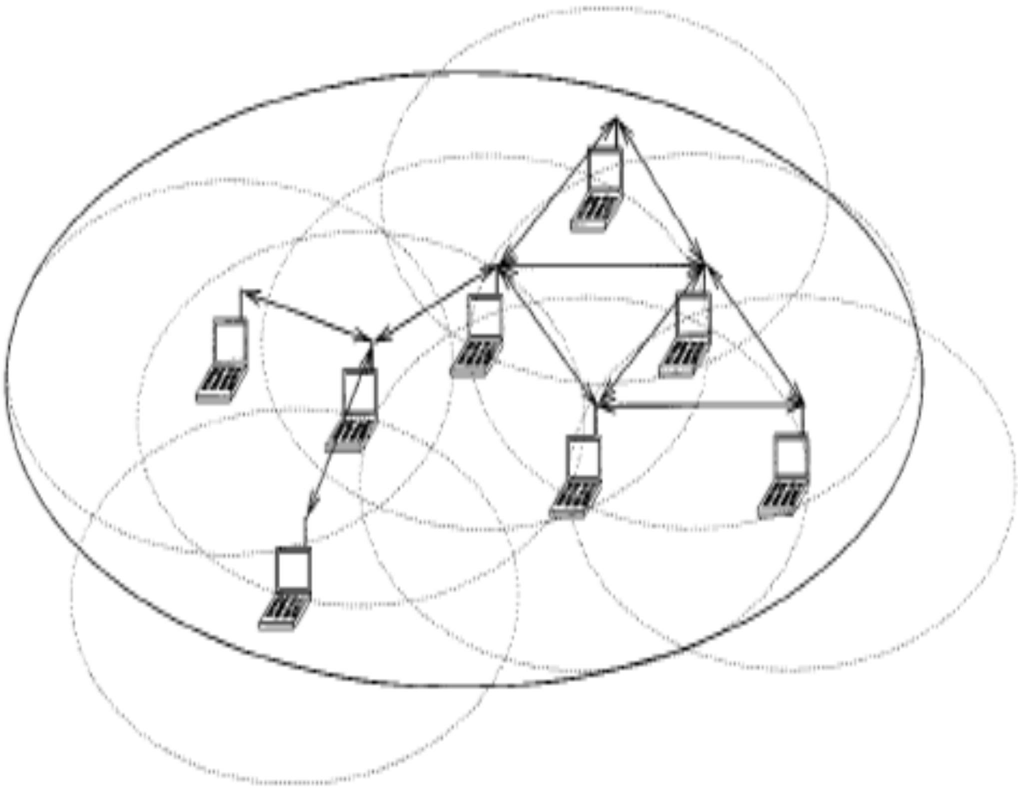

Figure 3.1: Wireless Ad-hoc Network [29].

In a radio network, achievable capacity depends on time and spatial parameters. Time parameters come from traffic patterns whereas spatial parameters are function of network size, radio interactions and node mobility. The difficult issue is estimating network capacity. Different researcher was trying to estimate in terms of throughput, find factor affecting capacity, and determine an approach in capacity estimations in wireless.

Gupta and Kumar [29] for static nodes and excluding MAC Protocol have considered a model in which n nodes are randomly located but fixed in a disk of unit area and each node has a random destination node. They showed that as the number of nodes n increases, the throughput per source and destination decreases to zero like O ($1/\sqrt{n}$) even allowing optimal scheduling and relaying of packets. Even [33] [32] tries by considering a node in mobility and come up with a result that shows capacity.

Basically, the overall network capacity in wireless network mostly depends on the following:

- **Physical channel conditions:** it means that capacity is determine the condition of the physical media. The bandwidth, data rate.

- **Efficiency of the MAC protocol:** The way the MAC protocol manages media access determine the Capacity experience of each node in the network. In managing media access there arise different overheads, which by themselves need capacity and also sometimes the occurrence of backoff.

- **Degree of Contention amongst the nodes:** this determines the demand of media access by the nodes in the network. Especially in a situation where there are a lot of nodes around that needs to use the media in this case the capacity experience of per node degrades.

3.3. Capacity in vehicular network

Vehicular networks are novel class of wireless networks that emerged to improvements in wireless technologies and the automotive industry. Vehicular networks are spontaneously formed between moving vehicles equipped with wireless interfaces that could be of homogeneous or heterogeneous technologies. It may happen that vehicles may connect through short-range wireless technologies and long-range wireless technologies. These different technologies have their own potential network capacity to contribute to the overall vehicular network.

ITS applications range from road safety applications oriented to the vehicle or to the driver, to entertainment and commercial applications for passengers. These different application and services are provisioned by the available network capacity.

Different applications have different communication requirement. These requirements determine their preference in using the available technology. For example safety applications requires low latency, so will choose to use a low latency wireless technology or it is best provisioned in low latency network. In typical vehicular network, exchange of road condition related information; access of entertainment applications by vehicles/passenger is a common phenomenon. Roadside units facilitate these communications and bridge the vehicles to different other large networks like Internet.

In a typical vehicular network environment, various information services and applications compete for the available network capacity. These services and applications are rooted from different participating nodes, especially vehicles. Sometimes, it happens that the contending information services and applications become many. Especially where vehicles density is large. Each vehicle requires a share from the total available capacity. But estimating the available capacity from vehicles' point of view, is a difficult task. Especially both short and long-range wireless communication technologies are available.

Measuring available capacity is interesting to various ITS applications. The knowledge of per vehicle available capacity can be beneficial, to make use of applications that have different communication requirements. For instance if a vehicle wants to generate a warning message, the available capacity may not be enough to satisfy the communication requirement of the message. So it will be difficult to pass this critical message to other peers, for better traffic flow. This and other important reasons attracted researcher's attention

3.3.1. Related work on capacity estimation

Vehicular network as a wireless Network may share different factors that affect the network capacity. But Hossein Pishro-Ni and his colleagues [31] assert that from the result they got by analyzing in the perspective of road geometry they say VANET (as one of Vehicular Network) have some unique characteristics. , It is observed that the road geometry plays an important role in the capacity of VANETs. In VANET nodes form a chain like structure of nodes in a straight along the roads. The work of Jin Yang L his colleagues whom they try to estimate the capacity of this kind of Ad-hoc wireless network. [31]. From what they studied, Let us see for communication on a chain where the source is the first node and the destination is the last node, they find via simulations a throughput of 0.25 Mbps for a 802.11 rate of 2 Mbps. The loss of capacity has several reasons. First, in a chain when a forwarder receives a packet, it has to send it to the next forwarder, then the next forwarder sends it to the next one. So, a forwarder of the chain receives the packet twice and sends it once. It decreases the utilization to 1/3 of the capacity. The second reason is interferences range is greater than radio range. In their simulations, they consider an interference range of 550 meters for a radio range of 250 meters. This decreases the bandwidth utilization to approximately 1/4. Lastly, the number of competing nodes (collision, retransmission, etc.) and the access protocols (RTS/CTS, etc.) also affect the overall Performance leading to the poor observed utilization (18 of the global capacity). It is important to note that the throughput depends on the 802.11 rates and the size of the packets.

In [34] the authors studied the inclusion of RSUs on Network capacity by considering a single RSU. They consider the RSU only to serve the communication between Vehicles. The by assuming the communication can happen between vehicles with each other and communication of vehicles with RSU with a bounded bandwidth of w1 and w2 respectively, assuming the don't interfere each other. They state a theorem which have an idea that when the number of RSUs is so small that it's unlikely that there exists at least one RSU in any section of length d(n) of the road, the capacity is virtually the same as the pure ad hoc case. Moreover by increasing the number of RSUs, so that we have at least one RSU in each section, the capacity increases almost linearly with the number of RSUs. Increasing the number of RSUs beyond a certain amount is of no use as the number of simultaneous transmissions each of them can handle limits capacity. And finally they tried to proof this assumption. The idea of their proof is that, there are several factors limiting the capacity, and in each region the dominant factors determine the achievable
Throughput. Factors affecting the capacity are the capacity of the ad hoc part of the network and capacity due to the RSUs.

Researcher tries to express the overall available network capacity in terms of network performance indicators. These indicators say a lot about guaranteed capacity available for vehicles. The above works say that, the available capacity differ depending on the architecture and situation at hand. Among the factor are the number of participating Vehicles, the road geometry, and the application that are contending for available channel. These attempts were considering only existence of one wireless technology. If it was in heterogeneous environment, the result may be different, as different wireless technologies contribute for overall network capacity.

In any network available capacity depends on the available nodes, the technology used (even whether wired or wireless), the topology and the network traffic load or number of connection requests. We know that if the network is congested the overall network performance greatly degrade and participating node will experience a poor performance. Vehicular network shares the above considerations.

Vehicular network uses either one or two wireless technologies. The shared nature of the wireless medium makes a vehicle, to share the transmission channel not just with other nodes in the network, but also with external sources of interference. Which at the end affect guaranteed network capacity.

Vehicular network participants depend on the road traffic, which determines number participating nodes and topology of the network.. When traffic congestion occurs, the number of communicating vehicles raises, which results network congestion. The number of vehicles and their mobility also affects the topology. It is clear that these will have effect on the guaranteed network capacity

In vehicular network, the available services and information sources, which are contending, affects capacity. Congestion level of the network is expected to increase with the number of contending services and applications.

From the above discussion, we can conclude that the available network capacity depends on the following factors; vehicle density (traffic congestion), mobility and contending applications

3.3.2. Vehicle density

Traffic congestion is a condition on road, which occurs when many vehicles are around to use the road. Slower speeds, longer trip times, and increased vehicular queuing characterize it. When traffic demand is great enough that the interaction between vehicles slows the speed of the traffic stream, this results in some congestion. As demand approaches the capacity of a road (or of the intersections along the road), extreme traffic congestion sets in.

One aim of ITS applications is avoiding traffic congestion, to make use of the road infrastructure efficiently. There are different warning message sent before the situation happen, to inform other vehicles about the road condition. So that drivers can choose best choice in their journey. However, it sometimes become out of control and traffic congestion occurs which results network congestion.

Network congestion rose from traffic congestion, which many vehicles will reside within same coverage and demanding for network capacity, will affect the throughput of the network. Once network congestion occurred, it will be difficult to get out of the situation by making use of safety messages, because there may not be sufficient capacity for communication. This lack of communication may create other unsafe situation. it will be good to take proper actions before network congestion happens, to avoid other dangerous situations. However, the awareness on the available capacity is precondition for making decisions.

Network congestion typical effects include Delay, packet loss. So it will be possible to express the available capacity, in terms of performance metrics. But let us keep in mind that poor performance may not only be the result of network congestions due to vehicles density, but also an aggregate effect of other network capacity affecting factors.

3.3.3. Mobility

Mobility is important element in vehicular network. Vehicles mobility follows a predicted pattern. But high mobility of vehicles causes very dynamic network topology [40], causing blinking communication links, which results dynamic guaranteed network capacity. Unlike nodes in MANETs, vehicles generally travel at much higher speeds, especially on highways (i.e., over 100 km/h). As such, network resources assigned to vehicles can become useless due to frequent link disconnections between a source and a destination [41]. It makes the performance experience of vehicles poor. The mobility natures of vehicles result short connection time that impacts performance experience.

In traffic congestion situation, the above assumption may not be the case i.e. higher speed implies low performance experience to vehicles. Suppose network congestion has occurred due to traffic congestion. Each vehicle is experiencing some performance. If vehicles were traveling slowly, congestion period will take longer time, which may make the average vehicles network performance experience poor. In other word, if vehicles have higher speed, it may make the final average performance level a better one by shortening congestion duration. But this is an assumption that should be examined. So while expressing the available capacity in terms of performance metrics, it may affect the end performance result.

3.3.4. Network load due to applications

The vehicle density and mobility affect the network capacity. However, also the numbers of applications (with different QoS requirements) contending have lion’s share impact. The individual application contribution depends on their capacity need. But Different applications collectively will have the influence to make the network congest. These applications vary from safety application to comfort applications, which comfort applications relatively need much bandwidth. But from the main target of vehicular network, it is preferred to provide safety application more capacity share.

Network congestions caused by applications are a result of different scenarios. For instance, a vehicle broadcast safety message, which then broadcasted multiple times by the receiving vehicles; as a result network will easily get congested. Network congestions is not only occurred due to safety message, but also other ITS application like infotainment application. Infotainment applications need huge bandwidth, which limits the number of vehicles that can be served. But at traffic congestion, if there are many infotainments application requests, the network will get congested. The network may reach to a very poor status, which close the possibility of provisioning of safety critical message.

Network congestion in vehicular network means a lot, as it is more related to safety. There should be a way to aware of the available network capacity per vehicles, so as to take relevant action for a better output. As we have said estimating the available network capacity per vehicles is not an easy task that it will be expressed in terms of performance metrics.

3.4. Thesis focus

Traffic congestion, especially in urban areas, results in network congestion due to a large number of contending services and information sources. Different factor contribute to the network congestion i.e. vehicles density, different application etc. At congestion, available capacity for each vehicle significantly varies. it is difficult to estimate or say what is the value of the available capacity, in shared wireless medium nature. But, Capacity estimation could ease decisions for taking relevant action, for the betterment of the network.

The available capacity for each node can be expressed through performance metrics, which say much on capacity reaching its limit. But it is good to keep in mind that we cant fully tell that the performance decrease is not only because of low available capacity as different factor add to it.

In this Thesis work, we will discover the performance experience of vehicles at various contexts. To perform this task we will design a simulation model, which compromise all aspects that affect available network capacity. It includes vehicles and RSU with communicating capability. The investigations are done, in a situation where there is traffic congestion i.e. many vehicles at same spot. The spot will be the coverage area of RSU. We will observe performance experience of vehicles within RSU coverage and through their communication to the RSU. The congestion spot and congestion duration will depend on the RSU coverage area. Simple applications will be used to mimic, as there are different applications, which use simple generation of network traffic.

