ENHANCED STABILITY OF CLUSTER-BASED LOCATION SERVICE MECHANISM FOR URBAN VEHICULAR AD HOC NETWORKS

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DEDICATION

To my parents, brothers, sister, wife and my daughters Zarmeen Akram and Mahroash Akram for their love, patience and understanding during my study.

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ABSTRACT

Vehicular Ad Hoc Networks (VANETs) are gaining tremendous research interest in developing an Intelligent Transportation System (ITS) for smart cities. The position of vehicles plays a significant role in ITS applications and services such as public emergency, vehicles tracking, resource discovery, traffic monitoring and position-based routing. The location service is used to keep up-to-date records of current positions of vehicles. A review of previous literatures, found various location-based service mechanisms have been proposed to manage the position of vehicles. The cluster-based location service mechanisms have achieved growing attention due to their advantages such as scalability, reliability and reduced communication overhead. However, the performance of the cluster-based location service mechanism depends on the stability of the cluster, and the stability of the cluster depends on the stability of the Cluster Head (CH), Cluster Member (CM) and cluster maintenance. In the existing cluster-based location service schemes, the issue of CH instability arises due to the non-optimal cluster formation range and unreliable communication link with Road Side Unit (RSU). The non-optimal cluster formation range causes CH instability due to lack of uniqueness of Centroid Vehicle (CV), uncertainty of participating vehicles in the CH election process and unreliability of the Cluster Head Election Value (CHEV). Also, the unreliable link with RSU does not guarantee that CH is stable with respect to its CMs and RSU simultaneously. The issue of CM instability in the existing cluster-based location service schemes occurs due to using instantaneous speed of the CH and fixed CM affiliation threshold values. The instantaneous speed causes the CM to switch the clusters frequently and fixed CM affiliation threshold values increase isolated vehicles. The frequent switching of isolated vehicles augment the CM instability. Moreover, the inefficient cluster maintenance due to non-optimal cluster merging and cluster splitting also contributes to cluster instability. The merging conditions such as fixed merging threshold time and uncertain movement of overlapping CHs within merging threshold time cause the cluster instability. Furthermore, the unnecessary clustering during cluster splitting around the intersection due to CH election parameters also increases cluster instability. Therefore, to address the aforementioned cluster instability issues, Enhanced Stability of Cluster-based Location Service (ESCLS) mechanism was proposed for urban VANETs. The proposed ESCLS mechanism consists of three complementary schemes which are Reliable Cluster Head Election (RCHE), Dynamic Cumulative Cluster Member Affiliation (DCCMA) and Optimized Cluster Maintenance (OCM). Firstly, the aim of the RCHE scheme was to enhance the stability of the CH through optimizing the cluster formation range and by considering communication link reliability with the RSU. Secondly, the DCCMA scheme focussed on improving the stability of the CMs by considering the Cumulative Moving Average Speed (CMAS) of the CH and dynamic CM affiliation threshold values, and finally, the OCM scheme enhanced the cluster stability by improving cluster merging conditions and reducing unnecessary clustering in cluster splitting. The results of the simulation verified the improved performance of the ESCLS in terms of increasing the location query success rate by 34%, and decreasing the query response delay and localization error by 24% and 35% respectively as compared to the existing cluster-based location service schemes such as HCBLS, CBLS and MoGLS. In conclusion, it is proven that ESCLS is a suitable location service mechanism for a wide range of position-based applications of VANETs that require timely and accurate vehicle locations.

ABSTRAK

Rangkaian Ad Hoc Kenderaan (VANET) memperoleh minat penyelidikan yang luar biasa dalam membangunkan Sistem Pengangkutan Pintar (ITS) untuk bandar pintar. Kedudukan kenderaan memainkan peranan penting dalam aplikasi dan perkhidmatan ITS seperti kecemasan awam, pengesanan kenderaan, penemuan sumber, pemantauan lalu lintas dan peralihan berdasarkan kedudukan. Perkhidmatan lokasi digunakan untuk menyimpan rekod terkini kedudukan kenderaan semasa. Tinjauan literatur mendapati pelbagai mekanisme perkhidmatan berdasarkan lokasi telah dicadangkan untuk menguruskan kedudukan kenderaan. Mekanisme perkhidmatan lokasi berasaskan kluster telah mendapat perhatian yang semakin meningkat kerana kelebihannya seperti skalabiliti, kebolehpercayaan dan overhead komunikasi yang berkurang. Walau bagaimanapun, prestasi mekanisme perkhidmatan lokasi berasaskan kluster bergantung pada kestabilan kluster dan kestabilan kluster bergantung pada kestabilan Cluster Head (CH), Cluster Member (CM) dan cluster maintenance. Dalam skema perkhidmatan lokasi berasaskan kluster yang sedia ada, masalah ketidakstabilan CH timbul kerana julat pembentukan kluster yang tidak optimum dan hubungan komunikasi yang tidak dapat dipercayai dengan Road Side Unit (RSU). Julat pembentukan kluster yang tidak optimum menyebabkan ketidakstabilan CH kerana kekurangan keunikan Kenderaan Centroid (CV), ketidakpastian kenderaan yang mengambil bahagian dalam proses pemilihan CH dan ketidakpercayaan Nilai Pemilihan Kepala Kluster (CHEV). Juga, hubungan yang tidak boleh dipercayai dengan RSU tidak menjamin bahawa CH stabil berbanding CM dan RSUnya secara serentak. Masalah ketidakstabilan CM dalam skema perkhidmatan lokasi berasaskan kluster yang ada berlaku kerana menggunakan kelajuan seketika CH dan nilai ambang gabungan CM yang tetap. Kepantasan seketika menyebabkan CM sering menukar kluster dan nilai ambang gabungan CM yang tetap meningkatkan kenderaan terpencil. Kenderaan yang sering bertukar dan terpencil menambah ketidakstabilan CM. Lebih-lebih lagi, penyelenggaraan kluster yang tidak cekap kerana penggabungan kluster yang tidak optimum dan pemisahan kluster juga menyumbang kepada ketidakstabilan kluster. Keadaan penggabungan seperti masa penggabungan tetap dan pergerakan CH yang bertindih dalam masa ambang penggabungan menyebabkan ketidakstabilan kluster. Selanjutnya, pengelompokan yang tidak perlu semasa pemisahan kluster di sekitar persimpangan kerana parameter pemilihan CH juga meningkatkan ketidakstabilan kluster. Oleh itu, untuk mengatasi masalah ketidakstabilan kluster yang disebutkan di atas, mekanisme Enhanced Stability of Cluster-based Location Service (ESCLS) dicadangkan untuk VANET bandar. Mekanisme ESCLS yang dicadangkan terdiri daripada tiga skema pelengkap iaitu Pemilihan Kepala Kluster yang Boleh Dipercayai (RCHE), Gabungan Anggota Kluster Dinamis Kumulatif (DCCMA) dan Pemeliharaan Kluster yang Dioptimumkan (OCM). Pertama, tujuan skema RCHE adalah untuk meningkatkan kestabilan CH dengan mengoptimumkan rangkaian pembentukan kluster dan dengan mempertimbangkan kebolehpercayaan hubungan komunikasi dengan RSU. Kedua, skema DCCMA memfokuskan pada peningkatan kestabilan CM dengan mempertimbangkan Nilai Purata Bergerak Kumulatif (CMAS) nilai CH dan ambang gabungan CM dinamik, dan akhirnya, skema OCM meningkatkan kestabilan kluster dengan memperbaiki keadaan penggabungan kluster dan mengurangkan pengelompokan yang tidak perlu dalam pemisahan kluster. Hasil simulasi mengesahkan peningkatan prestasi ESCLS dari segi peningkatan kadar kejayaan pertanyaan lokasi sebanyak 34%, dan penurunan kelewatan tindak balas pertanyaan dan kesalahan penyetempatan masing-masing sebanyak 24% dan 35% berbanding dengan lokasi berdasarkan kluster yang ada skim perkhidmatan seperti HCBLS, CBLS dan MoGLS. Sebagai kesimpulan, terbukti bahawa ESCLS adalah mekanisme perkhidmatan lokasi yang sesuai untuk pelbagai aplikasi VANET berdasarkan kedudukan yang memerlukan lokasi kenderaan tepat pada masanya.

