ENHANCED OFFLOAD AND GATEWAY SELECTION SCHEMES FOR HETEROGENEOUS VEHICULAR NETWORKS

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DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

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ABSTRACT

A Heterogeneous Vehicular Network (HetVNET) is a promising network infrastructure that integrate various network technologies ranging from IEEE802.11p Dedicated Short Range Communication to the Third Generation/Fourth Generation cellular networks. In such network environment, wireless fidelity access points (Wi-Fi APs) can be utilized by vehicle users to stabilize the Long-Term Evolution (LTE) 4G networks through offloading. However, in the case of Wi-Fi APs is not readily available, the vehicles have to organized themselves and select appropriate mobile gateway (MGW) to communicate to the cellular infrastructure. However, it can be observed that utilizing the opportunistic Wi-Fi APs to offload the LTE networks in a HetVNET environment is relatively easier said than done. This condition is due to the short coverage of Wi-Fi APs and weak deployment strategies of APs. Many studies have proposed that offloading schemes depend on the historical Wi-Fi connection patterns observed by an interest vehicle in making an offloading decision. However, depending solely on the historical connection patterns affects the prediction accuracy and offloading ratio of most existing schemes even when AP location information is available. Consequently, the researchers are facing the problem of selecting best MGW vehicle to aggregate vehicle traffics and reduce LTE load in HetVNET in case where the Wi-Fi APs are not available for offloading. The selection process exerts extra network overheads and complexity due to allowing clusters to be formed in this highly dynamic environment. The main objective of this research is to enhance offload and gateway selection schemes for HetVNET. Firstly, the offload is enhanced using multi-criteria wireless availability prediction (MWAP) scheme, which utilizes historical connection patterns, historical data rate information, vehicular trajectory computation to predict the next available AP and its expected data capacity in making offloading decisions. The proposed scheme is decentralized and focuses on urban scenarios whereby the likelihood of the interest vehicle to encounter Wi-Fi APs is high. Secondly, the gateway selection is enhanced by proposed a non-cluster adaptive Quality of Service (QoS) aware gateway selection (AQAGS) scheme that dynamically selects small number of vehicles to act as gateways to LTE network depends on the load status of LTE network and QoS requirement of the Vehicular Ad hoc Network applications. The AQAGS scheme is focuses on the highway whereby the likelihood of the vehicle to encounter the Wi-Fi APs is low. The proposed schemes are evaluated using simulation. In case of MWAP scheme, MATLAB simulator was used and for AQAGS, the integration of SUMO and NS2 simulators were utilized and benchmark with the related start-of-the-art schemes. The simulation results show that, MWAP scheme improves the offloading ratio by 9.8% and 28.5%, compared to the reference schemes respectively. In addition, the overall prediction error is reduced by 7.5% compared to the benchmarked scheme. Meanwhile, AQAGS scheme delivered 20.7% improvement in overall system throughput while maintaining acceptable QoS for both Voice over Internet Protocol and File Transfer Protocol applications in comparison with cluster based scheme.

ABSTRAK

Rangkaian Kenderaan Heterogen (HetVNET) adalah infrastruktur rangkaian baru yang mengintegrasikan pelbagai teknologi rangkaian dari Komunikasi Khusus Jarak Dekat IEEE802.11p ke rangkaian selular Generasi Ketiga/Keempat. Dalam persekitaran rangkaian ini, titik capaian kesetiaan tanpa wayar (AP Wi-Fi) boleh digunakan oleh pengguna kenderaan untuk menstabilkan rangkaian 4G Evolusi Jangka Panjang (LTE) melalui lepas beban. Namun, dalam keadaan AP Wi-Fi yang tidak tersedia, kenderaan tersebut perlu menyusun diri masing-masing dan memilih gerbang mudah alih (MGW) yang sesuai untuk berkomunikasi dengan infrastruktur selular. Penggunaan AP Wi-Fi untuk mengimbangi rangkaian LTE dalam persekitaran HetVNET nampak mudah, namun agak sukar untuk diimplementasi. Keadaan ini adalah disebabkan oleh liputan pendek AP Wi-Fi dan kelemahan strategi susunatur AP. Pelbagai kajian telah mencadangkan agar skema lepas beban disandarkan kepada corak sambungan Wi-Fi sejarah melalui pemerhatian kenderaan yang berkepentingan bagi membuat keputusan lepas beban. Kebergantungan khusus pada corak sambungan masa lampau sangat mempengaruhi kejituan ramalan dan nisbah lepas beban bagi kebanyakan skema sedia ada, walaupun maklumat kedudukan AP diketahui. Hasilnya, para penyelidik masih menghadapi masalah memilih kenderaan MGW terbaik untuk mengagregat trafik kenderaan serta mengurangkan beban LTE di HetVNET, terutamanya dalam kes AP Wi-Fi tidak sedia ada untuk lepas beban. Proses pemilihan tersebut telah meningkatkan lagi lebihan dan kekompleksan ke atas rangkaian akibat kelompok yang dibenarkan terbentuk dalam persekitaran dinamik sangat tinggi. Objektif utama penyelidikan ini adalah untuk meningkatkan skema lepas beban dan pemilihan gerbang bagi HetVNET. Pertamanya, lepas beban dipertingkatkan dengan menggunakan skema ramalan ketersediaan tanpa wayar berbilang kriteria (MWAP), dengan menggunakan corak sambungan sejarah, informasi kadar data sejarah, pengiraan trajektori kenderaan untuk meramalkan AP seterusnya dan kapasiti data yang dijangkakan bagi membuat keputusan lepas beban. Skema yang dicadangkan adalah tak berpusat dengan tumpuan menjurus kepada senario bandaran yang kebolehjadian kenderaan berkepentingan untuk menemukan AP Wi-Fi adalah tinggi. Keduanya, pemilihan gerbang akan dipertingkatkan dengan mencadangkan skema pemilihan gerbang penyesuaian Kualiti Perkhidmatan (QoS) bukan kelompok (AQAGS) yang secara dinamik akan memilih sejumlah kecil kenderaan untuk bertindak sebagai gerbang ke rangkaian LTE, bergantung kepada status beban rangkaian LTE dan keperluan QoS bagi aplikasi Rangkaian Ad hoc Kenderaan. Skema AQAGS akan difokuskan di kawasan lebuh raya yang mana kemungkinan bagi kenderaan untuk menemukan AP Wi-Fi adalah rendah. Skema yang dicadang akan disahkan melalui penyelakuan. Simulator MATLAB telah digunapakai untuk skema MWAP, manakala bagi AQAGS, integrasi antara simulator SUMO dan NS2 telah digunakan serta ditanda aras dengan skema terkini yang berkaitan. Hasil simulasi menunjukkan bahawa skema MWAP meningkatkan nisbah lepas beban sebanyak 9.8% dan 28.5%, masing-masing berbanding dengan skema rujukan. Selain itu, keseluruhan ralat ramalan dapat dikurangkan sebanyak 7.5% berbanding dengan skema penanda aras. Hasil kajian juga mendapati skema AQAGS dapat mempertingkatkan keseluruhan kadar celusan sebanyak 20.7% di samping mengekalkan tahap QoS bagi aplikasi Protokol Internet melalui Suara dan Protokol Pengangkutan Fail berbanding dengan skema berasaskan kelompok.

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LIST OF ILLUSTRATIONS

LIST OF ABBREVIATIONS

3G	Third Generation
ABV	Automatisation Basse Vitesse
ACK	Acknowledgement
AKTIV	Adaptive and Cooperative Technologies for Intelligent Traffic
AODV	Ad hoc On-Demand Distance Vector
AP	Access Point
AQAGS	Aware Gateway Selection
AVC	Gateway Available Capacity
BS	Base Station
BST	Base Station Transceiver
CDF	Cumulative Distribution Function
CDP	Correctly Decoded Probability
CH	Cluster Head
CMGM	Cluster-Based Multi-Metric Adaptive MGW Management Mechanism
CMVT	Clustered Virtual Mesh-Based Tree
CPO	Control Packet Overhead
CQI	Channel Quality Indication
D	Distance
DOVE	Data Offloading Through Spatio-Temporal Rendezvous in Vehicular Networks
DRIVE	Discovery of Internet Gateways from Vehicles
DSDV	Destination-Sequenced Distance Vector Routing Protocol
DSR	Dynamic Source Routing
DR-table	Data rate table
DT	Delay tolerance application
DT	Delay Tolerant
E-HWMP	Enhanced Hybrid Wireless Mesh Protocol
EPC	Evolved Packet Core
eNB	E-UTRAN Node B
FTP	File Transfer Protocol
FTP	File Transfer Protocol

GDT	Gateway Delay Time
GGSN	Gateway GPRS Support Node
GPS	Global Positioning System
GSM	Global system for mobile communications
GWadv	Gateway Advertisement
GWC	Gateways Candidates
GWCs	Gateway Candidates
GWrep	Gateway replay message
GWreq	Gateway request message
GWS	Gateway Selection
HARP	Hybrid Ad Hoc Routing Protocol
HetVNET	Heterogeneous Vehicular Network
HVN	Heterogeneous Vehicular Network
IoT	Internet of Thing
IP	Internet Protocol
ITS	Intelligent Transportation System
IV	Interest Vehicles
LAPGD	Location-Aided and Prompt Gateway Discovery Mechanism
LCD	Link Connectivity Duration
LLT	Link Life Time
LTE	Long-Term Evolution
MAC	Medium Access Control
MANET	Mobile Ad hoc Network
MGW	Mobile Gateway
MPRs	Multipoint relays
MWAP	Multi-criteria Wireless Availability Prediction
NDT	Non-delay tolerance application
NV	Neighbour Vehicle
OBUs	On-board Units
ODAM	Optimized Dissemination of Alarm Messages
OLSR	Optimized Link State Routing Protocol
OPs	Offloading Positions
OR	Offloading Ratio

OV	Ordinary Vehicle
PBR	Prediction based routing protocol
PDR	Packet Delivery Ratio
PE	Prediction Error
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
PT	Prediction Table
QoE	Quality of experience
QoS	Quality of Service
RATs	Radio Access Technologies
RET	Route Expiration Time
RN	Relay Node
RNC	Radio Network Controller
RREP	route reply
RREQ	route request
RSS	Receive Signal Strength
RSU	Road Side Unit
RV	Relay Vehicle
SAM	Simple Additive Metric
SAW	Simple Additive Weighting
SGS	Simplified Gateway Selection Scheme
SGSN	Serving GPRS Support Node
SKY	Start ITS from Kanagawa, Yokohama
SNR	Signal-to-noise ratio
SUMO	Simulation of Urban Mobility
SV	Source Vehicle
T	Time out
TTL	Time to live
UDP	Use Neighbour Discovery Protocol
UMTS	Universal Mobile Telecommunications System
V	Vehicle
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle

VANET	Vehicular Ad hoc Network
VII	Vehicle Infrastructure Integration
VIKOR	VIseKriterijumska Optimizacija i Kompromisno Resenje
VoIP	Voice over IP
VTG	Velocity Relative to Gateway
VWO	Vehicle Wi-Fi Offloading
VWO	Vehicular Wi-Fi Offloading
Wi-Fi APs	Wireless Fidelity Access Points
WLANs	Wireless Local Area Networks
ZRP	Zone routing protocol

LIST OF SYMBOLS

C_2	Position at a distance d from C_1.
H_t	Total number of information in PT
T_i	Total delay of packets received by the destination node
v_j	Velocity of NV
v_i	Velocity IV
AP_c	Current Wi-Fi AP connected
AP_f	Future Wi-Fi AP encounter
AP_p	Previous Wi-Fi AP contacted
AR_v	Average packet arrival rate
A_c	Coverage area of IV
C_1	Handoff trigger position.
$C_t(G)$	Current data rate used by the group G
C_{vmax}	Maximum traffics that can be served by NV.
D_{IVNV}	Separation distance between IV and NV
$D_t\ (G)$	The groups range data rate based on the position of AP
N_i	Number of packets received by the destination node
P_i	Metric value
P_{max}	Maximum value of the metric,
P_{min}	Minimum value of the metric
$Prob_1$	Probability of the next Wi-Fi AP_f using previously contacted
$Prob_2$	Probability of the next Wi-Fi AP_f of using the current Wi-FiAP_c
$Prob_3$	Probability of how close the IV moves to the predicted AP AP_f
$Prob_f$	Probability product
Pr_v	Average packet arrival rate
Ps_v	Average packet size.
RL_{eNB}	Residual load capacity
RSS_{IV}	Received signal strength
R_{max} *is the*	Maximum transmission range of IEEE802.11p
Th_{rss}	Threshold Receive Signal Strength
X_i	Scaled metric value of the metric,
b_{eNB}	Backoff value