The analysis will begin to investigate the impact of traffic congestion on network. Varying vehicle density will perform simulation and observe performance experience of vehicles. The relation of performance with capacity is studied. And also will try exploring, the effect mobility and network load due to applications. Statistics are collected that will help us to see performance better. Finally the result will be interpreted in terms of the impact it have on road traffic.

CHAPTER 4

SIMULATION

In this section the simulation model with different scenarios and parameters is described. The simulation model includes wireless channel, vehicle mobility and other relevant information related to capacity. The tools that are used at implementation, the tools description is also included.

4.1. Network Simulation

The rise of vehicular networks has encouraged the design of a set of new applications and protocols specifically for these kinds of networks. The evaluation of those and vehicles performance in outdoor experiments, by using large-scale networks to obtain significant results, is extremely difficult due to several issues concerning available resources, accurate performance analysis, and reproducible results. Indeed, it is neither easy nor cheap to have a high number of real vehicles and a real scenario for only practical purposes.

Simulation has become a crucial tool because it makes possible to build a dedicated vehicular network for any kind of evaluation and studies. Simulators also makes it easy, to gather statistical data about the network usage during the simulation, which helps in examining the intended problem. Moreover, it is possible to visualize the network and easily configuring different scenario using parameters makes it easy, for different angle evaluation. However, due to the complexity of the real world, there may be a little inaccuracy in the outcome. But simulation is common in research in studying different aspects of networks.

In this thesis work, performance experience of vehicles related to capacity is going to observed and analyzed. So for these we preferred to use a simulation for getting results, because of the reasons above. Through simulation, we can observe the performance of vehicles easily using a simulator. Vehicular network as a new network, there are a lot of effort done in perfecting vehicular network simulation. Beside the network part the core element in vehicular network simulation is mobility model, which really affect the performance result we may reach. For mobility model we have used a traffic simulator for making it resembles a real scenario.

4.2. Network Simulator

There are several network simulators, which are used in research area for simulating different research related works. Each of them has their own merits and demerits with related to performance and in their model library. For our work we have chosen OMNET ++ [35] for the network simulation. It has been said that it is well and best candidate simulator for wireless simulation. [36]

OMNET ++ is a discrete event simulation environment. it has been developed by András Varga In uses hierarchical way in designing simulation models. It provides component architecture for models. Components (modules) are programmed in C++, and then assembled into larger components and models using a high-level language (NED). Models are reusable once they are designed. OMNET ++ has extensive GUI support, and due to its modular architecture; the simulation kernel (and models) can be embedded easily into our applications. Although OMNET ++ is not a network simulator itself, it is currently gaining widespread popularity as a network simulation platform in the scientific community as well as in industrial settings, and building up a large user community. One factor may be is it is free for academic use.

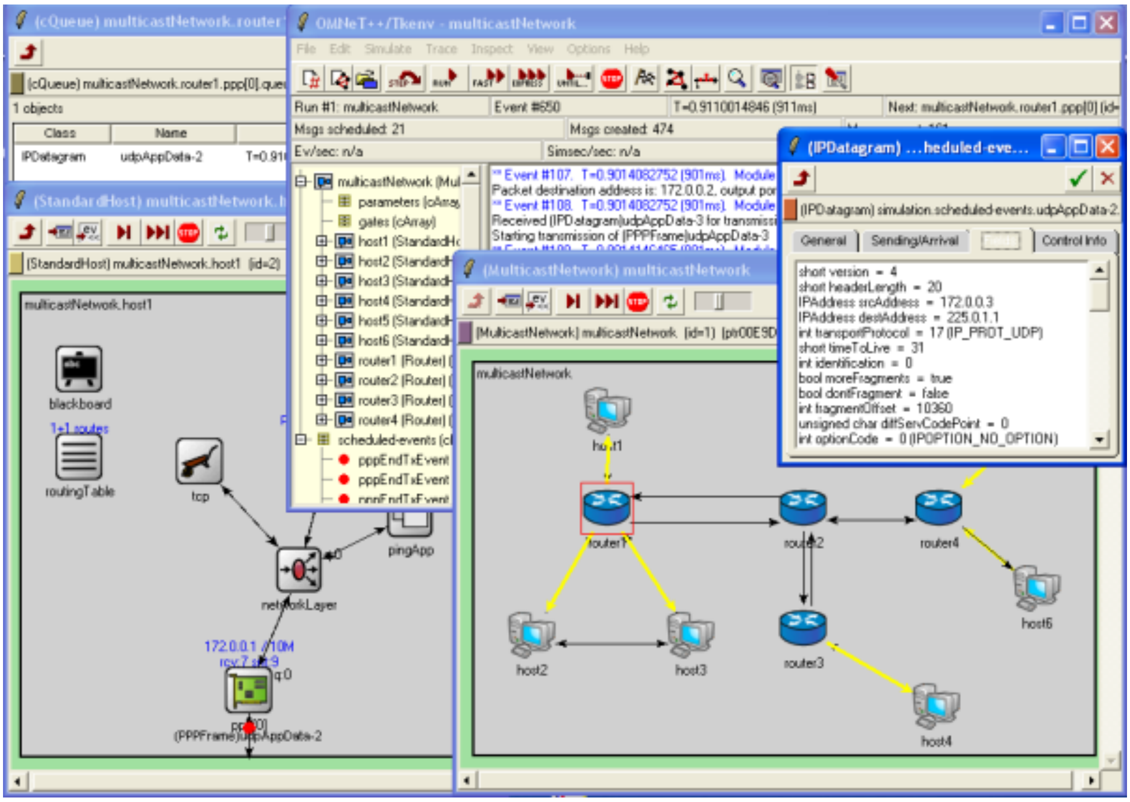

Figure 4.1: GUI interface of OMNET ++ [35].

While modeling in OMNET ++ the key elements are:

Topology: Describes relationship among elements, which is designed using NED language. it has also a GUI support.

Behavior: Describes how a node behaves. Which is defined using C++ code.

The top-level model is the system model, which embodies the complete simulation model and is referred as 'Network'. The high level Topology of the system may contains sub-modules of type compound modules, which themselves may have sub-modules or simple modules, which contain the algorithms in the modules and form the lowest level of module hierarchy. Thus the modules can be described to any depth of nesting as a result able to describe complex system models as a combination of a number of simple modules. The user implements the simple modules in C++, using the OMNET++ simulation class library. Modules communicate by message passing which can be a complex data structure. Modules may send messages directly to their destination or through a series of gates and connections to other modules. The messages can represent frames or packets in a computer network simulation. The local simulation time advances when the module receives messages from other modules or from the same module as self-messages, which is the representation of timers in simulation world. These self-messages are used to schedule events to be executed by itself at a later time.

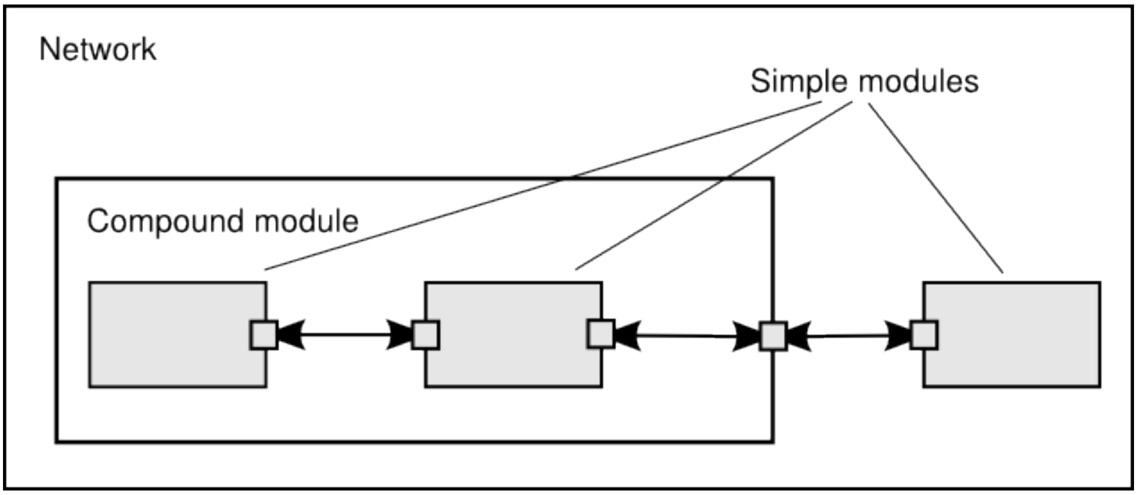

Figure 4.2: Simple and compound modules

OMNeT++ has external frameworks, which enable it to provide support for simulation of different types of networks. They are developed and released by different independent groups that are working for extending model libraries. The most known and used extensions are INET Framework and MixiM. These frameworks make it easy to extend and build on top of them.

Simulation in OMNET++ are easy to configure and run through initialization files, through which the various parameters in modules can be specified or changed and simulation re-run with requiring the re-compilation of the simulation setup. In this way OMNeT++ represents a simulation engine, keeping track of the events generated and making sure that messages are delivered to the right modules at the right time, thus accomplishing the task for discrete event simulation.

4.3. Road traffic simulator

In OMNET++ mobility support for network simulations is limited to simple mobility patterns. Examples that are available are the Random Waypoint or mass-based mobility models. It is widely accepted that such simple mobility patterns cannot be used for experiments in vehicular communication scenarios as road traffic patterns strongly differ from such simple mobility models.

More realistic mobility model that comprises exact characteristic of vehicles is achieved through traffic simulators. Among the existing traffic simulators, SUMO [37] is an open-source microscopic continuous-space and discrete-time vehicular traffic simulator developed at German Aerospace Centre. SUMO has a lot of important features, which help in making realistic road traffic. Among these features: the support for different vehicle types, multi-lane streets with lane changing, right-of-way rules at intersections, support of a graphical user interface and dynamic vehicular routing. While we use it with veins the graphical user interface is not important feature.

4.4. Veins -vehicles in network simulation

Veins [38] is an open source Inter-Vehicular Communication (IVC) simulation framework composed of an event-based network simulator OMNET++ and a road traffic micro simulation model SUMO. Its main focus is act as a framework for vehicular network communication. It is available through MixiM Framework of OMNET++ and provides modules specific to Vehicular communication. While connecting OMNET++ and SUMO it uses TraCI, which is an open-source interface that couples a road traffic simulator and a network simulator to enable real-time interactions.

Once veins successfully connect OMNET++ and SUMO, every vehicle in sumo is defined as a node in OMNET++; veins do this and also make mobility of nodes in OMNET++. Veins use a TCP connection and Python scripts to enable SUMO to act as a mobility model in OMNET ++. Sumo-launchd listening for event from OMNET ++.

4.5. Simulation set-up

In this section, basic components with their description and different simulation scenario with parameters are presented.

4.5.1. Highway module

The highway module is a compound module, which shows the top level of our model. It includes all relevant vehicular network components needed in road. It contains the basic modules that are need for wireless communication modeling in OMNET++. One of such module is Connection Manager module, which is responsible for establishing connections between nodes that are within the maximal interference distance of each other and tearing down these connections once they exceed this distance. The loss of connectivity can be due to mobility (i.e. the nodes move too far apart) or due to a change in transmission power or a crashed node etc. Another module included in this compound module is Roadside unit, that is the one putted on the side of the road and makes communication with the vehicles.

4.5.2. Car Module

The vehicles are implemented using the car module of the Veins. This module is the one that is corresponded to the node at road traffic generator (SUMO). While the road traffic generator SUMO generates vehicles, the corresponding car module is generated in OMNET++ through the help of veins.

For our simulation, the main focus was given to the application layer, the mac layer and physical layer. Here the Question is whether this simple configuration will make us capable of getting what we need for capacity related performance of vehicles, absolutely it will provided us results that will help for further analyze. Among the three layers for statistical collection we have focus on the mac layer.

The application layer used is simple one, just serves us for traffic generation and reception of packets according to the chosen type of application.

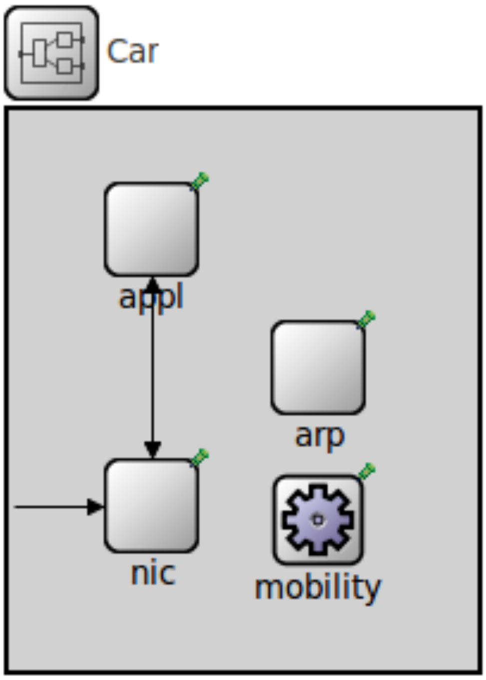

Figure 4.3: Car module

we have used the standard IEEE 802.11p, which is implemented in veins framework. Physical and Mac layer are based on the already available 80211.p model. The model encompasses the 80211.p DSRC PHY and MAC layers, including Access Categories for QoS, the Wave Short Message (WSM) handling, and beaconing WAVE service announcements, as well as multi channel operation, i.e. the periodic switching between the Control Channel (CCH) and Service Channels (SCHs). [39]

4.5.3. Road side unit (RSU)

The RSU are implemented with same configuration like Car module but use a static mobility. RSU periodically send a beacon to inform vehicles their address. So that it will be easier to identify for vehicles to where to send service request.

