AN EFFICIENT CLUSTER-BASED SERVICE MODEL FOR VEHICULAR AD-HOC NETWORKS ON MOTORWAYS

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Summary:

Vehicular Ad-Hoc Networks (VANET) can, but not limited to provide users with useful traffic and environmental information services to improve travelling efficiency and road safety. The communications systems used in VANET include vehicle-to-vehicle communications (V2V) and vehicle-to-infrastructure communications (V2I). The transmission delay and the energy consumption cost for maintaining good-quality communications vary depending on the transmission distance and transmission power, especially on motorways where vehicles are moving at higher speeds. In addition, in modern transportation systems, electric vehicles are becoming more and more popular, which require a more efficient battery management, this also call for an efficient way of vehicular transmission.

In this project, a cluster-based two-way data service model to provide real-time data services for vehicles on motorways is designed. The design promotes efficient cooperation between V2V and V2I, or namely V2X, with the objective of improving both service and energy performance for vehicular networks with traffic in the same direction. Clustering is an effective way of applying V2X in VANET systems, where the cluster head will take the main responsibility of exchanging data with Road Side Units (RSU) and other cluster members. The model includes local service data collection, data aggregation, and service data downloading. We use SUMO and OMNET++ to simulate the traffic scenarios and the network communications. Two different models (V2X and V2I) are compared to evaluate the performance of the proposed model under different flow speeds. From the results, we conclude that the cluster-based service model outperforms the non-clustered model in terms of service successful ratio, network throughput and energy consumption.

Keywords: VANET, cluster, V2X, data service, energy efficienvy

To

Mr Liguo Shi & Dr Qiuyun Cao

MY LOVING PARENTS

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It was a very impressive year: going to Aston University alone and doing MSc by Research programme have brought me much valuable progress and precious memory. A lot of effort and hard work have been put into this MSc. Project and, I am very glad that I finally achieved some achievements here. I want to give my special thanks to Dr Xiao-hong Peng, who has been taking care of me during the whole period of study. Dr Peng is a very kind and hard-working scholar, I have learned a lot from him. He helped me find the target to focus on and motivated me to keep going. I am also very appreciated for the support of Prof. Guang-wei Bai, who has been encouraging me from the beginning to the end.

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LIST OF ABBREVIATIONS

AP	Access Point
BSM	Basic Safety Message
BSS	Basic Service Set
CCH	Control Channel
CDMA	Code Division Multiple Access
CH	Cluster Head
CHA	Cluster Head Announcement
CHM	Cluster Head Maintain
C-ITS	Cooperative Intelligent Transport Systems
CM	Cluster Members
CPU	Central Processing Unit
CSMA	Carrier Sense Multiple Access
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance

DSRC	Dedicated Short-Range Communications
ETC	Electronic Toll Collection
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FDMA	Frequency Division Multiple Access
FN	Free Node
GPS	Global Positioning System
GSM	Global System for Mobile Communications
GUI	Graphical User Interface
GW	Gateway
HD	Highest Degree Clustering
IEEE	Institute of Electrical and Electronics Engineers
ITS	Intelligent Transportation Systems
ITS	Intelligent Transportation Systems
KSI	Killed or Seriously Injured
LID	Lowest-Id Clustering
LIDAR	Adaptive Id Reassignment Algorithm
LTE	Long-Term Evolution
LTE-V	Long Term Evolution for Vehicles
MAC	Medium Access Control
MANET	Mobile Ad-Hoc Network
MobHiD	Mobility-Aware Highest Degree
MOBIC	Mobility Clustering
MOVE	Mobility Model Generator for Vanet
NAV	Network Allocation Vector
NS2	Network Simulator-2
OBU	On-Board Units
OMNET++	Objective Modular Network Testbed in C ++
OPNET	Optimised Network Engineering Tool
OSI	Open Systems Interconnection
PDA	Personal Digital Assistant
PHY	Physical Layer
QoS	Quality of Service
RF	Radio Frequency
RSU	Roadside Units
SAE	Society of Automotive Engineers
SCH	Service Channels

SDP	Service Data Packet
SUMO	Simulation of Urban Mobility
TCP/IP	Transmission Control Protocol / Internet Protocol
TDMA	Time Division Multiple Access
TraCI	Traffic Control Interface
V2I	Vehicle-To-Infrastructure Communications
V2V	Vehicle-To-Vehicle Communications
V2X	Vehicle-To-Wireless-Devices Communications
VADD	Vehicle-Assisted Data Delivery
VANET	Vehicular Ad-Hoc Network
VanetMobiSim	Vanet Mobility Simulation Environment
VIP	Vehicle Information Packet
WAVE	Wireless Access in Vehicular Environments
WCA	Weighted Clustering Algorithm
WLAN	Wireless Local Area Network
WWAN	Wireless Wide Area Network

1. Introduction

It has been over three hundred years since the first steam-powered vehicle was invented in 1672 [1], automobiles are now playing a more and more crucial role in the military, business and daily consumer life. From a point where it was a luxury for only a small group of people, it has become an affordable method of transportation everyone can utilise, vehicles are improving the quality of people's life. Travelling by vehicles has brought people closer to each other and made life more convenient and enjoyable. It will take only a few hours to finish the journey which previously would have cost days to finish by non-motorized travelling methods (e.g. by foot or bicycles). In the meantime, with the development of information technology, more attention on the combination of transportation and intelligent communications system has arisen.

Nowadays, with the rapidly increasing number of vehicles, traffic congestion, car accidents and an increase fuel consumption are among the main challenges in the development of smart cities for Intelligent Transportation Systems (ITS) and Cooperative Intelligent Transport Systems (C-ITS) [2]. To address these problems and ensure highway safety and travel efficiency, it is vital to make traffic information (e.g. speed and vehicle density) and environmental information (e.g. weather and road condition) timely available for highway users and network operators. Such information can be collected and disseminated through a well-designed and managed vehicular network supported by advanced sensing, positioning and communications technologies.

Vehicular communications and sensing technologies provide essential support for services across the VANET. The VANET is an extended version of the Mobile Ad-hoc Network (MANET) [3] and is intended for improving driving safety and efficiency through both vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications[4]. V2V and V2I can be operated cooperatively, or combined together as V2X, to deal with complex traffic environments and play a key role in ITS. The Dedicated Short-Range Communications (DSRC) technology provides effective communications for automotive use, which specifically refers to a suite of standards for Wireless Access in Vehicular Environments (WAVE) [5] and supports both V2V and V2I communications. Vehicles equipped with sensors and on-board units (OBU) can collect local traffic and environmental information and exchange for the related service data of other regions (place of interest) with roadside units (RSUs). An RSU acts as an interface between vehicles and the vehicular network to provide vehicles with the service data requested and pass on the collected data to other parts of the network. VANET has shown good behaviour in studies of recent years, it is exected to bring integral benefits to the autopilot when fully implemented in the future.

1.1 Project Motivation

The development of transport system contributes to more convenient travel, however, more complicated road networks and larger amounts of vehicles also lead to many traffic problems. The key issue of safety one vital aspect that need addressed. The reported road casualties in Great Britain: quarterly provisional estimates year ending September 2016 [6] has shown that a total of 25,160 people were killed or seriously injured (KSI casualties) in the year ending September 2016, up by 6 percent from the previous year. Car occupant KSI casualties increased the most, by 10 percent to 9,480, and pedestrian KSIs increased by 3 percent to 5,480 in the year ending September 2016. The other problem is traffic congestion, which caused by the growing number of vehicles and not properly designed traffic infrastructures. Congestion would seriously affect people's travelling time and experience, especially at the peak time.

The rapid development of vehicular communications technologies can assist drivers in travelling more safely and efficiently. When drivers are able to learn the road information in time, including traffic condition and environmental status (i.e. the users are available of the real-time traffic information about their interested areas), the traffic safety and travelling efficiency can be effectively improved. Meanwhile, more efficient routes can be designed based on the traffic and environmental information, helping drivers spend less time and fuel when traveling. The traffic (e.g. speed, vehicle density) and environmental (e.g. weather and road condition) information differs in different areas but remains largely unchanged within a shorter range of travelling distance. Therefore, enabling the exchange of different areas' information across vehicular networks is an effective solution for reducing road congestion and improving energy efficiency.

Usually, V2I involves longer end-to-end delay and higher transmission power than V2V, and this results in lower service efficiency and higher energy consumption. The high mobility of vehicles also leads to big challenges for V2I transmission as the communications between vehicles and RSUs can only last for a short time. In addition, electric vehicles are turning up to be a new trend, where the battery is a major consideration. The connected vehicles will keep overhearing the channels and exchanging information when they are on the move and this will cost a significant amount of energy for continuous data sensing, transmission and processing, especially for V2I because it needs to cover a much longer distance than V2V.

As the communication requirements increase sharply due to the rising number of vehicles, the high mobility of vehicles in addition to a large number of transmission terminals in an ad-hoc network presents a great challenge in terms of high likelihood of congestion in data delivery and exchange in this environment. The impact of channel quality and application requirements are proposed in [7] by S.A.A. Shah *et al.* while introducing a multi-metric method to control transmission power and enhance system reliability. Another work by S. Misra, P. V. Krishna, and V. Saritha also proposes a channel assignment mechanism to improve energy efficiency in VANET [8] by applying the Learning Automata algorithm to reduce re-transmission times. It is important that transmission efficiency, system reliability and energy consumption are taken into consideration altogether because the future vehicles will be fully electric and powered by batteries.

A more efficient model of two-way service data transmission is required to provide the users with real-time traffic information service and improve the efficiency of both the traffic information service and the transmission energy.

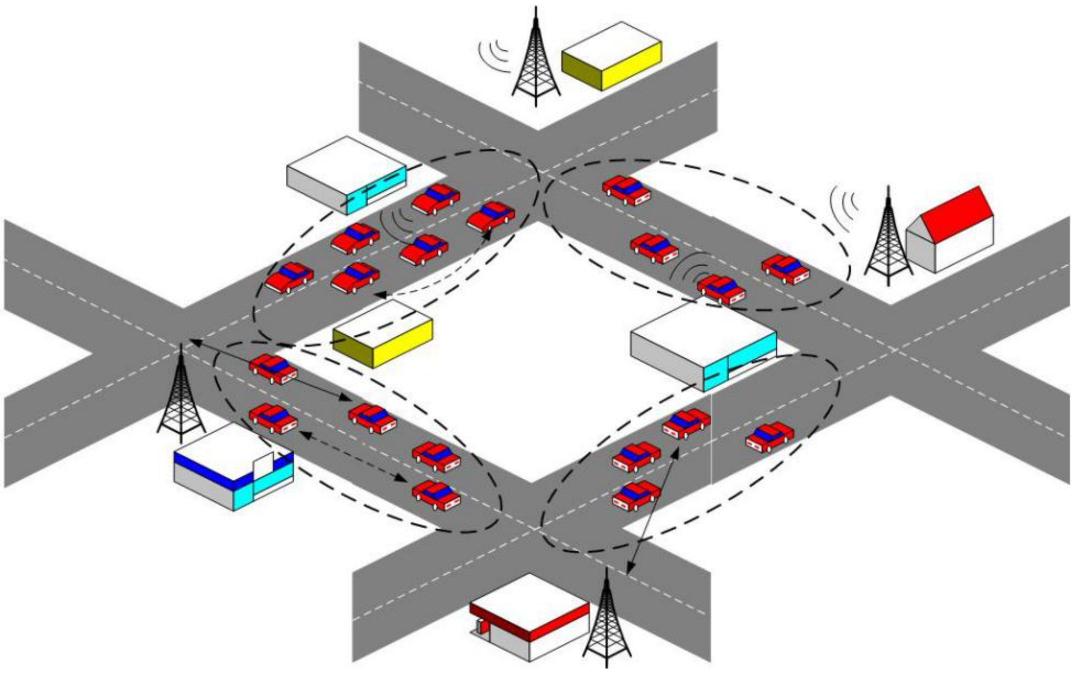


Figure 1.1 Clustering in VANETs

Applying clusters in VANETs is an effective way of improving the transmission efficiency. To form clusters in a VANET, vehicles are divided into small groups based on some rules as shown in Figure 1.1, where the cluster head can upload and download data on behave of other cluster members.

1.2 Research Focus

To address the challenges mentioned above, this project proposes a cluster-based service model. It enables effective V2X communications to significantly improve transmission and energy efficiencies by largely reducing V2I connections while guaranteeing the service quality. An optimized weighting metric is proposed in this paper incorporating the cluster head selection algorithm, in which vehicle position, mobility, connection and driver's behaviours are considered and combined together to affect the cluster head election. The V2X process in this work consists of V2I communications between cluster heads and RSUs as well as V2V communications between cluster heads and other cluster members. This model consists of both uploading local traffic/environmental data to the database by each vehicle and downloading required service data from RSUs. By analysing the performance of two different service models, we show the superiority of the clustered service model at both the service level and the energy level.

1.3 Layout

In this project, we build a cluster-based service model to provide vehicles information with low energy consumption and high service efficiency. The algorithm this model uses will be introduced and the service process will be described as well. Metrics are defined to effectively reflect the performance of the model and simulation experiments are designed to evaluate the model.

The thesis consists of 6 chapters. Chapter 2 introduces VANET and DSRC, including its characteristics, challenges, applications, common standards and communication modes. Chapter 3 introduces the concept of clustering and some classic clustering algorithms, then, a new clustering algorithm is proposed, and the details are described as well. Chapter 4 describes the proposed service model, including the packets classification and transmission process description, four evaluation metrics are also introduced. Chapter 5 compares different simulation tools and analyses the conducted simulation results. Finally, Chapter 6 mainly concludes the whole work and gives a proposal for future areas of work.

2. Vehicular Ad Hoc Networks

2.1 Introduction

A typical mobile network architecture uses an infrastructure (centralised) structure, where a central hub provides wireless communication services to other mobile nodes in the same network. Wireless Local Area Network (WLAN), Global System for Mobile Communications (GSM) are two typical examples of this architecture. A centralised network architecture is ideal if it works as a permanent network. Wireless routers that function as access points can cover a wide of areas due to their high power wireless radios and antennas.

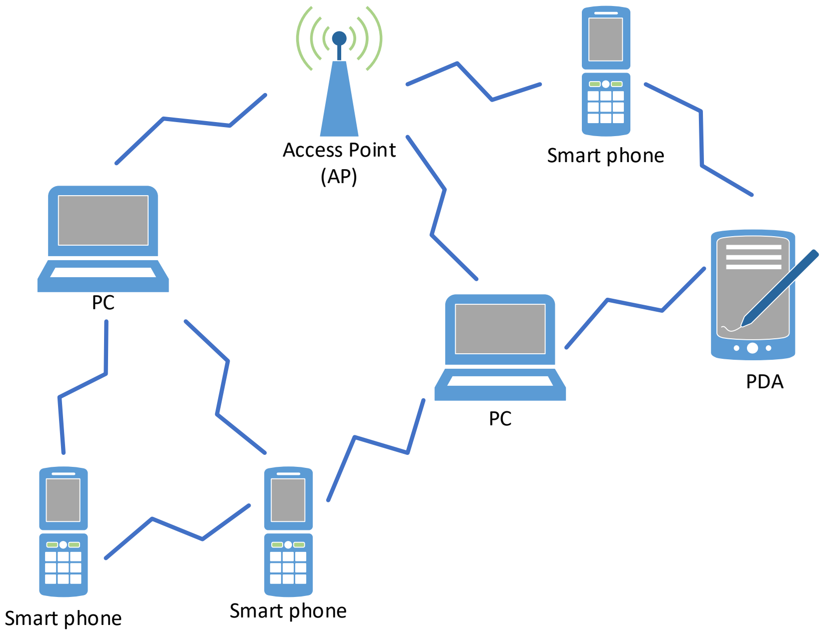


Figure 2.1 Mobile Ad Hoc Networks (MANETs)

Different from the centralised network, MANETs are infrastructure-less wireless networks. Nodes in MANETs can act as routers or access points as well, i.e. each moving node participates in the network can receive and forward data for each other. This type of networks does not rely on any pre-existing infrastructure or wired connections, it can be established at any time and anywhere. Therefore, in the condition of mobile networks, it shows more flexibility and supports high dynamic topology. As shown in Figure 2.1, a mobile ad-hoc network might consist of several types of devices such as laptops, PDAs, smartphones and other mobile platforms[9]. Each node can communicate directly with other nodes within its communication range. Communication between nodes in long distance can be realised via multi-hop routing.