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LIST OF ABBREVIATIONS

ARV	-	Aggregate Relative Velocity
AQD	-	Average Query Delay
APA	-	Affinity Propagation Algorithm
BM	-	Beacon Message
CA	-	Collision Avoidance
CA	-	Certificate Authority
CH	-	Cluster Head
CBLS	-	Cluster Based Location Service
CD	-	Current Distance
CHEV	-	Cluster Head Election Value
CHER	-	Cluster Head Election Range
CHEAM	-	Cluster Head Electing in Advance Mechanism
CHLT	-	Cluster Head Link LifeTime
CHL	-	Cluster Head Lifetime
CHCR	-	Cluster Head Communication Range
CIP	-	Center Intersection Point
CMAS	-	Cumulative Moving Average Speed
CM	-	Cluster Member
CML	-	Cluster Member Lifetime
CAM	-	Channel Access Management
CV	-	Centroid Vehicle
CMATV	-	Cluster Member Affiliation Threshold Value
CMAV	-	Cluster Member Affiliation Value
CSL	-	Cluster Speed Limit
CSMA	-	Carrier Sense Multiple Access
CTV	-	Cluster Threshold Value
DV	-	Direction Vector
DCCMA	-	Dynamic Cumulative Cluster Member Affiliation
DSRC	-	Dedicated Short Range Communications
ESCLS	-	Enhanced Stability of Cluster-based Location Service

ECB	-	Efficient Cost Based
ETSI	-	European Telecommunications Standards Institute
FLISLS	-	Fraction of Location Information Saved in Location Servers
GH	-	Group Head
GM	-	Group Member
GPS	-	Global Positioning System
GRPs	-	Geographical Routing Protocols
HCBLS	-	Hierarchical Cluster Based Location Service
IL	-	Intersection Leader
IEEE	-	Institute of Electrical and Electronics Engineers
ITS	-	Intelligent Transportation System
IV	-	Isolated Vehicle
IC	-	Intersection-based Clustering
I2V	-	Infrastructure to Vehicle
IVC	-	Inter Vehicular Communication
ID	-	Identity
IS	-	Intermediate Server
LBS	-	Location-based Services
LET	-	Link Expiration Time
LS	-	Location Service
LE	-	Localization Error
LOC	-	Location
LLT	-	Link LifeTime
LQ	-	Link Quality
LTE	-	Long Term Evolution
LRD	-	Left Relative Destination
MAC	-	Media Access Control
MATLAB	-	Matrix Laboratory
MALM	-	Mobility Assisted Location Management
MoGLS	-	Mobile Group based Location Service
MG-LSM	-	Mobile Group-based Location Service Management
MTT	-	Merging Threshold Time
NVC	-	Novel Vehicle Clustering

NS2	-	Network Simulator 2
OBU	-	On Board Units
OCR	-	Owned Communication Rate
OSM	-	Open Street Map
OCM	-	Optimized Cluster Maintenance
OMNET++	-	Objective Modular Network Testbed in C++
PDR	-	Packet Delivery Ratio
PD	-	Previous Distance
QoS	-	Quality of Service
QBLS	-	Quorum Based Location Service
QLSP	-	Quorum Based Location Service Protocol
QSR	-	Query Success Rate
QLS	-	Quorum-based Location Service
QRD	-	Query Response Delay
R	-	Range
RD	-	Relative Destination
RH	-	Regional Head
RL	-	Responsible Leaders
RS	-	Responsible Servers
RSU	-	Road Side Unit
RLQ	-	RSU Link Quality
RVM	-	Relative Velocity Metric
RLT	-	RSU Link LifeTime
RRD	-	Right Relative Destination
RCHE	-	Reliable Cluster Head Election Scheme
RTS/CTS	-	RTS/CTS - Request-to-send and Clear-to-send
RWCP	-	Reputation-based Weighted Clustering Protocol
PLM	-	Power Loss Metric
SCHR	-	Service Channel Range
SFLS	-	Semi-Flooding Location Service
SDN	-	Software Defined Network
SRD	-	Straight Relative Destination
SUMO	-	Simulation of Urban Mobility

SNR	-	Signal to Noise Ratio
SV	-	Source Vehicle
TCP	-	Transmission Control Protocol
TDMA	-	Time Division Multiple Access
TDFLS	-	Totally Distributed Flat Location Service
UN	-	Undecided Node
UAV	-	Unmanned Aerial Vehicle
VANETs	-	Vehicular Ad Hoc Networks
V2V	-	Vehicle to Vehicle Communication
VI	-	Variability Index
V2I	-	Vehicle to Infrastructure
V2V	-	Vehicle to Vehicle
WAVE	-	Wireless Access in Vehicular Environments
VEINS	-	Vehicles In Network Simulation
ZGLS	-	ZoomOut Geographic Location Service

LIST OF SYMBOLS

α	-	Alpha
Ω_i	-	Aggregate relative velocity
β	-	Beta
$\in$	-	Belongs to
ΔS_{thrsh}	-	CM affiliation threshold value
$\pm V_{th}$	-	CM affiliation threshold value
$M(i)$	-	Capability metric
t_i^b	-	Cluster head election time
t_i^m	-	Cluster headship loosing time
t_i^J	-	Cluster joining time
t_i^L	-	Cluster leaving time
C_{seg}	-	Centroid of the segment
$CMAS_n$	-	Cumulative Moving Average Speed of n vehicles
T_{resh}	-	Cluster member affiliation threshold value
$\hat{d}(n_i)$	-	Direction angle of the node i
$\overrightarrow{DV_{CH}}$	-	Directional vector of the CH
$\forall$	-	For all
γ	-	Gamma
ΔS_{max}	-	Maximum speed difference
ϕ_v	-	QoS metric
δ_i	-	Number of neighbors
Λ_v	-	Mobility Metric
$RD(v_j)$	-	Relative direction of the vehicle v_j
Π	-	Suitability value
$\cup$	-	Speed adjustment factor
Sign (ΔS_{ij})	-	Sign function
W_i	-	Weight factors

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CHAPTER 1

INTRODUCTION

1.1 Overview

Vehicular Ad Hoc Networks (VANETs) are emerging as integral part of Intelligent Transportation System (ITS) applications and services. The ITS utilizes the information technology and communication networks to provide the better quality, mobility, comfort and safety in smart cities. VANETs are used on a large scale in ITS applications which includes the different types of value added services like automation of toll payment, navigation, vehicle safety, traffic management, infotainment services and location-based services (Ghazi, Khattak, Shabir, Malik, & Ramzan, 2020; Sanguesa *et al*., 2016; Darwish and Bakar, 2015).

In fact, VANETs provide various services such as finding the closest parking slot, gas station or restaurants and discovering the position of any other vehicle including emergency vehicles, patrolling police vehicles and resource discovery vehicles. These services mainly depend on the accuracy and reliability of the location service (Al-Mayouf *et al*., 2016; Schoch, Kargl, Weber, & Leinmuller, 2008).

Moreover, Geographic Routing Protocols (GRPs) depend on the current location of vehicles to forward the messages. Every vehicle is equipped with a Global Positioning System (GPS). Vehicles get their position through a GPS and use a location service to get the position of other vehicles. These positions are maintained by a location service (Bilal and Ali, 2017; Liu *et al*., 2016).