PS_v	Average packet size
b_f	Expected average bandwidth
c_v	Back off value.
t_G	Maximum delay-tolerance value for the specific application.
t_{cf}	Time that will elapse before it meets the predicted Wi-Fi AP_f
v_i,	Velocity of *IV*
λ_v	Current traffics served by NV
b	Minimum bandwidth observed by the IV
$CPgen$	Total number of control packets generated
d	Distance
G	Application group
LC	Location coordinate
N	Frequency of the specific connection pattern observed
PF	Priority factor
Q	Queue
R	Receive packets and *S* is the sent packets.
S	Sent packets.
$seqNo$	Sequence Number
$sourceDir$	Source node direction
$sourceID$	Source identification
TG	Traffic generated by the IV
TO	Traffic offloaded
$TPgen$	Number of packets generated within the integration network
TTL	Time to live
WAP	Numbers of Wi-Fi APs anticipated precisely
WE	Number of Wi-Fi AP encountered
$A(G)$	Data the IV would transfer within maximum tolerable
$C(G)$	Expected data capacity
FP	First Packet
LP	Last Packet
V	Speed
p	Probability
β	Angle calculated at C_2

γ	Degree of application usage observed by the IV.
δ	Variety in LTE-eNB signal strength
ε	Channel fading condition of IV.
θ	Angle calculated at C_1
ω	Average angle

CHAPTER I

INTRODUCTION

1.1 INTRODUCTION

The transportation system continues to progress from concentrating on building new roads and repairing the old ones to more on making it smart and intelligence. The notion of intelligent transportation system (ITS) is to make the vehicles, roadside sign boards, traffic lights smart enough to communicate through wireless technologies (Faye & Chaudet 2016). The automotive industry and research community are currently contemplating on deploying networks among vehicles to enable inter-vehicle communication utilizing ad hoc architecture, which is referred to as vehicular ad hoc network or VANET. The envision of VANET which is characterized with self-organized and decentralized network administration makes the transportation system comfortable and reliable (Sharef et al. 2014).

The considerable capability of this inversion has been recognized by impressive development inside the vehicles themselves. Nowadays, most of the vehicles are equipped with onboard units (OBUs) which are used from vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication. It is expected that by the end of 2027, 100% of the vehicles will be equipped with OBUs(Etsi 2009). Nevertheless, a significant effort is shown in standardization activities on this technology. The enhancement of IEEE802.11 technology to IEEE802.11p is an example of such effort (Committee 2010). IEEE802.11p is standard communication technology for VANET communication over dedicated short-range communications (DSRC) wireless channels (Li 2010). It offers low cost and easy deployment though it suffers from high delays, poor QoS and weak scalability.

Due to these shortcomings, it is obvious that, VANET itself cannot cope with the increasing demands of network applications that vehicle users require while traveling. VANET must be integrated with other network technologies, such as Wimax, Wi-Fi, and cellular networks for-example third generation (3G), 4G long-term evolution (LTE), and 4GLTE advanced (LTE-A) to form a robust and reliable heterogeneous vehicular network (HetVNET)(Salvo et al. 2016). This particular cellular network is commonly adopted as the best option in providing dependable and pervasive Internet access to vehicles because it is well deployed and covers larger areas compared with other types of network technologies (Gramaglia et al. 2011). However, a simple integration of VANET to LTE can elevate the overload problem and degrade the QoS of both vehicle and non-vehicle users (Cheng & Shen 2016).

Several researchers focused on utilizing opportunistic Wi-Fi to offload cellular traffic generated by vehicle in HetVNET architecture (Gramaglia et al. 2011; Malandrino et al. 2012; Wang et al. 2016; Zhioua et al. 2014), which is called vehicle Wi-Fi offloading (VWO). The VWO is preliminarily debated as a promising research direction, provided that some issues unique arising in the vehicular environment such as short and intermittent connectivity, fast fluctuating wireless are properly overstepped. Refer to Figure 1.1; In HetVNET architecture the vehicles may contain different sensors such as scan tool, seat capacity check, and other sensors that will use OBU to communicate to the infrastructure network and other vehicles. Moreover, the vehicle user may have smart phone that also need seamless internet connection in this high mobility environment. Therefore, VWO to be efficient adopted, the Wi-Fi APs must be well deployed and vehicle user requires prior information regarding the next Wi-Fi AP accessibility.

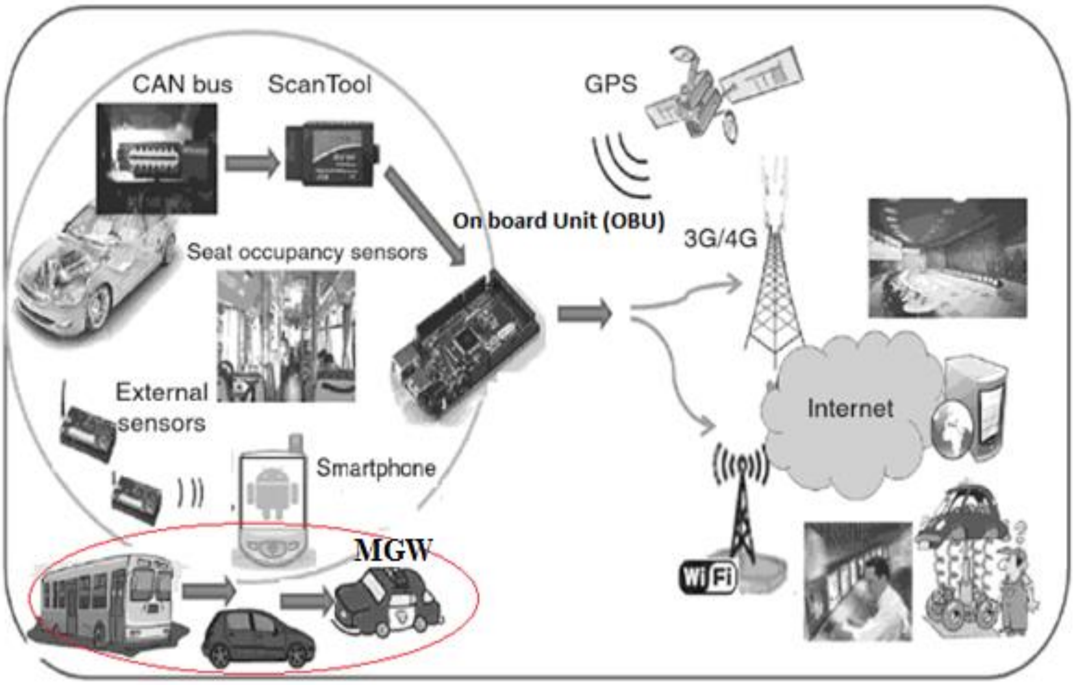

Figure 1.1 Heterogeneous Vehicle Network (HetVNET) Architecture (Paul et al. 2016)

Besides, in the area of poor Wi-Fi deployment for-example, highway or rural areas, the vehicles may select specific group of vehicles to act as mobile gateway (MGW) (refer Figure 1.1) that handle VANET traffics on behalf of LTE systems. Otherwise, the vehicles have to wait for long duration of time before encounter the next Wi-Fi APs. This will affect the delay requirements of different vehicular network applications. Consequently, it also affects the overall QoS of the applications.

The rest of this chapter is organized as follows; section 1.2, the research motivation that leads us to work on this domain is comprehensively discussed. Section 1.3, a detailed problem statement is explained. Section 1.4, the main research objective and its sub objectives are listed. Section 1.5, research contributions are highlighted and the last section 1.6, thesis organization is explained in detail.

1.2 RESEARCH MOTIVATION

According to Cisco Visual Index 2017, mobile data traffic will reach the following milestones within the next five years. (1) Monthly global mobile data traffic will be 49 exabytes by 2021, and annual traffic will exceed half a zettabyte. (2) The number of mobile-connected devices per capita will reach 1.5 by 2021. (3) The average global mobile connection speed will surpass 20 Mbps by 2021. (4) 4G traffic will be more than three-quarters of the total mobile traffic by 2021. (5) Over three-fourths (78 percent) of the world's mobile data traffic will be video by 2021.

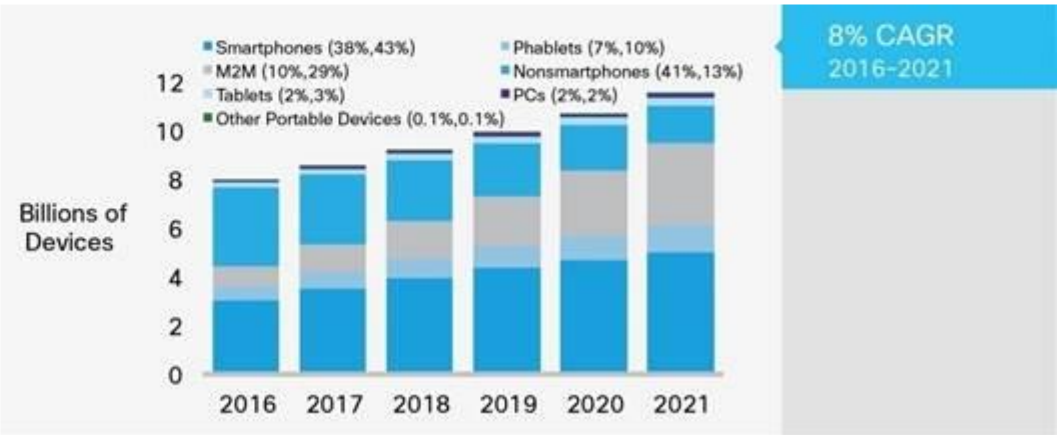

Figure 1.2 Global mobile devices and connections growth (Cisco Visual Networking Index 2017)

This prediction alerts the researchers and compels them to re-think on how to address this growth in the use of mobile-connected devices because with the current situation, the bandwidth operator will fail to manage the amount of traffic generated by cellular users. Traffic offloading through vehicular Wi-Fi network is among the current solutions to the growth explosion of data-hungry applications. Wi-Fi is used as unlicensed spectrum, and a large number of compatible devices can freely benefit from this technology. Wi-Fi networks are spread in many areas, including homes, universities, hotels, and petrol stations. Ablott (2013) reported that in 2013, China already had 3.83 million hotspots, whereas Japan had1.65 million home spots and 220,000 public Wi-Fi APs. In the same year, AT&T, a United States-based company, reported 32,000 hotspots. Zhioua et al., (2014), demonstrated that Wi-Fi could be feasibly used for outdoor Internet access in vehicle speed.

Due to this, it obvious that, Wi-Fi can be utilized to offload some delay tolerant (DT) applications that vehicle users, want to enjoy with, from cellular network especially in the area whereby Wi-Fi APs are well deployed. These applications include file transfer protocol (FTP), E-mails, software updates and other applications that are not delay sensitive in nature. Nevertheless, the presence of IEEE802.11p technology (that enables vehicles to communicate themselves) can also be utilized on the absence of Wi-Fi APs to reduce the number of direct connection to the cellular infrastructure. This will help to shift the load from the cellular network to the core of the VANET and relieve the cellular infrastructure usage.

1.3 PROBLEM STATEMENT

The increasing usage of smart phones, tablets, and other vehicular network devices with diverse networking and multimedia capabilities, and the associated growth in the use of all kinds of data-hungry multimedia services that passengers normally use while travelling, exert a big challenge to cellular infrastructure operators.

All of these devices will require a direct connection to cellular-based networks. Given this anticipation, cellular network overload is expected in the near future. Previous researchers focused on utilizing opportunistic Wi-Fi to offload cellular traffic generated by vehicle users (Balasubramanian et al. 2010; Lee & Lee 2012; Wang & Wu 2016; Chung-Ming et al. 2017) especial in urban environment. However, utilizing the opportunistic Wi-Fi APs to offload the LTE networks in a vehicular network environment is a relatively problematic task. This condition is due to the short coverage of Wi-Fi APs and weak deployment strategies of APs. In addition, depending solely on the historical connection patterns affects the prediction accuracy and offloading ratio of most existing schemes even when AP location information is available.

Consequently, the researchers are facing the problem of selecting best mobile MGW to aggregate vehicle traffics and reduce LTE load in HetVNET environment in case where the Wi-Fi APs are not available for offloading as in highway scenarios (Benslimane, Taleb, et al. 2011; Zhioua et al. 2015; Dharanyadevi and Venkatalakshmi 2017; Sharef et al. 2018). The selection process exerts extra network overheads and complexity due to allowing clusters to be formed in highly dynamic environment like VANET. It obvious the time used for clustering formation and cluster head (CH) election is more than the time required for data traffic exchange. This result to poor QoS maintenance due to frequency network disconnection caused by rapid dynamic changes of VANET topology. It increases the packet delay, packet loss, and control packet overhead while reducing the overall throughput of the VANET. Thus, it makes the QoS of different applications difficult to be guaranteed.