In recent years, to improve the safety and intelligence of transportation systems, smart cities and Intelligent Transportation System (ITS) is rising gradually[10]. Vehicular communications use the new generation of communications and data processing technologies to improve the current traffic efficiency, reduce energy consumption, increase the safety and convenience of transportation. Vehicular networks are key parts of an ITS to enhance safety and reduce traffic congestions. An intelligent vehicle equipped with an OBU and sensors can collect traffic and environmental information nearby, and by exchanging this information with other vehicles, infrastructures or other terminals, vehicular networks help to create a safe, comfortable, and efficient driving environment[11].

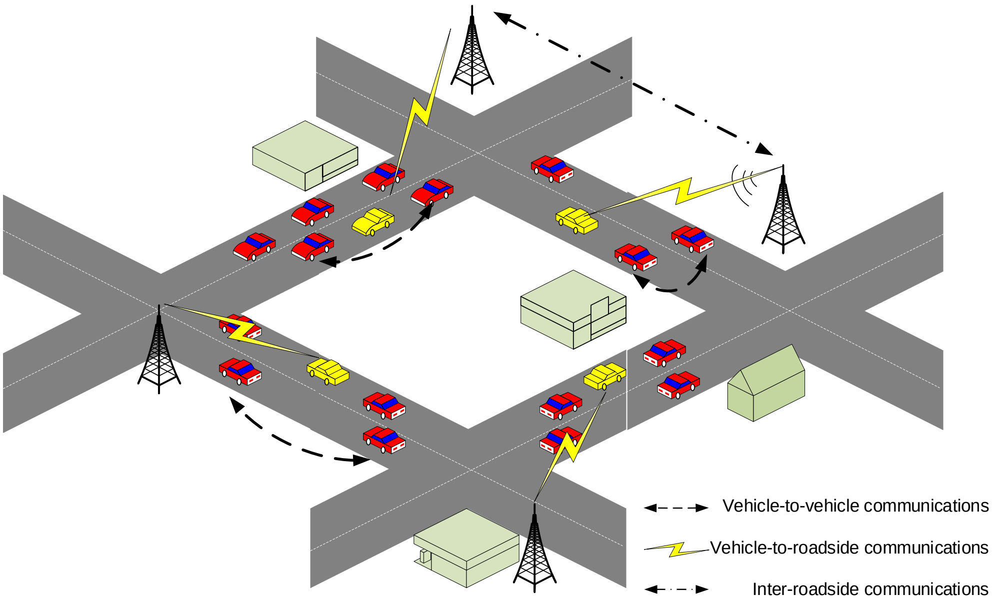


Figure 2.2 Vehicular Ad Hoc Network (VANET)

Vehicular Ad Hoc Network (VANET) is an extension of MANET, as shown in figure 2.2. It can be considered as a special case of MANET, where vehicles like cars, buses and ambulances act as the nodes in the networks. VANET differs from MANET in that the nodes have higher mobility in constrained routes, there are adequate energy and computing ability and hybrid network architecture[12, 13].

In the following sections, a more definite depiction of VANETs is introduced, including its features, challenges, applications and communication modes.

2.2 VANET

People started to pay more and more attention to VANET technologies in the early 1990s, and it has become an important issue in recent years. VANETs have played a promising role in traffic safety and driving efficiency. By sharing related traffic information among a group of vehicles nearby, drivers can avoid unexpected accidents at their blind spots such as corners or other complicated road environments. Vehicles such as ambulances and police cars in emergency situations could achieve a higher priority and vehicles around them can be alerted in time. Real-time traffic information can help drivers manage their travelling time and routes to avoid congestions and improve traffic efficiency. A better-organized routing strategy helps to reduce energy consumption and save resources[14].

2.2.1 Characteristics of VANET

VANET has unique characteristics compare to MANETs and other networks. learning about these characteristics helps to make the best use of the communications technologies and improve the experience of users.

1) High Dynamic Topology

In the various kinds of road structures (e.g. Manhattan grids, motorways or other different combinations of straight roads and junctions), vehicle movements show different patterns[15]. Although some general rules can be drawn from these movements, the distribution of vehicles shows high dynamic patterns. Thus, the topologies of vehicular networks change frequently, vehicles could leave a network and join another frequently. In VANET, vehicles organize the networks themselves while moving, so the numbers of vehicles involved in a network in different periods and areas are different. The lifetime of their connections varies and the signal transmission power changes dynamically as well.

2) Predictable Mobility

Different from MANET, where the nodes usually move randomly around the fields, the routes of each vehicle in VANET is predictable. This is because the vehicles are moving along the roads and are required to obey the traffic signs. By predicting the mobility, the services for the vehicles can be more dedicated. Also, more efficient routing protocols can be designed based on the vehicles moving patterns.

3) Different Priorities

The messages transmitted in VANET are different, in general, there are safety-related messages and normal service messages. So different priorities need to be set to make sure the emergent messages be delivered successfully first. Meanwhile, vehicles with special functions (e.g. ambulance, police cars, fire trucks, etc.) need higher priority to pass the roads. Therefore, messages need to be sent in VANETs to alert other vehicles in the area to ensure that vehicles with higher priority pass first.

4) Energy Resources

In MANET, nodes are powered by batteries whose energy is strictly limited, so battery lifetime is an important factor to consider in designing MANET. But in VANET, this limitation is not obvious: currently, most of the vehicles are powered by fuel or gas, which supplies enough power for vehicles. The electric vehicle is a new trend [16], and they use high capacity batteries to support both traffic and communications function. So, vehicles in VANET do not suffer from power shortage and support more applications.

5) Real-Time Information Exchange

Data dissemination in VANET includes vehicles exchanging real-time data with other vehicles as well as infrastructures and pedestrians. Traffic condition change rapidly, vehicles in VANET are required to exchange data frequently to collect information from others in time, so that the drivers can take proper actions. Additionally, for the VANET supported autopilot in the future, real-time information is necessary for vehicles to make decisions to ensure safety and comfort for passengers.

2.2.2 Challenges in VANET

A well-organized VANET system helps vehicles to achieve accurate, real-time services and thus helps to reduce accidents, congestion, and save energy. To better support communications in traffic scenarios, VANET face many challenges.

1) Quality of Service (QoS)

In VANET vehicles frequently change velocity, direction, relative position of other vehicles and network topology, this leads to the short lifetime of the connection between vehicles. The hidden terminal problem will also affect the service transmission. These will bring challenges in the aspects of message transmission delay, re-transmission times and transmission efficiency, which ensure the QoS for users in the VANET. Reasonable approaches for bandwidth allocation [17-20] or efficient routing protocols [21-23] will increase QoS. The solutions to improve QoS includes managing the transmission power, optimising the routing strategies and data dissemination algorithms etc.

2) Routing Protocols

Efficient routing protocols are needed to deliver the service messages with minimum time duration, including the service duration and the time spent waiting for a lost packet to be retransmitted. The protocols usually need to take the speed, positions of the vehicles, the traffic density, the hops to transmit and the overhead of scheduling into consideration[24-26]. Works in[27] by *J. Zhao* and *G. Cao* considered multi-hop data transmission in VANET introduced the idea of Vehicle-Assisted Data Delivery (VADD). A vehicle will carry a packet and forward it to a new vehicle which enters its neighbourhood.

The work also predicts the movement of vehicles from traffic pattern and road network to reduce delay. These kinds of protocols are suitable for multi-hop data dissemination but will cause much delay as a result of the high dynamic traffic topology.

3) Transmission power

Well-managed transmission power can improve the throughput of data delivery and increase energy efficiency[7], But transmission power is closely related to the numbers of vehicles and the distance between them. When the distance between two vehicles is far, more transmission power is needed to ensure the packets to be successfully delivered. On the other hand, when the transmission distance decreases, the transmission power needs to be decreased as well in order to avoid the interference and congestion.

4) Security

Security is one concerning challenge in VANET according to the network perspective. The safety information in VANET relates to the life of drivers and passengers. This wireless network could suffer from different attacks like fake services, interception of information, wrong position information, and packet dropping[3]. Vehicles in VANET need to be protected from outside attackers as well as inside vulnerability. False certification, fake GPS signals and other malicious attacks are threats to the VANET security. Authenticity, privacy, and usability are the three main aspects to consider in response to the security issues.

2.2.3 Application of VANET

The infrastructures set along the roads act as access points or a cache point to store and provide service information. The interaction among vehicles or between vehicles and RSUs could be applied to satisfy various kinds of real-life requirements. Traffic efficiency and road safety could be improved with the proper application of VANET.

1) Traffic Safety

Vehicles send messages to each other to help to avoid some potential dangers, especially when they are close to junctions or on a road with high vehicle density. Vehicles can receive warnings about another vehicle moving close from a blind spot, and they can also be alarmed when there is a sudden break take place in front of them even though it is still few vehicles away. When there is an emergency, e.g. fire trucks, ambulances passing by, vehicles could be informed earlier to make way. The traffic safety applications mainly include the following aspects:

(1) *Real-time information support:* The RSU has stored real-time traffic information of an area in a certain range. When vehicles in the transmission range of an RSU, they can request for the traffic data from the RSU to learn about the current traffic condition. This information helps to reduce traffic congestions and alerts vehicles whenever there is an accident etc.

(2) *Co-operative Message Transfer:* Information can be exchanged among vehicles as well. Vehicles close to each other can communicate directly and cooperate to avoid potential accidents, for example, sending out a lane-changing warning, sudden brake warning, control loss warning or pre-crash warning etc. If an accident has happened, the vehicles involved in the accident would send out alert messages about the accident location. In this case, the crashed vehicle could get in touch with the trailer on time and other vehicles could plan their routes earlier.

(3) *Traffic Control Notification:* Cars can spot an abnormal road condition such as road depression or the sudden appearance of animals or human etc., and alert other vehicles in the VANET. Junctions can assist accident zones and traffic signals are deployed to regulate traffic. When vehicles are aware of the frequently updated traffic signal conditions and receive the recommended speed before they arrive there, they could manage their velocities and pass the junctions safely and efficiently.

2) Traffic Efficiency

Traffic efficiency mainly focuses on the improvement of the throughput of transportation networks. The convenience of travelling can be enhanced by providing related information to both the drivers and the traffic managers. There are few a kinds of traffic efficient services as below:

(1) *Routes Management:* VANET helps drivers to make back up plans or decisions to deal with the unexpected problems like road congestions. It also provides drivers with enhanced route guidance and navigation based on some prediction algorithms.

(2) *Quick Payment:* The electronic payment has simplified the payment process and make it convenient for users to pay the fees while avoiding congestions caused by toll collection. Payment in traffic system includes toll collection, parking fee etc. Electronic Toll Collection (ETC) enables a toll collection point to read the OBU of the vehicle and collect tolls automatically. How much to pay is evaluate based on the data onboard and the detectors. ETC makes it

faster for drivers to pass the collection point and easier for toll operators to manage the toll collection.

3) Infotainment and Commercial Application

These applications will provide the drivers with information entertainment and services such as real-time news, websites access, streaming audio and video etc. The infotainment and commercial applications include:

(1) Wireless *Vehicle Personalization:* VANETs help with the personalized settings for vehicles and uploading vehicle statistics to infrastructures (e.g. RSUs) through wireless networks.

(2) *Internet Access:* Vehicles can access the Internet via RSU and achieve various information online.

(3) *Digital map downloading/updating:* Maps are available for drivers whenever they need them. Home stations and hot spots would support drivers to download the digital maps to their vehicles directly or update the old maps with the latest versions.

(4) *Multimedia entertainment:* In addition to the traditional car radio, more multimedia resources are available on-board: video/audio from the Internet, live shows etc. Passengers could enjoy more when they are travelling.

(5) *Commercial Advertisement:* Advertising is more targeted for both customers and sellers. The commercial information includes the closest petrol station, restaurants and other stores that drivers may interested in. the vehicles can receive the advertisements from stores or RSUs as they are passing by.

4) Other Applications

Aside from the applications above, VANET can also assist the police to improve the traffic management by searching vehicles or incidents, monitoring speeds and restricting entries to some areas. A better-organized vehicular network could also reduce emissions and build an environmentally friendly transportation system.

2.3 Dedicated Short-range Communication (DSRC)

During the development of intelligent transportation systems (ITS), Dedicated Short -Range Communications for Wireless Access in Vehicular Environments (DSRC/WAVE) have been developed to support vehicular communications. The United States, Europe and Japan have allocated different spectrums and standards for vehicular communications. The Federal Communications Commission (FCC) in the US first allocated 5.9GHZ band for DSRC, and a few years later, the European Telecommunications Standards Institute (ETSI) also established the 5.9GHZ DSRC to support ITS. Efforts have been made in Japan to support Electronic Toll Collection (ETC) systems[29], this has helped to save time and money as well as reduce vehicular emissions. The features of DSRC in these three regions are shown in Table 2.1.

Table 2.1 DSRC in different regions

Features	USA	Europe	Japan
Radio band	75 MHz	20 MHz	80 MHz
Data rate	3-27 Mbps	350 Kbps	1-4 Mbps
Radiofrequency	5.9 GHz	5.8 GHz	5.8 GHz

Different from cellular or Wi-Fi standards, Wireless Access in Vehicular Environments (WAVE) [30] standards work on DSRC band, allowing it to provide stability and secure data transmission for vehicular networks. Standards for WAVE mainly include IEEE 802.11p, IEEE 1609 family and SAE (Society of Automotive Engineers) J2735. The WAVE architecture is shown in Figure.2.4. IEEE 802.11p is developed from IEEE 802.11, it supports physical layer and lower MAC layer. The IEEE 1609 family supports upper MAC and higher layers. SAE J2735 is a message set which defines elements of different messages.

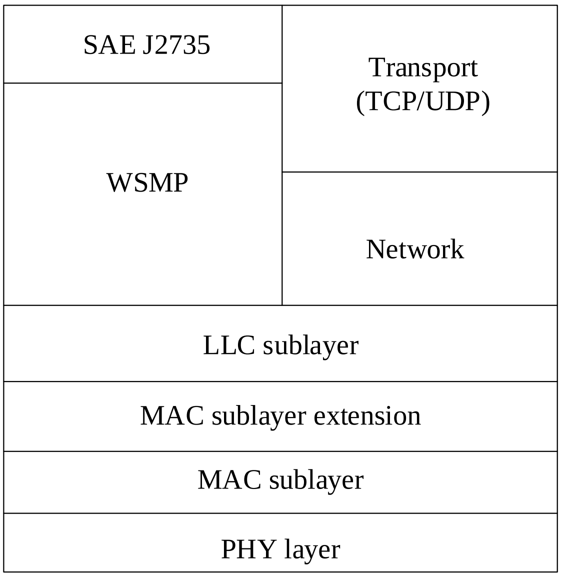


Figure 2.3 WAVE architecture.

2.3.1 IEEE 802.11p

IEEE 802.11p is developed from IEEE 802.11, where the spectrum operates in the 2.4GHz band. 802.11p works in DSRC frequency band and considers the condition where nodes are moving fast. In traffic scenarios, the connection between vehicles and RSUs lasts for only a short period, therefore, IEEE 802.11p defines a way to deliver messages between nodes without waiting for the procedure to join a Basic Service Set (BSS)[31]. This decrease in delay may cause the data to be sent through other available channels.

The 75MHZ band is divided into 7 channels in IEEE 802.11p, as shown in Figure 2.5, each channel owns 10MHz. The channel in the centre (Ch 178) is Control Channel (CCH). CCH is only responsible for security/ safety related correspondences, i.e. traffic safety messages. The other two channels on each side of CCH are Service Channels (SCH), they are dedicated to transmitting application/service data. Two adjacent SCH can merge as one 20MHZ channel in some cases. The last two channels on each end are reserved for special delivery when needed. In multi-channel tasks, the channels are generally scanned CCH first and then SCH.

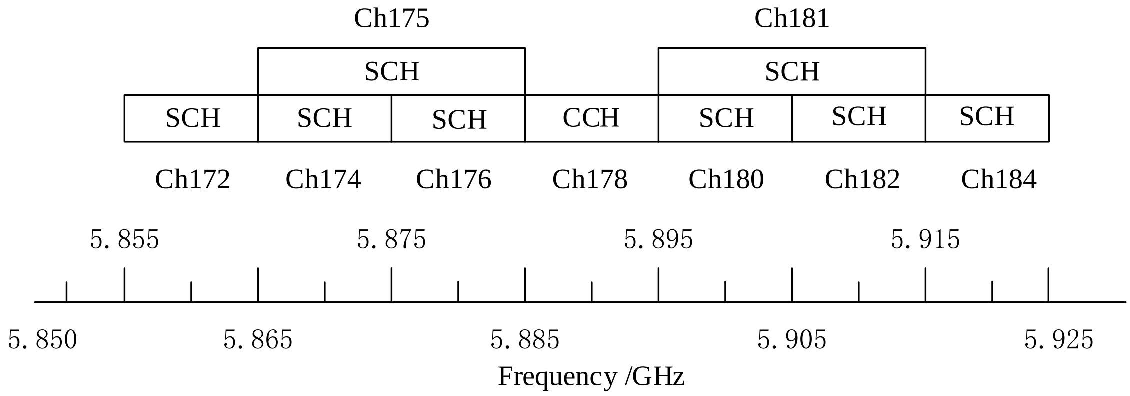


Figure 2.4 DSRC channels.

