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PII: S0167-739X(18)32931-5
DOI: https://doi.org/10.1016/j.future.2019.02.024
Reference: FUTURE 4777

To appear in: *Future Generation Computer Systems*

Received date : 21 November 2018
Revised date : 22 January 2019
Accepted date : 14 February 2019

MCA-V2I: A Multi-hop Clustering Approach over Vehicle-to-Internet communication for improving VANETs performances

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Abstract

The Internet of Vehicles is a new Intelligent Transportation System paradigm and a promising solution to improve conventional Vehicular Ad-hoc NETworks (VANETs) performances. It has received a great deal of attention in recent years, from many researchers. For this reason, several control mechanisms have been proposed for these networks to confront their challenges, such as dynamic topology and the scalability problem due to the high mobility of vehicles and the high number of connected vehicles, respectively. As an important mechanism used in a VANET, clustering has significantly improved the performance in numerous applications. In this regard, the present work proposes a new Multi-hop Clustering Approach over Vehicle-to-Internet called MCA-V2I to improve VANETs' performance. MCA-V2I is based on the reasonable assumption that a vehicle can connect to the Internet via a special infrastructure called a Road Side Unit Gateway. Once connected to the Internet, each vehicle can obtain and share the necessary information about its Multi-hop neighbors to perform the clustering process. This latter is performed using a Breadth-first search (BFS) algorithm for traversing a graph based on a Mobility Rate that is calculated according to mobility metrics. MCA-V2I strengthens clusters' stability through the selection of a Slave Cluster Head in addition to the Master Cluster Head. We evaluate the performances of the proposed scheme using network simulator NS-2 and the VanetMobiSim integrated environment.

Keywords: VANETs; Internet of Vehicles; Multi-hop Clustering; Mobility Rate; BFS Algorithm

1. Introduction

1.1. VANET Toward IoV: An Overview

The Internet of Vehicles (IoV) is an evolution of conventional VANET. It extends VANET's scale, structure and applications. This evolution leads to the emergence of new interactions at the road level among vehicles, humans and infrastructure [1]. It is an important field of research to improve conventional VANETs and their performances. Researchers have proposed several protocols for different aims and applications, such as data dissemination and aggregation, network overhead minimization, road safety, traffic management and mainly routing schemes.

Compared with VANET, IoV has many specific advantages and characteristics, such as developing and extending the exploitation of the Intelligent Transportation System (ITS) in different fields of research and industry [2]. The first main advantage is the quick and easy access to the Internet. This allows sharing safety information between vehicles and providing useful information, such as the availability of hotels, parking's location, gas stations and even drivers' comfort applications. The second advantage is the ability to support a significant number of connected vehicles (scalability). As a third advantage, Cloud Computing (CC) technology can be integrated into the vehicular networks. This emergent technology allows applications, resources and data to be stored in remote stations and servers that represent the Cloud, so that they can be used by clients with low capacity. The CC technology manages the large

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amount of data generated by the connected vehicles. Finally, the IoV expands basic types of VANET communications such as Vehicle-to-Vehicle (V2V) and Vehicle-to-Road Side Unit (V2R) to new types of communications, such as Vehicle-to-Internet (V2I), Vehicle-to-Person and Vehicle-to-Device.

The architecture of an IoV network is usually composed of two main parts: Access Network (AN) and Backbone Network (BN). AN includes two main components: On-Board Unit (OBU) and Road Side Unit (RSU). First, the OBU is a device installed on the vehicle using Wireless Access in Vehicular Environment (WAVE) technology to ensure connection safety and reliability. It consists of four modules: GPS module, internal acquisition module, Input–Output module and Vehicle-to-X (V2X) module (X can be a vehicle, person, RSU, infrastructure or Internet). Second, the RSU is a computing device installed on the roadside that provides communication services to vehicles [3]. On the other hand, BN includes three main components: Transportation Control Center (TCC), Cloud Center (CC) and Internet. First, the TCC takes charge of managing and controlling all the components of AN. Second, CC is a virtual center containing servers to store data, resources and applications to serve vehicles. Finally, the Internet is a global network providing a variety of services and information. Nowadays, numerous communication technologies can be considered in IoV for V2X connectivity. In this respect, Masini et al. [4] discuss in depth different wireless access technologies and highlight the advantages and the limitations of each technology, from IEEE 802.11p and its related standards to short-range Cellular-V2X, such as LTE-V2X standard and other complementary technologies, such as visible light communication (VLC) and millimeter-Waves, up to hybrid communication and 5G. Figure 1 illustrates the architecture of an IoV network.

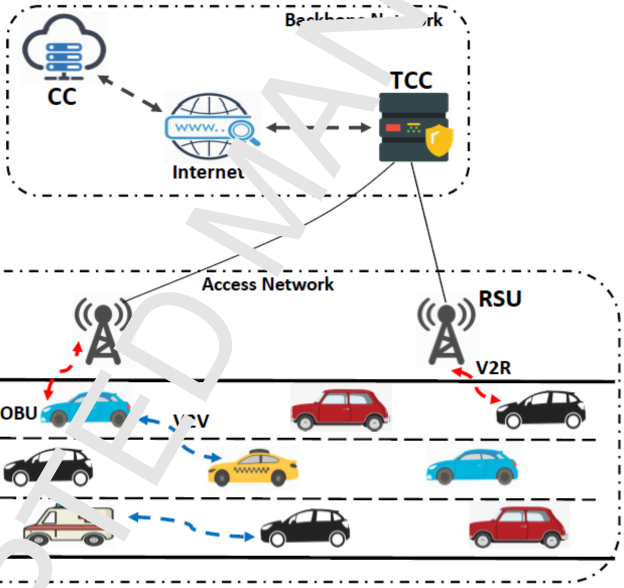


Figure 1: Network architecture for IoV.

1.2. Clustering in VANET

As an important control mechanism used in VANET, clustering has significantly improved the performances in numerous applications, such as data dissemination and aggregation, network overhead minimization, road safety, drivers' comfort and routing schemes. According to Yang et al. [5], clustering is the technique of dividing the network into groups of nodes called clusters. Each cluster has a cluster head and the rest of the nodes in the cluster are called cluster members. Typically, the clustering process is divided into five main phases: neighborhood discovery, Cluster Head (CH) selection, announcement, affiliation and maintenance [6].

To form stable clusters in VANET, many researchers have proposed various clustering protocols. These protocols differ from each other based on the criteria used to choose the CHs and perform the clustering process. Several of these protocols are detailed and discussed in Section 2.

1.3. Motivation

According to the available literature, most of the proposed clustering algorithms [7, 8, 9, 10, 11] are focused only on one-hop clustering, which only allows communication between a Cluster Member (CM) and its CH with one-hop distance at most. Consequently, the coverage area is very small, and many clusters are formed, which affects the network performance and increases the rate of overlapping between clusters. Moreover, because the VANET is a subclass of MANETs, several proposed protocols are derived from the MANET clustering schemes [12, 13]. However, these schemes do not consider the mobility characteristics, the dynamic topology and the limited driving directions of VANET; moreover, they do not consider energy problems [14]. Furthermore, most of the proposed clustering protocols do not use mechanisms that exploit the Internet and to take advantage of their large services to improve the performances of VANET. Several proposed mobility-based clustering approaches [15, 16, 17, 18] are based on the broadcast of control messages, which causes overloading of the networks and leads to many collisions, especially because the number of messages is high due to the multi-metric mechanism used.

1.4. Contribution

In this work we propose a new Multi-hop Clustering Approach over Vehicle-to-Internet communication called MCA-V2I to improve VANETs' performance. The main idea of this work is to perform a clustering algorithm using Internet access. MCA-V2I is based on the reasonable assumption that a vehicle can connect to the Internet via a special infrastructure called a Road Side Unit Gateway (RSU-G) to obtain and share the necessary information about its multi-hop neighbors to perform the clustering algorithm. It is performed using a Breadth-first search (BFS) algorithm for traversing the graph and based on a Mobility Rate (MR) that is calculated according to some mobility metrics such as node connectivity, average relative velocity, average distance and link stability. In MCA-V2I, a vehicle with low MR is suitable to be elected as the Master CH (MCH). Therefore, all the multi-hop neighbors of the new elected MCH become Cluster Members (CMs). The MCA-V2I scheme strengthens clusters' stability through the election of a Slave Cluster Head (SCH). We evaluate the performances of MCA-V2I using network simulator NS-2 and the VanetMobiSim integrated environment.