4.5.4. Mobility model

We have used Sumo traffic simulator, the mobility of the vehicles is invoked at SUMO. Each vehicle will emulate the driver behavior. We have used a simple line Road network with some curves in which each vehicles start from one point and end at some destination. Vehicles will flow back to back with out overtaking.

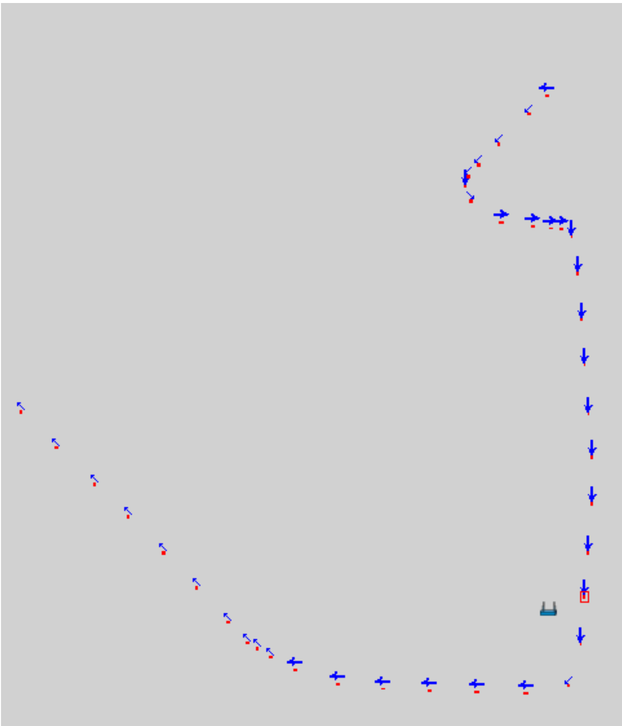

Figure 4.4: road network

4.5.5. Applications

In our simulation we assume to have two simple applications. These applications mimic different type of applications with their own communication pattern. Below the two applications are described.

* **Type-one Application**: In this type of communication, vehicles periodically send a Broadcast. The communication style could be like for example vehicles sending

periodically location, speed and other relevant information to other fellow in network that use this information.

* **Type-two Application**: vehicles will send a packet periodically to the nearby RSU and RSUs reply to the sending vehicle. It is like a peer-to- peer communication. For instance a vehicles may request a map from RSU and get that map or it may request weather conditions etc.

4.5.6. Simulation scenario

Different scenarios were prepared, in order to analyze the different capacity affecting factors. The main goal of the simulations scenario is to express available capacity in terms of performance metrics, which say much about capacity reaching its limit and independently to observe the impact of the different capacity affecting factors.

The performance metrics used are:

- **Packet Delivery Ratio:** it indicates delivery success in the network. The amount of packets received divided by the amount of packets sent. it is clear that if available capacity is low, the delivery ratio will be low. Especially if the network is reaching its limit delivery ration drops severely. It is shows the load on the potential capacity.

- **Packet Loss ratio**: it is the opposite of delivery ratio, which indicates the ratio in terms of the packet loss.

- **Packet RTT Delay**: The time taken by a packet when transmitted from a source vehicle to a RSU and to get reply back. In non-congested environment packet can transmit with low delay, but as demand increase we expect the delay to increase noticeably. So in Vehicular network when the network is congested we should expect delay to increase, as there are a lot of connection demands. Anyway it will be justified through simulation and will see the result.

• **Packet Delay:** The time taken by a packet when transmitted from a source vehicle to destination node (in our case RSU).

4.5.6.1. Vehicle density scenario

This scenario is done to study the effect of the number of vehicles and try to show capacity limit in terms of performance metrics. We vary the number of vehicles around, and according to their communication with RSU, we express the performance experience. We have used the same proportion of active vehicles for every simulation for each vehicle number. The results are averaged over 10 independent iterations.

Table 4.1: Parameters for vehicle density scenario

Simulator	Omnet++/Veins
Mobility Model	SUMO
No of Vehicles	10,20,30,40,50
Max Vehicle Speed	35km/hr
Inter-vehicle gap	2.5m
PHY/MAC	IEEE 802.11p(Veins model)
Maximum Transmission Power	20 mW
Thermal Noise	-110 dBm
Transmission Range	Around 300 meter
Bit Rate	18Mbps
Type-two Application Load (Active vehicles proportion)	50%
Simulation time	220

4.5.6.2Mobility scenario

Mobility is the one of the factor that affects the performance experience of a vehicle. Available capacity is expressed in terms of performance metrics. So this scenario is done to examine what is the effect of mobility. The simulation scenario is done, by varying the vehicle’s speed with fixed number of vehicles. The results are averaged over 10 independent iterations.

Table 4.2: Parameters for mobility scenario

Simulator	Omnet++/Veins
Mobility Model	SUMO
No of Vehicles	30
Max Vehicle Speed	5 km/hr, 20 km/hr, 35km/hr, 50 km/hr
Inter-vehicle gap	2.5m
PHY/MAC	IEEE 802.11p(Veins model)
Bit Rate	18Mbps
Maximum Transmission Power	20 mW
Thermal Noise	-110 dBm
Transmission Range	Around 300 meter
Type-two Application Load (Active vehicles proportion)	50%
Simulation time	220

4.5.6.3Network load due to applications scenario

Network may be over loaded by different applications, which make it congested. Even though different applications have different capacity need, the collective load on the network gives a greater picture of applications' effect on the available capacity. This scenario is done to observe the performance experience, which is a result of different application loads. This observation will come up the effect of Applications on the available capacity. The results are averaged over 10 independent iterations.

Table 4.3: Parameters for network load due to applications scenario

Simulator	Omnet++/Veins
Mobility Model	SUMO
No of Vehicles	30
Max Vehicle Speed	35km/hr
Inter-vehicle gap	2.5m
PHY/MAC	IEEE 802.11p(Veins model)
Maximum Transmission Power	20 mW
Thermal Noise	-110 dBm
Transmission Range	Around 300 meter
Bit Rate	18Mbps
Type-two Application Load (Active vehicles proportion)	20%, 40%, 60 %, 80%
Simulation time	220

CHAPTER 5

RESULT AND DISCUSSION

In this section, the results from the simulation scenarios are presented, and discussed with respect to different aspects that affect performance experience of vehicles. We performed the simulation and presented different performance indicators that are related to capacity.

5.1. Results of vehicle density scenario

Vehicles density is the cause, which creates traffic congestion. In traffic congestion situation many vehicles will be around for longer time. In vehicular network environment, when many vehicles are around the network will start to be congested, making available capacity to decrease. The congestion level depends with the number of communicating vehicles. In a congested network, the available capacity per vehicles will impact performance experience of vehicles. This simulation scenario is done to observe the performance experience of vehicles at different vehicles number and its relation with the available capacity. The simulation is done in way that 50% of the total numbers of vehicles are actively communicating type-two application and another two vehicles are using type-one application. The parameters used are as specified in Table 4.1.

Table 5.1: Simulation results of vehicle density scenario

Vehicles number	Type-two Applications Packets				Type-one Application Packets	
	Delivery Ratio (Per Packet)	Delivery Ratio (Per Vehicle)	RTT (Per Packet)	RTT (Per Vehicle)	Delivery Ratio	Noise Packets received
10	0.243587865	0.240004314	0.520559418	0.541146	0.621437174	786
20	0.152496626	0.141112478	0.522254624	0.566648	0.631782946	5186
30	0.122355289	0.10728122	0.526765207	0.584493	0.526815642	11362
40	0.106578276	0.085527693	0.528000857	0.591384	0.491909385	16295
50	0.100604375	0.071772761	0.518698996	0.575131	0.469409283	19410

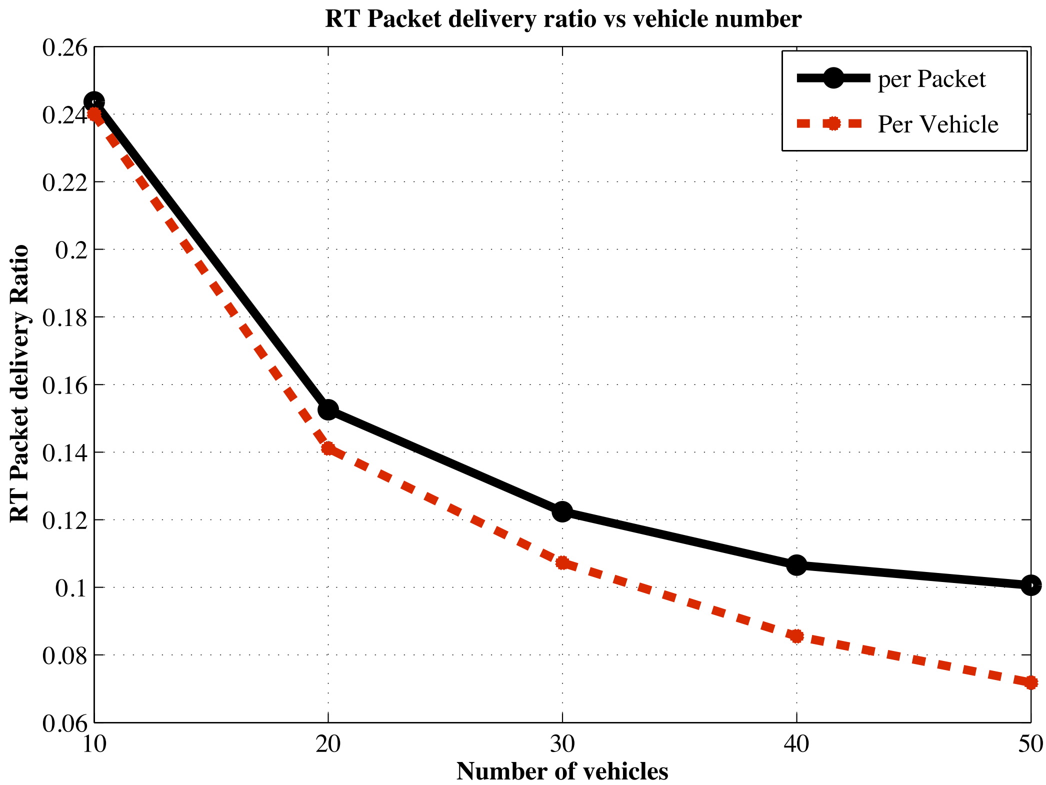

Figure 5.1: Graph showing packet delivery ratio with respect the number of vehicles

In Figure 5.1, it shows RT delivery ratio per packet and the average delivery ratio experience of vehicles. It is shown that when the number of vehicles is increasing, the delivery ratio is decreasing for round trip communication. When the number of vehicles increases, the delivery ratio is becoming worst. It indicates that the network is becoming congested and that the capacity has reached its limit at higher vehicle number level. Except for vehicles number 10, the delivery ratio for others is very high, which is a poor performance experience for vehicles. For instance, for vehicle number 50, delivery ratio is approaching to 0.1 for per packet delivery ratio where for per vehicle it is below 0.1. These results indicate same behavior we expected.

As the number of vehicles increase the two plots show a wider difference, which indicates fairness problem. Vehicles are not getting equal share of the capacity.

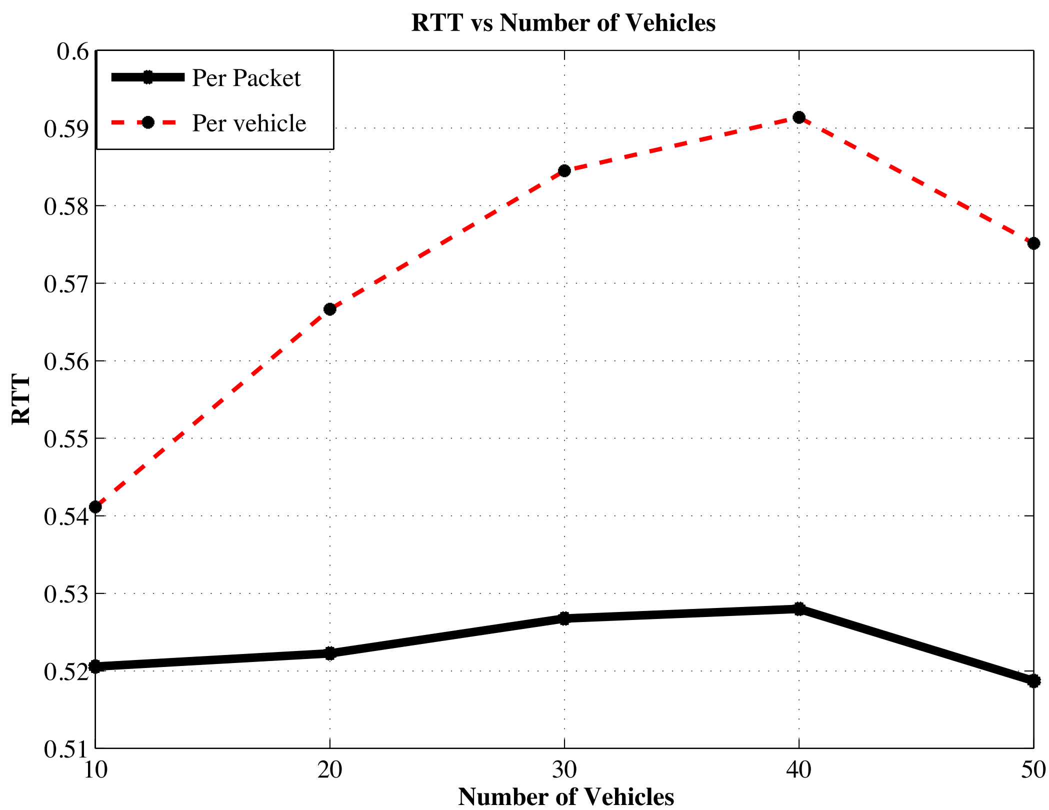

Figure 5.2: Graph showing RTT with respect the number of vehicles.

