Multi-Hop Cluster and LTE Based Heterogeneous Architecture for VANET

by

Seyhan Ucar

A Thesis Submitted to the
Graduate School of Sciences and Engineering
in Partial Fulfillment of the Requirements for
the Degree of

Master of Science

in

Computer Science and Engineering

Koç University

September 12, 2013

Koç University
Graduate School of Sciences and Engineering

This is to certify that I have examined this copy of a master's thesis by

Seyhan Ucar

and have found that it is complete and satisfactory in all respects,
and that any and all revisions required by the final
examining committee have been made.

Committee Members:

Assoc. Prof. Öznur Özkasap (Advisor)

Assist. Prof. Sinem Çöleri Ergen (Advisor)

Prof. Murat Tekalp

Prof. Attila Gürsoy

Prof. Özgür Barış Akan

Date:

To my family

ABSTRACT

Vehicular Ad-Hoc Network (VANET) is a promising Intelligent Transportation System (ITS) technology that enables numerous applications such as safety message dissemination, dynamic route discovery, gaming and entertainment. First part of the thesis focuses on constructing stable clusters by determining the vehicles sharing similar mobility pattern to provide robust communication with minimum overhead in the presence of highly mobile vehicles. In this context, we propose VMaSC: Vehicular Multi-hop algorithm for Stable Clustering, a novel clustering technique based on choosing the node with the least mobility through multiple hops. Extensive simulation experiments performed using Network Simulator (ns-3) with the vehicle mobility input from the Simulation of Urban Mobility (SUMO) reveal that VMaSC increases cluster head duration by 25% while decreasing the number of cluster head changes by 10

Second part of the thesis considers the integration of IEEE Wireless Access in Vehicular Environments (WAVE) and 3GPP networks (LTE). WAVE operates based on ad-hoc mode with IEEE 802.11p protocol and enables vehicle-to-x (V2X) communication with vehicles and roadside infrastructures. LTE is a state-of-the art technology for mobile communication and provides a cellular infrastructure based solution. We propose an architecture combining these two technologies to achieve the high data rates of IEEE 802.11p-based VANETs and wide coverage of 3GPP (LTE) technology simultaneously. In this architecture, vehicles are clustered based on our approach VMaSC, and elected heads operate as dual-interface node with the functionality of IEEE 802.11p and LTE interface. By performing extensive simulation experiments in ns-3 with the vehicle mobility input from the Simulation of Urban Mobility (SUMO), multi-hop clustered VANET-LTE integrated architecture has been demonstrated to achieve over 90% data packet delivery ratio with maximum delay below 1 second.

ÖZETÇE

Geçici araç ağları (GAA) güvenlik mesajları dağıtımı, dinamik rota keşfi, oyun ve eğlence imkanları sunan ümit verici bir Akıllı Taşıma Sistemleri teknolojisidir. Bu tez çalışmasının ilk bölümünde en az haberleşme ek yükü ile benzer hareket modellerine göre hareketli taşıtlar arasında kararlı gruplar kurup dayanıklı iletişim ağı oluşturmaya odaklanılmıştır. Bu bağlamda VMaSC isimli, taşıtsal çok kararlı gruplar bazlı en az hereketli taşıtın çok sekmeli olarak seçildiği yeni bir gruplama algoritması tasarladık. Ağ Simülatörü (ns-3) ortamında hareketlilik modelinin SUMO ile yapıldığı geniş çaplı simülasyonlar VMaSC adlı algoritmamızın grup liderlik süresini %25 arttırdığını , grup liderlik değişimini de %10 azalttığını ortaya çıkarmıştır.

Tez çalışmasının ikinci bölümü IEEE Taşıtsal Kablosuz Erişim Ortamları (TKEO) ile 3GPP (LTE) ağları entegrasyonunu üzerinedir. TKEO, IEEE 802.11p protokolü bazlı geçici modda çalışmakta olup taşıtlar arası ve taşıt - yol kenarı baz istasyonları arasında haberleşmeyi sağlamaktadır. LTE ise mobil haberleşme son teknoloji ürünü olup hücresel yapıda baz istasyonsal çözümler sunmaktadır. Bu çalışmada, yüksek veri hızlı IEE 802.11p bazlı GAA lar ile geniş yayın alanlı 3GPP (LTE) ağlarının birlikte çalıştığı bir yapı sunuyoruz. Bu yapıda taşıtlar gruplama algoritmamız olan VMaSC ile gruplanıyor ve seçilen lider IEEE 802.11p ve LTE arabirim özelliği ile çalışmaktadır. Ns-3 ortamında, hareketlilik modelinin SUMO ile yapıldığı geniş çaplı simülasyonlarda çok sekmeli gruplanmış GAA-LTE entagrasyonunun %90 veri paketi dağıtımını maximum gecikmenin 1 saniyenin altında gerçekleştirdiğini göstermiştir .

ACKNOWLEDGMENTS

Completing a Ms is truly a long journey that would not be possible to end successfully without the help and support of many people to whom author would like to express his gratitude. First and foremost, author especially wants to record his sincere gratitude to his supervisors, Dr. Sinem Ergen and Dr. Öznur Özkasap who were abundantly helpful and offered invaluable assistance, support and guidance.

Next, author gratefully expresses his sincere to his committee members, Professor Murat Tekalp, Professor Atilla Gürsoy and Professor Özgür Barış Akan for their help, support and participation politeness.

Author also shows gratitude to his fellow mates in Wireless Network Lab Group: Yalçın Şadi, Nabeel Akthar, İrem Nizamoğlu and in Multimedia, Vision and Graphics Group: Tolga Bağcı, Göktuğ Gürler and Tuğtekin Turan in for the stimulating discussions, for their help in problems that he met, and for all the fun they have had in the last two years. Also author thanks his home mates in Koc University: Hüseyin Güler & Burak Özen for their support, understanding and assistance throughout the duration of his studies.

Last but not the least, author would like to thank his family for giving birth to him at the first place and supporting him spiritually throughout his life.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

VANET is a promising Intelligent Transportation System (ITS) technology that enables many applications such as safety message dissemination [1, 2, 3], dynamic route planning [4], content distribution, gaming and entertainment [5].

Nodes in the VANET have routing capabilities that simplifies multi-hop communication, especially for gathering and disseminating road safety information. However, it has been indicated that the performance of the flat structure which works based on proactive or reactive routing schemes is low in a large dynamic VANET [6]. In other words, a flat structure falls into major drawback in providing scalability as the network size increases and in the face of vehicle mobility characteristics. On the other hand, hierarchical structure amplifies the effective broadcasting and data dissemination over large scale networks [7]. Consequently, a hierarchical architecture is essential for achieving performance guarantees in a large scale VANET. In this context, the first part of our work focuses on clustering in VANET where our main objective is proposing a stable and efficient cluster formation approach with minimum number of cluster heads to minimize the overhead of fast topology changes and maximize the amount of information transfer among cluster heads.

In VANETs clustering scheme, vehicles are divided into virtual groups and they are allocated to the same cluster according to cluster forming metrics. A typical cluster structure is shown in Figure 1.1 which shows that vehicles can function in different states such that cluster head (CH) which is local coordinator, cluster member (CM) which is assigned one of the cluster as an ordinary vehicle, cluster gateway (CG) which is non-cluster head node located in cluster intersection that helps data

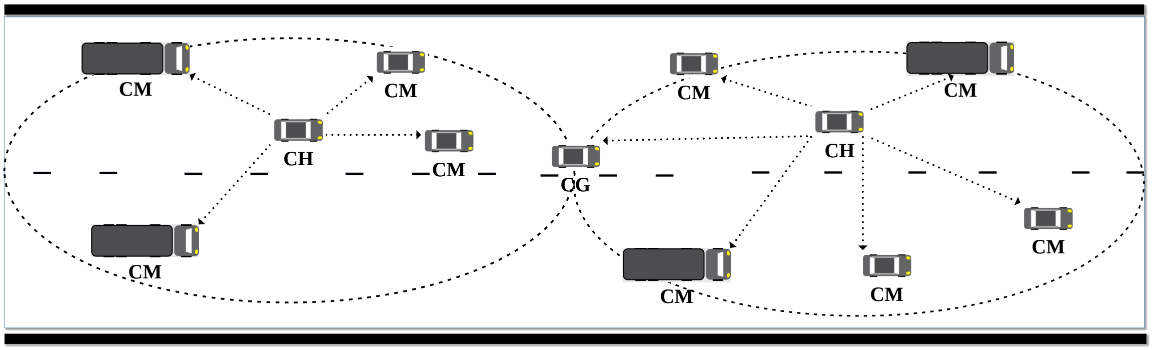

Figure 1.1: Clustered Network Topology

forwarding between clusters.

A stable cluster structure can provide efficient topology control and at least three benefits in terms of efficiency [8, 9]. First, cluster structure can coordinate the message transmission with the help of cluster head which enables reduced transmission collision. Second, clustering can improve the routing capability of VANETs in terms of data packet dissemination via using intersection vehicles, cluster gateways. Last, cluster structure divides the whole network into smaller parts and manages them individually where local changes such as leaving the attached cluster do not affect the entire network.

In spite of the aforementioned benefits, clustering in VANET has drawbacks such that fast topology change, intermittently connected network and various communication environment which make the clustering scheme costly. Thus, a clustering scheme should take these costs into consideration to improve effectiveness and scalability [10]. Cost of clustering in terms of different metrics is summarized in Table 1.1.

The second part of our work considers the integration of IEEE Wireless Access in Vehicular Environments (WAVE) and 3GPP networks (LTE) in VANETs. The VANET research effort becomes more important for advances development in V2X communication. The ideas in these studies are providing seamless connectivity and efficient communication to make Intelligent Transportation Systems safer. Majority of studies on vehicular communication concentrate on IEEE 802.11p-based Wireless

Table 1.1: Cost of Clustering

Cost Of Clustering	**Description**
Explicit Control Message for Clustering	Maintaining a cluster structure in dynamic network scenarios requires explicit message exchange between vehicle pairs such as neighbour discovery packets.
Effect of Re-clustering	Single cluster head election does not change the whole network topology in terms of cluster structure.
Mobility Assumption in Cluster Formation	Vehicles are assumed to be mobile in cluster formation and vehicles must handle the dynamicity to obtain accurate neighbour information.
Message Complexity	Message complexity measures the ratio of the total number of clustering related packets to the total number of packets generated within the VANET, namely clustering overhead.

Local Area Network which stands on dedicated short-range communication (DSRC) i.e the WAVE system. DSRC radio technology with a 75-MHz bandwidth at the 5.9-GHz band [11] is designed to reinforce low-latency wireless data communications among vehicles and from vehicles to roadside units. However, current IEEE 802.11p medium access control (MAC) cannot provide quality of service (QoS) for safety-critical applications with the proposed enhanced distribution coordination function [12].

The distinguishing characteristics of VANETs including highly dynamic topology, hard delay and reliability requirements of safety applications and various communication scenarios at different vehicle densities and different environments make IEEE 802.11p protocol perform inadequately. Due to the high speed of vehicles and unexpected driver behaviour, network topology changes and disconnections happen frequently. Moreover, some VANETs applications require hard delay constraint, high data delivery ratio and minimized delay. Another challenge in VANETs is various communication environments including highway and urban scenarios. In contrast to highway traffic scenarios, in urban scenarios there are buildings, trees, obstacles and even vehicles that make direct line of communication hard.

With the advances in wireless technology, new types of technologies started to be used as an alternative to IEEE 802.11p random access protocol. The General Packet Radio Service (GPRS), Universal Mobile Telecommunications System (UMTS) and Long Term Evolution (LTE) are remarkable ones. These technologies offer data services with infrastructure based communication and they are extensively advanced in Europe. Cellular communication is first used for safety application in Project Cooperative Cars (CoCars) [13]. Experimental results of CoCar have shown that UMTS achieved the requirement of the traffic safety application. Furthermore, dissemination of traffic hazardous warning message is accomplished below one second. Other alternative is the upcoming cellular technology LTE. In November 2009, Alcatel-Lucent Market Advantage studies European consumers related with demand for the LTE Connected Car service and its cost to the end user. The findings indicate that the LTE Connected Car service and Internet connectivity are strongly preferred by the end users. This makes researchers investigate the concept of LTE Connected Car service in [14] and [15] where the main intention is to make vehicles benefit from the Internet access by considering them as moving smart phones. While cellular systems are beneficial in terms of better coverage, they fall into major drawback of satisfying the time-critical safety application and depend on other performance metrics such as communication cost, available bandwidth, spectral efficiency of the radio interface and multi channel/carrier aspects [16].