The main contributions of this work are as follows:

1. A new multi-hop clustering model is proposed. Compared with one-hop clustering schemes, this model is designed to extend the coverage area of clusters, reduce the number of clusters, optimize the control overhead and improve cluster stability.
2. A Mobility Rate is introduced for the clustering algorithm. This parameter is calculated based on mobility metrics to satisfy the requirements of the new features of VANET, and to consider its mobility characteristics.
3. MCA-V2I provides Internet access to vehicles to obtain and share the necessary information to perform the clustering algorithm. This benefit significantly reduces the rate of control messages used in traditional clustering algorithms. Therefore, MCA-V2I can significantly improve the network overhead.
4. MCA-V2I strengthens clusters' stability through the election of an SCH in addition to the MCH.

The rest of this paper is organized as follows. Section 2 presents related work. Section 3 describes the preliminaries of the proposed approach. Section 4 introduces the proposed approach in detail. Section 5 presents the experimental results. Finally, a conclusion is presented in Section 6.

2. Related Work

Recently, several clustering schemes have been proposed for VANET. Several proposed schemes [7, 8, 9, 10, 11] focused only on one-hop clustering, which only allows communication between a CM and its CH with one-hop distance at most. Therefore, the coverage area is very small, and many clusters are formed, which affects the network performances and increases the rate of overlap between clusters. These protocols are not adaptable for highway areas due to the high mobility in this zone, where the network topology is very dynamic. Consequently, several multi-hop clustering schemes have been proposed in recent years [19, 20, 21] to extend the coverage area of clusters, reduce the number of clusters and improve cluster structure and stability.

On the other hand, several mobility-based clustering schemes have been proposed. Mobility-based clustering algorithm (MOBIC) [15] is a reference and the comparison clustering protocol used initially in Mobile Ad-hoc NETwork (MANET), and later on for VANET. The MOBIC protocol is similar to the Lowest-ID algorithm [12], but it uses the mobility metric as a basis of cluster formation and CH election.

Hafeez et al. [16] proposed a new clustering scheme for VANETs where CHs are selected based on their relative velocity and distance from vehicles within their neighborhood. Furthermore, the proposed protocol selects for each cluster a secondary CH (to be used as CH when the primary one becomes unavailable). The maintenance phase in the proposed scheme is adaptable to drivers' behavior on the road using a fuzzy logic inference system. The protocol is suitable to be applied in areas with high mobility, but CHs frequently change when they move fast or change their direction. The frequent change of CHs leads to a decrease in the performance of secondary CHs, which results in unstable clusters.

Ren et al. [17] proposed a new dynamic mobility-based clustering scheme suitable for an urban city scenario. The proposed approach uses several metrics, such as vehicles' moving direction, relative velocity, relative position and link lifetime estimation to perform the clustering process. Consequently, the size and number of control messages increase enormously, which affects the network performances in a negative way.

Hassanabadi et al. [18] introduce a new mobility-based clustering scheme for VANET, which forms clusters using the affinity propagation method [22] in a distributed manner. This proposed scheme uses vehicles' position and velocity information to perform a clustering algorithm. Typically, an affinity propagation algorithm requires several iterative loops that increase the delay time of the cluster formation phase.

Zhang et al. [19] propose a new multi-hop clustering approach to establish stable vehicle clusters. To perform the multi-hop clustering algorithm, a new mobility metric is introduced to represent relative mobility between vehicles in a multi-hop distance. In this approach, vehicles must identify the aggregate mobility of all N-hops distance neighbors. Consequently, numerous extra control overhead messages are generated within the network, which eventually reduces the efficiency of the clustering algorithm.

In Chen et al. [20], the authors proposed a new Distributed Multi-hop Clustering scheme for VANETs based on Neighborhood Follow (DMCNF) to increase cluster stability. The proposed approach allows vehicles periodically to choose their targets from one-hop neighbors in a distributed way. The DMCNF scheme generates CHs via a neighborhood to follow the relationship between vehicles.

In Ucar et al. [21], the authors present VMaSC: Vehicular Multi-hop algorithm for Stable Clustering. VMaSC is a new clustering technique based on choosing the vehicle with the least mobility computed as a function of the speed difference between neighboring vehicles as the CH through multiple hops. The main drawback of this protocol is the dependence on GPS device or location service to obtain mobility information.

Ucar et al. [23] propose a minimum overhead stable multi-hop cluster based on a data aggregation method called VeSCA to improve the VMaSC protocol [21]. The VeSCA scheme aims to reduce the number of data packets broadcasted and to maximize the aggregated data packet delivery ratio. The VeSCA approach uses several metrics, such as vehicle's direction, velocity, current clustering state, location and number of hops to CH, to form the clusters. Therefore, the size and number of the control messages increase enormously, which affects the cluster's performance in a negative way.

Goonewardene and Stipidis [24] introduce a new clustering algorithm named Robust Mobility Adaptive Clustering (RMAC) strategically to enable and manage highly dynamic VANETs for future ITS. It uses a new vehicle precedence scheme to identify adaptively the close one-hop neighbors and to form clusters based on a mobility technique, which includes several metrics, such as speed, position and vehicle's direction.

In Rawashdeh et al. [25], the authors present a novel clustering scheme suitable for highway areas with the aim of enhancing the stability and structure of the network topology. This technique takes the relative velocity as the main metric to form stable clusters. The authors also proposed a new multi-metric algorithm to select the CHs. The main drawback of this scheme is the dependence on device or location service.

Furthermore, many of the VANET clustering schemes are derived from MANET. However, VANET is characterized by high mobility, dynamic topology and limited driving directions. In Lin and Gerla [12], the authors propose an adaptive clustering architecture for multimedia support in a multi-hop mobile network called Lowest-ID protocol. In this scheme, nodes broadcast a Hello message containing their ID. Then, each node constructs a table, which contains neighbor nodes' ID information. Finally, the node that has the lowest ID will be selected as the CH and the remaining nodes are cluster members. Chatterjee et al. [13] present a Weighted Clustering Algorithm (WCA) that selects a node to act as a CH based on a combined weight of a node degree, average distance and average velocity.

3. Preliminaries

The following section describes the preliminaries of the proposed approach presenting the network model and system description.

3.1. Network Model

The proposed approach is based on the following assumptions. First, each vehicle in the network has a unique *id*, which is the MAC address of the OBU interface. Second, every vehicle is equipped with an OBU device using WAVE technology. Third, we have a highway with two roads (one for each direction), and three lanes for each road. Finally, several RSUs with a transmission range of 1.5 km are installed every 3 km on the sides of the highway area, to cover the entire vehicular network. If we assume that L is the length of the highway area, the approximate number N_{RSU} of RSUs necessary to cover the entire vehicular network is defined as follows:

$$N_{RSU} = \left\lceil \frac{L}{3} \right\rceil \tag{1}$$

The vehicular network topology is modeled as an undirected graph $G(V, E)$, where V is the set of vertices representing the vehicles in the network, and E is the set of edges representing the communication links between vehicles. There is a link $(i, j) \in E$, if and only if vehicles i and j are mutually in the coverage area of each other:

$$\exists\,(i, j) \in E \implies distance(i, j) \leq min(Tr_i, Tr_j) \tag{2}$$

where Tr_i and Tr_j are the transmission ranges of vehicles i and j, respectively.

Then, we have the following basic concepts of graph theory that will be used in our proposed scheme.

- **Node's neighbors:** It is the set of one-hop neighbors of node i, N_i, where

$$N_i = \{j \in V \mid \exists\,(i, j) \in E\} \tag{3}$$

- **Node degree:** It is the cardinality of one-hop neighbors set N_i of node i, where

$$Deg_i = |N_i| \tag{4}$$

- **Multi-hop neighbors of node:** It is the set of all nodes within multi-hops from node i, denoted by MN_i.
- **Multi-hop degree of node:** It is the cardinality of the multi-hop neighbors set of node i, denoted by MD_i, where:

$$MD_i = |MN_i| \tag{5}$$

- **Graph traversal:** Graph traversal means visiting every node (vertex) exactly once in a well-defined order from a given node v ($v \in V$) [26]. According to the order in which the nodes are visited, there are two main algorithms of traversals: Depth-First Search (DFS) and BFS [27]. In the proposed approach, we are interested in the BFS algorithm to perform the clustering process.

  The implementation of a simple BFS algorithm starting from a given source node s is shown in Algorithm 1. The purpose of the implementation is to visit every node exactly once. For this reason, the implementation uses a queue to mark nodes already visited. The algorithm works as follows:

  1. Start by adding the (given) node s to the queue and mark it as visited.
  2. Remove the head of the queue.
  3. Add single-hop neighbors of the removed node, that are not already visited to the queue and mark them as visited.
  4. Keep repeating steps 2 and 3 until the queue becomes empty.