The RTT time shows us an interesting result. In figure 5.2, it is shown that when the number of vehicles is increasing the RTT is increasing, except for the last one, which decreased considerably for both plots. The RTT is calculated considering the successfully received packets. So the reason for these may be, as successfully delivery rate have decreased, for the small successful ones may be have low RTT.

In our simulation we didn't constrained maximum RTT, had it been the case we hope that it will show a lower average RTT as fulfilling packet will make it below the threshold value we set.

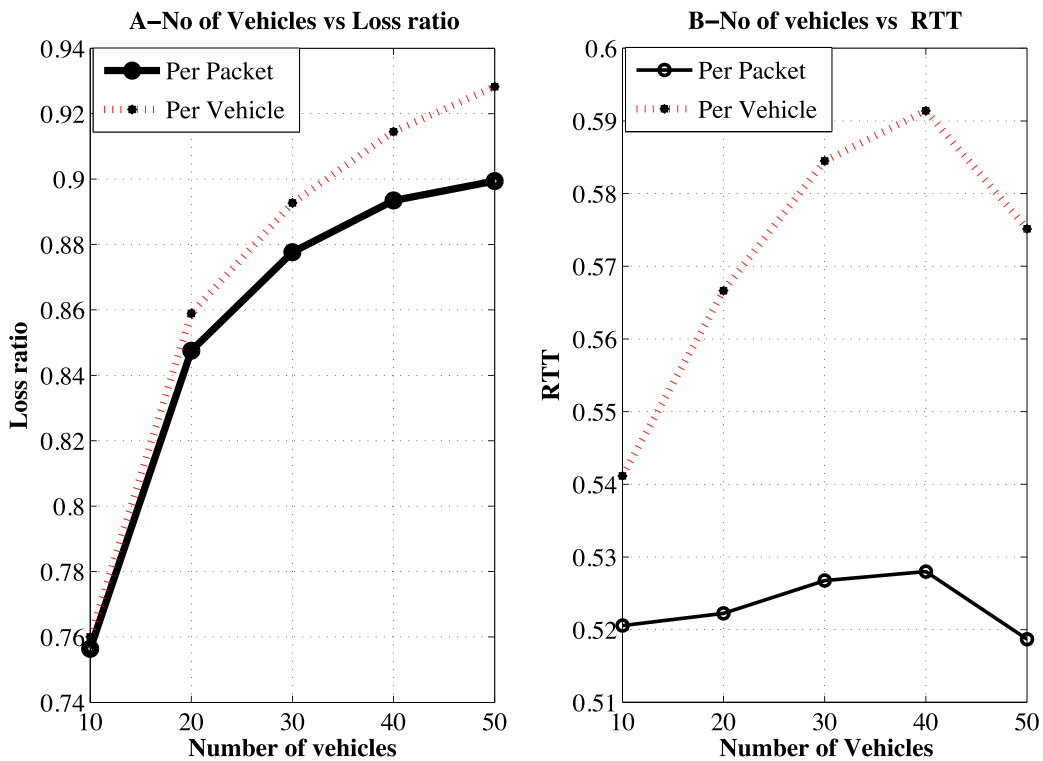

Figure 5.3: Graph showing Both (A) RTT loss ratio (B) Average RTT with respect the number of vehicles

To find out the correlation of loss and RTT and also to try to reason out the sudden decrease shown at RTT Figure 5.3 shows the two plots.

In the two plots, it is shown that when the number is increasing both the loss ratio and RTT are increasing for round trip communication. It shows a high correlation between RT loss ratio and RTT, but when number of vehicles is 50, there is unexpected decrease, which the corresponding loss ration is around 0.9. So we can conclude that between 40 and 50, the network has reached the total network capacity limit that the successfulness rate becomes impossible. The small successful one at the start of the simulation may be caused the low RTT, which results a lower RTT for 50 than 40. If there were time, it would be good to observe again taking action to avoid the effect at the start.

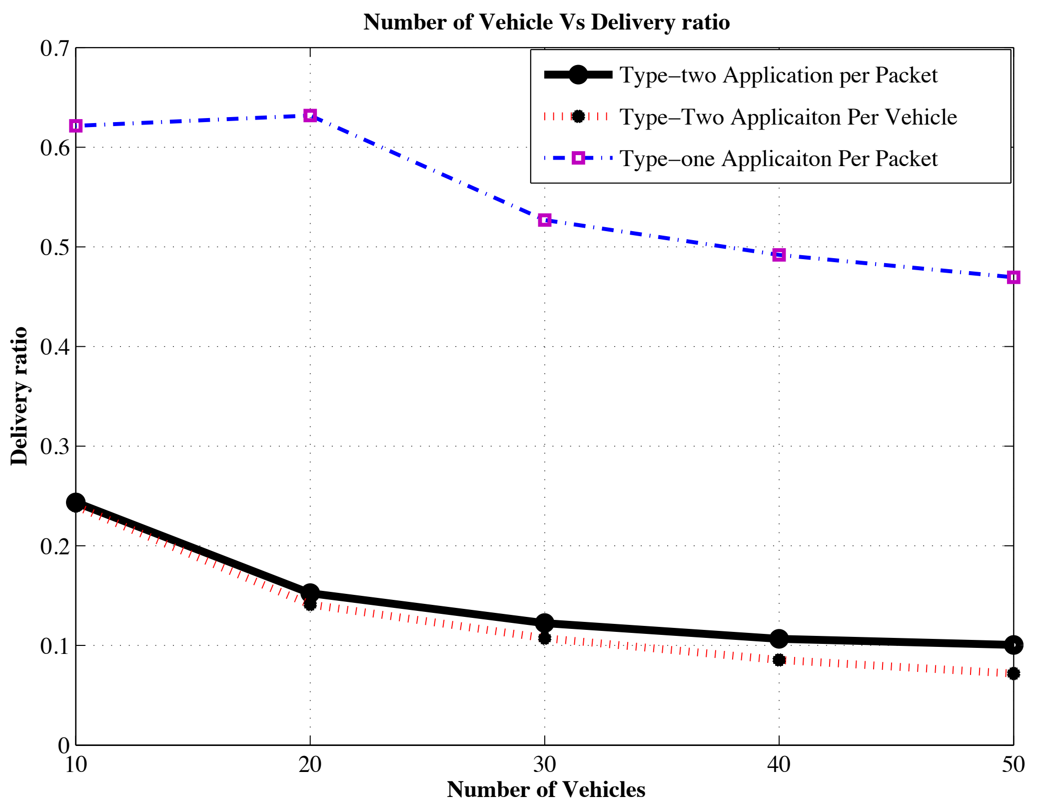

Figure 5.4: Graph shows delivery ratio of type-one and type two applications to compare with one trip and round trip.

It is clear that RT applications (type-two application) need more capacity than one-trip applications. In Figure 5.4, it shows comparison between the two. It is shown that with the number of vehicles increasing the behavior is similar for both types of applications. Type-one application has a better delivery ratio than Type-two application.

For Type-one application, after the number of vehicles is 30, delivery ratio is lowering revolving around 0.5. There are only two vehicles, using this kind of application for all vehicles number level. It is clear that Type-two application have impact on this application by consuming the available capacity.

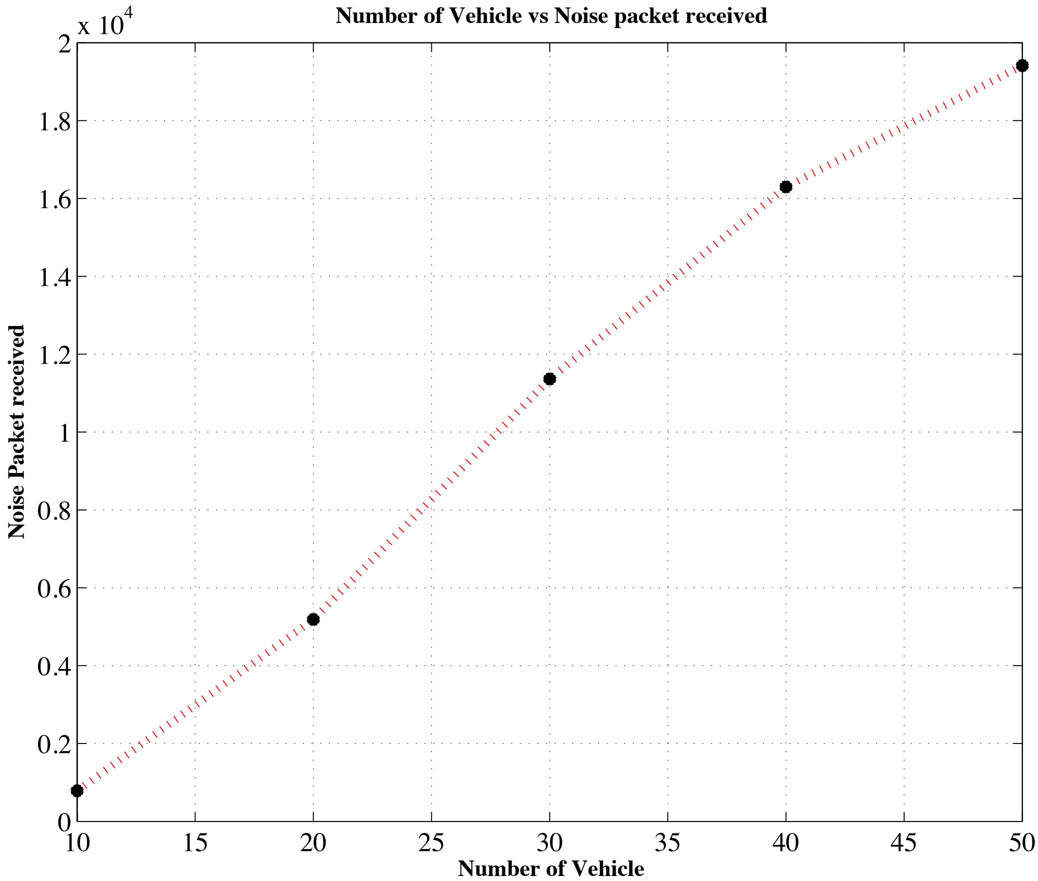

Figure 5.5: graph showing total noise packet received with respect to number of vehicles.

In wireless communication, when there are a lot of nodes around, the interference level increases. Vehicular network as one of wireless communication, interference increase as the number of vehicles around increases. In figure 5.5, the plot shows the interference level in terms of increase of the number of noise packets received by vehicles. It is shown that the number of noise packets is increasing with the increase of the number of vehicles. It is the result of many vehicles around and the high communication. These noise packets have effect in making vehicles not to able use the available capacity by overloading the channel.

5.2. Mobility

Mobility determines vehicles communication experience. In a very high-speed mobility, it creates frequent disconnection, which results poor performance to vehicles. From the above scenario, we observed that as the vehicles number increase the performance decrease. So next scenario, the impact of mobility by fixing the vehicles number to 30 is examined. The simulation scenario is done varying the speed limit of vehicles from 5 km/hr., 20km/hr., 35 km/hr., 50 km/ hr. Among the vehicles half of them are actively using Type-two application and 2 others are using type-one application. The parameters used are as specified in Table 4.2.

Table 5.2: Simulation results of mobility scenario

Speed (km/hr.)	Type-two Applications Packets				Type-one Application Packets	
	Delivery Ratio (Per Packet)	Delivery Ratio (Per Vehicle)	RTT (Per Packet)	RTT (Per Vehicle)	Delivery Ratio	Noise Packets received
5	0.106842508	0.118413959	0.388335713	0.4409492	0.104029991	2259
20	0.090124337	0.072834217	0.562026679	0.5915494	0.475649351	6888
35	0.125942232	0.106231	0.530440131	0.5796364	0.537354732	11406
50	0.148956357	0.13583167	0.506965367	0.5517424	0.486877343	10454

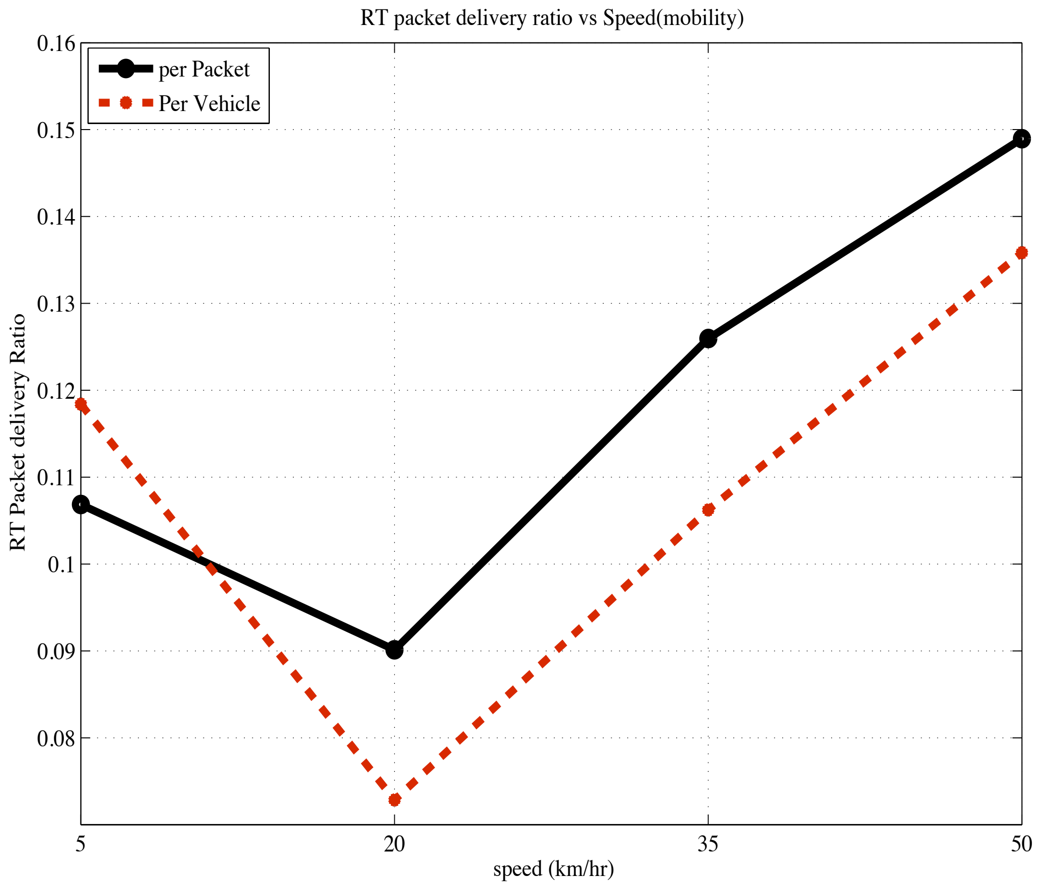

Figure 5.6: Graph showing average packet delivery ratio with respect to speed and 30 vehicles

In Figure 5.6, it is shown an interesting result. From the vehicles number scenario, we choose 30 to simulate and to observe the impact of speed (mobility). As we can see for all speed level, there is low delivery ratio, which may be because of higher applications load. From the plot for speed 5km/hr the delivery ratio is around 0.11 for per packet and 0.12 for per vehicle, which is very low. Even a worst situation is happened for speed 20km/hr, it shows below 0.1 delivery ratio. But when the speed is increasing the delivery ratio is becoming better, which it may be the result of that the congestion level is reducing because of faster speed. Our expectation was similar except for lowest here is when speed is 20km/hr. The fairness is an issue, which some vehicles takes capacity from others.