Location service is one of the essential applications in VANETs to provide the location of vehicles. However, locating vehicles' positions and maintaining an accurate view of the entire network are quite challenging tasks due to the high number of vehicles, and high and fast nodes mobility which results in rapid topological changes and sudden network disconnections. The development of a reliable, scalable, and stable location service is a big challenge in VANETs (Woo and Lee, 2018; Balouchzahi, Fathy, & Akbari, 2016).

1.2 Problem Background

Location service is utilized to store the current locations of vehicles in VANETs. Each vehicle depends on a location service to locate the up-to-date position of another vehicle. All vehicles get their positions through the Global Positioning System (GPS) and send them to the existing nearby location server. Location service is also responsible for collecting the periodic location updates and responding to location queries about the current position of the vehicles (Lu, Lin, Liang, & Shen, 2011; Brahmi, Boussedjra, Mouzna, Cornelio, & Manohara, 2010).

Location service mechanism depends on three basic components such as location server, location update and location query as shown in Figure 1.1. In the existing cluster-based location service literature, collection of schemes is named as mechanism. The location servers maintain the location information of vehicles. These location servers may be in the form of a vehicle, RSU or any fixed regional server. In the location update, every vehicle sends its location periodically to the nearest location server. In the location query, every vehicle that needs the location of another vehicle sends a request to its respective location server. If the location server has the location information of requested vehicle, it will respond back with the location information. Otherwise, it will carry out the query by forwarding this request to a higher-level server (Boussedjra, Mouzna, Bangera, & Pai, 2009).

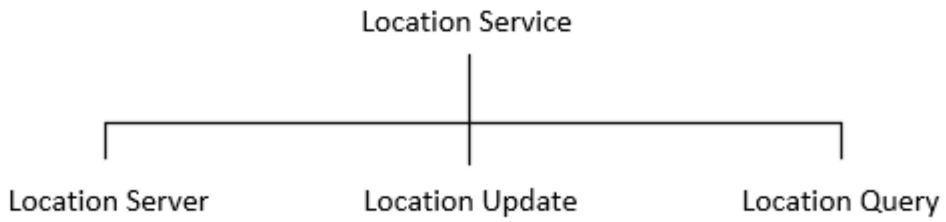

Figure 1.1 Location Service Components

To perform different location service functions such as location updates and location queries, several schemes have been proposed in VANETs. Location service schemes are divided into various categories based on different characteristics. These location service schemes are classified into two main classes such as flooding-based and rendezvous-based schemes (Ayaida, Fouchal, Afilal, & Ghamri, 2012). The Rendezvous-based schemes are further divided into Quorum-based and cluster-based. Moreover, cluster-based location service schemes are categorized into static cluster-based location service and dynamic cluster-based location service. The different categories of the existing location service schemes are given in Figure 1.2.

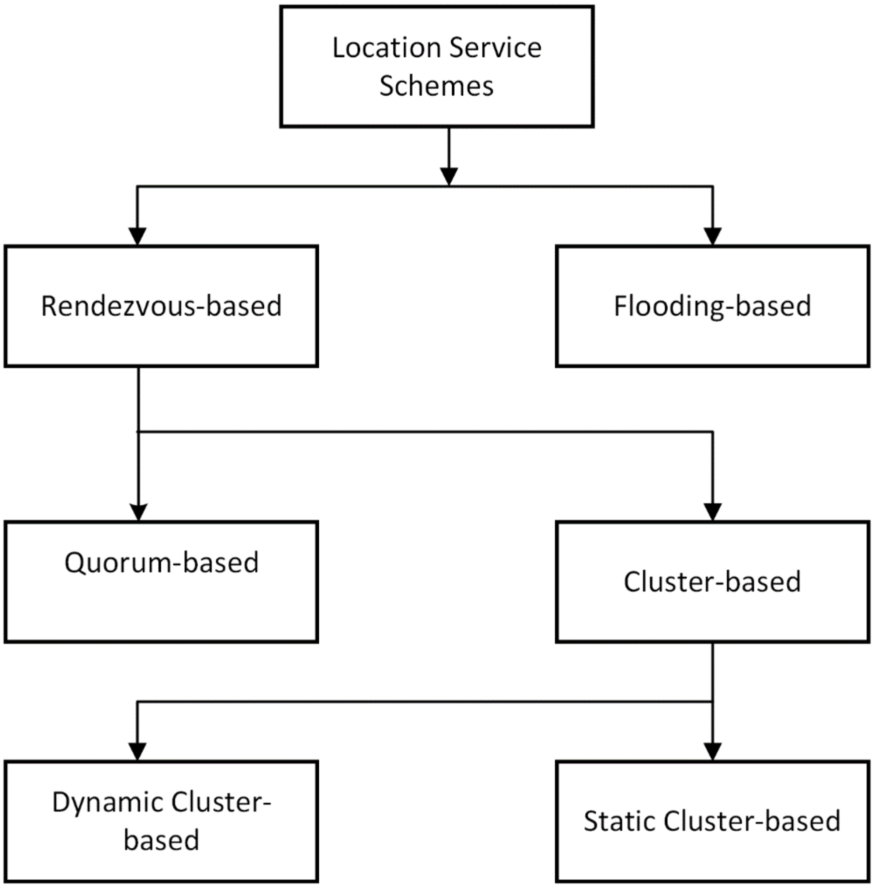

Figure 1.2 Location Service Scheme Categories

In the flooding-based location service schemes, each vehicle periodically broadcasts its location to update the location table of other vehicles in VANETs. These schemes depend on the flooding approach for the location update and query (Mühlethaler, Renault, & Boumerdassi, 2020; Boumerdassi and Renault, 2016). The location updates and queries are simple in these schemes. However, the flooding schemes are inefficient and not suitable for large scale networks which creates scalability and network management problems. The flooding schemes suffer from the high network congestion and low throughput (Balouchzahi *et al*., 2016; Garg, Pandey, & Singh, 2014).

However, rendezvous-based location service schemes designate specific vehicles based on predefined criteria to work as location servers. These location servers are distributed over the whole network. Every vehicle updates its position to a location server that lies within its range. Rendezvous-based location service schemes are further divided into two categories such as quorum-based and cluster-based location service (Ayaida, Barhoumi, Fouchal, Ghami, & Afilal, 2014).

The quorum-based schemes are proposed to overcome the limitations of the flooding-based schemes. The quorum-based schemes depend on the intersection point between a location query quorum and a location update quorum to provide the location of a vehicle. The quorum-based location service schemes make two groups of vehicles: an update quorum and a search quorum. The location of a vehicle is updated along the update quorum while a query for vehicle's location is sent along the search quorum until it reaches at a vehicle which is the intersection of both update and search quorum. In the quorum-based schemes, the location updates and location queries are simple but have limitations during quorum construction phase. As a result, quorum-based location service schemes have quorum boundary issues and high quorum construction overheads which results in high network overheads. Quorum-based schemes are not effective for VANETs due to their complexity in forming and maintaining quorums due to constraints like roads layout and void areas (Ashok, Pai, & Mouzna, 2011).

The aforementioned non-cluster based location service schemes in VANETs generate a large number of messages through broadcast or partial broadcast. Thus, the schemes based on broadcast approach cause congestion because all the recipients re-broadcast the message and vehicles receive multiple copies of same messages. The collision and loss of location updates and queries increase which affects the performance of the location service. To overcome these issues, clustering approach has been proposed to limit the communication of vehicles within the location servers. Cluster-based location service is more efficient because aggregated messages are sent to the location servers.