IEEE 802.11p-based VANETs high data rates and large coverage of 3GPP technology show that ad hoc WAVE system and the infrastructure based 3GPP networks are complementing each other [17]. This motivates researchers to examine the union of both technologies into a hybrid solution. Integration of VANETs and 3GPP networks is addressed in studies [18], [19], [20], [21] and [22]. The proposed architectures facilitate mobile data access for vehicles at any moment and in any where. To overcome the frequent topology change, one common approach in these works is applying dynamic clustering. Clustering makes it possible to provide system performance, such as throughput and end-to-end delay. Clustering in VANETs was implemented based on metrics such as speed, location, direction of movement, radio power levels

[23]. However, deficiencies of these clustering techniques are; they all form one-hop clusters where only direct communication is allowed and they do not aim to provide stability of extracting vehicle mobility in a highly dynamic environment for multi-hop clusters. Clustering scheme for hybrid architecture, where cluster head acts as dual-interface node, should be designed in such a way to conserve clusters from completely re-construct when some local events such as movement into other clusters or die of cluster head occur.

1.1 Contributions

Our first goal is to develop an algorithm to construct stable multi-hop clusters with minimum number of cluster heads in VANET. Then, we evaluate the performance of the proposed clustering scheme with different metrics of interest. The original contributions of the first part are listed as follows:

- We propose a novel mobility metric, that is periodically exchanged and used for similarity calculation among vehicles. By using piggybacked information, on receiving a packet, each vehicle updates the mobility metric and shares it with its neighbours.

- We propose multi-hop clustering algorithm (VMaSC) with novel mobility metric by taking into account the cluster stability in terms of cluster head duration, cluster member duration and cluster head change, the clustering cost with evaluation of clustering overhead in highly dynamic scenarios.

- We consolidate real-world road topology which is generated by the microscopic mobility model provided by Simulation of Urban Mobility (SUMO) [24]. SUMO is a microscopic and continuous road traffic simulation package designed to handle large road networks. To the best of our knowledge, our proposed approach VMaSC is the first work to simulate multi-hop clustering under realistic vehicle mobility which is generated by realistic mobility generator SUMO.

Our next goal is to propose a heterogeneous architecture combining IEEE 802.11p and multi-hop cluster based VANET and LTE. The original contributions of the second part are listed as follows:

- We propose a heterogeneous architecture combining clustered VANET and LTE. In this architecture, we use VMaSC for the stable and efficient multi-hop clustering with minimum number of cluster heads. It aims to minimize the overhead of fast topology changes and the amount of information transfer among cluster heads by including vehicle's direction of movement and instantaneous speed to overcome the dynamicity problem of VANETs. To the best of our knowledge, the proposed architecture is the first work to simulate the hybrid VANET-LTE platform in multi-hop constructed clusters.

- We test the proposed heterogeneous architecture under a realistic scenario where we consolidate real-world road topology generated by the microscopic mobility model provided by (SUMO) [24]. This is the first work to analyze VANET-LTE integrated network topology characteristics over a large scale highway using a realistic vehicle mobility model.

- We analyze the performance of the proposed architecture over various performance metrics including data packet delivery ratio, average delay and maximum delay.

1.2 Organization

The rest of the thesis is organized as follows. Chapter 2 gives the literature review on clustering in VANET and hybrid VANET architectures. Chapter 3 explains VMaSC: the vehicular multi-hop algorithm for stable clustering in VANET and its comparative performance results. Chapter 4 explains the hybrid architecture where IEEE Wireless Access in Vehicular Environments (WAVE) and 3GPP networks (LTE) are integrated, and described the performance results. Finally, concluding remarks and future work are given in Chapter 5.

Chapter 2

RELATED WORK

In this chapter, we provide the literature review on clustering in VANET and hybrid VANET architectures.

2.1 Clustering in VANETs

The clustering scheme has attracted many researchers in the area of wireless ad-hoc networks in recent years, and clustering has been extensively studied in the past both in field mobile ad-hoc networks (MANET) and VANETs.

The metrics used in determining the cluster head in the MANET literature are; node unique id where lowest-id is elected as cluster head [26]; received signal strength where mobility is estimated by comparing received power of consecutive messages and less mobile one is elected as cluster head [27]; enhancement of lowest id where re-clustering is invoked in only two cases; when two cluster heads move into the reach range of each other and when a mobile node cannot access any cluster head [28], [29]; node's movement, where node's placement, which is greater than the predefined threshold, used and mobile node with less displacement becomes a head [30]; without any metric, where mobile node becomes cluster head when it has something to send [31]. However, these proposed metrics and algorithms are not suitable for VANET because [27] and [30] are only feasible and effective with group mobility behaviour and their performance may be degraded in VANET where mobile node moves randomly with high speed and changes speed time to time. Another reason is the stationary assumption where mobile nodes are assumed to be static in the cluster formation [28], [29], [31] which contradicts with highly mobile characteristics of VANETs.

Table 2.1: Related Work on Clustering in VANETs

Ref.	**Cluster Forming**	**Head Election**	**Radius**	**Head Communication**	**Mobility Traces**	**Performance Criteria**
[32]	Direction	Time-Out Mechanism	1-Hop	Cluster Gateway	Built-in Mobility Model	Packet Delivery Ratio, Clustering Overhead
[33]	Direction	Neighbours vehicle number, Mobility	1-Hop	Cluster Gateway	Simulator Mobility Model [34]	Successfully Transmitted Data Packet
[35]	Local Aggregate Mobility	Lowest Local Aggregate Mobile	N-Hop	No Information Provided	Free Way Mobility Model and Manhattan Mobility Model	Head Duration,Member Duration and Head Change
[36]	Direction	Comparison of Region Vehicles Entrance	1-Hop	No Information Provided	Car Following Mobility Model	Packet Reduction In Transmission, Collision Rate
[37]	Direction	No Information Provided	1-Hop	Store-Carry-Forward [38]	Car Following Mobility Model	Cluster Life Time, Cluster Size
[39]	Direction	Time-Out Mechanism	1-Hop	Head Communication	Car Following Mobility Model	Head Duration, Head Relative Speed
[40]	Direction	Distance and Direction	1-Hop	Head Communication	Car Following Mobility Model	Head Change
[41]	Head Invitation Message	Linear Distance Based Spatial Dependency	1-Hop	Cluster Gateway	Reference Region Group Mobility Model [42]	Head Duration, Head Change
[43]	Speed, Direction, Location	Neighbours Number, Relative Speed	1-Hop	No Information Provided	Car Following Mobility Model	Cluster Life Time, Number Of Cluster
[44]	Head Invitation Message	Direction, Neighbours Number, Range	1-Hop	No Information Provided	Simulator Mobility Model [45]	Head Duration, Member Duration, Connectivity
[46]	Head Invitation Message	Velocity, Mobility, Estimated Connection Time	K-Hop	No Information Provided	VanetMobiSim [47]	Number Of Clusters, Overhead

Investigation of the clustering mechanisms in VANET on the other hand focuses on one-hop clustering. Table 2.1 presents previous clustering works in VANETs with their comparison. The existing clustering mechanisms in VANETs use cluster formation metrics such as direction of movement [32], [33], [36], [37], [39], [40], receive of invitation message [41], [44], [46] weighted combination of different metrics [35], [43]. After cluster forming, communication among clusters is done by cluster gateway [32], [33], [41], direct cluster head communication [39], [40] where it is assumed that cluster heads are in communication range of each other, and specialized protocol [37].

In [32], the vehicles are divided into clusters based on their travelling direction, and then head nodes are selected to forward data packets. Head node selection is based on successful reception of head invitation messages. If a vehicle does not get head messages in a predefined amount of time, it announces itself as the new cluster head.

The formation and maintenance method of clustering in [33] are performed by a combined process introduced in [48] and [49]. According to number of neighbours, connectivity and mobility, each vehicle measures the weight that points out its suitability as a cluster head. An elected cluster head indicates its status by sending frequent hello packets.

The approach proposed in [36] uses Global Positioning System (GPS) and digital map to determine the travel paths of vehicles. By using digital maps, travel path is divided into regions. By comparing the vehicles entrance into a region, cluster head election is achieved by the first vehicle entering the region announces itself as the cluster head.

In [37], an empirical study of sparsely connected VANETs is presented and it is shown that vehicles in the same direction are said to be within the same cluster if the communication is done with one another in a one-hop or multi-hop fashion. The study also addresses the statistical properties of clusters in disconnected VANETs in terms of cluster size and cluster life time.

In [39] and [40], time-out mechanism is used to elect cluster heads. If vehicles do not hear periodic invitation messages from the cluster head, they advertise themselves as cluster head. Member selection relies on successful reception of head invitation messages and consecutive request and response messages to get authorization from the cluster head.

Another study [41] proposes a distributed group mobility adaptive (DGMA) clustering algorithm based on the linear distance of a node's movement instead of its instantaneous speed and direction. Nodes compute spatial dependency value using the relative direction and speed ratio and share with neighbours. Based on the received values, node with higher value announces itself as cluster head and generates invitation messages.

In [43], the speed difference between vehicles is used to construct cluster structure in VANET and a multi-metric cluster head election based on location, neighbour number and direction is proposed. After cluster head election, members, which are 1-hop far away from the cluster head, are assigned to cluster based on speed difference.

A weighted clustering technique where cluster head election based on metrics such that neighbour number, transmission range and direction of vehicles is proposed in in [44]. Member vehicles are determined through head invitation message reception.

On the other hand, multi-hop clustering algorithms proposed for VANETs focus on using metrics such as packet delay [35] and estimated connection time [46]. In [35], vehicles periodically broadcast beacon messages. After receiving two consecutive messages, the vehicle calculates relative mobility with other vehicles in its N-hop neighbourhood via using the packet delay. The relative mobility metrics are then summed up as an aggregate mobility metric where the lowest aggregate mobility is selected as cluster head and other vehicles join the cluster when they receive the messages from cluster head.

Author in [46], modifies the algorithm in [50] namely MDMAC to adapt to the changes in the network topology. MDMAC uses weighted technique to select cluster head based on parameters of location, velocity and direction where vehicle with the biggest weight in its neighbourhood is chosen to be a cluster head. MDMAC differs from [50] in re-clustering when two cluster heads meet each other. MDMAC estimates the connection time between cluster heads and uses the estimated time as parameter to apply re-clustering.

Since a cluster structure is a kind of hierarchical structure, many papers investigate clustering scheme for VANETs. However, deficiencies of these clustering techniques are; they all form one-hop clusters where only direct communication is allowed and they do not aim to provide stability of extracting vehicle mobility in a highly dynamic environment for multi-hop clusters. Furthermore, in one-hop clustering re-election of cluster head (re-clustering) can affect the structure of many clusters and can cause whole network topology change [10].

On the other hand, multi-hop clustering schemes proposed in VANETs focus on using metrics such as packet delay where variation in packet delivery delay is used to construct clusters [35], weighted combination of different metrics with estimation [46] to detect the topology change in network. However, synchronization among vehicles and drastic changes in the inter-vehicular distance due to unpredictable driver behaviour make packet delivery delay and estimated connection time parameters unsuitable for VANETs. Therefore, multi-hop clustering with hop-limit is necessary for VANETs to tolerate vehicles movement with less re-clustering, less overhead and long-life clusters.

2.2 Hybrid VANET Architectures

In the area of 3GPP related network architectures, there have been some recent works. In [18], authors suggest a solution that uses 3G cellular networks for both data communication and dissemination of control information. To achieve that, a signalling solution based on existing operator capabilities is constructed, and tested for the case of VANET routing improvement in urban scenarios. Extensive simulation results show that proposed solution improves the routing performance in terms of packet delivery ratio and end-to-end delay.

In [19], the authors propose a hybrid framework for cluster management in vehicular networks where the organization of clusters is managed by LTE Evolved Node B (eNodeB). Proposed framework named LTEV2X benefits from both IEEE 802.11p and LTE to gather data from vehicles and forward to the central server. In LTEV2X, after cluster head election cluster head gains functionality of sending clustering data of itself and its members to the eNodeB via LTE. The proposed architecture aims at constructing hierarchical structure with the help of LTE where data packet dissemination is out of concern.

Other architectures that consider the VANETs and UMTS integration are proposed in [20] and [21]. In these works, vehicles are clustered according to direction of movement, UMTS received signal strength, and the IEEE 802.11p transmission range. Authors propose mobile gateway discovery steps which are named multi-metric mobile gateway selection, gateway handover and gateway discovery/advertisement mechanisms. Proposed gateway discovery mechanism is used to select minimum number of LTE interface enabled gateway vehicles in order to link VANET into UMTS network. It is based on Simple Additive Weighting (SAW) [52] technique where used metrics are mobility of the cluster head, its UMTS RSS and the stability of its link with the source vehicles. Authors address the gateway discovery and management rather than effect of clustering on system performance. High dynamic nature of VANET makes hybrid VANET architectures require stable clustering technique in terms of cluster life-time and clustering overhead.

