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АТЕСТАЦІЙНА РОБОТА
Пояснювальна записка

Рівень вищої освіти другий (магістерський)

Дослідження рішень маршрутизації у мережах обміну даними між транспортними засобами
(Investigation of Routing Solutions in Vehicular Networking)
(тема)

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2020 р.

Не містить відомостей, заборонених до відкритого опублікування

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(повна назва)

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«____»___________2020 р.

ЗАВДАННЯ
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студентові Мтюмб Абі Трезор
(прізвище, і'мя, по батькові)

1.Тема роботи : Дослідження рішень маршрутизації у мережах обміну даними між транспортними засобами (Investigation of Routing Solutions in Vehicular Networking) затверджена наказом по університету від 23.03.2020 р. №469 Ст

2.Термін подання студентом роботи до екзаменаційної комісії: __.__.2020 р.

3.Вихідні дані до роботи: провести аналіз сучасних тенденцій та застосувань телекомунікаційних мереж на базі технології VANET; зробити детальний огляд протоколів маршрутизації VANET; засоби аналітичного та імітаційного моделювання VANET.

4.Перелік питань, які потрібно опрацювати в роботі: 1. Аналіз сучасних тенденцій та застосувань телекомунікаційних мереж на базі технології VANET. 2. Огляд протоколів маршрутизації VANET. 3. Проведення стохастичного моделювання трафіку VANET. 4. Класифікація та порівняльний аналіз програмних засобів імітаційного моделювання VANET. 5. Аналіз результатів аналітичного та імітаційного моделювання. 6. Пропозиції щодо маршрутних рішень у мережах обміну даними між транспортними засобами.

5.Перелік графічного матеріалу із зазначенням креслень, плакатів, комп’ютерних ілюстрацій:

1. Титульний. 2. Опис проблеми. Об'єкт, предмет та мета дослідження. 3-4. Аналіз VANET. 5-7. Класифікація протоколів маршрутизації VANET. 8-11. Стохастичне моделювання трафіку у VANET. 12-15. Засоби моделювання VANET. 16. Висновки. 17. Апробація результатів дослідження.

6. Консультанти розділів роботи

Найменування розділу	Консультант (посада, прізвище, ім'я, по батькові)	Позначка консультанта про виконання розділу	
		підпис	дата
Основна частина	професор Єременко Олександра Сергіївна		

КАЛЕНДАРНИЙ ПЛАН

№	Назва етапів роботи	Термін виконання етапів роботи	Примітка
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Керівник роботи ________________ професор Єременко О.С.
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РЕФЕРАТ

Пояснювальна записка: 93 с., 32 рис., 6 табл., 34 джерел.

МАРШРУТИЗАЦІЯ, ПРОТОКОЛ, VANET, IoV, V2V, AODV, МОДЕЛЮВАННЯ

Об’єкт дослідження – процес маршрутизації у мережах обміну даними між транспортними засобами (VANET).

Предмет дослідження – методи та протоколи маршрутизації у мережах обміну даними між транспортними засобами.

Мета роботи – аналіз методів і протоколів маршрутизації у VANET з метою підвищення ефективності передачі даних.

Методи досліджень – аналітичне моделювання, симуляція, формалізація та порівняння.

У цей час мережі обміну даними між транспортними засобами значно підвищують ефективність інтелектуальних транспортних систем. Але в умовах росту кількості вузлів (транспортних засобів) у мережі виникає проблема забезпечення ефективної маршрутизації.

У роботі проведено аналіз сучасного стану протоколів маршрутизації у VANET. Розглянуто їхні достоїнства та недоліки. Особлива увага приділена використанню засобів моделювання VANET. Симулятор мережі розгорнуто для імітації мережної частини VANET з метою проведення детального моделювання на рівні пакетів джерела, отримувача, передачі трафіку даних, прийому, фонового навантаження, маршрутів і каналів.

Розроблено математичну модель для дослідження безпроводового каналу зв’язку VANET.

ABSTRACT

This thesis contains 93 pages, 32 figures, 6 tables, and 34 sources or references.

ROUTING, PROTOCOL, VANET, IoV, V2V, AODV, MODELING

The object of research is a process of routing in the vehicle networks (VANET).

The subject of research is the methods and protocols of routing in vehicle networking.

The purpose of the work is the analysis of methods and protocols of routing in VANET in order to increase data communication efficiency.

Research methods are analytical modeling, simulation, formalization, and comparison.

At this time, vehicular networking significantly increases the efficiency of intelligent transport systems. However, with the growing number of nodes (vehicles) in the network, there is a problem of ensuring efficient routing.

The analysis of the current state of routing protocols in VANET is carried out in the work. Their advantages and disadvantages are considered. Particular attention is paid to the use of VANET simulation tools. The network simulator is deployed to simulate the networking part of VANET with the aim of conducting a detailed packet-level simulation of source, destinations, data traffic transmission, reception, background load, routes, and links.

A mathematical model for research of the wireless channel in VANET communication is presented.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS, SYMBOLS, UNITS AND TERMS

ADAS – Advanced driver assistance services

API – Application Programming Interface

AODV – Ad Hoc on Demand Distance Vector Routing

APs – Access Points

BBU – Base Band Unit

BS – Base Stations

CAR – Connectivity Aware Routing

CBDRP – Cluster-Based Directional Routing Protocol

CBLR – Cluster-Based Location Routing

CBR– Cluster-Based Routing

CCU – Central Connectivity Units

CCN – Centric Centric Networking

CGSR Cluster Gateway Switch Routing Protocol

CICN – Centric Information-Centric Networking

CT – Core network and Terminals

CSDNC – Central SDN controller

C-RAN – Cloud Radio Access Network

C-V2V – Cellular V2V

DADCQ – Distribution-Adaptive Distance with Channel Quality

DECA – Density-Aware Reliable Broadcasting Protocol

DIR – Diagonal Intersection based Routing protocol

DONA – Data Oriented Network Architecture

DSDV – Destination-Sequenced Distance-Vector Routing

DSR – Dynamic Source Routing

DNS – Domain Name System

DSRC – Dedicated Short-Range Communications

DTN – Delay Tolerant Network

DV– CAST Distributed Vehicular Broad-cast Protocol

DYMO – Dynamic MANET On Demand Routing Protocol

FC-BBUCs – Fog Computing BBU Controllers

FC-CHs – Fog Computing-Cluster-heads

FC – Fog Computing

FSR – Fisheye State Routing

FC-ZCs – Fog Computing-Zone Controllers
FC-Vehicles – Fog Computing-Vehicles
GEOPPS – Geographical Opportunistic Routing
GPSR – Greedy Perimeter Stateless Routing
GPCR – Greedy Perimeter Coordinator Routing
GPS– Global Positioning System
GpsrJ+ Greedy Perimeter Stateless Routing for Wireless Networks
GyTAR – Greedy Traffic-aware Routing
GSR – Geographic Source Routing
GeoDTN+Nav – Geographical Delay Tolerant Network + Nav
HIPERLAN2 – High Performance Radio Local Area Network type 2
HLAR – Hybrid Location-Based Ad Hoc Routing Protocol
ICN – Information-Centric Networking
IoT – Internet of Things
IEEE 802.11 – Institute of Electrical and Electronics Engineers 802.11
IEEE 802.11p – Institute of Electrical and Electronics Engineers 802.11p
IoV – Internet of Vehicles
ITS – Intelligent Transportation Systems
IVC – Inter-vehicle communication
JARR – Junction-based Adaptive Reactive Routing
JOSM – Java Open Street Map Editor
LSDNC – local SDN controllers
LTE – Long Term Evolution
LET – link estimation time
LSR – Link Source Routing
LS – Link State routing
MANETs – Mobile Ad-hoc Networks
Mobicast – Mobile Just in Time Multicasting Protocol
MOVE – Vector Routing Algorithm
MPR – Multipoint Relays
NBI Network Based Interfaces
NED – Network Description language
NIC – Network Interface Card
No-DTN – No-Delay Tolerant Network
OBU – On Board Units

OTN – Optical Transmission Network
OEM – Original Equipment Manufacturer
OLSR – Optimized Link State Routing Protocol
OPNET – Optimized Network Engineering Tools
OMNET++ – Objective Modular Network Testbed in C++
PGB – Preferred Group Broadcasting
POCA – Position-Aware Reliable Broadcasting Protocol
QoS – Quality of Service
QoE – quality of the consumer experience
RAN – radio access networks
RAR – Roadside-Aided Routing
RSUs – RoadSide Units
RREQ – Route Request
RREP – Routing Reply
RIRP – Reliability- Improving Position-Based Routing
ROMSGP – Receive on Most Stable Group-Path
ROVER – Robust Vehicular Routing
RRHs – Remote Radio Heads
SA – Services and System Aspects
SADV – Static-Node-Assisted Adaptive Data Dissemination in Vehicular Networks
SBI – Service-Based Interfaces
SDN – Software-Defined Networking
SUMO – Simulation of Urban Mobility
SKVR – Scalable Knowledge-based Vehicular Routing
TBRPF – Topology Dissemination Based on Reverse-Path Forwarding
TORA – Temporally Ordered Routing Algorithm
TSG – groups of technical specifications
URLs – Uniform Resource Locators
VADD – Vehicle-Assisted Data Delivery in Vehicular Ad Hoc Networks
VANET – Vehicle Ad-Hoc Networks
V2V – Vehicle to vehicle communication
V2I – Vehicle to Infrastructure communication
VISSIM – Verkehr In Stadten SIMulations Models

WAVE – Wireless Access for Vehicular Environment
WAN – Wide Area Network
WDNs – Wireless Distributed Networks
WIFI – Wireless Fidelity
WLAN – Wireless Local Area Network
WRP – Wireless Routing Protocol
ZOR – Zone of Relevance
ZOF – Zone of Forwarding
ZRP – Zone Routing Protocol
ZHLS – Zone-Based Hierarchical Link State
5G NR – Standard New Radio
3GPP – 3rd Generation Partnership Project
5GPPP – 5th Generation Partnership Project Protocol

INTRODUCTION

The new era of the Internet of Things is driving the evolution of conventional Vehicle Ad-hoc Networks into the Internet of Vehicles (IoV) [1-4]. With the rapid development of computation and communication technologies, IoV promises huge commercial interest and research value, thereby attracting a large number of companies and researchers [5-12].

As is well-known, VANET [1-5] turns every participating vehicle into a wireless router or mobile node, enabling vehicles to connect to each other and, in turn, create a network with a wide range. Next, as vehicles fall out of the signal range and drop out of the network, other vehicles can join in connecting vehicles to one another to create a mobile Internet. We determine that VANET only covers a very small mobile network that is subject to mobility constraints and the number of connected vehicles. Several characteristics of large cities, such as traffic jams, tall buildings, bad driver behaviors, and complex road networks, further hinder its use. Over the past several decades, there has not been any classic or popular implementation of VANET. The desired commercial interests have not emerged either. Therefore, VANET's usage has begun to stagnate.

In contrast to VANET, IoV has two main technology directions: vehicles networking and vehicles intelligentialize. Vehicles networking are consisting of VANET (also called vehicles interconnection), Vehicle Telematics (also called connected vehicles) and Mobile Internet (vehicle is as a wheeled mobile terminal). Vehicles' intelligence is that the integration of driver and vehicle as a unity is more intelligent by using network technologies, which refers to the deep learning, cognitive computing, swarm computing, uncertainty artificial intelligence, etc. Therefore, IoV focuses on the intelligent integration of humans, vehicles, things and environments and is a larger network that provides services for large cities or even a whole country. IoV is an open and integrated network system with high manageability, controllability, operationalization and credibility and is composed of multiple users, multiple vehicles, multiple things and multiple networks. Based on the cooperation between computation and communication, e.g., collaborative awareness of humans and vehicles, or swarm intelligence computation and cognition, IoV can obtain, manage and compute the large-scale complex and dynamic data of humans, vehicles, things, and environments to improve the computability, extensibility and sustainability of complex network systems and information services. An ideal goal for IoV is to finally realize in-depth integration of human-vehicle-thing-environment, reduce social cost, promote the efficiency of transportation, improve the service level of cities, and ensure that humans are satisfied with and enjoy their vehicles. With this definition, it is clear that VANET is only a sub-network of IoV. Moreover, IoV also contains Vehicle Telematics [2], which is a term used to define a connected vehicle interchanging electronic data and providing such information services as location-based information services, remote diagnostics, on-demand navigation, and audio-visual entertainment content. For IoV, Vehicle Telematics is simply a vehicle with more complex communication technologies, and the intelligent transportation system is an application of IoV, but vehicle electronic systems do not belong to IoV.

Chapter 1 deals with the analysis of current trends and applications of telecommunication networks based on VANET technology and its supporting technologies that makes it what it is today in the field of intelligent transport system. VANET is just a conduit for messages to spread among its peers, while IoV enables processing of such messages based on its sensing capabilities, and then some more. Finally, IoV has the two most important elements, i.e., users and network. For a simple IoV, wireless access is its user, and routing is its network. Some of these technologies include but not limited to IoV, SDN, ICN, Fog computing etc. The combination of the aforementioned technologies forms the basic appendages for a fully functional modern day VANET network.

Chapter 2 gives an insight into routing protocols, algorithms and solutions in VANET. VANET that is a subset of another technology termed MANET, has come to fill the need that a modern form of transport requires. VANET is getting progressively well known in rush hour gridlock administration particularly in a portion of the created nations. It can be ordered into well-being-related application where it can spare a large number of lives every day and non-security applications for business reason. Because of its erratic portability and discontinuous network availability, a solid end-to-end way among the source and the goal is relatively incomprehensible and consequently specially appointed steering conventions are connected in VANET. Notwithstanding, the greatest test in VANET is not the steering issue, yet the collaboration between the hubs. Indeed, even the best directing convention would not be helpful when the hubs do not take part in sending the information.

Chapter 3 seeks to address and analyze the use of modelling method in VANET with stochastic modelling method being preferred as the choice model to adopt for reason of its inherent characteristics which will present a near perfect simulation (it is worth mentioning that there is no perfect equality when it comes to simulation results and real life results) when it comes to VANET simulation. Example of this inherent property is that can be applicable in both single and multiple lanes on a road segment for which the performance measures for each vehicle can be evaluated independently. This chapter also proposes the use of an M/G/c/c (Kendell notation) state dependent queuing model for road traffic flow. The model is based on finite capacity queuing theory which captures the stationary density-flow relationships, making it suitable for our instance. Numerical research and performance analysis will be performed using a steady-state distribution of a Markov chain model of M/M/1/c, model was used to analyze the routing protocol AODV, which was the used case in this analysis; it was observed that the queuing model provides the best estimates of network performance factors such as system usage, average throughput, probability of waiting and probability blocking.

Finally, Chapter 4 summarizes the various tools used in VANET simulation. VANET simulation is applied to diverse and large-scale scenarios and should take into account the specific characteristics of the vehicle environment. In addition to this, the evaluation of VANETs in such complex environments would lead to inaccurate results. Therefore, the choice of the VANET simulation tool is necessary because it may reflect the lack of compatibility with real traffic models resulting in disappointing outcomes. In addition, for a wholesome simulation, there are three main trends in simulation tools relevant to current VANET researches that have been observed: network simulators, mobility simulators and VANET simulators.

CHAPTER 1

ANALYSIS OF CURRENT TRENDS AND APPLICATIONS OF TELECOMMUNICATION NETWORKS BASED ON VANET TECHNOLOGY

1.1. Technology and application of IoV

Over a decade ago, both industrial and academic researchers proposed many advanced technologies for the application layer, the mobile model and the channel model, the physical layer and the data link layer, the network layer and the transport layer, and security and privacy; these technologies are all used in IoV. In this chapter, we only focus on giving an overview of the technologies and their applications in IoV. The overview describes the activation of the IoV, maintenance of the IoV, and IoV applications.

For the activation and maintenance of the IoV, we only summarize the wireless access technology and the routing technology. There are several reasons for focusing on these two technologies. Firstly, most researchers working on IoV focus on wireless access and routing, for which the number of proposed research works are the highest. Secondly, wireless access technologies play an important role in IoV. A good wireless access technology can significantly improve the quality of vehicle service, while a bad wireless access may often lead to the breakdown of services. As is well-known, routing technology is the research core of traditional networks. For IoV, while routing is still the core of the inter-vehicle network, it is also essential for delivering the control message. Finally, IoV has the two most important elements, i.e., users and network. For a simple IoV, wireless access is its user, and routing is its network [1, 2, 4, and 6].

1.2. SDN VANET

The growth of technical revolution towards 5G Next generation networks is expected to meet various communication requirements of future Intelligent Transportation Systems (ITS). Motivated by the consumer needs for variety of ITS applications, bandwidth, high speed and ubiquity, researches are currently exploring different network architectures and techniques, which could be employed in Next generation ITS. To provide flexible network management, control and high resource utilization in Vehicular Ad-hoc Networks (VANETs) on large scale, a new hierarchical 5G Next generation VANET architectures have been proposed [13, 14]. The main idea behind this new architecture is that the control plane is separated from the data plane by SDN technology. The control will be made up of two layers; one temporary located in the fog and one permanently located in the cloud, this is to accommodate large data/packets and enable efficient routing.

In turn, the next stage of telecommunications will go far beyond accelerating data transmission speeds up to 10 Gigabits per second, opening new opportunities in transportation, medicine, manufacturing, many other industries and other areas of life. This technology dramatically improves the speed and consistency of 4G connections, higher spectral efficiency, better signaling and coverage over 4G, less latency in a millisecond, hundreds of thousands of wireless detection connections, running simultaneously [15]. In addition to faster and more consistent wireless connection to users, 5G technology will contribute a great technological innovation in the vehicle industries with the driverless car; in medicine, allowing medical robots to become more common and doctors to perform more complex or difficult operations remotely; improving the efficiency of robots in manufacturing industries for wider use and with fewer errors. 3GPP (3rd Generation Partnership Project) is the body that regulates cellular standards, announced the first official standard of 5G, called the 5G NR standard (new radio), in December 2017. The 3GPP includes three groups of technical specifications (TSG) including RAN (radio access networks), SA (services and system aspects) and CT (core network and terminals). Qualcomm has always been involved in the development of 5G products and its research can be useful to 3GPP in designing the right standards. 5GPPP is considered as one of the pioneers of the standardization of the 5G protocol. These two groups are Even if the 5G is not yet available, we can think about a future generation 6G, is proposed to integrate 5G with satellite networks for Global coverage, to resolve the needs of the user that the 5G will not be able to satisfy. In the next 10 years we will assist to a technological scandal, whose data transmission could go up to 1 Terabits per second. In 2018, the Center for Wireless Communications of the University of Oulu financed a project of the Academy of Finland "6 Genesis", research program that will be devoted to the conceptualization of 6G. In this program, new generations of mobiles will appear every 10 years, maybe around 2030 the 6G will be deployed. Another group of research from Terranova is working on a possibility of the 6G network connection that will be so fast and stable for 400 gigabits per second, transmission with a terahertz range.

1.2.1. Multi-Level SDN with Vehicles as Fog Computing Infrastructures as the Integrated Architectures for 5G-VANETs

Before going in depth to describe this new networking architecture, it is imperative that we look at each of its individual technologies that make up the 5G VANETs.

1.2.1.1. Software-Defined Networking

Software-defined networking (SDN) technology is an approach to network management that enables dynamic, programmatically efficient network configuration in order to improve network performance and monitoring making it more like cloud computing than traditional network management. Originally, SDN were utilized in wired networks, however it has been found to be very useful implementing it in wireless networks and vehicular networks as well. SDN is known to be efficient in controlling networks in different aspects such as wireless resource optimization (i.e., channel allocation, interference avoidance), load balancing (data offloading), adaptive clustering and packet routing.

An SDN implementation in vehicular networks is made up of three logical layers: the forwarding layer, control layer, and the application layer. In addition, it has an imbedded API (consisting of two parts: The first pat API connects the control layer and the application layer. The other part of the API offers a way to make the controller interacts with the forwarding layer) for easy usability when performing network operations.

The key idea behind SDN is to detach the control plane from the data plane thereby offering highly flexible, automated and centralized controlled of the network architecture.

1.2.1.2. Fog computing

Fog computing as defined by Cisco in 2012 is an extension of cloud computing from the core to the edges of the network. It refers to a decentralized computing structure, where resources, including the data and applications, get placed in logical locations between the data source and the cloud thereby in some form extending the functions of cloud computing and bringing it to the edge of the network, Contrary to cloud computing, where the service is more centralized, enabling creation of refined and better applications or services. In the context of vehicular networking, fog computing suits applications with low latency and context-awareness requirements like video streaming, contextual speed alert, augmented reality, enhanced perception, etc. the figure below shows a pictorial representation of a fog computing network.

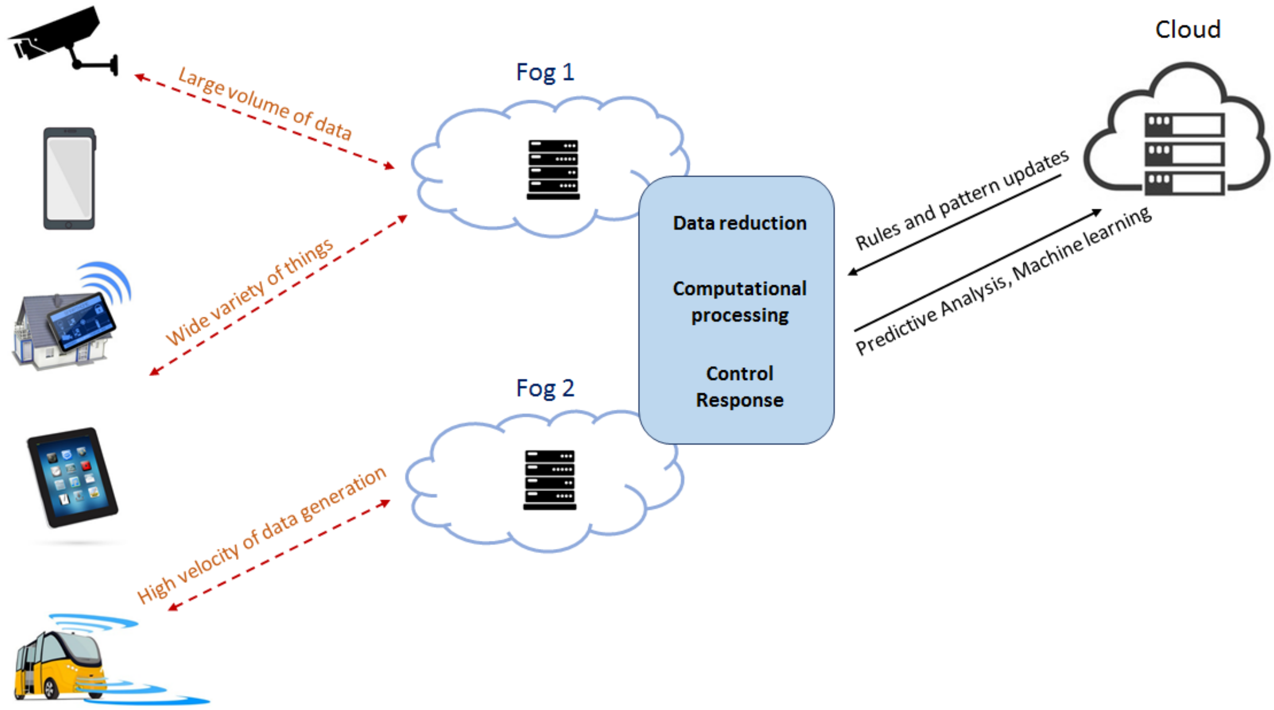

Fig. 1.1. Fog architecture as proposed by Cisco [13]

1.2.1.3. Multi level SDN-based 5G vehicular architecture with vehicles as Fog computing infrastructures – VISAGE

The spectacular emergence of connected and autonomous vehicles coupled with their ever growing demands on processing, computation and communication resources pose new challenges to provide reliable vehicular services. Here, a combination of a multi-level SDN Approach and a fog computing architecture based on Vehicles as Infrastructures paradigm, called VISAGE, is proposed for future 5G-VANET systems. By using vehicles as fog infrastructures and integrating them with local SDN controllers, the QoS of vehicular applications and protocols becomes more efficient in terms of computation time and communication delays. Also during non-peak traffic periods, the parked cars can be used for communication and computation. Hence vehicles can be considered as an infrastructure also by electing a vehicle inside the fog to be the local SDN controller. The working methodology, the architecture of VISAGE is made up of two sub-models: Permanent cloud where resides the central SDN controller (CSDNC), and temporary fogs where local SDN controllers

(LSDNC) are the decision makers. The advantage of using this hybrid technology is that, a local controller working together with normal vehicles forms a fog cell and behaves as a sub-SDN, which can run real-time applications and can store a huge amount of data.