In clustering, vehicles are grouped together to formulate a cluster based on certain rules. There exists at least one Cluster Head (CH) in every cluster which is designated as a moving local location server. The other vehicles in the cluster are named as Cluster Members (CMs) (Shah, Malik, Rahman, Iqbal, & Khan, 2019; Cooper, Franklin, Ros, Safaei, & Abolhasan, 2016). The cluster-based location service schemes work in multiple levels, specifically two or three levels, to manage the location of vehicles. Cluster-based location service is also called as hierarchical-based location service. It collects and keeps the locations of its CMs (Huo *et al*., 2016; Fan, Haran, Dillenburg, & Nelson, 2005). The cluster-based location service schemes are further divided into two categories such as static cluster-based location service and dynamic cluster-based location service.

The static cluster-based location service depends on the static clusters. In the static clustering, the location of the cluster is predefined through dividing the area into fixed segments. The group of vehicles in a segment forms the cluster. In some cases, Road Side Unit (RSU) is also used to form static clusters. In each segment, the vehicle that is nearest to the center of the segment is elected as a CH. The other vehicles join the cluster as CMs. Every vehicle in a cluster sends its location to the CH. CH sends the locations to RSU that acts as a higher-level location server. Static clustering has some advantages such as simple cluster formation and low signaling cost during CH election (Singh and Kaur, 2015). However, the CH election depends on fixed locations. Location servers are elected without considering mobility parameters. When these location servers leave their respective areas, new location servers are defined. Due to this, location server election process occurs frequently that affects the performance of the location service. The CHs depend on intermediate servers to update the locations to higher level server. Likewise, frequent handover occurs when location server moves between different areas. Due to the abovementioned issues, CH and CM change frequently. Consequently, the CH and CM instability increases, which affects the performance of the location service.

The dynamic cluster-based location service relies on dynamic clustering. The dynamic clustering is also termed as mobile clustering. It depends on the mobility parameters such as speed and position to make the clusters. In the static clustering, clusters are defined by dividing the road into fixed segments as shown in Figure 1.5. A separate CH is elected for each segment. The lifetime of CH is limited to segment. The CHs and CMs switch between different clusters. Whereas in dynamic clustering, the clusters are not bounded to the fixed partition of the road as shown in Figure 1.4 and in Figure 1.6, CHs and CMs move with clusters. The main advantage of dynamic clustering is the reduction of reclustering by moving the cluster with the vehicles (Abdel-Halim, Fahmy, & Bahaa, 2019; Dhugga, Sharma, & Sharma, 2015; Singh and Kaur, 2015). In dynamic cluster-based location service, vehicles having similar mobility characteristics form one cluster and move within clusters as shown in Figure 1.3.

Based on the aforementioned discussion, it is obvious that the cluster-based location service schemes have more advantages in terms of scalability, reliability, communication overhead as compared to the non-cluster based location service schemes. Furthermore, the dynamic clustering is more flexible as compared to static clustering (Woo and Lee, 2018; Asoudeh, Mehrjoo, Balouchzahi, & Bejarzahi, 2017).

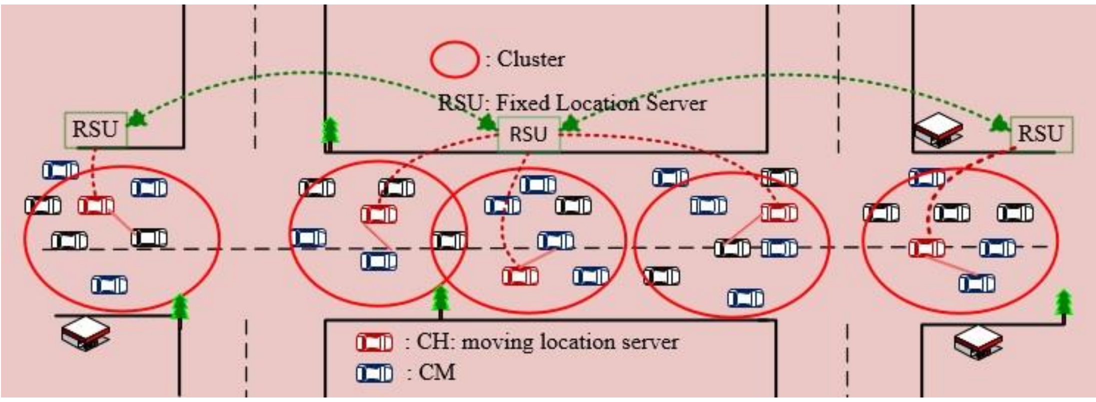

Figure 1.3 Clustering Based on Dynamic Clusters

The performance of the cluster-based location service depends on the stability of the cluster. The stability of the cluster relies on the CH, CM, cluster maintenance clustering parameters, communication overhead and isolated vehicles as mentioned in Figure 1.4 (Bi *et al*., 2020; Woo and Lee, 2018).

In the clustering approach, one vehicle is elected as a CH, other vehicles join the cluster as CMs. The CH not only performs cluster management functions such as communication with its CMs, inter-cluster communication, information exchange with RSUs, also performs other functions in the cluster-based location service such as to keep and update the location information of its CMs to higher-level location servers. The CH responds to different queries about the location of other vehicles in the network. The unavailability of the CH due to any reason breaks the cluster. All the communication between CH and other vehicles disrupted, hence the performance of the working application halted. The stability of the CH is the basic requirement to maintain the stability of the cluster.

In the cluster-based location service, the CM is the vehicle whose position is maintained in the location servers. The frequent switching of the CMs between different clusters affects the location updates and location queries. The stability of the CM is another key component for the cluster-based location service.

After electing CH and affiliating CMs, the cluster maintenance is another important component to maintain the stability of the cluster. During cluster maintenance, different events such as CM leaving, joining, cluster overlapping, and cluster merging are maintained to enhance the cluster stability.

The stability of the cluster depends on the parameters used to elect CH, CM and cluster maintenance. Some of the important parameters are speed, distance, direction, number of neighbours, link lifetime, destination, signal-to-noise ratio, fixed size road segments, road id and density. Due to rapid topological changes in VANETs, speed is considered as a most important parameter while forming the clusters. The combination of various parameters is used to increase the cluster stability, while keeping the requirements of different applications.

Communication overhead is another important parameter that impacts the stability of a cluster. With the increase of the communication messages, the network overhead increases which causes the delay and collision of messages. The communication links between CH and CM breaks, which ultimately affects the stability of the cluster.

The isolated vehicles are not part of any cluster. These vehicles send CM affiliation messages continuously to become the member of the clusters. With the increase of isolated vehicles, the number of CM affiliation messages increases, which creates extra communication overhead in the network. The communication between CH and CM is disrupted which reduces the lifetime of the CH and CM.

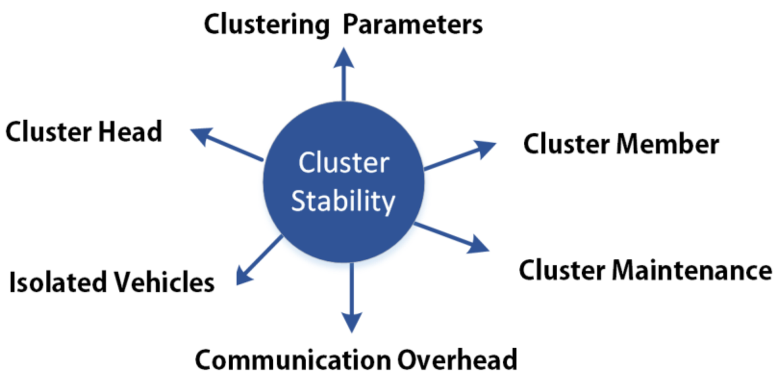

Figure 1.4 Dependence of Cluster Stability

Although the cluster-based location service schemes improve the performance of the location service by optimizing location updates and location queries, but limitations still exist due to frequent CH and CM changes which is discussed in the following subsections.