In summary, the following problems will be tackle in this research.

1. Limited decision criteria/parameter to implement an efficient offload and gateway selection for urban and highway HetVNET scenario/environment

2. Low prediction accuracy and offloading ratio due to the dependency of single criterion on predicting Wi-Fi availability and its performance, especial in urban scenario.

3. Poor QoS maintenance due to frequency network disconnection resulted from the formation of clusters before gateway selection process takes place in highway scenario.

1.4 RESEARCH OBJECTIVES

The main objective of this research is to enhance the offload and gateway selection schemes for HetVNET by providing better prediction accuracy and offloading ratio while improving the QoS for different VANET applications.

The sub objectives of the research are:

1. To enhance offload and gateway selection criteria based on offloading ratio and mobile gateway selection parameters for urban and highway HetVNET scenario/environment.

2. To design a multi-criteria wireless availability prediction (MWAP) scheme for vehicular Wi-Fi offloading and a new non-cluster adaptive QoS-aware multi-metrics gateway selection (AQAGS) scheme in non-offloading area based on urban and highway HetVNET scenarios respectively.

3. To simulate and evaluate the design with different scenarios and performance metrics.

1.5 RESEARCH SCOPE

Generally, the research will be based on HetVNET architecture comprises of VANET (i.e., IEEE802.11p), Wi-Fi and LTE. The main focus is inside the LTE Coverage Zone whereby, the vehicles have the chance to connect to always on cellular network. Moreover, this research will dwell with two scenarios, urban and highway scenarios. In case of urban scenario, this research will only focus on the utilization of opportunistic Wi-Fi APs for offload LTE traffics. Utilization of other types of the networks infrastructure (for-example WiMAX) which may be available alongside the road is out of the scope of this research. Nevertheless, in case of highway scenario, a number of LTE E-UTRAN Node B (eNB) may be available along the highway. However, our scope is only inside single LTE eNB, the handover process between one eNB to another will not be consider by this research. Furthermore, in this research only two types of VANET applications are consider for evaluation purpose, delay sensitive application (i.e., VoIP) and non-delay sensitive application (i.e., FTP) other types of applications like high Quality videos and others are not taken into consideration.

1.6 THESIS OUTLINE

This thesis is organized into six chapters. Chapter One is the introductory part which comprises of the research background which includes the needs and the main focus of this research. The problem statement and the gaps need to be filled by this research are clearly explained. Then, research objectives are outlined. This includes the main and sub objectives. Lastly, the thesis contributions in the research community are highlighted and briefly explained.

Chapter Two, focuses on reviewing related works in this domain. However, first the chapter discusses the overview of VANET. This includes the characteristics of VANET, application of VANET and current ongoing projects in VANET. The chapter also discusses the HetVNET architecture that mostly used in this domain. Then, the chapter reviews and analyses the current published works on LTE load reduction methods using offload and mobile gateway selection techniques.

Chapter Three, discusses the general methodology that is used to validate the proposed scheme in this research. A general description of the research methodology is given, followed by a brief description about the proposed scheme. Two proposed schemes MWAP and AQAGS are briefly explained. Then, the developed simulation models used to validate the proposed schemes are described. Finally, the system performance metrics that used to characterize the network service quality are defined.

In Chapter Four, a multi-criteria wireless availability predication (MWAP) scheme is discussed in detailed. This includes, the detailed designing and development of the MWAP scheme, implementation of the MWAP scheme, and performances analysis of the MWAP scheme compared to the existing schemes in the state-of-art.

In Chapter Five, a new non-cluster adaptive QoS-aware multi-metrics gateway selection scheme is deeply discussed. Again, the designing, implementation and performance evaluations of this scheme compared to the existing scheme in the start-of-art are detailed elaborated.

Finally, in Chapter Six, the conclusion and research future directions are highlighted.

CHAPTER II

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents a comprehensive review of related works as the basis of understanding the needs of this research. Morever, this chapter discovers, different issues and challenges that exist in the current state-of-art. Furthemore, this chapter highlights the importance of this research in contributing and extend the current state-of-art in this domain.

Firstly, the chapter discusses briefly overview of the VANET, in term of its basic concept, features and applications. Secondly, this chapter discusses in detail the concept of HetVNET, which is the promising architecture of vehicular network. Different integration of VANET and other infrastructrure network such as Wimax, Wi-Fi and cellular based network are explored. However, it must be noted that the research scope is based on HetVNET comprises of VANET, Wi-Fi and LTE network. Therefore, the chapter investigates in detail the current overload problem of LTE network in this scope.

Two methods of reducing the LTE network load in HetVNET scenario have been discussed together with the issuses and gaps related to current proposed techniques in the state-of-arts.Vehicle Wi-Fi offloading is the first method that is detailed investigated. Several techniques involves in this method are explained. The strengthes and weakeness of each techniques are highlighted. Then, the gaps that this research work expect to fill from the exisiting techniques is briefly elaborated.

Second method is using gateway selection method whereby MGW is used to aggregate the vehicle traffics and act as the gateway to LTE infrastructure network. This reduces the number of connection to LTE network. However, the main challenge of this method is in selecting the best MGW in highly dynamic inveroment like VANET. Several gateway selection (GWS) techniques are critically reviewed. The gaps exist are deeply explored and the proposed GWS scheme that can enhance the MGW selection process and improve QoS of the application are briefly discussed.

Lastly the qualitative comparison of the reviewed techniques involves in VWO and GWS is highlighted . The strength and the weaknesses of each techniques are being outlined.

The rest of this chapter is organized as follows; Section 2.2, presents the overview of VANET Section 2.3, discusses the concept of HetVNET. Section 2.4, load reduction from the cellular network in HetVNET is discussed. Section 2.5, presents the vehicular Wi-Fi offloading concept. Section 2.6, discusses related research works on vehicular Wi-Fi offloading in HetVNET. Section 2.7, highlights the comparison and discussion of issues related to vehicular Wi-Fi offloading in HetVNET. Section 2.8 discusses the load reduction through VANET in HetVNET. Section 2.9, explains the related research works on gateway selection in HetVNET. Section 2.10 highlights the comparison and discussion of issues related to gateway selection in HetVNET and lastly, Section 2.11, summaries this chapter.

2.2 OVERVIEW OF VANET TECHNOLOGY

VANET is particular kind of mobile ad hoc network (MANET) is which the mobile nodes are replaced with the vehicles. In VANET, each vehicle is comprised with the network interfaces which enable them to communicate with each other, or to the infrastructure. Two modes of communication are available (V2V and V2I). V2V is the communication between the vehicles in pure ad hoc manner. Each vehicle uses it IEEE802.11p to exchange information with other vehicles. However, in V2I, the vehicles can have the chance to communicate direct to infrastructure networks that are deployed alongside the roads. Figure 2.1 shows different communication scenario exists in VANET.

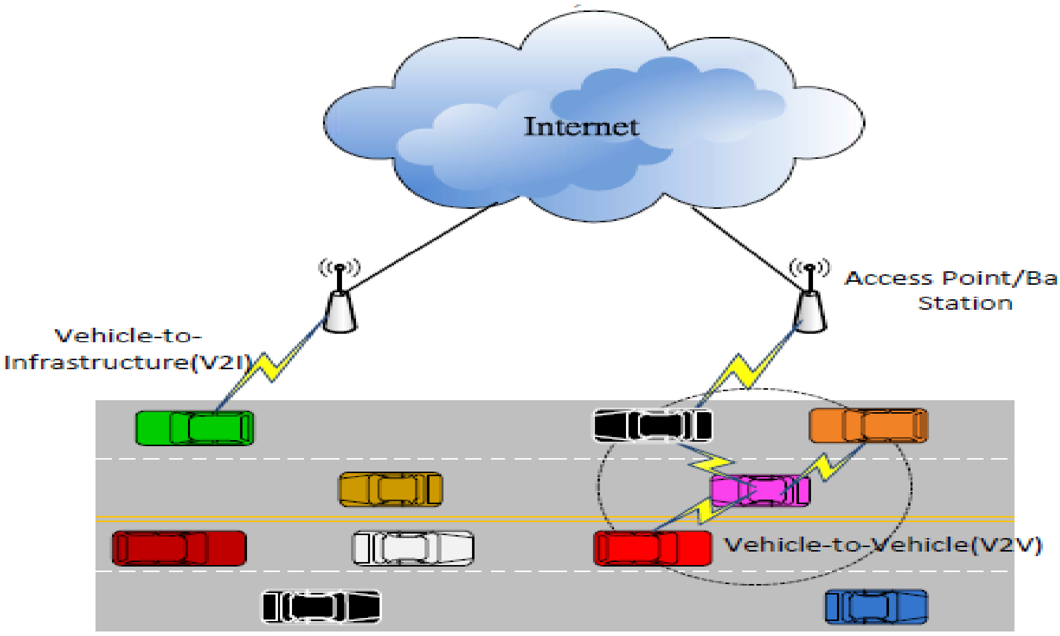

Figure 2.1 V2V and V2I paradigm (Chang et al. 2010)

2.2.1 VANET Characteristics

As described earlier, VANET is the special type of MANET; however, there are some unique features that distinguish itself from MANET. Node movement is the main feature that distinguishes VANET from MANET. In VANET the vehicle movement depends on the driver's behaviour and the condition of the roads. It can range from slow (i.e. during to congestion), normal (i.e. urban scenario) to high speed (i.e. highway scenario). This leads the research to think differently when design and develop this kind of network. Some of distinguished characteristics of VANET are:

1. Dynamic Network Topology

The main factor that influences the network topology is the vehicle speed. In VANET the vehicle speed is unpredictable i.e., the driver can increase or decrease speed depends on the driving behaviour of the driver and the nature or condition of the roads. In highway, the vehicle moves faster and makes the communication time between the vehicles to be short which cause faster link broken. The consequence of this is unreliable and unstable network topology. Moreover, data exchange between the vehicles and infrastructure influences the driver's decision and causes the changes of the network topology. This can result into unstable network topology. Furthermore, frequently changing of the network topology leads to inefficient usage of network resource caused by small network diameter, and result into some paths not to be utilized before broken.

2. Variable Network Density

In VANET, network density is depending on the vehicular density. The vehicle density is not constant, it may increase or decrease depends on the time, day and location. In the major city especial during the rush hours, the network density expected to be high. However, this is not the case in the rural area, or isolated area. Furthermore, network density on the highway scenario is expected to be different than the urban scenario. Night hours are difference than morning time and weekdays are not the same as the weekends. This distinct feature makes most of the proposed VANET protocols or schemes to be scenario oriented.

3. Predictable mobility

Mobility of the vehicles in VANET is not totally random as it follows certain patterns. These patterns depend on the road topology, speed limit, traffic conditions and nature of the driving behaviour of the driver. It can be expected that the normal driver follows certain patterns in daily movement. There are some common routes and destinations that frequently used by the drivers. This makes the prediction of the future position of the vehicle to be more feasible.

4. Power Issue

VANET is different from MANET because power is not a problem in VANET. All of the communication devices depend the power from vehicle itself and obviously possess plenty of power. This is difference from MANET, sensor and other mobile devices poses limited battery life which limits the proficient operation of MANET network. Therefore, when we investigate the VANET problem, power is not a constraint.

5. Frequent network disconnection

Frequency network disconnection is common problem in Vehicular scenario. This is due to the nature of VANET network which frequently involves network topology change. The implication of this problem is high amount of packet loss, long delay and degradation of the overall throughput of the network.

2.2.2 VANET Applications

VANET applications can be classified depend on different perceptive of views on VANET system. According to Lèbre et al. (2014) VANET system can be view in three perspectives.

1. Vehicle Centric View

In the vehicle centric view, the vehicle is viewed as a transportation entity which allows moving from one place to another. This view only focuses on the vehicle itself not the things inside or outside the vehicles. This view has the weakness because the vehicle does not move alone; there are some passenger (s) insides as well as roads, buildings and other infrastructures from the outside environment.

2. Network Centric View

In network centric view, all the entities (i.e. car, roads, buildings, traffic lights, base stations, access points) are interacting together as a single network. Vehicle can interact with base stations, traffic lights can govern the vehicle movements and vehicle can interact with other vehicles. In network centric perspective, numerous parameters need to be considered such as mobility movement of the vehicles, interference due to building, wireless coverage etc. This view is quite realistic than the simple vehicle centric view.