In [22], authors address cluster head based multicasting and quality of service enabled communication. They incorporate IEEE 802.11p VANETs with 3GPP LTE to gain seamless multimedia session among virtually grouped vehicles. Vehicles are grouped into clusters based on the same metrics proposed in [21]. However, cluster head election mechanism associates the IEEE 802.11p transmission rate, the LTE Uplink/Downlink Channel Quality Indication (CQI) and the relative distance metrics. In group communication, multicasting within VANETs is managed by the cluster heads. A minimum number of gateways (GW) are selected from CHs and LTE interfaces are activated only by GWs to communicate with the eNB. However, authors use dynamic mesh-based multicast tree for lower-level communication amongst VANET which increases the overhead and affects the performance of the VANET. VANET integrated architectures stand in need of minimized overhead in both clustering and communication among vehicles.

In [53], authors introduce a new protocol which considers the vehicle movements to predict the future behaviour of vehicles, and constructs a route with the longest lifetime to connect to the wired network. The protocol uses two metrics, which are named Link Expiration Time (LET) and Route Expiration Time (RET). LET and RET are used to have more stable route to gateways and to manage better quality of network. By using these metrics, authors aim to build pro-active communication between the vehicles and gateways by measuring the stability of the links. In this work, authors use the vehicle movement to predict the future behaviour which contradicts high dynamic nature of VANET. To overcome the problem of fast topology change, hierarchical structure is one of the solution among researchers.

In [54], authors propose another hybrid work that integrates MANET with 3GPP UMTS, and address the issues of adaptive gateway management mechanism for multi-hop B3G networks and the selection of mobile gateways in an integrated MANET-UMTS heterogeneous network. Selection of the gateway is based on multi-attribute decision making theory and SAW [52] techniques where used metrics are residual energy, UMTS signal strength and mobility speed of the gateway candidates.

The use of cellular communication within the VANETs is common nowadays. In contrast to the existing studies, our work aims to increase the routing in terms of the data dissemination in VANETs with the assistance of LTE network over a multi-hop clustered network topology. Multi-hop clustering enables vehicles to tolerate the fast topology changes and to have longer life time in terms of cluster head duration and cluster member duration. Elected cluster heads from multi-hop clusters can act in dual interface mode and link the VANET to the LTE in order to achieve providing connectivity and forwarding data packets.

Chapter 3

VMASC: VEHICULAR MULTI-HOP ALGORITHM FOR STABLE CLUSTERING IN VANETS

In a clustering scheme, vehicles are divided into virtual groups based on the defined cluster forming metrics. Clustering in VANETs was implemented using metrics such as speed, location, direction of movement, and radio power levels [23]. However, clustering scheme for highly dynamic networks should be designed in such a way to conserve clusters from complete re-construction when some local events such as movement into other clusters or die of cluster head occur. This chapter explains our multi-hop algorithm VMaSC proposed for stable clustering in VANET, and discusses its comparative performance results.

3.1 VMaSC System Model

Clustering in VANETs increases the stability of inter-vehicular links which contributes to efficient data dissemination. In VMaSC, clustering performed based on aggregated metrics of direction of vehicle movement and average relative speed. Each vehicle has one cluster head and all nodes in a cluster can communicate with the cluster head in a number of hops that is less than a maximum pre-determined value (hop limit). Figure 3.1 shows an example of clustered network topology, where in clusters (dotted circles), middle vehicle is the cluster head and vehicles that are n-hop far away, are n-hop cluster members. In VANET, the cluster formation technique should be designed with the goals of minimizing the number of cluster heads change in the network, maximizing the duration of cluster head and cluster member to provide the stability and minimizing the overhead of forming the clusters. In this section, we describe the states of the vehicles, the algorithm for cluster formation and maintenance, and

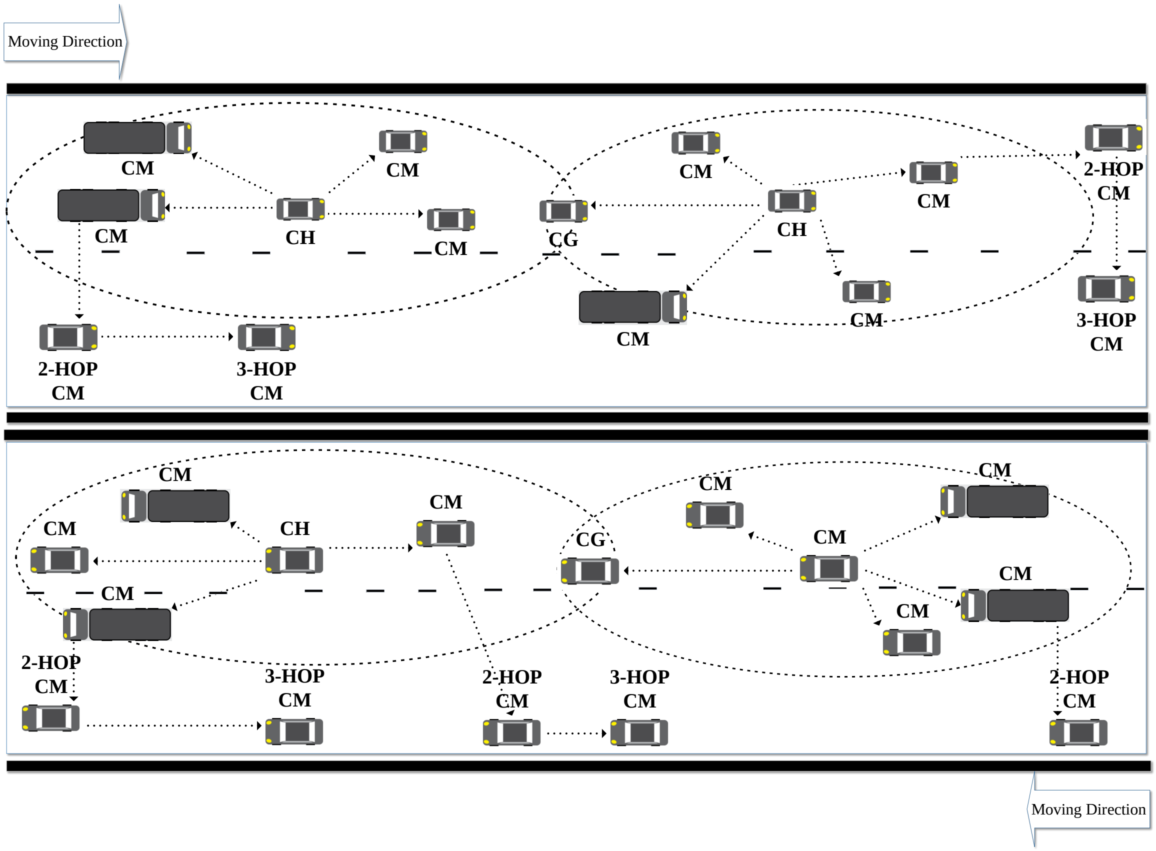

Figure 3.1: Clustered Structure Illustration

multi-hop clustering mechanism. The notation used is presented in Table 3.1.

3.1.1 States of Vehicles

Each vehicle can operate under one of the five states as described below.

- INITIAL (IN) is the starting state of the vehicles. Vehicles stay in this state and start to receive/send hello packets with piggybacked clustering related attributes and build $LOCAL\_KNOW$. $LOCAL\_KNOW$ keeps vehicle's information such that direction, current state, current speed, current hop counter, average relative speed, maximum allowable hop number, connected cluster head id, connected cluster member.
- STATE ELECTION (SE) is the state of the vehicles where the vehicles make

Table 3.1: VMaSC Notation

Notation	**Description**
IN	Initial State
SE	State Election
CH	Cluster Head
CM	Cluster Member
CG	Cluster Gateway
$CLUSTER\_INFO$	Constructed Cluster Information
V_{timer}	Vehicle's Timer
V_{state}	Vehicle's Current State
$AVGREL_{speed}$	Vehicle's Average Relative Speed
$MEMBER_{ch}$	CH's Connected Member Counter
$MEMBER_{cm}$	CM's Connected Member Counter
CH_ADV	CH's Advertisement Packet
MAX_HOP	Max. Hop Between CH and CM
MAX_CH	Max. Member CH can serve
MAX_CM	Max. Member CM can serve
$LOCAL\_KNOW$	Vehicle's Local Knowledge Base
$JOIN\_REQ$	Vehicle's Join Request Packet
$JOIN\_RESP$	Join Response for Join Request
$TRY_{connect}$	CH and CM's Try To Connect Flag
$MERGE\_REQ$	CH's Merge Request
$HELLO\_PACKET$	Vehicle's Periodic Hello Packet
$DATA\_PACKET$	Vehicle's Periodic Data Packet
ID_{DATA}	Data Packet Generator Id
SEQ_{DATA}	Data Packet Sequence Number

decision about the next state by using $LOCAL\_KNOW$ based on Algorithm 1.

- CLUSTER HEAD (CH) is the state of the vehicles which are less mobile in regard to its neighbours.
- CLUSTER MEMBER (CM) is the state of the vehicles where the vehicles are attached to a constructed clusters.
- CLUSTER GATEWAY (CG) is the states of the vehicles where non-cluster head nodes locate and link neighbouring clusters in order to forward information between clusters.

3.1.2 Cluster Formation and Maintenance

Algorithm 1 SE Algorithm

```
Start $V_{timer}$
while $V_{timer}$ is not expired do
    if $LOCAL\_KNOW$ contains $CH$ then
        for all $CH$ in $LOCAL\_KNOW$ do
            if $TRY_{connect}$ flag of current $CH$ is false then
                if $AVGREL_{speed}$ is smaller than current vehicle then
                    if $MEMBER_{ch}$ is smaller than $MAX\_CH$ then
                        Send $JOIN\_REQ$ and start timer for reply
                        Wait for $JOIN\_RESP$
                        if $JOIN\_RESP$ is received in given amount of time then
                            Connect to $CH$, set $V_{state}$ to $CM$
                            Exit from SE Algorithm
                        else
                            Set $TRY_{connect}$ flag of current $CH$ to true
    for all $CM$ in $LOCAL\_KNOW$ do
        if $TRY_{connect}$ flag of current $CM$ is false then
            if $AVGREL_{speed}$ is smaller than current vehicle then
                if $MEMBER_{cm}$ is smaller than $MAX\_CM$ then
                    if $MAX\_HOP <$ current connection hop then
                        Send $JOIN\_REQ$ packet and start timer for reply
                        Wait for $JOIN\_RESP$
                        if $JOIN\_RESP$ is received in given amount of time then
                            Connect to $CM$, set $V_{state}$ to $CM$
                            Exit from SE Algorithm
                        else
                            Set $TRY_{connect}$ flag of current $CM$ to true
    if $AVGREL_{speed}$ is smallest in $LOCAL\_KNOW$ then
        Broadcast $CH\_ADV$ packet, set $V_{state}$ to $CH$
        Exit from SE Algorithm
    else
        Wait for $CH\_ADV$ packet
```

Via broadcasted $HELLO\_PACKET$ in each state, vehicles collect the clustering related metrics; direction, current state, current speed, current hop counter, average relative speed, maximum allowable hop number, connected cluster head id, connected cluster member. For each received $HELLO\_PACKET$, vehicles construct and update $LOCAL\_KNOW$ with received metrics. When the vehicle timer is expired, vehicle shifts state to SE and clustering process is triggered. Via using $LOCAL\_KNOW$, average relative speed is calculated as follows: vehicle first checks the $LOCAL\_KNOW$ for vehicles which are in the same direction. The reason for considering only same direction vehicles is to maximize the duration of the cluster heads. The relative mobility of the vehicle is then calculated by finding the average of the relative speed ($AVGREL_{speed}$) of all the same direction neighbours as

$$AVGREL_{speed} = \frac{\sum_{j=1, j \neq current}^{n} |S_{current}(t) - S_j(t))|}{n} \tag{3.1}$$

where n is the number of same direction neighbours, $current$ is the index of the vehicle evaluating the relative mobility, $S_j(t)$ is the speed of the j-th same direction neighbour. The cluster head election rests on calculated average relative speed of vehicles. In order to extend the life time of cluster, less mobile vehicle in regard to its neighbour is elected as cluster head.