1.2.1 Cluster Head Instability

The CH is the core component of the cluster-based location service. The CH collects the location information of its members and updates these locations to a higher-level server along with responding and forwarding location queries. The CH does not only perform the location service functions but also execute the cluster management functions. The performance of the location service mainly depends on the stability of the CH.

In the static cluster-based location service, the road is divided into segments. The vehicle nearest to the center of the segment at any instant is elected as a CH as shown in Figure 1.5 (Aissaoui *et al.*, 2015). This approach simplifies the CH election and reduce the management functions by defining the CH election range. However, the election of the CH is bounded to the fixed point without considering the speed parameter. Furthermore, the CH is elected without including the link reliability with the RSU. Also, due to the fixed size road segments, communication range of neighbouring CHs overlaps each other. The CMs of these segments receive CM requests from the multiple CHs. The location information of these CMs is not updated due to the collision of the messages. Due to the frequent change of CHs, non-optimum cluster formation range and unreliable link with the RSU, the CH instability increases.

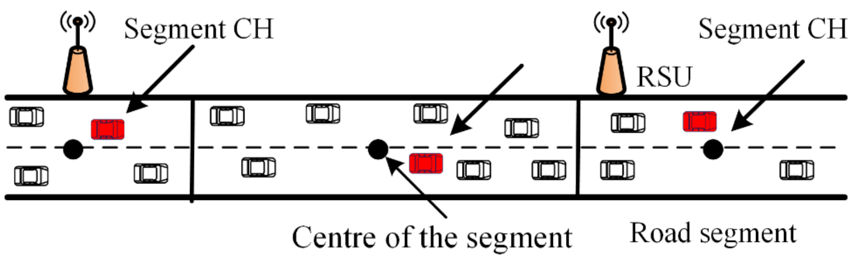

Figure 1.5 Static Cluster Head Election

A Cluster Based Location Service (CBLS) scheme proposed by Asoudeh et al. (2017) depends on the dynamic clustering to provide the location of a vehicle. Every vehicle broadcasts its Cluster Head Election Value (CHEV) that depends on speed, distance and number of directly connected vehicles to its neighboring vehicles. Each vehicle compares the CHEV with its own value. If a neighbour has better CHEV, the vehicle will broadcast the information of that vehicle. Same procedure is performed by all the vehicles, until, a vehicle which has optimum CHEV is elected as a CH as shown in Figure 1.6. To control flooding, messages have delay more than threshold value are discarded.

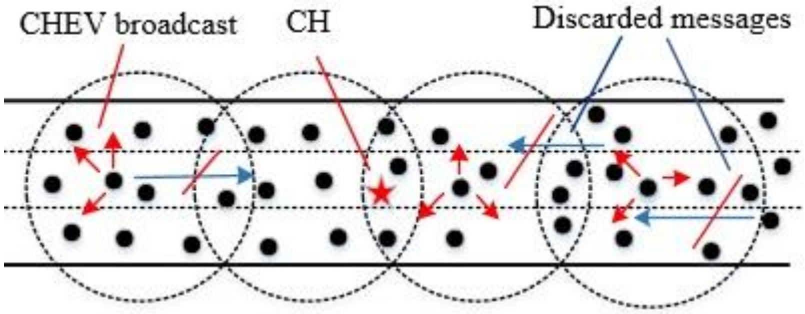

Figure 1.6 Dynamic Cluster Head Election

Although CBLS scheme tries to reduce the CH instability by using dynamic clustering and considering mobility parameters, CH instability still exists due to undefined cluster formation range. The reason is that every vehicle broadcasts its information to its neighboring vehicles, and in turn, each neighbor vehicle sends that information to its neighboring vehicles. Also, CHEV does not confirm a vehicle that is elected as CH with stable speed and least distance from all other vehicles. According to this scheme, a vehicle which has either highest speed or lowest speed or highest distance difference or lowest difference is elected as CH. Moreover, during CH election, the reliability of link between CH and higher level server is overlooked.

The Mobile Group-based Location Service (MoGLS) scheme proposed by Woo and Lee (2018), focusses on Cluster Member (CM) affiliation, however, as a part of his scheme, a CM that does not receive Beacon Messages (BM) from its CH within a certain time, elects itself as a CH and sends membership advertisement messages over the network. It means the CM that does not receive messages from the CH due to congestion or contention or collision of messages, advertises itself as a CH without considering its mobility, cluster formation range and link reliability with the RSU which leads to an unstable CH election.

The aforementioned location service schemes utilize the clustering approach to improve the performance of the location service by electing a stable vehicle as a CH. However, CH instability still exists due to non-optimum cluster formation range and due to unreliable link of the CH with the higher-level location server. The following studies based on general clustering (in which clusters are formed without the requirements of any specific application) tried to address aforementioned issues.

Arkian, Atani, Pourkhalili, and Kamali (2015) depend on the static and dynamic CHs to enhance the cluster stability. Every RSU is working as a static CH. The dynamic CH is elected from vehicles on the basis of distance, speed, neighbourhood degree and RSU Link Quality (RLQ). The proposed scheme improves the cluster stability by using mobility and Quality of Service (QoS) metrics. The link reliability with the RSU is considered while electing the CH. The leading vehicle starts the process of the clustering. The mobility and RLQ metrics are computed independently without synchronizing each other. This factor does not ensure that a vehicle that is most stable with its neighbours also has a reliable link with the RSU. Similarly, it does not guarantee that a vehicle having a reliable link with the RSU is also most stable with its neighbours.

The Base Station (BS) collects the information about the number of vehicles in the network and divides the area into different partitions based on the density of vehicles and number of required clusters (Qureshi, Abdullah, Bashir, Iqbal, and Awan, 2018). The BS defines the centroid of each partition. The CH for each partition is elected on the basis of signal strength and direction of other vehicles and distance from the centroid. The partition is based only on density without considering the length of the road. There may be very high density in a small area which leads to the increase in number of clusters. Due to the neighbouring clusters, the overlapping area increases. Besides this, speed of the vehicles and reliable link with the BS are ignored while electing the CH. Due to static approach, the number of clusters and CH instability increases.

Pal, Gupta, Prakash, and Tripathi (2018) define the centroid of cluster on the basis of the current position of vehicles. The CH is elected from the vehicles in the range of the centroid by considering the speed and distance from the centroid. The uniqueness of the centroid is affected due to different number of vehicles in the neighbor table of each vehicle, which does not ensure a reliable cluster formation range. Also, CH is elected without considering the reliability with the RSU.

In the light of earlier mentioned related works, it is observed that the cluster-based location service schemes are more focused on improving the location service functions such as location updates and location queries schemes instead of reducing the cluster instability. Existing CH election schemes which include HCBLS, CBLS and MoGLS increase the CH instability due to non-optimum cluster formation range and unreliable link with the RSU. In the aforementioned studies, a Centroid Vehicle (CV) is defined before the cluster formation range. CV is elected from the vehicles on the basis of neighbour table. Each vehicle has a different table which compromise the uniqueness of the CV, which ultimately affects the number of vehicles in range. In the HCBLS scheme, clusters are defined based on the road partitions. Each CH sends and receives messages up to 400m on both sides of it. Due to overlapping range, expected CHs receive multiple messages from neighboring vehicles. Collision of messages take place which affects the location updates and location queries. In CBLS and MoGLS, CH is elected without defining a specific range. The messages beyond a certain delay are discarded. The communication overhead increases during CH election. The collision of messages increases. The overlapping range and undefined range leads to non-optimum cluster formation range. These issues calculate unreliable Cluster Head Election Value (CHEV) which result in unstable CH election. Consequently, these issues increase the CH instability. The location updates and location queries suffer due to the CH instability which is acting as a lower-level location server. The performance of the location service degrades in terms of the query success rate, query response delay and localization error. Therefore, a reliable CH election scheme should be incorporated in VANETs that addresses the aforementioned issues effectively.