3. User Centric View

In user centric views, the concentration is more on the users or passengers inside the vehicles. Each user has his own desires, as well as behaviours and users do not have a uniform driving habit.

Depend on these views, VANET applications can be classified into four main groups.

a) Safety Applications

The goal of this group of applications is to avoid and reduce the number of road accidents by giving a driver a prior information about the road conditions. This includes, crash warning, lane charge warning, and emergence breaking. The applications fall on this group are classified as crucial and sensitive applications. Delay and reliability are important criteria in designing these types of applications. Thus, in order to reduce the delay, these types of applications adopt V2V communications. Moreover, each vehicle experiences the safety emergence issues need to alert other vehicles in a real time. This increases the reliability requirement. Figure 2.2 shows the propagation of accidents messages which alert other vehicles to reduce the speed or change the lanes in real time.

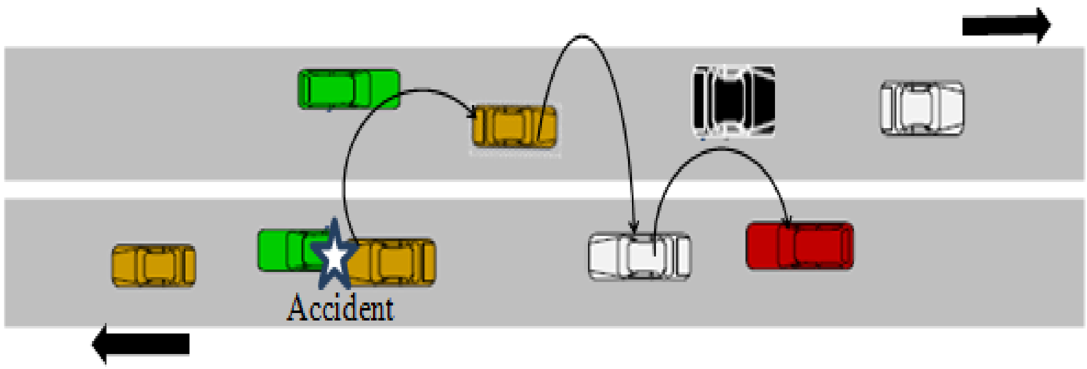

Figure 2.2 Accident Alert message (Alawi et al. 2012)

b) Efficiency Traffic Control Applications

This group of applications includes traffic jam, cross road and interception detectors. The applications normally use a floating car data obtained from the users' mobile phones in the driven vehicles. Each mobile phone of the vehicle user acts as sensor, sensing the road network conditions and uploads to the cellular infrastructure. The information includes vehicle directions, speed and time. The system of collecting this information is centralized whereby the central system (i.e. cellular network) collects and analyses the information and broadcast again to all other vehicles in its coverage zone.

However, using cellular network as centralized system to process this information is not feasible because it increases the burden to cellular network. This causes a higher delay which can compromise the efficient of the applications. The most ideal solution is to decentralize it by utilizing VANET network and permit the vehicles or road side units which are ahead to communicate the traffic condition in inverse course of the vehicles movement stream as shown in Figure 2.3.

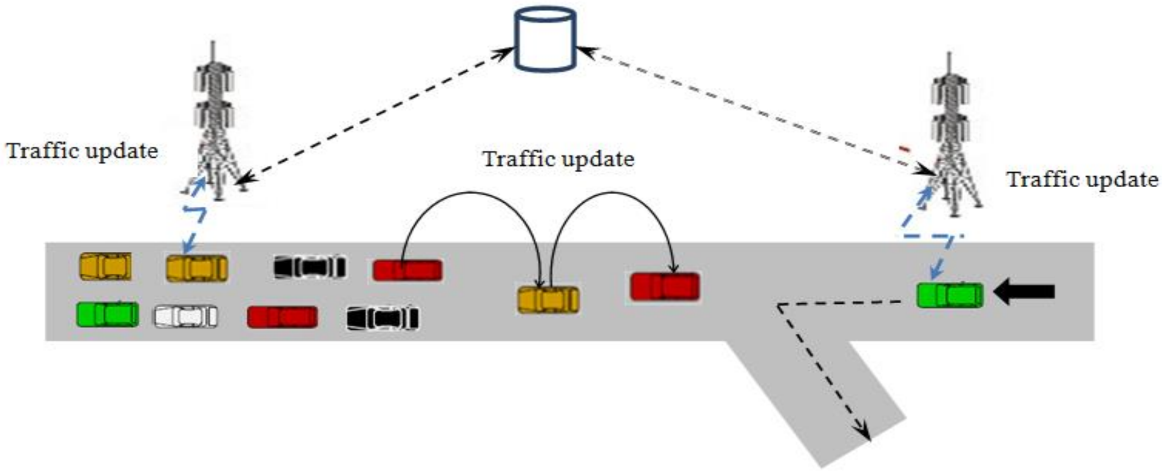

Figure 2.3 Congestion avoidance in VANET (Alawi et al. 2012)

c) Comfort Applications

This group of applications intends to make the driver receives information that will make the trip comfortable and enjoyable. This information needs to be available and reliable whenever the vehicle user requests it. It includes gas stations location, hot spot information, restaurants locations, parking availability, alternate route suggestion, tourist attractions areas. Usually, this information does not require high bandwidth and the vehicles can exchange themselves or use the road side unit (RSU) to request this information.

d) Interactive and Entertainment Applications

The goal of these applications is to entertain the vehicle users and passengers on board. This includes, file sharing, internet access, interactive gaming both inter vehicle and distribution gaming, video conferencing and internet of thing (IoT) applications. These applications need higher connectivity and availability in order to efficiently utilize.

e) Autonomous Vehicles

Autonomous Vehicle (AV), or simply known as self-driving vehicle, is a technology that intends to partly or fully replace the driving task that was previously conducted by a human driver (Hashim & Omar 2017). Equipping cars and light vehicles with this technology will likely reduce crashes, energy consumption, and pollution and reduce the costs of congestion. The AV technology is divided to several levels depends on the automation process used.

- Level 0: The human driver is in complete control of all functions of the car.
- Level 1: One function is automated.
- Level 2: More than one function is automated at the same time (e.g., steering and acceleration), but the driver must remain constantly attentive
- Level 3: The driving functions are sufficiently automated that the driver can safely engage in other activities.
- Level 4: The car can drive itself without a human driver.

In order to achieve higher level of the automation process (i.e., level 4), Figure 2.4 highlights some of the technologies that need to incorporate to reach fully automation process.

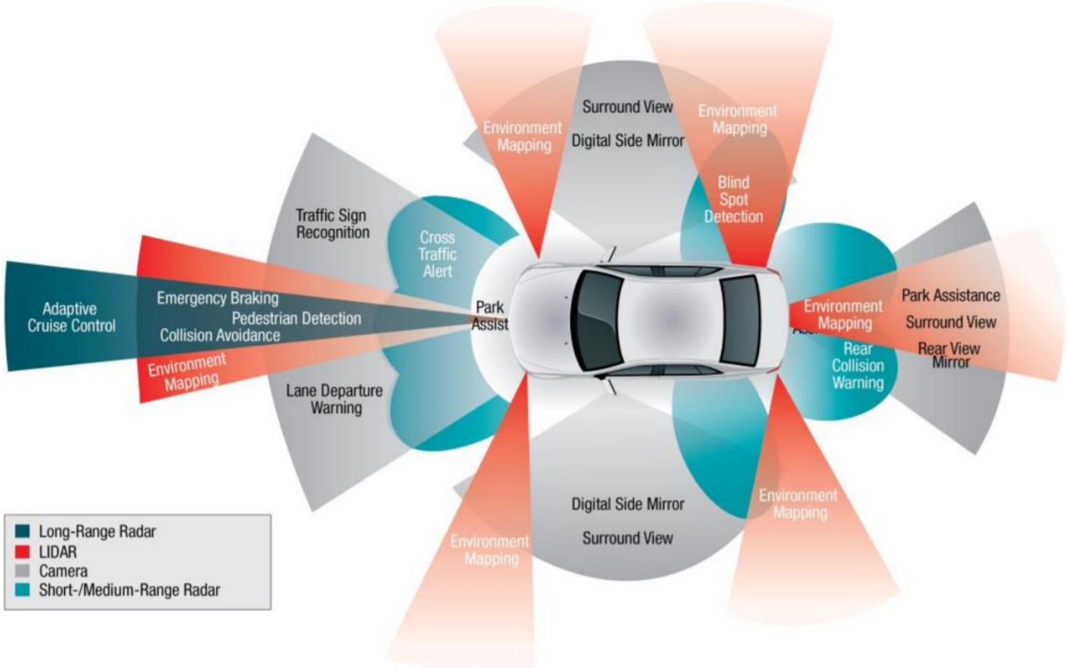

Figure 2.4 Driving Automation with Sensing Technologies and Control Intelligence (Insights 2016)

With the advancements in computational architectures, sensing technology along with significant cost reductions, AV progress has accelerated tremendously. Strong competition among technology companies and conventional car manufacturers has seen various introduction and target date implementation. Software and technology companies such as Google, Apple and Intel were among the first to establish their AV programmes, in which it provides huge publicities and attracted talents from various disciplines to work on AV. Google AV (Waymo) started testing its self-driving technology in California since 2009 and have already achieved a total mileage of over 1.5 million miles (Google 2016). Besides, GM, Ford and Renault-Nissan Alliance are among the forerunners in automated driving. Singapore has started their first driverless taxi since August 2016 in a limited public trial on the streets of Singapore and full services are expected to be ready in 2018 (Reuters 2016). In addition, Japan has also announced that AVs could be used to ferry people around Tokyo during the 2020 Olympics and Paralympics (Anderson et al. 2016). Moreover, Malaysian is also on track towards completing autonomous vehicle research and development (R&D) by 2025 (Hashim & Omar 2017).

2.2.3 Autonomous Vehicles Projects

There is a number of AV projects which are conducted around the globe that focuses on the realization of this type of technology. Table 2.1 gives the summary of ongoing and completed projects in this domain (Hashim & Omar 2017).

Table 2.1 Autonomous Vehicles Projects (Hashim & Omar 2017)

Project Name	Description	Status
Waymo(Google)	Testing autonomous driving	By 2018
Toyota	Fully autonomous highway driving	By 2020
Honda	Fully autonomous highway driving	By 2020
Volvo and Nissan	IntelliSafe Autopilot and Drive in urban traffic	By 2020
Mercedes-Benz	E-Class and Drive Pilot	Early 2020
Ford	Ride-hailing and ride-sharing services in a geo-fenced area	By 2021
BMW	Self-driving electric vehicle	By 2021
Jaguar and Land-Rover	Building fully autonomous car	By 2024
Hyundai and Kia	In talk with Google	By 2023
Mazda and Mitsubishi	Doing advanced safety systems	No set date
Subaru	Adding partial systems	No set date
Volkswagen	I.D. concept for self-driving mode	No set date
Porsche and Ferrari	Refuse AV	None

2.3 CONCEPT OF HETEROGENOUS VEHICULAR NETWORK (HetVNET)

In a heterogeneous vehicular environment, vehicle users have the opportunity to use different types of the radio access technologies with varying capability and load at different locations. The development of ITS makes the OBU devices to poses multiple interfaces which can be connected to multiple networks simultaneously (Alawi, Saeed, et al. 2012; Alawi et al. 2014).

Though, the operating environment of these networks may change rapidly especially in a high dynamic network environment. The use of multiple network technology in vehicular scenarios was developed as a result of the significant increase in the diverse applications with different performance requirements. This increase requires vehicles to be intelligent enough to select or to integrate different network technologies for a specific networking scenario. For example, the experiment in Deshpande et al. (2010) indicates that Wi-Fi tended to exhibit frequent network disconnections while delivering high throughput in mobile scenarios. Cellular networks provide similar or lower throughput than Wi-Fi but with good coverage. These two networks complement each other.

Therefore, hybrid network design is needed, and cellular traffic can be shifted to the Wi-Fi network. Such modification will improve performance; reduce congestion, and lower costs. Many researchers have studied the integration of VANET into Wi-Fi or 3G/4GLTE radio access technologies in vehicular scenarios.

2.3.1 VANET–Wi-Fi Integration

Several works are investigating the feasibility of using VANET–Wi-Fi integration to provide drive-through Internet access on a moving vehicle. This integration will reduce the burden for cellular network by redirecting the traffic to drive-through Wi-Fi networks. In (Zhao et al. 2008), the performance of VANET–Wi-Fi integration was experimentally investigated. As shown in Figure 2.5, VANET and IEEE802.11 APs were connected using a multi-hop relay mechanism. The study proposed a V2V relay (V2VR) scheme that extended the coverage area of roadside APs. The relay mechanism was used under the following conditions:

1. The source vehicle (SV) was outside the coverage area of the specific Wi-Fi AP, but it was moving toward it. In this condition, the SV needed to find the front vehicle to act like a relay vehicle (RV). This RV must be inside the coverage zone and act as relay for the SV to communicate with the infrastructure.