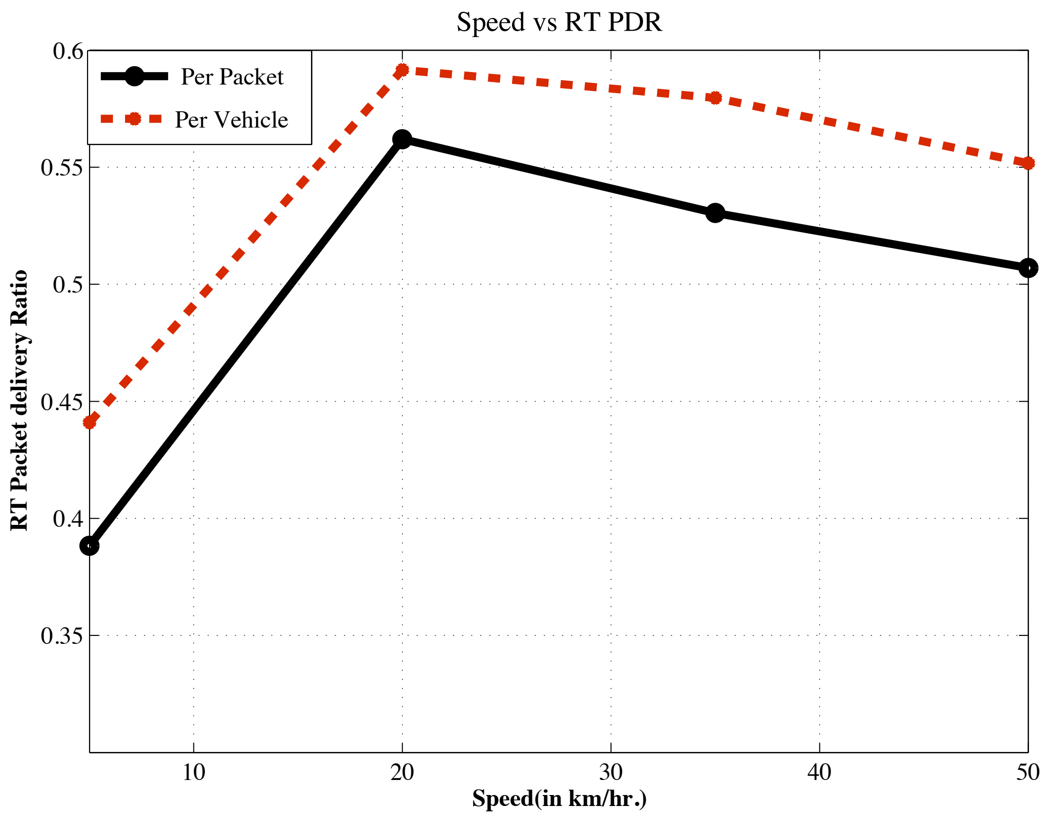

Figure 5.7: Graph showing RTT with respect speed.

The RTT shows us an interesting result. In Figure 5.7, it is shown that speed 5 km/hr. have a smallest RTT and it reaches its peak value for 20 km/hr. (It is wired result that we can't figure it out what is the exact reason. It needs a more investigation) and starts to fall to a lower value. The RTT time is for 5 km/hr. is a lowest value we get even including the whole simulation scenarios. It may because while the vehicles are moving slower the time to be far from the RSU coverage area is long. So it happens that if the packet is successful at least it will reduce distance delay time. For 20 km/hr., which have the peak value, vehicles are experiencing a worst performance; even the successfully delivered ones are punished by longer RTT.

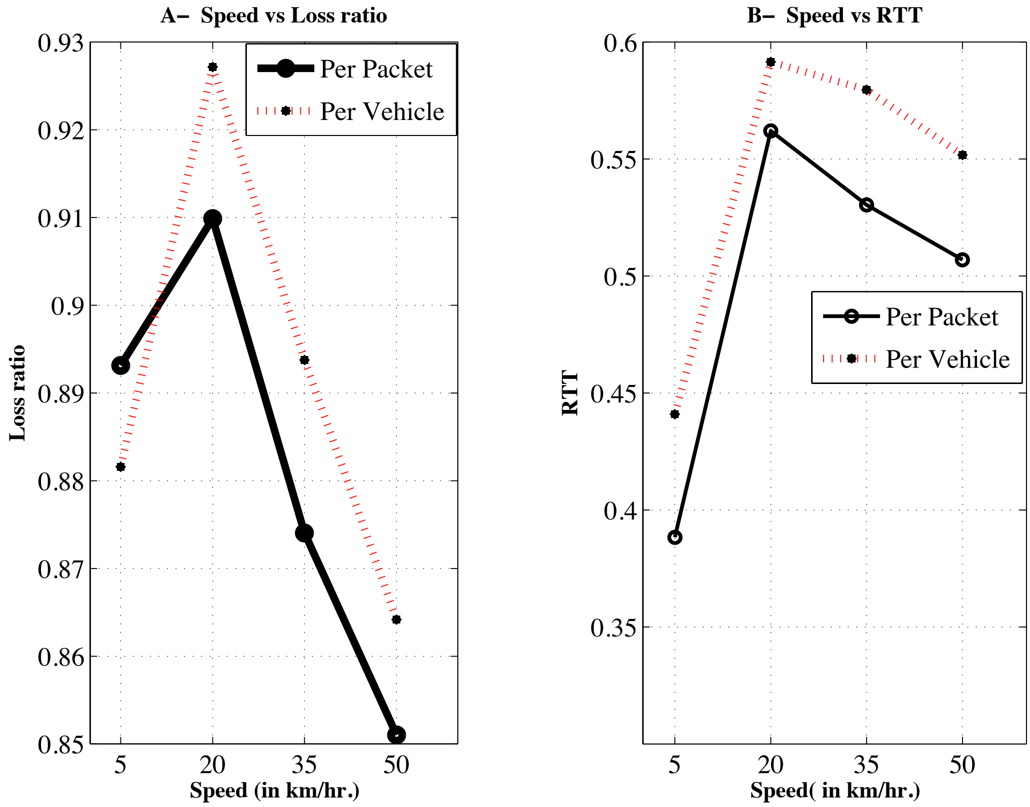

Figure 5.8: Graph showing Both (A) RTT loss ratio (B) RTT with respect speed.

In figure 5.8, let us see the relation of loss ratio and RTT for better judgment and for reaching a better conclusion for the interesting result. We can see that the plots are like a mirror image. When the speed is 20 km/hr., both the loss ratio as well as RTT shows a peak value. Which indicates the high correlation of RT loss ratio and RTT. It is shown that as loss reaches to its peak, the corresponding RTT value is high, which indicates the small successful one are having a long RTT time. Loss gets a lower value when speed is last one whereas Delay gets the lowest one at minimum speed.

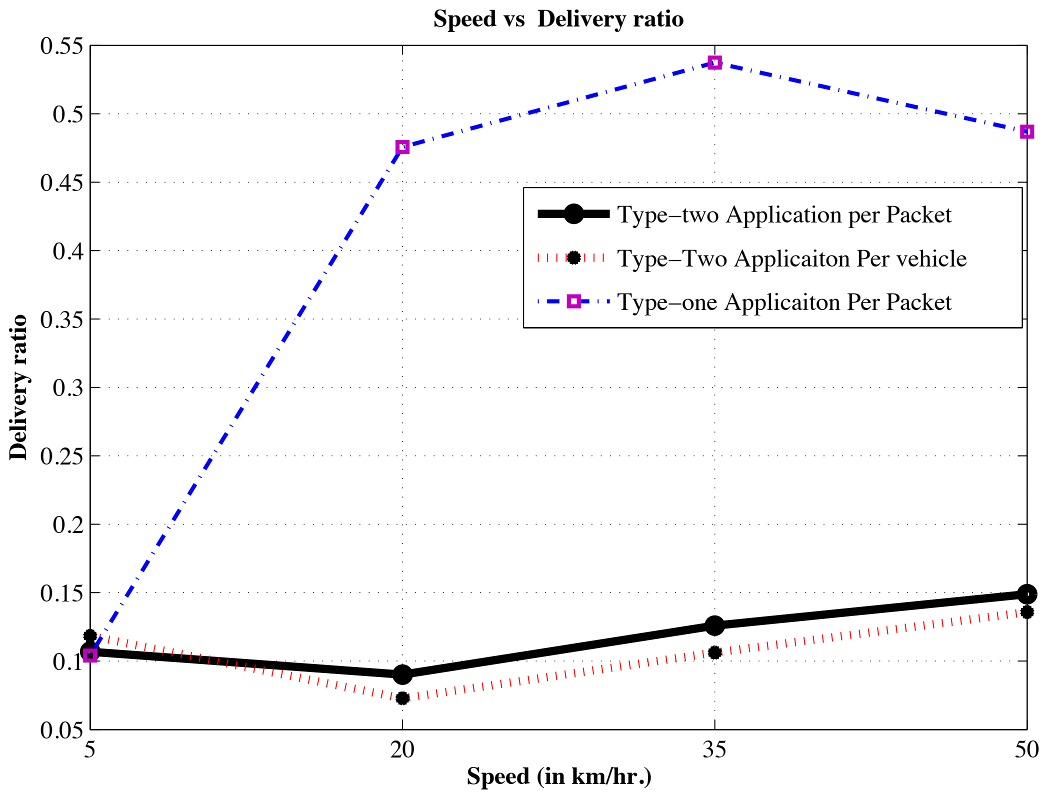

Figure 5.9: Graph shows delivery ratio of type-one and type two applications

In Figure 5.9, the graph shows that with the increase of maximum speed the behavior is same for both type of applications, except for the last speed level, which delivery ratio for type-one application violate the increasing graph, may be the type-two applications load is impacting it. are more The case may The delivery ratio for type-one application is increasing more rapidly than that of type-two application. Both show a very low delivery ratio when the speed is 5 km/hr., which is because the congestion duration is taking longer which results a worst status. For speed 20 km/hr., it shows a lowest for type-two applications, whereas for type-one it shows a rapid increase. This shows the correlation of speed with the performance experience depends on the situation, whether there is congestion or not. So the effect of mobility on the available capacity depends on the situation at hand.