1.2.2 Cluster Member Instability

The key responsibility of the cluster-based location service is to provide the location of CMs through CH that is acting as lower-level location server. Location service performance depends on the less frequent change of CM affiliations in the cluster. The following section critically analyze the existing CM affiliation schemes.

In the static cluster-based location service scheme, the collection of the vehicles in each segment defines the cluster (Aissaoui et al., 2015). One vehicle that is nearest to the center of the segment is elected as a CH and other vehicles in the segment affiliate with the CH as CMs. The CH collects the location information of these CMs and sends that information to a higher-level location server. The CM affiliation in the static cluster-based location service is simple and does not require any exchange of messages to affiliate with the CH. However, the vehicles are affiliated with a new CH in each segment. The location updates from the CH to a higher-level server are affected. The vehicles join and leave the clusters frequently. In addition, the lifetime of each CM in a cluster is limited to segment size. Moreover, the CH election and CM affiliations are not based on mobility parameters; instead; these two rather rely on bounded cluster region. Due to the speed difference, some of vehicles are not affiliated to the CH and remain isolated. The CM instability increases due to frequent CM changes and isolated vehicles.

In the CBLS scheme, the CM affiliation depends on the speed difference with the CH. The CH allows those vehicles to join the cluster whose speed difference with the CH is less than 18 km/h. Moreover, the maximum number of CMs in each cluster is limited to 20 (Asoudeh et al., 2017). The stability of the CM in a cluster is increased by using speed. However, due to sudden and frequent topology changes, speed varies instantaneously which does not ensure the long lifetime of a CM in the cluster. Also, those vehicles whose speed difference is greater than 18 km/h cannot affiliate to the cluster. The isolated vehicles increase in the network due to fixed CM affiliation threshold values. The location information of these vehicles are not updated to the location servers.

The MoGLS scheme proposed by Woo and Lee (2018) addresses the CM instability by using speed and distance parameters to affiliate the vehicles as CMs. Every vehicle calculates its sojourn time, the time that a vehicle remains in the range of a CH for which it is responsible, compares this sojourn time with fixed threshold value sent by the CH. If the value of the sojourn time is greater than predefined threshold value, the vehicle joins the cluster as a cluster member otherwise waits for the messages from the other CH. If there are more than one CHs in neighboring area, the vehicle joins the cluster with a greater sojourn time as shown in Figure 1.7.

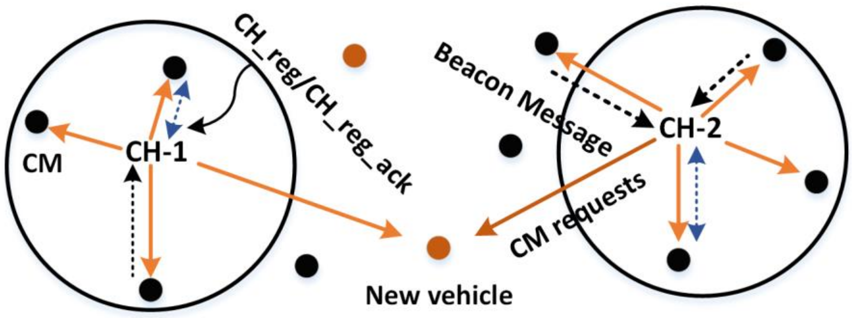

Figure 1.7 Cluster Member Affiliation

In the proposed MoGLS scheme, the CM stability is improved by considering mobility parameters. The sojourn time calculation depends on the instantaneous values of the speed. It is not based on optimum values of the speed due to which the CM and CH soon become out of the range and the CM again continues its search for another cluster. The vehicle joins and leaves the clusters shortly and frequently. This factor affects the lifetime of a CM in a cluster. Also, some of vehicles could not affiliate with the cluster due to predefined fixed threshold values. The number of the isolated vehicles increases in the network due to which network overhead and cluster instability increase.

The aforementioned location service schemes improve the performance of the location service by reducing CM instability. However, CM instability still exists due to unreliable link with the CH and instantaneous values of the speed. Moreover, the number of isolated vehicles in the network increases due to CM affiliation criteria which depends on predefined fixed CM affiliation threshold value to join the cluster.

The positions of the isolated vehicles are not updated to the server due to which query success rate decreases.

Cambruzzi *et al*. (2016) and Huo *et al*. (2016) vehicles depend on the LLT to affiliate with the CH. The vehicles join the cluster based on the larger staying time in a cluster. The CM affiliation threshold value is determined by vehicle itself. Although, the number of the isolated vehicles decreased, however, CMs switch between different clusters due to instability of the existing CHs. Moreover, the LLT depends on the instantaneous value of the speed, which does not confirm a reliable CM affiliation. The lifetime of a CM in a cluster decreases.

Senouci, Aliouat, and Harous (2019a) CM affiliation relies on the speed difference to allow a vehicle to join the cluster. The Undecided Node (UN) sends a joining request to the nearby CH. The CH computes the relative speed with UN, then compares this value with the average speed of the whole cluster. If the relative speed is less than or equal to average speed of the cluster, then the CH allows the UN to join as a CM. The existing scheme is more flexible in terms of fixed CM threshold value as compared to the previous studies. The CM threshold value depends on the average speed of the cluster. However, it does not make sure a direct relation with the speed of the CH which does not ensure a reliable affiliation. Similarly, relative and average speed are based on instantaneous values of the speed. Moreover, vehicles whose speed is greater than average speed cannot join the cluster. The number of isolated vehicles in the network increases which ultimately increase the CM instability.

More precisely, with the frequent and rapid changes in VANETs, instantaneous mobility information obtained through beacon messages results into inaccurate link estimations (Srivastava, Prakash, & Tripathi, 2020). Isolated nodes continuously search nearby clusters to affiliate. If the number of isolated nodes in the network increases, the network congestion and network overhead also increases which lead to poor network performance (Huo *et al*., 2016).

Based on the previous discussion, it is observed that CM instability issue occurs due to considering instantaneous speed of the CH while affiliating with the cluster. Also, each CH defines a threshold value to allow the vehicles with the existing cluster. However, due to fixed threshold values, some of the vehicles could not affiliate to any cluster and remain isolated. Instantaneous values lead to unreliable affiliation with the CH. The affiliated CM change clusters frequently. The location updates and location queries are affected. Also, due to fixed threshold values, the number of isolated vehicles increases. Isolated vehicles continuously send and receive messages to affiliate with the nearby clusters. The exchange of communication messages between CH and CH increases which leads to extra communication overhead. The delay and collision of messages increases. The locations of isolated vehicles are not updated to any cluster which ultimately affects the performance of the location service.

The lifetime of each CM in a cluster reduces due to the CM affiliation scheme. These issues increase the CM instability which ultimately affects the performance of the location service in terms of query success rate, query response delay and localization error. There is a need to improve the existing cluster member affiliation schemes by considering a reliable link with the CH and dynamic CM affiliation threshold values to reduce the CM instability.

1.2.3 Cluster Maintenance Instability

Due to high mobility of the vehicles, the cluster structure and network topology change frequently. Several events are triggered at cluster level (Cheng and Huang, 2019) such as, existing CM loses its affiliation with the current cluster, the existing CH deteriorates its stability or disappears due to issues in communication hardware, overlapping of the clusters in neighboring area and cluster splitting around the intersection. The stability of the clusters is suffered due to these events (Bi *et al.*, 2020).

The cluster maintenance is a continuous process that monitors the stability of the existing clusters and performs maintenance accordingly to manage these events. The aim of the cluster maintenance is to maintain the cluster structure and reduce cluster instability (Awan, Din, Almogren, Guizani, & Khan, 2020; Joshua, Duraisamy,

& Varadarajan, 2019). In this research, the cluster maintenance is performed by focusing on the cluster merging and cluster splitting.