2. The SV moved away from the Wi-Fi AP. In this scenario, the SV needed to select the rear vehicle as RV, which was supposed to be inside the Wi-Fi AP coverage zone to communicate with the infrastructure.

The experimental results showed that the V2VR scheme improved the network utilization and extended the drive-through access range.

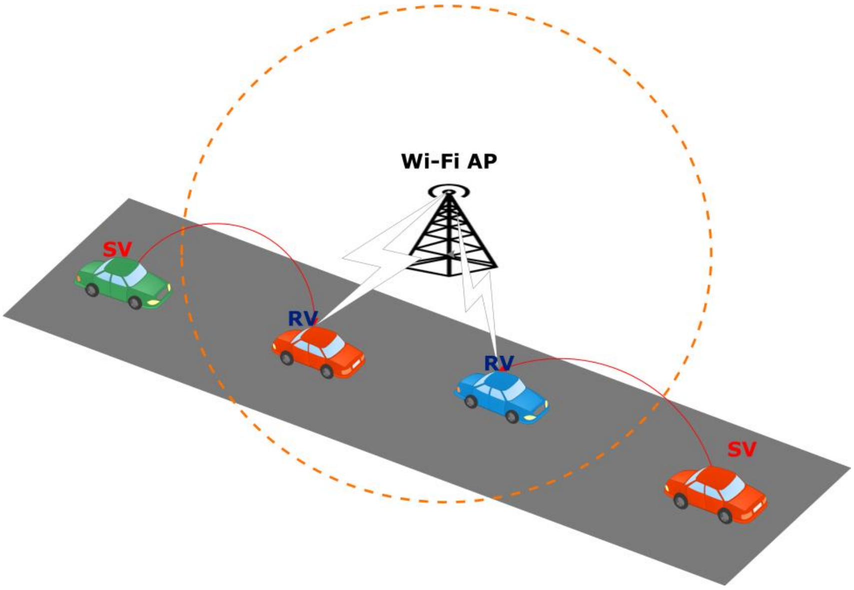

Figure. 2.5 Access APs through relay mechanism

Different experiments were performed in (Wellens et al. 2007) to examine the performance of IEEE802.11-based wireless local area networks (WLANs) in a vehicular environment. Several IEEE802.11 technologies, such as IEEE 802.11a, 802.11b, and 802.11g, were used in both V2V and V2I scenarios. The authors found that the vehicle speed did not influence the network performance. The vehicle distance and a clear line of sight were proven to be important parameters for the network performance.

2.3.2 VANET- Cellular Network Integration

The integration of VANETs and cellular networks to form HetVNET is generally a promising architecture in vehicular communication in consideration of the constraint of the IEEE 802.11 technology with respect to the coverage area it offers (Malik et al. 2015). VANET can be integrated with cellular networks, such UMTS, 3G, or 4GLTE. Many works have been conducted under this integration because of its advantages in terms of the large coverage area and high data rates offered by cellular networks and IEEE802.11p networks, respectively.

Mir & Filali (2014) investigates the performances of LTE and IEEE802.11p technology in a vehicle environment. The study was conducted in different network conditions, parameters, and application requirements. The effects of the speed, density, and transmission frequency of vehicles on the performance of these two technologies were evaluated. The evaluation mainly determined the scalability, latency, mobility, and reliability of these technologies for several vehicular applications.

The model that was used to evaluate these standards is shown in Figure 2.6. Two approaches were applied for vehicle Internet connection, namely, one using LTE cellular infrastructure as the backbone of the Internet connection and another using an IEEE802.11p-based vehicle network. Vehicles can connect directly with the base station (BS) named as LTE E-UTRAN Node B (also named LTE eNB as in Figure 2.6). The LTE eNB was responsible for the communication between OBU and infrastructure network.

Contrariwise, the vehicles could use IEEE802.11p network technology to communicate with the other vehicles or with the respective RSU. Different RSUs were connected to the RSU gateway, which acted as a link from VANET to the Internet. NS-3 was used to simulate these two standards, and the results showed that the LTE standard exhibited better data delivery ratio, reliability, and acceptable latency requirement.

Conversely, IEEE802.11p showed a significant packet delivery ratio and throughput for a small group of vehicles. However, the investigation did not consider the overload exerted on the LTE network when a large number of vehicles connected directly with the LTE network. The study also did not highlight how the overall network performance would be affected. Each standard was considered single technology not integrated technology. Therefore, new studies are needed to evaluate these two standards in an integrated scenario.

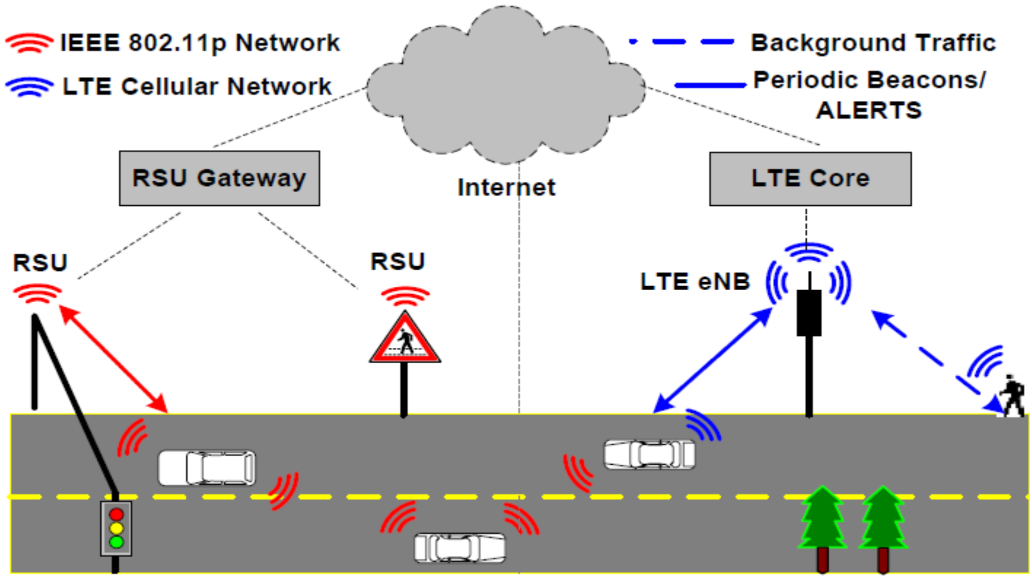

Figure 2.6 Vehicular networking scenario using IEEE802.11p and LTE (Mir & Filali 2014)

Other studies on integrated VANET–celluar architurecture were found in (Devarajan et al. 2013; Sivaraj et al. 2011). Two types of vehicles were identified. One type refers to the vehicles with E-UTRAN interface enable and were inside or moving into the LTE coverage zone, named as gateway candidates (GWCs).The other type refers to ordinary vehicles that were either outside the 4G active zone or with a disabled or absent E-UTRAN interface. However, (Devarajan et al. 2013) focused on evaluating the peformance of integrating VANET–LTE networks for effective group communication. In the study, the researchers did not provide much details on how the evaluation was conducted. They also did not explain how clustering formation and QoS were achieved. They concluded that the integration of VANET–LTE networks exhibited higher packet delivery ratio and lower delay than those of standalone VANET networks.

2.4 LOAD REDUCTION FROM THE CELLULAR NETWORK IN HetVNET

In the most recent couple of years, we have recorded the increasing number of data-hungry applications over cellular networks. Given the current situation, mobile operators may not have adequate bandwidth to cope with the amount of traffic generated by their users. Many initiatives have been conducted by cellular networks to deal with this data proliferation. Such initiatives are investing in radio access networks or core networks. However, these investments are extremely expensive and limited.

Other alternatives are to reduce data usage and control connection speed. Again, these approaches negatively affect the customer's satisfaction. An efficient alternative, known as mobile data offloading, has recently been proposed (Khan 2015). Mobile data offloading is described as a mechanism to deliver the traffic intended to cellular networks to other available network technologies. This method gathers the attention of the researchers in this particular field (Ding et al. 2011; Hagos 2015; Yongmin et al. 2011).

Nevertheless, we normally spend a significant amount of time on the road, and we need a good connection to the Internet or other vehicular network applications during this time. Vehicles are then among the largest cellular resource consumers. Simple integrate VANET with cellular network increase the overload problem on the cellular side. Several researches proposed different techniques on load reduction of the cellular network in Vehicular scenarios.

The proposed techniques can be classified into two main groups. First group comprises of all techniques that utilized other wireless medium to offload cellular data. Here the most common medium used for offloading are Wi-Fi and Femtocell. However, this research focuses on using Wi-Fi as a medium for offloading cellular data which termed as VWO, Wi-Fi is recognized as one of the primary offloading technologies (Aijaz et al. 2013). Some part of the data targeted for cellular infrastructure can be directed to Wi-Fi. Thus, the congestion due to cellular infrastructure can be reduced. 65% of the total 3G mobile data can be offloaded through Wi-Fi (Kyunghan et al. 2013).This makes the Wi-Fi offloading one of the favourable solutions.

The second group contains all techniques that reduce the traffic from cellular network in the area whereby no any wireless medium that can be utilized for offloading purpose. In this area, the VANET network needs to organize itself in search a way that a small number of vehicles termed as MGW vehicle are used to connect to the cellular network on behalf of the other vehicles. This reduces larger number of vehicles to interact direct to cellular infrastructure by allowing the traffics to be offloaded to the VANET network. Moreover, the network congestion on the cellular side is reduced and throughput, packet delivery ratio and overhead on the cellular side of the network are improved. In case the selected gateways lose its optimality in term of communication performance, a new gateway with better performance will be chosen as a replacement. However, the main challenge faced here is on the proper method of gateway discovery and selection in this highly dynamic environment whereby the contact time of the vehicles is unpredictable.

2.5 VEHICULAR Wi-Fi OFFLOADING (VWO)

Vehicular Wi-Fi offloading is one of the potential solutions for offloading cellular networks (Gramaglia et al. 2011; Malandrino et al. 2012; Zhioua et al. 2014). VWO involves re-routing the data targeted to cellular networks to opportunistic Wi-Fi vehicular networks. These data are either generated by vehicles or vehicle users. We summarize the following points to show the need of VWO and how cellular operators can benefit from it.

1. Vehicle users acquire the opportunity to use Wi-Fi networks, which are cheaper than cellular networks.

2. VWO is suitable for most data-hungry applications that need low delay and high throughput.

3. The problem of limited spectrum will be solved, and cellular operators will be able to offer high-bandwidth-consuming applications through Wi-Fi.

4. Onboard applications will experience improved service capacity and capability given the high data rates and good QoS offered by Wi-Fi networks.

2.5.1 Vehicular Wi-Fi Offloading Architecture and Application Requirement

The general architecture of most proposed VWO techniques in the literature is generally based on Figure 2.7, in which HetVNET is used. Two network technologies, namely, VANET and cellular network are integrated to form the HetVNET architecture. The VANET network is composed of IEEE802.11p technology, which enables inter-vehicle communication. Cellular network infrastructure comprises eNBs linked to the LTE-evolved packet core. We assume that OBU is set to each vehicle and is responsible for V2V and V2I connections. Each OBU contains two interfaces; one is for V2V, and the other is for V2I. A fixed RSU is positioned along the road and assists vehicles to connect to the Internet or other applications. Normal mobile users, who cater for the cellular networks for both downloading and uploading along with the vehicular network traffic, are also involved in escalating the overloading problem. Vehicles can interact with infrastructure for downloading or uploading in multiple ways. The interaction can be direct from the cellular network, through the RSU, or through the elected vehicle as a content relay in a carry-and-forward manner. From the VWO general architecture in Figure 2.7, different offloading techniques based on specific application requirement and offloading medium are proposed in the literature.