Algorithm 1 BFS algorithm

```
Input: graph G(V, E), start node s
Q{}: BFS queue
Q ← {s}                                   ▷ Initially, Q contains s
Mark s as visited
while ! empty Q do                        ▷ Q is non-empty
    Remove the head u of Q
    foreach neighbor v of u
    if v is unvisited then
        Add v to the back of Q
        Mark v as visited
    else
        ignore v
    end if
    end foreach
end while
```

3.2. *System Description*

3.2.1. *Network architecture*

Our proposed scheme's architecture is illustrated in Figure 2. It is mainly composed of vehicles, OBUs, RSUs-G, TTC, CC and Internet. The definitions of the different components and communication types between them are as follows.

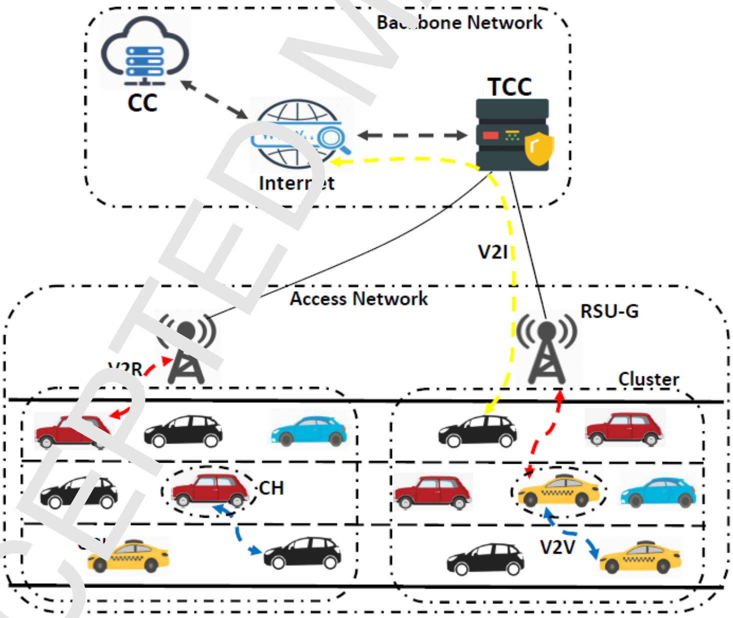


Figure 2: Network architecture for the proposed approach.

1. **Vehicle:** It is the mobile node and the main component for our network architecture. Each vehicle is equipped with a GPS devise.
2. **On-Board Unit (OBU):** It is a terminal equipment mounted on board a vehicle to provide a mutual wireless communication between the vehicle and surrounding vehicles and infrastructures. It uses the Wireless Access in Vehicular Environment (WAVE) standard, which is based on the emerging IEEE 802.11p specification [28].

3. **Road Side Units Gateway (RSUs-G):** These are fixed communication infrastructure units distributed on the roadside. They are controlled and managed by the Transportation Control Center (TCC) through wired communication channels. They use use IEEE 802.11p communication technology for V2I communication. Compared with conventional RSUs, the RSUs-G have an extension in terms of features. First, they provide a registration feature for vehicles to join the network. Second, they contain an integrated DHCP server to ensure automatic IP address configuration for the vehicles. They act as gateways for the vehicles to allow them to access the backbone network and to exploit the services provided by the Internet and Cloud Center (CC). Finally, they are responsible for aggregation, updating and distributing real-time traffic information to the vehicles.
4. **Transportation Control Center (TCC):** It is responsible for network initialization, interconnecting RSUs-G and exchanging data between them. It represents the interface between the Access Network (AN) and the Internet network.
5. **Cloud Center (CC):** It is a virtual server that is based on a cloud computing platform over the Internet. It has features similar to a standard server. CC contains cloud servers to store and share data, resources and applications to serve vehicles on demand to perform the clustering algorithm.
6. **Vehicle-to-Vehicle (V2V) communication:** It is the basic communication type in VANET. It allows the direct wireless transmission of data between vehicles and does not rely on fixed infrastructure. This type of communication is established if and only if the vehicles are mutually in the coverage area of each other. The choice of efficient relay selection process in V2V communication is considered as one of the significant challenges in vehicular network. In this regard, numerous relay selection mechanisms have been proposed in the literature [29, 30]. Consequently, proper selection of relay selection process can provide a high delivery ratio, acceptable overall end-to-end communication delays and efficient bandwidth usage.
7. **Vehicle-to-RSU-G (V2R) communication:** It takes place between vehicles and RSU-G fixed infrastructure through wireless transmission. It is the first step for vehicles to access the Internet. In the proposed approach, when a vehicle wants to send a message to an RSU-G, it first determines whether the RSU-G is within its transmission range. If this is the case, the vehicle sends the message directly to the RSU-G through the wireless communication. Otherwise, it uses a greedy forwarding mechanism and checks whether it has a neighbor vehicle closer to the RSU-G. If it finds one, the vehicle sends the message to this neighbor vehicle so that the latter forwards the message to the RSU-G. Otherwise, the vehicle keeps the message (keeps carrying it) until it meets a neighbor vehicle closer to the RSU-G.
8. **RSU-G-to-Vehicle (R2V) communication:** It takes place between RSU-G and vehicles. When an RSU-G wants to send a message to a vehicle, it first examines whether the vehicle is within its transmission range. If this is the case, the RSU-G sends the message directly to the vehicle. Otherwise, it looks for another destination RSU-G which contains the target vehicle in its coverage area via the backbone network. Then, the RSU-G sends the message to this destination RSU-G so that the latter forwards the message to the target vehicle.
9. **Vehicle-to-Internet (V2I) communication:** It is a virtual communication type that allows the vehicle to access the Internet via RSU-G and TCC.

3.2.2. *Definition and notation*

In this section, definitions and notations used in the proposed clustering approach are introduced.

1. **Multi-hop Clustering Record (MCR):** In our proposed approach, each node has a record called MCR that contains a set of information needed for the clustering process. It is composed of three fields: node identifier (*id*), node mobility rate (MR) and set of single-hop neighbors of this node (SN). Figure 3 shows the structure of MCR with a simple example.

id: 7	MR: 1.51	SN: {4, 9, 11, 18, 21}

Figure 3: MCR structure.

2. **Mobility Rate (MR):** It is a parameter introduced by our approach to be used during the clustering process. It is based on a combination of the mobility metrics described below.

- **Node Connectivity (NC):** It depends on the degree Deg_i of node i, where

$$NC_i = Deg_i \tag{6}$$

- **Average Relative Velocity (ARV):** A lower ARV of the node relative to its neighbors indicates that the node has a more stable state. Let us assume that $P_1(x_1, y_1)$ is the position of node i at time T_1 and $P_2(x_2, y_2)$ is the position of node i at time T_2. Δd_i is the distance traveled by node i over time Δt ($\Delta t = T_2 - T_1$).

$$\Delta d_i = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{7}$$

  Thus, the velocity v_i of node i over time Δt is computed as:

$$v_i = \frac{\Delta d_i}{\Delta t} \tag{8}$$

  Finally, the average relative velocity ARV_i of node i is computed as:

$$ARV_i = \frac{1}{NC_i} \sum_{j=1, j \neq i}^{NC_i} |v_i - v_j| \tag{9}$$

- **Average Distance (AD):** It is the average distance between a node and its neighbors. A node that has a minimum AD is closer to the center of its neighborhood. The AD_i of node i is computed as the cumulative mean square distance to its neighbors divided by its NC_i as follows:

$$AD_i = \frac{1}{NC_i} \sum_{j=1, j \neq i}^{NC_i} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{10}$$

- **Link Stability (LS):** It represents the link stability of the node relative to its neighbors. It depends on the AD variation rate. Let us assume that $AD_i(t1)$ is the average distance of node i at time $t1$ and $AD_i(t2)$ is the average distance of node i at time $t2$. The link stability $LS_i(T)$ of node i over a time $T(T = t2 - t1)$ is calculated as follows:

$$LS_i(T) = |AD_i(t1) - AD_i(t2)| \tag{11}$$

Therefore, the mobility rate MR_i of node i is calculated based on the previous parameter as follows:

$$MR_i = \frac{LS_i(T)}{NC_i} + \sqrt{(\ln(1 - \frac{ARV_i}{v_{max}}))^2} + \frac{AD_i}{maxD_i} \tag{12}$$

where $maxD_i$ is the maximum distance between node i and its neighbors. v_{max} is the maximum velocity allowed on the road.

3. **Notations:** Various notations used in the proposed approach are given in Table 1.
4. **Message types:** Our clustering scheme uses several types of messages. Table 2 describes the different types of messages.
5. **Vehicle States:** In the proposed clustering scheme, vehicles can be in one of the following states: Undefined Node (UN), Master Cluster Head (MCH), Slave Cluster Head (SCH) and Cluster Member (CM). Statuses are defined as follows:

Table 1: Notations used in this study.