The transmission power for each channel is also different, the control channel can obtain higher transmit power, while service channels have lower power limitation for transmitting signals.

MAC layer protocols can be classified into centralised protocols and distributed protocols, however, to better adapt to the decentralised structure of VANETs, distributed MAC protocols become better choices to provide effective communications in VANETs[32, 33]. Protocols such as Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA) and Code Division Multiple Access (CDMA) determine the access to the medium without any contention, and thus collision probability can be reduced.

The first random access protocol is ALOHA, which simply determines the transmission by detecting the channel collision[34]. Slotted ALOHA or S-ALOHA is proposed based on the original ALOHA. Time slots in slotted ALOHA help to improve the overall throughput[35]. Comparing to Carrier Sense Multiple Access (CSMA), ALOHA shows poor performance when there are multiple sending and receiving terminals involved.

The MAC layer in 802.11p uses Carrier Sense Multiple Access with collision avoidance (CSMA/CA) protocols[36] which only allow packets transmission if the medium is free, i.e. the node detects the channel condition first and transmits packets when the channel is vacant. If the channel is not available, it backs off for a random time and detects again till the channel is free. The medium detection consists of two processes: one is listening to the physical medium to sense physical carrier, and another one is observing Network Allocation Vector (NAV) which represents the transmission duration.

2.3.2 IEEE 1609 family

The IEEE 1609 standards family for WAVE is shown in Figure 2.4. It defines parts of the WAVE architecture, protocols for network communications, safety-critical and non-safety-critical applications, and regulations for multichannel operations in VANETs. Four important protocols in the IEEE 1609 family play the key rules to support the seamless connection of WAVE applications in VANETs, the four standards are briefly introduced as below:

- IEEE 1609.1 is a standard for WAVE, which acts as the resource manager. It describes the key segments and features of WAVE system. It also supports the command message format and storage assist the applications in communicating between the devices onboard.
- IEEE 1609.2 provides security services for application and management messages. It supports the security issues by characterizing the security administrations for WAVE systems to ensure the data security. The message processing format is defined based on the message requests. IEEE 1609.2 supports common security services such as confidentiality, authentication, authorization and integrity[5].
- IEEE 1609.3 is a network and transport service, which supports secure WAVE data exchange. It defines network and transport services and the routing plans. Administrations, which work at the network and transport layers, can be divided into data-plane administrations to transport traffic, and management-plane administrations to arrange and support frameworks.

- IEEE 1609.4 supports multi-channel operations in MAC layer. MAC layer coordinates the data transmission to make sure the packets are transmitted to proper RF channel at the right time, and IEEE 1609.4 is used to manage channel coordination and support MAC service data unit delivery.

2.3.3 Society of Automotive Engineers J2735 Standard

The Society of Automotive Engineers J2735 Standard (SAE J2735) specifies how a message is sent, including its data frames and data elements specifically for the applications in the DSRC/WAVE communications systems[37]. Although this standard is mostly dedicated to DSRC, this message set and its data frames and elements also have the potential to be used when the applications are related to other wireless networks. The SAE J2735 defines the message structures and introduces sufficient background information to help users to understand the messages and implement the messages according to the DSRC standards.

In SAE J2735, the Basic Safety message, or BMS is the core in vehicular communications. It contains the information of vehicle state, e.g. position, heading, speed, etc. It provides a mechanism for communicating a variety of vehicle state information. The SAE J2735 basic safety message (BSM) also consists of several data frames including the vehicle status data frame, which in turn contains the desired data elements (and is also referenced by the Probe Vehicle Data Message). The vehicle status data frame is therefore examined for the weather-related data elements as it applies to all messages that incorporate it.

2.4 Cellular Communications

Cellular technologies are applied to support vehicular communications especially over long distances. In recent years, the concept of LTE-V (Long Term Evolution for vehicles) has been proposed and become a new topic[38]. Cellular networks enable high capacity networks to support high bandwidth demand, they can cover wide communication ranges and increase the lifetime of link connections. Based on the development of cellular technologies in the past years, cellular networks for vehicular communications show a good perspective. But the centralized network structure has limited the quality of both V2I and V2V communications.

2.5 Communications Modes

Enabling information sharing among vehicles and infrastructures will help to improve the travelling efficiency and safety for drivers. Information can be collected from the sensors and other devices on board the vehicle[39], such as telemetry sensors, radar and GPS, the RSUs can store data from the database or vehicles nearby. These data can be sent out to satisfy any other nodes with requirements. In this process, V2V and V2I are mainly involved, which can be included as V2X communications.

2.5.1 V2V Communications

The V2V communications model is shown in Figure 2.2, V2V in VANET refers to vehicle-to-vehicle communications, where vehicles equipped with OBUs can communicate directly inside their radio ranges. The applications involve the data delivery from one vehicle to other vehicles in the communication range. Because the V2V communications can be implemented flexibly without any assistance of infrastructures, the frequently exchanged information helps drivers to drive efficiently and safely. In this communication mode, data transmission among vehicles is reliable and has low latency[40, 41].

However, most V2V applications are based on exchanging information (e.g. BSM) with other vehicles in the neighbourhood via the vehicular networks. However, if vehicles fail to send and receive messages (e.g. OBUs are not equipped or broken), the V2V communications can be very unreliable especially when the topologies of vehicles are unstable. In addition, V2V communications do not provide access to external network resources (e.g., the Internet) to users.

2.5.2 V2I Communications

V2I refers to the communications between vehicles and infrastructures, it involves the deployment of infrastructures along the roadsides and the different applications that can contribute to the quality of service from infrastructures to vehicles.

Figure 2.2 illustrates V2I communications between RSUs and vehicles. V2I communications provide reliable safe and mobile service applications across the network for vehicles. Vehicles send information or requests to the RSUs and receive information services sent back from the RSUs via V2I. The RSUs deployed along the roads can support traffic services for vehicles such as information about road conditions or other areas or parking lot availability and token collection, etc. Moreover, the RSUs can also act as access points (APs) for wireless local area networks(WLAN) and wireless wide area network (WWAN)[41].

However, it will take more power and end-to-end delay in V2I than in V2V to realise seamless connectivity for vehicles, and the deployment of RSUs and other infrastructures is also a costly approach.

2.5.3 V2X Communications

V2X communications involve the communications between vehicles and the communications between vehicles and other terminals, e.g. RSUs, traffic signal towers, mobile devices, etc.

In V2X communications, V2V and V2I cooperate to guarantee the QoS of vehicular networks. For example, when the traffic density is low, pure V2V communications cannot provide vehicles with a stable connection, so the cooperation of V2I communications help to prevent connection loss and improve the link quality[42-45]. V2X communications extend the service range of traditional V2V models and improve the efficiency of V2I and thus can reduce the cost[46]. Figure 2.6 shows a V2X scenario where both V2V and V2I are involved. In this scenario, information can be delivered to farther terminals with a shorter delay.

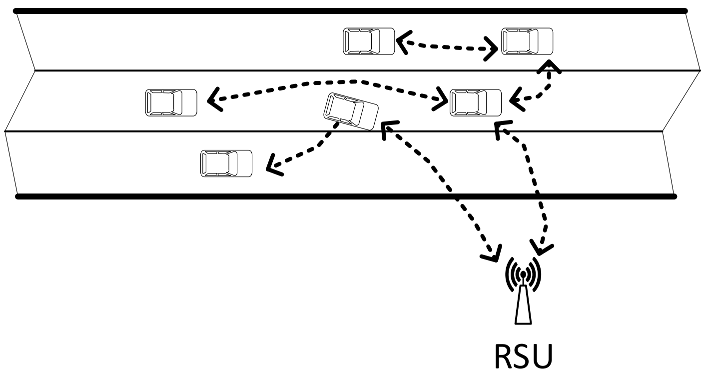


Figure 2.5 V2X scenario

A lot of work has been done to improve the connectivity in V2X communications. In general, there are three main approaches for data dissemination: opportunistic data dissemination[47], vehicle-assisted data dissemination[27], and cooperative data dissemination[48, 49].

In opportunistic data dissemination, the delivery of messages would proceed when the node is within in a certain range (vehicles and RSUs) detect each other. *M. A. Leal, M. Röckl, B. Kloiber, F. d. P. Müller, and T. Strang* proposed the data dissemination in [47], it is adaptive to the specific time and distance information, messages are delivered depending on the vehicular densities in the vehicular network. The performance evaluation includes the average waiting time that vehicles spent but failed to receive the notification within a certain distance and the receptions ratio. With the help of store and forward functions, this protocol can reduce the retransmission times efficiently even in low traffic density areas.

Another work in[27] *by J. Zhao and G. Cao* considered multi-hop data transmission in VANET introduced the idea of Vehicle-Assisted Data Delivery (VADD). A vehicle will carry a packet and forward it to a new vehicle which enters its neighbourhood. The work also predicts the movement of vehicles from traffic pattern and road network to reduce delay. This kind of protocol are suitable for multi-hop data dissemination but will cause much delay as a result of the high dynamic traffic topology.

The idea of cooperative is to combine V2V communications with V2I. As *K. Liu, J. K.-Y. Ng, J. Wang, V. C. Lee, W. Wu, and S. H. Son* has described in [48], the RSU is installed along the road and provides services to passing vehicles via V2I communications. Meanwhile, a vehicle is able to share its cached data items with their neighbours via V2V communication. In this case, vehicles do not have to wait till they get access to the RSU to get the service from it, so the transmission efficiency is raised. In the work by *Q. Wang, P. Fan, and K. B. Letaief* in[49], more infrastructures (base stations) routes are considered. Those base stations are placed along a road, the messages are broadcast timely. Vehicles driving pass their coverages will receive the information seamlessly via V2I communications. Because there is space between the base stations where vehicles are not covered by either base station, V2V communications are required as well to forward the information from vehicles with the service data to the vehicles outside the base station's coverage. The key point is to decide the handover mechanism to make sure the connection is stable.

With pure V2I communication, vehicles cannot be served outside the coverage of an RSU. However, with some extra help from V2V communications, the system is capable of serving vehicles which are out of this certain ranges. Moreover, data dissemination via V2V communications can help to reduce the overhead of rebroadcasting from RSUs to serve some vehicles which are too far to receive high-quality services. Thus, the cooperative communications by both V2V and V2I can further enhance the robustness and efficiency of data services[50].

3. Cluster-Based Vehicular Communication

3.1 Introduction

Clustering is an efficient approach to combine V2V and V2I together as V2X, it divides the nodes in a network into different small groups which function as a whole. As is shown in Figure 3.1, a cluster consists of at least one cluster head (CH), cluster members (CM), and gateways (GW). A cluster head is selected based on some clustering head selection algorithm and plays the key role in a cluster. Gateways exist in the groups where at least one node is in the transmission range of two or more clusters. Cluster members are other ordinary nodes involved in a cluster. If a node has some data to transmit outside of its transmission range, it can forward it to its cluster head, and the cluster head would pass it on to the destination directly or via a gateway, in this case, data dissemination is more power efficient. Clustering can also be used for routing management, network structure optimization and transmission efficiency improvement. Two classic clustering algorithms that are widely applied in ad hoc networks are the Lowest-ID (LID) and the Highest Degree (HD) clustering.

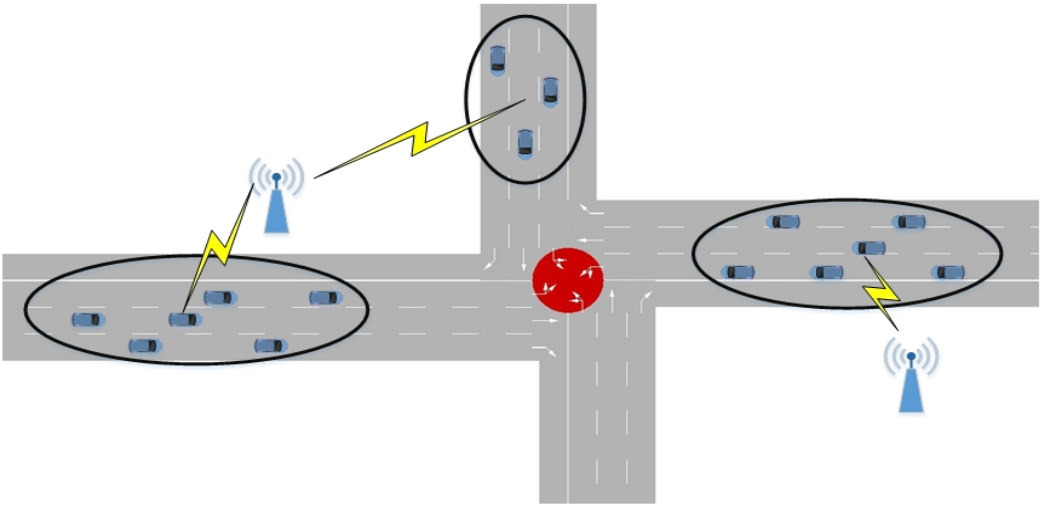


Figure 3.1 Clusters in VANET

Lowest-ID clustering defines the node with the lowest ID among its neighbours in each cluster as a cluster head. Figure 3.2 shows the results of applying LID to form clusters among ten nodes, each cluster is identified by its cluster head's ID. The nodes in the coverage of two cluster heads function as gateways (node 8, node 9). The work done by *D. Gavalas, G. Pantziou, C. Konstantopoulos, and B. Mamalis*[51] introduced an algorithm for efficient and energy-balanced clustering of mobile ad hoc networks, called Lowest ID with Adaptive ID Reassignment algorithm (LIDAR). The algorithm is a modified version of Lowest-ID algorithm. LIDAR takes both mobility and the energy consumption of nodes into consideration to provide a more stable cluster set. This algorithm reduces control traffic volume and also increases broadcast frequency for highly mobile network configurations. The change of cluster heads in Lowest-ID algorithm is very infrequent, which cost it less resources to maintain the clusters. The number of members in a cluster with LID remains in a relatively stable level to keep a high throughput. *P. Basu, N. Khan, and T. D. C. Little* presented Mobility Clustering (MOBIC) in[52] taking the mobility of mobile nodes into consideration while forming clusters.

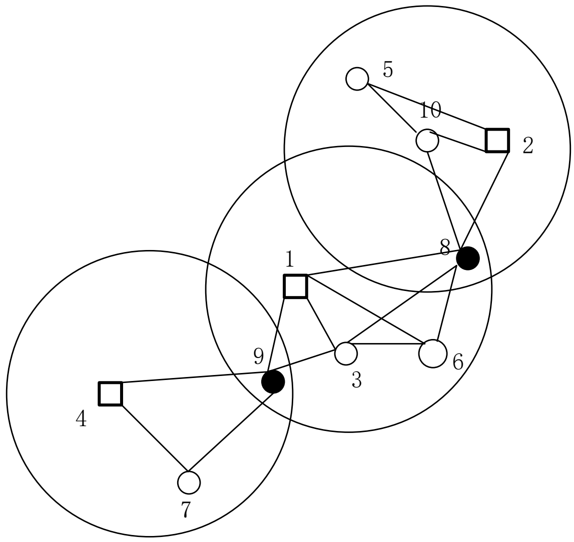


Figure 3.2 Clustering based on LID algorithm

Highest Degree clustering is another common clustering algorithm proposed by *M. Gerla and J. T.-C. Tsai*[53] in ad hoc networks, where the CH is the node with the maximum connectivity degree, i.e. the node with the most free one-hop neighbours is chosen as the cluster head (hello messages are periodically broadcast to detect one-hop neighbours). The goal of this algorithm is to minimize the cluster number. Each node has learned the number of its neighbours, which is achieved by counting the hello messages from others. The node with the highest number of neighbours, i.e. the highest degree, is chosen as the cluster head. If several nodes own the same number of one-hop neighbours, the node with the lowest-ID becomes the cluster-head, and the other neighbours become the cluster members. This procedure is then repeated until all nodes belongs to at least one cluster (nodes in more than one cluster function as gateways). As shown in Figure 3.3, applying HD to form clusters among the same 10 nodes above, node 5, 7, 8 will be selected as cluster heads, node 2, 10 and node 3, 9 are gateways, in this case, node 5,7 could cover more nodes if there is any. The number of cluster heads is relatively low in HD algorithm, therefore, it potentially decreases the routes between the source node and the destination node. MobHiD[54] was proposed after HD algorithm by

C. Konstantopoulos, D. Gavalas, and G. Pantziou, it is designed for MANETs environments and optimised the performance of clusters in some simple mobility models.