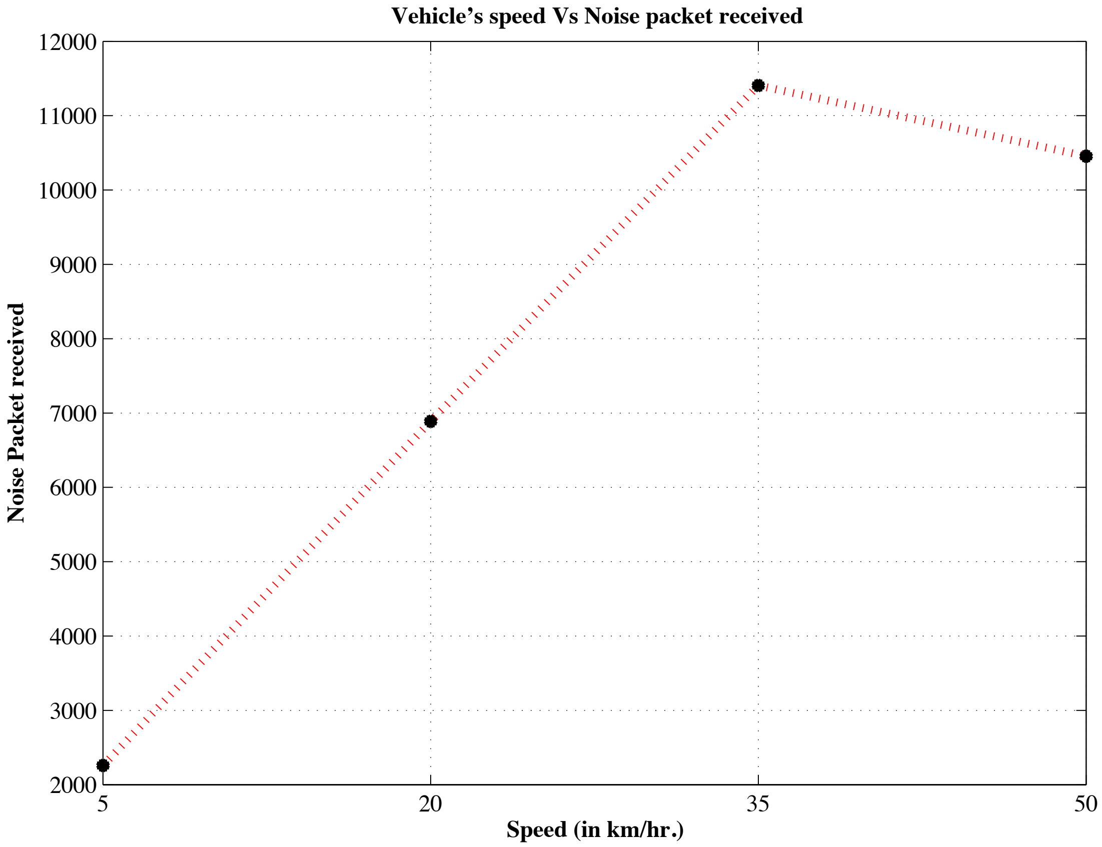

Figure .5.10: graph showing total noise packet received with respect to speeds.

To some extent to depict the interference level, Figure 5.10 shows interference level in terms of number of noise packet received at each vehicle. It is shown that the number of received noise packet is increasing with respect to increase in speed. But when speed is 50 km/hr, it decreases a little bit. It may be because it is having a better delivery ratio which packets with a SNIR level are becoming low. As we have a faster speed the congestion level somewhat not stays longer which avoids packets that have an SNIR below threshold.

5.3. Applications

Vehicle density and mobility controls the available network capacity for individual vehicles. However the impact of application is inevitable. Safety or/and comfort applications have their own share on the consumed bandwidth. To observe the impact of many application requests, we perform the simulation scenario by fixing the vehicles number to 30 and 35 km/hr speed. 20%, 40%, 60% and 80% load of Type-two application (Active vehicles proportion) and 2 others using type-one application are used. The parameters used are as specified in Table 4.3.

Table 5.3: Simulation results of applications scenario

Type-two Application Load	Type-two Applications Packets				Type-one Application Packets	
	Delivery Ratio (Per Packet)	Delivery Ratio (Per Vehicle)	RTT (Per Packet)	RTT (Per Vehicle)	Delivery Ratio	Noise Packets received
20	0.499925004	0.518755195	0.484989725	0.470970054	0.671106557	3876
40	0.155830835	0.140849211	0.53666689	0.582064848	0.5687974	9018
60	0.093774406	0.07985887	0.558969114	0.584092761	0.534512265	13291
80	0.049512808	0.039540083	0.537729872	0.560492584	0.46239718	19501

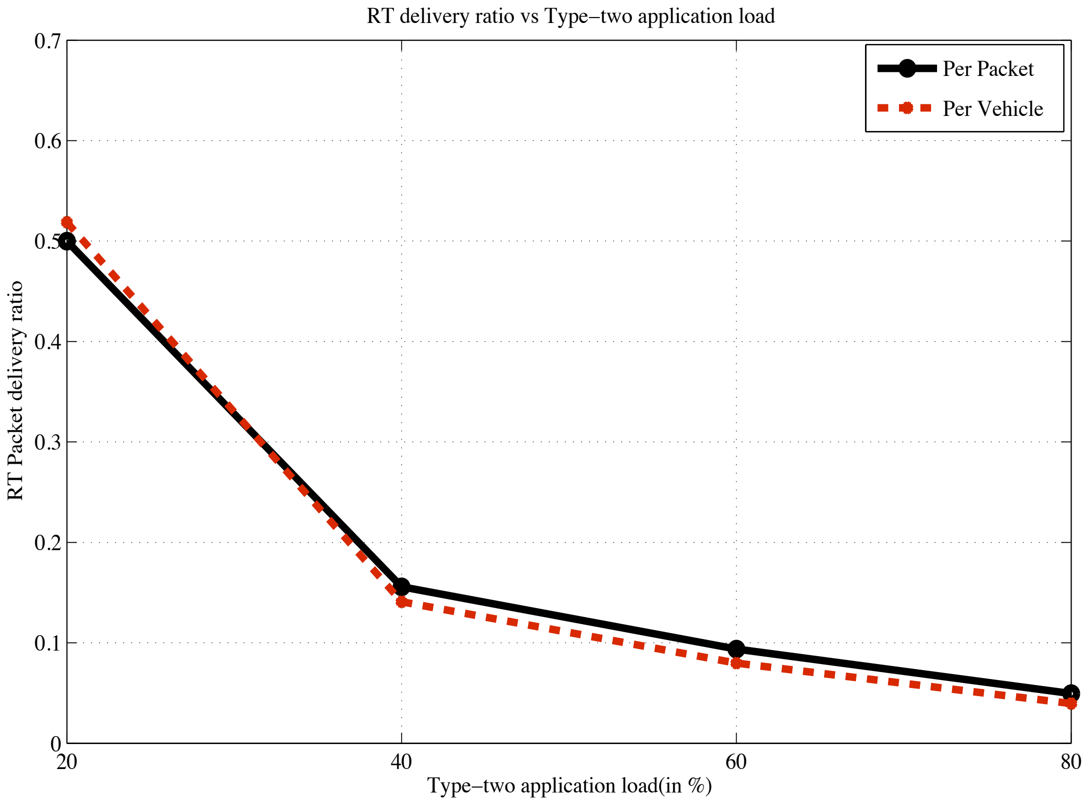

Figure 5.11: Graph showing packet delivery ratio with respect to Type-two application load

In figure 5.6, the plot shows impact of different application load. The delivery ratio is falling to lowest value with the increase of application load. As we can see from the graph for 80% load the delivery ratio is below 1%, which is very worst. For low load i.e. 20%, it show good delivery ratio. The result implies that the network is starting to be congested, which results a low delivery ratio. For all application loads, vehicles are almost getting a equal share of capacity. Vehicles are almost getting equal share of the capacity, which is a good result.

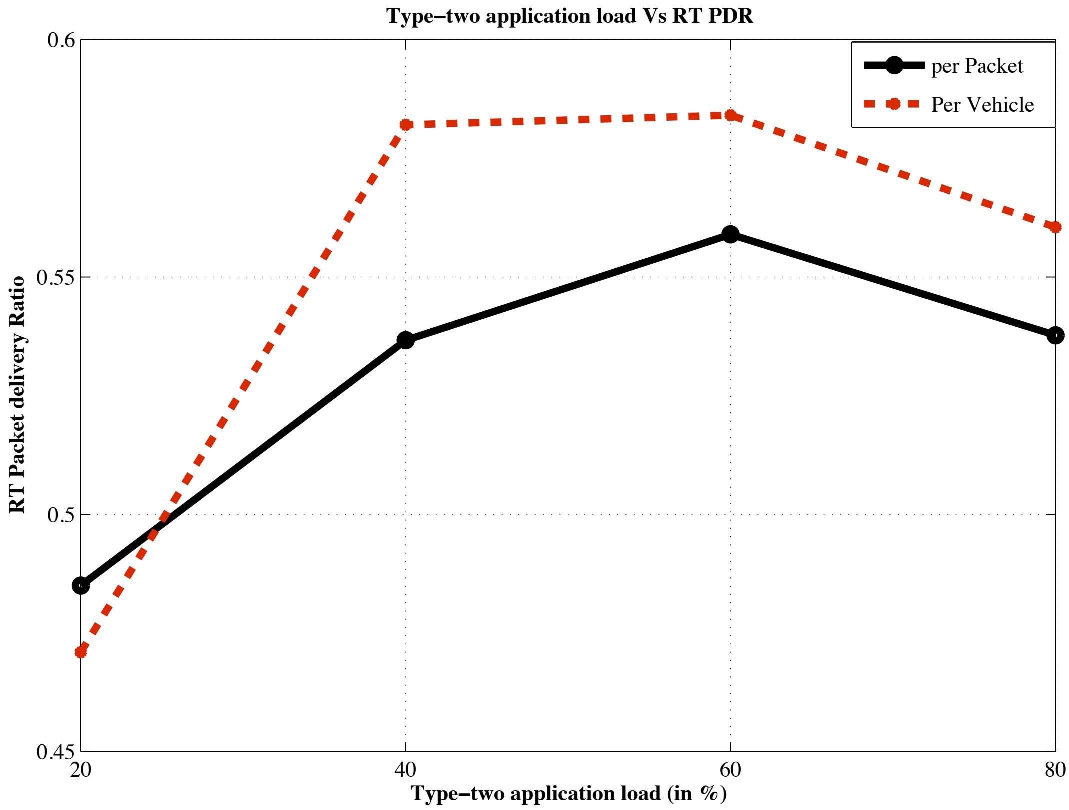

Figure 5.12: Graph showing RTT with respect to Type-two application load

From Figure 5.12, the graph shows a smallest RTT when the load is 20%. Then it shows an increase excluding the 80%, which shows a little decrease for both plots. For 20% load per-vehicles RTT have a better RTT time than that of per-packets. For last load level, it may happen that for successful one have a better RTT. This may happened because of that successful reception happened at the start of the simulation with lower RTT. So if there was enough time we further try to avoid this effect and observe for better judgment.

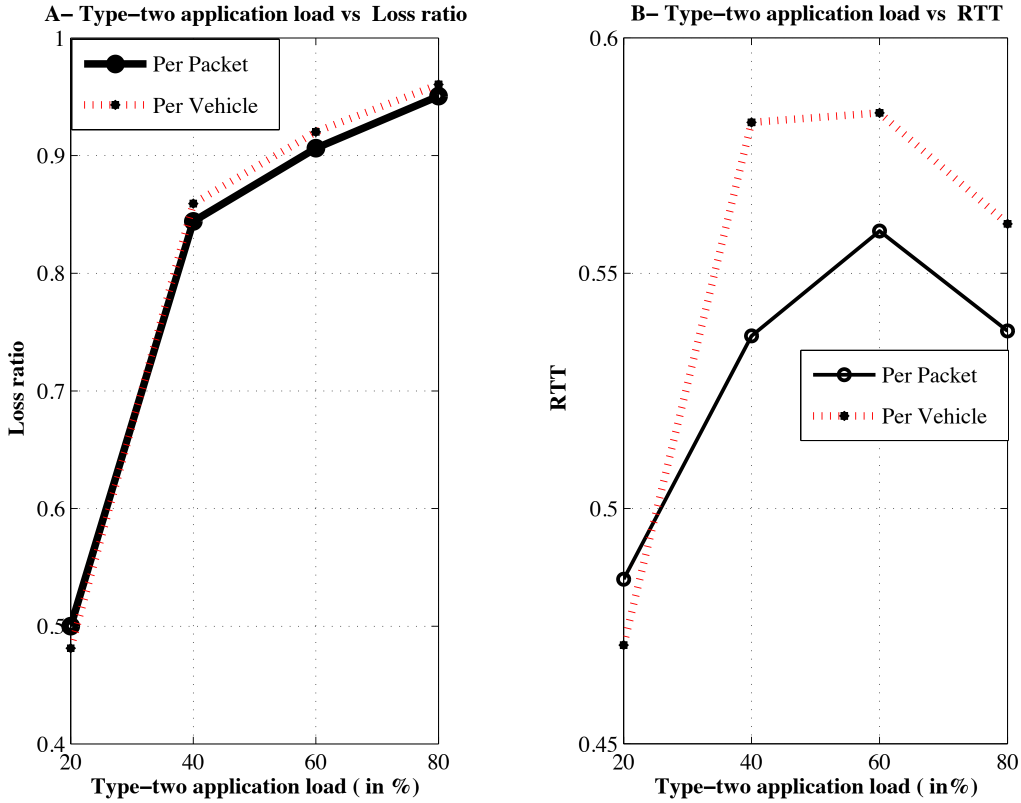

Figure 5.13: Graph showing Both (A) RT loss ratio (B) RTT with with respect to Type-two application load

We can see from figure 5.13 that the two graphs are strictly increasing except for that of RTT, which shows a lower RTT value for higher load. This implies that as the loss is very worst reaching around 100% obviously the small successful one are getting a relatively lower RTT. This outcome may result from that the little successful one's at the start of the simulation where there are small numbers of vehicles that could show this a relative lower RTT.