Symbols	Description
$\mathtt{id}_i$	Identity of vehicle i
$\mathtt{RSU\text{-}G\_id}_i$	Identity of RSU-G i
$\mathtt{Tr}_i$	Transmission range of vehicle i
$\mathtt{P}_i$	Position of vehicle i
$\mathtt{Ed}_{(i,j)}$	Euclidean distance between vehicles i and j
$\mathtt{Deg}_i$	Degree of node i
v_i	Velocity of vehicle i
$\mathtt{C}_i$	Cluster i
$\mathtt{MCH}_i$	Master Cluster Head of cluster i
$\mathtt{SCH}_i$	Slave Cluster Head of cluster i
$\mathtt{CM\_list}_i$	Member list of cluster i

Table 2: Message types in this study.

Message	Source	Destination	Description
HELLO	RSU-G	Vehicles	Notify vehicles
REGISTER	Vehicle	RSU-G	Vehicle registration
BEACON	Vehicle	Neighbors	Exchange information
SHARE	Vehicle	RSU-G	Share the MCR
ANNOUNCE	MCH	RSU-G	Announce new MCH
REPLY	Vehicle	MCH	Confirm membership
NOMINATION	MCH	Vehicle	SCH nomination

- **UN:** Initial state of a vehicle, it does not belong to any cluster.
- **MCH:** Vehicle that has the task of coordination among cluster members.
- **SCH:** The vehicle that will replace the MCH, in case it becomes unavailable or leaves the cluster.
- **CM:** A vehicle in a cluster but it is not an MCH or an SCH.

4. Proposed Approach

In this section, we introduce a new Multi-hop Clustering Approach over Vehicle-to-Internet communication called MCA-V2I for improving VANETs performance. The main idea of this work is to execute a clustering algorithm using Internet access. MCA-V2I is based on the reasonable assumption that a vehicle can connect to the Internet via a special infrastructure called a Road Side Unit Gateway (RSU-G) to obtain and share the necessary information about its multi-hop neighbors to perform the clustering process. This latter is performed using a BFS algorithm for traversing a graph and based on a Mobility Rate (MR), which is calculated using mobility metrics such as node connectivity, average relative velocity, average distance and link stability. In MCA-V2I, a vehicle with low MR is suitable to be elected as Master CH (MCH). The MCA-V2I scheme also strengthens clusters' stability through the election of a Slave Cluster Head (SCH). The MCA-V2I approach is composed of six phases: registration, neighborhood discovery, MCH selection, announcement, affiliation and maintenance. The rest of this section describes these phases in detail.

4.1. Registration

Initially, when a vehicle enters the road and decides to join the network, its OBU system is turned on. On the other hand, each RSU-G is required to broadcast a HELLO message which includes its location and identity information to the vehicles. When a vehicle comes into the coverage area of an RSU-G and receives the broadcast message, it sends a REGISTER request to register with the backbone network (Internet) and the RSU-G. When an RSU-G receives the REGISTER request, it forwards the registration request to the TCC to confirm the registration of this vehicle and provide it an IP address by sending a CONFIRM message. When a vehicle receives the confirmation, it changes its state to UN and starts the clustering algorithm. Figure 4 summarizes the steps of the registration phase in a sequence diagram format.

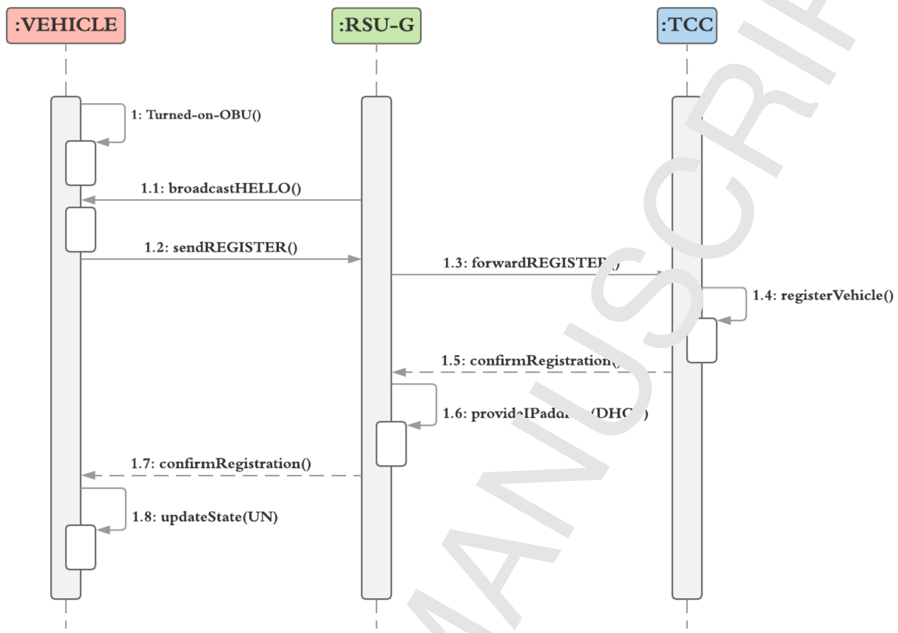


Figure 4: Sequence diagram of the registration phase.

4.2. *Neighborhood Discovery*

To announce its existence, each vehicle broadcasts a periodic BEACON message to its single-hop neighbors, including its MAC address (*id*), its velocity (calculated based on equations 7 and 8), its transmission range and its position (two-dimensional coordinates). After receiving the BEACON message from all its single-hop neighbors, each vehicle calculates the following parameters: Node Connectivity (NC), Average Relative Velocity (ARV), Average Distance (AD) and Link Stability (LS). The values of these parameters are used to compute its Mobility Rate (MR). Then, each vehicle sends a SHARE message containing its MCR to the RSU-G to share its MCR in the backbone network (CC) with all vehicles in the network. Figure 5 shows the steps of the neighborhood discovery phase in a sequence diagram format. The neighborhood discovery process including the MCR construction is described in Algorithm 2.

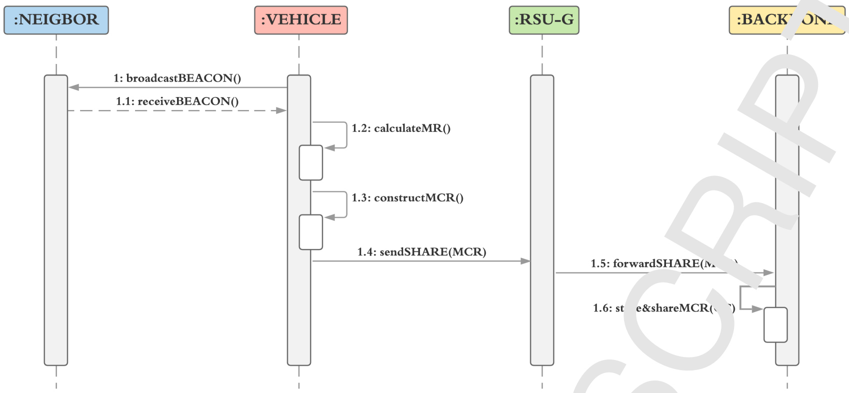


Figure 5: Sequence diagram of the neighborhood discovery phase.

Algorithm 2 Neighborhood_discovery(i)

Struct multiHopRecord
{
id : identifier
MR : Mobility Rate
SN{} : Single-hop Neighbors set
}
MCR_i: multiHopRecord
N_i{}: Neighbors set
Broadcast BEACON(i, v_i, Tr_i, P_i) message
Receive BEACON(id, v, Tr, P) messages from neighbors
foreach received BEACON(j) message
if distance(i,j) < min(Tr_i, Tr_j) **then**
    $N_i \leftarrow N_i \cup j$
end if
end foreach
$Deg_i \leftarrow |N_i|$
Calculate MR_i based on equations 6 to 12
MCR_i[id] $\leftarrow i$
MCR_i[MR] $\leftarrow MR_i$
MCR_i[SN] $\leftarrow N_i$
Send SHARE(MCR) to RSU-G

4.3. Master CH Election

To elect the MCH, each vehicle tries to establish a connection to the Internet via an RSU-G, to traverse its multi-hop neighbors using the BFS algorithm based on its MCR and the MCRs (of other vehicles) shared in the backbone network. During the traversal, each vehicle saves all visited vehicles (Multi-hop neighbors (MN)) and compares its MR with their MRs. If its MR has the lowest value, the vehicle must update its state to MCH and add all the vehicles crossed before in its CM *List*. Otherwise, the vehicle elects the vehicle that has the lowest MR value as its new MCH and updates its variable myMCH (the variable that indicates the *id* of the MCH). Then, it moves to the affiliation phase. If there are two or more vehicles that have the lowest MR, the vehicle that has the lowest *id* will be elected as MCH. The MCH election process using BFS traversal is described in Algorithm 3.