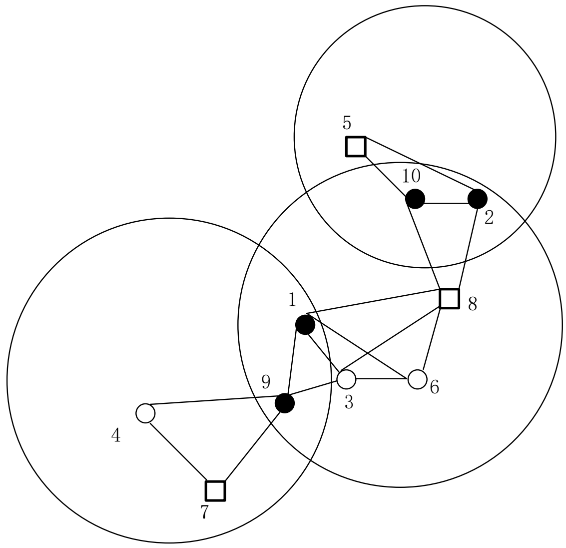


Figure 3.3 Clustering based on HD algorithm

Beacon-based clustering algorithm relies on regular beacon exchanging, which enables the nodes to be aware of the status of their neighbours. Based on these status, a node will decide the status of itself. The status of cluster head will maintain the same unless it receives a beacon from other CH which have more cluster members. This method is mainly focusing on decreasing cluster changes and increasing cluster lifetime. But on the other hand, the size of a cluster always has the potential to become larger, therefore, this may affect the transmission efficiency of the cluster.

3.2 WCA Algorithms in Mobile Ad-hoc Networks

In this project, a weighted clustering algorithm (WCA) is mainly considered. The WCA algorithm[55] proposed by *M. Chatterjee, S. K. Das, and D. Turgut* introduced a concept of 'combined weight' which takes the degree of neighbours, mobility and battery into consideration to form clusters in MANET. The cluster size and lifetime can both be kept in relatively reasonable ranges. The WCA algorithm has flexible abilities to show good performance in the dynamic topology of mobile ad hoc networks. The cluster head is selected in the consideration of combined factors of mobility, transmission power and battery power. All these factors can be adjusted to make a different contribution to the final decision. These factors are now discussed.

- Degree-difference of neighbours Δ_v

Each node has a different number of neighbours which defines its degree. When the number of neighbours a cluster head has reaches an ideal level, the cluster system could perform as efficient as is expected without overloading the cluster head. The difference between this ideal number of neighbours and the number of neighbours a node really has reflects the potential competitiveness of the node in cluster head access, and can be expressed by the equation.

$$\Delta_v = |d_v - \delta| \tag{3-1}$$

where δ is the ideal number of neighbours a cluster head can handle and d_v is the node degree.

- Distance between neighbours D_v

The total distance between a node v, and all its neighbours, v' ($v' \in N(v)$) affects the transmission power that will be costed to maintain the communication with its neighbours. A farther distance indicates higher transmission power.

$$D_v = \sum_{v' \in N(v)} \{dist(v, v')\} \tag{3-2}$$

- Mobility M_v

The mobility is illustrated by the average speed of a moving node from the beginning to the current moment. In this duration T, the lower the average speed is, the more stable the node is and thus is more suitable to be the cluster head.

$$M_v = \frac{1}{T}\sum_{t=1}^{T}\sqrt{(x_t - x_{t-1})^2 + (y_t - y_{t-1})^2} \tag{3-3}$$

- Time duration as a cluster head P_v

The cluster head is the key role of delivering control and other messages, the transmission process requires a lot of energy from the nodes supported by batteries, especially from the cluster heads. The more time spent being a cluster head, the more energy consumption it has taken. The duration of a node acting as a cluster head as the battery power consumption is then indicated by P_v.

Combining all these factors together, the metric to select the cluster head is shown as below:

$$W_v = w_1\Delta_v + w_2 D_v + w_3 M_{vi} + w_4 P_v \tag{3-4}$$

where $w_1, w_2, w_3, w_4 > 0$ are adjustable to decide the contributions from each of the factors discussed above, and $w_1 + w_2 + w_3 + w_4 = 1$.

The cluster forming process is as below:

Step 1. Find the degree of all the nodes d_v.

Step 2. Compute the degree-difference for every node v.

Step 3. Compute the total distances between every node and its neighbours, D_v.

Step 4. Compute the average velocity for every node during its travelling time, M_v.

Step 5. Compute the duration of a node being a cluster head, P_v. It indicates the battery power has been consumed.

Step 6. Calculate the combined weight W_v for each node v.

Step 7. Choose the node with the smallest W_v as the cluster head. All the neighbours of the chosen cluster head are no longer allowed to participate in the election procedure.

Step 8. Repeat steps 2–7 for the remaining nodes not yet selected as a cluster head or become cluster members.

The WCA algorithm is optimized by considering genetic algorithms in[16] *by L. Situ*. The cluster heads and cluster members from the parent WCA are recorded in chromosomes defined by the fitness function, these chromosomes are passed on by genetic algorithms. Every cluster head tends to cover the nodes nearby as much as possible so that the total number of cluster heads is kept to a low level. This algorithm shows a better performance in clustering compared with the original WCA.

3.3 Proposed Clustering Algorithm in VANET

In a MANET, cluster heads are elected by considering the position, neighbours, mobility, and battery power of the sensors and nodes in the network. However, in VANETs, the conditions are different: vehicles are not restricted by the battery power like the nodes in MANET but their mobilities in VANET are more restricted by traffic rules and road topologies. Therefore, the factors involved in forming clusters need to be adjusted to fit in the vehicular network environments.

Clustering in VANET needs to be adjusted in accordance with traffic features: high mobility of vehicle nodes, regular moving tracks and directions. etc. The clustering algorithm for forming and maintaining clusters should ideally be stable and adaptive to node mobility or sudden changes in network topology, as well as provide reliable end-to-end communications across the VANET.

Clustering in VANET is an extension of clustering in MANET, where the mobility and channels show different features. On the road networks, vehicles equipped with communication devices group themselves into clusters according to some rules applicable to the road environment and traffic characteristics. One node in a cluster is selected as the cluster head and other nodes as cluster members. Cluster heads are responsible for different functions in different application environments. Cluster size is not fixed and usually depends on the communication range of vehicles and the traffic environment. In the environment where the nodes have high mobility, cluster stability is a key factor to consider. In some traffic scenarios, some vehicles are prevented from joining in a cluster by some filters to improve the transmission efficiency, for example, on a two-way straight road, a vehicle is not allowed to join in the cluster that is running in the opposite direction.

Based on the WCA algorithm, we propose a new weighted metric to elect cluster heads in VANET. The metrics involved include the position, mobility, connectivity and driving behaviours of drivers. The following sections introduce the proposed clustering algorithm for VANET.

3.3.1 Nodes Status

There are three types of nodes (vehicles) in a VANET: free node (FN), cluster head (CH), cluster member (CM). The clustering algorithm considers the one-hop neighbours of each node and the cluster size is decided by cluster head's communication range. CH is responsible for collecting data and service requests from CMs, uploading current driving information (e.g. traffic is normal or congested), and requesting services from the RSU.

3.3.2 Packets

1) VIP

Vehicle information packet (VIP): It carries the basic vehicle information: vehicle ID, velocity, position, etc. VIP is used for a node to start the cluster forming process and exchange vehicle information with neighbours.

2) CHA

Cluster Head Announcement (CHA): When a node considers its weight low enough to be a CH, it will broadcast a CHA to announce its weight value W_i. If a node has a smaller W_i than that of the CHA it receives, it will send its CHA to argue.

3) CHM

Cluster Head Maintain (CHM): A node with the smallest W_i is elected as CH, and it then sends CHM to all its neighbours to declare its identity (CH ID). This packet is broadcast periodically if CH considers its status is still suitable to be a cluster head.

4) SDP

Service Data Packet (SDP): SDP consists of two parts: head and context. The head includes the packet ID, sender ID and time stamp. The context part carries the actual communication message such as service requests and collected information.

3.3.3 Cluster Head Election

The suitability of a CH is evaluated by a combining weighting metric. The factors that could affect the election of CH include distance, velocity, connectivity and driving behaviour.

The position of each node is obtained from the GPS device. As CH tends to be in the middle of a cluster, the average distance between CH and CMs should be as short as possible. The average relative distance between a candidate node n_i and its neighbours, P_i, is given by:

$$P_i = \frac{1}{N_i}\sum_{j=1}^{n}\sqrt{(x_j - x_i)^2 + (y_j - y_i)^2} \tag{3-5}$$

where N_i is the number of neighbours of node n_i, x_i and y_i are coordinates of n_i, and x_j and y_j are coordinates of the neighbours of n_i where $j \in \{1, 2, \cdots, n\}$.

The velocity of CH should be close to the average velocity of current flow, so it can have more stable communication with its members. This velocity stability, V_i, is represented by the difference between the velocity of the candidate node, v_i, and the average velocity of the traffic flow, i.e.:

$$V_i = \left| v_i - \frac{1}{N_i}\sum_{j=1}^{n} v_j \right| \tag{3-6}$$

where v_j is the velocity of the j-th neighbour of n_i.

Nodes could have different numbers of neighbours, so the number of neighbours of node n_i can be denoted as N_i, which reflects the connectivity of n_i. If N_i is too small, there might not be much improvement in service efficiency or energy efficiency when using clusters. The ideal connectivity, denoted as σ, represents the maximum number of neighbouring nodes within one hop without causing traffic congestion and is given by:

$$\sigma = 2R_t \times 133 \times N_L / 1000 \tag{3-7}$$

where R_t is the transmission range of each vehicle and r, N_L is the number of lanes. The constant value 133 represents the highest possible density (vehicles/(lane·km) [56]. A better connectivity can be achieved if the number of a node's neighbours is closer to this ideal value. The connectivity denoted as C_i is then given by:

$$C_i = \left| N_i - \sigma \right| \tag{3-8}$$

The last factor is the acceleration of node n_i, denoted by a_i, which reflects the driving behaviour and shows how stable a vehicle is when running along the road and can be obtained from sensors onboard. The driving behaviour denoted as D_i is defined as:

$$D_i = |a_i| \tag{3-9}$$

The four factors: P_i, V_i, C_i, and D_i, described above can be jointly used to decide the suitability of a node to become a cluster head. We consider these factors equally important, so the weighting metric that we propose for electing the CH is the summation of the normalized values of these four factors, which is given by:

$$W_i = P_i' + V_i' + C_i' + D_i' \tag{3-10}$$

where

$$P_i' = \frac{P_i}{P_{\max i}},\ V_i' = \frac{V_i}{V_{\max}},\ C_i' = \frac{C_i}{\sigma},\ D_i' = \frac{D_i}{D_{\max}} \tag{3-11}$$

$P_{max,\,i}$ is the distance between the node n_i and the farthest vehicle from it, V_{max} is the speed limit set by the traffic rules that a vehicle can reach in the flow, D_{max} is the maximum absolute value of acceleration that a vehicle can reach.

Based on above discussions, the defined weight metric, W_i, will be used to elect CH based on the criteria: a smaller W_i indicates higher suitability for the CH.

3.3.4 Cluster Forming and Maintaining

A. **Cluster Forming**

Any node whose status is a free node (FN) can start the cluster forming process by sending VIP to its neighbours. The cluster forming process is shown in Figure 3.4. The dissemination of VIP among the neighbours enables each node to calculate its weight value W_i which is the basis of CH election. A node with the smallest W_i wins as CH. If a node achieves a W_i smaller than the weight threshold, $W_{Threhold}$ ($W_i < W_{Threhold}$), it will send CHA to its neighbours to announce its suitability. When a node receives a CHA, it will compare its weight W_i with its own and send another CHA to argue if it has a smaller W_i. Otherwise, the node will keep waiting for CHM from others to confirm the CH ID. After sending a CHA, if a node has not received any argument during a threshold window T_w, it generates and sends CHM to declare its identity as CH of its neighbours. Every node which receives this CHM will mark the CH ID as its head ID. If a node receives another CHM shortly after the one from the first CH, it compares and decides the new CH based on their weights. The CH election is carried out when there is any node starts the election, based on which the CH is dynamically adjusted. Once a CH is successfully elected, the cluster based on this CH is then decided.

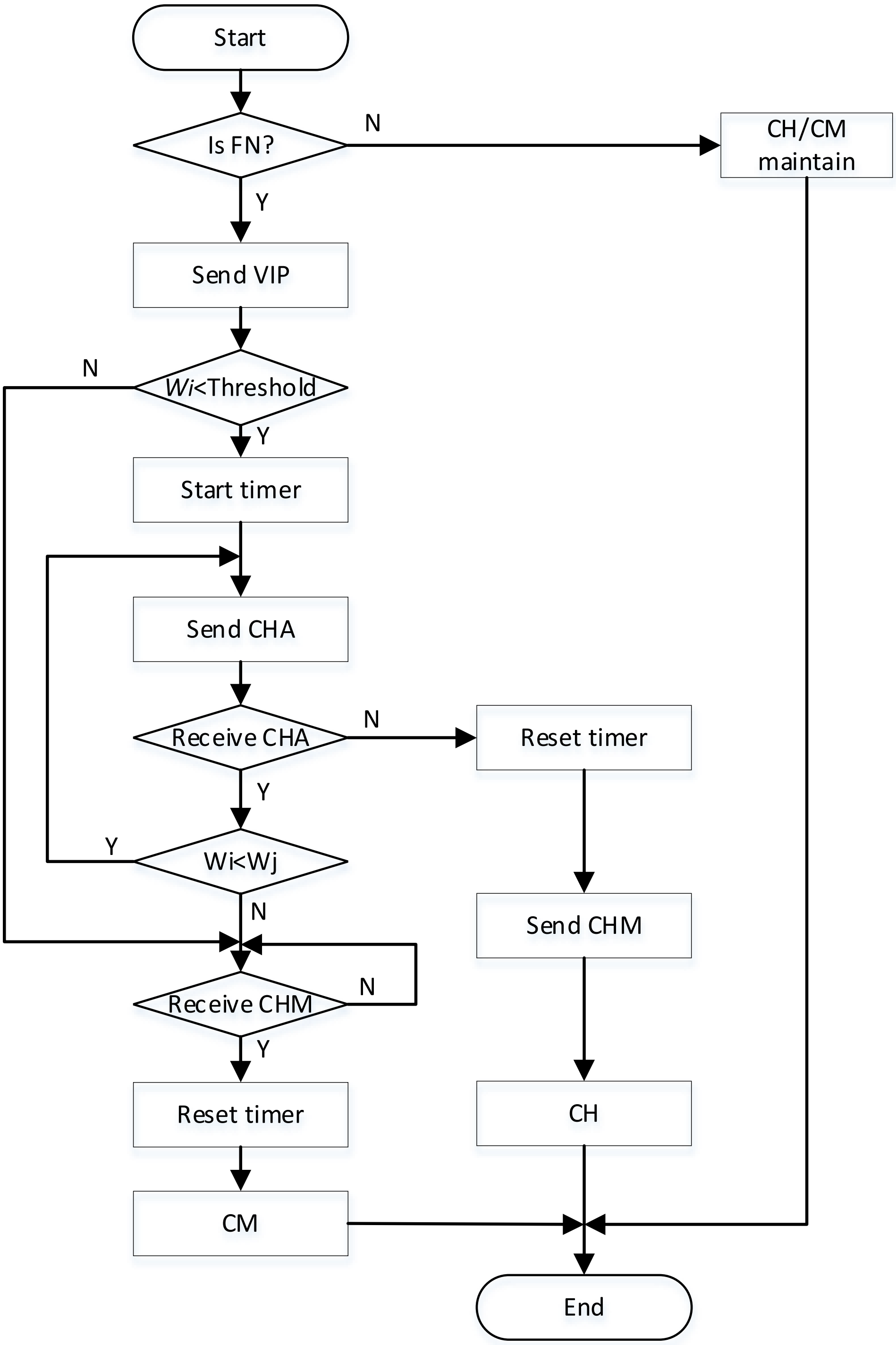


Figure 3.4 Cluster forming process

B. Cluster Maintaining

The cluster is required to have a high communication efficiency and low maintaining cost. Therefore, the way to maintain a cluster should be effective and simple. The CH ID is added to each CM in the same cluster, but CH does not keep the list of its members. The CH chooses to be the CH or change its status by monitoring its driving condition.