In SE, the decision to become cluster head, cluster member and n-hop cluster member is made as described in Algorithm-1. Since the main objective of clustering scheme is electing minimum number of cluster heads, Algorithm-1 first tries to set up a connection between existing cluster heads . Via using $LOCAL\_KNOW$, vehicle controls CH existence and $MEMBER_{ch}$. After CH control, $TRY_{connect}$ flag is controlled (Line 5) in order to check if it is tried to be connected before. If it is not then $AVGREL_{speed}$ is compared between CH and current vehicle (Line 6). To extend the CM lifetime, CH whose relative mobility resembles current vehicle the most is elected by comparing $AVGREL_{speed}$ and vehicle sends $JOIN\_REQ$ packet to inform the CH about the connection request (Line 8) and starts timer for $JOIN\_RESP$. If vehicle receives $JOIN\_RESP$ from cluster head in given amount of time, vehicle changes state to CM (Lines 11) and exit from SE algorithm. Response waiting is controlled via timer where if vehicle does not receive $JOIN\_RESP$ in predefined amount of time, vehicles set try to connect flag of CHs and CMs to true in their $LOCAL\_KNOW$ to not try again previously tried CHs and CMs in the next SE algorithm execution (Line 14).

Next step of Algorithm 1 depends on allowable MAX_HOP between CH and CM. If the hop number is 1 which means 1-hop clustering is in progress, next step is cluster head election.

The cluster head election stands on calculated relative mobility with respect to its neighbours (Lines 27-31). We believe that selecting less mobile vehicle in regard to its neighbour can prolong the life time of cluster. Therefore, vehicles which have the smallest $AVGREL_{speed}$ are elected as cluster head. Elected cluster heads announce themselves via broadcasting CH_ADV packets (Line 28) and exit from SE algorithm (Line 29). Other vehicles, which are in SE, waits for CH_ADV packets and if advertisement packet is received, it follows the procedures $JOIN\_REQ$ and $JOIN\_RESP$ to get authorization from CH else they stay in SE until V_{timer} expires. When V_{timer} is expired, they trigger SE algorithm again and try to connect existing clusters or construct new one.

If MAX_HOP is greater than or equal to 2 then constructed clusters are in multi-hop. The main logic behind multi-hop clustering is re-broadcasting which is controlled by one of $HELLO\_PACKET$ attributes, current hop counter (hop limit), in order to prevent system from flooding. Vehicles which receive $HELLO\_PACKET$ first increase the current hop counter by one and compare it with MAX_HOP. If current hop counter is less than MAX_HOP, vehicle attaches its id, $AVGREL_{speed}$ and current state into packet as a sender information and rebroadcasts it. Via applying the hop counter approaches, vehicles in MAX_HOP distance are reached.

After reaching MAX_HOP distance vehicles, Algorithm 1 is executed as follows. Vehicles attempt to connect to existing cluster members and try to use the CM as much as possible (Lines 15-26). In multi-hop clustering, first trial takes aim at 1-hop CM whose mobility is the most similar to itself. If no 1-hop cluster members found that satisfies the $AVGREL_{speed}$ smallness condition, next step is controlling the MAX_HOP and trying to find a vehicle which is not more than MAX_HOP distance from CH. If no vehicles found then a new cluster is constructed by selecting new cluster head (Lines 27-31).

For cluster maintenance, VMaSC follows timer and packet reception mechanism to avoid unnecessary cluster head releases when two cluster heads pass by each other in a short period of time. When two cluster heads meet each other, they both start timer and count the cluster head related packets. When timer expires, if they are still in communication range, they share $CLUSTER\_INFO$ and high mobile CH gives up its cluster head role by sending $MERGE\_REQ$. Otherwise, they both function in cluster head status.

3.2 Simulation & Results

We implemented our algorithm VMaSC on Network Simulator - ns3 (Release 3.13) [51] and used the topology of the network generated by SUMO [24]. Extensive simulations are performed and analysis results are presented in this section. The acceleration and overtaking decision of the vehicles are determined by using the distance to the leading vehicle, travelling speed, dimension of vehicles and profile of acceleration deceleration. Our scenarios consist of a two lane and two way road which is used to simulate the microscopic mobility of vehicles. For each scenario, simulation runs 600 seconds, and the clustering process starts at 300 second where all vehicles are on the road. General simulation parameters are illustrated in Table 3.2.

Table 3.2: VMaSC Simulation Parameters

Parameters	Value
Simulation Time	300 s
Mobility	SUMO
Area range	1000 m * 1000 m
Maximum Velocity	10 - 35 m/s
Number Of Vehicles	100
Transmission Range	200 m
Max. Head Member Number	5
$HELLO\_PACKET$ period	200 ms
$DATA\_PACKET$ period	1 s
V_{timer} value	2 s

3.2.1 Algorithms Used For Comparison

For comparison with VMaSC, recent multi-hop clustering algorithms NHop [35] and MDMAC [46] are implemented. In NHop clustering, relative mobility is computed based on the variation of the packet delay of two consecutive messages [35], and MDMAC clustering uses a weighting strategy and estimates the connection time when two heads meet each other [46].

In NHop clustering [35], the basic idea is allowing the vehicle nodes to broadcast beacon messages periodically. By receiving two consecutive beacon messages, a vehicle can calculate relative mobility with other vehicles in its N-hop neighbourhood. The relative mobility metrics are then used to calculate the aggregate mobility metric; the vehicle nodes which have the lowest aggregate mobility are selected as cluster head nodes. Other vehicle nodes will join the cluster when they receive the messages from cluster head nodes. In [35], a new mobility metric is used to represent the N-hop relative mobility between two vehicle nodes. The ratio of packet delivery delay of two consecutive packets is used to calculate the N-hop relative mobility. Every vehicle node broadcasts a beacon message in its neighbourhood for every beacon interval. In the beacon message, the time when the vehicle broadcast the messages is encapsulated. When the neighbour node receives the beacon message, it calculates the packet transmit delay and saves the packet delay in a data structure called neighbour list. If a vehicle node receives two consecutive beacon messages from the same node, it can compute the relative mobility between them. The formula used to compute the relative mobility metric is as follows.

$$RelM(i,j,n) = 10 \log \frac{PktDelay_{new}(i,j,n)}{PktDelay_{old}(i,j,n)} \tag{3.2}$$

Based on the relative mobility metrics for neighbours in N-hop distance, the vehicle computes the aggregate mobility value. The aggregate mobility metric equals the summary of the relative mobility times a weight value for all neighbour nodes in N-hop. The weight metric is used to represent the contribution of different relative mobility to the whole aggregate mobility. Because the vehicle node which can access in less hops is prone to stay in the N-hop neighbourhood longer, the weight value of that vehicle node should be assigned a small value. The vehicle which has higher hops has more possibility to change the clusters. After calculating the aggregate mobility metric, vehicle broadcasts its aggregate mobility value in the N-hop neighbourhood. The vehicle node which has the smallest aggregate mobility value is selected as the cluster head node; and other vehicle nodes work as the cluster member nodes.

A new solution for clustering in VANETs named MDMAC is described in [46]. MDMAC is a modification of the DMAC algorithm (Distributed and Mobility-Adaptive Clustering) [50]. DMAC can adapt to the changes in the network topology caused by the nodes mobility, and it is suitable for any mobile environment. MDMAC is an adaptation of the DMAC solution to meet the road traffic mobility patterns. The main idea of the DMAC is that node with the biggest weight in its neighbourhood is chosen to be a cluster head. Cluster head announces itself via periodically sending cluster head advertisement packet. During the weight calculation, metrics of velocity and mobility are used. MDMAC differs from DMAC in re-clustering when groups of vehicles move in different directions. In such a case, the moment of meeting is usually very short and changing cluster structure at this moment may lead to another re-clustering, immediately after groups move outside their transmission range. Nodes estimated the connection time and decide to re-cluster. A method for estimating the connection time (so called freshness) of two moving nodes is introduced. With the freshness value computed, it is possible to avoid re-clustering when two nodes come into connection range only for a short period of time, for example when the node with a high weight overtakes group of nodes. Next advantage of the MDMAC is periodical sending of HELLO messages. Via HELLO messages, nodes have an up-to-date information about their neighbours weights. Updating neighbours weights is not a problem when nodes weights are constant. However, out-of-date neighbours weights (variable in time) can lead to non-optimal clustering.

3.2.2 Performance Metrics

The performance of the clustering approach VMaSC is evaluated in terms of Average Cluster Head Duration, Average Cluster Member Duration, Clustering Overhead, Cluster Head Change metrics defined as follows.

- Average Cluster Head Duration is the time period from when vehicle changes state to CH to when vehicle leaves this state and goes to another state (e.g SE). Average cluster head duration is computed by dividing total cluster head duration into total number of state changes from CH to another states.

- Average Cluster Member Duration is defined as the time interval from joining specified cluster as member in CM state to leaving the connected cluster by changing the state. By dividing the total cluster member duration into total cluster member changes, average cluster member duration is calculated.

- Clustering Overhead measures the ratio of the total number of clustering related packets (e.g. CH_ADV, $JOIN\_REQ$) to the total number of packets generated within the VANET.

- Cluster Head Change is defined as the number of state changes from CH to another state (e.g. SE or CM).

3.2.3 Simulation Results

Average Cluster Head Duration

The average cluster head durations under different velocity with different algorithms are given in Figure 3.2. The effect of maximum hops in clustering process is taken into account by varying the hop limit as 1, 2 and 3.

Figure 3.2 indicates that VMaSC has good performance in terms of cluster head duration compared to NHop and MDMAC. The graph demonstrates that regardless of used metrics in clustering, average cluster head duration generally tends to decrease

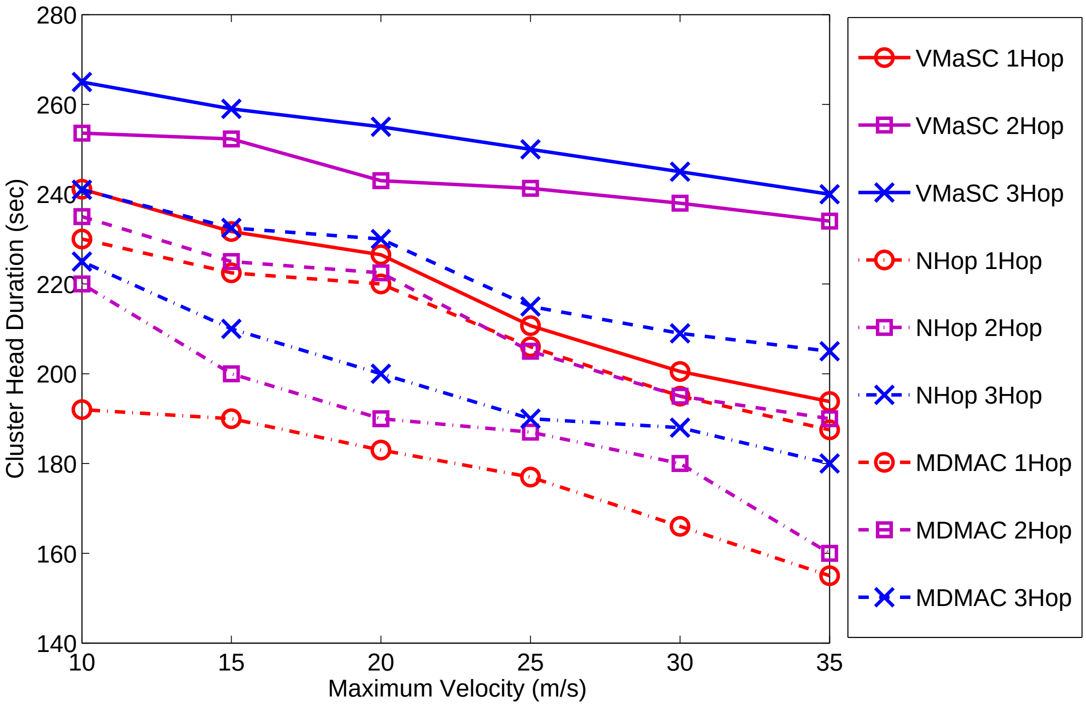

Figure 3.2: Average Cluster Head Duration in different Vehicle Maximum Velocity

along with the increase in vehicle velocity. This is because when the vehicle velocity increases, the topology of network becomes more dynamic. Other metric that significantly affects the cluster head duration is MAX_HOP to the cluster head. Average cluster head duration increases as MAX_HOP increases. This can be explained that in multi-hop scenarios cluster head has higher chance to find member to serve which makes cluster head stand in CH longer. The result indicates that our approach VMaSC outperforms other multi-hop clustering approaches NHop and MDMAC. The major difference between VMaSC and other protocols is to prolong the lifetime of cluster heads, VMaSC elects both cluster heads and members based on criteria which enables head-member pair to have strong connectivity.