The core elements of VISAGE are as listed below:

- CSDNC - represents the global intelligence which controls all the network behaviors of the entire SDN-based VANET system. It also orchestrates the resources management between different fogs for computation and communication services.
- LSDNC (fog cell head): This represents the local intelligence in the dynamic fog. It is responsible of forming the fog cell and incorporates SDN services through the installation of SDN components: SDN operating system, virtual machines, network and computation services, etc.
- Fog nodes: They form the fog cell and are locally administrated by the LSDNC. Localized at the edge of the proposed architecture, fog nodes allow the increase in the computation and communication capabilities of the fog cell. Each fog node is equipped with an OBU responsible of IEEE 802.11p based communication and also a cellular technology enabling D2D communication between vehicles (cellular V2V communication).
- Customers: can be vehicles, individuals, and organizations. They have insufficient capabilities to perform some computation tasks by themselves, or need a communication hub to access to the Internet.
- Base stations (BS): to ensure communications between fog nodes and the cloud.

The topological structure of VISAGE as shown below in Fig.1.2 fog nodes are equipped with enhanced storage space, computational and communication devices. They use short range communication such as IEEE 802.11p and cellular V2V (C-V2V) technologies to exchange data with vehicles in their coverage regions. It can be seen that the fog cell heads signal their fog-SDN capabilities by calling close vehicles which they can transfer data to. Also other road side units and pedestrians equipped with IoT devices will be sending broadcast message by the fog head node.

The logical structure of VISAGE, as shown in Fig (1.3) below shows that, it is made up of the data plane, control plane, and application plane. The application plane thereafter handles different application requirements from customers and vehicles.

These requirements are thereafter translated to a set of rules and strategies and transferred to the control plane using the NBI interface. The application plane is made up of applications ranging from the security services to efficiency and entertainment services.

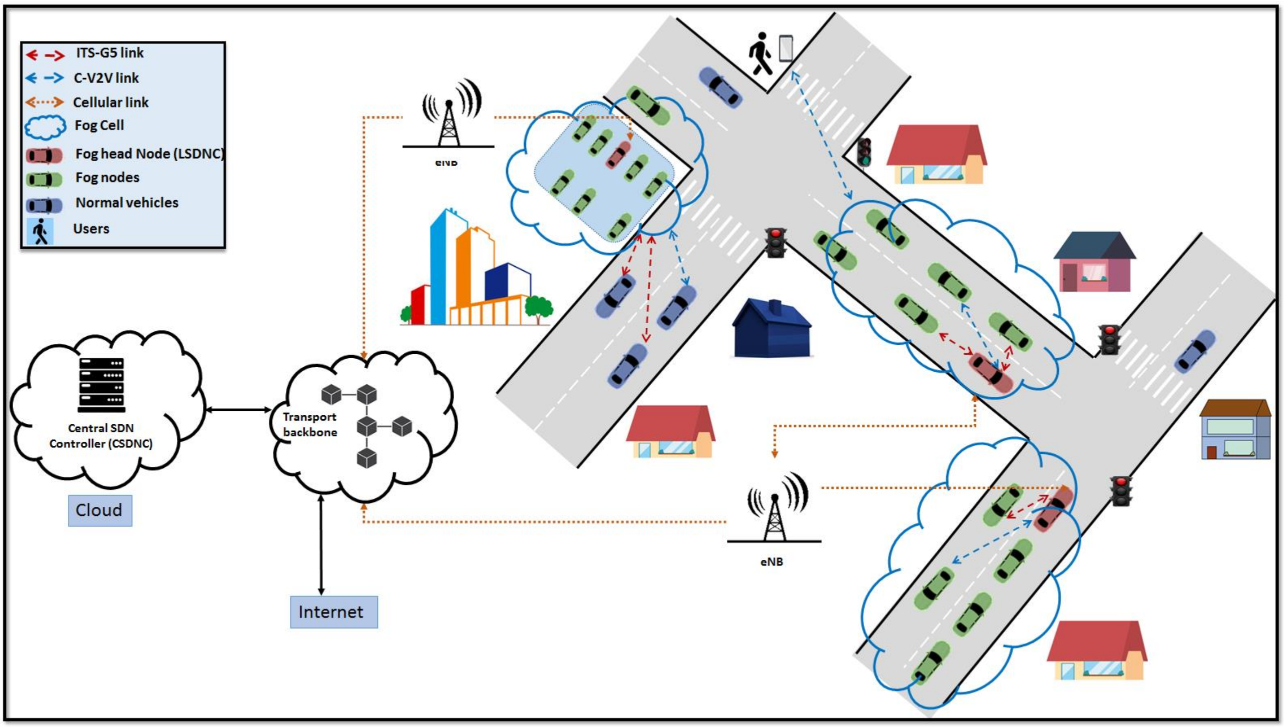

Fig. 1.2. Topology structure of Fog based 5G Multi Level SDN networks [13]

The architecture with two layers of sub-control is explained by the adoption of a hybrid SDN control scheme. The higher-level central SDN controller (CSDNC) (permanent cloud) defines specific policies and forwards those to local controllers to indicate how specific applications or behaviors should be handled based on their local information. The local controllers are the control center for the fog cells. This control layer is dynamic because the SDN capacities are implemented on the vehicle, and more precisely on the fog head node. The latter represents the mobile gateway, and then all the other cars in the same fog cell communicate with the cloud via the fog cell head. Communication between the fog head and other fog cell members could be through 802.11p and cellular V2V technologies, as the latter are capable of providing fast communication with low latencies. The choice of the local controller can be similar to the election of a cluster head in the already existing cluster algorithms proposed for VANETs. As such, a technique presented in, where clustering is performed on the basis of two entities: the cellular base station and the mobile gateway candidates (fog cell head in our case), can be easily adapted to the selection of the local controller inside the fog. To deal with possible dysfunction situations, electing a backup fog node with SDN capacities to guarantee homogeneous communication and calculation services would be essential. This selection decision may be based on the SDN and the fog capacities of the candidates concerned and its planned journey time on the roads. The recovery controller identifier is then sent to the fog nodes via flow rules and stored in the flow table. Local and central SDN controllers can be configured with the following modules:

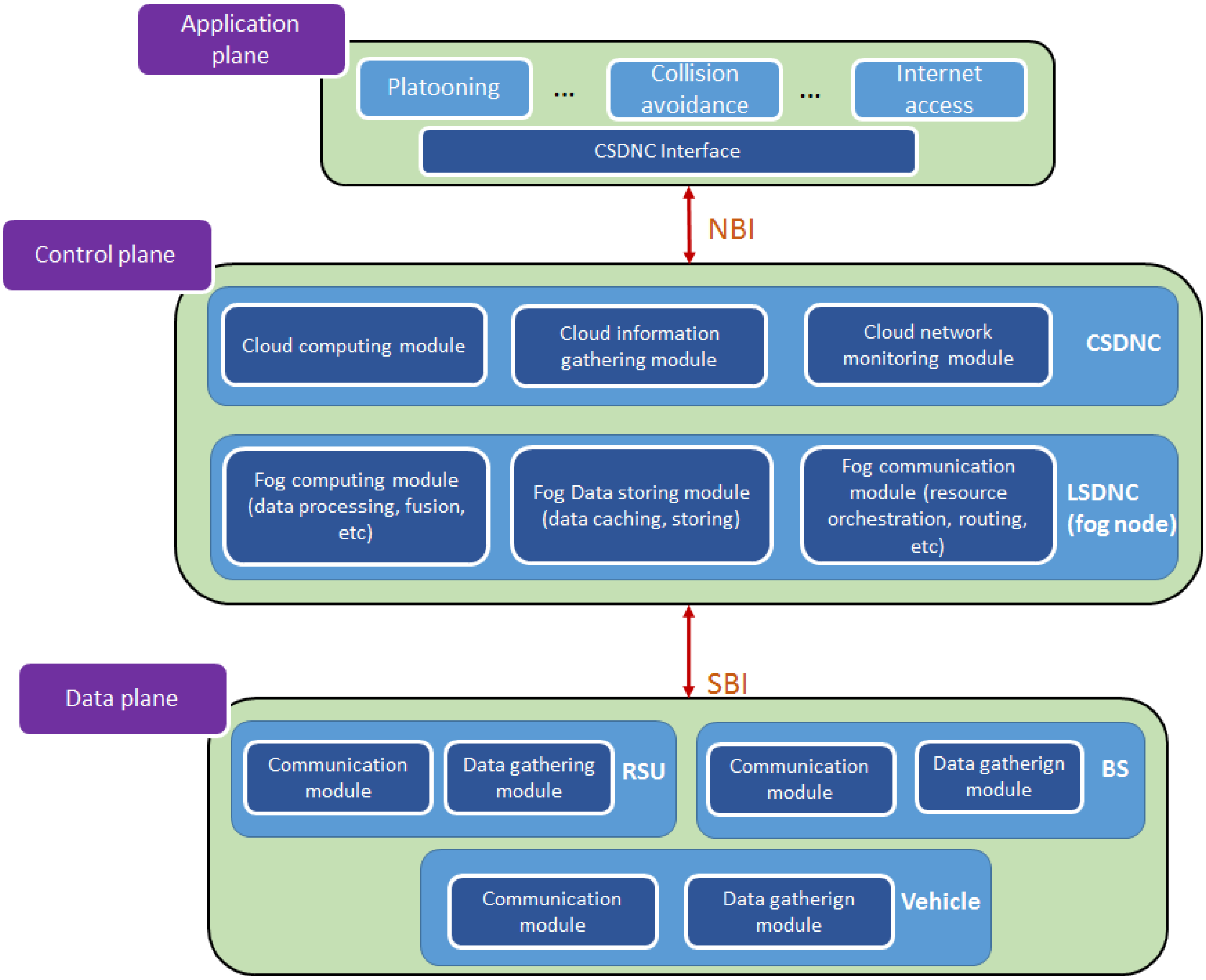

Fig. 1.3. Logical Structure of Fog based 5G Vehicular Multi Level SDN networks [13]

- A computer module: represents the intelligence of the controller. The vehicles inside the fog cell represent potential computing resources for the fog cell. The main function of the computer module is to process and process the data received from neighboring vehicles, users and applications.

- Data storage and caching: backing up the popular data context at vehicle fog nodes helps reduce transmission time for applications sensitive to vehicle delay. In addition, caching can improve the quality of the consumer experience (QoE), particularly in retrieving content sensitive to delays. As such, users of online social networks tend to value content highly recommended by their friends, which can be previously coached in the fog cell. Additionally, with the help of local fog caching, the download time of videos can be reduced when cached on local fog nodes.
- Communication module: residing at the low level of the control system (dynamic fog), its main role is to define the resource orchestration policy which allows the system to efficiently allocate network resources to users. Its functions can range from load balancing to interference management and data routing. For the central controller, residing in the cloud, its main task is to design the resource orchestration logic on which the local controllers will be based to allocate different network resources in order to minimize interference and packet loss. Its global view of the whole system is acquired thanks to the resource monitoring module which will have a regularly updated view of resource consumption and the general state of the network of local controllers.

1.2.2. 5G Next generation VANETs using SDN and Fog Computing Framework

As time passes, it is normal to find old technologies incompatible or sometimes unable to cater for and meet present day demands. So it is the same thing with vehicular networks as present day ITS services and infrastructure will be insufficient for future VANET solutions, hence future vehicular networking model is expected to adopt current cellular solutions like 3G, 4G Long term Evolution, 3GPP just to mention a few and they are all going to be fused together to form one architecture with each contributing its own strength while another, making up for the lapses found in another in terms of resources and network topology. For instance, an LTE systems offer the benefits of large coverage, high throughput and low latency. But, due to high vehicle mobility and dynamic network topology, it is relatively challenging to provide satisfied ITS services only through LTE systems. Integrating different access networks technologies like DSRC and LTE is proposed to be a potential solution to meet various ITS service requirements. However when one takes a deeper look into this heterogeneous style for VANET, it won't be difficult to find out some inherent faults and lapses too, example being that due to high mobility and rapidly changing topology of VANETs, the handoffs(which maybe in the form of power differences, device incompatibility etc) among different wireless access infrastructures are more frequent, as compared to traditional wireless networks, so therefore to cover this lapses, SDN has been proposed as a promising technique that will play a key role in the design of 5G wireless communication networks. SDN is proposed to be an effective technology to be capable of supporting the dynamic nature of VANETs and ITS applications, by facilitating flexible network management and optimization on large scale with unified abstraction to provide consistency in services with the frequent topology changes and varying QoS demands in VANETs. To achieve this purpose, a combination of SDN, Cloud Computing, and Fog Computing are expected to be future candidate technologies for 5G VANETs. However, it is worth nothing that Some initial studies have also been carried out to integrate either of these technologies into Vehicular Communication Networks and it has been found that The frequent handover problem in dense scenarios of VANETs, reduces the performance of SDN at RSUs and also been realized that the scalability of Wireless Distributed Networks (WDNs) is improved by using techniques like; clustering, multichannel routing and zoning.

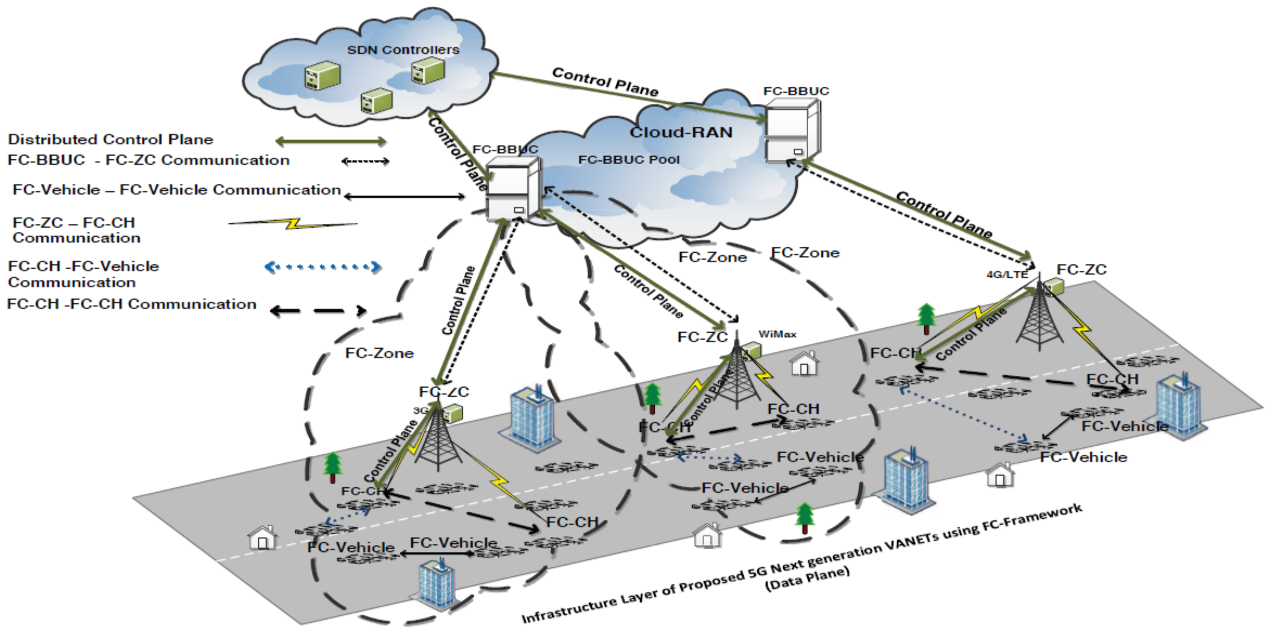

Fig. 1.4. Topology Structure of 5G Next generation VANETs using SDN and Fog Computing (FC) Framework [14]

Presently Cloud Radio Access Network C-RAN is being touted as the present solution for heterogeneous networks. In C-RAN, all RAN functionalities are performed in the centralized BBU pool, in cloud based infrastructure, which are connected to RRHs through fiber cables. As shown in the Fig. 1.4, this work highlights the proposed 5G Next- generation VANET architecture by employing the concepts of SDN, C-RAN and fog computing illustrating the separation between the data plane and control plane via SDN, which is based upon the open platform of CRAN.

1.2.2.1. Topology Structure of Fog Computing (FC) Framework, C-RAN and SDN controller

For the proposed 5G next generation to function efficiently, the fog computing framework should be configured at the edge of the network and should be made up the following components as listed below. The hierarchy of the individual element that makes up the 5G next generation VANET architecture is shown below in fig. 1.5.

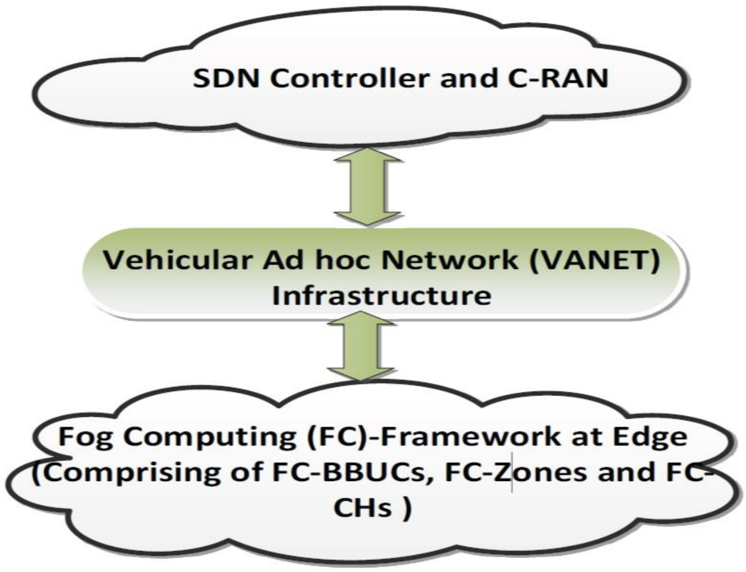

Fig. 1.5. Hierarchy of SDN controller, Cloud-RAN and Fog computing framework [14]

- Fog Computing-Zone Controllers (FC-ZCs): The FCZCs are the computing enhanced (CPU and storage) wireless access infrastructures such as, RSUs; Base Stations (BSs) connected with the BBU controllers, through broadband connections. Most of the data are processed and saved by this component. It responsible for the control of devices (vehicles) in their own vicinity (FC-zones or FC-Clusters), and is not sent to the SDN controller, unless required.

- Fog Computing-Cluster-heads (FC-CHs:) this are part of the FC zones FC-CHs are the vehicles, equipped with SDN enabled On Board Units (OBUs) and it is been controlled by the FC-ZCs.
- Fog Computing-Vehicles (FC-Vehicles): this component is also equipped with SDN enabled OBUs. Its main function involves, packet forwarding, sensor localization system like Global Positioning system (GPS), power control, channel selection, interface selection and transmission mode (V2V or V2I communication).
- Fog Computing BBU Controllers (FC-BBUCs): this part acts as a bridge between connecting VANET infrastructure with the SDN controller. In addition, it also acts as the as digital unit that is responsible for implementing the base station functionalities, from baseband processing to packet processing.
- SDN Controller: this part is the core component and without it this architecture will be very limited in its functionality. SDN controllers are responsible for network management and operations such as, rule generation, resource allocation and mobility management. Furthermore, SDN controllers are also responsible for Fog Orchestration and resource management of fog.
- Optical Transmission Network (OTN): this part is responsible for transmitting and receiving digital signals to and from the FC-BBUC pool through optical fibers.

1.2.2.2. Logical Structure of proposed 5G Next generation VANET Architecture

The logical structure of proposed architecture is divided into three layers; the data plane, control plane and the application plane as shown in the Fig 1.6 below.

The data plane/layer can be configured to perform Information gathering of FC-Vehicles, FCCHs, FC-ZCs, FC-BBUC. It uses different sensors to record information related to position, speed and direction of vehicles and CCTVs, network cameras, lane checking cameras, etc. Also this plane is also capable of enabling communication between the vehicles. The control plane decides the flow rules or policy rules. The control plane includes SDN controllers,FC-BBUCs, FC-ZCs and FC-CHs. The FC-BBUC is the main control center or fog controller of fog framework.

The application plane is responsible for generating rules and strategies, based on different application requirements of users/vehicles, and forward these rules to the control plane.

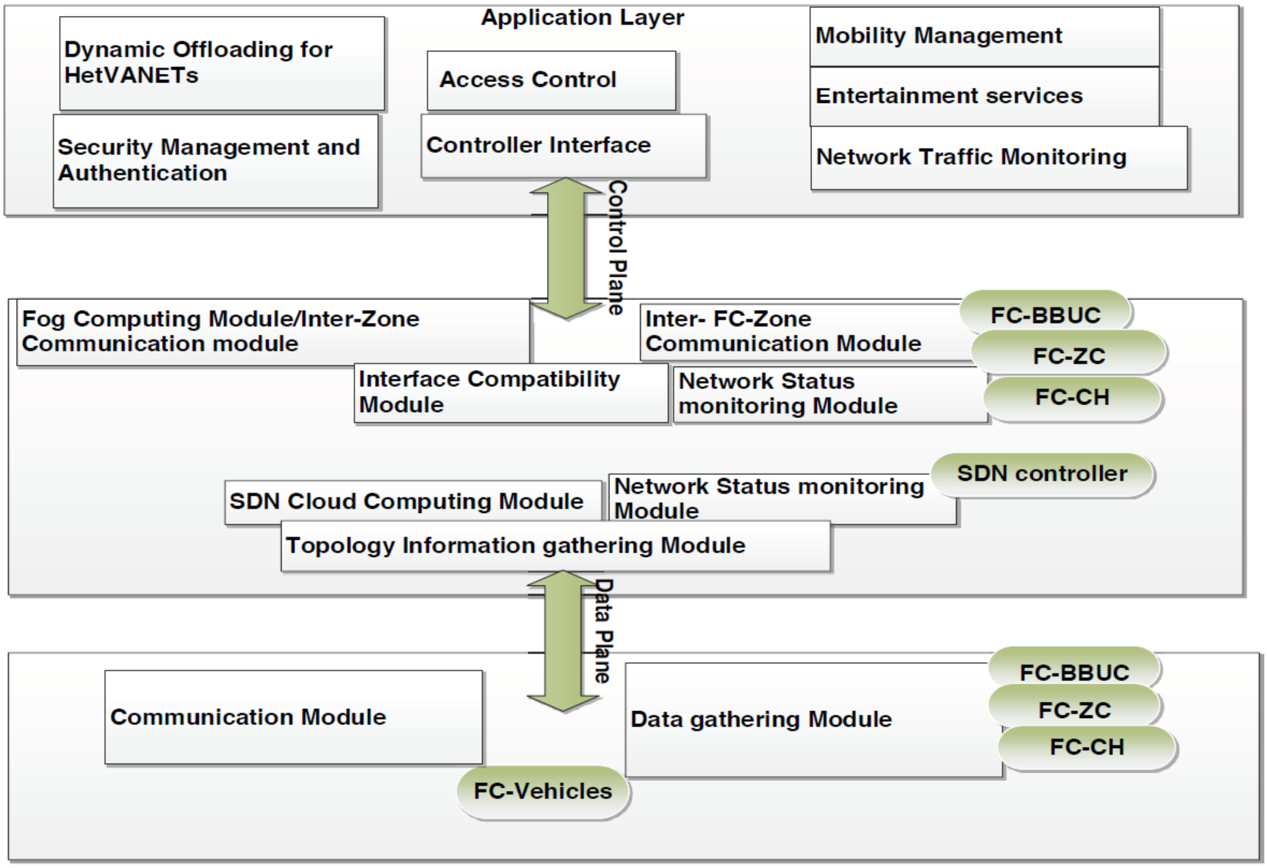

Fig. 1.6. Logical Structure of proposed 5G Next generation VANETs [14]

1.3. Information-Centric Networking Architectures for VANET

Information-Centric Networking (ICN) is an attempt to change the focus of the current Internet architecture. The current architecture focuses on creating a conversation between two machines. This is apparent in the naming system in which URLs, through DNS resolution, indicate a machine to communicate with in order to receive data or perform an action. The goal of ICN architecture is to shift the focus from connecting to another machine to fetching data. In ICN systems, the data is given a name rather than the machine.

One will easily find out that each of the communication technologies for vehicular networking has its own strengths and weaknesses with respect to the communication relations. Cellular technologies are widely available and useful to transmit large amount of data by providing higher bandwidth capacity, for example from cloud systems (V2C), but lack in capabilities such as multicast messages. WIFI technologies are also widely available, however limited to smaller cell sizes compared to cellular networks and therefore more suitable for infrastructure communication (V2I) such as roadside units (RSU). Short range communication technologies such as DSRC are specifically designed for V2V considering tight latency requirements and are more suitable for safety critical applications, however, lack in transmitting large amount of data. These facts call for several requirements regarding the network architecture such as:

1. Support for ever-changing communication paths;
2. Abstraction from different networking technologies and;
3. Focusing on the data to be exchanged rather than the nodes to be accessed.

In recent years, Information-Centric Networking (ICN) has been identified as a potential paradigm to solve the issues set by connected vehicles. By changing the addressing scheme to directly address data instead of the location where the data resides, the resulting loosely coupled communication model facilitate features such as mobility. That is to say ICN depart from the traditional host-based communication model and bring the focus of content from application layer to network layer.