CH maintaining: A CH keeps tracking its driving status to evaluate whether to be CH or not. The driving status includes its current speed, acceleration and driving direction. If there are no obvious changes of its driving conditions and the condition of $W_i < W_{Threhold}$ still meets, it re-sends its CHM to confirm its CH ID; otherwise, it sends VIP to start a new cluster forming process and changes its status as FN.

CM maintaining: When a node becomes a member of a cluster, it keeps the ID of CH. If it keeps overhearing the CHM from the same CH, it keeps the CH ID. If CM continuously overhears two CHMs from another CH, it changes its CH ID to the new one and becomes a member of a new cluster. If CM overhears no CHM for a period of time, it switches its status to FN and sends out a VIP.

4. Cluster-Based Cooperative Service Model

4.1 Introduction

In the pure V2I service model, only RSUs deployed along highways provide data service for drivers. However, too much V2I transmission involved in the service model will affect the transmission efficiency and cost too much power. This energy and time consumption of a V2I service model can be reduced by combining V2V and V2I together to provide service.

To reduce the V2I communications in service process, in this section, a cluster-based service model is proposed, where the vehicles are grouped into clusters based on their mobility, connectivity and driving behaviours. RSUs are located in different sections along highways and share a database server in the back-end as shown in Figure.4.1. The vehicles act as nodes in the VANET concerned.

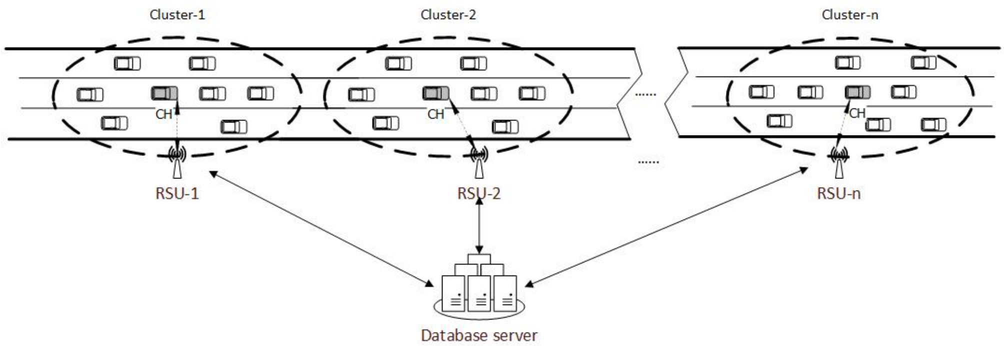


Figure 4.1 Cluster-based service model

The database server keeps the traffic and environmental information of the regions in a certain area, which is big enough to cover the short-term interests of most vehicles on roads. The information in the server is updated periodically when vehicles upload the latest information to the server. The information includes the velocity of traffic flow, traffic density, weather conditions and the road status.

The vehicles are grouped into clusters to collect information and request for services. A cluster head (CH) is elected to gather and aggregate information collected from cluster members (CMs) and disseminate service packets to CMs. Only CH can directly communicate with RSU, this communication includes uploading information to the server via RSU and disseminating the service data obtained from RSU to CMs through the broadcast.

To reduce the transmission cost, CH does not keep the list of its members, every CM stores the CH's ID to identify its cluster. When CH broadcasts the service packets, CMs who have the same CH ID and the targeted service ID will receive the service packets.

The communications system follows the standards of IEEE802.11p, which specify 7 channels including one control channel and 6 service channels. Each channel has 10MHz and at power levels up to 44.8dBm for RSUs and 33dBm for vehicles. The control channel is used for exchanging control messages and safety information, while service channels are used for delivering service information packets.

This system model enables real-time information sharing. In addition, it helps to reduce the cost of energy because it shifts a significant amount of data transmissions from V2I to V2V due to the cluster approach adopted. RSU only needs to communicate with CHs, resulting in reduced transmission collision and energy consumption at RSUs.

The uplink and downlink transmissions of the proposed service model are described as below.

4.2 Uplink Transmission

The vehicles on the roads have different regions of interests and tend to learn the environmental and traffic conditions in those regions in advance. They also collect current traffic information from their onboard sensors. Upon generating a message with a high priority (e.g. an accident), it is their responsibility to report it to CH. Each vehicle generates packets including vehicle ID, request ID and CH ID. Every CM submits the requests along with the collected information to CH and then set the timer to wait for services. On receiving the packets, CH aggregates the collected information and forward it as well as the aggregated requests from CMs to RSU.

The traffic/environmental information includes the flow's current average speed, position, weather (rain, fog, lights etc.) and traffic conditions (smooth or congested etc.). As this information is mainly obtained from the onboard sensors of vehicles, vehicles in a smaller range may gather similar information, especially the weather and other environmental information. In addition, different vehicles may generate requests for the same destinations. Therefore, all the uploaded data from CMs are more than the aggregated data at the CH, building upon which the uploading efficiency can be improved. CH integrates the data from CMs, including the service requests and collected data. An emergent message (e.g. accidents alerts) will be marked with a higher priority.

Each RSU maintains its own database to store the recent service information collected from different CHs in its communication coverage. This contributes to the real-time service of the model by exchanging and updating information of other areas with the database. In this case, vehicles in one area can learn the information about a larger range of areas ahead, which helps drivers to choose the best routes to reach their destinations, and which avoid congestion and accidents, and which makes drivers aware of the travelling time they will spend.

4.3 Downlink Transmission

After receiving the packets from CH, RSU updates the database with collected information and generates the service packets with the requested data. This data is delivered to CH via V2I. CH will then continuously broadcast each service packet to its members via V2V. Once overhearing the corresponding service ID and CH ID, CM will store the packets and mark the received request as satisfied. If CM is not satisfied (i.e. CM did not receive the requested service data) during a waiting time threshold, this request is considered as failed, a new request will be generated and sent to its CH again.

As one service may be requested by multiple vehicles (e.g. three cars are interested in the traffic information of the same area), CH disseminates data to CMs by broadcasting. This helps to reduce the transmission cost. When CH broadcasts the service packets, CMs which marked the same CH ID and targeted service ID will receive and save the service packets. Our model provides real-time service for vehicles, with which drivers could manage their routes and time efficiently.

In addition, the application of clustering has transferred most of the data delivery between RSU and vehicles (i.e. V2I) to the data exchange between cluster members to cluster head (i.e. V2V). In this way, both transmission collision and energy consumption at RSUs level can be reduced.

This service model follows the standards of IEEE 802.11p and IEEE 1609 family, which specifies 7 channels including one control channel and 6 service channels. Each channel has 10MHz. The control channel is used for exchanging control messages and safety information, while service channels are used for delivering service information packets.

4.4 Energy Model

The proposed service model divides vehicles into clusters to improve the service efficiency and reduce energy consumption. We only consider one-hop neighbors of each vehicle to make sure the stability. The energy model in one round of transmission includes two sections as shown in Figure 4.2: the uplink and downlink transmissions.

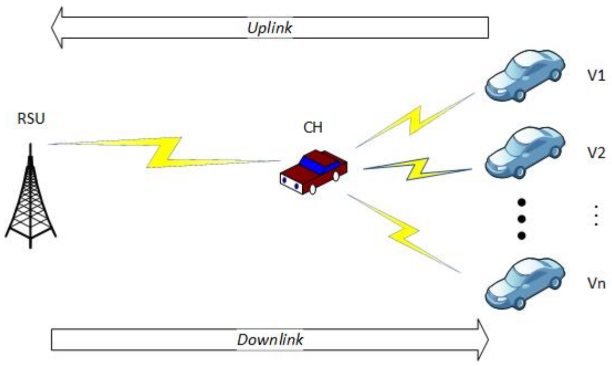


Figure 4.2 Uplink and downlink models

To better analyze the performance, we consider two different service models: one is to provide services based on clusters (V2X) and the other one is to provide services without clusters (pure V2I). In the proposed service model using cluster-based V2X, both V2V and V2I are used for uplink transmission and downlink services. However, higher transmit power is required in the V2I mode than in the V2V mode as the distances between RSU and vehicles are generally much longer than the distances between vehicles themselves within a cluster. In this subsection, we will discuss the energy performances of the cluster-based service model as well as the non-cluster service model where services are delivered through V2I only.

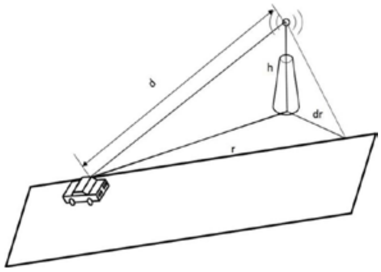


Figure 4.3 Distance between vehicle and RSU.

In the V2I mode, the distance between a vehicle and RSU is changing while the vehicle moves along the highway. Assuming on a straight highway and a vehicle moving at a fixed speed, the distance between the vehicle and the RSU's antenna when the *i*-th transmission takes place (d_i) shown in Figure 4.2 is calculated by:

$$d_i = \sqrt{r_i^{\ 2} + h^2} \tag{4-1}$$

where r_i is the distance between the vehicle and the RSU and h is the height of the RSU antenna.

The transmission power for V2V mainly depends on the distance between CH and the farthest CM from CH. In the V2V mode with a normal traffic flow, the interval between two vehicles remains almost the same. As CH tends to be in the middle of a cluster, the more vehicles involved in the cluster, the bigger transmission range (*d*) there will be. Denote the distance between two vehicles as $d_{i,j}$, then:

$$d_{i,j}^{*} = \arg\max_{i \in n} \max_{j \in n} \{d_{i,j}\} \tag{4-2}$$

Denote the transmission power of the *i*-th transmission by a vehicle to another vehicle as P_{tvi}, the transmission power of the *i*-th transmission by a vehicle to a RSU as P_{tri}, the lowest receive power at another vehicle as P_{rv}, the lowest receive power at RSU as P_{rr}, the path loss of a transmission link between two vehicles as $L_{pvi,}$ and the path loss of a transmission link between the vehicle and the RSU as $L_{pri.}$ Then, the minimal required transmission power for this vehicle is:

$$P_{tvi} = P_{rv} \cdot L_{pvi} \tag{4-3}$$

$$P_{tri} = P_{rr} \cdot L_{pri} \tag{4-4}$$

where the two path losses in (4-3) and (4-4) are defined by (using the two-ray model [57]):

$$L_{pvi} = \frac{{d_{vi}}^{4}}{{h_{vt}}^{2}{h_{vr}}^{2}G_{vt}G_{vr}} \tag{4-5}$$

$$L_{pri} = \frac{{d_{ri}}^{4}}{{h_{vt}}^{2}{h_{rr}}^{2}G_{vt}G_{rr}} \tag{4-6}$$

where G_{vt}, G_{vr} and G_{rr} are the antenna gains of the transmitting vehicle, the receiving vehicle and the RSU, respectively, h_{vt}, h_{vr} and h_{rr} are the antenna heights of the transmitting vehicle, the receiving vehicle and the RSU, respectively, d_{vi} and d_{ri} are the distance between vehicles and the distance between the vehicle and the RSU, respectively.

In the non-cluster service model, only V2I communications take place in both uplink data transmission and downlink service delivery. Therefore, the total transmission power, P_{tn}, consists of the power used for uplink transmission, P_{up}, and power for downlink transmission, P_{down}, i.e.

$$\begin{aligned} P_{tn} &= P_{up} + P_{down} \\ &= N\sum_{i=1}^{N_{tv}} P_{tvi} + N\sum_{i=1}^{N_{tr}} P_{tri} \end{aligned} \tag{4-7}$$

where P_{tvi} is the uplink transmission power of a vehicle for the *i-th* transmission, P_{tri} is the downlink transmission power of a RSU for the *i-th* transmission, and *N* is the total number of vehicles that communicate with RSU via V2I, N_{tv} is the total number of uplink transmissions and N_{tr} is the total number of downlink transmissions.

We assume that the transmission time spent on each uplink transmission is identical, i.e. t_{tv} and the P_{tvi} is constant for all uplink transmissions. Similarly, t_{tr} is defined as the transmission time for each downlink transmission and P_{tri} is constant for all downlink transmissions. Therefore, the total energy consumed in the non-cluster service model is given by:

$$E_n = P_{up}t_{tv} + P_{down}t_{tr} \tag{4-8}$$

In our proposed model, cluster head aggregates the collected data from each member and these data could have great similarity when cluster members are in a similar environment but may also differ from each other because of the unique requirement each vehicle should meet. This leads to different transmission time spent in V2I communications, depending on the level of data aggregation carried out by the cluster head. The similarity level of the data from different cluster members will affect the data size for cluster head to transmit to RSU. In addition, only the cluster head involves V2I communications.

In this model, the uplink transmission power consists of power for V2V (CMs to CH), P_{utv}, and power for V2I (CH to RSU), P_{utr}; and the downlink transmission power is also divided into two parts, i.e. power for V2V (CH to CMs), P_{dtv}, and power for V2I (RSU to CH), P_{dtr}. The total transmission power, P_{tc}, in the proposed service model can be calculated as:

$$\begin{aligned} P_{tc} &= P_{up} + P_{down} \\ &= [\, P_{utv} + P_{utr} \,] + [\, P_{dtv} + P_{dtr} \,] \\ &= [\,(N-1)\sum_{j=1}^{N_{utv}} P_{utvj} + \sum_{j=1}^{N_{utr}} P_{utrj} \,] \\ &\quad + [\,(N-1)\sum_{j=1}^{N_{dtv}} P_{dtvj} + \sum_{j=1}^{N_{dtr}} P_{dtrj} \,] \end{aligned} \tag{4-9}$$

where N is the number of vehicles in a cluster, P_{utvj} is the transmission power of the *j-th* transmission of a CM to the CH (uplink V2V), P_{utrj} is the transmission power of the *j*-th transmission of the CH to the RUS (uplink V2I), P_{dtvj} is the transmission power of the *j-th* transmission of the CH to a CM (downlink V2V), P_{dtrj} is the transmission power of *the j-th* transmission of the RUS to the CH (downlink V2I), N_{utv}, N_{utr}, N_{dtv}, and N_{dtr} are the total numbers of uplink V2V, uplink V2I, downlink V2V and downlink V2I transmissions, respectively.

We assume that the transmission time spent on each of N_{utv} transmissions is identical and represented by t_{utv}. This assumption applies also to each of N_{utr}, N_{dtv}, and N_{dtr}, respectively, which result in t_{utr}, t_{dtv} and t_{dtv}. the total energy consumed in the cluster-based service model is given by

$$E_c = P_{utv}t_{utv} + P_{utr}t_{utr} + P_{dtv}t_{dtv} + P_{dtr}t_{dtr} \tag{4-10}$$

In uplink V2I transmissions, the transmission time will be reduced as result of data aggregation at the CH due to the similarity of data collected from CMs. For this reason, t_{utr} is a result of scaling of the original time duration required for transmitting all the data collected by CH from CMs, which is t'_{utr}, by applying a scaling factor W_s, i.e.

$$t_{utv} = t'_{utv}W_s \quad (0 \leq W_s \leq 1). \tag{4-11}$$

4.5 Performance Evaluation

In this paper, the following three metrics are applied to evaluate the performance of the proposed system.

4.5.1 Service Ratio

Service ratio (γ). It is the ratio of the number of successful delivered requests n_s to the total number of requested services n. This is a vital metric to evaluate the effectiveness of the V2X system. This performance metric is given by:

$$\gamma = \frac{n_s}{n} \tag{4-12}$$

4.5.2 Average Service Delay

Average service delay (τ). It is defined as the average duration from a vehicle submitting a request to it finally receiving the service packets, which is expressed by:

$$\tau = \frac{\sum_{i=1}^{n_s} t_{si} + n_{us} \cdot t_p}{n_s} \tag{4-13}$$

where t_{si} is the time duration of the i-th successful service transmission, n_{us} is the number of unsuccessful service requests, and t_p is the waiting time a vehicle spends for the service which is not delivered.

4.5.3 System Throughput

Throughput (η). It is a widely applied metric to evaluate the transmission efficiency of a system. It is defined as the average size of data successfully delivered in a time unit.

$$\eta = \frac{p_s}{T} \tag{4-14}$$

where p_s is the total size of delivered service packets, T is the total transmission time.

4.5.4 Energy Consumption

Energy Consumption (E_C). It shows the amount of energy (Joule) will be cost to transmit one bit of data.

When CH receives all the requests and collected local data, it will aggregate the data before forwarding it to the RSU. The aggregation degree, A_I, is defined as:

$$A_I = \frac{j}{n'} \quad (4\text{-}15)$$

where, j = 1, 2, … n', n' is the number of CM whose data are successfully received by CH.