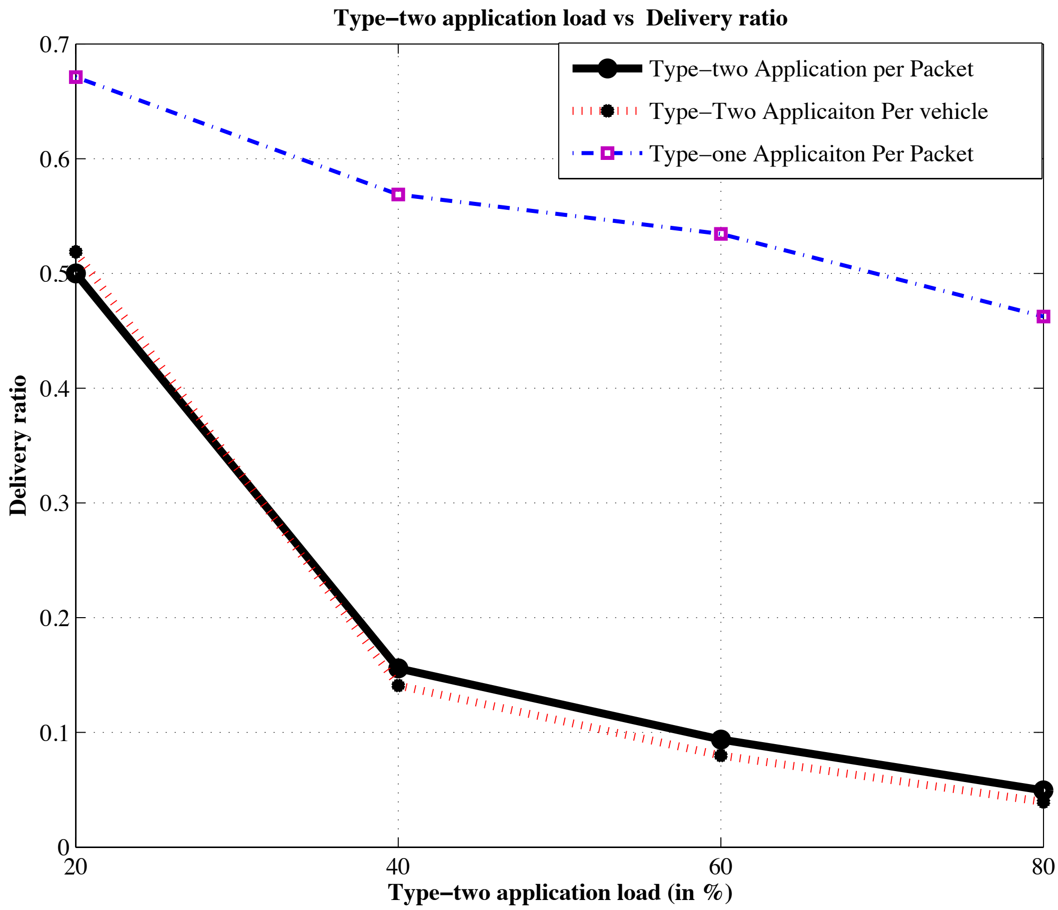

Figure 5.14: Graph shows delivery ratio of type-one and type two applications with respect to Type-two application load

Figure 5.14, it shows that with the increase of maximum speed the behavior is same for both type of applications, decreasing delivery ratio. For the lowest applications load both are getting a better performance that it is not seen even from all simulation scenarios. This shows, the great impact of application load on overloading capacity and giving vehicles a worst performance experience for vehicles. As it is expected Type-one application has a better delivery ratio than Type-two application.

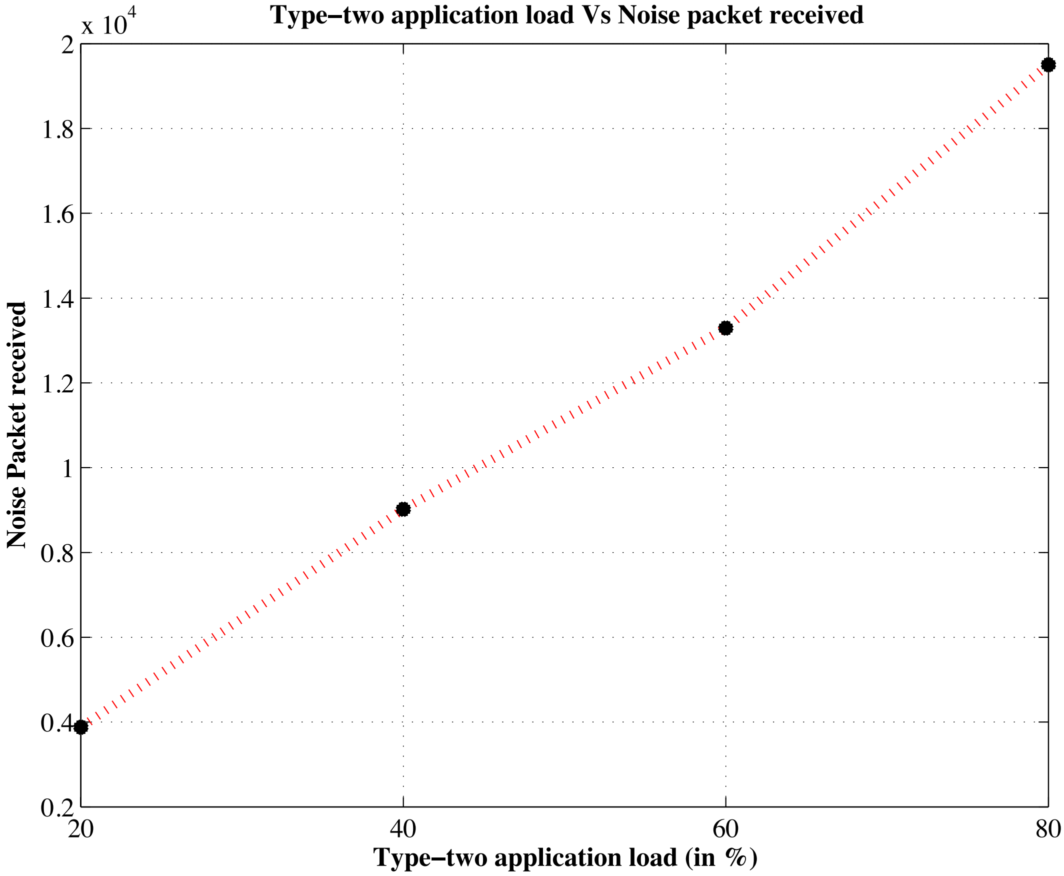

Figure .5.15: graph showing total noise packet received with respect to Type-two application load

In figure 5.10 shows interference level in terms of number of noise packet received at each vehicle. The number of received packet is increasing with respect to increase load. Even if the number of vehicles is equal i.e 30, the number of noise packets received increase with application load. It is because numbers of active vehicles are increasing, sending packets and overloading the available capacity, which results increase in the interference level. And also with the same number of vehicles, with the increase of active ones the gap between them is small, which is one reason for increase of interference.

5.4. Observations and Recommendation

Among the many significant promise of vehicular network, one is to reduce the congestion that is occurring in road traffic, for better utilization of infrastructure and for avoiding different life treating problems. To achieve these goals, it is needs the dissemination of different messages to the whole participating vehicles and the proper reception by receivers.

Safety is one of the most important and significant applications of vehicular networks. Vehicles communicate information about traffic and road conditions with each other, as well as with fixed network nodes like RSU. Examples are warning messages that are generated by approaching emergency vehicles, cars that stopped or vehicles stuck in a road tunnel because of an accident. Typically, safety messages need to be broadcasted to all vehicles traveling over a geographical area, and need to be delivered with high reliability and low delay. It is therefore the congestion problem is a big question for safety applications.

As we have seen from our results the performance metrics indicates that in a very congested situation the available capacity for vehicles will be low. It tells the difficulty to fulfill safety application communication requirement. This situation further may create threatening troubles, in such a way that vehicles could not successfully disseminate safety messages through the network to avoid accidents and dangerous situations. So it leads to a worst situation that is even beyond congestion.

From our study and results we identified that the core threating factors, which affect available capacity, are vehicle density and load due to different application. So for these factors we have to give a proper solution to create a smooth communication among vehicles that result a harmonious traffic environment.

Vehicles density creates traffic congestion, which results network congestion. Vehicle traffic congestion is reflected as delays while traveling. Traffic congestion has a number of negative effects and is a major problem in today's society. So Several preventive techniques have been deployed to deal with this problem. It needs more effort to come up an efficient technique to avoid this problem, through vehicular network. It is clear that working on this technique will at the end be a solution for the network congestion problem.

Another reason for network congestion is the existence of load due to applications. Different applications have different consumption of bandwidth. But the significance of the applications is an important thing in vehicular network.it is known safety and efficiency application are very important applications. But as there are other comfort applications which mostly bandwidth consuming, it affects safety and efficient applications. So the available capacity may not be good enough to provision all these application reliably.

Additional transmission lines, fatter pipes, and improved efficiency are common responses to network congestion. However, this strategy works better for wired networks than for wireless networks such as vehicular network. Increasing capacity with additional channels and improving channel efficiency are important steps in handling the substantial growth of vehicular network. However, capacity improvements alone will not solve this complex challenge.

Policy management will play a fundamental role in implementing QoS in vehicular network communication. Policy management is the process of applying rules for resource allocation and network use. It is a mechanism, in which according to the situation of the network different access control policies are applied, in order to utilize the available network capacity and also in order to avoid different problems that may arise from network congestion. In our study we have used RSU coverage as the congestion area. So we think of a way that revolves around RSU to handle the problem. So we recommend application of policy at RSU, for a better network performance. But first let us say elements used in our recommendation.

1- Application Type

Different application requires different reliability, time delay, data rate and QoS guarantee. Especially safety applications need a good reliability in reaching the whole network. At the time of congestion to provide the need level of reliability is difficult. And safety applications are more significant than others.

2- **Network Conditions**

In order to provide a smooth and reliable network we should make use of network-side information of the system, the performance information is a good input in order apply policy to avoid network congestion and to realize load balance among different networks effectively.

As we discussed high importance is given for safety application instead of comfort applications. Most comfort applications like video streaming consume available capacity. So in a congested environment, we should have a mechanism to limit comfort application so as to make a space for safety applications.

RSU gets different warning information about the road condition. So from this information and from comfort application requests, it could estimate how is the congestion level of the traffic as well as the network. This capability of RSU can help in taking precaution action before the occurrence of congestion.

From the information it collects, RSU will start controlling the resource by blocking new request of comfort applications not only blocking them and informing them the condition about network congestion. The threshold value in which this action should starts depends on the deployed network capacity and the road condition. The policy application needs more study as different polices depend on the situation at hand.

CHAPTER 6

CONCLUSION AND FUTURE WORK

The goal of the work behind this report was to study the different aspects that affect the vehicular network capacity. The approach to the problem has been to design a simulation model for investigating performance experience of vehicles, especially in congestion condition and observing the performance experience correspondence with available capacity. The different aspects effect on performance experience and capacity was also studied independently.

Before designing the simulation model, a comprehensive study was done on vehicular network communication. We identified components of vehicular network, the different communication mode, the different wireless technologies available; the challenges of vehicular network and capacity relate issues. We tried to identify the different factor affecting capacity. These are vehicle density; mobility and network load due to different applications and study them. Then, Simulation model implementation was done, using OMNET++ and veins framework that is comprises modules that are related to vehicular networks. In addition, we applied vehicular mobility model, which produce more realistic and reliable results that is SUMO that supports realistic vehicular movement scenario.

Trough three different scenario, we observed vehicles performance experience with respect to the different aspects which affect capacity. The results derived from the simulation shows that vehicle density and load due to applications have greater impacts, which cause worst performance degradation to vehicles. It indicates that these two are core capacity affecting factors, which have a direct relationship with capacity. The available capacity, in vehicles' perspective is certainly depends on these two elements.

The mobility scenario on different speed of vehicles shows a better performance result for higher speed levels. From the result, we came to know even if mobility is a treat for frequent disconnection, in a congested situation the higher speed a vehicles have the lower the congestion be, the better performance result. So the aggregated available network capacity of vehicles is a result of this all capacity affecting factors.

We also observed a fairness issue between vehicles that some of them steal capacity from others. This situation may raise the problems we mentioned in an abundant capacity; due to fairness issue that safety message from the victim vehicles could not successfully delivered. So it needs a proper attention to fix this problem.

The result indicates that network congestion will as result affect the road traffic, by closing the possibility of information exchange between vehicles. It is clear that a road traffic that is dependent on ITS application will incur a big problem due to lack of available capacity. So a more dangerous situation that is more that traffic congestion problem may occur. So a proper solution should be implemented for better situation and for increasing available capacity at any time for vehicles. We have recommended applying a policy to monitor the application load on the network through RSU in which RSU will detect a possible congestion and do preventive actions.

6.1. Future Work

In this thesis, while we were designing a simulation model, we have included all aspects that could affect capacity, including the inclusion of long-range communication (cellular network). However, at implementation, we could not include this component. The simulation tool (OMNET++) used was the best candidate in such a way that its hierarchical approach in designing simulation model was easy to track and the extensive models available in OMNET++. Unfortunately, it did not include cellular networks, but despite of this we thought it was the best tool that suited the rest of the task.

Therefore, as future work, by finding a way to get a long-range model, it is nice to see what effect it has on the vehicles' performance and on the aggregated available capacity, while long-range wireless technology and short-range wireless technology are together.