Instead of addressing information by location and thus greater attention is being focused on the data instead of the infrastructure involved. Such as Dedicated Short-Range Communications (DSRC) and WAVE, ICN is heterogeneous in nature and is independent of the underlying link layer and is therefore promising to overcome interoperability issues, achieving this by reducing data exchange on the networking layer to the packet types (Interest and Data). ICN adopts a forwarding paradigm in which packets are routed by content names and cached at relays on the data path; the Fig. 1.7 below, can shows the relationships in vehicular connectivity.

This even have a lot more negative effects when one considers its implementation in networking of everyday objects especially at a time of internet of things. The ICN paradigm thus serves as a possible solution to service heterogeneous IoT environments including infrastructure, wireless and ad hoc environments.

The working principles of ICN are based on the feature that it is directly concerned about the data as the chief means for distributing information. Based on a loosely coupled communication model, the paradigm uses content identifiers such as naming schemes to provide access to data directly which are represented as Information Objects within the network. As a result, it separates data from its physical location thereby reducing losses in time for frames/packets, enabling some form of caching at any network element such as routers and end user devices (vehicles or RSU). The loosely coupled communication model that ICN adopts avoids unnecessary data transmission within the overall network because data is only transmitted on paths where the consumer is currently connected or to be connected soon. Data can be sent to caches nearby the consumer proactively, especially popular data, which decreases latency. Furthermore, ICN reduces data exchange on the networking layer to its packet types (interest and data) thereby eliminating interoperability issues. In ICN-based architectures the data may be reached at the source or at any node in the network holding it within its cache.

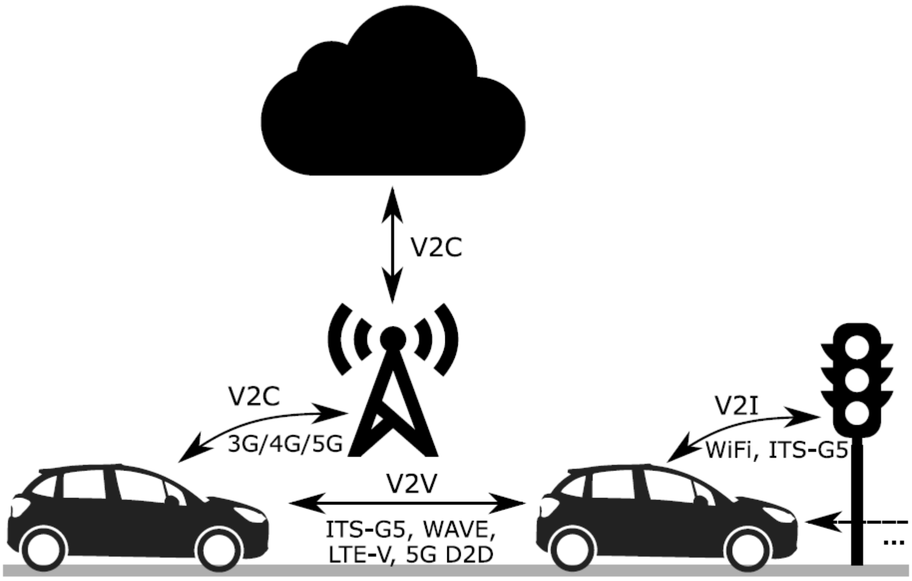

Fig. 1.7. Vehicular communication relations [8]

1.3.1. Use cases for Information-Centric Networking for Vehicular Networking

It is worth nothing that despite the proposed efficacy of this new paradigm, ICN in some forms are still not applicable in practical situations, some of this ideal scenarios where ICN can be implemented includes but not limited to the following: a Collision Warning System, a Vehicular Battery Integration and Service and an Automatic Parking System. But before describing these scenarios, we envisage a harmonized ecosystem across different IoT domains based on ICN which shows a common but decentralized space for information exchange between different kinds of communication participants. The figure 1.8 below gives an illustration how an ICN will serve different purposes. It depicts how its functionality is not limited to cars alone but a lot of IoT devices as well. The ICN system is at the core of this service but unlike cloud networking in which it resembles, it moves most of the functionalities to the network and transport layer such as decoupling consumer and producer of data, mobility management and in-network caching/processing. This is what makes ICN a desirable and dependable technology for the future of vehicular network architecture.

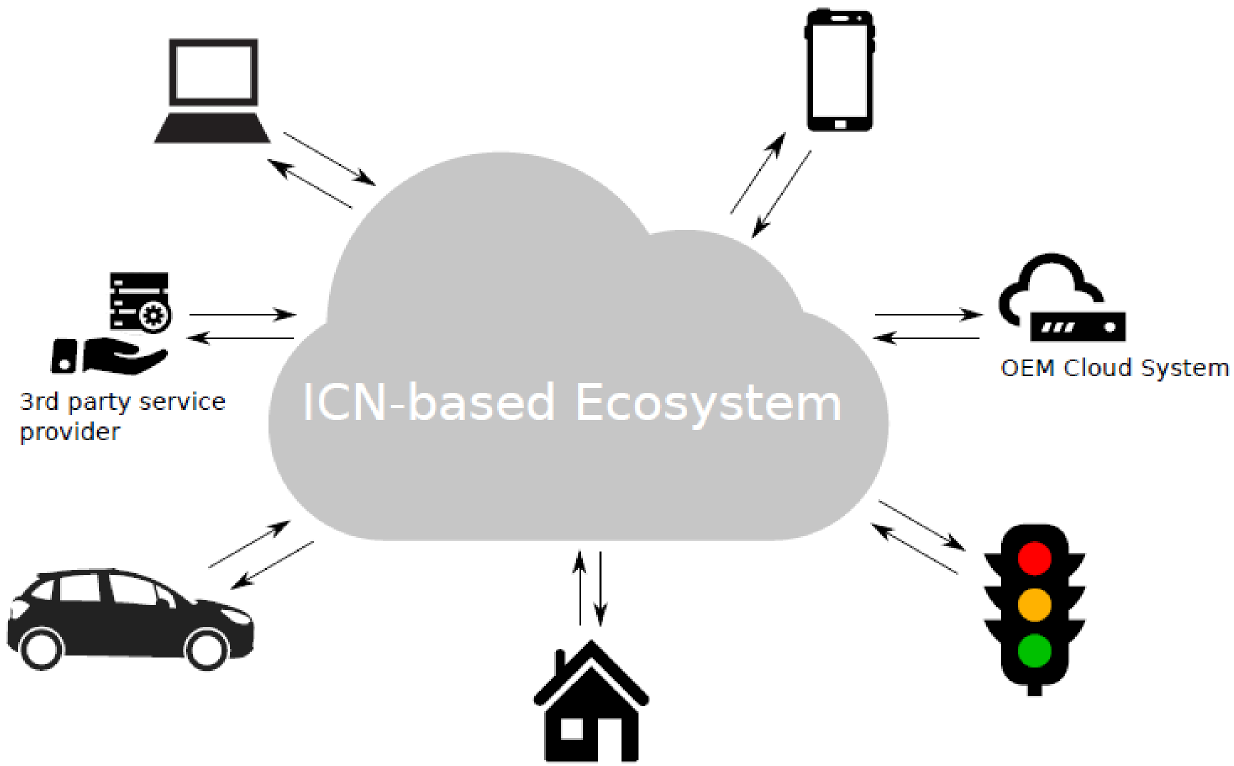

Fig. 1.8. An ICN-based platform serving heterogeneous IoT environments such as connected vehicles [8]

1.3.2. Exemplary use cases within an ICN Based Platform for Connected vehicles

- Collision Warning Service: One of the main duties of an ICN is to provide safety which is of most paramount. Here the vehicles are equipped with different OBUs such as sensors (camera or radar), and communication technologies such as LTE or WAN, together all these devices will act as a warning system to alerts the vehicles of an impending hazard or traffic situation. In ICNs the naming scheme used to access information is decisive to discover and receive the right information in time. The figure below illustrates the scenario of a collision warning service.

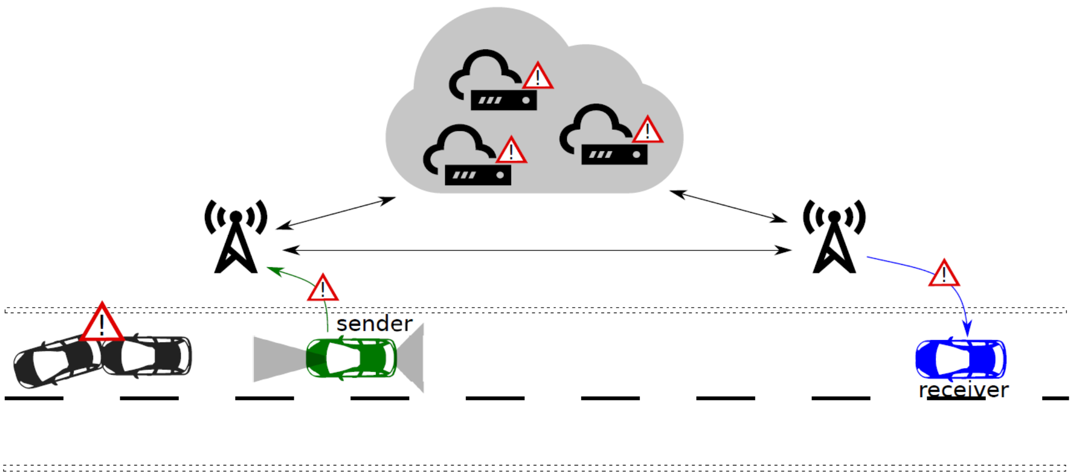

Fig. 1.9. Exemplary scenario of the collision warning service when vehicles provide hazard information, while the network assists in disseminating warning messages to approaching vehicles [8]

- Vehicular Battery Integration Service: this designs aims to address and equip modern cars with information about its energy source, especially at a time like now where electric vehicles is slowly becoming a household item, this system will be able to send alerts to the driver and nearby cars of a loss of power to a particular vehicle. The figure below shows a pictorial illustration of this service.

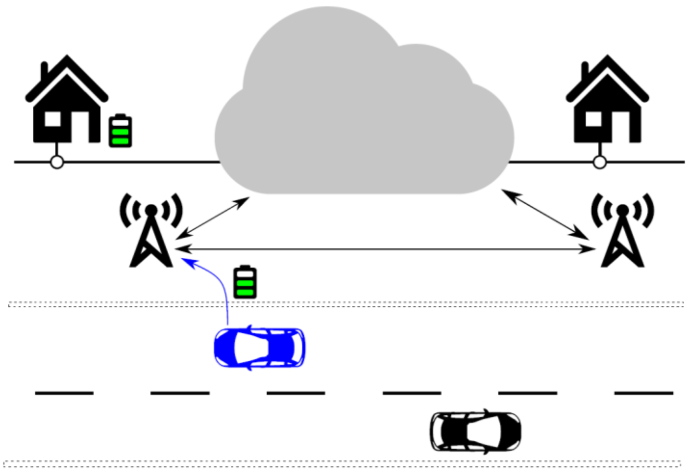

Fig. 1.10. Exemplary scenario of the battery integration service when the blue vehicle sends the battery information to a dedicated smart home during the journey [8]

- Community-based Parking Service: this system as the name suggest has to do with parking related issues. Either to find parking spots for vehicle or allowing entry/access to a particular parking lot. Vehicles driving along the road are able to detect available parking spots using built-in sensors such as the ultra-sonic sensor, and offer such information in the network that is accessible through a map already designed, so vehicles if they need such service will consult such maps via this ICN designs there by reducing searching time and costs (fuel/energy) as well as optimizing the traffic flow. The figure below shows an illustration of this paradigm.

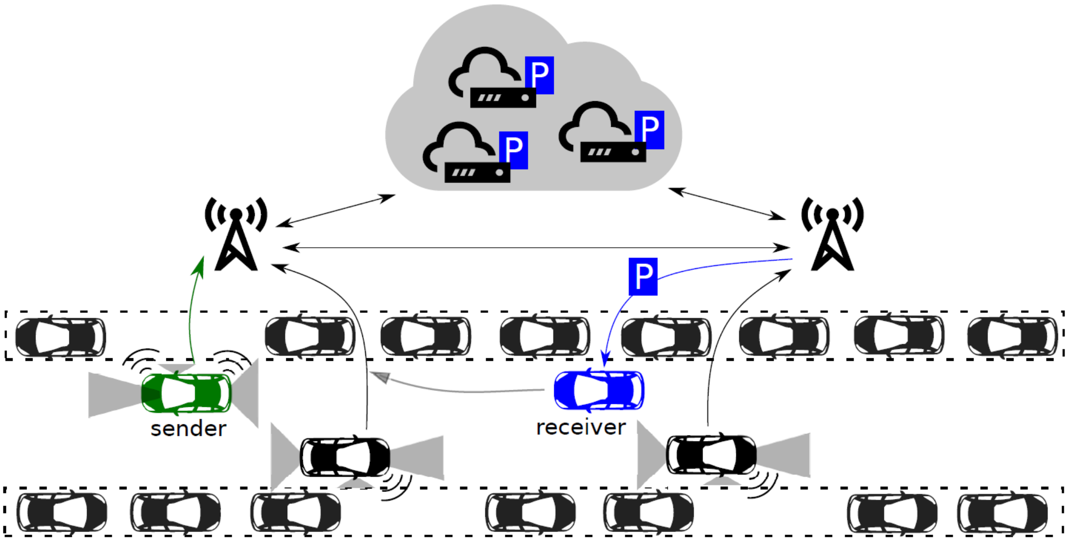

Figure 1. 11. Exemplary scenario of the community-based parking service based on Passing vehicles (green) detect and share available spots, while approaching vehicles (blue) consult parking service instances for the closest available spot [8]

1.3.3. ICN requirements for connected Vehicles

It is worth nothing that despite the fact that are many variations of ICN, each of those variations has as its core designs methods/technology that are common to all of them and these include: Naming, Mobility, Routing caching and transport, security and interoperability and community.[Grewe2018]

- NAMING here, here, ICN decouples contents from locations. The network can identify content and its associated requests. Naming data objects is an as important pillar for ICN as addressing hosts is for today’s Internet. According to this new paradigm, the consumer requests content by its name instead of using its network localization. That being said that all content must be identified by using a unique, persistent and location-independent name.

Unlike the current Internet sending-receiving approach, contents in ICN are named, where names are either hierarchical or flat. In ICN, the name of the content is decoupled from its location with the intention to supply it to the requesting subscriber. Hence, content retrieval follows a receiver-driven approach and therefore avoids control of subscribers over the content, as done in the IP-based architecture. In the ICN-based VANET, content may be easily discovered as compared to the IP-based VANET, because ICN does not need the original server (producer) to be connected every time content is requested. Furthermore, content retrieval from different producers, for instance, map from a common RSU, becomes easier through combining requests for contents with the same names. This process simplifies the process of data delivery for the incoming requests. ICN naming brings significant assistance to vehicular communications by allowing forwarding vehicles to handle contents on the basis of application requirements. Named data transmission provides ICN-based VANET with robustness to connection interruptions and hereby characterizes vehicular Internet. Besides providing syntactic and semantic information, naming capabilities to define the scope of the data are useful to simplify data discovery across different IoT domains. Such feature describes the boundaries the data is offered or used by the network participants such as the information context or access related information. For instance, the community-based parking service example, the provided name ensures that only a group of subscribed vehicles within a certain geo-location receive the information of available parking slots. Finally when dealing with naming in ICN of connected vehicles, the following are considered as naming requirements:

- Machine/human readable;
- Self-describing;
- Support of scoping;
- Support of flexible schemes capabilities

• MOBILITY, in the internetwork of vehicles, due to how highly mobile the nodes/cars, it is expected that any vehicle or node can join or leave a network at any instance, and should be able join another network without delay. Such degree of mobility results in high variations and fast changing network topology and challenges network structures to provide seamless connectivity. The network architecture needs to account the movement of vehicles within and between local networks.

Mobility is a critical challenge to the ICN deployment corresponding to all emerging technologies. In ICN, when subscribers change their location, their connectivity is changed from one node to the other. However, as no IP address is used to route contents, it is transparent, in contrast to IP, in which addresses are changed. In the VANET environment, content objects must pass a centralized facilitator (vehicle having sensors) before reaching the actual subscriber. This is the most crucial module because contents in VANETs travel along a longer path rather than the best one. The number of available communication technologies forms the basis for heterogeneous vehicular networks. It is assumed, that vehicles are equipped with built-in central connectivity units (CCU) supporting multiple communication interfaces and technologies e.g. cellular or WIFI and employs a feature termed; multi-homing (a technique to access data from multiple access points and multiple sources simultaneously, for example to increase availability). The following are considered as requirements when dealing with mobility of ICN:

- Support of consumer and producer mobility;
- Support of seamless connectivity;
- Multi-channel;
- multi-homing

• ROUTING, CACHING AND TRANSPORT, due to inherent characteristics of VANET, such as low bandwidth capacity, high latency, communication failures and difficulty in data exchange due to high mobility nature of its nodes, it will be difficult to cater for the needs of modern nodes (cars) and roads, however the advent of ICN seems to solve some of this issue. Firstly, an ICN architecture is capable of a process called reactive routing and forwarding and this possible because ICN is loosely coupled hence eliminating delays in data exchanges. It also allows for caching everywhere among the nodes in the network or wireless access point achieving this by a process termed proactive caching, which describes a class of strategies taking action before a request is sent by a consumer consequently assigning the data to the right nodes in the network thereby reducing the total number of cache objects and reducing latency.

With respect to the group of routing, caching and transport requirements, the following metrics are considered for the comparison in the subsequent section:

- Reactive and predictive routing;
- Proactive and reactive caching;

- Caching nodes;
- Extensibility of the protocol and;
- The support of flexible data chunk sizes.

• SAFETY AND SECURITY, this attribute can’t be overemphasized since it forms the basis of why we need a functional ICN Numerous Internet security issues are mainly caused by data disruption at the application layer, which is primarily happened because of the IP (a best effort delivery but unreliable protocol). On the other hand, as ICN is a content-driven paradigm, content is published when it is requested. This approach curtails the transmission of unsolicited content objects and thereby automatically provides content security, which is achieved by using content names. In addition, ICN also affords malicious content filtering through in-network security policies. Furthermore, ICN adds a point of indirection among the subscribers of requested contents, i.e., the content requests are assessed by in-network nodes before reaching the producer.

Regarding safety and security relevant aspects, the following requirements are taken into account for evaluation of available ICN approaches in the context of connected vehicles:

- Authentication;
- Authorization;
- Data integrity;
- The support of other QoS mechanisms.

• INTEROPERATABILITY AND COMMUNITY, this requirement is necessary due to economics and compact ability factors. The automotive industry is a vast place filled with loads of engineering designs, car suppliers and car manufacturers, they will always be a tussle between cost and efficiency and it may seem impossible for all the key players to agree on one particular solution for an ICN architecture, so therefore it is imperative that for an ICN architecture to be realized and deployed it must be interoperable and compatible among various other technologies of ICN from other vendors. In addition, it has to convince the rather conservative automobile industry that this technology is workable, safe and seamless in its approach so as to be given the go ahead to migrate to a classic host centric communication approach.

The following are required when considering interoperability and community approaches:

- Interoperability to other ICN architectural approaches
- Availability of source code and license model;
- Active community

Ideally ICN networks can be implemented to solve issues ranging from but not limited to collision warning/detection, Vehicular Battery Integration Service and Community-based Parking Service.

Finally, it is worthy of note that most modern designs for ICN VANET are still in their conceptual stage and have not been applied to full functionality in real world scenario, some of the designs of ICN include but not limited to DONA, CCN, SAIL and most recently CICN. In addition, it is being predicted that ICN will replace the current IP-based model with the name-based content-centric model, as it aims at providing better security, scalability, and content distribution.

Conceptually the vision of ICN VANET is not limited to cars but involves other components of the IoT and Internet as well. This includes IoT devices, such as from the Smart Home domain, from the car manufacturer (OEM), third party server infrastructures or the (mobile) devices of end customers.

CHAPTER 2

OVERVIEW AND COMPARATIVE ANALYSIS OF ROUTING ALGORITHMS AND SOLUTIONS IN VANET

2.1. Basic principles of VANET communication

A Vehicular Ad-Hoc Network (VANET) is the newest paradigm of wireless multi-hop networks. It emerged from MANETs with the mobile nodes being the vehicles on the roads. Vehicles communicate using wireless communication in a multi-hop fashion for disseminating information. These connected vehicles are known as intelligent vehicles and are equipped with a wireless communication module and sensors that monitor the interior and exterior surroundings and provide assistance/ alerts to the driver via an on-board unit (OBU) [16].

Many standards have been introduced for VANET wireless communication with the most dominant being the Wireless Access for Vehicular Environment (WAVE) standard. WAVE is an amendment of the IEEE 802.11 standard for WLAN and it is standardized to be known as IEEE 802.11p [16].

Vehicles communicate with one another and with Road Side Units (RSUs) for relaying and sharing messages and information that will support many ITS application domains such as safety applications (e.g., broadcasting safety warnings), traffic management applications, road condition monitoring applications, infotainment applications (e.g., Internet access), advanced driver assistance services (ADAS) applications (e.g., automatic toll collection, remote diagnostics), to name a few.

Four communication patterns are available in VANET communications [16]:

1. Beaconing (1-hop broadcasting for position and velocity information).
2. Geocasting (sending information to an area of interest).
3. Unicasting (sending information to a specific destination).
4. Information dissemination (flooding the surrounding area with information). Figure 2.1 illustrates these communication patterns.

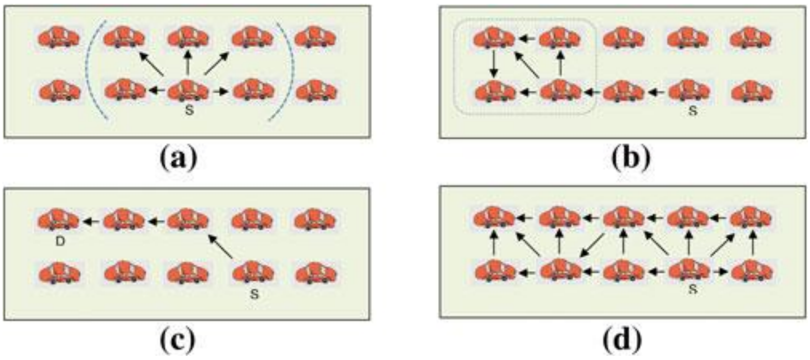

Fig. 2.1. VANET communication patterns: a Beaconing, b Geocasting, c Unicasting, and d Information dissemination [16]

Among these communication patterns, Geocasting, Unicasting, and information dissemination are based on multi-hopping for delivering information. Both geocasting and Unicasting require establishing a routing path between the source and the destination (which may be a specific area or node). Information dissemination may not need finding a definitive route but needs some routing functionalities for handling data redundancy and broadcast storms.

Routing protocols are used by a router to find out the optimal path for communication between nodes, they govern the way that two communication entities exchange information; it includes the procedure in establishing a route, decision in forwarding, and action in maintaining the route or recovering from routing failure. They are plethora of routing protocols, but this chapter is going to classify them into two distinct categories of Ad hoc routing protocols; which are reactive and proactive routing protocols. In proactive routing protocols, control packets are constantly broadcast and flooded among nodes to maintain the paths or the link states between any pair of nodes even though some of paths are never used. A table is then constructed within a node such that each entry in the table indicates the next hop node toward a certain destination. In this process, nodes continuously update the routing table, thus giving it its distinct feature (where the routing information such as the next forwarding hop is maintained in the background regardless of communication requests) as a result increasing the routing overhead which is more or less a drawback of this protocol. Proactive routing does not require the route discovery process. It is suitable for safety related applications. Nevertheless, maintenance of unusual paths causes more consumption of bandwidth. In reactive routing protocols as oppose to proactive routing, opens a route only when it is necessary for a node to communicate with another node. It uses the route discovery process, which introduces high initial latency. It maintains only the routes, which are currently in use thereby saving the bandwidth and reduces the burden on the network. This protocol is further classified as hop-by-hop routing or source routing. Unlike proactive routing, only text node and destination information is provided. Whereas in proactive the complete information of route is comprised in the data packet. Comparatively, hop-by-hop routing is better both in terms of throughput and delay.

2.2. Generic Routing Model for wireless multi-hop routing protocol

In this section, we will present a generic routing model that can be used to form the foundation of a wireless multi-hop routing protocol. We will present the functionalities as blocks and methods that can be selectively utilized and combined together to form a wireless routing protocol suitable for any wireless multi-hop network. This generic model can be further extended and enhanced with auxiliary functionalities to meet specific requirements per network paradigm.

Each component will be presented with its own various functionalities that will be available to the protocol designer to choose from. The output and the input of each component will be shown to clarify the interactions between the various components. The proposed generic model is shown in Fig. 2.1.

The route discovery component has five options/functions for the designer to choose from:

- proactive with distance vector;
- proactive with link state;
- reactive with deterministic routing;
- reactive with self-routing (which requires that each node discovers its neighbors; therefore, it calls the neighbor discovery function which feeds it with the neighbors list);
- Hybrid discovery.

The route selection component has three functions for the protocol designer to choose from:

- source-based selection;
- destination-based selection;
- Intermediate-based selection.