Average Cluster Member Duration

Figure 3.3 shows the comparative average cluster member duration results for different algorithms in different velocities.

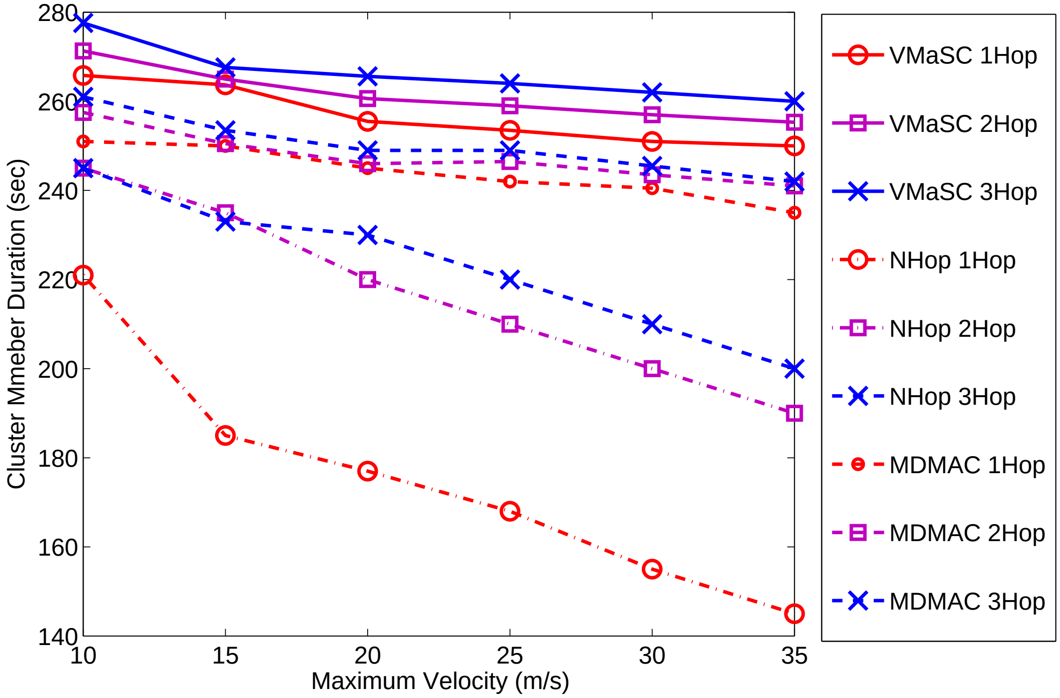

Figure 3.3: Average Cluster Member Duration in different Vehicle Maximum Velocity

Figure 3.3 shows that as the vehicle velocity increases frequent topology changes makes the cluster member duration shorten. Due to highly dynamic network, vehicles do not hear head related packets and they endure SE longer or advertise themselves as CH. However, after some time either vehicles hear another cluster head or they do not find any CM to serve. When the timer expires, vehicles go to SE and try to connect existing CH and CM. Eventually, vehicles either become CM or new cluster is constructed where in both cases total cluster member duration is increased. Another metric that plays role on member duration is the number of maximum hops between cluster head and cluster member. When the MAX_HOP increases, average member duration also increases. Vehicles connect to existing clusters by controlling the hop limit and become a member in multi-hop distance which makes vehicles stay in CM longer.

Clustering Overhead

The performance of the three protocols in terms of clustering overhead in different velocities is illustrated in Figure 3.4.

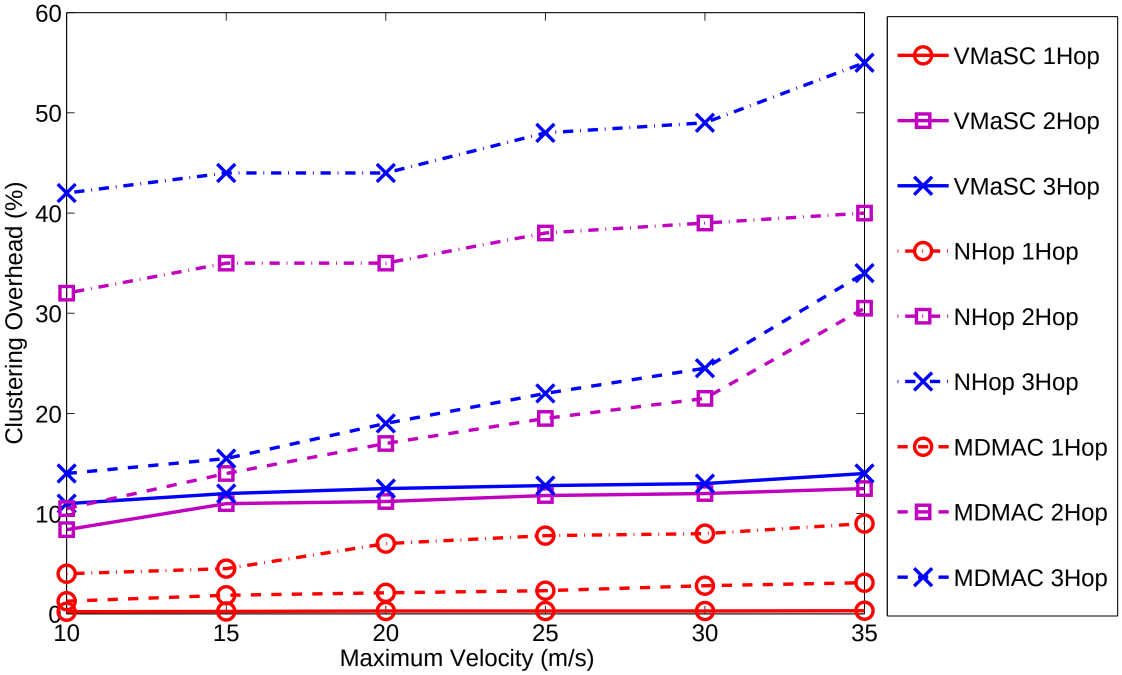

Figure 3.4: Clustering Overhead in different Vehicle Maximum Velocity

Due to constructed cluster structure stability in terms of head duration and member duration, VMaSC clustering overhead is smaller when compared to NHop and MDMAC. Fast network topology change causes drastic increase in clustering-related information exchange in NHop and MDMAC clustering. One of the key metrics that affects the clustering overhead is dissemination of $HELLO\_PACKET$ in multi-hop scenarios. As the hop number increases the overhead also increases. This is because to reach the n-hop vehicles, $HELLO_PACKET$s are re-broadcasted by controlling the hop limit. In VMaSC, we eliminate the control overhead caused by active clustering where clustering is applied periodically. Due to timer based cluster maintenance in VMaSc, clustering is applied when it is necessary which decreases the clustering overhead.

Cluster Head Change

Figure 3.5 shows the cluster head change of the three protocols as a function of the maximum velocity of vehicles.

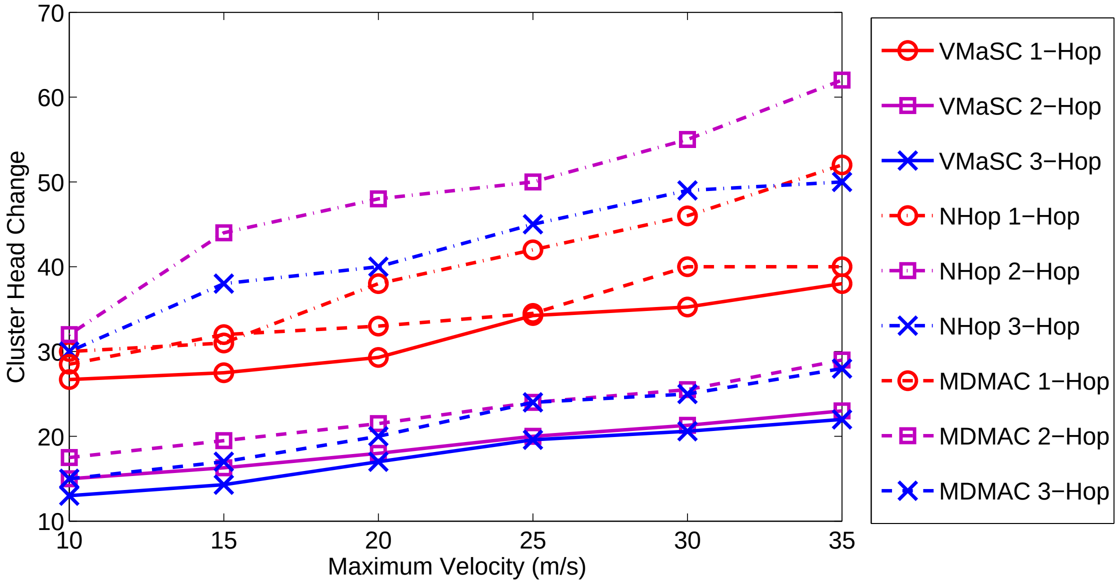

Figure 3.5: Cluster Head Change in different Vehicle Maximum Velocity

When the vehicle velocity increases, head change number also increases. This is because of the network dynamics where the more velocity the vehicles have, the more dynamic the network topology is. In contrast to multi-hop clustering in NHop and MDMAC, VMaSC can reduce the rate of cluster head change number because cluster heads do not release the head status whenever they have member to serve. In NHop and MDMAC clustering, member election is based on cluster information reception, and thus the connection between head-member pair is weaker than our multi-hop clustering VMaSC. Another issue that effects cluster head change is contacts of two passing cluster heads. For cluster maintenance, VMaSC follows timer and packet reception mechanism to avoid unnecessary cluster head releases when two cluster heads pass by each other in a short period of time.

Chapter 4

LTE BASED HETEROGENEOUS ARCHITECTURE FOR VANET

In this chapter, we propose a novel framework where the main idea is to integrate WAVE and LTE radio modules into a single device and permit them work concurrently in order to disseminate data packets.

4.1 Heterogeneous Architecture System Model

The network illustration of union of clustered VANETs and LTE network is demonstrated in Figure 4.1. The topology shows a road with VANETs where vehicles are grouped based on their direction of movement and average relative speed. In our proposed hybrid architecture, vehicles are equipped with two set of interfaces denoted by IEEE 802.11p and LTE which can operate simultaneously. An eNB base station is positioned in the center of the road and the VANET is considered to be under the coverage region of eNB.

The main objective of proposed hybrid architecture is effectively and efficiently forwarding data packets over multi-hop clustered network in a large scale network with the help of LTE. Vehicles are clustered based on multi-hop clustering technique VMaSC by considering cluster stability and clustering cost. In this architecture, vehicles are assumed to be under coverage of single eNodeB where roaming and handover issues are not considered.

Referring to Figure 4.1, after cluster formation CM vehicles forward data packets to its connected CM or CH. When CH receives data packets, it applies update in the $LOCAL\_KNOW$ and disseminates data packets to the cluster members and to other clusters. In hybrid architectures, CHs function based on Algorithm 2.