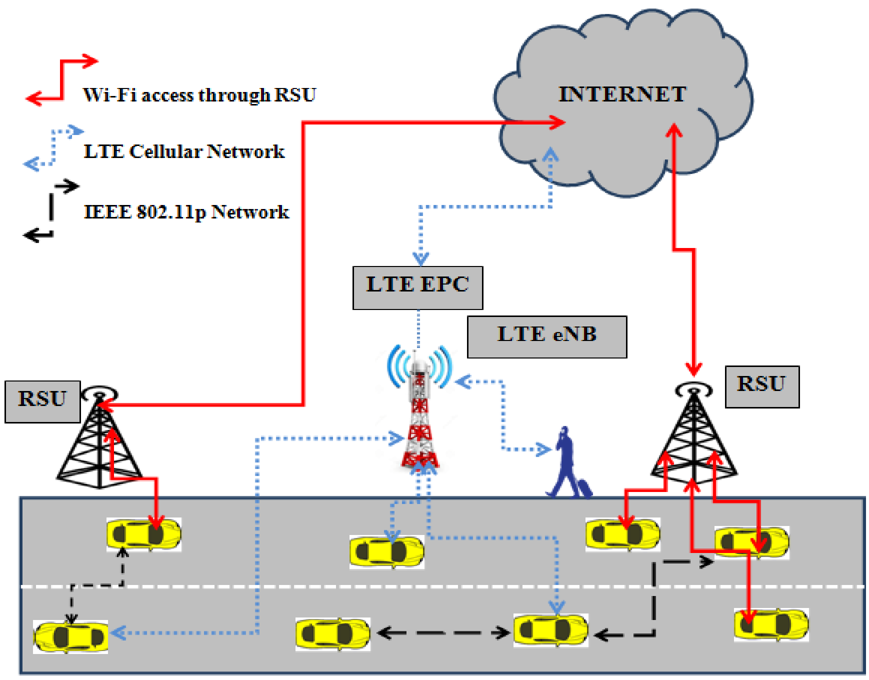

Figure 2.7 Vehicle Wi-Fi Offloading Scenario

Two groups of applications, namely, safety and non-safety applications, were present in VANET (Andreone 2005; Enkelmann 2003). Safety applications are crucial in informing drivers about the critical safety information exchange among vehicles or infrastructures (i.e., RSUs). Examples include road landslide, road curve, and sudden downhill. Sudden brake warning or road annunciations are also safety applications. On the contrary, non-safety applications are used to comfort onboard passengers and drivers. Among the examples of non-safety applications are Internet browsing, toll fee collection, and onboard advertising for VWO. The applications are broken down further into delay-sensitive and delay-insensitive applications.

Safety applications have received more attention in the literature than non-safety ones because of the delay-sensitive nature of the former (Yuan et al. 2013). Most safety applications can be disseminated in a V2V mode using IEEE802.11p technology (refer to Figure 2.8) without involving the infrastructure. This condition reduces the necessity of offloading to this type of application. By contrast, non-safety applications request data on demand basis. These applications need to interact directly with cellular networks or any other type of infrastructure networks (refer to Figure 2.8) for high QoS. Heavy traffic to/from cellular networks is generated by these applications. If these applications are allowed to send and receive traffic direct to/from the cellular networks, the overloading problem to the cellular networks will escalate.

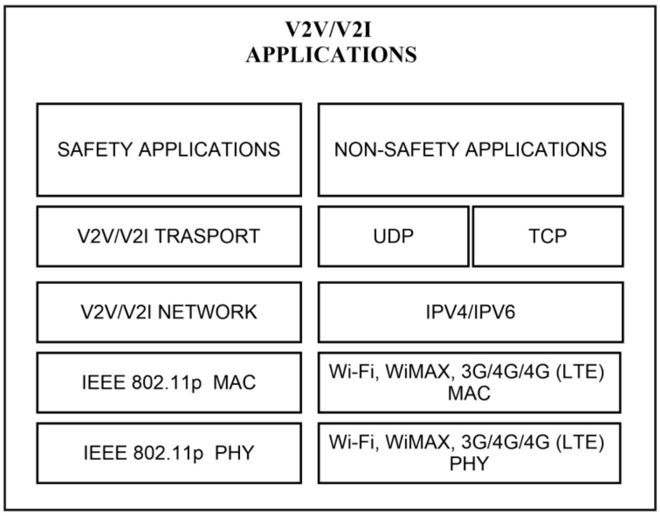

Figure 2.8 Vehicular application communication stack

As discussed, non-safety applications are primary candidates that need to be offloaded from cellular infrastructure. Designing an offloading mechanism that can efficiently offload these applications from cellular networks and meet QoS requirements is easier said than done. Works in (Gramaglia et al. 2011; Malandrino et al. 2012; Zhioua et al. 2014) considered the vehicular system as a medium for offloading non-safely applications from the cellular infrastructure networks. In (Zhioua et al. 2014), an analytical study was performed to quantify the amount of data that can be offloaded through VANET. In the same study, the investigation was also made to understand the effects of data volume and load on channel contention. The volume of the data flow was inversely related to the percentage of content offloading. The authors pointed out that 100% offloading of data traffic could be achieved for low data volumes, which was better than the results obtained previously in (Malandrino et al. 2012).

Nevertheless, in (Malandrino et al. 2012), the authors investigated the effect of content downloading by ITS users in terms of the load exerted on cellular infrastructure. The analytical method was used, and the problem was formulated by maximizing the cost function related to channel access and flow conservation. Their investigation revealed that 80% of the total traffic could be offloaded from the cellular network using content downloading through ITS. Both (Malandrino et al. 2012; Zhioua et al. 2014) works focused on best-effort services. Though, the necessity of having efficient offloading techniques with QoS provisioning for non-safety applications is high. Table 2.2 (3gpp 2012) shows the degree of complexity in designing the offloading mechanism for different application requirements.

Table 2.2 Degree of complexity in designing the offloading mechanism for different application requirements (3gpp 2012)

Application	**Category**	**Characteristics**	**Latency threshold (ms)**	**Mode**	**Technology**	**Offloading challenges**
VoIP	Non-safety	Delay Responsive	<100	V2I	3G/LTE/Wi-Fi/ WiMAX	High
Video conference	Non-safety	Delay Responsive	<150	V2I or V2V	3G/LTE/Wi-Fi/ WiMAX	Medium

To be continued…

…continuation

Game	Non-safety	Delay Interactive	Action:<80 interactive:<250ms	V2I or V2V	3G/LTE/Wi-Fi/ WiMAX	Medium
Safety	Safety	Delay Reliability	Life-critical safety:<100 Safety warning:<100	V2V–V2I	DSRC/RFID/ Bluetooth/Wi-Fi	Low/Non
Non-interactive, i.e., email, FTP, video downloads, photos	Non-safety	Reliability	<300ms	I2V	3G/LTE/Wi-Fi/ WiMAX	Low

2.5.2 Performance Measurement of VWO Techniques

Most of the load reduction strategies in VANET are evaluated using the standard network performance metrics such as throughput, packet delay, packet loss, and packet delivery ratio. However, for the VWO techniques, these have to be evaluated in both users and network perspective. Table 2.3 summarizes the standard metrics used to evaluate any offloading techniques. In VANET, power saving and fairness are not crucial metrics because the vehicles possess plenty of power, and all network devices depends on the power from the vehicle itself. Thus, from these metrics, three metrics are specifically used in evaluating the VWO techniques, these such as offloading efficiency (Malandrino et al. 2012; Munyoung et al. 2015; Rebecchi et al. 2014), offloading overhead (Gramaglia et al. 2011; Malandrino et al. 2012; Munyoung et al. 2015; Nan et al. 2014; Rebecchi et al. 2014), and quality of experience (QoE) (Burger et al. 2015; Klessig et al. 2014; Siris et al. 2014). These metrics are combination of different standard network performance metrics. Figure 2.9 shows an evaluation model for VWO techniques.

Table 2.3 Mobile Data Offloading Metrics

Offloading metrics	Description	Viewpoint	VANET	Value
Offloading efficiency	Fraction of the total traffic offloaded to the total traffic generated by the vehicle network.	Operator	√	High
Offloading overhead	Depend on amount of control packets that need to determine the new media for offloading traffics.	Operator	√	Low
Quality of Experience	Depend on user satisfaction	User	√	High
Power Saving	Depend on of energy per bit used	User	×	High
Fairness	Depend on uniformity distribution of the resource	User	×	High

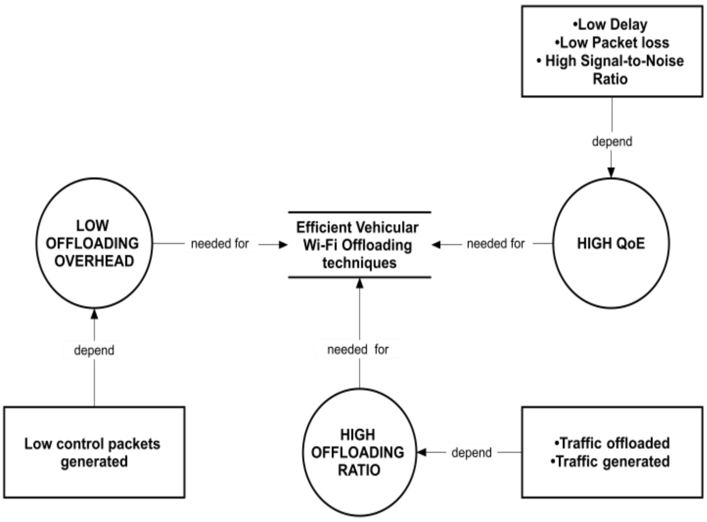

Figure 2.9 VWO Evaluation Mode

From Figure 2.9, it is clearly seen that, any efficient VWO techniques should exhibit high offloading efficiency. This means that large amounts of data traffic that are targeted to cellular network are offloaded to other available networks. In addition, VWO technique should show low offloading overhead. The offloading overhead depends on the number of control packets needed to be exchanged before offloading process takes place. Low control packets generated results of low overhead offload. Moreover, VWO should demonstrate high QoE, which depends upon the end-to-end delay of the packet transmitted from the source to the receiver. QoE also depends on the packet loss and signal-to-noise ratio (SNR). As shown in the Figure 2.8, high QoE needs low delay, low packet loss, and high SNR.

2.6 RELATED RESEARCH WORKS ON VEHICULAR Wi-Fi OFFLOADING IN HetVNET

The issues of offloading cellular data to either Wi-Fi or Femtocells are continuously studied. However, Wi-Fi is known as a standard offloading medium for cellular infrastructure (Aijaz et al. 2013).The offloading process can be managed by either user or operator (Man Hon & Jianwei 2015). In user-managed offloading, each user is free to select any available network technology for offloading. In the operator-managed offloading, the operator is responsible for monitoring the user's behaviour and available network load. If the operator notes that the network is congested, the operator immediately starts the offloading process.

This research focus on user-managed offloading because the operator-managed offloading is not sufficient when the offloading medium (i.e., Wi-Fi) is vastly loaded and the delay requirement of applications is tight (Man Hon & Jianwei 2015). For user-managed offloading, part of the traffic intended to the cellular network is redirected to Wi-Fi to reduce the congestion on the cellular infrastructure side.

Many techniques are proposed to offload cellular traffic through the vehicular system. However, these techniques have their own weaknesses and strengths. The following subsections review the different proposed state-of-the-art techniques that are closely related to our proposed offloading scheme, together with their weaknesses and strengths.

2.6.1 Content Downloading-Offloading Techniques

Content downloading is the primary source of traffic in access network and is a prime candidate to be offloaded (Dimatteo et al. 2011).

Content downloading in vehicular scenario is based on the paradigm shown in Figure 2.10. This paradigm will help us to discuss the following different content downloading scenarios in vehicular communication.

1. Contents can be downloaded/uploaded directly from/to cellular networks without any offloading techniques.

2. Contents can be downloaded from fixed RSUs using a direct link to the downloader.

3. Connected forwarding can be used to transfer stream of contents from RSUs *via* RV to the downloader in multi-hop fusion (i.e., I2V2V).

4. Carry-and-forward mechanism in which the storage and carriage of the data are conducted by the relays, can be used for delivery to the downloader or alongside the communication link (i.e., V2V) to another relay.

From the literature, most of the proposed techniques used concepts (2) and (4) shown in Figure 2.10 for load reduction from cellular networks. However, limited studies have been conducted to exploit concept number (3) for offloading purpose.