The energy it takes to transmit one bit of data in uplink (E_{Ub}) is defined as below:

$$E_{Ub} = \frac{E_U}{B_U} = \frac{E_{UV} + E_{UI}}{B_{UI}} \quad (4\text{-}16)$$

where B_{UI} is the size of data transmitted in uplink. B_{UI} is decided according to the path loss and data aggregation, which is shown as below:

$$B_{UI} = (1 - P_{UI}) \cdot B_A \quad (4\text{-}17)$$

$$B_A = (1 - P_{UV}) \cdot (A_I \cdot B_{UV}) \quad (4\text{-}18)$$

where P_{UV} and P_{UI} are the path loss rates in the V2V and the V2I process of uplink respectively, B_A is the aggregated data size, B_{UV} is the size of data transmitted from the vehicles via V2V.

It is similar to the downlink, except there is no aggregation as there are no duplicated data sending from RSU. So, the energy consumption in downlink (E_{Db}) is defined as:

$$E_{Db} = \frac{E_D}{B_D} = \frac{E_{DV} + E_{DI}}{B_{DV}} \quad (4\text{-}19)$$

where B_{DV} and B_{Di} are the sizes of data transmitted by V2V and V2I in downlink, it is affected by the path loss rate:

$$B_{DV} = (1 - P_{DV}) \cdot B_{Di} \quad (4\text{-}20)$$

$$B_{Di} = (1 - P_{Di}) \cdot B_D \quad (4\text{-}21)$$

where P_{DV} is the path loss rate in V2V of the downlink, P_{Di} is the path loss rate in the V2I period of the downlink.

Above all, the energy consumption of the whole system is:

$$E_C = \sum_{i=1}^{n_U} E_{Ub} + \sum_{j=1}^{n_D} E_{Db} \quad (4\text{-}22)$$

where n_U is the total number of uplink transmissions and n_D is the total number of downlink transmissions.

5. Simulation and Results Analysis

5.1 Simulation Tools

Compare to the real-life experiments, simulation is a more efficient way to evaluate the performance of some complex protocols, models or systems. Nowadays, many powerful simulators have been developed to evaluate the performance of VANET. The simulation of VANET includes the mobility and network simulators. In the next few sections, we will introduce some mobility and network simulators that are commonly applied in VANETs.

5.1.1 Mobility Simulators

Mobility simulators generate nodes which can follow some moving traces defined on realistic traffic scenarios. The trace and mobility definition data can be exported and cooperate with other simulators such as network simulators. VanetMobiSim[58], MOVE[59] and SUMO[60] are three common mobility simulators for VANET.

VanetMobiSim can generate mobility models both macroscopically and microscopically. It supports multiple formats of source file import and can produce trace files that can cooperate with other network simulators. Users can also generate the maps defined by themselves, but VanetMobiSim do not support multiple types of mobile nodes (i.e. multiple vehicle types in VANETs), it is not suitable for complex road networks.

MOVE (MObility model generator for VEhicular networks) is a portable mobility simulator and is convenient to use. With a simple GUI guide, users can quickly generate the trace files needed and export to support a bigger VANET project. However, the version of other simulators it supports is very limited and cannot follow the latest development of VANET now. It is not recommended to use to build big and complicated traffic networks.

SUMO (Simulation of Urban MObility) is another powerful open source software to establish traffic scenarios, including enough traffic details (e.g. large number of vehicle nodes, road topologies, traffic lights, vehicle features, mobility models, etc.) to complete the traffic network description. SUMO support complicated traffic structures and support importing the real-life maps.

5.1.2 Network Simulators

Network simulators establish the data transmission process including packets generating, senders, destinations, backgrounds, channels, propagation models and routing protocols etc. For the network simulation, there are tools like OPNET (Optimised

Network Engineering Tool)[61], NS-2 (Network Simulator-2)[62] and OMNET++ (Objective Modular Network Testbed in C ++)[63].

OPNET is a commercial network simulator platform, it supports both wired and wireless networks and is widely used in network development. The network structure in OPNET includes nodes, networks, and simulation process. There are many protocol models in this environment, for example, TCP/IP, 802.11 series, 3G and LTE etc. OPNET mainly focuses on the evaluation of the network quality of service (QoS) but it costs much more money than other open source simulators.

NS-2 is an open source simulator for networks that contains many network protocols and tools. NS-2 focuses on the simulation of OSI models, including the physical layer. The simulation of the packets is very detailed, which results in the limitation on large-scale network simulation.

OMNET++ is an object-oriented modular discrete event simulation tool. OMNET++ provides a GUI editor to simplify the network designing and description, it also provides supporting tools to learn the network structures and data flow. It has its own platform to provide useful models and simulation strategies and support large-scale network simulations. OMNET++ operate at a fast rate when simulating network protocols.

There are models to combine the mobility and network simulation tools together to simulate the VANET performance, for example, the combination of NS-2 and SUMO or OMNET++, SUMO and veins[64]. Veins is a simulation platform established for VANETs, it can run in OMNET++ and combine the simulation with the trace file from SUMO together.

The integration of simulation tools can provide a more detailed simulation of both traffic condition and data dissemination.

5.1.3 Simulation Tools Analysis

To simulate network operations in VANETs, the network simulators listed above show powerful functions and have their own features. OPNET supports many functions needed for VANETs, but it focuses on the evaluation of the network quality of service (QoS) and cost more than other open source simulators. NS-2 has been applied for a long time, but its implementation of models in the level of packets is too complexed, this would consume much more resources of the CPU and the Memory because the scale in VANETs simulation is usually very large. OMNET++ is one of the most efficient network simulators with a graphical user interface(GUI) and modular core design, it is able to run on multiple operating systems. The network topology can be independently defined and the node mobility is also supported in the simulation. Being widely supported by the research community, it has shown more advantages in VANETs.

The mobility factors in VANETs includes the vehicles, the road topologies, and the routes etc. the simulation tools should be able to generate all these files which can support the network simulator as well. Table 5.1 shows the features of the three mobility simulation tools. From the table below, it can be concluded that SUMO has the good ability to meet the requirement while VanetMobiSim cannot support the variety mobility simulations. MOVE meets most of the requirements too, but it only supports a few versions of simulators, thus it is not very practical.

From the analysis above, SUMO and OMNET++ are chosen as the simulation tools. The veins model can be applied to combine the mobility and network communication together to realise the VANET simulation.

Table 5.1 Mobility simulation tools

	VanetMobiSim	*SUMO*	*MOVE*
Software			
Portability	yes	yes	yes
Open source	yes	yes	yes
Console	×	yes	yes
GUI	yes	yes	yes
Continuous development	×	yes	×
Ease of setup	Moderate	Moderate	Easy
Ease of use	Moderate	Hard	Moderate
Maps			
Real	yes	yes	yes
User-defined	yes	yes	yes
Random	yes	yes	yes
Manhattan	×	×	×
Voronoi	yes	×	×
Mobility			
Random waypoint	yes	yes	yes
STRAW	×	yes	yes
Manhattan	×	yes	yes
Downtown	×	×	×
Traffic models			
Macroscopic	×	×	×
Microscopic	yes	yes	yes

Multilane roads	yes	yes	yes
Lane changing	yes	yes	yes
Separate directional flows	yes	yes	yes
Speed constraints	yes	yes	yes
Traffic signs	yes	yes	yes
Intersections management	yes	yes	yes
Overtaking criteria	yes	-	-
Large road networks	-	yes	yes
Collision-free movement	-	yes	yes
Different vehicle types	×	yes	yes
Hierarchy of junction types	×	Yes	yes
Route calculation	yes	Yes	yes
Traces			
Import different formats	yes	Yes	yes

5.2 Scenario Description

The simulation of the traffic scenes and communication model is performed using SUMO[65] and OMNET++[66]. OMNET++ is an extensible, modular, component-based C++ simulation library and framework, it supports varies kinds of network simulation development. SUMO is a powerful traffic simulator, which supports multiple road topologies and vehicle attributes. SUMO can cooperate with other network simulators via its Traffic Control Interface (TraCI) modules.

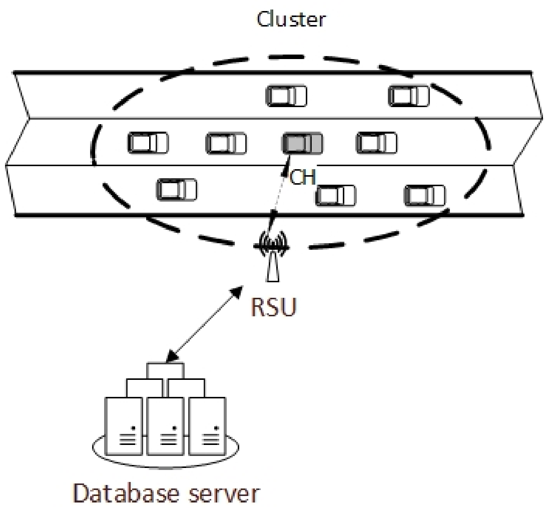


Figure 5.1 Simulation model-V2X group

We generate a one-way straight road with three lanes on SUMO, the vehicles in each lane are running as a flow, the model is shown in Figure.5.1. Because the condition in every cluster is different, according to the Highway Code[67], the safe stopping distances are related to the driving speed as shown in Figure.5.2. Considering the communication range of V2V, which is usually 300 meters, the number of vehicles in a cluster on the motorway is related to the flow speed as well. We define six scenarios for simulation when the flow speed is 32, 48, 64, 80, 96, 112 km/h respectively. The relation between vehicle numbers and flow speed is shown in Figure.5.3.

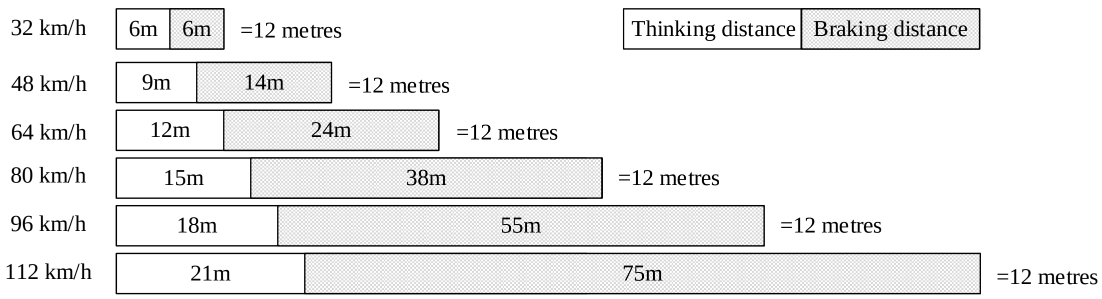


Figure 5.2 Safe stopping distances at different speeds.

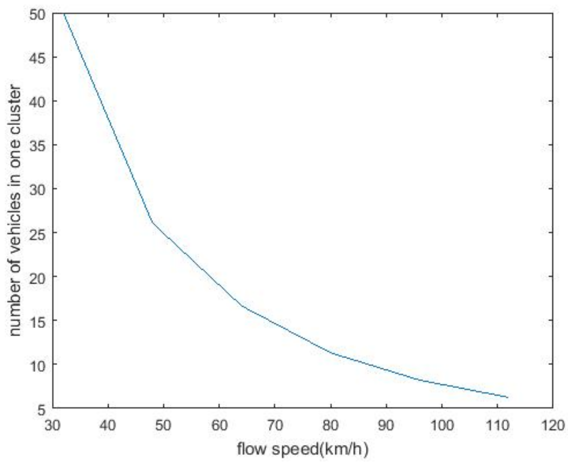


Figure 5.3 The relation between vehicle numbers and flow speed.

Another group of vehicles without clustering (i.e. without V2V process) is set so that the performance can be compared and is shown in Figure.5.4. In this non-cluster group, the same number and velocity are set in each scenario. Once the vehicles enter the communication range of the RSU, they upload collected data and service requests directly to RSU. The RSU parses the data packets and transmits the requested service back to vehicles straight away via V2I.

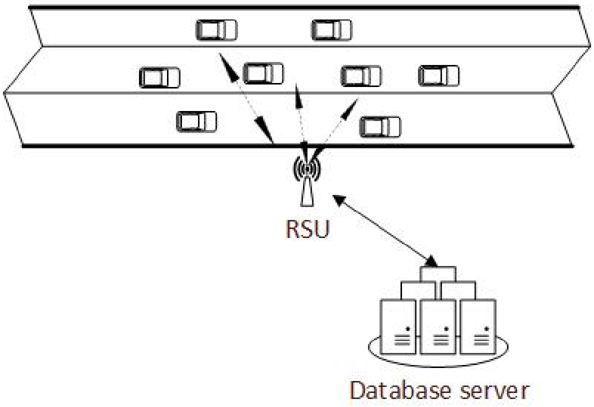


Figure 5.4 Control group-V2I group

The communication model is configured based on IEEE 802.11p and IEEE 1609 family. Including the parameters of PHY layer and MAC layer. The transmission power for V2V depends on the distance between cluster head and the furthest members. It is shown as Table 5.2. Other simulation parameters are shown in Table 5.3, the two-ray model is used as an analogue model. The transmission power for V2I is computed based on the distance between vehicles and RSU, and the size of each traffic information message is 1000 bits. The data rate is set to 6Mbps and 12 Mbps. Every vehicle randomly generates up to 20 to 25 requests and every service ID ranges from 1 to 100, the requests will be submitted to the cluster head. The simulation scenarios and operations are shown in Figure.5.5 and Figure.5.6.

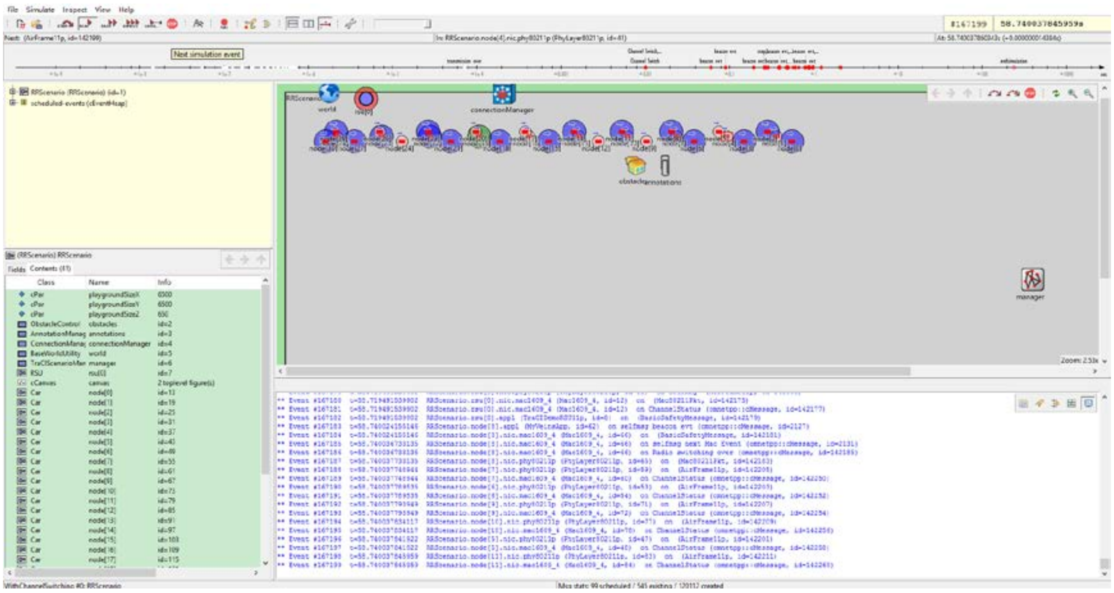


Figure 5.5 Simulation process of V2X group

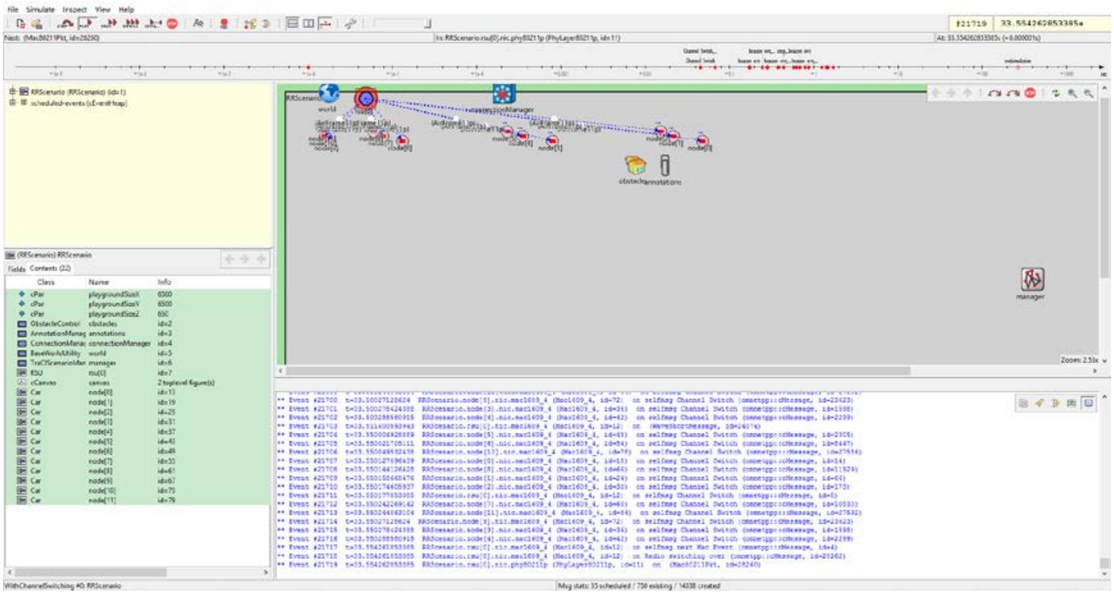


Figure 5.6 Simulation process of V2I group

Table 5.2 Transmission power for V2V and V2I

Flow speed *(km/h)*	32	48	64	80	96	112
V2V *(mW)*	0.802	1.020	0.899	0.867	0.925	0.711
V2I *(mW)*	2.885	2.898	2.890	2.841	2.878	2.821

Table 5.3 Simulation parameters

Parameters	*Value*
Frequency band	5.850-5.925 GHz
Channel bandwidth	10-20 MHz
Receive power sensitivity	-89dBm
Propagation model	two-ray model
Data rate	6Mbps, 12Mbps
Number of requests	20-25
Data size	1000 bits
Number of lanes	3
Simulation time	300s

The simulation results are analyzed to evaluate the performance of the service ratio, average service delay, throughput and energy consumption.