Figure 6 illustrates a simple example of the MCH election phase using the BFS algorithm with source vehicle 5 colored in red and its multi-hop neighbors colored in black. Table 3 presents the different parameters of the vehicles.

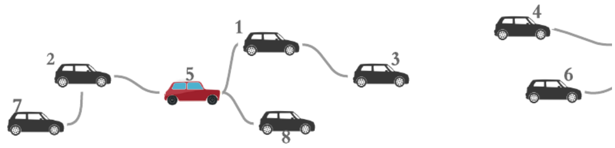
First, the queue (Q) contains the source vehicle {5}. Then, the algorithm removes the head of Q (5) and adds its neighbors {1,2,8} one by one to the back of Q. For each added node, the algorithm marks it as visited (colored in red) and checks if this node has an MR less than the MR of the source node. This process repeats iteratively until all the multi-hop neighbors are visited. At the end of this example, the source vehicle 5 has the lowest MR compared with its multi-hop neighbors. Consequently, vehicle 5 becomes the new MCH and all its multi-hop neighbors become CMs. The state of this cluster becomes as follows: Cluster {MCH: 5; CMs: 1,2,8,3,7}.

Algorithm 3 MCH_election(i)

```
Input: MCR_i
Q{}: BFS queue
Q ← {i}                                              ▷ Initially, Q contains i
MN_i{}: Multi-hop Neighbors set
minMR: minimum MR
id_minMR: id of the node that has minMR
minMR ← MCR_i[MR]
id_minMR ← i
while ! empty Q do                                   ▷ Q is non-empty
    Remove the head j of Q
    foreach node k in MCR_j[SN]
    if k is unvisited then
        Add k to the back of Q
        MN_i ← MN_i ∪ k
        if minMR > MCR_k[MR] then
            minMR ← MCR_k[MR]
            id_minMR ← k
        end if
        Mark k as visited
    else
        ignore k
    end if
    end foreach
end while
if id_minMR = i then
    state_i ← MCH                                    ▷ Update state to MCH
    CM_list_i ← MN_i
else
    myMCH ← id_minMR                                 ▷ Update its MCH
end if
```

Table 3: Vehicles' parameters.

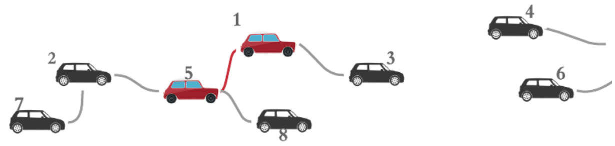
MCR[id]	MCR[MR]	MCR[SN]
5	1.46	{1,2,8}
1	1.69	{5,3}
2	1.74	{5,7}
8	1.93	{5}
3	1.81	{1}
7	2.07	{2}



(a) Initial network.

Queue (Q)	minMR	id_minMR
{5}	1.46	5

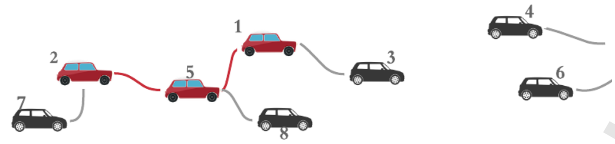
(b) Initial values.



(c) First iteration.

Queue (Q)	minMR	id_minMR
{1}	1.46	5

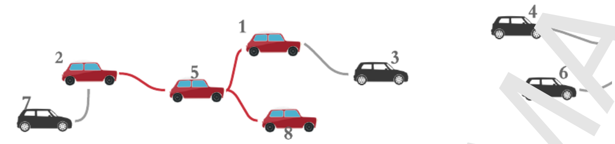
(d) Corresponding values.



(e) Second iteration.

Queue (Q)	minMR	id_minMR
{1,2}	1.46	5

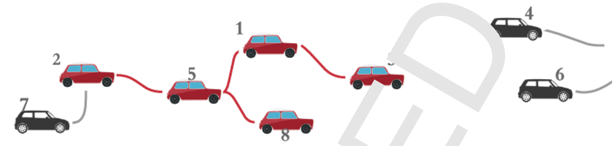
(f) Corresponding values.



(g) Third iteration.

Queue (Q)	minMR	id_minMR
{1,2,8}	1.46	5

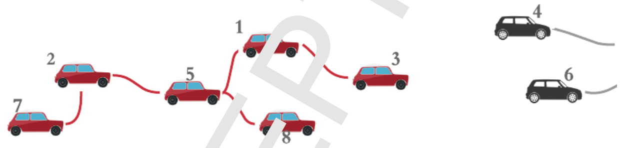
(h) Corresponding values.



(i) Fourth iteration.

Queue (Q)	minMR	id_minMR
{2,8,3}	1.46	5

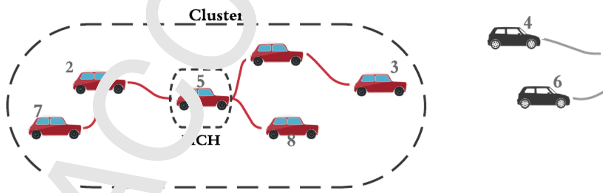
(j) Corresponding values.



(k) Final iteration.

Queue (Q)	minMR	id_minMR
{7}	1.46	5

(l) Corresponding values.



(m) Final cluster state.

Queue (Q)	minMR	id_minMR
{}	1.46	5

(n) Final corresponding values.

Figure 6: Example showing MCH election phase using the BFS algorithm.

4.4. *Announcement*

Each vehicle, having determined itself as the new MCH, must announce its election. For this reason, each MCH must try to establish a connection to the Internet and send an ANNOUNCE message to the RSU-G including its *id*, its CM_list and its cluster *id* to share its cluster state in the backbone network (CC).

4.5. *Affiliation*

Each ordinary vehicle (not MCH) accesses the backbone network via the RSU-G, to find its affiliation and the cluster to which it belongs. When an ordinary vehicle finds the cluster to which it belongs, it compares the MCH *id* of this cluster with its myMCH variable. If they are the same, the vehicle sends a REPLY packet to this MCH, updates its state to CM and its cluster *id*. Otherwise, the vehicle ignores this event and moves to the maintenance phase to join the appropriate cluster. On the other hand, each MCH, after receiving all the REPLY packets, updates its CM_list. At the end, each MCH must select a vehicle with the lowest MR value among the cluster members (except itself) as Slave CH (SCH). Then, the MCH sends a NOMINATION message to the designated vehicle. The vehicle that receives the NOMINATION message updates its state to SCH. Figure 7 illustrates the steps of the MCH election, announcement and affiliation phases in a sequence diagram format.

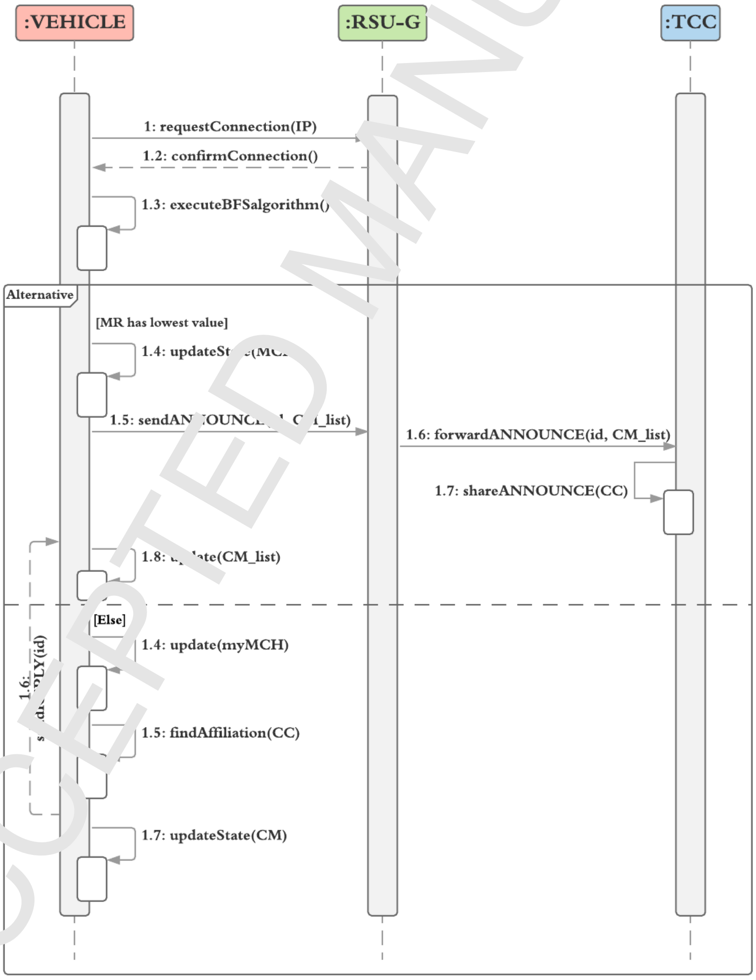


Figure 7: Sequence diagram of MCH election, announcement and affiliation phases.