The choice of which function to be used depends on the route discovery function that has been chosen (e.g., the reactive self-routing discovery requires the use of intermediate-based route selection).

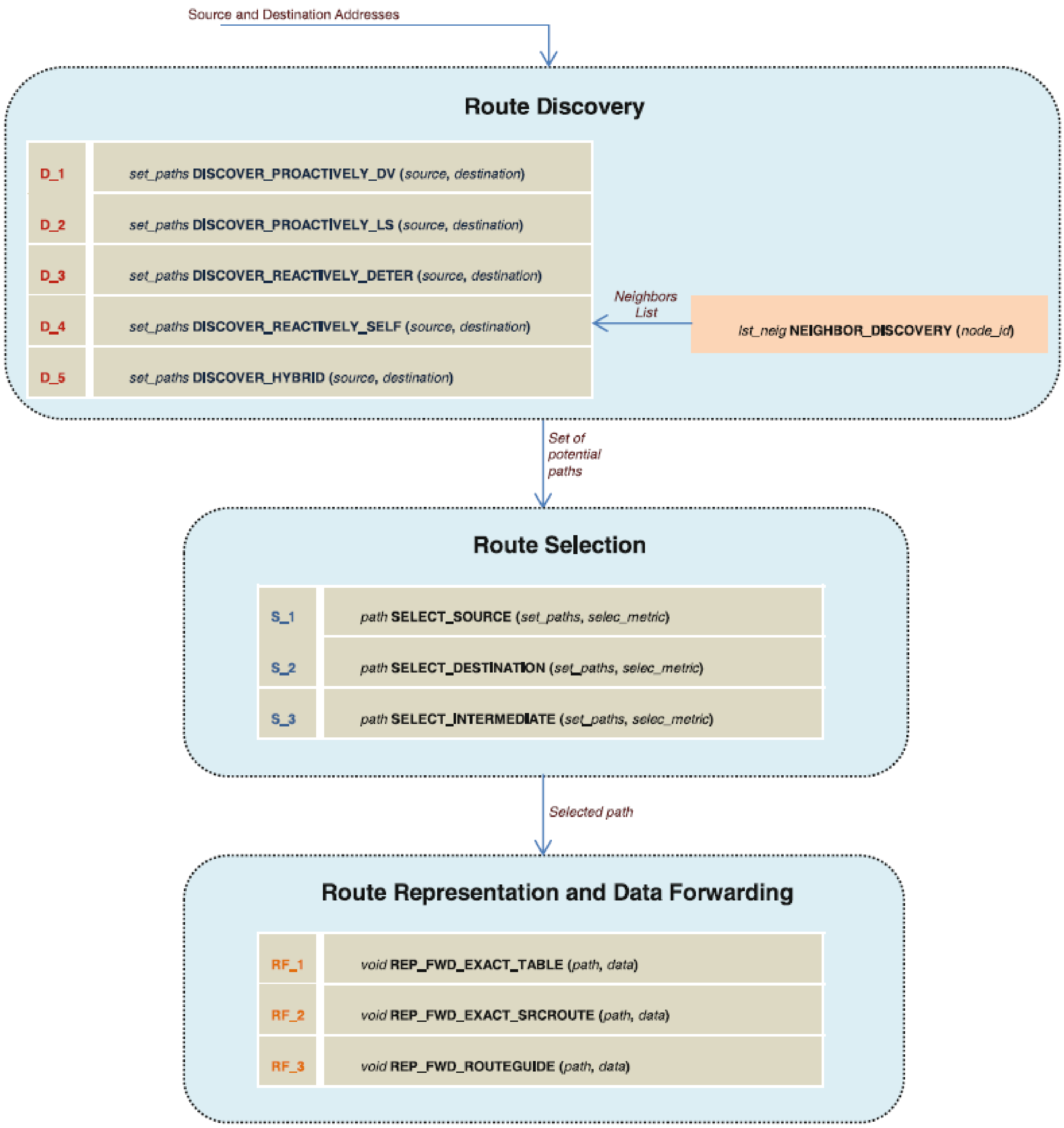

Fig. 2.2. Generic Routing Model for wireless multi-hop routing protocol [16]

Finally, the route representation and data forwarding component has three functions available for the designer’s choice:

– representation and forwarding using exact route with routing tables;
– representation and forwarding using exact route with source routing;
– Representation and forwarding using route guidance.

Again, the choice of the appropriate function strictly depends on the chosen discovery function (e.g., the reactive self-routing discovery requires the use of route guidance).

The following pseudo-code (Fig. 2.3) shows the interaction and dependency of the route selection function and the route representation and data forwarding function to be chosen and the already chosen discovery function. For simplicity, we refer to the functions by codes (these codes are shown in Fig. 2.2 next to their associated functions).

Pseudo -code for choosing the route selection function and the route representation and data forwarding function based on the chosen discovery function

```
if D_1 or D_2  is chosen then
        choose S_1 and RF_1
else if D_3 is chosen then
        choose S_1 or S_2 or S_3  and   RF_1 or RF_2
else if D_4  is chosen then
        choose S_3 and RF_3
else if D_5  is chosen then
        // For the proactive part
        choose S_1 and RF_1
        and
        // For the reactive part
        if D_3  is chosen then
                choose S_1 or S_2 or S_3   and   RF_1 or RF_2
        else if D_4  is chosen then
                choose S_3 and RF_3
        end if
end if
```

Fig. 2.3. Pseudo-code for choosing the route selection function

By breaking down the functionalities into blocks and methods, the protocol designer can choose whatever functionalities are preferred and suitable for the intended paradigm and application. In addition, the designer can replace the chosen functionality of each component without having to redesign the whole protocol. The protocol design is based on a set of blocks that can be edited separately.

In implementing or modifying any of the functionalities, the protocol designer should consider including the scalability and self-configuration features as they are both basic features for all wireless multi-hop routing protocols.

2.3. Distinguishing features and design considerations of routing for VANET

There were many trials for using MANET routing protocols with VANETs, based on the idea that a VANET is a special type of MANET. These trials did not achieve the expected performance as the VANET environment showed that it presents some unique challenges and features that entail the development of a set of new routing protocols or the adaptation of some current MANET protocols to meet the vehicular environment needs. Some of these distinguishing challenges and features are [16]:

1) *Highly Dynamic Topology*:

Since vehicles are moving at high speeds, especially on highways, the topology in a VANET is subject to frequent changes. Routing protocols should provide mechanisms for maintaining the followed routes and handling link changes.

2) *Intermittent Connectivity*:

It can be a common case in VANETs that a vehicle will not find a neighbor in its vicinity to forward its data to and it will have to keep the data till it comes into contact with another vehicle. This will be the case in sparse environments. Even in dense environments, traffic lights and stop signs may lead to some network partitions. Routing protocols should provide mechanisms for handling this intermittent connectivity. The most common mechanisms are the Store-Carry-Forward mechanism for delay-tolerant networks and either the use of Road Side Units (RSUs) for relaying messages, or depending on finding an alternative path using a recovery mechanism in delay-sensitive networks.

3) *Restricted Mobility Patterns*:

Vehicles mobility patterns are restricted by road topology and speed limits. This may be considered advantageous because these restricted patterns can help in predicting future conditions (e.g., traffic conditions and vehicles positions). This feature will help the routing protocols to make more informed decisions.

4) *Sufficient Resources*:

Vehicles have several advantages over other types of mobile nodes, including abundant power, processing, and storage resources; these will provide more flexibility for routing protocol design. VANET routing protocols can relax the need for energy-efficient routing mechanisms. In addition, having sufficient processing and storage resources, VANET routing protocols do not have to be compact in size and complexity.

5) *Delay Constraints*:

As the most common applications supported by VANETs are related to safety, VANET applications often impose hard delay constraints. Routing protocols should ensure continuous connectivity for such applications to avoid incurring any delays due to disconnections and expedite the connection setup times to keep the transmission delay as low as possible.

6) *Availability of Information Providers*:

The vehicle's sensor readings can be utilized in the routing protocols to enhance their functionalities. For example, GPS position information and the vehicle's speed obtained from the speedometer can be used to assist in designing efficient location-based routing protocols. Unlike the other types of networks where position and velocity information require adding special components to the nodes, most vehicles already have these components built-in. In addition, with the availability of the on-board unit that can have access to navigation software and road maps, these sources of information can help routing protocols to make better informed decisions regarding the optimum paths.

All these distinguishing challenges and features should be considered in designing a routing protocol for VANETs to be as efficient as possible and to meet the requirements and needs of the vehicular environment; the most important design considerations are handling the highly dynamic topology and intermittent connectivity to maintain connectivity among vehicles.

In addition, each network paradigm has certain design considerations that distinguish its routing requirements from the other paradigms and impose designing a distinctive set of routing protocols to meet such requirements and performance goals (Fig. 2.4).

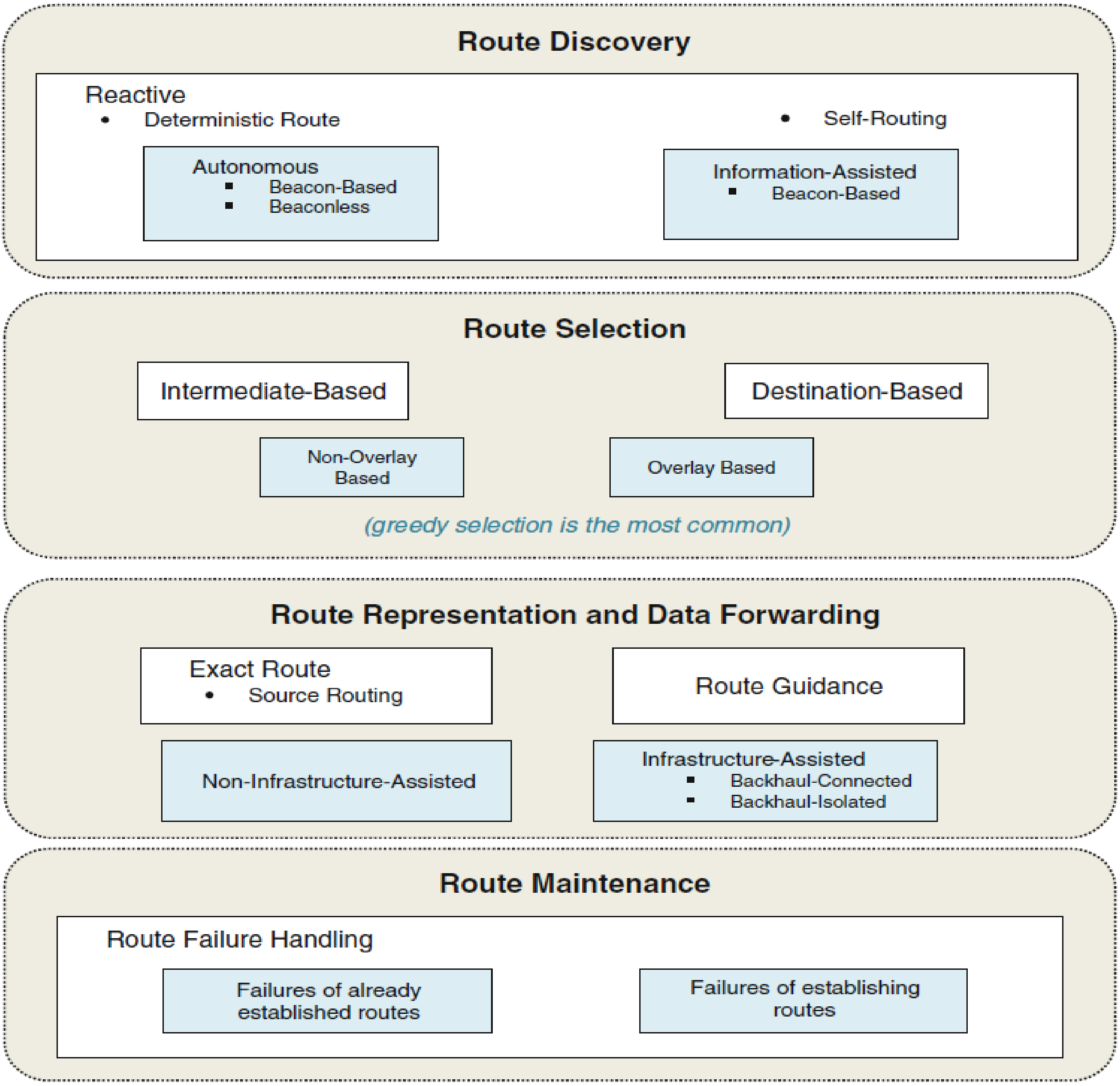

Fig. 2.4. Core components and functionalities of VANET routing [16]

2.4. Classification of VANET routing protocols

Classification of VANETs routing protocol somewhat poses a problem in the sense that they have significant potential to host diverse applications associated with traffic safety, traffic efficiency and infotainment. Thus, classifying routing protocols in VANETs are somewhat complicated and pose a challenging task due to the high mobility of nodes making topology of the network dynamic and causing frequent links disconnections, for this, the selection of routing protocol heavily depends on the nature of the network. Consequently, single routing protocol is not sufficient enough in meeting all the different types of networks. Different researchers classify VANET in various ways depending on different strategy and parameters. Below are some forms of the classification based on different approaches by researchers [10-12, 16-23].

VANET routing protocols can be either MANET protocols that are found/amended to be suitable for the vehicular environment and characteristics, or specifically-designed protocols that are designed with the VANET challenges and features considered. Based on this view, VANET routing protocols can be classified either to be topology-based or position-based protocols. This classification is illustrated in Fig. 2.5.

The topology-based protocols are the MANET protocols that are suggested to be suitable for use with VANETs. As they are not designed specifically with the VANET requirements and features in mind, the topology-based routing protocols do not prove to be efficient compared to position-based protocols.

The position-based routing protocols prove to be the best candidates for the VANET routing functions. Some of these protocols are inherited from some MANET ones and others are newly-designed. With remarkable performance improvements over topology-based schemes, position-based routing is most commonly used and studied. Most of the protocols available in the literature and those that are currently being proposed are based on this routing scheme. The position-based protocols can be further classified into delay-tolerant protocols and non-delay-tolerant protocols

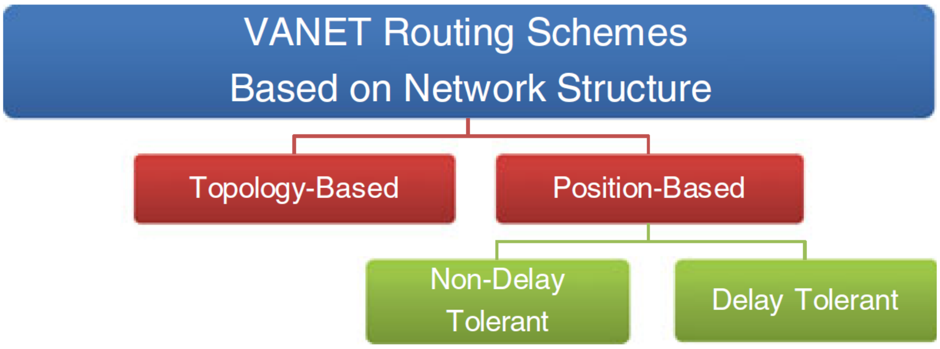

Fig. 2.5. General classification of VANET routing protocols [16]

2.4.1. Position based routing Protocols

This routing protocol is also called geographical routing protocol and it utilizes geographic information to route their data rather than network address making it most suitable and stable for high mobility than topology based routing protocols (whom modus operandi is store data and find its shortest path). In this protocol, all nodes and neighbors depends on position pointing devices like GPS to determine their locations. It uses the location information to deciding for forwarding; hence it is not required to maintain a routing table or state link information [19]. The nodes also have the knowledge of source (which stores the position of destination in its header and help to forward the destination regardless of route discovery, route maintenance and network topology), the destination and other neighboring nodes. Position based routing provides hop-by-hop communication to vehicular networks; hence there is no need to maintain information about topology, route maintenance and discovery.

Its routing is carried out through path selection; link estimation time (LET), forwarding and recovery.

There are three types of routing based protocols: Delay Tolerant Network (DTN) Protocols, Non-Delay Tolerant Network (Non-DTN) Protocols and hybrid.

- Delay tolerant network (DTN): This is an approach to network architecture that seeks to address the technical issues in heterogeneous networks that may lack continuous network connectivity. These protocols, tolerant the delays and use store and forward strategy for forwarding. If neighbor nodes are not available at the moment, the node then holds the message until the neighbor is available and finally forwards the messages. These protocols are more suited in scenarios where communication networks has characteristics like frequent disconnection of networks, large scale, long unavoidable delays, limited bandwidth, power constraints and high bit fault rates. Some examples of these protocols are Motion Vector Routing Algorithm (MOVE), Geographical Opportunistic Routing (GEOPPS), and Vehicle-Assisted Data Delivery in Vehicular Ad Hoc Networks, (VADD), Scalable Knowledge-based Vehicular Routing (SKVR), and Vehicle-assisted Data Delivery (VADD).
- Non-Delay Tolerant Network (Non-DTN) Protocols: In this protocol the packet transmission is made-up on two modes of operation. First method is Greedy Forwarding; in this method the node directly transmits a packet to neighbor node which is closer to destination. Packet has the location information of neighbor node, destination and data. The location information of neighbor node is sent to the currently active node using beacon messages. In some cases, the source node does not contain the closer node to destination. In these scenario, greedy forwarding fails, so to recover this problem the Perimeter method is used. This method uses the right-hand-rule to transmit a

packet. When the packet reaches the local maximum the right-hand rule is invoked. It directly sends a packet to destination. GPSR produces good results in highway environment compare to urban area. In Urban areas the direct communication is rare due to the presence of more buildings and trees. Some examples of Non-DTN protocols are Greedy Perimeter Stateless Routing (GPSR), Greedy Perimeter Coordinator Routing (GPCR), Reliability-Improving Position-Based Routing (RIRP), GpsrJ+, Junction-based Adaptive Reactive Routing (JARR), Greedy Traffic-aware Routing (GyTAR), Geographic Source Routing (GSR).

- Hybrid protocol: These are protocols that are formed by merging two or more concepts from delay tolerant and non-delay tolerant protocols to achieve a desired result. Examples of such protocols are Hybrid Location-Based Ad Hoc Routing Protocol (HLAR), GeoDTN+Nav.

2.4.2. Geocast routing protocol

Geocast routing is a robust routing system and it’s considered by some researchers that it belongs to multicast position based routing [2, 19]. These protocols send the messages to all vehicles depending on the pre-defined geographical region, these regions are divided into zones and then communication is carried out in those zones. Its objective is to deliver the packet from source node to all other nodes within a specified geographical region (Zone of Relevance ZOR). In Geo cast routing vehicles outside the ZOR are not alerted to avoid unnecessary hasty reaction, thus packets are dropped when any nodes leaves the ZOR. This protocol also employs are technique called Zone of Forwarding (ZOF). It normally defines a forwarding zone where it directs the flooding of packets in order to reduce message overhead and network congestion caused by simply flooding packets everywhere. In the destination zone, Unicast routing can be used to forward the packet. One pitfall of Geocast is network partitioning and also unfavorable neighbors, which may hinder the proper forwarding of messages. Some examples of this protocol are Robust Vehicular Routing (ROVER), Mobile Just in Time Multicasting Protocol (Mobicast) Cluster-Based Directional Routing Protocol (CBDRP), Cluster-Based Location Routing (CBLR), and Cluster-Based Routing (CBR).

2.4.3. Topology Based Protocols

These protocols belong to traditional MANETs routing protocols. It uses link information which stores in routing tables to forwarding packets from source to destination. Topology Based Routing Protocols operates by maintaining routing tables for storing the link information, then based on this stored data, it forwards packet from source vehicles to destination vehicles. Also it makes use of global information for making routing decisions and in the process will try to find the best possible route, resulting in delay before forwarding the data to its destination, either maintaining a route table or searching the path is mandatory. If one considers the fact that the nodes in this case are highly mobile, this protocol will appear too inconsistent to cater for VANET needs and thus considered the slowest among other protocols. This routing protocol is further divided into three categories: proactive, reactive and hybrid protocol:

- Proactive protocols: also called table driven protocols, it builds tables so that it can receive the information which is updated all the time by continuously exchanging of packets in the network. In this a beneficial point is that an exact image of network will be reminded by each node till it founds the network image. Hence, it concludes that it takes very less time. Various protocols in this are FSR, DSDV, OLSR, CGSR, WRP, TBRPF, LSR, and TDR.
- Reactive protocols: also termed as on demand routing protocols created and designed in such a manner to overcome the overhead that was created by proactive routing protocols. It is totally different from proactive protocols because there is no information of the entire network, which is also change. So, this protocol is made by which it can easily target the way. Various reactive protocols are AODV, PGB, DSR, TORA and JARR.
- Hybrid protocols: It is the combination of both (proactive and reactive) the protocols so that it can reduce the overhead of proactive and initial route discovery of reactive protocols. Examples of hybrid protocols are Zone Routing Protocol (ZRP) and Zone-Based Hierarchical Link State (ZHLS).

2.4.4. Infrastructure Based Routing Protocol

In Infrastructure based routing protocols, the communication takes place between vehicles and the Access points (APs) installed on road side. These APs work as a bridge between vehicles for message transfer. The designing of infrastructure units is simple as most of the functionality is embedded into APs. HIPERLAN2 and IEEE802.11 use infrastructure mode for their functioning. This routing protocol basically uses the Roadside Units (RSU) so that the route packets can be easily reachable to vehicles. It can be possible along the roads only and there will normally be a transmission range. Infrastructure mode in VANET scenario plays a major role when the vehicle density is low. The traffic is under control at night, therefore, the vehicles may move at higher speeds which allow the two vehicles to move out of each other's transmission range very quickly. In this scenario, the functionality of RSUs comes into play. RSUs send traffic alerts and provide an interface for vehicles to communicate with each other. The only disadvantage of using infrastructure units for communication is that in some critical situations such as earthquake, cyclone, flood or some form of any natural disaster, the RSUs are destroyed, rendering the whole system completely useless.

Examples of the most popular Infrastructure based protocols are; Roadside-Aided Routing (RAR) and Static-Node-Assisted Adaptive Data Dissemination in Vehicular Networks (SADV).

2.4.5. Transmission Strategy and Routing Information

In this form of classification, the routing protocol is based on the routing information used in packet forwarding and transmission strategy focused on network performance like overhead, delay and packet loss etc. the transmission style may be in the form of the form of Broadcast, Multicast or Geo-cast with each of them having their own peculiar scenarios with which they are most favored.

– Broadcast: in this method, packets are sent over the network and the message flooded in the broadcast domain to route discovery hence everyone in the network is capable of obtaining information been sent from a source. This strategy may achieve reliable transmission by delivery packets via many nodes however its downside is that it going to take a lot of useful bandwidths in attempt to accommodate all the packets been sent. Furthermore, it is worth nothing that nodes in which a particular packet isn't meant for will drop it as soon as it gets it.

- Some examples of this broadcast style protocols include Some protocols are Density-Aware Reliable Broadcasting Protocol (DECA), Position-Aware Reliable Broadcasting Protocol (POCA), Distributed Vehicular Broad-cast Protocol (DV-CAST) and Distribution-Adaptive Distance with Channel Quality (DADCQ).
- Multicast: the strategy is somewhat similar to broadcast in the sense that they both send data over the network without a specific node destination address, however in this case, the packets send a message to a specific group (in a design that is somewhat similar to VLANs) in the network using multi-hop technique and only that group of members in the network received that message only. Multicast routing in VANETs can be further classified into two types that are geo-cast and cluster-based. In a bid to design a functional system combining both abilities of multicast and broadcast, a strategy termed Spatiotemporal Multicast/Geocast; it considers the time and location of a node factor.
- Unicast: in this strategy, the packet is sent from a single source to a single destination that is already assigned thereby saving bandwidths and reducing collision domains. It uses either multi-hop or store and forward scheme to achieve its purpose during transmission. It further classified into two classes; min delay and delay bounded. Min delay focuses on minimizing the delivery delay time from source to destination and delay bounded low level of channel utilization. Examples of these protocols are GPCR, VADD, CAR, DIR, ROMSGP, Reliable Routing and GV GRID.

2.5. Comparison of VANET routing protocols

In an ideal situation, a routing protocol as regards to VANETs should be completely functional and reliable, covering all issues such as; Delay and information retransmission, handling changes in network topology, effectiveness in the midst of environmental interferences, be able to be scalable, and to still be effective during off peak periods by still being able to broadcast messages. Unfortunately, VANET routing protocols is not a one size fits all when it comes to practical scenarios, it is observed that due to mobility constraints and high dynamics inherent in various routing protocol, one protocol maybe very useful in certain network environment and less useful in others (Table 2.1, 2.2).