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APPENDEX

Each simulation iteration results

A- Vehicles density scenario

Vehicles Number = 10						
Seed Number	Type-two Applications Packets				Type-one Application Packets	
	Delivery Ratio (Per Packet)	Delivery Ratio (Per Vehicle)	RTT (Per Packet)	RTT (Per Vehicle)	Delivery Ratio	Noise Packets received
0	0.118421053	0.116786505	0.470355016	0.493355979	0.670682731	662
1	0.100877193	0.098009751	0.485916645	0.514314413	0.652	475
2	0.103649635	0.101482222	0.444044416	0.475319253	0.632	781
3	0.425844347	0.422429403	0.470708163	0.496713096	0.580645161	890
4	0.099270073	0.097599237	0.522580579	0.530327591	0.6	1118
5	0.090775988	0.088613214	0.522223341	0.573840781	0.612	637
6	0.325	0.31519125	0.58451266	0.661197021	0.646586345	724
7	0.432352941	0.433132389	0.540841312	0.562962034	0.540322581	908
8	0.350954479	0.342499834	0.459321657	0.499456924	0.63052208	893
9	0.392647059	0.384299332	0.597881574	0.603979921	0.64919354	777

Vehicles Number = 20						
Seed Number	Type-two Applications Packets				Type-one Application Packets	
	Delivery Ratio (Per Packet)	Delivery Ratio (Per Vehicle)	RTT (Per Packet)	RTT (Per Vehicle)	Delivery Ratio	Noise Packets received
0	0.070496084	0.063485371	0.501269099	0.546579921	0.694835681	5601
1	0.055417701	0.049238911	0.467906053	0.500612676	0.674556213	4126
2	0.065491184	0.058636784	0.440713147	0.511476434	0.680751174	4626
3	0.075837743	0.062929767	0.45313273	0.554015543	0.661971831	3974
4	0.340468909	0.29321272	0.504046926	0.582076731	0.688679245	4152
5	0.076534903	0.067959258	0.583851046	0.595466268	0.612149533	5334
6	0.278145695	0.255259883	0.544847686	0.614611986	0.56097561	5744
7	0.173669468	0.158240821	0.577409755	0.594967736	0.497076023	6407
8	0.295008913	0.277893447	0.548345575	0.548345575	0.212121212	5972
9	0.145256917	0.124267817	0.618332404	0.618332404	0.698113208	5925

Vehicles Number = 30						
Seed Number	Type-two Applications Packets				Type-one Application Packets	
	Delivery Ratio (Per Packet)	Delivery Ratio (Per Vehicle)	RTT (Per Packet)	RTT (Per Vehicle)	Delivery Ratio	Noise Packets received
0	0.054390564	0.042739337	0.448806331	0.456839322	0.642487047	10419
1	0.048841578	0.038205125	0.508928151	0.587787316	0.505102041	10385
2	0.054375	0.042918589	0.509151862	0.591913887	0.536082474	10813
3	0.056355667	0.044598731	0.464262723	0.543292358	0.656410256	9806
4	0.235090153	0.208064392	0.494252472	0.566715755	0.412121212	12761
5	0.059244792	0.047287422	0.502528189	0.588449949	0.658163265	9991
6	0.254035088	0.229416301	0.521831783	0.581093604	0.345864662	12135
7	0.139338494	0.110322031	0.593827635	0.688986971	0.506329114	12199
8	0.242424242	0.218435025	0.595681947	0.595681947	0.445783133	11610
9	0.113837764	0.090825246	0.644178295	0.644178295	0.469072165	13503

Vehicles Number = 40						
Seed Number	Type-two Applications Packets				Type-one Application Packets	
	Delivery Ratio (Per Packet)	Delivery Ratio (Per Vehicle)	RTT (Per Packet)	RTT (Per Vehicle)	Delivery Ratio	Noise Packets received
0	0.046813311	0.031414175	0.448806331	0.456839322	0.607142857	15312
1	0.042553191	0.028642215	0.508928151	0.587787316	0.494897959	15126
2	0.047437296	0.032194819	0.509151862	0.591913887	0.510204082	15878
3	0.049180328	0.033439945	0.464262723	0.543292358	0.58974359	15122
4	0.206432749	0.177619288	0.502176799	0.572170555	0.357512953	17405
5	0.050668151	0.034400226	0.502528189	0.588449949	0.602040816	14074
6	0.203974284	0.175766964	0.52019034	0.563643855	0.335329341	17687
7	0.110590989	0.075254917	0.572186462	0.668400825	0.486842105	16525
8	0.218085106	0.185244153	0.620044302	0.620044302	0.431952663	16779
9	0.109028961	0.08130023	0.721306083	0.721306083	0.469072165	19043

Vehicles Number = 50						
Seed Number	Type-two Applications Packets				Type-one Application Packets	
	Delivery Ratio (Per Packet)	Delivery Ratio (Per Vehicle)	RTT (Per Packet)	RTT (Per Vehicle)	Delivery Ratio	Noise Packets received
0	0.044125465	0.02501047	0.448806331	0.456839322	0.56122449	18647
1	0.040625	0.022913772	0.508928151	0.587787316	0.505102041	17585
2	0.045218295	0.025719749	0.509151862	0.591913887	0.489795918	18632
3	0.046997389	0.026720237	0.464262723	0.543292358	0.569230769	17601
4	0.190424374	0.14624249	0.490093542	0.54916057	0.331550802	20447
5	0.048071844	0.027379832	0.502528189	0.588449949	0.596938776	16799
6	0.188761593	0.161680859	0.519066612	0.543115987	0.278688525	21668
7	0.105058366	0.060039379	0.572186462	0.668400825	0.47133758	19171
8	0.205420054	0.159667756	0.568254521	0.568254521	0.448979592	21806
9	0.101676582	0.062353066	0.654103305	0.654103305	0.422680412	21745

B- Mobility scenario

Speed= 5 km/hr.						
Seed Number	Type-two Applications Packets				Type-one Application Packets	
	Delivery Ratio (Per Packet)	Delivery Ratio (Per Vehicle)	RTT (Per Packet)	RTT (Per Vehicle)	Delivery Ratio	Noise Packets received
0	0.108033241	0.12658201	0.27330566	0.40688162	0.142857143	1658
1	0.148688047	0.17960676	0.415509136	0.469757448	0.133333333	1444
2	0.153698367	0.211964252	0.438688674	0.482758042	0.112149533	1970
3	0.133397313	0.129227767	0.400624801	0.459569549	0.149425287	1588
4	0.097609562	0.096591745	0.407170227	0.463029593	0.089041096	2834
5	0.087160262	0.064087665	0.265739226	0.393478808	0.141025641	1342
6	0.086382114	0.07992339	0.450223594	0.442691251	0.095238095	2052
7	0.06122449	0.045672338	0.375619618	0.438121469	0.067961165	3249
8	0.094017094	0.109422144	0.441292441	0.441292441	0.095890411	3334
9	0.099722992	0.141061517	0.411912394	0.411912394	0.054347826	3124

Speed= 20 km/hr.						
Seed Number	Type-two Applications Packets				Type-one Application Packets	
	Delivery Ratio (Per Packet)	Delivery Ratio (Per Vehicle)	RTT (Per Packet)	RTT (Per Vehicle)	Delivery Ratio	Noise Packets received
0	0.0551291	0.042870518	0.390565827	0.495107163	0.078125	7218
1	0.065010957	0.050872028	0.456718843	0.548749762	0.485714286	6636
2	0.07437408	0.05792108	0.481119825	0.513359647	0.564285714	5415
3	0.053932584	0.041422059	0.368986329	0.506878203	0.452173913	5493
4	0.115695793	0.098341034	0.613581223	0.614323394	0.4	8454
5	0.037307974	0.033538456	0.472625441	0.543076464	0.557823129	7099
6	0.157894737	0.116950724	0.62660556	0.685294734	0.58974359	6610
7	0.112173913	0.084971118	0.649909297	0.727983732	0.619565217	7616
8	0.129380054	0.098627339	0.613531593	0.613531593	0	5955
9	0.134020619	0.102827814	0.667189967	0.667189967	0.428571429	8388

Speed= 35 km/hr.						
Seed Number	Type-two Applications Packets				Type-one Application Packets	
	Delivery Ratio (Per Packet)	Delivery Ratio (Per Vehicle)	RTT (Per Packet)	RTT (Per Vehicle)	Delivery Ratio	Noise Packets received
0	0.054641211	0.043172096	0.448806331	0.456839322	0.675257732	10514
1	0.04875	0.038218327	0.508928151	0.587787316	0.596938776	10598
2	0.056320401	0.044604741	0.464262723	0.543292358	0.625641026	10186
3	0.251778094	0.205116062	0.509290744	0.563735826	0.396341463	11702
4	0.059399478	0.047186412	0.502528189	0.588449949	0.642857143	9843
5	0.254035088	0.215381213	0.521831783	0.575341161	0.345864662	12135
6	0.163610719	0.130315296	0.596936274	0.651765787	0.503184713	12223
7	0.239721254	0.203996479	0.530296942	0.59306057	0.469945355	12508
8	0.114540466	0.091353808	0.644178295	0.644178295	0.443298969	13375
9	0.054375	0.042965564	0.591913887	0.591913887	0.579487179	10980

Speed= 50 km/hr.						
Seed Number	Type-two Applications Packets				Type-one Application Packets	
	Delivery Ratio (Per Packet)	Delivery Ratio (Per Vehicle)	RTT (Per Packet)	RTT (Per Vehicle)	Delivery Ratio	Noise Packets received
0	0.056355667	0.044624028	0.461611547	0.528050003	0.442708333	10798
1	0.05864005	0.04563059	0.520808267	0.615490886	0.548717949	10161
2	0.04996877	0.038774032	0.435589134	0.55338305	0.466666667	10454
3	0.050561798	0.040092003	0.521304822	0.626865834	0.489690722	10511
4	0.273901809	0.249542476	0.520278324	0.544703008	0.36	8915
5	0.060436137	0.047463129	0.549357793	0.514248256	0.545918367	10893
6	0.260012715	0.241109668	0.469247987	0.478855099	0.487046632	11220
7	0.248086735	0.249920356	0.501915342	0.525834883	0.494845361	11149
8	0.23255814	0.203961932	0.502049367	0.502049367	0.556701031	10223
9	0.211501597	0.197198487	0.627944193	0.627944193	0.43902439	10223

C- Load Due to Applications scenario

Type-two Applications load= 20 %						
Seed Number	Type-two Applications Packets				Type-one Application Packets	
	Delivery Ratio (Per Packet)	Delivery Ratio (Per Vehicle)	RTT (Per Packet)	RTT (Per Vehicle)	Delivery Ratio	Noise Packets received
0	0.473841555	0.452906176	0.528338793	0.503972906	0.709183673	3982
1	0.563527653	0.574056906	0.607834209	0.607909627	0.591836735	2650
2	0.446935725	0.47892696	0.518158964	0.493642608	0.678571429	4559
3	0.46038864	0.462000893	0.48518286	0.439297922	0.668367347	4692
4	0.561561562	0.581802672	0.38039609	0.356123956	0.74742268	3080
5	0.503736921	0.53257261	0.544642928	0.554850146	0.683673469	3683
6	0.543674699	0.566817217	0.484521252	0.368094519	0.641025641	3168
7	0.457013575	0.479518039	0.412379573	0.412957241	0.706185567	4297
8	0.534534535	0.59533875	0.514718889	0.514718889	0.584615385	3839
9	0.453996983	0.463611724	0.458132728	0.458132728	0.701030928	4816

Type-two Applications load= 40 %						
Seed Number	Type-two Applications Packets				Type-one Application Packets	
	Delivery Ratio (Per Packet)	Delivery Ratio (Per Vehicle)	RTT (Per Packet)	RTT (Per Vehicle)	Delivery Ratio	Noise Packets received
0	0.077992278	0.06373182	0.560813935	0.621763326	0.581632653	8772
1	0.070053888	0.055937871	0.492674078	0.567621513	0.617346939	7577
2	0.073133179	0.058616283	0.496627063	0.572786493	0.61025641	8792
3	0.090769231	0.073087661	0.471924849	0.568354591	0.649484536	8053
4	0.306938776	0.2920887	0.499590861	0.546252725	0.477419355	9221
5	0.075558982	0.061453078	0.530929754	0.518890422	0.653061224	7457
6	0.277317881	0.251003803	0.509902813	0.553577067	0.584615385	9435
7	0.261047463	0.240954953	0.62629321	0.6515333	0.56185567	9926
8	0.260694108	0.237554652	0.554412236	0.554412236	0.385869565	10455
9	0.092248062	0.074063287	0.665456808	0.665456808	0.524822695	10492

Type-two Applications load= 60 %						
Seed Number	Type-two Applications Packets				Type-one Application Packets	
	Delivery Ratio (Per Packet)	Delivery Ratio (Per Vehicle)	RTT (Per Packet)	RTT (Per Vehicle)	Delivery Ratio	Noise Packets received
0	0.026659697	0.020445578	0.462368658	0.402479485	0.611398964	13111
1	0.043933054	0.034640842	0.510085175	0.644638664	0.595854922	13443
2	0.026123302	0.019600107	0.460672954	0.595789115	0.607142857	13851
3	0.138398115	0.110203405	0.582644406	0.649084491	0.512820513	12990
4	0.138398115	0.110203405	0.582644406	0.649084491	0.512820513	12990
5	0.034285714	0.026618229	0.441670662	0.433277787	0.586734694	13677
6	0.2	0.180514604	0.596096298	0.665854648	0.247191011	14118
7	0.10614192	0.084180508	0.618368203	0.631922392	0.540540541	10868
8	0.201247166	0.178836262	0.557617042	0.557617042	0.363636364	14408
9	0.048680352	0.033345766	0.611179492	0.611179492	0.577319588	13462

Type-two Applications load= 80 %						
Seed Number	Type-two Applications Packets				Type-one Application Packets	
	Delivery Ratio (Per Packet)	Delivery Ratio (Per Vehicle)	RTT (Per Packet)	RTT (Per Vehicle)	Delivery Ratio	Noise Packets received
0	0.017391304	0.013199833	0.348500715	0.313152283	0.566326531	20487
1	0.026271186	0.018818832	0.474884996	0.512525495	0.546391753	19359
2	0.019140791	0.013805218	0.328879903	0.42471515	0.488095238	18384
3	0.025745811	0.01926403	0.390613663	0.524531951	0.285714286	18735
4	0.081495686	0.058067052	0.563404129	0.609268136	0.175324675	18987
5	0.034599156	0.024841174	0.501769105	0.626653654	0.515306122	20629
6	0.130270014	0.108399343	0.621429012	0.689125821	0.558974359	20042
7	0.035911602	0.026133993	0.622690511	0.67009117	0.680412371	16340
8	0.101726552	0.084724084	0.601112681	0.601112681	0.308176101	22171
9	0.039532794	0.028147268	0.633749496	0.633749496	0.283870968	19884