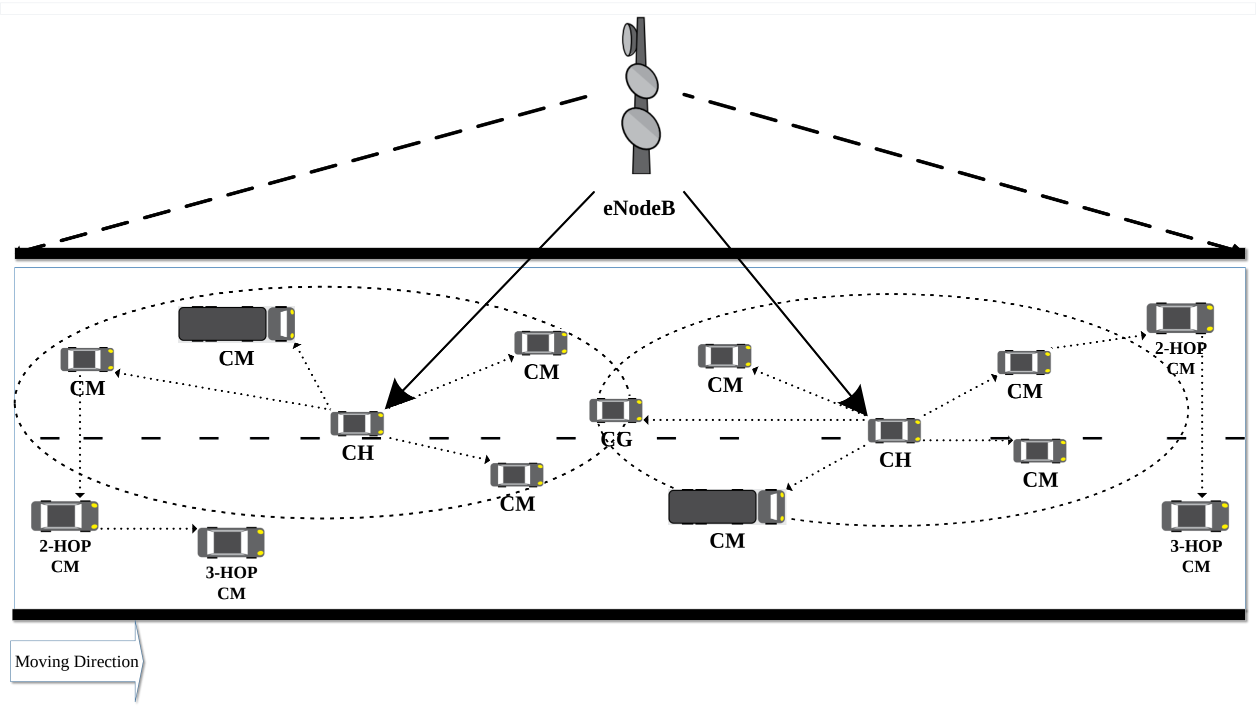

Figure 4.1: VANET-LTE Integrated Architecture

In CH state, vehicles are responsible for coordinating the dissemination of $DATA\_PACKET$. $DATA\_PACKET$ can come from either $eNodeB$ or cluster itself. CH first controls the $DATA\_PACKET$ if it comes from $eNodeB$ (Line 2). If $DATA\_PACKET$ comes from $eNodeB$, CH decodes the data packet and extracts the generator id ID_{DATA} and data packet sequence number SEQ_{DATA} in order to refresh the $LOCAL\_KNOW$ (Line 3). After extracting information, uniqueness of the received packet is checked. This is achieved by investigation of the $LOCAL\_KNOW$ in regard to (ID_{DATA}-SEQ_{DATA}) 2-tuple (Line 4). If current data packet is received for the first time, CH refreshes the $LOCAL\_KNOW$ and disseminates into own cluster by including its own id (Lines 5-7). If $DATA\_PACKET$ is generated by cluster member, same steps are applied except current data packet is also delivered to $eNodeB$ to be disseminated to other CHs.

Algorithm 2 VANET-LTE CH State Data Forwarding Algorithm

```
for all received $DATA\_PACKET$ do
    if $DATA\_PACKET$ is from $eNodeB$ then
        Extract $ID_{DATA}$ and $SEQ_{DATA}$
        if ($ID_{DATA}$-$SEQ_{DATA}$) not $\exists$ in $LOCAL\_KNOW$ then
            Update $LOCAL\_KNOW$
            Attach $CH$ id into $DATA\_PACKET$
            Broadcast $DATA\_PACKET$ into cluster
        else
            Update $LOCAL\_KNOW$
    else if $DATA\_PACKET$ is from $CM$ or $CH$ itself then
        Extract $ID_{DATA}$ and $SEQ_{DATA}$
        if ($ID_{DATA}$-$SEQ_{DATA}$) not $\exists$ in $LOCAL\_KNOW$ then
            Attach $ID_{DATA}$ and $CH$ id into $DATA\_PACKET$
            Broadcast $DATA\_PACKET$ into cluster
            Create $LTE$ $DATA\_PACKET$
            Forward to $eNodeB$
        else
            Update $LOCAL\_KNOW$
```

4.2 Simulation & Results

In this section of performance VANET-LTE integrated network is evaluated. We implemented VANET-LTE integrated architecture on Network Simulator - ns3 (Release 3.17) [51] and used the topology of the network generated by SUMO [24]. Implemented scenario is the same as the clustering scenario in Figure 3.1 in terms of roads and mobility. An additional eNodeB is positioned in the center of the road and it is assumed that VANET is under coverage of eNodeB. Elected cluster heads activate the LTE interface and start to communicate with the LTE network. Tables 4.1 and 4.2 list the simulation parameters of the VANET and integrated LTE networks, respectively.

4.2.1 Algorithms Used For Comparison

For comparison purposes, NHop [35] and MDMAC [46] multi-hop clustering techniques are integrated with LTE namely NHop-LTE and MDMAC-LTE. Details of the clustering scheme used in NHop and MDMAC are given in Section 3.2.1. In addition to this, the clustering mechanism proposed in [21] where one of clustering metrics is

Table 4.1: NS3 Simulation Parameters For VANET

Parameters	Value
Simulation Time	300 s
Mobility Model	SUMO
Area range	1000 m x 1000 m
Maximum Velocity	10 - 35 m/s
Max. Hop (Hop Limit)	1,2 and 3 hops
Number Of Vehicles	100
Transmission Range	200 m
CH Max. 1-Hop Member Number	5
$HELLO\_PACKET$ period	200 ms
$HELLO\_PACKET$ size	64 bytes
$DATA\_PACKET$ period	1 s
$DATA\_PACKET$ size	1024 bytes

Table 4.2: NS3 Simulation Parameters For LTE

Parameters	Value
$eNodeB$ Scheduler Type	RrFfMacScheduler
Pathloss Model	Friis Propagation Loss Model

RSS, is implemented and named as RSS-LTE.

Integrated architectures NHop-LTE, MDMAC-LTE and RSS-LTE also make use of our data forwarding algorithm. After cluster formation CM vehicles forward data packet to its connected CM or CH. When CH receives data packets, it applies update in the $LOCAL\_KNOW$ and disseminates data packets to the cluster members and to other clusters. In hybrid architectures, CHs function based on Algorithm 2.

The other algorithm RSS-LTE used for comparison is LTE integration of the clustering scheme in [21]. In RSS-LTE, clustering is performed in three steps based on the direction of vehicle's movement, UMTS Received Signal Strength (RSS), and inter-vehicular distance. Proposed clustering starts with the basis of direction of movement in two stages. Initially, it is carried out relative to their moving directions and then relative to the position of the UMTS Node B. Next step is refining the clustering operation via using the UMTS RSS. The rationale behind using the UMTS signal strength lies in assumption that RSS has better consistency compared to metrics such as mobility speed. Additionally, the mobility speed of vehicles, moving along a particular direction, is implicitly reflected in their UMTS RSS. Irrespective of the variation in the mobility speed of the vehicles, the UMTS RSS keeps increasing if the vehicles move towards the base station, and vice versa. Having clustered vehicles based on their directions of movement and the UMTS signal strength, following step is to cluster them using their IEEE 802.11p wireless transmission range: a pair of vehicles, whose inter-vehicular distance is less than or equal to their IEEE 802.11p transmission range, form a new sub-cluster or join an existing one.

4.2.2 Performance Metrics

The performance of the integrated network is evaluated in terms of Data Packet Delivery Ratio (DPDR), Average Delay, Maximum Delay metrics defined as follows.

- Data Packet Delivery Ratio (DPDR) is defined as the ratio of the total number of successfully transmitted $DATA_PACKET$s to the total number of $DATA_PACKET$s sent from the sources to the destinations. DPDR ratio is evaluated with respect to maximum velocity, vehicle density and cluster head change.

- Average Delay used in our specification specifies how long it takes for a $DATA\_PACKET$ to travel across the network from one vehicle to another. Investigation of average delay is accomplished by doing analysing in different vehicle velocity.

- Maximum Delay refers to recorded maximum amount of time that sent $DATA\_PACKET$ reaches to the destination. Evaluation of maximum delay is done in regard to maximum velocity vehicles have.

4.2.3 Simulation Results

Data Packet Delivery Ratio (DPDR)

Figure 4.2 demonstrates better performance of proposed VMaSC-LTE integrated architecture in terms of data packet delivery ratio (DPDR). The graph indicates that as the network dynamicity increases, DPDR generally has a tendency to decrease. This can be explained via dynamicity awareness of underlying cluster structure that has great effect on the performance. Even though CG approach is used in $DATA_PACKET$s forwarding in NHop and MDMAC, one of the main differences between compared protocols and our proposed VMaSC-LTE protocol is the fact that mobility is considered as a highly important metric in underlying multi-hop cluster structure.

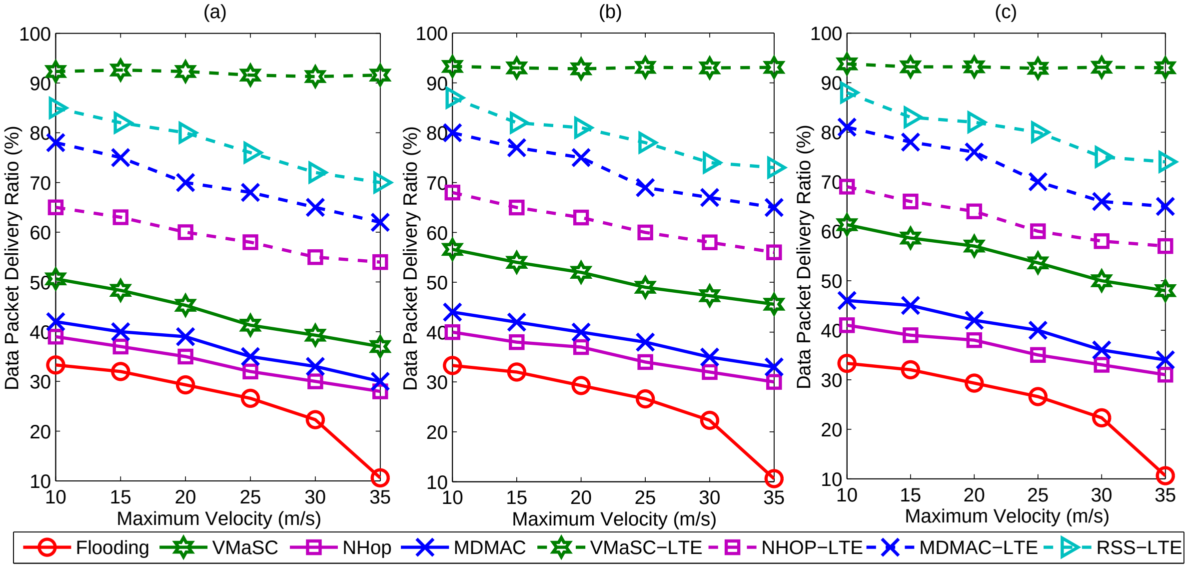

Figure 4.2: Data Packet Delivery Ratio in different maximum velocity and hops (a) 1 Hop, (b) 2 Hop (c) 3 Hop

Another metric that has effect on DPDR is cluster head change number. Hence, the cluster structure can be stabilized and the clustering related control overhead can be reduced by limiting the cluster head change. Figure 4.3 and Figure 4.4 analyze the effect of cluster head change on DPDR in different densities where density is calculated by averaging the value of distance between upper-most and back-most vehicle over the road length during the whole simulation.

Figure 4.3 presents the performance of VMaSC and VMaSC-LTE hybrid architecture over different densities. Intuitively, in low density network the performance of $DATA\_PACKET$ dissemination is low. This can be explained by the fact that in low density network there is disconnection problem in network and VMaSC could not find gateway vehicle CG to forward $DATA\_PACKET$ between clusters. Compared to VMaSC, the $DATA\_PACKET$ dissemination in VMaSC-LTE is performed via using the eNodeB which facilitates higher DPDR. As the density increases, DPDR also increases. However, in high density network, control overheads for cluster maintenance increases drastically which causes packet collision and wireless medium contention. Therefore VMaSC performs inadequately in high density network.