Table 2.1 – Comparison of position based routing protocols [19]

Parameters	GpsrJ+	GyTAR JARR	GSR	SKVR	VADD	GEOPPS	GeoDTN +Nav
Traffic-aware	No	Yes	No	No	Yes	No	No
Forwarding Strategy	Greedy	Greedy	Greedy	Greedy	Greedy	Greedy	Greedy
Buffering	No	No	No	Yes	Yes	Yes	Yes
Overlay or Non-Overly	Yes	Yes	Yes	No	No	No	No
Predictive	Yes	Yes	No	No	Yes	No	No
Virtual Infrastructure required	No	No	No	No	No	No	No
Map based required	No	Yes	Yes	No	Yes	Yes	Yes
Location Services	Yes	Yes	Yes	No	Yes	Yes	Yes
Environment required	City	City	City	City	City	City	City

Table 2.2 – Comparison of Broadcast Routing Protocols [19]

Protocols	On the Broadcast storm Problem	DV-CAST	Broadcast Methods
Impacted by traffic flow	Yes	Yes	No
Road direction	Single Direction	Dual direction	Single Direction
Fragmentation Solution	Probability Rebroadcast	Reverse traffic Flow	Range Restriction
Map needed	No	No	No
Environment	Highway	Highway	Highway

Each individual routing solution works better in one particular terrain or scenario but will be ineffective when deployed in another scenario or environment. For example, when one deploys a position based routing, it is suitable for high mobility areas and it's scalable, but its downside is it requires positions of nodes to find services and since it requires GPS, it may not function well in tunnels. Furthermore, there is wastage of bandwidth; its storage requirement is high. As regards reactive routing protocols, one will have noticed that less resource is consumed as a result of absence of routing tables and saves bandwidth as it is beaconless. However, they are delays in route discovery and maintenance and there is disruption of nodes communication due to excess flooding. Finally, in terms of throughput and delay, reactive routing is always preferred to proactive. Results of comparison under different features of the routing protocols presented in the Table 2.3 and Table 2.4.

Table 2.3 – Comparison of Multicast/Geocast Routing Protocols [19]

Protocols	DRG	IVG	Mobicast Routing
The mobility of describing the zone	No	No	Yes
Spatial temporary	No	No	Yes
Spatial relevance	Yes	Yes	Yes
Map needed	No	No	No
Environment	Highway	Highway	Highway
Realistic traffic Flow	No	No	No

Some advantages and disadvantages of selected routing protocols are described in the following subsection.

2.5.1. AODV Routing Protocol

Ad Hoc on Demand Distance Vector Routing (AODV) is an example of pure reactive routing protocol. AODV belongs to multihop type of reactive routing. AODV routing protocol works purely on demand basis when it is required by network, which is fulfilled by nodes within the network. Route discovery and route maintenance is also carried out on demand basis even if only two nodes need to communicate with each other. AODV cuts down the need of nodes in order to always remain active and to continuously update routing information at each node.

Table 2.4 – Comparison of Transmission Strategy [19]

Transmission Strategies	Methods Used	Strengths	Limitations
Unicast	Info delivery from a single source to a single destination	Less overhead more privacy minimum packet delay	Link frequently configure and maintain packet loss, less reliability
Multicast	Geocast send messages from source to group of destinations using geographical address cluster divide the networks info cluster and cluster head manage all communication	Efficient routing by sending one copy to multiples node minimum networks consumption and dealy easy to implement and transparent to changeable addresses (no requirement to receiver's address)	
Broadcast	Packets floods to all nodes within the broadcast domain	More reliable and fewer packets loss	Consumes bandwidth routes loop, network congestion, less network throughput more packet delay

The selected inherent advantages and disadvantages of this particular routing protocol are stated below;

Advantages:

- Destination sequence number is useful to find the recent route.
- Bandwidth is not wasted unnecessarily.
- It reduces memory requirements.
- Not maintain unusual routes.
- It reduces burden on the network.
- It quickly responses to link breakage inactive routes.
- It can be applied to large population of nodes.

Disadvantages:

- It needs more time for connection setup and not suitable for safety related applications.
- It consumes extra bandwidth.

2.5.2. DSR Routing Protocol

It is similar to AODV in that it forms a route on-demand when a transmitting node requests one. However, it uses source routing instead of relying on the routing table at each intermediate device. The DSR protocol is a simple and efficient routing protocol designed specifically for use in multi-hop wireless ad hoc networks of mobile nodes. DSR allows the network to be completely self-organizing and self-configuring, without the need for any existing network infrastructure or administration. The protocol is composed of the two main mechanisms of Route Discovery and Route Maintenance, which work together to allow nodes to discover and maintain routes to arbitrary destinations in the ad hoc network. All aspects of the protocol operate entirely on demand, allowing the routing packet overhead of DSR to scale automatically to only what is needed to react to changes in the routes currently in use. The protocol allows multiple routes to any destination and allows each sender to select and control the routes used in routing its packets, for example, for use in load balancing or for increased robustness [20].

Its advantages and disadvantages are stated below.

Advantages:

- Guarantees loop free operation.
- It avoids infinite loop.
- It does not require periodic updates.

Disadvantages:

- It generates overhead for many number of nodes of the route in the packet header.
- It has burden on the network.
- Unable to repair broken link locally.
- Worse performance with high mobility pattern Because of periodic beaconing it consumes extra bandwidth.

2.5.3. OLSR Routing Protocols

The Optimized Link State Routing (OLSR) is a table-driven, proactive routing protocol developed for MANETs [20]. It is an optimization of pure link state protocols in that it reduces the size of control packet as well as the number of control packets transmission required.

This protocol reduces the control traffic overhead by using Multipoint Relays (MPR), which is the key idea behind OLSR. A MPR is a node's one-hop neighbor which has been chosen to forward packets. Instead of pure flooding of the network, packets are just forwarded by a node's MPRs. This delimits the network overhead, thus being more efficient than pure link state routing protocols.

OLSR is well suited to large and dense mobile networks. Its advantage and disadvantages are stated below.

Advantages:

- Optimization over pure link state routing.
- Reduce unnecessary retransmission LS advertisements.
- It is suitable for large and dense ad-hoc networks and also for high mobility networks.
- It avoids initial latency and useful for safety related applications.
- New routes can easily be finding out which provides routing efficiency.

Disadvantages:

- It generates routing overhead.
- High network resource consumption.
- It uses high network bandwidth.
- Generates burden on the network.

2.5.4. DYMO Routing Protocol

This routing protocol is more or less an improvement to the Ad hoc On-Demand Distance Vector (AODV) Routing protocol and shares many of its benefits [20]. It is, however, slightly easier to implement and designed with future enhancements in mind. This protocol can work as both a pro-active and as a reactive routing protocol, i.e. routes can be discovered just when they are needed. In any way, to discover new routes the following two steps take place:

A special Route Request (RREQ) messages is broadcast through the MANET. Each RREQ keeps an ordered list of all nodes it passed through, so every host receiving an RREQ message can immediately record a route back to the origin of this message. When an RREQ message arrives at its destination, a Routing Reply (RREP) message will immediately be passed back to the origin, indicating that a route to the destination was found. On its way back to the source, an RREP message can simply back trace the way the RREQ message took and simultaneously allow all hosts it passes to record a complementary route back to where it came from.

So as soon as the RREP message reaches its destination, a two-way route was successfully recorded by all intermediate hosts, and exchange of data packets can commence.

Its advantages and disadvantages are stated below.

Advantages:

- It is simple and easy to implement.
- It provides loop free routes by using a unique sequence number for each node.
- It has a better route maintenance process.
- It has good performance.
- Its routing table is less memory consuming than AODV even with path accumulation feature.

Disadvantages:

- Unnecessary overhead in low mobility environments.
- It does not perform well with low mobility.

CHAPTER 3

STOCHASTIC TRAFFIC MODELING IN VANET

3.1. Stochastic modeling VANET application

Models that consider uncertainty are known as stochastic models, as opposed to deterministic models, which assume all data are known with certainty. In a variety of applications of traffic flow, including traffic simulation, which is our area of concentration, real-time estimation and prediction, one requires a probabilistic model of traffic flow. The usual approach to constructing such models involves the addition of random noise terms to deterministic equations, which could lead to negative traffic densities and mean dynamics that are inconsistent with the original deterministic dynamics.

Even if many decision makers realize the existence of uncertainty, most used decision models are deterministic. The reason for such a choice is that stochastic models are typically more difficult to solve than the deterministic ones. The common tendency is to try to solve very detailed deterministic models. As perfect forecasting does not exist, real data are very often different from the data used in the models. This results in fact in poor decisions being taken. To avoid such pitfalls, we advocate the use of stochastic models when uncertainty may play a significant role especially in scenarios like that of VANET networks where routing and near perfect predictions of road side unit (RSU) is of very vital.

Route selection and management are one of the key issues in Vehicular Ad-hoc Networks – VANETs. The medium access control is based on IEEE 802.11p standard and has been created for Vehicle to Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) communications. However, in VANET, issues like route request, route reply, route discovery, and maintenance are not addressed properly. In this chapter, we investigated the impact of multi-hop routing in the queuing system (M/G/c/c) along with the focus of the performance of VANETs based on the probability of waiting for the queue, system utilization, mean throughput and blocking probability between V2V communications.

Researchers from various fields such as transportation engineering, civil engineering industrial engineering etc. have proposed different techniques to study traffic interaction, but this work utilizes a generalized M/G/c/c state dependent queuing model to analyze the performance of a congested roadway segment since it can represent congestion in traffic flow more appropriately and accurately [24, 25]. This representation captures the features of roadway segments, which can accommodate a finite number of vehicles and the deterioration in service time as a function of the number of vehicles occupying the roadway. In modeling pedestrian and vehicular traffic flow, a link of a road network is modeled with c servers set in parallel, where c is the link capacity (the maximum number of occupants in the link). The model assumed that the average speed ν_n depends on the number of occupant's n on the road, according to a non-increasing density-speed relationship. Based on Tregenza's empirical studies, linear and exponential congestion models are developed for the average pedestrian/vehicles speed in traffic links [24]. The linear congestion model is based on the idea that the service rate is a linear function of the number of occupants in the link and is given as follows.

First form is

$$\nu_n = \nu_f \frac{(c-n+1)}{c}, \tag{3.1}$$

While the exponential congestion is based on the idea that the service rate is related to the number of occupants; mathematically, it is represented as

$$v_n = v_f exp\left[-\left(\frac{n-1}{\beta}\right)^{\Upsilon}\right]. \tag{3.2}$$

Whereβ represents the shape parameters and Υ represents the scale parameter.

Mathematically they can be represented with the following equations:

$$\beta = \frac{a-1}{[\ln(v_f/v_a)]^{1/\Upsilon}} = \frac{b-1}{[\ln(v_f/v_a)]^{1/\Upsilon}}, \tag{3.3}$$

$$\Upsilon = \ln\left(\frac{ln v_a/v_f}{ln(v_b/v_f)}\right)/\ln\left(\frac{a-1}{b-1}\right), \tag{3.4}$$

where the values a and b are arbitrary points used to fit the exponential curve.

The arrival process of cars into the link is assumed to be Poisson with rate λ, while the service rate is general and depend on the number of occupants n on the link. A normalized service rate $f(n)$is defined as the ratio of average speed to free speed, in order to capture congestion effects, and is taken as

$$f(n) = v_n/v_f, 0 \leq f(n) \leq 1.$$

In the linear case we have$f(n) = (c - n + 1)/c$, while in the exponential case, we have$f(n) = exp[-((n-1)/\beta^{\Upsilon})]$.

The stationary probability distribution $P_n = P(N = n)$ of the number of occupants N in the M/G/c/c state dependent to be stochastic equivalent to a pure Markovian M/M/c/c queuing model.

3.2. Stochastic traffic modeling using M/G/c/c queuing model in VANETs

This section presents the use of an M/G/c/c state dependent queuing model for road traffic flow [24, 25]. The model is based on finite capacity queuing theory, which captures the stationary density-flow relationships. It is also inspired from the deterministic Godunov scheme for the road traffic simulation. Since vehicular networks are dynamic in nature, the M/G/c/c model is the perfect fit for this instance. Its queuing system of arrival and service process for multiple servers (vehicles or nodes in this instance) is best, efficient, fast and easy to control when considered with high number of servers in a system. In addition, it is also applicable in both single and multiple lanes on a road segment for which the performance measures for each vehicle can be evaluated independently. The M/G/c/c queuing model is characterized as general distribution by its mean and coefficient of variation.

As stated above, the inherent nature of VANETs is dynamic and it is characterized by stochastic model, hence making use of the M/G/c/c model is most likely to yield near perfect and accurate prediction. The M/G/c/c queuing model is used for the traffic distribution in each channel of future vehicular networks. It is applied to the supply functions and demand of vehicle passing from source node to the destination node.

For an M/G/c/c to function effectively and produce worthy results, by providing arrival and service guarantee, the Road Side Units (RSU) gets connected directly to the evolved node (in some cases the available base stations) link between servers and directly connected to the internet. This is illustrated in the Fig. 3.1 where the Road Side Unit (RSU) to vehicle connection is based on Vehicle to Infrastructure (V2I) communication protocol while the vehicle to vehicle is achieved through the Vehicle to Vehicle (V2V) communication style in a VANET system.

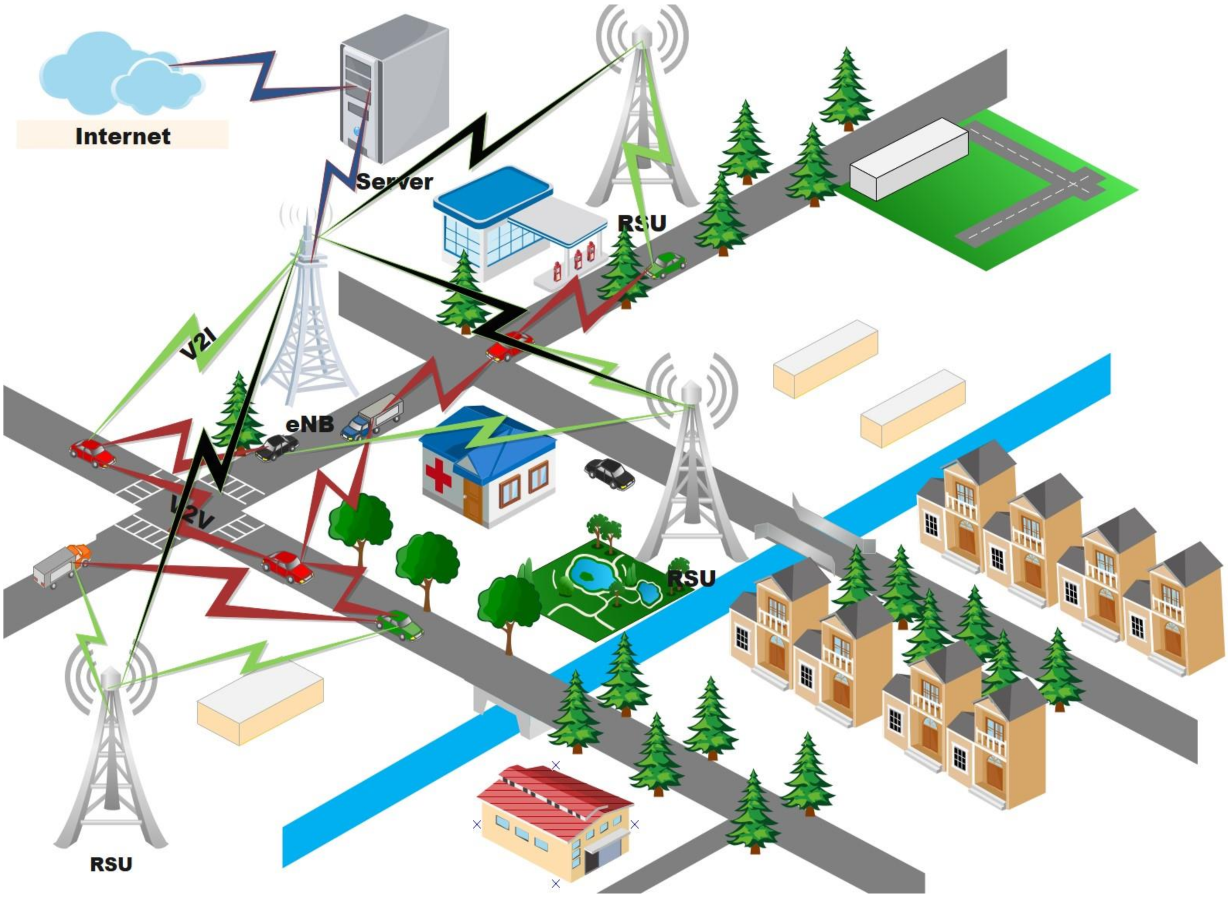

Fig. 3.1. System model of multi-hop VANET communication

In a broad sense, the M/G/c/c queuing model is made up of a queuing station with a single or multiple servers. As stated above the queuing model to be used in this work is the M/G/c/c state distribution model. It can be represented as shown in the figure below.

It is observed that the vehicle arrival and service rate are independent and identically distributed (*i.i.d*) in the form of general service time distribution [24, 25]. The vehicle arrival follows a Poisson distribution with arrival rate λ_t, service rate is μ_t, and number of server model with Poisson input c and system/buffer capacity *c*. then the blocking probability of stochastic traffic distribution within a wireless channel is gotten by the equation:

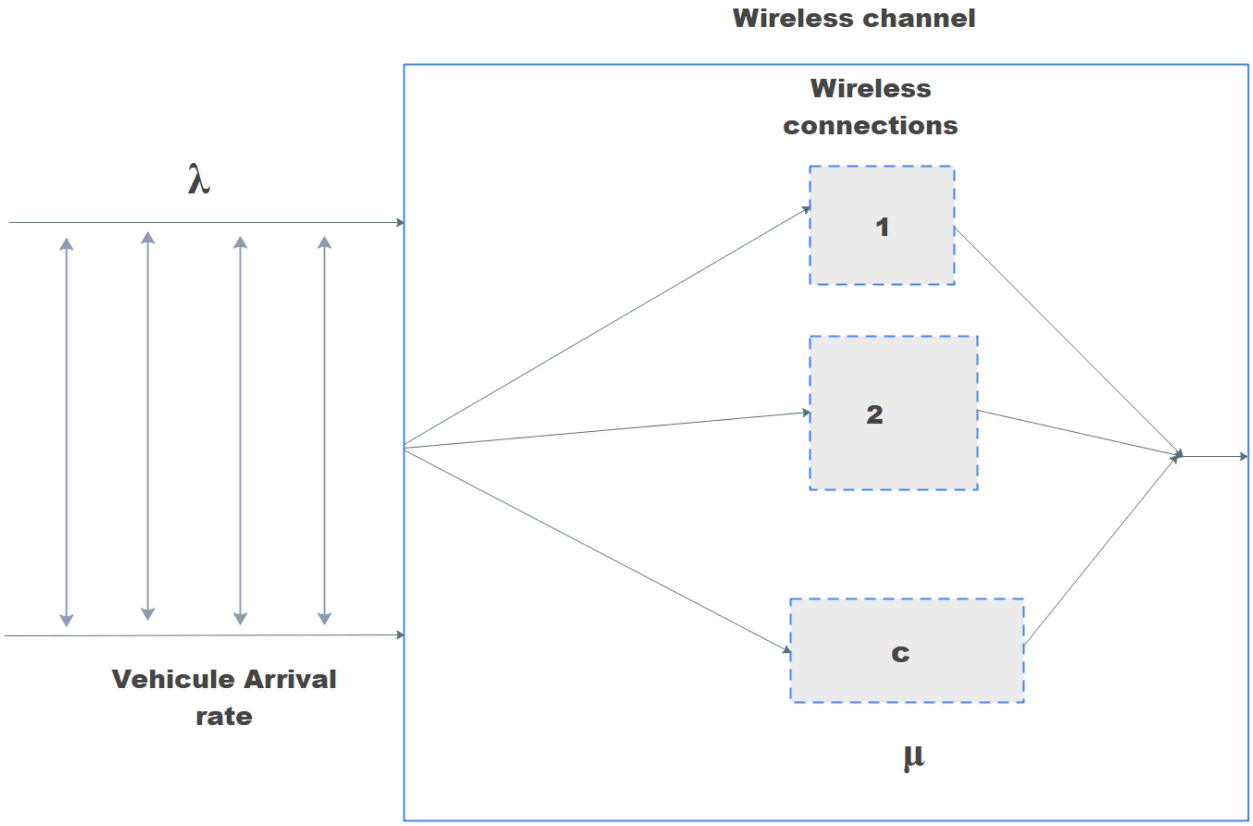

Fig. 3.2. Queuing System of M/G/c/c modeling in wireless channel

$$p_b(i) = \frac{\left(\frac{\lambda_t}{\mu_t}\right)^i / i!}{\sum_{j=0}^{i} \frac{\left(\lambda_t/\mu_t\right)^j}{j^i}}, \qquad (3.5)$$

Where i and j are the numbers of wireless connections available in the wireless channel and this formula follows the service time distribution of Erlang is loss formula. The steady state probability distribution using M/G/c/c queuing model follows the stochastic model of an M/M/c/c queuing model. This probability distribution is given as follows:

$$p_i = \frac{\left(\lambda_t L_i / v_{f_i}\right)^i}{\prod_{j=1}^{i} j f(j)} p_o for i = 1, \dots, c, \qquad (3.6)$$

$$p_o = \left(1 + \sum_{i=1}^{c} \frac{\left(\lambda_t L_i / v_{f_i}\right)^i}{\prod_{j=1}^{i} j f(j)}\right)^{-1}, \qquad (3.7)$$

Where L_i is the length of the link connection between sources to destination and v_{f_i} is the vehicle free speed on highway corresponding to one occupant in the link. The blocking probability distribution is given as:

$$p_{bc} = \frac{\left(\lambda_t L_i / v_{f_i}\right)^i}{\prod_{j=1}^{i} jf(j)} p_o, \tag{3.8}$$

In addition, the throughput is given as

$$\Theta = \lambda_t (1 - p_{bc}). \tag{3.9}$$

The expected number of cars in the section:

$$\bar{N} = \sum_{n=1}^{c} n P_n. \tag{3.10}$$

The expected service time:

$$W = \bar{N} / \Theta. \tag{3.11}$$

In the analysis of this work, the Ad hoc On-demand Distance Vector (AODV) routing protocol is used. As illustrated in the figure below, when the source node needs to communicate with a neighboring node in the network, it sends a route request (RREQ) data message. The node receives the RREQ message and sends back a route reply (RREP) data message to the neighboring node.

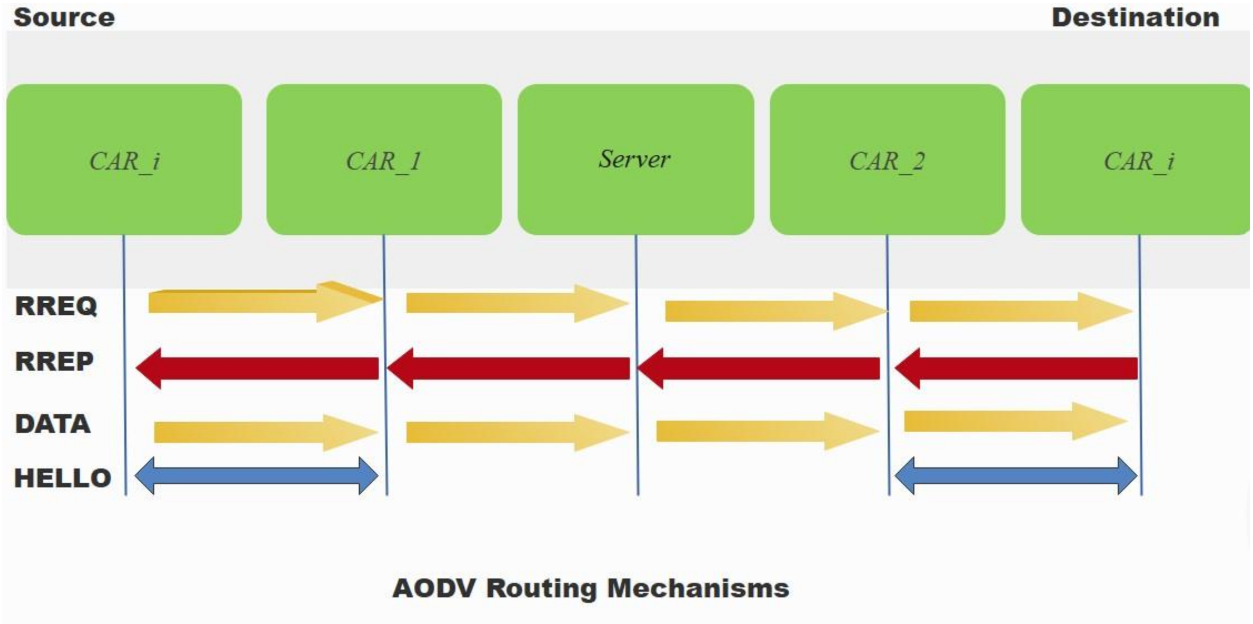

Fig. 3.3. Packets sequence diagram for AODV Routing mechanisms

3.3. Numerical research and performance analysis

Numerical research and performance analysis will be performed using a steady-state distribution of a Markov chain model of M/M/1/c. In the vehicular communication network, performance analysis consists of limited resources, such as the probability of waiting, the use of the system, the average speed and the probability of blocking depending on the increased number of vehicle flows and of the traffic control approach. It is used to alleviate traffic control and congestion problems using queuing networks. The routing protocol monitors the AODV protocol from Source to Destination against a data rate and a packet size; optimization of the stochastic network for data broadcasting for VANETs with multi-hop routing is presented in a V2V communication. Analysis for simplification of calculations will be performed with the multi-server queue M/M/1/c. V2V multi-hop communications in vehicle networks choose a route from source to destination which is the shortest route using the proposed AODV routing protocol with consideration for network performance and optimal number of links and presented a model of stochastic network optimization using multiple servers. After studying the network performance, we found that the queuing model provides the best estimates of network performance factors such as system usage, average throughput, probability of waiting and probability blocking. These factors depend on the packet arrival rate and the service time.