4.6. Maintenance

The aim of this phase is to maintain the cluster structure and stability as long as possible. Because of the high mobility of vehicles, the cluster structure and network topology change frequently. For this reason, several events are triggered at the cluster level. The different events with their maintenance are described as follows.

4.6.1. MCH leaving discovery

In each cluster, the SCH vehicle periodically monitors the state of the MCH vehicle using a private communication link. If an SCH does not receive a periodic message from its MCH over a time period T, it means that the MCH has left the cluster. The SCH must replace the MCH immediately and takes over as the new MCH of cluster. Therefore, it must change its state to MCH. Then, it elects a new SCH among the cluster's members based on their MRs. Furthermore, it broadcasts an update message to its CMs to inform them to update their MCH (myMCH variable). Finally, the new MCH must inform the CM that it has been elected as the new SCH to change its state to SCH. The old MCH must change its state to UN and join another cluster.

4.6.2. Clusters merging

The proposed approach can react with clusters overlapping. However, when two neighbor clusters have a big overlapping rate over a period Tm (Time merging), a cluster merging process is invoked. Typically, the merging procedure results in two MCHs at the same time for the final cluster obtained. Therefore, only one MCH is selected to manage all of the CMs of the merged clusters. Thus, the MCH that has the largest number of cluster members (cardinality of the CM_list) is elected as the new MCH for the cluster obtained and its SCH becomes also the SCH for the cluster obtained. The other MCH and SCH must change their state to CM.

4.6.3. Leave a cluster

Each MCH monitors its CMs through the exchange of periodic messages to keep track of members in the cluster. When a member moves out of the cluster range over a time period T, the MCH detects this event and immediately removes this node from its members' list (CM_list). Then, the MCH sends a message to its SCH indicating this change to perform the necessary updates. On the other hand, if CM does not receive the periodic message from its MCH over a time period T, it must change its state to UN and join another cluster.

4.6.4. Join a cluster

When a UN vehicle approaches toward a cluster (comes inside its communication range), it sends a join request including its position and velocity to the nearest CM of the cluster. The CM forwards this join request to its MCH, which calculates its relative velocity with this UN vehicle. If this relative velocity is less than or equal to the average relative velocity of the cluster, the MCH adds this UN vehicle to its CM_list and sends a reply to this UN to confirm its cluster membership. Consequently, this UN changes its state to CM and joins the cluster. Furthermore, the MCH must send an update message to its SCH indicating this change.

4.7. Theoretical Analysis

In this section, we discuss the rational and performance of the proposed clustering approach.

4.7.1. MCH selection algorithm complexity

Based on Algorithm 3, we assume that every vehicle and its multi-hop neighbors are modeled by an undirected graph $G(V, E)$, where V is the set of vertices, representing the vehicles and E is the set of edges representing the set of communication links between vehicles. Assume n ($n = |V|$) is the number of vehicles and m ($m = |E|$)is the number of communication links between them. According to Algorithm 3, for a given vehicle i to browse its multi-hop neighbors (MN_i), it must execute a BFS algorithm. Each vehicle visited by i is inserted into the queue and marked as visited. Because the insertion to the queue is done in $O(1)$, the time complexity in the worst case to traverse all the multi-hop neighbors is $O(n)$. Moreover, the edges between the traversed vehicles are visited at most m times. Therefore, the complexity of Algorithm 3 is $O(n + m)$.

4.7.2. Message overhead analysis

The message overhead counts all the control messages received by each vehicle in the network during the clustering process. To simplify the analysis, the following definitions are used.

- ***N:*** The number of vehicles in the network.
- ***R:*** The number of RSUs-G installed on the roadside (see equation 1).
- ***h_i:*** The number of vehicles which have received the HELLO message broadcasted by the RSU-G i.
- ***b:*** The number of the BEACON messages broadcasted by a vehicle. $b = \Theta(1)$ because b is proportional to node velocity v and inversely proportional to the transmission range Tr, and both v and Tr are less than or equal to some constants [31].
- ***c:*** The number of the elected MCHs.
- ***r_i:*** The number of REPLY messages received by an MCH i.
- Φ_{REG}**:** The overhead of the registration phase.
- Φ_{NEIGH}**:** The overhead of the neighborhood discovery phase.
- Φ_{ANN}**:** The overhead of the announcement phase.
- Φ_{AFF}**:** The overhead of the affiliation phase.
- Φ_{TOTAL}**:** The total overhead.

During the registration phase, each RSU-G broadcasts a HELLO message to invite the vehicles to join the network. Then, each vehicle sends a REGISTER request to the appropriate RSU-G. Thus, the registration phase message overhead Φ_{REG} may be expressed as follows:

$$\Phi_{REG} = \Theta(N) + \Theta(\sum_{i=1}^{R} h_i) \tag{13a}$$

Knowing that $(\sum_{i=1}^{R} h_i) \leq N$, so:

$$\Phi_{REG} = \Theta(N) \tag{13b}$$

During the neighborhood discovery phase and to announce its existence, each vehicle sends a BEACON message to its single-hop neighbors. Then, each vehicle sends a SHARE message (to share its MCR) to the appropriate RSU-G. Therefore, the neighborhood discovery phase message overhead Φ_{NEIGH} can be expressed as follows:

$$\Phi_{NEIGH} = \Theta(b.N) + \Theta(N) \tag{14a}$$

$$\Phi_{NEIGH} = \Theta(\Theta(1).N) + \Theta(N) \tag{14b}$$

$$\Phi_{NEIGH} = \Theta(N) \tag{14c}$$

During the announcement phase, each elected MCH must send an ANNOUNCE message to the RSU-G. Thus, the announcement phase message overhead Φ_{ANN} may be expressed as follows:

$$\Phi_{ANN} = \Theta(c) \tag{15}$$

During the affiliation phase, every MCH node receives a number of REPLY messages from its multi-hop neighbors. Then, each MCH sends a NOMINATION message to the member elected as SCH. Therefore, the affiliation phase message overhead Φ_{AFF} can be expressed as follows:

$$\Phi_{AFF} = \Theta(\sum_{i=1}^{c} r_i) + \Theta(c) \tag{16a}$$

Knowing that $(\sum_{i=1}^{c} r_i) \leq N$ and $c \leq N$, so:

$$\Phi_{AFF} = \Theta(N) \tag{16b}$$

Finally, the total message overhead Φ_{Total} is as follows:

$$\Phi_{TOTAL} = \Phi_{REG} + \Phi_{NEIGH} + \Phi_{ANN} + \Phi_{AFF} \tag{17a}$$

$$\Phi_{TOTAL} = \Theta(3N) + \Theta(c) \tag{17b}$$

Knowing that $c \leq N$, so:

$$\Phi_{TOTAL} = \Theta(N) \tag{17c}$$

4.7.3. Clustering properties

To meet the requirements imposed by the VANET characteristics and to demonstrate the effectiveness of the proposed approach, the following clustering properties must be verified.

Definition 1. *Safety property: Each cluster has one and only one MCH, and each ordinary vehicle can belong to only one cluster.*

The safety property ensures that every cluster has a unique MCH. It also ensures that each ordinary vehicle belongs to only one cluster at a time. A safety property asserts that nothing bad happens during the clustering algorithm.

Lemma 1. *The safety property is satisfied.*

Proof 1. *According to Algorithm 3, vehicle i is an MCH if it satisfies the following conditions:*
Condition 1: *It has the lowest Mobility Rate (MR) compared with its multi-hop neighbors.*
Condition 2: *It has the lowest id, if two or more nodes have equal MR (the smallest one):*

$$MR_i = MR_j = .. = MR_k \implies id_i = min(id_i, id_j, .., id_k) \tag{18}$$

This implies that each cluster has a single MCH. On the other hand, each ordinary vehicle (not MCH) elects the node that has the lowest MR value among its multi-hop neighbors as its MCH (myMCH). Then, it must send a REPLY message to the appropriate MCH to confirm its membership. So, each node can belong to only one cluster. As a result, the safety property is verified.

Definition 2. *Liveness property: Cluster formation phase terminates and each vehicle is either a UN, MCH, CM or an SCH at a given time.*

The liveness property ensures that the clustering algorithm progresses normally and ends after a finite time and each vehicle is in a stable state at a given time. Typically, a liveness property asserts that something good eventually happens.