5.3 Simulation Results and Analysis

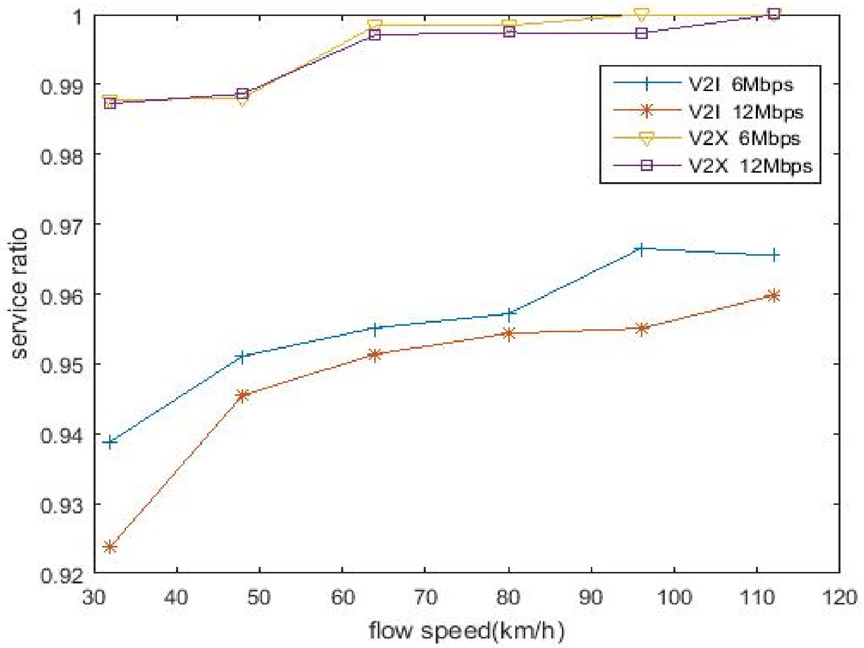


Figure 5.7 Service ratios of V2X groups and V2I groups

Figure.5.7 shows different service ratios of V2X groups and V2I groups under 6 different scenarios with different flow speeds and vehicle densities. The cluster groups reach higher and more stable service ratios in all the scenarios at both 6Mbps and 12Mbps data rates than non-cluster groups. The service ratio of non-cluster groups shows a rising trend with the increase of the flow speed. That is due to the lower density, which decreases the data uploading and services downloading, and thus reduces the transmission collision and congestion. When the flow speed is low, the distance between vehicles is relatively short, this leads to more vehicles being involved in the same transmission range and thus more service requests and collected data need to be transmitted. In this condition, by grouping vehicles in clusters, transmission load between vehicles and the RSU are reduced. So, there will be less collision in the cluster group than in the non-cluster group. When vehicles move out of the communication range of RSU, vehicles without clusters will not be able to receive service packets directly anymore. But with clusters, because CH has stored the service data from RSU, CMs could still obtain service from CH as long as they are in the same cluster.

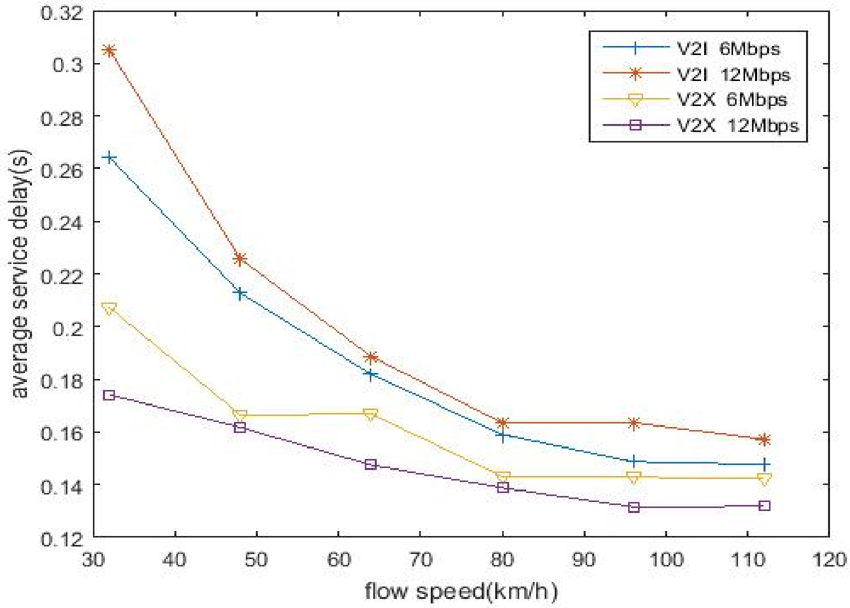


Figure 5.8 Average service delay of V2X groups and V2I groups.

The average service delay is shown in Figure.5.8. This delay includes the time spent on transmitting the service data and the time spent to wait for re-transmitting when the previous service delivery is failed. In the non-cluster group, each vehicle has to wait for service data from the RSU one by one. This delay is decreased in groups with clusters, this is because only CH is involved in V2I in cluster groups. What's more, CH aggregates the service requests ahead, vehicles in one cluster with the same requests can receive the service data together when CH broadcasts service packets. Due to the lower service ratio in Fig.7, the time spent to re-transmit service data in non-cluster groups is also more than cluster groups. When the flow speed increases, there will be less communication collision and congestion as the number of vehicles is decreased, therefore, vehicles with clusters do not show as many advantages as they are at a slower speed. In fact, when the transmission load is small, clustering does not contribute much to the service delay because the data aggregation and re-distribution in the cluster group also cost time. In general, the average service delay for all vehicles in the cluster group is shorter than in the non-cluster groups.

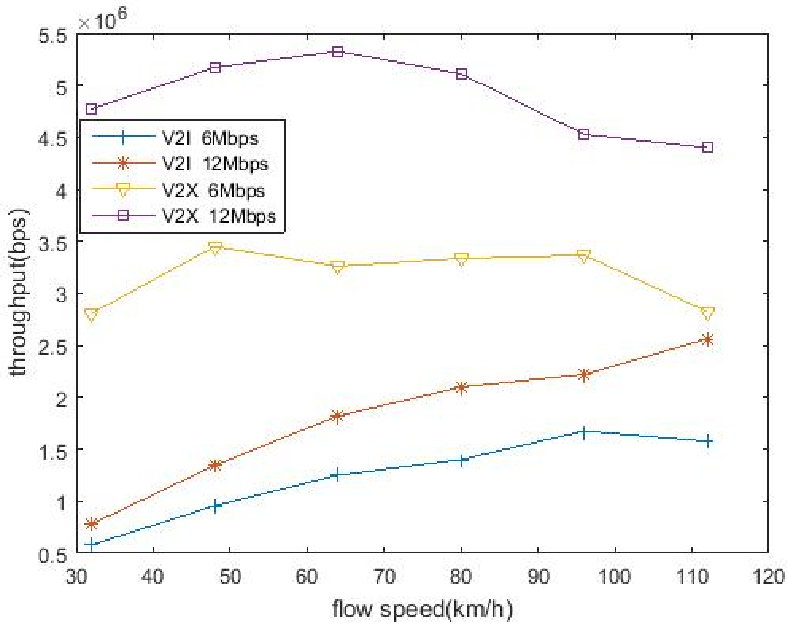


Figure 5.9 Throughput of V2X groups and V2I groups.

Figure.5.9 shows that the throughput of the cluster groups clearly outperforms the non-cluster group under all six different scenarios. The throughput of cluster groups keeps a higher and more stable level than the non-cluster groups. The throughput of the clustered group at 6Mbps is over 2 times higher than that of the non-cluster groups, when the data rate turns to 12Mbps, the difference increases up to more than 2-4 times that of non-cluster groups. When there are fewer service requests under a faster speed scenario, the non-cluster groups could complete more data transmission within the same transmission time unit.

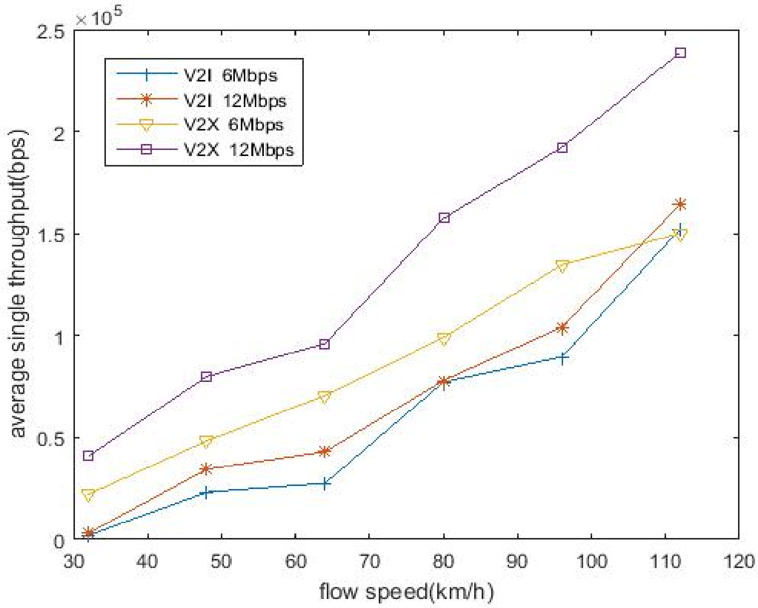


Figure 5.10 Average Throughput of each individual vehicle

The average throughput of each individual vehicle in Figure.5.10 shows the throughput level of each individual vehicle at different flow speeds. With the increase of flow speed, the throughput of individual increases as well. Groups with higher data rate show higher throughput in general. Under smaller speed, clustered vehicles achieve higher throughput because clustering helps to improve the transmission efficiency. As higher data rate enables vehicles to transmit more data at the same time unit, so when the flow speed increases, vehicles without clusters but in a higher data rate also achieve higher throughput.

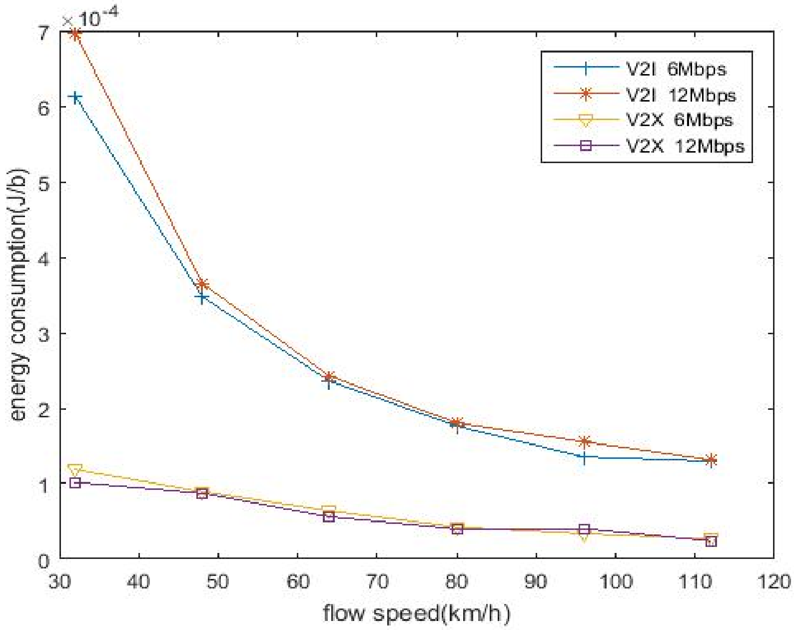
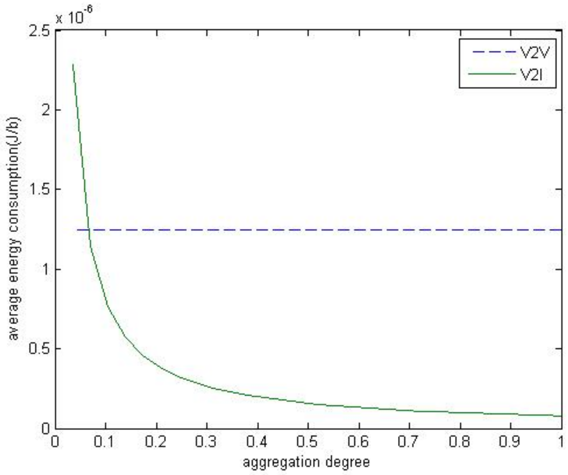
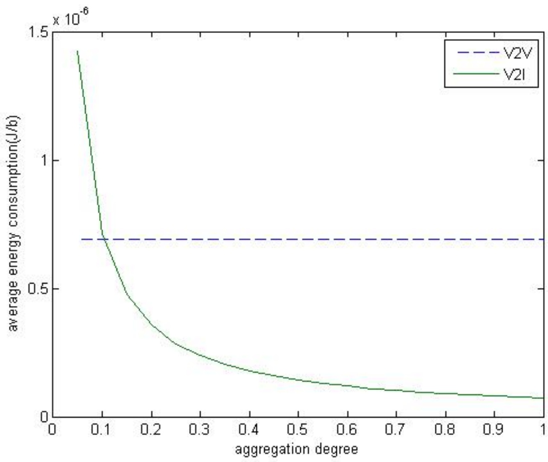


Figure 5.11 Energy consumption of V2I and V2X groups

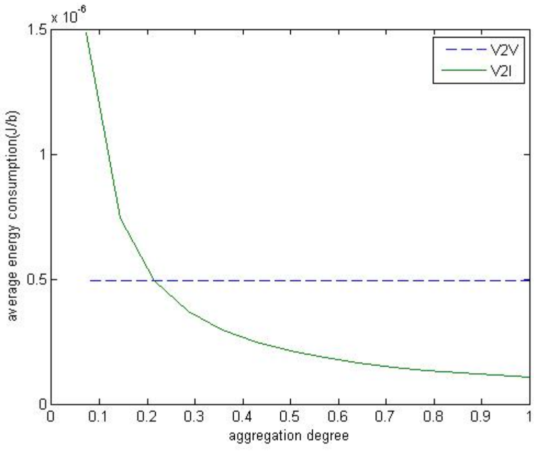
Figure.5.11 shows the energy consumption of the two models. Energy consumption in this paper is defined as the amount of energy cost to deliver one bit of data. Vehicles with clusters exchange data via V2X communications, mainly via V2V communication, while the non-cluster group only relays on V2I communications. When the flow speed is slow, there are more vehicles involved in the transmission range, and thus vehicles need to spend more time to transmit data in long distance. It takes more energy to transmit data between vehicles and the RSU, so, the average energy it takes to transmit data in cluster groups is much less than it in non-cluster groups.



a) Flow speed 80km/h



b) Flow speed 96km/h



c) Flow speed 112km/h

Figure 5.12 Relation between aggregation degree and energy consumption

Figure.5.12 shows the relationship between aggregation degree and the energy consumption of the V2V and the V2I transmission in the uplink under different vehicle densities. The aggregation degree indicates the different level of data aggregation: 0 refers to no data aggregated at all and 1 indicates that all the data from each vehicle is the same. TABLE.II shows that the transmission power in V2I mode is much greater than it in V2V mode. In V2V transmission, the average distance between vehicles and the CH under the same speed remains the same in the traffic flow, so, when the aggregation degree increases, the transmission power to send each packet remains the same as well. But in the V2I process, when more data are aggregated together, there will be fewer data to be transmitted and there will be fewer transmission times as well. Therefore, when the data aggregation degree is greater, the energy consumed to transmit each bit of data is decreased. When there is more data to be transmitted from the CH to the RSU (i.e. the aggregation degree is lower than the crossing point in fig.12), models with clusters, where V2V plays an important role to deliver packets inside clusters, will show much more advantages in energy efficiency.