The state space diagram for M/M/1/c queuing system is following:

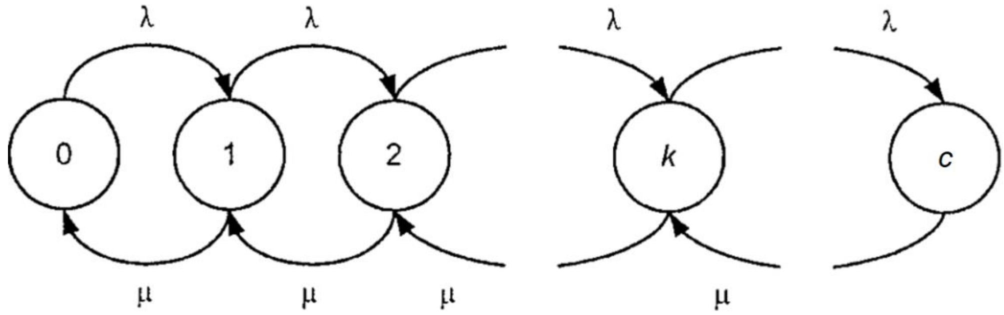

Fig. 3.4. State space diagram for M/M/1/c

Here the probability distribution of number of vehicles in the M/M/1/c system is defined in the form:

$$p_k = \frac{1-\lambda_t/\mu_t}{1-(\lambda_t/\mu_t)^{c+1}}\left(\lambda_t/\mu_t\right)^k,\ 0 \le k \le c, \tag{3.12}$$

$$p_0 = \frac{1-\lambda_t/\mu_t}{1-(\lambda_t/\mu_t)^{c+1}}, \tag{3.13}$$

Where c is the system capacity (number of vehicles);

$\rho = \lambda_t/\mu_t$ is the system utilization.

The blocking probability of stochastic traffic distribution within a wireless channel will be obtained using the following equation:

$$p_b = p_k(k = c) = \frac{1-\lambda_t/\mu_t}{1-(\lambda_t/\mu_t)^{c+1}}\left(\lambda_t/\mu_t\right)^c. \tag{3.14}$$

For numerical research, the MATLAB environment has been used [27-29]. The input data for investigation:

– $\lambda_{t1} = 0.15$ veh/sec, $\mu_{t1} = 1$ veh/sec, $\rho_1 = 0.15$;
– $\lambda_{t2} = 0.5$ veh/sec, $\mu_{t2} = 1$ veh/sec, $\rho_2 = 0.5$;
– $\lambda_{t3} = 0.8$ veh/sec, $\mu_{t3} = 1$ veh/sec, $\rho_3 = 0.8$.

The MATLAB source code had been written for calculation the probability distribution of number of vehicles in the M/M/1/c system using equations (3.12) and (3.13), as well as formula (3.14) was used for calculation the blocking probability for every case of utilization:

```
clearall
clc
c_max=20; % buffer capacity
c=[0:1:c_max]; % number of vehicles
% Case 1
lambda_t1=0.15; % veh/s
mu_t1=1; % veh/s
rho1=lambda_t1/mu_t1;
p0_1=(1-rho1)/(1-(rho1)^(c_max+1)) % probability P0
     p0_1 = 0.8500
pk_1=((1-rho1)/(1-(rho1)^(c_max+1)))*rho1.^c;
pb_1=((1-rho1)/(1-(rho1)^(c_max+1)))*rho1.^c_max % blocking
probability
     pb_1 = 2.8265e-17
% Case 2
lambda_t2=0.5; % veh/s
mu_t2=1; % veh/s
rho2=lambda_t2/mu_t2;
p0_2=(1-rho2)/(1-(rho2)^(c_max+1)) % probability P0
     p0_2 = 0.5000
pk_2=((1-rho2)/(1-(rho2)^(c_max+1)))*rho2.^c;
pb_2=((1-rho2)/(1-(rho2)^(c_max+1)))*rho2.^c_max % blocking
probability
     pb_2 = 4.7684e-07
% Case 3
lambda_t3=0.8; % veh/s
mu_t3=1; % veh/s
rho3=lambda_t3/mu_t3;
p0_3=(1-rho3)/(1-(rho3)^(c_max+1)) % probability P0
     p0_3 = 0.2019
pk_3=((1-rho3)/(1-(rho3)^(c_max+1)))*rho3.^c;
pb_3=((1-rho3)/(1-(rho3)^(c_max+1)))*rho3.^c_max % blocking
probability
     pb_3 = 0.0023
plot(c,pk_1,'m',c,pk_2,'b--',c,pk_3,'r-.');
xlabel('Number of vehicles in the system')
ylabel('Probability')
legend('\lambda_t_1=0.15 veh/sec, \mu_t_1=1 veh/sec',...
'\lambda_t_2=0.5 veh/sec, \mu_t_2=1 veh/sec',...
'\lambda_t_3=0.8 veh/sec, \mu_t_3=1 veh/sec')
gridon
```

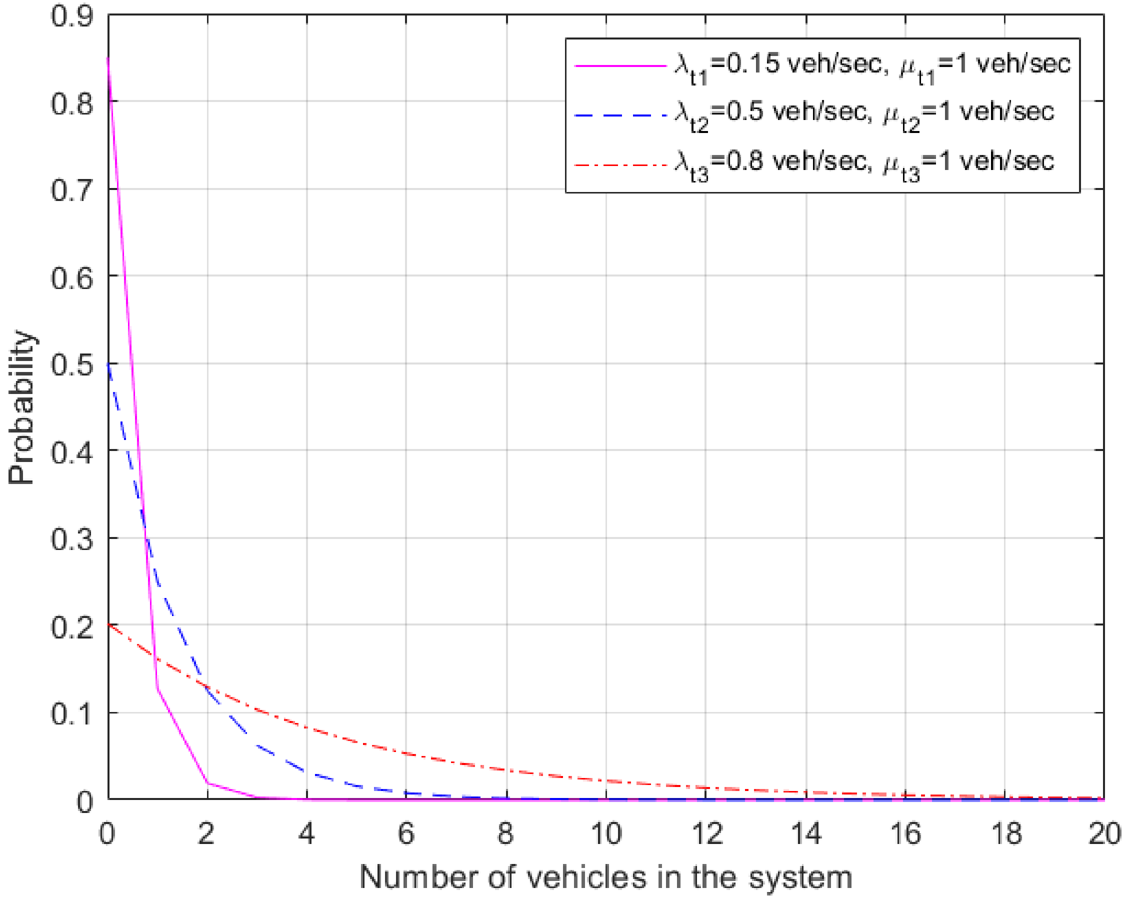

Fig. 3.5. Probability distribution for M/M/1/c modeling wireless channel

The dependency on utilization changing from 0.05 to 1 is presented below with the corresponding MATLAB code:

```
clearall
clc
c_max=20; % buffer capacity
c=linspace(1,c_max); % number of vehicles
rho=linspace(0.05,1);
[R,C] = meshgrid(rho,c);
Pk=((1-R)./(1-(R).^(c_max+1))).*R.^C;
figure(1)
mesh(C,R,Pk)
ylabel('Utilization')
xlabel('Number of vehicles in the system')
zlabel('Probability')
```

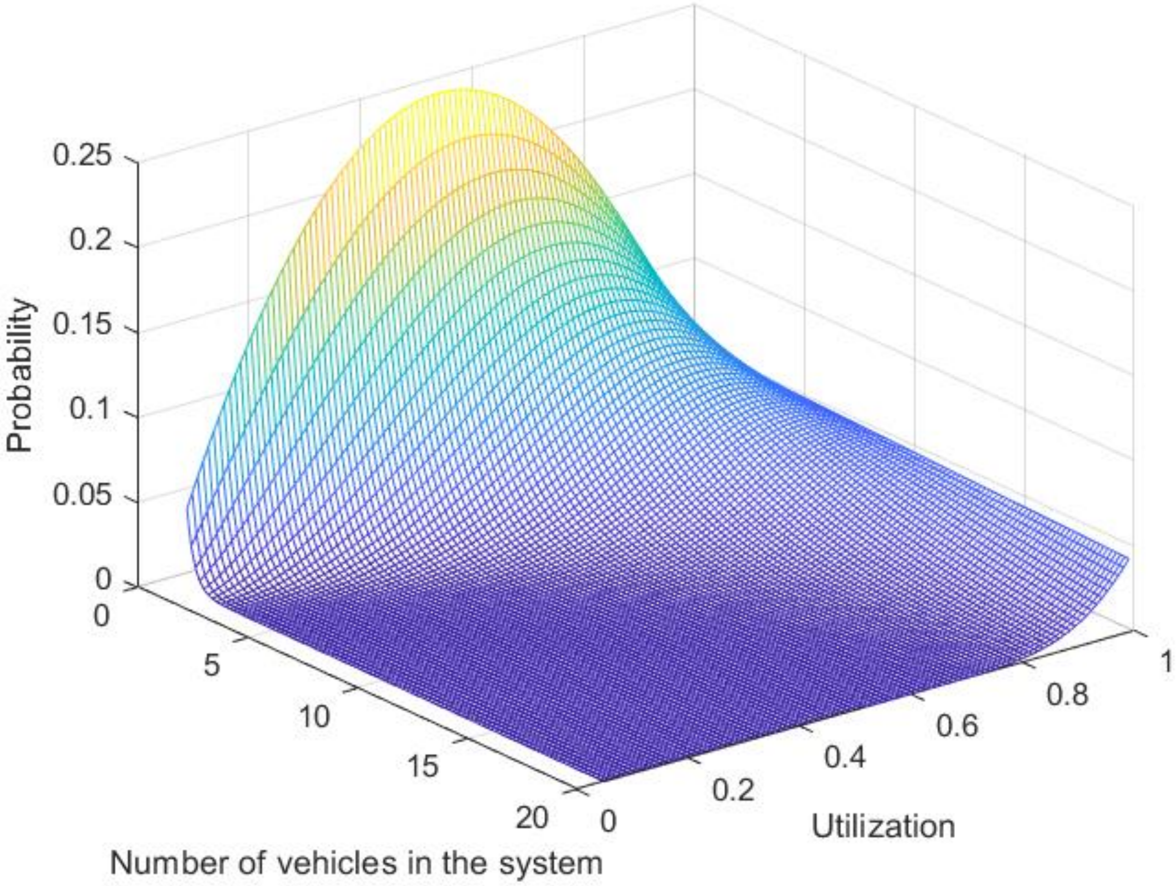

Fig. 3.6. Dependency of the probability distribution with respect to utilization for M/M/1/c wireless channel

The following MATLAB code aimed at obtaining the behavior of blocking probability (3.14) when the system capacity *c* is changing:

```
clc;
clearall;
c=19;
rho=0.05:0.05:0.95;
n=1:c; % capacity is changing from 1 to 19
fori=1:19
forj=1:19
    p(i,j)=(1-rho(i))*(rho(i)^n(j))/(1-rho(i)^(n(j)+1));
end
end
figure(1)
mesh(n,rho,p)
ylabel('Utilization')
xlabel('Maximum number of vehicles in the system')
zlabel('Blocking probability')
```

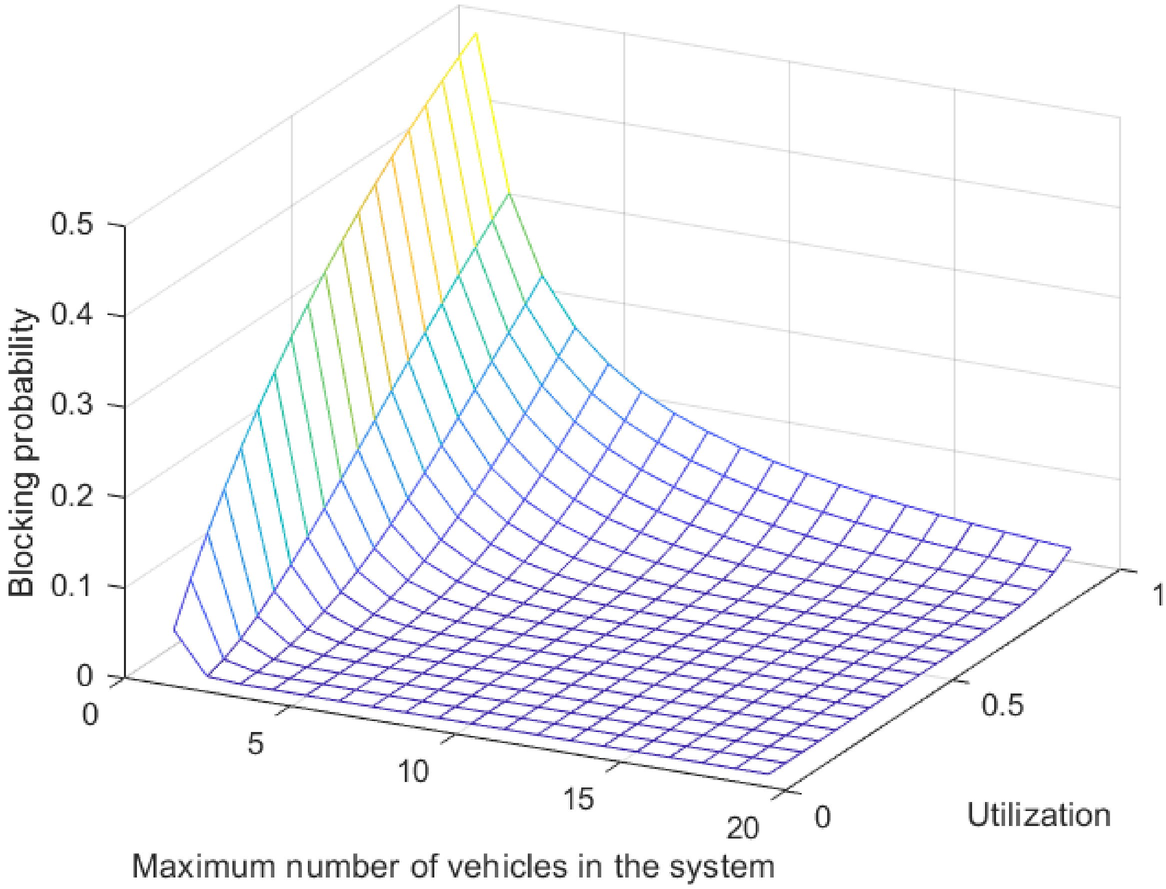

Fig. 3.7. Dependency of the blocking probability with respect to utilization and system capacity for M/M/1/c wireless channel

CHAPTER 4

MODELING AND SIMULATING TOOLS FOR VEHICULAR NETWORKING

4.1. Comparison of Tools for VANET Simulating

Road traffic management is one of the big problems in many cities of the world today that needs to be taken into account more. Lack of suitable technologies to support the measures; for the exchange of traffic information leading to an increased risk of road accidents. However, the financial consequences of these road accidents increase over time.

In this case, the driver or road user must have the ability to anticipate and react to hazards. Wireless communication between vehicles will help improve road safety by exchanging warning messages frequently. Consequently, the use of ad hoc mobile networks (MANET) makes it possible to achieve wide dissemination of wireless communications. Ad Hoc Vehicle Networks (VANETs) have emerged as a subset of MANETs and considered one of the most difficult classes in the area of wireless networks. There was therefore an urgent need to improve the current transport system with regard to road safety and the efficiency of the system to adapt to the growth of vehicles in the near future. For this, Intelligent Transportation Systems (ITS) is used to provide assistance for various traffic applications.

VANET simulation is applied to diverse and large-scale scenarios and should take into account the specific characteristics of the vehicle environment. Thus, testing and implementing vehicle networks in reality requires a lot of money and hard work. In addition to this, the evaluation of VANETs in such complex environments would lead to inaccurate results. Alternatively, simulation tools can be used to simulate complex scenarios with more precise results compared to a platform of real test benches [30].

Therefore, the choice of the VANET simulation tool is necessary because it may reflect the lack of compatibility with real traffic models resulting in disappointing results.

With difficulties in real experimentation with inter-vehicle communication (IVC) in VANETs, realistic simulation is considered a pillar of the validation and evaluation of the performance of IVC protocols. There are three main trends in simulation tools relevant to current VANET researches that have been observed:

network simulators, mobility simulators and VANET simulators.

4.1.1. Network Simulators

Based on this approach a network simulator is deployed to simulate the networking part of VANET, that is it is concerned with performing detailed packet-level simulation of source, destinations, data traffic transmission, reception, background load, route, links and channels. There are many Network simulators, but among these, the following are the most widely used: OMNeT++, OPNET, JiST/SWANS, NS2 and NS3. In addition, it is worth noting that each of the aforementioned list, have their own merits and shortcomings hence some can be suitable for a particular situation and will be useless in other situation. For example, in the research community, OMNeT++ is widely supported and considered as an excellent network simulator because of its embedded modern facilities ranging from excellent graphical interface to modular core design. It is also cross platform, hence it can run on LINUX/Unix and Windows operating systems, it is also embedded with higher range of network protocols and provides powerful support to accurately simulate MAC and physical layer. Furthermore, it can also be used for modeling of multiprocessors, distributed hardware systems and performance evaluation of complex software systems.

In comparism with other popular simulators, OMNET++ will be preferred. For instance, as against NS2, NS2 has complexity in implementing the mobility models within the framework. As a part of that, as it consumes a higher percentage of the CPU and the Memory when simulate hundreds of nodes in NS2. Hence it is not suitable for VANET since it has scalability issues.

As against N3 which is an upgrade to N2, which helps deals with the scalability issues found in N2, however, it is still in its development cycle and thus don’t the majority of network protocols and its physical layer needs some improvements.

As against JiST/SWANS, this simulator is now somewhat obsolete, since its last version doesn’t supports and meets modern VANET requirements and they have not been any upgrade.

The Table 4.1 shows the comparison among the various network simulators

Table 4.1 – Comparison of the Network Simulation Tools [30]

Criteria/ simulator	OMNeT++ VEINS	NS-2	GloMoSim	Jist/ SWANS	SNS
Software Portability	✓	✓	✓	✓	✓
Freeware	✓	✓	✓	✓	✓
Open source	✓	✓	✓	✓	✓
Large networks	✓	✓	✓	✓	✓
Scalability	High	Poor	High	High	High
Available Examples	✓	✓	✓	✓	✓
Continuous Development	✓	X	X	X	X
Console	✓	✓	✓	✓	✓
GUI	✓	✓	✓	✓	✓
Ease of setup	✓	✓	✓	✓	✓
Ease of use	✓	✓	✓	✓	✓
VANET					
802.11p	✓	✓	X	X	X
Obstacles	✓	X	X	X	X
Vehicular traffic flow model	✓	✓	X	X	X

4.1.2. Mobility Simulators

Based on this approach, aside the network simulator, the other core part that makes a VANET simulation possible and accurate is the Mobility simulator, which reflects, as close as possible, and the real behavior of vehicular traffic. In order to develop realistic simulators, researchers and companies try to refine some models.

An example of these realistic simulators is PARAMICS, TRANSIM, MOVE, VISSIM, and CORSIM with each having their own unique characteristics and functionality [30].

Firstly, PARAMICS is considered to be a professional parallel microscopic traffic simulator. It could be used to simulate work zone, urban area, highways and intersections. It consists of a combination of micro-simulation software in which it is considered to be highly performance tools.

TRANSIM was developed based on traces which help in providing the movement of vehicles through urban grid, however, this particular simulator has limitations when deployment, due to the fact that it has compatibility issues not being able to work with network simulators.

MOVE is used for VANET simulation to produce realistic mobility models in rapid manner. It represents an interface with real world databases such as Google Earth and TIGER. Its output is a trace file which is compatible with many network simulators such as Qualnet (Qualnet Network Simulator) and NS2. The results of MOVE are more promising than the ones obtained from Random Waypoint model

VISSIM is a microscopic simulator proposed by PTV America which used as a commercial tool. It is based on a time step and behavior based micro simulation model. It is developed to support multithreading making the simulation performance more efficient coupled with its own graphical user interface and its own component programming interface(COM) allowing users to manipulate the simulator with whatever language there are suitable with (be it C++, python etc). Besides that, it could be used to support 3D animations and 3D modeling.

Lastly, CORSIM is regarded as a perfect tool for analyzing traffic operations. It evaluates or measures new technologies regarding ITS. It is a microscopic traffic simulation software package which used to simulate surface roads and highways. CORSIM is used to simulate various traffic conditions and geometry conditions which could be complicated. Its output is a Measure of Effectiveness (MOE) file. CORSIM is an effective tool because it allows achieving high level of precision in vehicle ad hoc networks.

4.1.3. VANET Simulators

Based on this approach, in order for there to be a successful modeling and simulation, both the network and traffic/mobility simulators must be combined with the network part taking care of keeping the simulator up to date periodically and on time since any latency in the arrival time of messages may lead to an accident. While the traffic / mobility section is responsible for monitoring the movement of nodes in the network. For example, in real world, vehicles react to their environment when they receive alarm messages to clear access, decrease speed, maintain a larger distance with a vehicle in front of or necessity to change itinerary. Coupled simulators are more recommended in such situations. They model both the impact of mobility and network simulators on each other. Thus, while the mobility simulator provides macroscopic and microscopic information about roads and vehicles, the network simulator controls the road traffic and allows changes on it with respect to exchanged messages. Hence both of the simulators can't be mutually exclusive, when one wants to obtain a near perfect simulation result.

Below are few examples of bidirectional coupled simulators:

- GrooveNet was developed by The Carnegie Mellon University GrooveNet is implemented in C++ and Qt graphics cross-platform library in Linux it is embedded with a powerful graphical interface and uses real maps extracted from the TIGER database. It is an integrated simulator that supports multiple models that characterize communication, travel and traffic control. Alas, it has the ability to incorporate real-world traffic-related entities into simulation study, which is achieved by simulating V2V communication within a real street map-based topography. It has the capability to simulate thousands of vehicles and add different new models with regard to applications, networking, security and vehicles interaction. As a part of that, GrooveNet provides support to multiple network interfaces which are events triggered and GPS from the vehicle's onboard computer. The architecture of GrooveNet covers trip, mobility and message broadcast models over different kind of physical and link layer communication.

Despite all its essential characteristics, it does have some inherent drawbacks such as; the current limitations are that map database does not indicate one-way streets and the altitude of the street, hence lacking proper documentation.

- Realistic Joint Traffic and Network Simulator for VANETs (TraNS): This is an open source project, developed in school of computer and communication sciences at EPFL, Switzerland. Traffic and network simulation environment (TraNs) is a simulation environment that is capable of integrating both a network simulator and mobility generator in order to build a realistic vehicular ad-hoc network simulator. TraNs integrate between SUMO as mobility generator tool, and NS-2 as network simulator, it provides feedback between both vehicle behavior and mobility model. TraNs is implemented in Java and C++ languages, and it can work under

Linux and Windows platforms. TraNs can work in two modes: network centric mode and application centric mode. In network centric mode there is no feedback between the mobility generator SUMO and the network simulator NS-2, the mobility traces transferred from the mobility generator to the network simulator through parser with no feedback from the network simulator, the parser converts the traces from SUMO into a suitable format to be transferred to NS-2 through this parser.