Lemma 2. *The liveness property is verified.*

Proof 2. *First, because every vehicle can determine its cluster according to Lemma 1, the cluster formation phase will terminate. Second, based on the transition state (see Figure 8), each transition from one state to another is due to an event. The possible transitions are described in Table 4.*

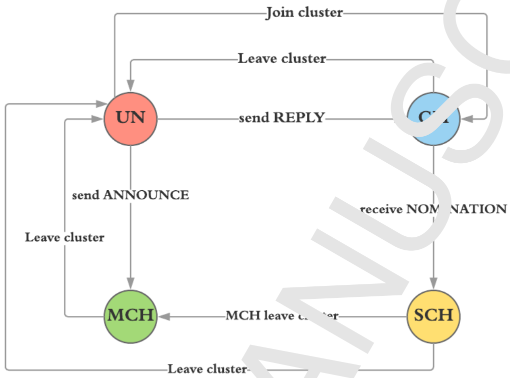


Figure 8: Vehicles state transition.

Table 4: Transitions and their corresponding events.

Transition	Event	Phase
`UN to CM`	UN sends REPLY message to MCH	Cluster formation
`UN to CM`	UN joins a new cluster	Maintenance
`UN to MCH`	UN sends ANNOUNCE message to RSU-G	Cluster formation
`CM to SCH`	CM receives NOMINATION message from MCH	Cluster formation
`SCH to MCH`	MCH leaves the cluster	Maintenance
`SCH to UN`	SCH leaves the cluster	Maintenance
`CM to UN`	CM leaves the cluster	Maintenance
`MCH to UN`	MCH leaves the cluster	Maintenance

5. Performance Evaluation

In this section, we study the performances of the proposed MCA-V2I approach using the network simulator NS-2 [32] and VanetMobiSim [33] integrated environment. The simulation is performed on a machine with Intel *i*5 (4th generation) processor and 8 GB of RAM. Mobility is simulated on a one-directional highway of 6 km length with three lanes. There are 2 RSUs-G installed on the roadside. Physical and MAC layers are configured according to the 802.11p standard. The speed of vehicles varies uniformly between 10 m/s and 35 m/s (≃ 40 km/h – 125 km/h). Moreover, the transmission range of vehicles is varied from 100 m to 300 m. The simulation period in this work is 360 s. The vehicles were assigned to random positions and they move according to the mobility model, named the Intelligent Driver Model including Lane Change (IDM-LC) [34, 35], which is integrated into VanetMobiSim. The propagation model used is Two-ray Ground. The different simulation parameters are listed in Table 5.

Table 5: Simulation parameters.

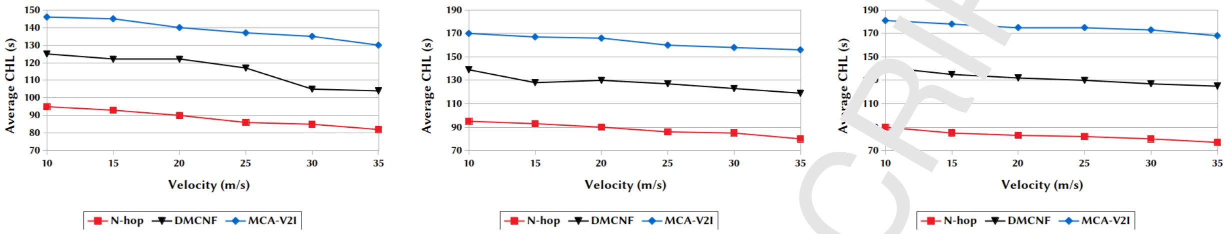
Parameter	Value
`Simulation time`	360 s
`Simulation area`	6000 m × 50 m
`Transmission range`	100 – 300 m
`Number of RSU-G`	2
`Number of vehicles`	60 – 180
`Propagation model`	Two-ray Ground
`Mobility model`	IDM-LC
`MAC/PHY protocol`	802.11p
`Velocity of vehicles`	10 – 35 m/s
`Maximum allowed velocity` (v_{max})	40 m/s

We compare the results of our proposed approach MCA-V2I to two well-known protocols for VANET belonging to the same family of multi-hop clustering, named N-hop [19] and DMCNF [20]. The comparison is based on the following metrics:

- **Cluster Head Lifetime (CHL):** The interval of time from when a vehicle changes its state to CH until this vehicle leaves this state and changes to another state (e.g., UN). The average CHL is calculated by dividing the total CHL by the total number of state changes from CH to another state. A longer CHL leads to more reliable communication with minimized overhead.
- **Cluster Member Lifetime (CML):** The interval of time from when a vehicle changes its state to CM (join a cluster) to when this vehicle changes from this state to another state. The average CML is computed by dividing the total CML by the total number of state changes from CM to another state. A longer CML can show the stability of the constructed clusters and the effectiveness of the maintenance techniques used.
- **Cluster Head Change Number (CHCN):** The number of state changes from CH to another state (e.g., UN). Low CHCN can demonstrate the cluster's stability.
- **Cluster Number (CN):** The number of clusters formed during the simulation period. Fewer clusters can indicate the efficiency of the clustering algorithm.
- **Clustering Overhead (CO):** The total number of control messages received by each vehicle in the network during the phase of cluster's formation.
- **Message Delivery Latency (MDL):** Refers to the average delay or time taken for a message to be transmitted from a source to a destination.
- **Message Delivery Ratio (MDR):** The average number of messages that have been successfully received by the destination divided by the average number of messages sent by the source.

5.1. *Cluster Head Lifetime (CHL)*

Figure 9 shows the average CHL of the proposed MCA-V2I approach versus DMCNF and N-hop protocols under different transmission ranges. According to Figure 9, we observe that when a vehicle's velocity increases, the average CHL of MCA-V2I, DMCNF and N-hop decreases relatively. This is because the network topology becomes very dynamic due to the high mobility of vehicles, which makes it difficult for the cluster's heads to maintain stable connections with their CMs. On the other hand, when the transmission range increases, the average CHL also increases. This can be justified by the fact that in a wide range of transmission, the coverage area of the cluster increases and that the CH can find at least one CM to serve it, so that a vehicle continues to reside in the state CH for a longer period of time. In both DMCNF and N-hop, the vehicles that have the smaller average relative velocity with their single-hop neighbors are suitable to be elected as CH. Consequently, this metric alone may lead both protocol DMCNF and N-hop to elect CHs which have very low connectivity with their CMs. However, in MCA-V2I, the election of MCHs is performed using mobility rate, which combines more than one metric, such as node connectivity, average relative velocity, average distance and link stability with their single-hop neighbors, in which the vehicles that have the lowest MR are elected as MCH. Thus, as shown in Figure 9, MCA-V2I outperforms both DMCNF and N-hop in term of CHL.

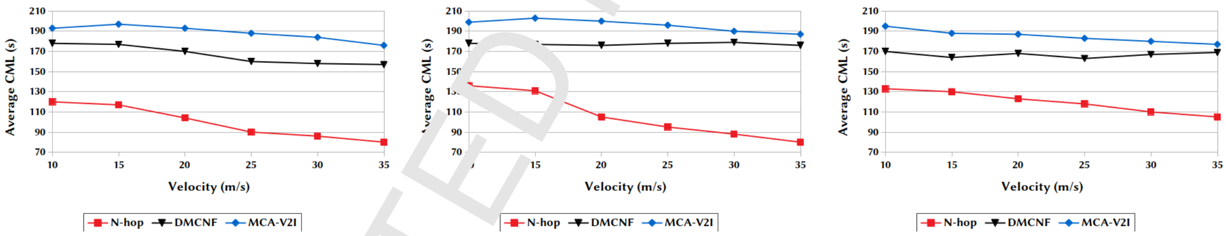


(a) (b) (c)

Figure 9: Cluster Head Lifetime (CHL) under different transmission ranges. (a) 100 m. (b) 200 m. (c) 300 m.

5.2. *Cluster Member Lifetime (CML)*

Figure 10 shows the average CML of MCA-V2I versus DMCNF and N-hop scheme under different transmission ranges. As shown in Figure 10, the vehicle velocity moderately affects the CML for MCA-V2I compared with DMCNF and N-hop, owing to the effective clustering algorithm used. This latter allows the CMs to maintain stable connections with their MCHs. Furthermore, the election of SCHs in addition to MCHs makes it possible to increase the cluster's stability and avoid the reclustering. On the other hand, when the transmission range increases, the average CML also increases. This can be justified by the fact that in a wide range of transmission, the coverage area of the cluster increases, which gives the CMs a large area of movement without the loss of communication links with their MCHs. Thus, the MCA-V2I scheme outperforms both N-hop and DMCNF in terms of CML.



(a) (b) (c)

Figure 10: Cluster Member Lifetime (CML) under different transmission ranges. (a) 100 m. (b) 200 m. (c) 300 m.