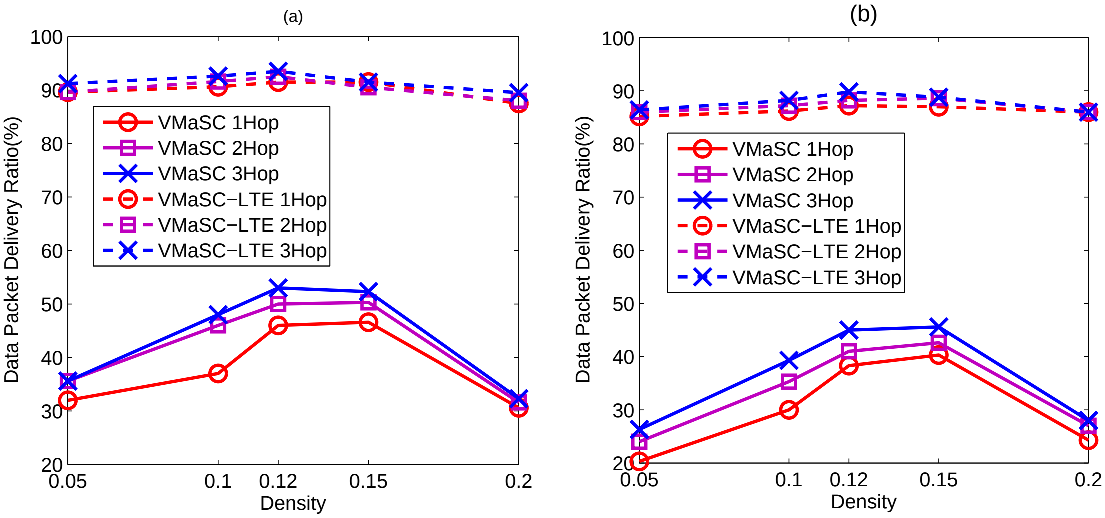

Figure 4.3: Data Packet Delivery Ratios vs Vehicle Density (a)Maximum Velocity 10 m/s, (b)Maximum Velocity 35 m/s

The effect of cluster head change over DPDR is evaluated in Figure 4.4. It can be seen that in low dense network, announced CH suffers from the lack of CM which makes CH relinquish its CH status and reduce the DPDR. For that reason the

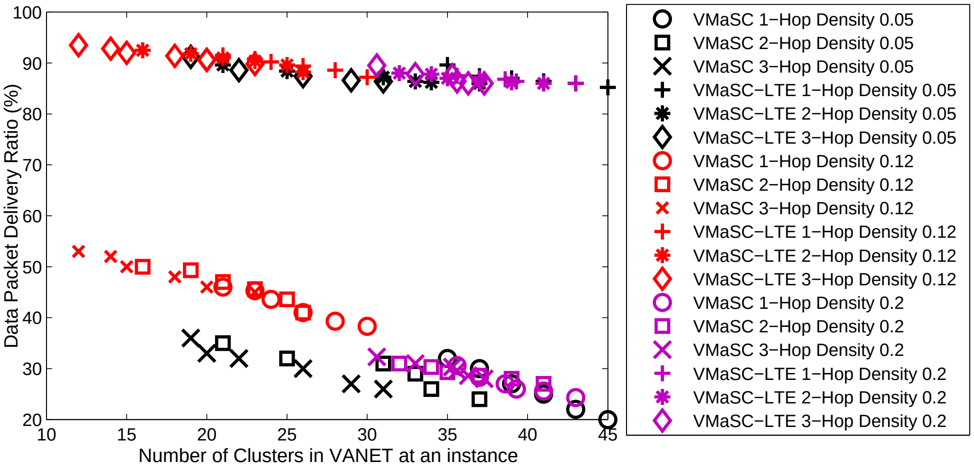

Figure 4.4: Data Packet Delivery Ratios vs Cluster Head Change

cluster head change number in low dense network in both VMaSC and VMaSC-LTE scenarios is high. However, the high number of cluster change does not have huge effect on VMaSC-LTE architecture. As the density increases the CHs find members to serve and cluster head change number also decreases in both scenarios. However, in high dense network due to contention and packet collision, vehicles do not hear CH related packets and constructed clusters become unstable. This makes DPDR reduce in dense network scenarios.

Average Delay

In Figure 4.5, the time elapsed between sending a $DATA\_PACKET$ (by a particular source vehicle) till the delivery to the destination vehicle is plotted for varying maximum velocity in different number of hops. As can be seen from the Figure 4.5, as the hop number increases the average delay in VMaSC, NHop and MDMAC also increases. This is because in both scenarios the $DATA\_PACKET$ are forwarded via CG. As the network dynamicty increases, it becomes difficult to maintain the cluster structure and find a CG to forward packets between clusters.

Compared to VMaSC, NHop and MDMAC, in LTE integrated scenarios the average delay is above the flooding. This can be explained via the $DATA\_PACKET$

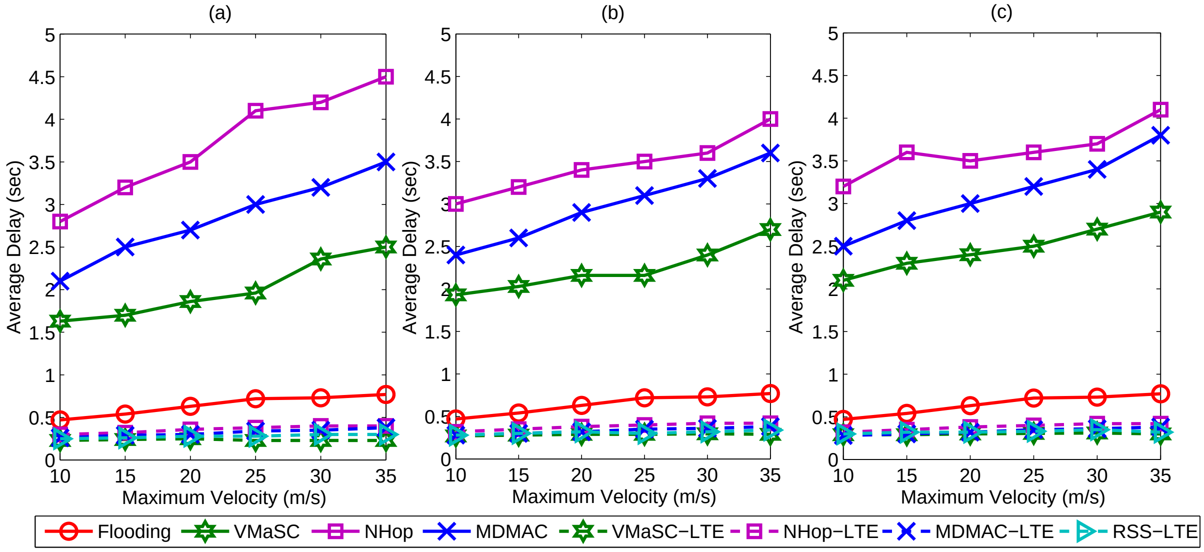

Figure 4.5: Average Delay vs Maximum Velocity (a) 1 Hop, (b) 2 Hop (c) 3 Hop

forwarding technique where cellular network is used in hybrid architectures. Instead of finding a CG, $DATA_PACKET$s are forwarded via eNodeB and disseminated into cluster with the help of LTE.

Maximum Delay

The maximum delay refers to recorded maximum amount of time that sent $DATA\_PACKET$ reaches to the destination. The graph in Figure 4.6 shows the maximum delay analysis of protocols in different vehicle velocities.

As shown in Figure 4.6, regardless of the underlying protocol, maximum delay decreases along with increase in the vehicle's velocity. This is related with the constructed cluster structure where velocity increase makes hard to perform cluster maintenance.

Another metric that has effect on maximum delay is number of hops. Generally as the hop number increases in VMaSC, NHop and MDMAC, the maximum delay has tendency to increases as well. This is related with CG data forwarding approach. In multi-hop scenarios, it becomes difficult to find a CG to forward data packet.

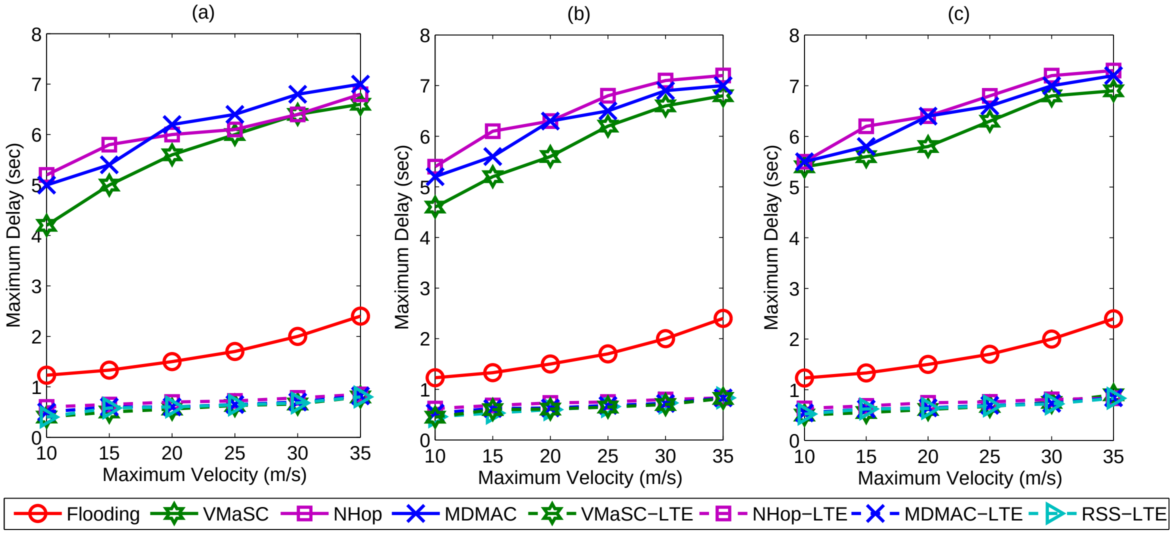

Figure 4.6: Maximum Delay vs Maximum Velocity (a) Maximum Velocity 10 m/s, (b) Maximum Velocity 35 m/s

Chapter 5

CONCLUSION

In the first part of thesis, we introduced a stable multi-hop clustering technique based on the changes in the relative mobility of the vehicles which is calculated by finding the average of the relative speed of all the same direction neighbours. Clustering is beneficial in term of packet collision, packet transmission and stability of inter-vehicular links. In this context, we consider multi-hop clustering with the cluster stability and clustering cost related metric to ensure increase in system performance. We modeled our approach VMaSC on ns-3 using the realistic mobility traces of SUMO and compared its performance to previously proposed multi-hop cluster approaches called NHop, where variation in packet delay is used, MDMAC where weighted combination of different metrics is used with the estimation strategy. Simulation results show that proposed clustering approach VMaSC outperforms NHop and MDMAC clustering in terms of cluster head duration, cluster member duration, clustering overhead and cluster head change metrics at various vehicle velocity scenarios in different number of hops. The main objective in the first part of thesis was to construct a hierarchical cluster structure with stable cluster forming metrics that prolongs the cluster life time at the same time keeps the clustering cost tolerable.

In the second part of the thesis, we introduced a novel architecture that integrates 3GPP/LTE networks with VANET networks. In this architecture, vehicles are clustered in multi-hop using our approach VMaSC where relative mobility and direction of vehicles are considered in both cluster heads and cluster members election. By integrating VANET with LTE, high data rate can be coupled with wide-range of communication. In the envisioned clustered VANET/LTE network, cluster heads connect to the LTE network using its LTE interface, they serve as a relay node for other vehicles in their vicinity to access the LTE network, by receiving data from cluster members (using its IEEE 802.11p interface) and relaying the data to the LTE network.

We modeled VMaSC-LTE hybrid architecture on ns-3 using the realistic mobility traces of SUMO. In order to demonstrate performance of proposed hybrid architecture, the comparison between VMaSC-LTE and clustering integrated approaches of RSS-LTE, NHop-LTE and MDMAC-LTE is performed. The performance of the hybrid architecture VMaSC-LTE is evaluated using network simulations and performance metrics of data packet delivery ratio over velocity, density and cluster head change, average delay and maximum delay. Extensive simulation results demonstrated that the integrated system shows acceptable values in terms of data packet delivery ratio and average delay and maximum delay.

As future work, we plan to extend the VMaSC-LTE integrated architecture for other services and test it for different type of traffic scenarios.

BIBLIOGRAPHY

[1] R. Chen, W.-L. Jin, and A. Regan, "Broadcasting safety information in vehicular networks: issues and approaches," *IEEE Network*, vol. 24, no. 1, pp. 20–25, Jan-Feb 2010.

[2] W. Chen and S. Cai, "Ad hoc peer-to-peer network architecture for vehicle safety communications," *IEEE Communications Magazine*, vol. 43, no. 4, pp. 100 – 107, April 2005.

[3] M. Torrent-Moreno, J. Mittag, P. Santi, and H. Hartenstein, "Vehicle-to-vehicle communication: Fair transmit power control for safety- critical information," *IEEE Transactions on Vehicular Technology*, vol. 58, no. 7, pp. 3684 – 3703, September 2009.

[4] J. Nzouonta, N. Rajgure, G. Wang, and C. Borcea, "Vanet routing on city roads using real-time vehicular traffic information," *IEEE Transactions on Vehicular Technology*, vol. 58, no. 7, pp. 3609 – 3626, September 2009.