Existing cluster-based location service schemes are focused on location updates, location queries, CH elections, CM affiliations to improve the performance of the location service. On the other hand, these schemes overlooked cluster maintenance which is a compulsory component to improve the stability of the clusters. However, general clustering schemes depend on cluster maintenance to reduce the cluster instability. Several schemes are proposed to address the cluster instability in the cluster maintenance.

The stability of the cluster is affected when several clusters co-exist within a short distance. The clusters overlap each other. The merging of clusters depends on the overlapping range of the clusters and on the duration (also called Merging Threshold Time (MTT) before the start of the merging. Due to topological changes in VANETs, the distance and range change suddenly and frequently. So, in order to make merging effective, the overlapping CHs wait up to MTT before the start of the merging. After completing the merging, the next step is to elect the CH for the merged cluster. The CMs of the merged cluster affiliate with the new CH (Awan *et al.*, 2020; Farooq, Ali, & Rehman, 2016; Lin *et al.*, 2016).

The merging of the cluster is initiated when a CH determines that all its CMs are merged into another cluster; the distance between CHs is less than 100m; and sojourn time is greater than threshold value (Woo and Lee, 2018). The proposed MoGLS scheme tried to make the merging of the cluster stable by adding range, distance and sojourn time conditions. However, the MTT does not ensure that merging clusters move towards each other or move away from each other. During MTT, the merging clusters may move away from each other while staying in the range of each other. The merging is started and completed which lead to unstable merging. Moreover, the new CH is elected without considering the reliable link with the RSU. These issues increase the cluster instability.

Senouci *et al*. (2019a) merging process is invoked when two neighbouring clusters overlap each other over a merging time. The CH with large number of the CMs is elected as a CH of the merged cluster. Although, the proposed study simplifies the merging criteria, however, the merging range and MTT are not defined. Also, the new CH is elected without the link reliability with the RSU. Due to these issues, the merging of the clusters is not affective and cluster instability increases.

When one CH comes into the range of another CH and both CHs are moving in the same direction, then the cluster merging starts (Haider, Abbas, Boudjit, and Halim, 2020). The vehicle which is at the middle of the merged cluster is elected as a CH of the merged cluster. Although merging criteria is simple but without defining the specific values of the merging conditions such as range and MTT, the merging process is triggered frequently which increases cluster instability. Moreover, CH depends only on the distance from the other vehicle without considering link status with the RSU.

The aforementioned cluster maintenance schemes reduce the cluster instability by performing the cluster merging; however, there is still a need to improve cluster merging by optimizing the merging conditions which includes overlapping distance and Merging Threshold Time (MTT). Furthermore, the CH of the merged cluster is elected without considering the reliable link with the RSU. So, overlapping causes management and communication issues which increases the cluster instability.

Cluster instability occurs around the intersection due to divergent of the traffic flow towards straight, left and right as arrowed in Figure 1.8. Existing CH moves only in one direction and CMs of other directions lose their affiliations from the CH. The following section analyzes the existing cluster splitting studies around the intersection.

Zhao, Liu, Wu, and Liu (2016) depend on the direction of the vehicles to manage the clustering around the intersection. It is supposed that each vehicle knows its turning direction before entering into the intersection area. The vehicles are considered within the intersection area, when the distance between center of the intersection and vehicles is less than 2R, where R is the transmission range. The most middle vehicle in each direction is elected as a CH. Although the existing study tries to split the existing cluster based on the direction parameters, but some limitations still exist such as, when the existing cluster enters into the intersection area, the vehicles of this cluster is splitted into three sub-clusters on the basis of left, right and straight direction as shown in Figure 1.8. The CH of the existing stable cluster is re-elected. The cluster instability increases due to clustering after entering the intersection area and reclustering after leaving the intersection area. The CHs of the split clusters are elected without considering the link status with the RSU. These issues increase the cluster instability which degrades the performance of the location service.

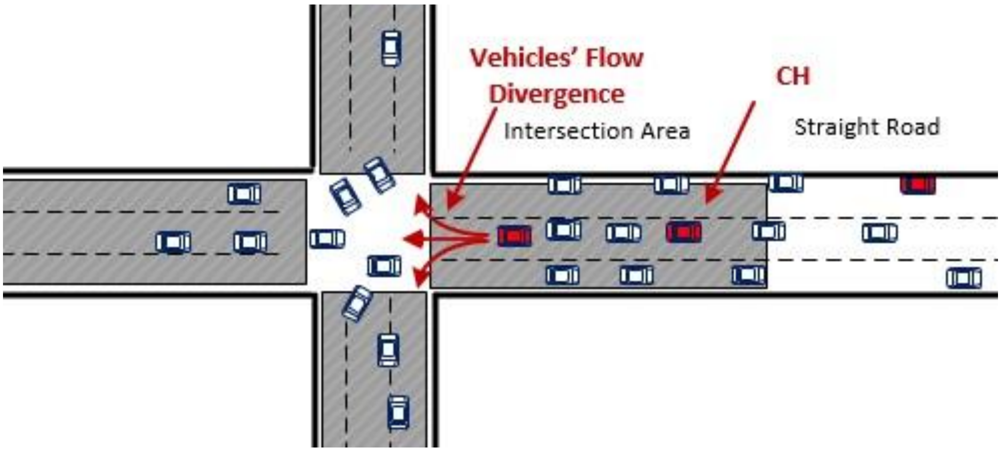

Figure 1.8 Cluster Instability Around the Intersection

Zhou, Wu, and Wang (2017) attempt to improve the existing schemes by reducing the clustering in the intersection area. In the proposed algorithm, the Base Station (BS) elects the CH from the road segment which has large number of neighbors and lowest Cluster Head Election Value (CHEV). The Weighted CHEV depends on the relative position between vehicles and the relative distance from the vehicle to the BS. The existing study tries to reduce the unnecessary clustering around the intersection by electing only one CH in the intersection area. The CH election is based only on distance parameter. The link reliability of CH with the BS is included by considering the distance from the BS. Here, only CH has to managed the whole intersection traffic. At the intersection, the vehicles are moving in different directions. The elected CH can move only in one direction. When the distance between CH and vehicles of other road sections increases beyond the communication range, vehicles will lose their affiliations; as a result, the cluster instability increases.

According to the aforementioned information, existing studies try to manage the clustering around the intersection. Existing schemes performs the clustering when cluster enters the intersection area and reclustering when cluster leaves the intersection area. Even a stable cluster is reclustered. Cluster instability increases due to unnecessary clustering. New CHs are defined at the cost of cluster instability. Also, new CHs are elected without considering the link status with the RSU.

Cluster instability increases due to non-optimal cluster merging and splitting. In the cluster merging, overlapping CHs wait up to merging threshold time before the start of the merging. The merging threshold time depends on the fixed value or on the update interval of only one CH. Also, the merging threshold time does not ensure that overlapping clusters moves towards each other or away from each other which leads to unreliable cluster merging. The collision of messages in the overlapping area increases. The location updates and location queries are affected due to overlapping of neighbouring CHs. Also, around the intersection, due to non-optimal cluster splitting cluster instability increases. The non-optimal CH election parameters lead to unnecessary clustering around the intersection. The communication overhead around the intersection increases. The collision of messages increases. The location updates and location queries of CMs are affected. The inter-cluster interference, congestion, the contention and message loss increases due to non-optimum cluster merging and splitting. Due to these issues, cluster instability increases. So, there is a need to improve the existing cluster maintenance schemes to improve the performance of the location service.

It concludes from the aforementioned discussion that although cluster-based location service is preferred due to its advantages over non-cluster based location service, but limitations still exist in terms of the cluster instability as identified in the section 1.3.