5.3. *Cluster Head Change Number (CHCN)*

Figure 11 shows the average CHCN of MCA-V2I versus N-hop and DMCNF approaches under different transmission ranges. Figure 11 demonstrates that the average CHCN when using N-hop and DMCNF is higher than when MCA-V2I is used. The reason for this improvement is the effective initial MCHs selection using mobility metrics and Internet access, which allows the MCHs to keep stable connections with their CMs as long as possible.

5.4. *Cluster Number (CN)*

Figure 12 illustrates the average number of clusters of the MCA-V2I scheme versus N-hop and DMCNF schemes under different transmission ranges. According to Figure 12, the proposed approach has fewer clusters compared with both N-hop and DMCNF due to the effective multi-hop clustering process that is based on combined mobility metrics and the BFS algorithm. On the other hand, when the transmission range increases, the average CN decreases. This can be justified by the fact that in a wide range of transmission, the coverage area of the cluster increases, which gives the MCHs the ability to handle more vehicles.

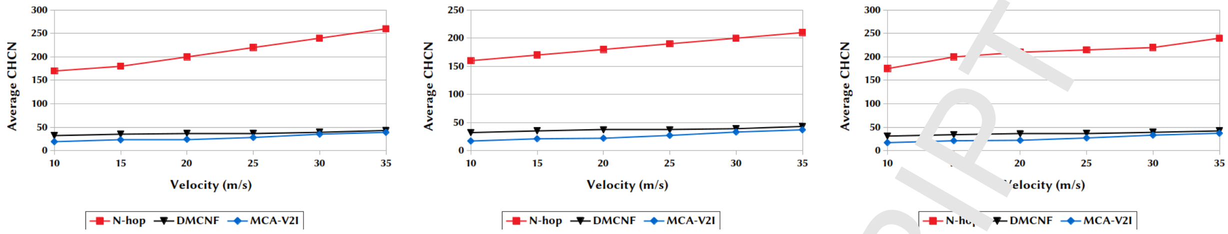


Figure 11: CH Change Number (CHCN) under different transmission ranges. (a) 100 m. (b) 200 m. (c) 300 m.

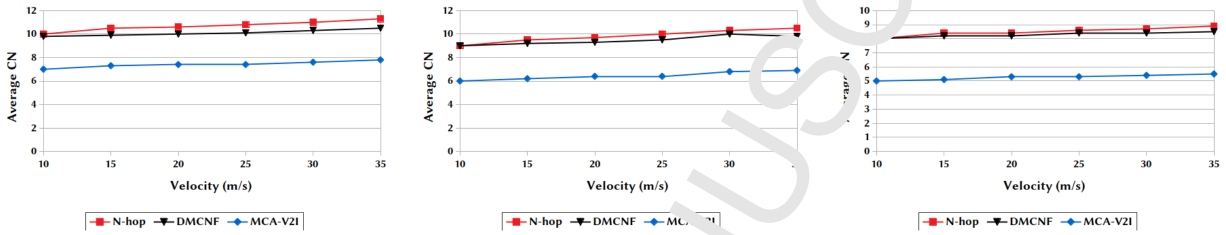


Figure 12: Cluster Number (CN) under different transmission ranges. (a) 100 m. (b) 200 m. (c) 300 m.

5.5. *Clustering Overhead (CO)*

Figure 13 depicts the average clustering overhead of MCA-V2I, N-hop and DMCNF for different velocity values. MCA-V2I significantly decreases the number of overhead messages compared with N-hop and DMCNF. In MCA-V2I, every vehicle can access the Internet and exploit the shared MCRs to perform the clustering process. This results in a significant reduction in the number of control overhead messages. On the other hand, each vehicle in N-hop and DMCNF exchanges a control message with all its single-hop neighbors to calculate the relative mobility between them, to elect the CHs. This leads to an increase in the number of control overhead messages in both N-hop and DMCNF.

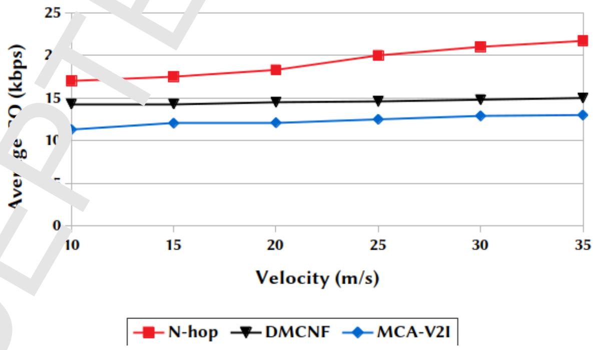


Figure 13: Clustering Overhead (CO).

5.6. *Message Delivery Latency (MDL)*

Figure 5.6 illustrates the message delivery latency (in ms) of MCA-V2I, N-hop and DMCNF as a function of the number of simulated vehicles. The message delivery latency inversely proportional to the number of vehicles. High density of the vehicles improves the connectivity of the networks and therefore there are more chances to deliver the message with the shorter expected delivery delay to the destination. Compared with DMCNF and N-hop, our proposed MCA-V2I scheme exhibits the lowest message delivery latency for all numbers of simulated vehicles.

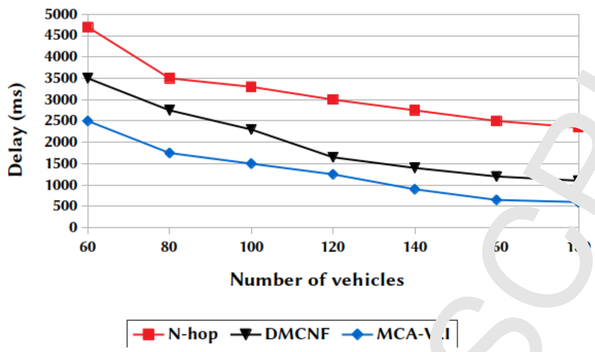


Figure 14: Message Delivery Latency (MDL)

5.7. Message Delivery Ratio (MDR)

Figure 14 illustrates the message delivery ratio of MCA-V2I, N-hop and DMCNF as a function of the number of simulated vehicles. The message delivery ratio increases quickly with the increase in the number of vehicles. This is because the growth of the density of vehicles improves the connectivity of the network and therefore more chances to deliver the message successfully. Compared with DMCNF and N-hop, our proposed MCA-V2I scheme exhibits the highest message delivery ratio for all numbers of simulated vehicles.

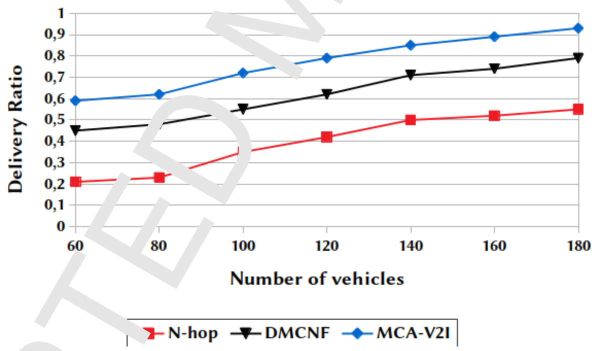


Figure 15: Message Delivery Ratio (MDR).

6. Conclusion

In this paper, we propose a new Multi-hop Clustering Approach over Vehicle-to-Internet communication called MCA-V2I for improving VANETs' performances. MCA-V2I allows vehicles to connect to the Internet via a special infrastructure called a Road Side Unit Gateway (RSU-G) so that each vehicle can obtain and share the necessary information about its Multi-hop neighbors to perform the clustering process. This latter is performed using a BFS algorithm for traversing the graph and based on a Mobility Rate (MR), which is calculated according to mobility metrics. The MCA-V2I approach strengthens the cluster's stability through the election of a Slave Cluster Head (SCH) in addition to the Master Cluster Head (MCH). Our simulation uses network simulation NS-2 and the VanetMobiSim integrated environment. The simulations' results show that the proposed scheme MCA-V2I outperforms N-hop and DMCNF schemes in terms of CH lifetime, CM lifetime, CH change number, number of clusters, clustering overhead, message delivery latency and message delivery ratio.

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- A new multi-hop clustering model is proposed. Compared with one-hop clustering schemes, this model is designed to extend the coverage area of clusters, reduce the number of clusters, optimize the control overhead and improve cluster stability.
- A Mobility Rate is introduced for the clustering algorithm. This parameter is calculated based on mobility metrics to satisfy the requirements of the new features of VANET, and to consider its mobility characteristics.
- MCA-V2I provides Internet access to vehicles to obtain and share the necessary information to perform the clustering algorithm. This benefit significantly reduces the rate of control messages used in traditional clustering algorithms. Therefore, MCA-V2I can significantly improve the network overhead.
- MCA-V2I strengthens clusters' stability through the election of an Slave CH in addition to the Master CH.