In application centric mode, this is dedicated to applications that influence vehicles behavior during the traffic simulation runtime such as emergency alerts and collision avoidance applications. In this mode there is feedback between SUMO and NS-2 through an interface called TraCI, which handles the multi dimension communication between SUMO and NS-2, hence in this mode, both mobility generator and network simulator should operate simultaneously. Simulation supports by the vehicular technology through IEEE802.11p protocols stack and allows automated road networks generation from TIGER and Shape file maps as well as automated random vehicle routes generation. In application-centric mode, mobility traces are not generated prior to network simulation, rather both simulators run simultaneously. This coupled simulation is achieved by Traffic Control Interface (TraCI). To control vehicle mobility, the TraCI interface uses the atomic mobility commands, such as stop, change lane and change of speed.

- National Chiao Tung University network simulator (NCTUns) is an integrated framework for vehicular ad-hoc networks that combine between network simulator and mobility generator to build up a simulator that could be used in VANET networks. This integration provides a fast feedback loop between the two modules. Furthermore, it supports multi-core processors and parallel programming. Unlike TraNs, it combines network simulator and mobility generator in one module by extending network simulator to include the capabilities of mobility generators and road network simulations. NCTUns is a C++ based simulator that runs on Linux Fedora platform. Its architecture is composed of four major parts: the graphical user interface (GUI), simulation engine (SE), car agent (CA), and signal agent (SA). NCTUns has a powerful GUI that allows the user to generate the configuration files that should be provided in the simulation of the network, this GUI include five main functions: road network construction, car profile setting, vehicle deployment, vehicle movement setting, and network topology setting. NCTUns supports protocols for both wired and wireless IP networks including Ethernet-based fixed Internet, IEEE 802.11b/e wireless LANs, EEE 802.16d/e WiMAX wireless networks, DVBRCS satellite networks, multi-interface mobile nodes for heterogeneous wireless networks and IEEE 802.11p/1609WAVE wireless vehicular networks standards. It can simulate maximum number of 4096 nodes, but it has a major drawback that it runs on Linux Fedora platform, this poses great problem for many researchers and limit the usage of the simulator.

- VEINS: Vehicles in Network Simulation is a cross plat-formed open source simulation framework that is very robust and highly scalable in addition, its simulation results are not heavily dependent on the mobility model that was used. Veins framework was developed under MiXiM framework with the purpose of simulating wireless networks with providing detailed models of wireless networks, mobility, connectivity and MAC layer protocols of the network simulator OMNeT++.

It is an integrated framework that integrate between an event based network simulator (OMNET++) and mobility generator SUMO (for road traffic simulation models which can import realistic mobility traces from real world experimentation based on real maps data bases such as TIGER and OpenStreetMap, including buildings, sign spots and lane counts). It connects between the two simulators though a TCP socket, where the communication protocol of this socket is standardized as Traffic control interface (TraCI). This communication allows bidirectional coupled simulation between SUMO and OMNET++, where the movement of vehicles in SUMO is directly reflected as movement of the nodes in the network simulator OMNeT++. VEINS have the ability to provide online re-configuration and re-routing of vehicles in response to network simulator. It comprises detailed models of IEEE 802.11p and IEEE 1609.4 DSRC/WAVE protocols stack, with multi-channel operation, QoS channel access control, noise effects, interference effects and many propagation models for shadowing effects produced by buildings and vehicles.

4.2. Using of the Specific Tool

Based on the approach above for tackling simulation as outlined above, its left the pick out the near perfect simulator which encompasses both the network portion and the traffic/mobility portion in order to achieve the desired aim. In regards to the network part, the OMNeT++ and NS2 are considered to be the most popular and efficient network simulators which meet the required needs and the recommended software in modeling the wireless networks. As a part of that, OMNeT++, NS-3 and JiST are efficient in simulating large scale networks [30]. Furthermore, when the traffic/mobility simulator is considered, care must be taken due to the fact that most mobility simulators are good when modeling small scale instances, but when applied to real life scenarios, a lot of inadequacies will be experienced, hence, in order to realistically simulate VANETs, a bidirectional coupled simulation of trusted road traffic and network traffic must be used. In fact, a simple movement trace from a real world experiment suffices in many situations. But this approach may not be the best in other situations related to information and safety scenarios where the vehicles must react quickly to the received messages including for example: speed adaption or making decisions on route changes. To this end, a feedback loop is necessary. Due to this connection, the traffic simulator has the ability to react on event messages sent by the network simulator.

When one compares this approach to those that rely on trace data, its only shortfall is in the situation is that results of the traffic simulation cannot be reused in the format of trace file and vehicles behavior could be influenced by the network communication and, therefore, has to be calculated on the fly in a real-time manner.

In recent years, there have studies carried out to select the most suitable VANET simulation tool. For example, MOVE, a simulation tool is proposed to successfully integrate NS2 and SUMO. Another study was conducted to introduce TraNS in order to jointly connect NS2 and SUMO. Besides that, STRAW (Street Random Waypoint) mobility model was proposed in which real map data and street information are used to extract mobility traces. Another example is the NCTUns and GrooveNet simulation environments. In both cases their embedded road traffic and network simulation are difficult to be tested and validated since they were built independently, therefore their results are difficult to use when it is compared with proven reference point or standards of simulation frameworks.

Finally, VEINS which incorporates LTE frameworks in it's working methodology so as to cover the shortfall (simulating heterogeneous vehicular networks, especially regarding support of LTE networks). a standalone Veins have.

In conclusion, Veins framework is chosen as a recommended VANET Simulator, which coupled SUMO with OMNeT++.

The table bellows shows the various comparison and one will see why VEINS has an upper hand above the rest of the simulation technique.

Table 4.2 – Comparison of the analyzed VANET Simulation Tools [30]

Criteria / simulator	Groove Net	TraNS	NCTUns	VEINS
Portability	X	X	X	✓
Freeware	✓	✓	X	✓
Open source	✓	✓	X	✓
Language	C++	JavaC++	C++	C++
Documentation	X	✓	✓	✓
Available examples	X	✓	X	✓
Continuous development	X	X	✓	✓
Console	X	X	X	✓
GUI	✓	✓	✓	✓
Ease of setup	Moderate	Moderate	Hard	Easy
Ease of use	Moderate	Moderate	Moderate	Easy
Wireless Technology				
VANETs	✓	✓	✓	✓
MANETs	X	X	✓	✓(OMNET++)
Sensors	X	X	✓	✓(OMNET++)
LTE	X	X	X	✓
Platooning	X	X	X	✓
Hybrid	✓	X	✓	✓
Realistic propagation models	✓	✓	✓	✓
Scalability	✓	✓	✓	✓

4.3. Examples of using VANET simulators

Two major applications were used in our researchers in VANETS simulation. For the implementation of the applications, it is necessary to choose VANET simulation and to analyze the functionalities and capacities that they provide to develop, simulate and test. The simulators had to be able to simulate VANET as well as control the application to imitate the behavior of communication between several cars on road traffic. Vehicles in Networks Simulation (VEINS) were chosen because they offer interoperability between SUMO and OMNET++ with all the required functionalities. The features provided and more details on the components that make up VEINS which will be explained in more details.

4.3.1. VEINS

VEINS is the result of the "VEINS research project" [32], developed by Christoph Sommer, Dr. Falko Dressler and David Eckhoff in the Department of Computer Networks and Communication Systems, University of Erlangen, Germany. Their objective was to realistically simulate Inter-Vehicle Communications (IVC). Their realization on the bidirectional coupling [34] between traffic and network simulate the effects of VANET application on vehicle mobility.

Thus, the simulation combining a dedicated network simulator, OMNET ++ and a dedicated Traffic Simulator, Simulation of Urban Mobility (SUMO) were implemented. Traffic Control Interface (TraCI) is used to link the two simulators, making this interconnection possible. This allows the network simulation to trigger the traffic simulation and vice versa. Here are some important features of VEINS:

- It is Open source software; hence it can be extended and scaled up where necessary;
- Builds on vehicle mobility;
- It uses WAVE network layer models IEEE 802.11p and IEEE 1609.4
- Simulations on a single workstation or extended to a cluster of computers are possible.
- Obstacle model which takes into account the shadow effects caused by buildings.

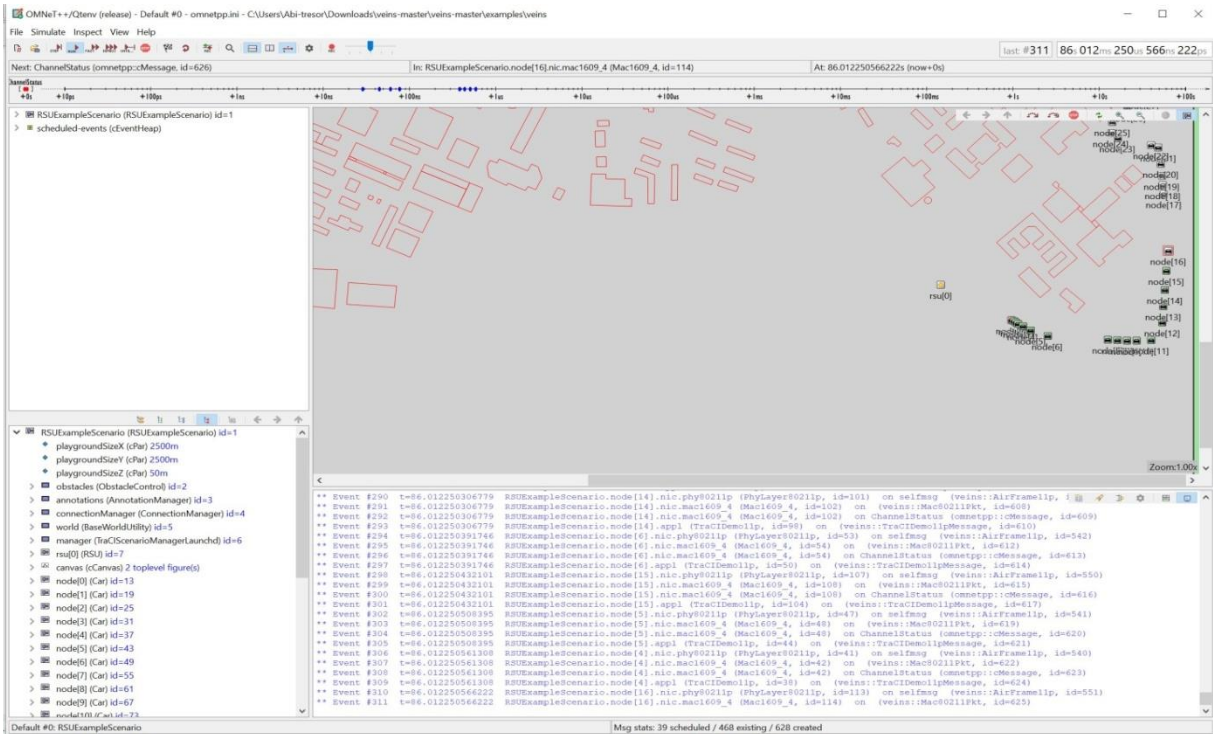

Fig. 4.1. Illustration of Node in VEINS

Figure 4.1 shows the numbers of nodes that will be connected. These nodes will receive information from the source node which will be transmitted to all nodes.

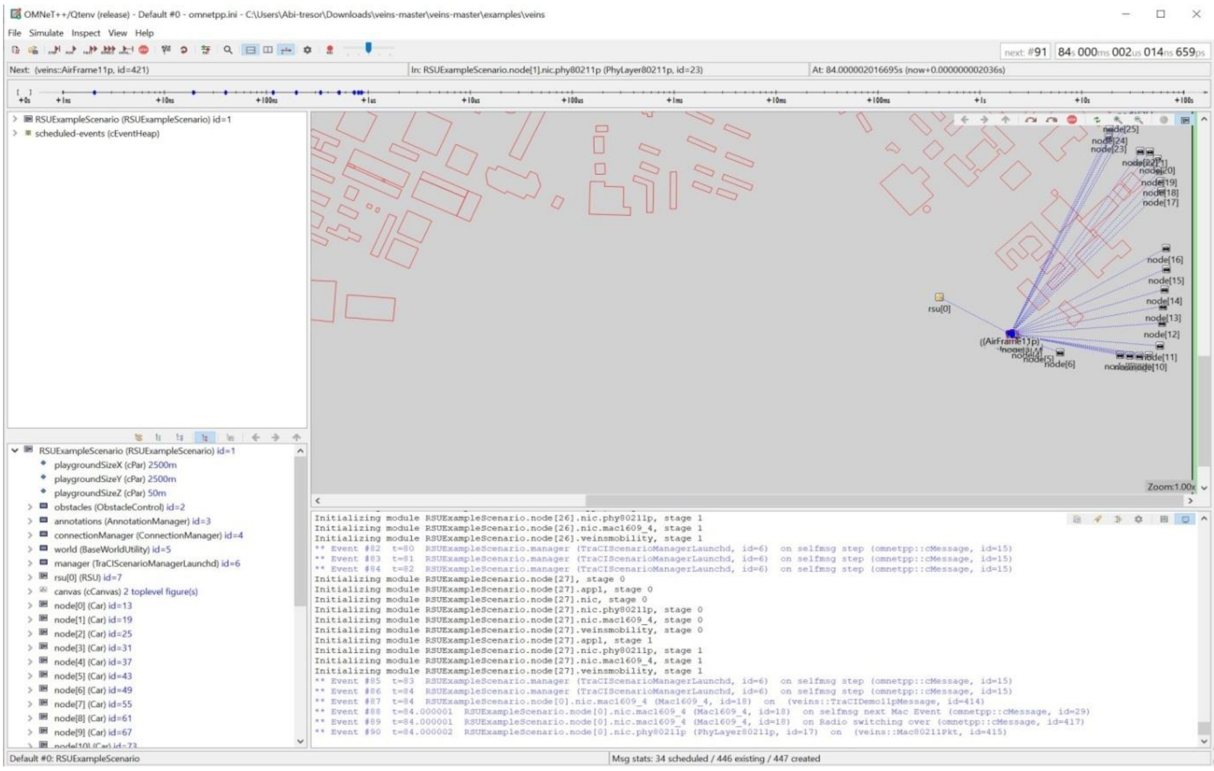

Fig. 4.2. Illustration of the creation of routes between nodes in VEINS

The creation of routes allows the verification of the possibility of being able to transmit information from the source to the destination. This figure 4.2 shows the possibility of seeing the source create a routing to facilitate the interconnection between the nodes on OMNET ++ using a SUMO data.

4.3.2 Simulation of Urban Mobility (SUMO)

SUMO is a fast and portable microscopic traffic simulator developed by the Institute of Transport Systems of the German Aerospace Center using the C ++ standard [31]. It is open source, under GPL license. It models the mobility of vehicles microscopically, which means that each vehicle in the simulation is explicitly modeled and has its own route. Other vehicle characteristics such as acceleration, deceleration and length vary depending on the type of vehicle. Here are the features provided by SUMO:

- It is Open source;
- Discrete time vehicle movement - where the position of each vehicle in the scenario is updated at each time step.
- Several types of vehicles such as cars, trucks, vans, each with unique characteristics such as acceleration, deceleration and top speed, are associated with them.
- Multi-lane streets with lane change
- Vehicles follow the priority rules;
- Open GL graphical user interface that provides a graphical view of the current simulation with features such as locating tracking vehicles during execution.
- Interoperability with other applications during execution.

Scenarios under OpenStreetMaps [33] can be imported. OpenStreetMaps is the online map, which allows users to update and maintain maps. In addition, it allows you to export map data in several formats. SUMO supports import as:

- Road networks;
- Speed limits
- The number of routes;
- Traffic lights;
- Turn restrictions.

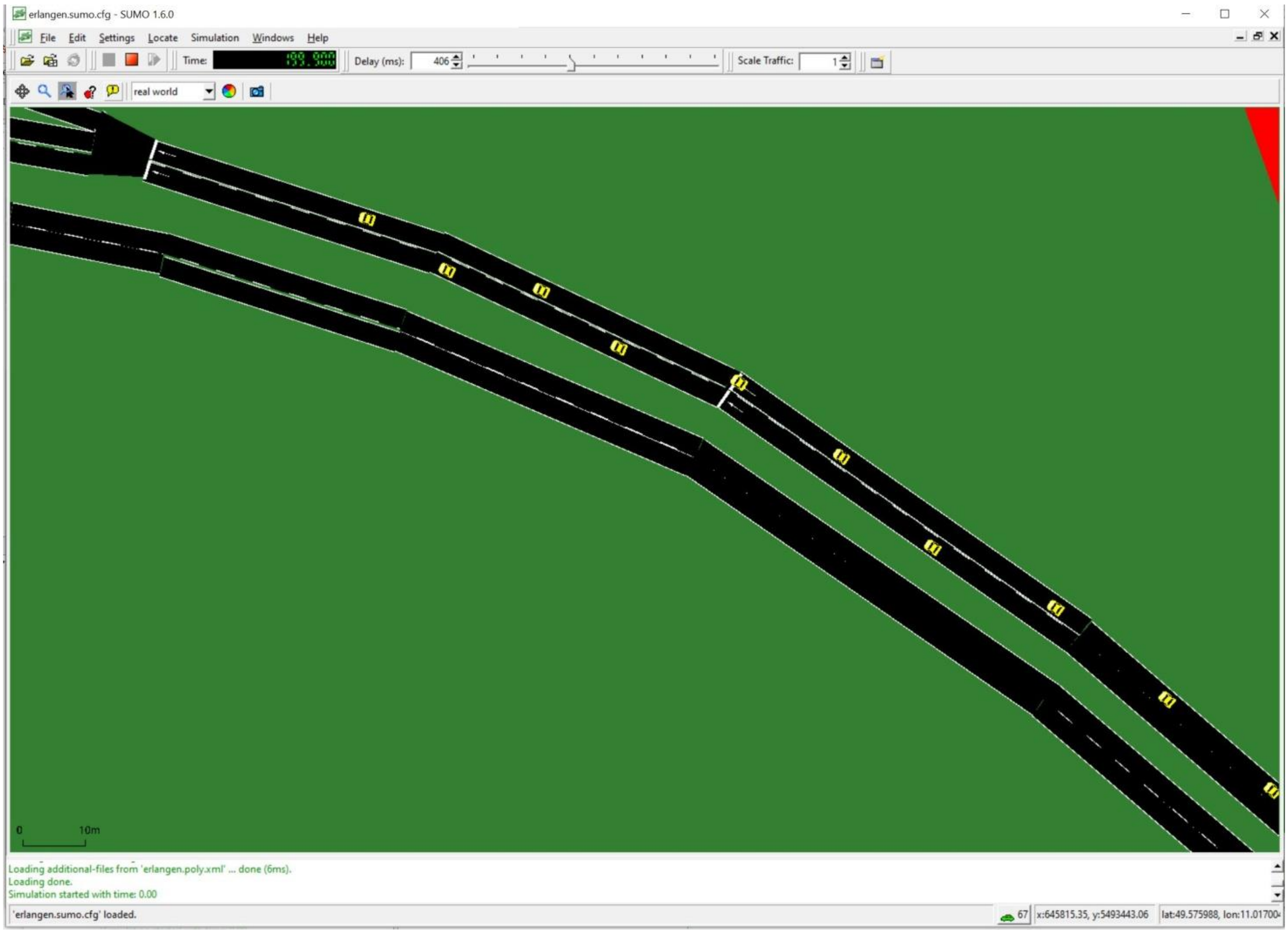

Fig. 4.3. Illustration of the traffic in SUMO

All configurations and data entries such as route and network definitions are accepted in XML files. In addition, it provides a suite of other support applications that help import / generate the network and traffic for simulation. The following applications are of interest in our work:

- Sumo-gui: provides a graphical user interface to the simulation, allowing the user to observe the simulation in action, it can also be used to display the properties relating to the vehicles and road networks to be modified. As a functionality Sumo-gui allowing the user to follow a particular vehicle also available. Graphically displays information about the different components that make up the scenario.
- Netconvert: allows the user to import road networks from different carpets and generate a road network conforming to the SUMO format. This tool supports i map import from OpenStreetMaps [33]
- Polyconvert: allows the user to import other components such as points of interest and buildings from OpenStreetMaps.

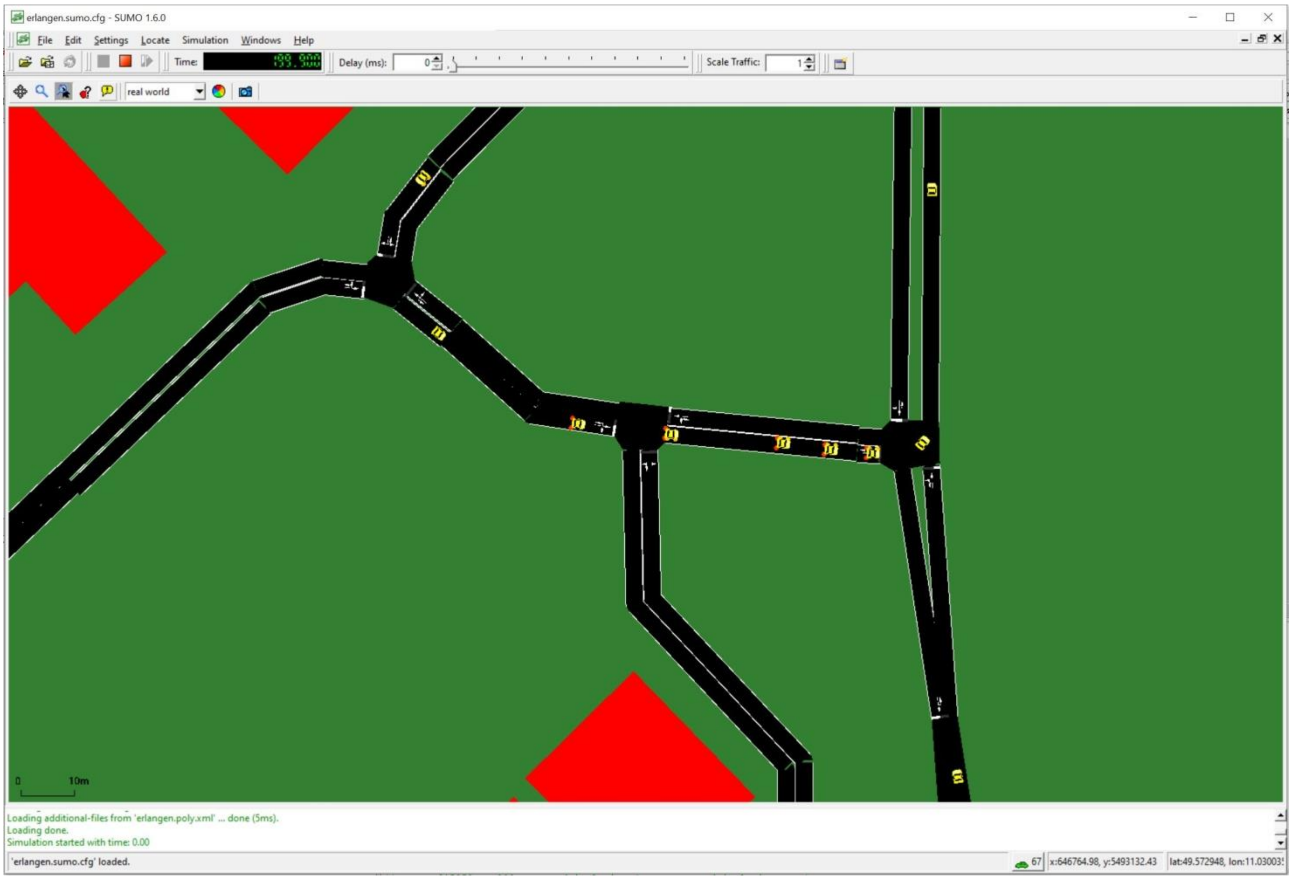

Fig. 4.4. Illustration of a typical road network in SUMO

The figure has been explicitly labeled to explain it in detail. An "edge" in SUMO refers to the road connecting and intersections. Each edge of the network is associated with a unique identifier. Vehicle routes in SUMO are defined as a chain which is a collection of Edge IDs. Here, each edge has only one lane.

4.3.3. OMNET ++

OMNET ++ is a C ++ based object-oriented discrete event network simulation framework with generic architecture and can be used to simulate the following:

- Wired and wireless communication networks;
- Protocol modeling;
- Multiprocessors and distributed hardware systems.