[5] W. Chen and S. Cai, "Ad hoc peer-to-peer network architecture for vehicle safety communications," *IEEE Communications Magazine*, vol. 43, no. 4, pp. 100 – 107, April 2005.

[6] J. Nzouonta, N. Rajgure, G. Wang, and C. Borcea, "VANET routing on city roads using real-time vehicular traffic information," *Vehicular Technology, IEEE Transactions on*, vol. 58, no. 7, pp. 3609–3626, 2009.

[7] N. Sofra, A. Gkelias, and K. Leung, "Route construction for long lifetime in VANETs," *Vehicular Technology, IEEE Transactions on*, vol. 60, no. 7, pp. 3450–3461, 2011.

[8] A. McDonald and T. Znati, "A mobility-based framework for adaptive clustering in wireless ad hoc networks," *Selected Areas in Communications, IEEE Journal on*, vol. 17, no. 8, pp. 1466–1487, 1999.

[9] T.-C. Hou and T.-J. Tsai, "A access-based clustering protocol for multihop wireless ad hoc networks," *Selected Areas in Communications, IEEE Journal on*, vol. 19, no. 7, pp. 1201–1210, 2001.

[10] J. Yu and P. H. J. Chong, "A survey of clustering schemes for mobile ad hoc networks," *Communications Surveys Tutorials, IEEE*, vol. 7, no. 1, pp. 32–48, 2005.

[11] A. International, "Standard specification for telecommunications and information exchange between roadside and vehicle systems 5 ghz band dedicated short range communications (dsrc) medium access control (mac) and physical layer (phy) specifications,," *Standard Specification for Telecommunications and Information Exchange Between Roadside and Vehicle Systems 5 GHz Band Dedicated Short Range Communications (DSRC) Medium Access Control (MAC) and Physical Layer (PHY) Specifications,*, 2009.

[12] X. Ma, J. Zhang, X. Yin, and K. Trivedi, "Design and analysis of a robust broadcast scheme for VANET safety-related services," *Vehicular Technology, IEEE Transactions on*, vol. 61, no. 1, pp. 46–61, 2012.

[13] Project Cooperative Cars, CoCar @ONLINE. [Online]. Available: http://www.aktiv-online.org/english/aktiv-cocar.html/

[14] LTE-Connected Cars, ng Connect Program @ONLINE. [Online]. Available: http://www.ngconnect.org/index.htm/

[15] H. Abid, T.-C. Chung, S. Lee, and S. Qaisar, "Performance analysis of LTE smartphones-based vehicle-to-infrastrcuture communication," in *Ubiquitous In-*

telligence Computing and 9th International Conference on Autonomic Trusted Computing (UIC/ATC), 9th International Conference on, 2012, pp. 72–78.

[16] T. Mangel, T. Kosch, and H. Hartenstein, "A comparison of UMTS and LTE for vehicular safety communication at intersections," in *Vehicular Networking Conference (VNC), 2010 IEEE*, 2010, pp. 293–300.

[17] A. Damnjanovic, J. Montojo, Y. Wei, T. Ji, T. Luo, M. Vajapeyam, T. Yoo, O. Song, and D. Malladi, "A survey on 3GPP heterogeneous networks," *Wireless Communications, IEEE*, vol. 18, no. 3, pp. 10–21, 2011.

[18] I. Lequerica, P. Ruiz, and V. Cabrera, "Improvement of vehicular communications by using 3G capabilities to disseminate control information," *Network, IEEE*, vol. 24, no. 1, pp. 32–38, 2010.

[19] G. Remy, S. M. Senouci, F. Jan, and Y. Gourhant, "LTE4V2X: LTE for a centralized VANET organization," in *Global Telecommunications Conference, GLOBECOM IEEE*, 2011, pp. 1–6.

[20] T. Taleb and A. Benslimane, "Design guidelines for a network architecture integrating VANET with 3G & beyond networks," in *Global Telecommunications Conference, GLOBECOM IEEE*, 2010, pp. 1–5.

[21] A. Benslimane, T. Taleb, and R. Sivaraj, "Dynamic clustering-based adaptive mobile gateway management in integrated VANET - 3G heterogeneous wireless networks," *Selected Areas in Communications, IEEE Journal on*, vol. 29, no. 3, pp. 559–570, 2011.

[22] R. Sivaraj, A. Gopalakrishna, M. Chandra, and P. Balamuralidhar, "QoS-enabled group communication in integrated VANET - LTE heterogeneous wireless networks," in *Wireless and Mobile Computing, Networking and Communications (WiMob),IEEE 7th International Conference on*, 2011, pp. 17–24.

[23] S. Vodopivec, J. Bester, and A. Kos, “A survey on clustering algorithms for vehicular ad-hoc networks,” in *Telecommunications and Signal Processing (TSP), 35th International Conference on*, 2012, pp. 52–56.

[24] SUMO - Simulation of Urban MObility. [Online]. Available: http://sumo.sourceforge.net

[25] S. Ucar, S. Ergen, and O. Ozkasap, “VMaSC: Vehicular multi-hop algorithm for stable clustering in vehicular ad hoc networks,” in *Wireless Communications and Networking Conference (WCNC),IEEE*, 2013, pp. 2381–2386.

[26] M. Gerla and J. T.-C. Tsai, “Multicluster, mobile, multimedia radio network,” *Wirel. Netw.*, vol. 1, no. 3, pp. 255–265, 1995. [Online]. Available: http://dx.doi.org/10.1007/BF01200845

[27] P. Basu, N. Khan, and T. Little, “A mobility based metric for clustering in mobile ad hoc networks,” in *Distributed Computing Systems Workshop, 2001*, pp. 413 –418.

[28] C. chuan Chiang, H.-K. Wu, W. Liu, and M. Gerla, “Routing in clustered multihop, mobile wireless networks with fading channel,” 1997.

[29] J. Yu and P. Chong, “3hbac (3-hop between adjacent clusterheads): a novel non-overlapping clustering algorithm for mobile ad hoc networks,” in *Communications, Computers and signal Processing. PACRIM. 2003 IEEE Pacific Rim Conference on*, vol. 1, pp. 318 – 321 vol.1.

[30] Y. Zhang and J. M. Ng, “A distributed group mobility adaptive clustering algorithm for mobile ad hoc networks,” in *Communications. ICC ’08. IEEE International Conference on*, pp. 3161 –3165.

[31] T. J. Kwon, M. Gerla, V. Varma, M. Barton, and T. Hsing, “Efficient flooding with passive clustering-an overhead-free selective forward mechanism for ad

hoc/sensor networks," *Proceedings of the IEEE*, vol. 91, no. 8, pp. 1210 – 1220, 2003.

[32] T. Song, W. Xia, T. Song, and L. Shen, "A cluster-based directional routing protocol in VANET," in *Communication Technology (ICCT),12th IEEE International Conference on*, 2010, pp. 1172–1175.

[33] B. Wiegel, Y. Gunter, and H. Grossmann, "Cross-layer design for packet routing in vehicular ad hoc networks," in *Vehicular Technology Conference VTC Fall.IEEE 66th*, 2007, pp. 2169–2173.

[34] K. Nagel and M. Schreckenberg, "A cellular automaton model for freeway traffic," *J. Phys. I France.*, vol. 2, no. 12, 1992.

[35] Z. Zhang, A. Boukerche, and R. Pazzi, "A novel multi-hop clustering scheme for vehicular ad-hoc networks," in *Proceedings of the 9th ACM international symposium on Mobility management and wireless access*, ser. MobiWac. New York, NY, USA: ACM, 2011, pp. 19–26. [Online]. Available: http://doi.acm.org/10.1145/2069131.2069135

[36] N. Maslekar, M. Boussedjra, J. Mouzna, and L. Houda, "Direction based clustering algorithm for data dissemination in vehicular networks," in *Vehicular Networking Conference (VNC),IEEE*, 2009, pp. 1–6.

[37] N. Wisitpongphan, F. Bai, P. Mudalige, V. Sadekar, and O. Tonguz, "Routing in sparse vehicular ad hoc wireless networks," *Selected Areas in Communications, IEEE Journal on*, vol. 25, no. 8, pp. 1538–1556, 2007.

[38] O. Tonguz, N. Wisitpongphan, F. Bai, P. Mudalige, and V. Sadekar, "Broadcasting in VANET," in *Mobile Networking for Vehicular Environments*, 2007, pp. 7–12.

[39] H. Su and X. Zhang, "Clustering-based multichannel MAC protocols for QoS provisionings over vehicular ad hoc networks," *Vehicular Technology, IEEE Transactions on*, vol. 56, no. 6, pp. 3309–3323, 2007.

[40] M. Venkata, M. Pai, R. Pai, and J. Mouzna, "Traffic monitoring and routing in VANETs- a cluster based approach," in *ITS Telecommunications (ITST), 2011 11th International Conference on*, 2011, pp. 27–32.

[41] Y. Zhang and J. M. Ng, "A distributed group mobility adaptive clustering algorithm for mobile ad hoc networks," in *Communications. ICC. IEEE International Conference on*, 2008, pp. 3161–3165.

[42] J. Ng and Y. Zhang, "A mobility model with group partitioning for wireless ad hoc networks," in *Information Technology and Applications, ICITA. Third International Conference on*, vol. 2, 2005, pp. 289–294.

[43] Z. Y. Rawashdeh and S. Mahmud, "A novel algorithm to form stable clusters in vehicular ad hoc networks on highways." in *EURASIP J. Wireless Comm. and Networking*, 2012, p. 15.

[44] A. Daeinabi, A. G. Pour Rahbar, and A. Khademzadeh, "VWCA: an efficient clustering algorithm in vehicular ad hoc networks," *J. Netw. Comput. Appl.*, vol. 34, no. 1, pp. 207–222, Jan. 2011.

[45] T. Nadeem, P. Shankar, and L. Iftode, "A comparative study of data dissemination models for VANETs," in *Mobile and Ubiquitous Systems - Workshops, 3rd Annual International Conference on*, 2006, pp. 1–10.

[46] G. Wolny, "Modified DMAC clustering algorithm for VANETs," in *Systems and Networks Communications. ICSNC*, 2008, pp. 268–273.

[47] M. Fiore, J. Harri, F. Filali, and C. Bonnet, "Vehicular mobility simulation for VANETs," in *Simulation Symposium, ANSS. 40th Annual*, 2007, pp. 301–309.

[48] R. Aquino-Santos, R. M. Edwards, and A. Edwards, "Cluster-based location routing algorithm for inter-vehicle communication." in *VTC Fall (2)*. IEEE, 2004, pp. 914–918.

[49] M. Chatterjee, S. K. Das, and D. Turgut, "WCA: A weighted clustering algorithm for mobile ad hoc networks." *Cluster Computing*, vol. 5, no. 2, pp. 193–204, 2002.

[50] S. Basagni, "Distributed clustering for ad hoc networks," in *Parallel Architectures, Algorithms, and Networks. (I-SPAN) Proceedings. Fourth International-Symposium on*, 1999, pp. 310–315.

[51] Network simulator, ns-3 @ONLINE. [Online]. Available: http://www.nsnam.org/

[52] F. Setiawan, S. Bouk, and I. Sasase, "An optimum multiple metrics gateway selection mechanism in MANET and infrastructured networks integration," in *Wireless Communications and Networking Conference, IEEE WCNC.*, 2008, pp. 2229–2234.

[53] A. Benslimane, S. Barghi, and C. Assi, "An efficient routing protocol for connecting vehicular networks to the internet," *Pervasive and Mobile Computing*, pp. 98–113, 2011.

[54] R. Manoharan, S. Rajarajan, S. Sashtinathan, and K. Sriram, "A novel multi-hop B3G architecture for adaptive gateway management in heterogeneous wireless networks," in *Wireless and Mobile Computing, Networking and Communications, WIMOB. IEEE International Conference on*, 2009, pp. 447–452.

VITA

SEYHAN UCAR was born in Malatya, Turkey on 15th October. He received his early education from Malatya Anatolian High School, Malatya. He completed B.Sc degree in Computer Science and Engineering from Izmir Institute of Technology (IYTE), Izmir, Turkey in 2011. He joined M.Sc program in Computer Science and Engineering at Koc University in 2011 as a research and teaching assistant. During his study he worked on clustering algorithms, heterogeneous wireless networks and distributed systems. He has co-authored two conference papers in IEEE Wireless Communication and Networking Conference (WCNC), 2013 and IEEE Distributed Simulation and Real-Time Network (DS-RT), 2013, and also has a journal paper under submission.