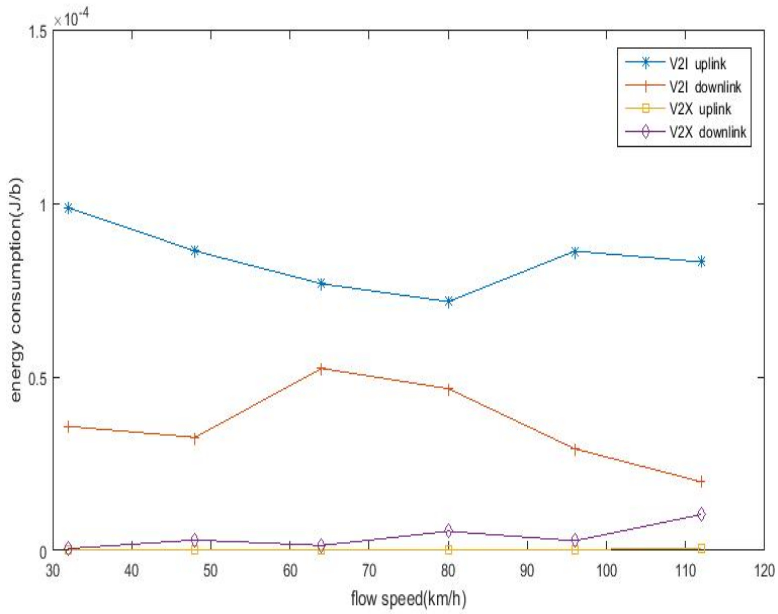


Figure 5.13 Energy consumption in uplink and downlink

Figure.5.13 shows the energy consumption in the uplink and downlink respectively. In the clustered model, there is much lower energy cost to transfer data from every single node to the RSU. Because the requests and the collected data from each CM are aggregated by the CH, so there will be fewer data to be transmitted via V2I in the uplink. Compare to the non-cluster model, the energy consumption in the clustered model is much lower and stable. In the model without clusters, every node transmits its data to the RSU respectively, because all the packets are delivered via V2I, it will cost more energy to finish the transmissions. Therefore, the average energy consumption in both links of the clustered model is superior to the conventional non-cluster model.

6. Conclusions and Future Work

6.1 Conclusions

With the development of communications and networking technologies, vehicles tend to be smart and environmentally friendly. This has led to the requirements of traffic data services and the improvement of energy efficiency. This research project is focused on improving the data service efficiency of vehicles on motorways and the battery efficiency of electronic vehicles.

In this work, an efficient clustering and cluster head election algorithm is proposed first, which is based on the idea of 'combined weight' that considers the mobility of vehicles, driving behaviours, efficiency of data exchange and service delivery. Then, the traffic data service process is designed, including data collection, data aggregation and service data delivery. Considering the transmission features in VANETs, four evaluation metrics are introduced to assess the performance of the proposed service model. Tools such as OMNET++ and SUMO are applied to simulate the model performance, with SUMO being used to design the motorway scenarios and OMNET++ used to configure the communications process and design the network protocols. A non-clustered model with pure V2I communications is also assessed in the simulation to compare its performance with that of the proposed model. The simulation results show that our service model could provide vehicles with the requested service data efficiently at low energy consumption. Compare to the pure V2I communications, our model shows higher service ratio with lower service delay and energy consumption. This is because only CHs are responsible for direct communications with the RSU and disseminating service data to other vehicles in the network via V2V. in this way, most of the high-power transmission (V2I) process has been transferred to low-power transmission (V2V), so the energy consumption in delivering service data is effectively reduced.

By providing vehicles with real-time traffic and environmental information, vehicles are able to elect the best routes to their destinations, so that the travelling time can be reduced, and the road safety can be improved. The improvement of the energy efficiency is shown in two aspects: firstly, it costs less power to transmit data via V2V than via V2I, so the total energy consumption in cluster-based V2X communications can be significantly reduced, which is especially important for electronic vehicles. Secondly, as vehicles can receive real-time traffic and environmental related data through V2X to manage the routes and travelling time and safety-related alarms help to reduce sudden brakes, etc., much less energy is required to reach the destination.

The achievements of this work include:

1. We have proposed a cluster-based service model for vehicles on motorways to receive the requested services and manage their routes and travelling time.
2. We have designed a new weighting metric to elect cluster head, considering the position, velocity stability, connectivity and driving behaviours.
3. We have proposed a two-way transmission model, where local traffic and environmental information is collected and submitted to the backbone network in the uplink, and the real-time service data is transmitted from the network to the vehicles in the downlink.
4. We have proposed a new service delay metric which considers not only the delay in successful transmissions, but also the delay in unsuccessful transmissions or service delivery. This metric reflects a more realistic service time efficiency of the model.
5. The energy model of this two-way service model is built and analysed, including the system energy model, and uplink and downlink energy models.
6. Different simulation tools are compared and evaluated, of which two efficient simulators – SUMO and OMNET++ are elected for this project after comparison.
7. The performances of the proposed model in terms of service ratio, average service delay, throughput and energy consumption are analysed in comparison with the non-cluster service model.
8. A paper based on the results of this work has been published by and presented at the 10th EAI International Wireless Internet Conference (16-17 December 2017).

6.2 Future Work

There are some extended ideas related to this work worth considering. For example, the data aggregation method will be extended to develop specific aggregation algorithms with consideration of the position of vehicles, the similarity of data based on the information entropy collected from different vehicles. In addition, cellular mobile communications facilities such as LTE for vehicles (LTE-V) could support higher transmission rates, especially when the 5G platform becomes available in the near future.

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APPENDIX

A. Published work

[1] **Yongyue Shi**, Xiaohong Peng, Guangwei Bai. Cluster-Based Cooperative Data Service for VANETs [C]. Proc. of 10th EAI International Wireless Internet Conference, Tianjin, China, November 2017

B. XML scripts supported by SUMO


```
<?xml version="1.0"?>
<!-- debug config -->
<launch>
        <copy file="erlangen.net.xml" />
        <copy file="erlangen.rou.xml" />
        <copy file="erlangen.sumo.cfg"
type="config" />
</launch>

<?xml version="1.0" encoding="UTF-
8"?>

<configuration
xmlns:xsi="http://www.w3.org/2001/XML
Schema-instance"
xsi:noNamespaceSchemaLocation="htt
p://sumo.dlr.de/xsd/netedit.exeConfigur
ation.xsd">

   <input>
      <sumo-net-file
value="D:\Aston\project\Simulation\Mobi
lity\erlangen.net.xml"/>
   </input>

   <output>
      <output-file
value="D:\Aston\project\Simulation\Mobi
lity\erlangen.net.xml"/>
   </output>
   <processing>
      <no-turnarounds value="true"/>
      <offset.disable-normalization
value="true"/>
      <lefthand value="false"/>
      <junctions.corner-detail
value="0"/>
   </processing>

</configuration>

<net version="0.27"
xmlns:xsi="http://www.w3.org/2001/XML
Schema-instance"
xsi:noNamespaceSchemaLocation="htt
p://sumo.dlr.de/xsd/net_file.xsd">

   <location netOffset="0.00,0.00"
convBoundary="0.00,55.00,1000.00,55.
00" origBoundary="-10000000000.00,-
10000000000.00,10000000000.00,1000
0000000.00" projParameter="!"/>

   <edge id=":1_0" function="internal">
      <lane id=":1_0_0" index="0"
speed="8.89" length="0.10"
shape="500.00,46.75 500.00,46.75"/>
      <lane id=":1_0_1" index="1"
speed="8.89" length="0.10"
shape="500.00,50.05 500.00,50.05"/>
      <lane id=":1_0_2" index="2"
```

```
speed="8.89" length="0.10"
shape="500.00,53.35 500.00,53.35"/>

    </edge>


    <edge id="e0" from="0" to="1"
priority="1" length="1500.00">

        <lane id="e0_0" index="0"
speed="8.89" length="1500.00"
shape="0.00,46.75 500.00,46.75"/>

        <lane id="e0_1" index="1"
speed="8.89" length="1500.00"
shape="0.00,50.05 500.00,50.05"/>

        <lane id="e0_2" index="2"
speed="8.89" length="1500.00"
shape="0.00,53.35 500.00,53.35"/>

    </edge>

    <edge id="e1" from="1" to="2"
priority="1" length="1000.00">

        <lane id="e1_0" index="0"
speed="8.89" length="1000.00"
shape="500.00,46.75 1000.00,46.75"/>

        <lane id="e1_1" index="1"
speed="8.89" length="1000.00"
shape="500.00,50.05 1000.00,50.05"/>

        <lane id="e1_2" index="2"
speed="8.89" length="1000.00"
shape="500.00,53.35 1000.00,53.35"/>

    </edge>


    <junction id="0" type="unregulated"
x="0.00" y="55.00" incLanes=""
intLanes="" shape="0.00,54.95
0.00,45.15"/>

    <junction id="1" type="priority"
x="500.00" y="55.00" incLanes="e0_0
e0_1 e0_2"
intLanes=":1_0_0 :1_0_1 :1_0_2"
shape="500.00,54.95 500.00,45.15
500.00,54.95">

        <request index="0"
response="000" foes="000" cont="0"/>

        <request index="1"
response="000" foes="000" cont="0"/>

        <request index="2"
response="000" foes="000" cont="0"/>

    </junction>

    <junction id="2" type="unregulated"
x="1000.00" y="55.00" incLanes="e1_0
e1_1 e1_2" intLanes=""
shape="1000.00,45.15
1000.00,54.95"/>


    <connection from="e0" to="e1"
fromLane="0" toLane="0" via=":1_0_0"
dir="s" state="M"/>

    <connection from="e0" to="e1"
fromLane="1" toLane="1" via=":1_0_1"
dir="s" state="M"/>

    <connection from="e0" to="e1"
fromLane="2" toLane="2" via=":1_0_2"
dir="s" state="M"/>


    <connection from=":1_0" to="e1"
fromLane="0" toLane="0" dir="s"
state="M"/>

    <connection from=":1_0" to="e1"
fromLane="1" toLane="1" dir="s"
state="M"/>

    <connection from=":1_0" to="e1"
fromLane="2" toLane="2" dir="s"
state="M"/>


</net>


<?xml version="1.0" encoding="UTF-
8"?>

<routes>

   <vType id="vtype0" accel="2.6"
decel="4.5" sigma="0.5" length="4.5"
minGap="96" maxSpeed="32"
color="1,1,0"/>

   <vType id="vtype1" accel="3.2"
decel="2.5" sigma="0.5" length="4.5"
minGap="73" maxSpeed="27"
color="1,0,0"/>

   <vType id="vtype2" accel="4.2"
decel="3.5" sigma="0.5" length="4.5"
minGap="53" maxSpeed="23"
color="1,0,1"/>

   <vType id="vtype3" accel="3.2"
decel="4.5" sigma="0.5" length="4.5"
minGap="36" maxSpeed="18"
color="1,1,0"/>
```

```
  <vType id="vtype4" accel="3.2" decel="2.5" sigma="0.5" length="4.5" minGap="23" maxSpeed="14" color="1,0,0"/>

  <vType id="vtype5" accel="4.2" decel="3.5" sigma="0.5" length="4.5" minGap="12" maxSpeed="9" color="1,0,0"/>

   <route id="route01" edges="e0 e1"/>

  <flow id="flow0" type="vtype5" route="route01" begin="0" period="3" number="36" departLane="0"/>

  <flow id="flow1" type="vtype5" route="route01" begin="2" period="3" number="36" departLane="1"/>

  <flow id="flow2" type="vtype5" route="route01" begin="3" period="3" number="36" departLane="2"/>


  </routes>
```

```
<?xml version="1.0" encoding="UTF-8"?>
<root>
	<AnalogueModels>
		<AnalogueModel type="TwoRayInterferenceModel">
			<parameter name="alpha" type="double" value="2.0"/>
			<parameter name="carrierFrequency" type="double" value="5.890e+9"/>
		</AnalogueModel>

	</AnalogueModels>
	<Decider type="Decider80211p">
		<!-- The center frequency on which the phy listens-->
		<parameter name="centerFrequency" type="double" value="5.890e9"/>
	</Decider>
</root>
```

```
  <?xml version="1.0" encoding="iso-8859-1"?>
<configuration xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation="http://sumo.sf.net/xsd/sumoConfiguration.xsd">
   <input>
      <net-file value="erlangen.net.xml"/>
      <route-files value="erlangen.rou.xml"/>

   </input>

   <time>
      <begin value="0"/>
      <end value="1000"/>
      <step-length value="0.1"/>
   </time>

   <gui_only>
      <start value="true"/>
   </gui_only>

</configuration>
```

C. Configure File in OMNET++

```
[General]
cmdenv-express-mode = true
cmdenv-autoflush = true
cmdenv-status-frequency = 1s

ned-path = .

network = RRScenario

##########################################################
#             Simulation parameters                      #
##########################################################
debug-on-errors = true
print-undisposed = false

sim-time-limit = 300s

**.scalar-recording = true
**.vector-recording = true

**.debug = false
**.coreDebug = false

*.playgroundSizeX = 6500m
*.playgroundSizeY = 6500m
*.playgroundSizeZ = 650m

##########################################################
# Annotation parameters                                  #
##########################################################
*.annotations.draw = true

##########################################################
#             TraCIScenarioManager parameters            #
##########################################################
*.manager.updateInterval = 1s
*.manager.host = "localhost"
*.manager.port = 9999
*.manager.autoShutdown = true
*.manager.launchConfig = xmldoc("erlangen.launchd.xml")

##########################################################
#                        RSU SETTINGS                    #
##########################################################
*.rsu[*].mobility.x = 500
*.rsu[*].mobility.y = 100
*.rsu[*].mobility.z = 8

#*.rsu1[*].mobility.x = 1000
#*.rsu1[*].mobility.y = 100
#*.rsu1[*].mobility.z = 3

*.rsu[*].applType = "TraCIDemoRSU11p"
*.rsu[*].appl.headerLength = 80 bit
*.rsu[*].appl.sendBeacons = false
*.rsu[*].appl.dataOnSch = false
*.rsu[*].appl.beaconInterval = 1s
*.rsu[*].appl.beaconPriority = 3
```

```
*.rsu[*].appl.dataPriority = 2

##########################################################
#            11p specific parameters                     #
#                    NIC-Settings                        #
##########################################################
*.connectionManager.sendDirect = true
*.connectionManager.maxInterfDist = 2600m
*.connectionManager.drawMaxIntfDist = false

*.**.nic.mac1609_4.useServiceChannel = false

*.**.nic.mac1609_4.txPower = 20mW
*.**.nic.mac1609_4.bitrate = 12Mbps
*.**.nic.phy80211p.sensitivity = -89dBm

*.**.nic.phy80211p.useThermalNoise = true
*.**.nic.phy80211p.thermalNoise = -110dBm

*.**.nic.phy80211p.decider = xmldoc("config.xml")
*.**.nic.phy80211p.analogueModels = xmldoc("config.xml")
*.**.nic.phy80211p.usePropagationDelay = true

##########################################################
#                    WaveAppLayer                        #
##########################################################
*.node[*].applType = "MyVeins"
*.node[*].appl.headerLength = 80 bit
*.node[*].appl.sendBeacons = true
*.node[*].appl.dataOnSch = false
*.node[*].appl.beaconInterval = 1s

##########################################################
#                      Mobility                          #
##########################################################
*.node[*].veinsmobilityType.debug = true
*.node[*].veinsmobility.x = 0
*.node[*].veinsmobility.y = 0
*.node[*].veinsmobility.z = 1.895

[Config WithoutChannelSwitching]

[Config WithChannelSwitching]
*.**.nic.mac1609_4.useServiceChannel = true
*.node[*].appl.dataOnSch = true
*.rsu[*].appl.dataOnSch = true
```