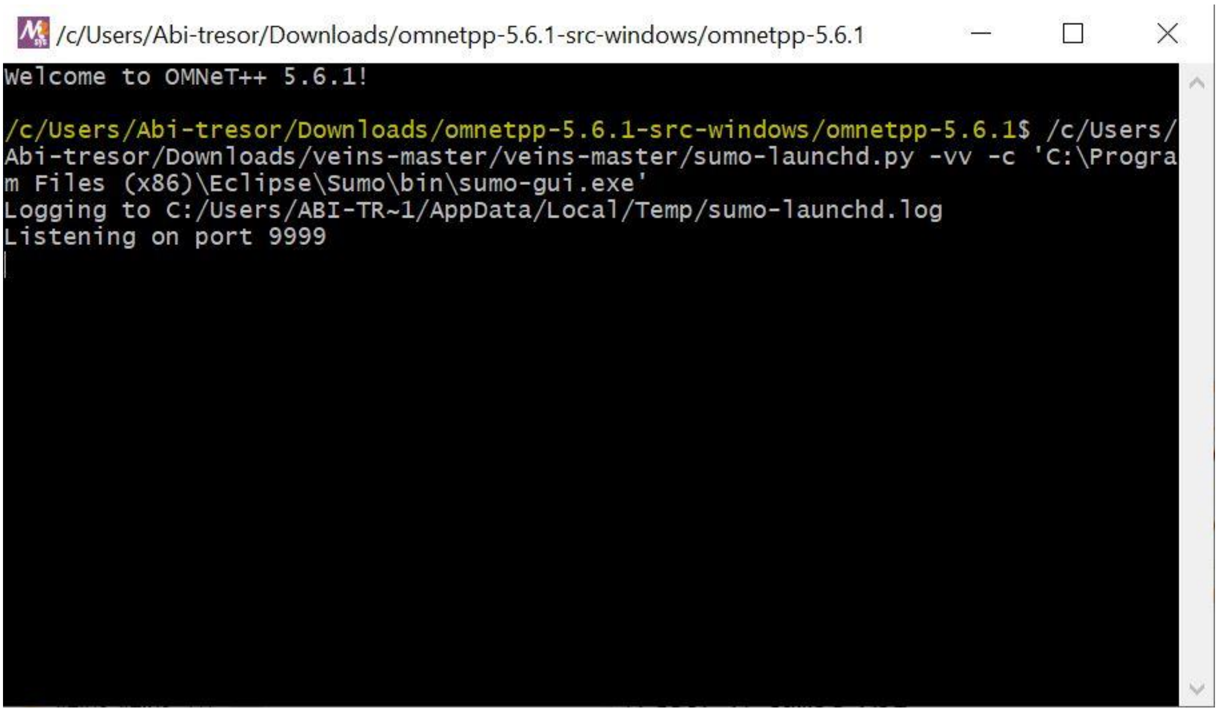

Fig. 4.5. Illustration of the OMNET++

OMNET ++ was developed at the Technical University of Budapest, Department of Telecommunications and is available free for academic use. It provides the infrastructure and tools for writing simulations and is not a ready-made network simulator. A simulation model in OMNET ++ consists of a well-structured arrangement of reusable "modules" which are connected to each other and can pass messages between them. The smallest building block of a simulation model is called a "simple module". Simple modules are written in C ++ and can be made to behave as you wish. The simple modules are grouped into compound modules. Simple and compound modules communicate by sending messages to each other's via connections that extend between modules or other compound modules.

A composite module forming a network interface card (NIC) in OMNeT ++ is illustrated as Simple modules that can be used to model algorithms using C ++ wherever necessary.

OMNET ++ provides the tools necessary to define the structure of the entire system by providing the following functionality:

- Hierarchically nested modules.
- Inter-module communication using messages via channels.
- Flexible module settings.
- NED (Network Description Language) used to define the network topology.
- Graphic and text editing of NED files.

An OMNET ++ simulation model consists of the following elements:

- .ned files coded using the network description language (NED) which describes the position and connections between the different modules. In addition, the values of the parameters relating to simple modules can be defined here.
- .msg files which contain the message definitions defining various types of messages with data fields which are then translated by OMNeT ++ into C ++ classes.
- C ++ source files for simple modules.
- Simulation kernel used to manage the simulation and the library of simulation classes, all in C ++.
- The .ini file is used to explicitly specify modifiable parameters for all modules involved at any level of the hierarchy.

Configuration of the simulation

The simulation configuration here consisted in first modeling the mobility of the vehicles using SUMO as desired, then in configuring the application in OMNeT ++ before running the simulation.

4.3.4. SUMO Configuration

This part is consisting to describe the steps to prepare a SUMO traffic simulation to use to simulate VANET.

4.3.4.1. Export the map from OpenStreetMap

The roadmap on which VANETs is to be simulated is imported from openstreetmap.org by manually selecting the desired area and using the 'export as .osm' option to download a map.osm file, which is an xml file with a schema defined by openstreetmap.

4.3.4.2. Java Open Street Map Editor JOSM

Java Open Street Map Editor is a tool used to manually edit .osm files. The imported map.osm also contains other information such as railway networks, electricity distribution lines, rivers, points of interest, walkways, and cycle paths.

Java Open Street Map Editor is used to modify the map. Unnecessary nodes are removed and if necessary, from no New nodes are added to create new routes and also to create buildings in the scenario. When a node is deleted using JOSM, it is not actually deleted from the .osm file, but instead an "action" attribute with a "deleted" value is added to that node. All of these nodes are removed using an open source command line xml tool called XML Starlet using the following commands.

The resulting .osm file contains only the road network and the buildings required for the simulation scenario.

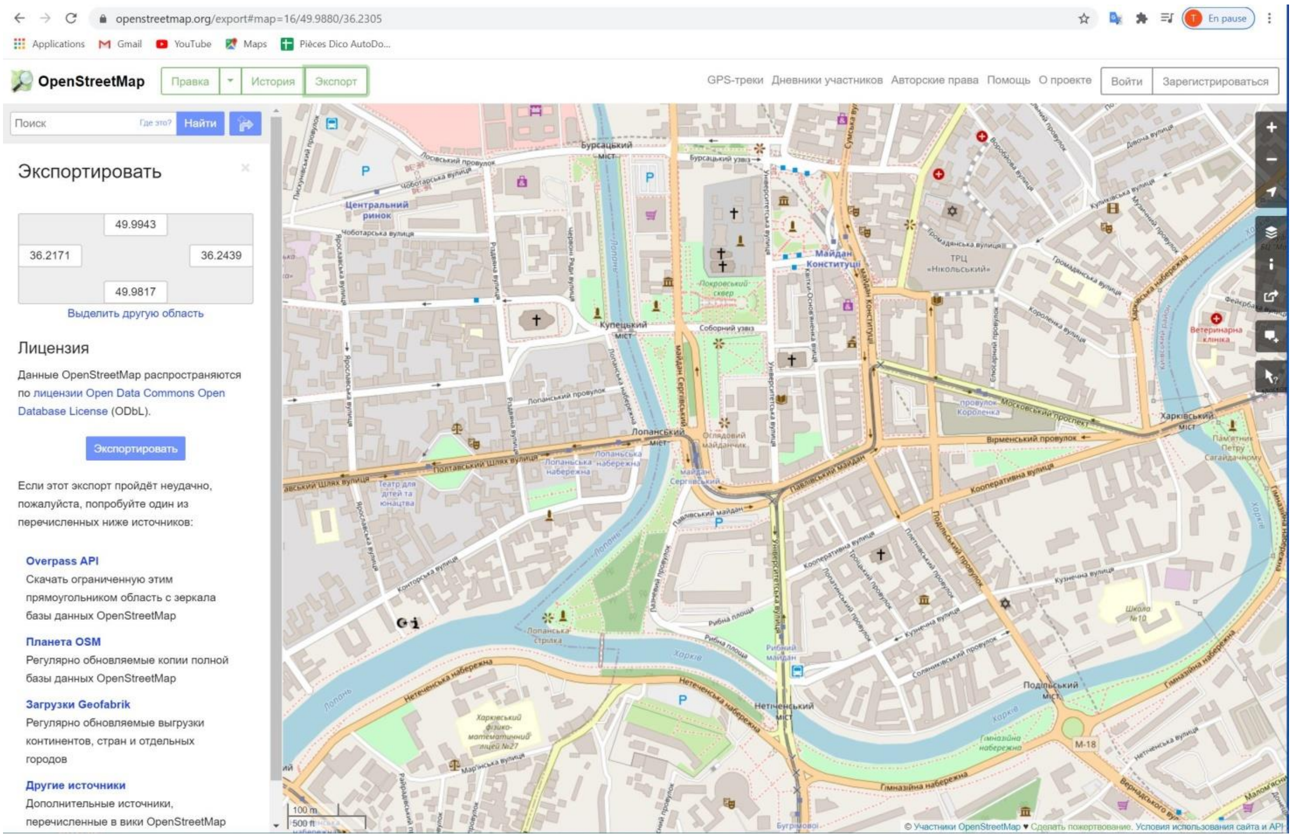

Fig. 4.6. Illustration of Export the map from OpenStreetMap

4.3.4.3. Sumo network using NETCONVERT

SUMO provides a command line application called Netconvert which is used to import and generate road networks usable by SUMO and other tools present in the SUMO package. In addition, it projects the geographic coordinates (Latitude and Longitude) to the x-y coordinates and also applies the offset required to translate the axes in the first quadrant. The following command line arguments are passed to obtain the desired road network.

```
netconvert--osm -files map.osm -o map.net.xml
```

4.3.4.4. Vehicle routes using RandomTrips

The map.net.xml file resulting from the previous step is now used to generate a Trips file using the RandomTrips python script provided as part of the SUMO package. This script generated a set of random route definitions demand for routes between two points on the road network, which are then used in the creation of vehicle routes. The following command line command is used

```
Python PATH \ r a n d o m T r i p s. py -n map.net.xml -r
map.rou.xml -e -l
```

The map.net.xml is used to generate vehicle routes using the Duarouter.exe application which is again part of the SUMO package. The following command is used. The Obstacles module in OMNET ++ which is responsible for modeling obstacles requires an xml file with a special schema definition used to define the obstacles in the scenario. Polyconvert.exe, an application part of the SUMO package is used to extract the polygons buildings from the .osm file using the following command.

```
polyconvert --osm -files map.osm --net -file map.net.xml -type
-file osmpolyconvert.type.xml -o map.poly.xml
```

The file shares a diagram similar to the .poly.xml file and can be used directly, but only after inverting the axes. This is necessary because the sumo coordinate axes are those of the first quadrant, while those of OMNET are those of the fourth quadrant. Each sumo scenario is associated with a .sumo.cfg file which points to the corresponding .net.xml and .rou.xml files to be used, as well as the beginning.

The simulation in OMNET ++ can be controlled by providing the modifiable parameters required by module used in the simulation using the .ini file corresponding to this simulation. The parameters used and their specific values are described below with examples of the .ini file.

```
/c/Users/Abi-tresor/Downloads/veins-master/veins-master/sumo-launchd.py -vv -c 'C: \Program Files (x86)\Eclipse\Sumo\bin\sumo-gui.exe'
```

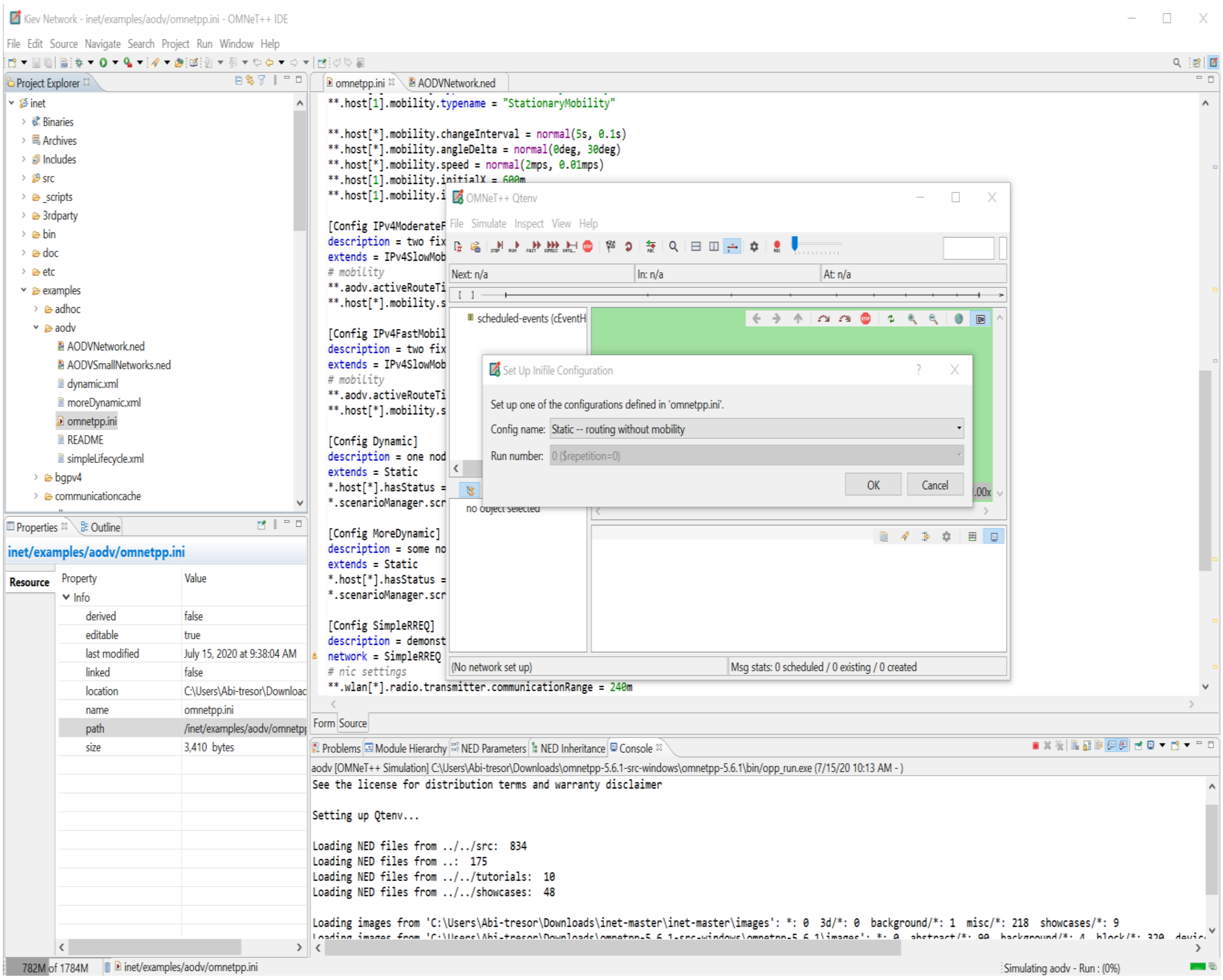

Fig. 4.7. Set up configuration omnetpp.ini

In this description OMNET ++ can be used in various problems domains and consist of modulate that communication with message passing:

- Modeling of wired and wireless communication network.
- Protocol modeling
- Modeling of queuing networks
- Modeling of multiprocessors and other distributed hardware systems
- Validating of hardware architectures
- Evaluating performance aspects of complex software systems.

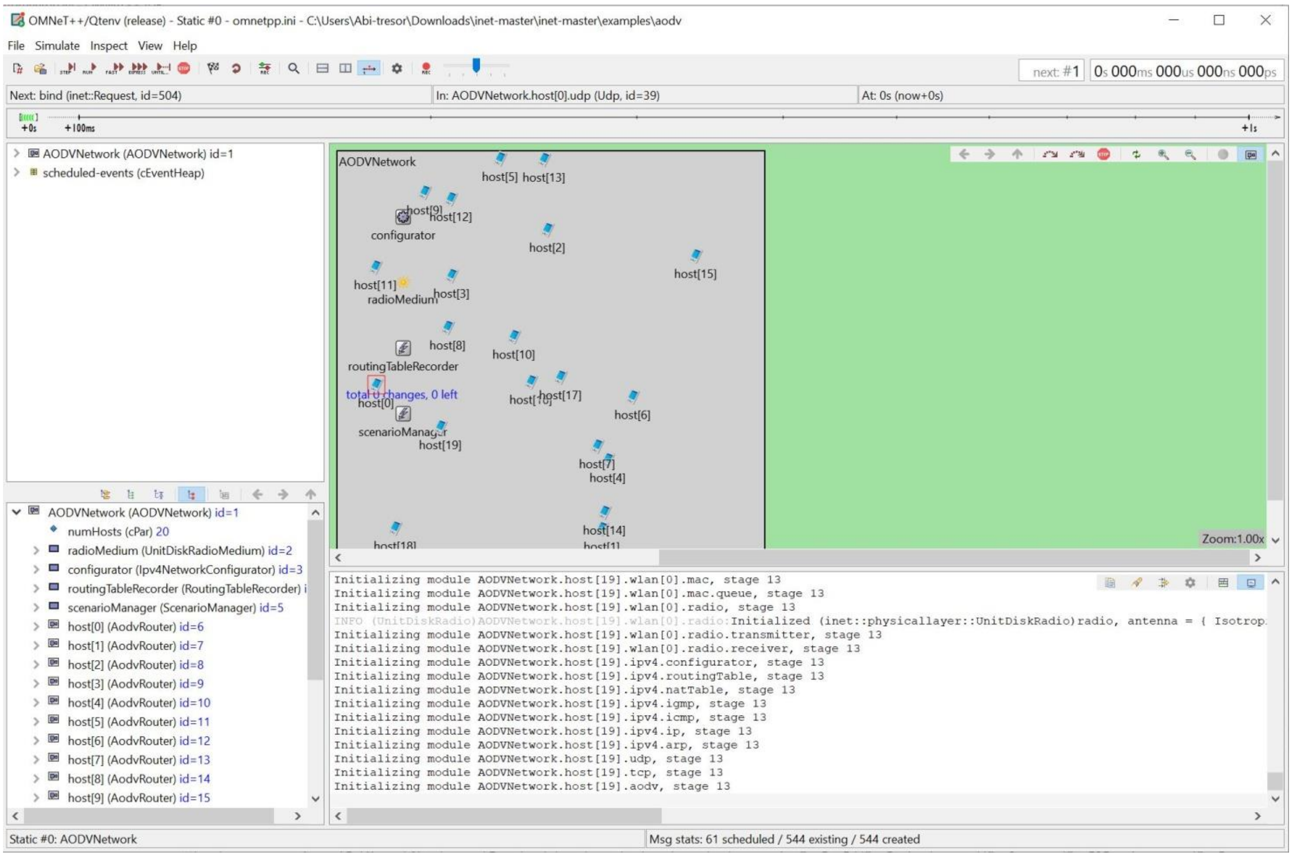

Fig. 4.8. Initializing of modules Hosts

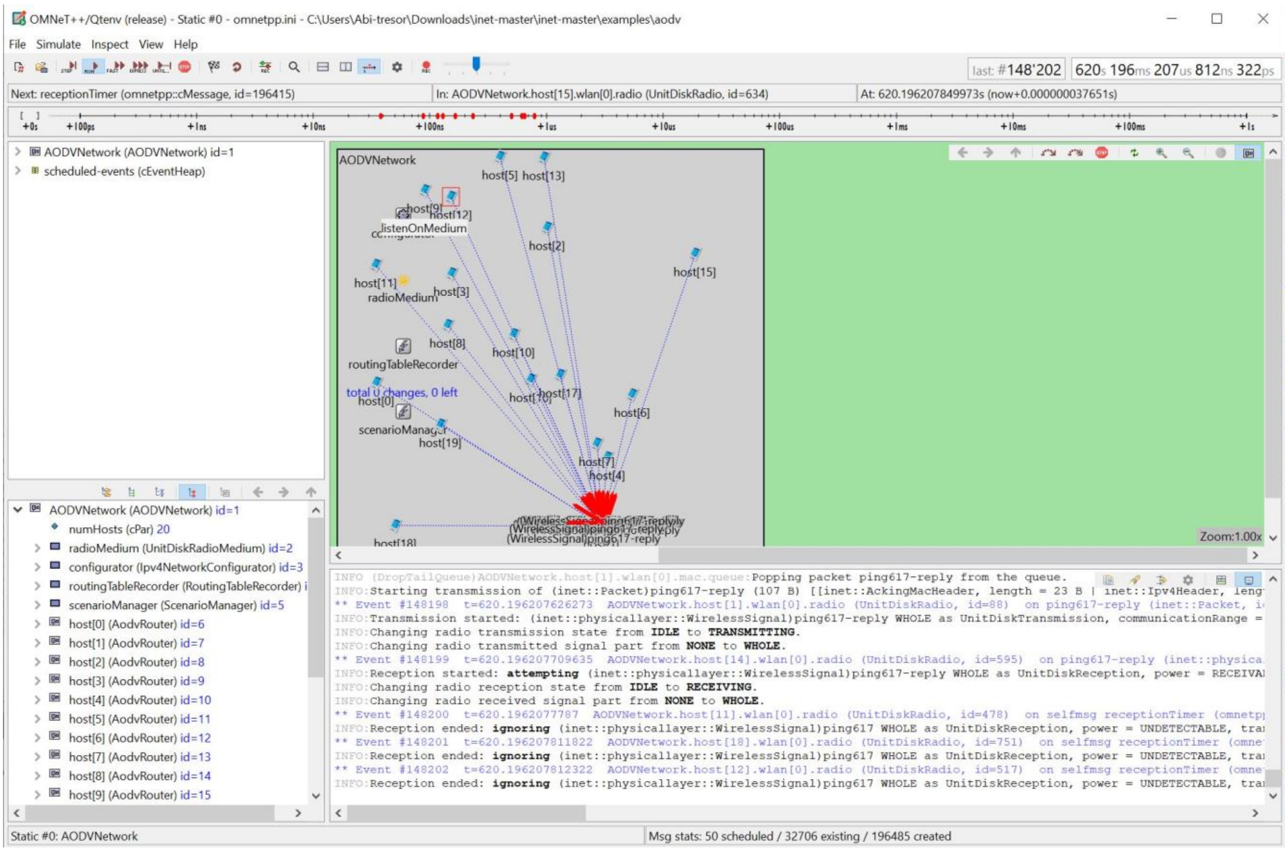

Fig. 4.9. Transmission of the message from the source to the Hosts

The initialization of each node makes it possible to be able to visualize the nodes that are ready to receive the message, which will be emitted by the source, this message after routing analysis, as well as refer the link between the source and the destination.

In the Fig. 4.9 when the transmission begins, the signal is loaded into the transmitting radio to be sent to the receiving Disk unit. The size of the playing field is fixed at the maximum size of the map to prevent vehicles from going out of bounds. The mobility of the vehicle in the any directions is managed by the mobility model and therefore set to zero. But the position is defined on a constant value.

CONCLUSION

This thesis work, titled investigation of routing solutions in VANET, aims to analyze the improved efficiency in vehicular networking in relation to a particular routing model employed. The methodology applied is through simulation and analytical models and then a comparison is done of the various routing protocols, which will give an insight on which is best to apply or employ in a particular environment. Furthermore, the modeling and simulation results were obtained using the SUMO and ONMETT++ simulation tools.

The first chapter sheds light on the current trends and applications of telecommunications networks based on VANET technology. Introducing the concept of SDN and how it can be employed in making intelligent transport system (ITS) more efficient. How SDN can be combined with another concept called fog computing to realize even better result than a standalone SDN. Here we will see that an SDN implementation in vehicular networks is made up of three logical layers: the forwarding layer, control layer, and the application layer. Lastly a novel concept was introduced. This concept is called ICN; its working aim is to change the focus of the current Internet architecture. The current architecture focuses on creating a conversation between two machines.

The second chapter then throws light on the various routing models and then comparatively analyzing the various routing algorithms and solutions in VANET. The chapter starts by giving a brief introduction into the concept of VANET, then goes to highlight the four different communications pattern used in VANET. Furthermore, the concept of routing protocols was introduced where the reader will realize that they are plethora of routing protocols and it has somewhat proved difficult if one wants to categorize them into groups. However, this work did separate them into two groups; proactive and reactive routing protocol based on their modus operandi. In addition, different factors (mostly environmental) were considered, to know which works best for a particular scenario. Finally, the chapter rounds up by making comparisons of the various routing protocol, stating in a table each of strong and weak points in a particular environment.

The third chapter discussed the stochastic modeling in VANET application, first off stating reasons why this model was used (traffic modeling using M/G/c/c queuing model) using the Ad hoc On-demand Distance Vector (AODV) routing protocol. Then numerical research and performance analysis were done using the steady-state distribution of a Markov chain model of M/M/1/c. lastly for the numerical research, the MATLAB environment was used.

The fourth chapter then dives into the modelling and simulating method deployed in this work. It first off acknowledges the fact that it is somewhat difficult to do a proper simulation due to fact that VANET simulation is applied to diverse and large-scale scenarios and should take into account the specific characteristics of the vehicle environment. Thus, testing and implementing vehicle networks in reality requires a lot of money and hard work. However, there are three main trends in simulation tools relevant to current VANET researches that have been observed: network simulators, mobility simulators and VANET simulators. It then goes further to explain each of them highlighting their various merits and demerits.

Finally, the chapter concludes by recommending specific tools for the VANET simulation called the Veins framework, which works by coupling SUMO with OMNET++ to achieve the results as shown in the work.

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