1.3 Problem Statement

The cluster-based location service relies on the stability of the cluster. Cluster stability is frequently affected because of high mobility, unreliable communication links, and frequent changes in the topology. In the cluster-based location service, every CH updates the locations of its CMs to RSU. In the existing cluster-based location service schemes HCBLS, CBLS and MoGLS, CH election is based on the reliable link with other vehicles ignoring the link reliability with the RSU. Moreover, CH is elected without optimum cluster formation range. The unreliable link with the RSU and non-optimum cluster formation range surge CH instability. The CM is the vehicle whose position is cached in the location servers. However, due to the reliance on instantaneous values of the speed, CMs join and leave clusters frequently. Likewise, some of the vehicles are not affiliated to any cluster due to the fixed CM affiliation threshold values. The isolated vehicles in the network increase. These issues increase the CM instability. After electing the CH and affiliating the vehicles as CMs, the cluster stability depends on the efficiency of the cluster maintenance schemes. However, non-optimum cluster merging and splitting; and unreliable links with the RSU increase the cluster instability. In the cluster-based location service, location updates and location queries are negatively affected with the CH instability, CM instability and non-optimum cluster maintenance schemes. The CH and CM stability is measured by CH lifetime and CM lifetime. The higher value of the CH lifetime represents that CH is more stable and serve the cluster for longer time. Also, the higher value of CM lifetime indicates that CM remains affiliated for larger time. The location updates and location queries are improved which ultimately enhance the performance of the location service in terms of the query success rate, query response delay and localization error. The lower values of CH lifetime and CM lifetime leads to CH instability and CM instability respectively.

1.4 Research Questions

The following research questions are formulated based on the discussion provided in Sections 1.2 and 1.3.

i. How to improve the process of electing a CH in order to enhance the CH stability?
   a) How to calculate the cluster formation range that increases cluster stability?
   b) How to evaluate the reliability of communication link between the potential CH and RSU in order to enhance the CH stability?
ii. How to enhance the process of affiliating a vehicle in order to improve the CM stability?
   a) How to evaluate a reliable CH to affiliate a vehicle to improve CM stability?
   b) What are the necessary parameters to calculate CM affiliation threshold value to reduce the isolated vehicles in the network?
iii. How to enhance the process and conditions of cluster maintenance to improve cluster stability.?
   a) What are the merging conditions need to be optimized to increase the cluster stability?
   b) What are the parameters that should be considered for reducing the unnecessary clustering to improve the cluster stability?
   c) What are the significance parameters that should be considered to enhance the link reliability with the RSU?

1.5 Research Aim

The main aim of this research is to develop an Enhanced Stability of Cluster-based Location Service (ESCLS) mechanism to improve the performance of the location service in terms of Query Success Rate (QSR), Query Response Delay (QRD) and Localization Error (LE).

1.6 Research Objectives

The objectives of this research are designed based on the research questions mentioned in the Section 1.4 as follows.

i. To develop a reliable CH election scheme that reduce the frequent CH changes and enhance the link reliability with the RSU to improve the CH stability.
ii. To enhance a CM affiliation scheme that reduce the frequent CM changes and isolated vehicles to improve the CM stability.
iii. To optimize a cluster maintenance scheme to stabilize the cluster merging and cluster splitting to improve the cluster stability.

1.7 Research Contribution

The main contribution of this research is an ESCLS mechanism which is an integrated outcome of following schemes:

i. The Reliable Cluster Head Election (RCHE) scheme enhances the CH stability through optimizing the cluster formation range and improving the link reliability of the CH with the RSU. The performance of the RCHE is evaluated in terms CH lifetime, QSR and QRD.
ii. The Dynamic Cumulative Cluster Member Affiliation (DCCMA) scheme improves the CM stability through enhancing the link lifetime with the CH and using dynamic CM affiliation threshold values. The performance of the DCCMA is evaluated in terms of CM lifetime, QSR and fraction of vehicles saved in the location servers.
iii. The Optimized Cluster Maintenance (OCM) scheme enhances the cluster stability by optimizing cluster merging and splitting. The performance of the OCM is evaluated in terms of QSR, QRD and LE.

1.8 Research Scope

The scope of this research is as follows:

iv. Communication between Vehicle to Vehicle (V2V) and Vehicle to RSU is based on IEEE 802.11p standard.
v. Focus on Urban VANETs which means network scenario is considered inside the city.
vi. In this study V2V, Vehicle to Infrastructure (V2I) and Infrastructure to Vehicle (I2V) communications are considered.
vii. The network scenario does not include complex city topologies such as bridges, tunnels, and curved roads. Also, the network scenario does not include U-turns.
viii. Security-related issues for vehicles and RSUs are not considered.

1.9 Significance of the Research

This research contributes significantly to the field of ITS as it focusses on developing the cluster-based location service mechanism that provides a wide range interesting application such as to find the position of parking slot, emergency vehicles, resource discovery vehicles, tracking and position-based routing. The ESCLS mechanism is also applicable in other VANETs application such as routing, security, information dissemination that depends on clustering approach to provide the communication between vehicles. The performance of these application improves through the enhanced cluster stability of ESCLS mechanism. Furthermore, as ESCLS provide a reliable communication between CH and RSU, so the performance of the applications that exploits RSU as a gateway increases.

1.10 Thesis Organization

The rest of this research work is organized as follows.

Chapter 2 provides a comprehensive literature review. This includes the fundamental information about VANETs, clustering and location service. In particular, the available solutions thoroughly examined to highlights the novelty of this research, in terms of cluster head election, cluster member affiliation and cluster maintenance.

Chapter 3 presents the research methodology. This includes the proposed framework and simulation setup. The operational and research framework highlight the proposed phases of the ESCLS such as RCHE, DCCMA and OCM. The proposed scheme is simulated using network simulator Objective Modular Network Testbed in C++ (OMNET++). The Simulation of Urban Mobility (SUMO) is used as a traffic simulator. The Vehicles In Network Simulation (VEINS) is used as a middleware framework to connect OMNET++ and SUMO. The various assumptions and limitations are also considered in the simulation setup of this research.

Chapter 4 demonstrates the development of the RCHE scheme. It addresses the problem of cluster head instability. The simulation results are evaluated on the basis of speed and density to observe the lifetime of the CH.

Chapter 5 presents the development of the DCCMA scheme. It addresses the problem of the cluster member instability by enhancing the reliability with the CH and using dynamic CM affiliation threshold values. Moreover, the simulation results are also analyzed to observe the effect of speed and density on the lifetime of the CM.

Chapter 6 details the development of the OCM scheme. It addresses the problem of cluster instability due to the overlapping of the neighbouring clusters and unnecessary clustering during cluster splitting. The performance of the proposed cluster maintenance scheme is evaluated through simulation.

Chapter 7 concludes this work by summarized research achievements and outlines the future research directions.

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LIST OF PUBLICATIONS

Journal with Impact Factor

1. **Mujahid**, M. A., Bakar, K. A., Darwish, T. S., & Zuhra, F. T. (2020). Cluster-based location service schemes in VANETs: current state, challengesand future directions. *Telecommunication Systems*, 1-19. https://doi.org/10.1007/s11235-020-00732-3. **(Q3, IF: 2.314)**

Indexed Journal

1. **Mujahid**, M. A., Bakar, K. B. A., Darwish, T. S., Zuhra, F., Ejaz, M. A., & Sahar, G. (2020). Emergency Messages Dissemination Challenges Through Connected Vehicles for Efficient Intelligent Transportation Systems: A review. *Baghdad Science Journal*, 17(4), 1304-1319. http://dx.doi.org/10.21123/bsj.2020.17.4.13-04 **(Indexed by SCOPUS)**