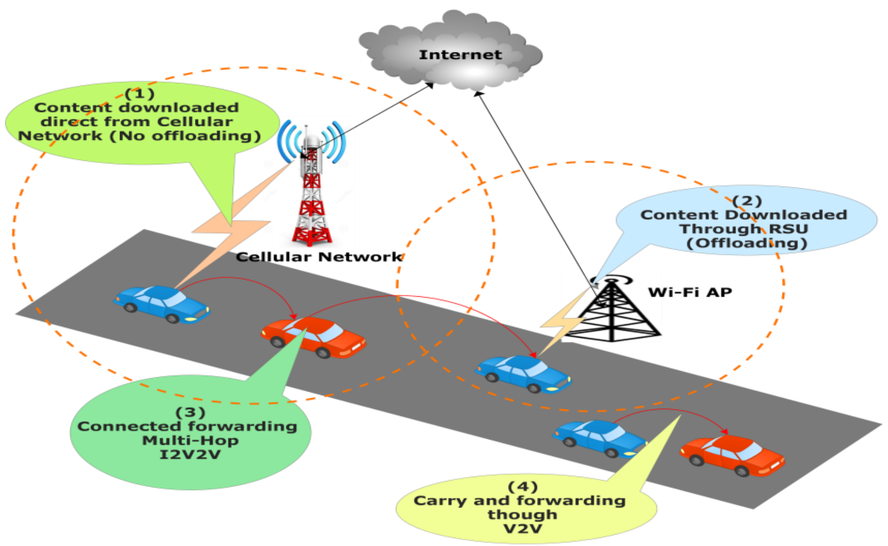

Figure 2.10 Content download paradigm in vehicular communication

Malandrino et al. (2012) proposed the model to evaluate the effectiveness of using ITS to offload the contents needed to be downloaded from cellular networks. Fixed RSU was used to predict the vehicle mobility. The proposed model is based on prediction using probabilistic presentation of the inter-node contact commonly known as fog-of-war. This prediction was then used to decide which data should be fetched and toward which vehicles should be transmitted. The fetched data could be scheduled to reach a particular relay or downloader.

Fixed RSUs were used alongside the road but inside the cellular network zone. V2V and I2V communications were based on the DSRC protocol. Vehicles that wanted to download tried to fetch data from RSU (I2V) or used opportunistic RV (V2V) before contacting the cellular infrastructure. Vehicles outside the RSU coverage could communicate directly with the cellular infrastructure. In case of V2V communication and unfinished download before time out (T), which was set at T=120s, the remaining portion was downloaded directly from an incentive cellular network. From this study, 80% offloading was achieved using this technique. However, deployment strategies for RSU were not examined.

Malandrino et al. (2013) showed that RSU deployment strategies had direct effects on content downloading in a vehicular environment. They affected both throughput and delay. The use of maximum flow strategy for RSU displacement led to improve throughput and delay performances. This strategy was followed by the crowded and contact approaches. The random strategy deployment yielded the worst performance.

Besides, Nan et al. (2014) proposed analytical framework for offloading cellular data using Wi-Fi in the vehicular scenario. The framework was based on the assumption that the vehicle user used Poisson process for arrival data services. Vehicle users could use either cost-effective Wi-Fi network (termed as want-to) or cellular network (have-to). The M/G/l/K queuing model was used to study the relationship between the effectiveness of offloading and the average delay of the service. The result showed that when the arrival rate increased, the average delay of the service also increased, whereas the offloading effectiveness decreased.

Klessig et al. (2014) proposed queuing system to model data offloading based on data flows in an elastic fashion. In this model, data offloading was used dynamically, in which the cell range was extended along with the close monitoring of inter-cell interference. Thus, all vehicle users that experienced overload or were served by macro cells that were congested were forced to connect to smaller BSs dynamically. This study stated that when using data offloading, 41.3% of network capacity could be attained.

2.6.2 Mobility Prediction and Pre-fetching Offloading Techniques

Several works proposed the offloading techniques based on vehicle mobility prediction (Malandrino et al. 2014; Siris & Anagnostopoulou 2013; Siris & Kalyvas 2012). In case of technique proposed by Malandrino et al. (2014), the RSU is responsible for predicting the future movement of the vehicle. By doing so, the RSU can have prior knowledge on what to be fetched from the network and how to be scheduled for transmission. In this work, the query management server is assumed to be available alongside the network infrastructure which handles all the content request queries sent by the vehicle through the RSU or cellular network (see Figure 2.11).

Each query must contain the content identifier and current vehicle position. These two parameters are used to identify the content that needs to be pre-fetched as well as to foresee the vehicular direction movement. At the point where the vehicle moves outside the RSU range without completely downloading the content, the query controller sends the awaiting demand content information to the RSUs along the traveling direction of the vehicle. RSUs obtains the remaining part of the content and delivers to the vehicle either directly or through the relay method. The RSUs must be smart and quick enough to predict the best method of sending the data to the vehicle before the content timeout expired. To do so, RSUs consult with the vehicular traffic manager, which is responsible for gathering all information regarding speed, position, and vehicle’s direction in real time. When the timeout expired, the vehicle fetches the remaining content directly from the cellular network. The accuracy of this method was measured based on the fog-of-war model (Malandrino et al. 2012). However, prediction accuracy shows insignificant impact on offloading efficiency. Seventy percent (70%) of the cellular traffic is managed to be offloaded in both vehicular traffic conditions and sparse RSU deployment.

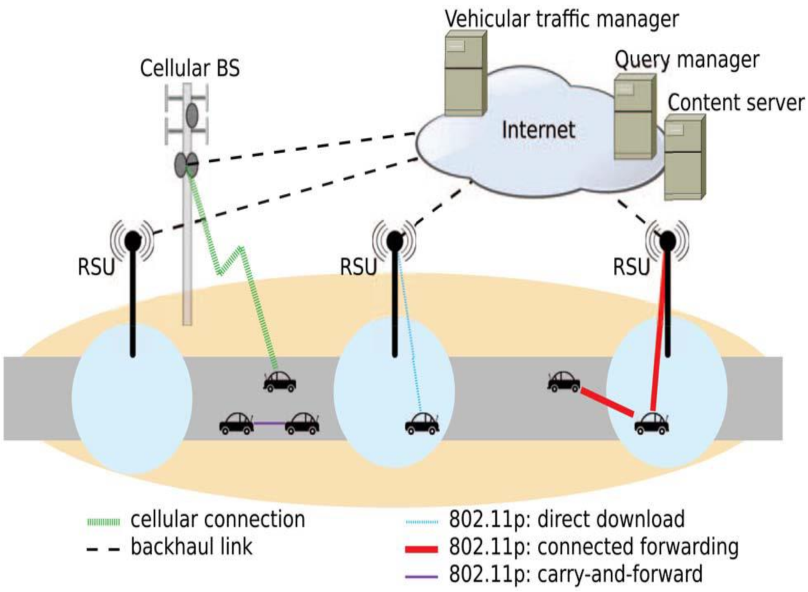

Figure 2.11 Pre-fetched mechanism for content download (Malandrino et al. 2014)

Siris and Anagnostopoulou (2013) and Siris and Kalyvas (2012) proposed the mobility prediction and pre-fetching methods that cater both the delay and non-delay tolerance applications. In the case of delay tolerance applications, the proposed algorithm focuses on maximizing the amount of data transferred through Wi-Fi. Meanwhile, the mobile node needs to estimate the duration that it will spend inside the Wi-Fi coverage zone and the amount of traffic is sent through Wi-Fi. Using these two parameters, the amount of data needs to be sent *via* cellular network; the time the mobile node will have cellular network access only can be easily calculated. From this, the minimum throughput that the mobile node expects from the cellular network can be estimated. When the mobile node is moving away from the Wi-Fi coverage zone, the amount of pre-fetched data traffic and its offset should be estimated for the next Wi-Fi AP. This offset depends upon the estimated amount of data that the mobile node will transfer though the cellular network. Whenever the pre-fetched data missed due to inaccuracy, time estimation must be directly obtained from the original file location.

Moreover, in the case of the non-delay tolerance applications, the algorithm is similar to the delay tolerance applications. Though for non-delay tolerance traffic, the concern is more on minimizing the delay; to do that, the proposed algorithm here always estimates the maximum throughput that the mobile node will expect from the cellular network. The result revealed that, using mobility prediction and pre-fetching method, 50% of delay tolerance traffic can be offloaded compared to the standard offloading methods. Furthermore, for the non-delay traffic, mobility prediction and pre-fetching method achieved 15–25% Wi-Fi offloading compared to the offloading scheme that involved neither prediction nor pre-fetching.

Bravo-Torres et al. (2015) proposed the virtual nodes intersection-based routing (VNIBR) protocol, which combines both topological and geographical, intersection-based routing to optimize mobile data offloading in urban scenarios. The proposed protocol shows significant performance in high-traffic density. However, in sparse traffic scenario, the protocol exhibits high overhead. Furthermore, from this work, the amount of data that can be offloaded is not discussed.

Otsuki and Miwa (2015) designed a content delivery algorithm that uses route prediction information for efficient content sharing among the vehicles. The proposed algorithm works in combination with V2V and V2I and can be used in a scenario where the vehicles generate a real-time data. In this algorithm, the data intended for the cellular network using V2I are rerouted and shared among the vehicles using inter-vehicles communication (V2V). However, from this work, the degree of route prediction accuracy is not investigated.

Deshpande et al. (2009) discussed a pre-fetching mechanism (see Figure 2.12) which uses the APs along the predicted vehicle routes cache to deliver the content to the vehicles when possible. This mechanism relies on the fact that driving behaviour is not random; it follows some specific patterns, which makes the prediction of mobility and connectivity of the driver possible by utilizing its historical information with reasonable accuracy. The mechanism works as follows (see Figure 2.11): (1) SV sends a REGISTER message to its connected AP (i.e., AP1). The REGISTER message contained the address of the needed file. (2) The AP replies with PF_OFFER message which contained the byte range information (i.e., beginning and end offset) of the content that needed to be pre-fetched. (3) The SV calculates the byte range that can be used by the subsequent encounter APs(n) to pre-fetch the file, and the PF_REQUEST constructs a message and sends to its connected AP. When AP received this message, it forwards to the respective APs (AP1, AP2…AP(n)). (4) Upon receiving a PF_REQUEST, all APs use the server to pre-fetch the required byte range. (5) Assuming all or segment of the byte range has been pre-fetched, the AP needs to pre-fetch just the rest of the segment. (6) Otherwise, the SV downloads the entire file directly from the internet or through AP1. Using this idea, the proposed mechanism shows that above 50% of the throughput gains under 90% confidence level.

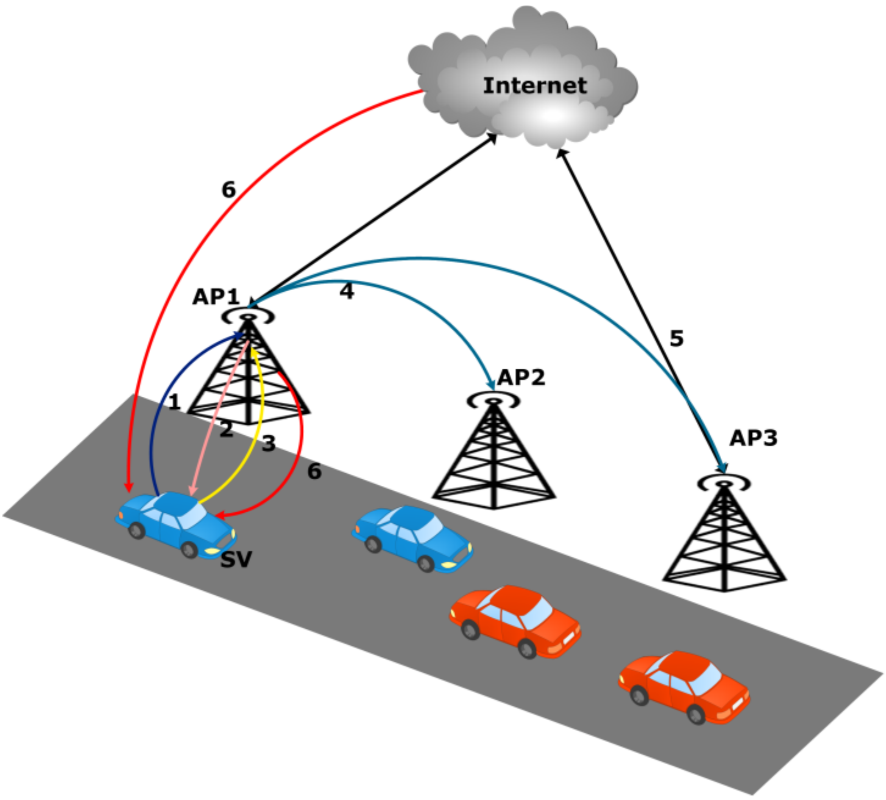

Figure 2.12 The architecture of pre-fetching protocol

2.6.3 Handoff Offloading Techniques

Pin et al. (2015) proposed a technique to reduce high packet loss, which normally occurs during the handoff procedure. The proposed technique is based on the assumption that a group of APs have the same Internet protocol (IP) address and medium access control (MAC) configuration. During the uplink time, when the SVs (client) send the packet, the packets are likely to be received by several APs within the vehicle communication range (refer Figure 2.13).

The transmission becomes successful only when any AP managed to receive the data correctly. When the data are received by the AP, acknowledgement (ACK) must be send to the SV. However, as pointed out, several APs may receive the data and a number of ACK must be sent to SV, which may lead to unwanted ACK collision. To solve this problem, ACK detection function was proposed to handle collisions of ACK from multiple APs. Moreover, group unicast was utilized in exploiting the diversity of multiple APs. During the downlink time, two steps are involved to deliver the packet bound for SV. In the primary step, multicast method is used to send the packet to a group of APs, as opposed to using unicast to send the packet direct to SV. All the APs inside the same multicast group are kept up progressively to send the required packets to the SV. The next step is for SV to periodically send solicitation messages to APs and obtain the required packets from the pool of APs.

The proposed technique revealed that the number of AP deployments affects the system throughput. However, the deployment strategies of APs were not discussed. Meanwhile, Gramaglia et al. (2011), developed a solution that provides a continuous Internet connection using opportunistic WLAN. The proposed solution uses 3G to maintain a seamless connection. Subsequently, the said solution uses WLAN to offload some traffic from the 3G network. The following handover techniques between the 3G to multi-hop WLAN networks were proposed:

1. Handover between 3G and WLAN. This is a handover whereby the vehicle moves the traffic from 3G to WLAN.

2. Handover between WLAN and 3G. In this technique, the vehicle connects to both 3G network and WLAN. If the vehicle foresees that the WLAN connection is deteriorating, the WLAN traffic will be moved to 3G networks.

3. WLAN to WLAN handover. This handover occurs between the different RSU(s) encountered by the vehicle to ensure the consistency of seamless connection.

The simulation results show that up to 80% of network traffic can be reduced from the cellular network.

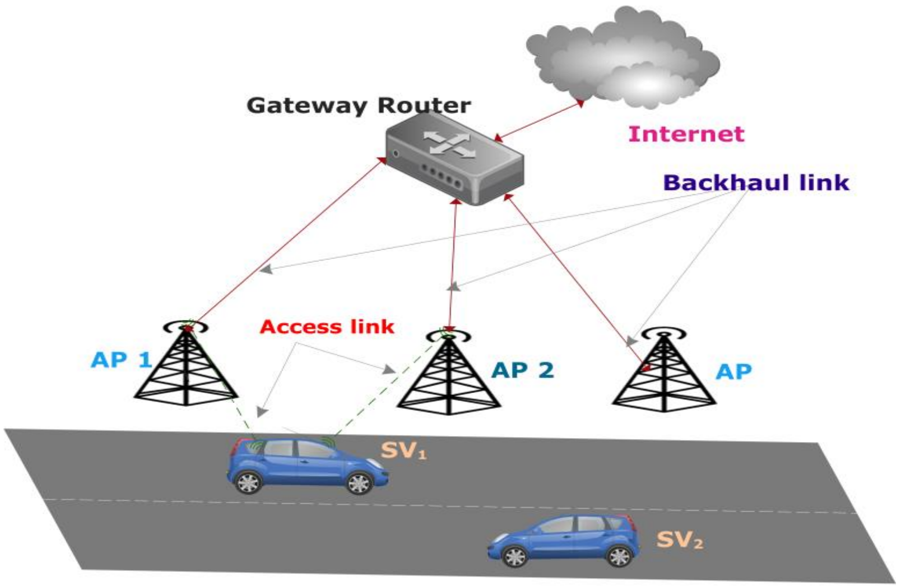

Figure 2.13 Uplink and downlink of SV using group of APs

2.6.4 RSU Prediction Offloading Techniques

It can be understood that, vehicles' mobility in VANET is not random; it normally follows certain patterns that depend on the road topology, traffics lights, and driver frequency destination points. However, these patterns are inconsistent and require the availability of additional parameters, such as vehicle velocity, locations, and direction, to accurately predict the next user location. Previous authors proposed several next user location prediction techniques based on the Markov prediction model (Gambs et al. 2012; Nicholson & Noble 2008; Prasad & Agrawal 2010).

Nicholson and Noble (2008) proposed the breadCrumbs system to predict mobile connectivity. This system adopts the second-order Markov predictor that involves the previously visited and current locations to predict the future location. The said system also establishes an AP quality database to store the bandwidth observed from different APs. The breadCrumbs system can forecast connectivity by combining the mobility prediction and AP quality database. Their results show that the prediction accuracy of breadCrumbs is >70% for the first prediction step. However, its accuracy decreases when the step number increases.

Nevertheless, Prasad and Agrawal (2010) adopted the hidden Markov model to predict the future AP based on previously encountered AP and currently connected AP. Their work shows that the prediction error increases exponentially as the AP number increases.

Furthermore, Gambs et al. (2012) proposed an algorithm that predicts the future user location utilizing the number (*n*) of previously visited locations. The proposed algorithm was developed based on the mobility Markov chain. The accuracy of the algorithm was confirmed utilizing three datasets, and the result shows that the prediction efficiency of the algorithm is between 70% and 95% when the number of previously visited locations (*n*) is 2. Moreover, the authors highlighted that no significant outcome was obtained in terms of the prediction efficiency when *n* increased. Most of the proposed mobility prediction models focus on low mobility. The said issues are not properly addressed for high-mobility models such as VANET.

Almulla et al. (2014) and Zhang and Yeo (2013) discussed the issue of predicting the next AP encounter by mobile users in a vehicle scenario. However, Zhang and Yeo (2013) utilized a contact map to anticipate the next potential APs and their respective transition probabilities. The proposed contact map was represented as a graph, where the vertex symbolizes the AP, and the edges represent the transition contexts. A table of three columns was created to store the contact map information. These three columns store the coordinates of the next AP, previous AP, and transition probabilities. Whenever a vehicle user wants to predict the next AP, he/she employs the lookup function to view the table and foresee the next AP that it can encounter. However, the prediction in the said work relies only on the previously connected AP to determine the future contacted AP. Vehicle trajectory is not considered, which is crucial to optimize the prediction accuracy. This research uses vehicle trajectory computation to enhance the prediction accuracy and offloading ratio.

Furthermore, Almulla et al. (2014) considered the AP positions and vehicle movement direction in predicting the future AP. A global positioning system (GPS) was employed to obtain the AP position and vehicle movement direction. The vehicle user has to create a queue of three elements contains the coordinates of the three latest different positions of the moving vehicle. The vehicle has to determine if the distance between the previous and current vehicle positions is larger than the pre-determined distance threshold to update this queue. If yes, then the oldest value in the queue is removed and a new position is inserted. However, if the queue contains three values (i.e., full), then two angles are computed and compared with the pre-defined angle threshold. If the calculated angles are larger than the angle threshold, then the vehicle detects the turning effect that improves the prediction mechanism to the next AP. However, the proposed method suffers from false positive and negative errors when detecting the turning event of the vehicle.

François and Leduc in (2007) compared the performance of the centralized and decentralized strategies in foreseeing future wireless availability. The authors investigated these two strategies and evaluated their reliability and accuracy. The AP is the prediction agent in the centralized approach and predicting the future APs of the connected mobile users is one of its duties. By contrast, each mobile user in the decentralized approach predicts the future AP himself. Utilizing the real dataset demonstrates that the decentralized approach shows more reasonable accuracy compared with the centralized approach. This result was also confirmed in (Balasubramanian et al. 2010; Lee & Lee 2012; Wang & Wu 2016), where the decentralized approach was utilized, and the prediction accuracy was significantly improved.

Recently, several VWO methods were proposed in this domain. The goal of these methods is to employ Wi-Fi APs encountered by the vehicles to offload cellular data. However, the vehicle must have prior information of the availability of the next APs and their expected data capacity for the proposed method to be feasible. This mechanism can help the vehicle user to make an earlier decision depending on the delay application requirement imposed by the specific application.

Balasubramanian et al. (2010) proposed the Wiffler model which reduced the cellular network capacity. This model utilized the basic prediction model to identify the next Wi-Fi network connection. Although that forecast was made to postpone exchanges for more data offloading on Wi-Fi, this condition is only conceivable when the deferrals lessen the utilization of 3G and when the exchanges can be refined inside the threshold tolerance level of a specific application. For delay or loss-sensitive applications, such as VoIP, and when Wi-Fi fails to send the data within a specified time slot, Wiffler instantly shifted the transfer to 3G. The experimental results showed that the proposed model reduced the 3G usage by 45%, with a delay tolerance of 60s. Nevertheless, approximately 20% prediction error was observed for 100s prediction time interval. More accurate prediction algorithms are needed to optimize offloading performance.

Lee and Lee (2012) designed offloading techniques based on a historical table maintained and updated by each moving vehicle to improve the offloading efficiency and prediction error. The historical connection table stores the coordinates of the APs accessed by the vehicles alongside the road. Their work focuses on the urban scenario, and a GPS is assumed to be available for obtaining the vehicle locations. From this work, the prediction process starts only when the table has a sufficient information for prediction. Two conditions must be evaluated and satisfied for the vehicle to make an offloading decision: (1) the estimated time to reach to the next AP must be less than the delay requirement of the specific application, (2) the expected data capacity of the next AP must be larger than the predicted amount the vehicle would send to the next AP. When both conditions are satisfied, the vehicle will wait and start the transfer only upon encountering the next AP. The offloading efficiency at a speed of 10m/s is lower than that of high-speed vehicles (i.e., 15m/s). The ineffectiveness of the present AP to anticipate the future AP is due to the vehicle utilizing an alternate route or coming from an opposite direction, which results in a potential undiscovered future AP.

Munyoung et al. (2015) developed a framework for predicting the vehicular trajectory for offloading. The proposed framework, data offloading through spatio-temporal rendezvous in vehicular networks (DOVE), enabled content files intended to be delivered using cellular networks to be requested and delivered by the vehicular network. DOVE primarily predicted the mobility of a vehicle by using trajectories based on the GPS navigation. Suitable offloading positions (OPs) for vehicles to extract the needed files, in the absence of a cellular network, were then selected. The OPs comprised a number of relay nodes (RNs), which overlapped within the vehicle trajectory. Figure 2.14 illustrates the concept of RN and OPs in the DOVE framework.RN_2 and RN_5 were candidates of OP. From these candidates, time–prediction-based set-covering algorithm was used to select the best RN. If the selected RN had the requested file, the vehicle (*V*) path through that RN could retrieve that file using the DSRC link. RN stored the file for future request. The buffer issue of the RN was not elaborated. However, the research showed that 57% of cellular link usage could be offloaded through the vehicular network. The number and speed of vehicles had direct effects on the offloading ratio.

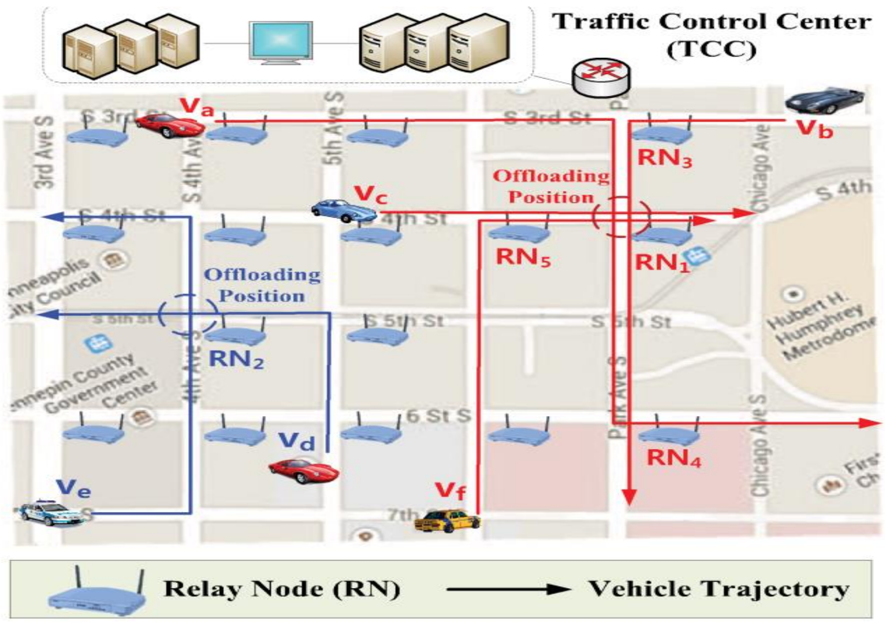

Figure 2.14 DOVE framework and RN concept(Munyoung et al. 2015)

Wang and Wu (2016) proposed an offloading mechanism that offloads cellular data and maintains user satisfaction. The offloading mechanism depends on predicting the next AP the vehicle can encounter. The said work is based on the assumption that the meeting interval of the vehicles and APs takes after the exponential Gaussian distribution. The vehicle must calculate the time to reach the next AP to make an