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Clustering in Vehicular Networks

Seminararbeit im Fach Informatik

2. Februar 2018

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Seminararbeit im Fach Informatik

vorgelegt von

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geb. am 10. November 1989
in Danapur, India

angefertigt in der Fachgruppe

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(Gaurav Kumar Singh)
Paderborn, 2. Februar 2018

Abstract

This thesis captures an overview of ideas, techniques, results and future possibilities of clustering in vehicular networks. Clustering is a technique to group nodes based on a selected criterion which defines certain level of similarities among the nodes. Grouping the nodes together in such a way helps to define or design a set of functionalities applicable only to the group and can be applied to the smaller sub-set. In a Vehicular Ad Hoc Network (VANET) environment, clustering presents possibilities to group vehicles based on a parameter of interest and help to reduce the network traffic, achieve better network throughput and effective information dissemination.

In this thesis, I try to present some of the parameter and methodologies used for clustering in VANETs along with some evaluation criterion. First chapter presents the motivation behind the clustering and outlines the basic set of problems which is presented by vehicular networks which the researches are trying to address. The second chapter describes the methodologies grouping them based on the main parameters used for clustering. The third chapter introduces the evaluation techniques along with some important metrics used to compare the effectiveness of the algorithms and analysis of results. Finally, the thesis captures some ideas which will give an overview of the future research work on this topic.

Contents

Chapter 1

Introduction

Along with the advancement in wireless networking in the past two decades, there has been a lot of research targeted towards developing techniques to minimize the network overhead and achieve effectiveness within the system. A special class of wireless network was developed called Wireless Ad Hoc Network (WANET), which allowed nodes to communicate with each other without the need of special infrastructure such as bridges and routers. WANET led to use of wireless communication for special applications with needs of distributed control. Shortly, use of Mobile Ad Hoc Network (MANET) increased which allowed continuous movement of the nodes. This was followed by use of wireless networking among vehicles to create Vehicular Ad Hoc Network (VANET) which allows communication of various parameters among vehicles focused towards applications for safety and cooperative driving. The use of wireless networks in various domains has led to a lot of research focused towards improvements and optimization which are often valid for all domains.

Clustering in wireless networks involves grouping nodes together which are geographically close to each other based on a certain set of parameters. Parameter selection for clustering depends mostly on the type of application which would use the clustered network. In VANETs, clustering of vehicles into groups provides a basis for limiting the networking overhead and interference by efficiently defining the target nodes for communication and designing filters to limit the traffic. Due to the possibility of selecting huge range of parameters, numerous solutions have been proposed which target various scenarios in the VANETs. Vodopivec, Bešter, and Kos [1] and Bali, Kumar, and Rodrigues [2] presents a detailed overview of research work in this field in past years. In the following sections we would look at some of the important terminologies to create a general overview of clustering in VANET and help us discuss and understand the methodologies better.

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1.1   Terminologies

In this section, we look at some of the common terminologies used widely across the methodologies for clustering in VANETs.

- **Cluster Member (CM):** All the nodes which become part of the cluster and participate in the communication within the cluster.

- **Cluster Head (CH):** Each cluster is supposed to elect one of the CM to act as the CH based on some rules. It is possible for any CM to be elected as the CH but some of the algorithms may apply specific requirements for a CM to be elected to ensure stability of the cluster. The responsibilities of a CH may vary but in general, it is responsible for the maintenance of the cluster (addition and removal of nodes) and communication with the external nodes (other CHs and Road Side Unit (RSU)s).

- `HELLO` **Message:** Also referred as `DISCOVER`, is the first message sent by a vehicle to identify the presence of existing cluster. This is mostly a broadcast frame.

- `INVITE` **Message:** This is transmitted by a CH or a CM in respond to a received `HELLO` message if the requesting vehicle is found fit to join the cluster.

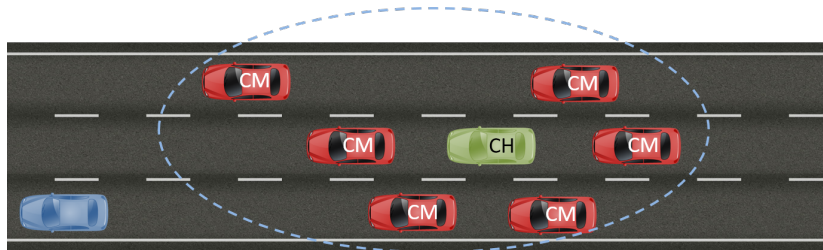Figure 1.1 shows a typical cluster organization with one CH and multiple CMs.

Figure 1.1 – Typical VANET cluster

Chapter 2

Clustering methodologies

To achieve a robust and effective communication in the high mobility environment, VANET applications use various parameters to cluster the nodes into meaningful sub-groups based on the application requirement. This leads to a wide range of clustering methodologies which define applications specific algorithms useful for respective application or a generic algorithm with possibility to handle different requirements. In this chapter, we discuss some of the common parameters used individually or in combination with each other to define thresholds for vehicles to join cluster and cluster head selection along with some methodologies which uses them for clustering.

2.1 Clustering Parameters

Parameters play an important role to build stable cluster effectively which can be used to perform the application specific communication with minimal overhead. Some of the common parameters which are used by the algorithms to form basis for threshold calculation are summarized in Table 2.1.

Parameter	Description
Vehicular mobility	This is the most common parameter used in the algorithms. Mobility of the vehicles are measured in terms of relative velocity and average velocity over time of the vehicle

| Parameter	Description
Direction of the travel	In many cases, information to be shared between vehicles only has relevance if the vehicles share the same path and direction. This knowledge can be used by the algorithms for forming trajectory tables or assigning Road IDs to compare directions and route
Destination	Used by applications which give importance to route taken by the vehicles to provide longer stable cluster
Density	Mostly used to differentiate sparse and dense networks and define different communication model to ensure reliable communication in both scenarios
Unique ID	Simplest clustering parameter, commonly used to identify and cluster vehicles requiring multi-hop reliable communication
Location	Used with application requiring location based information such as intersection support and congestion avoidance

Table 2.1 – Common clustering parameters

2.2 Typical clustering Operations

To group vehicles together, there are two main set of operations used by the clustering algorithms. First are the cluster creation operations as shown in Figure 2.1.

As the name suggest these operations are used to create a new cluster after verifying the fitness of the participants. Figure 2.1a shows a case where there is no vehicle around. The vehicle first sends the HELLO messages to discover presence of another cluster and after a certain timeout identifies that there is no one around and starts a new cluster, becoming the new CH. The second operation depicted in Figure 2.1b is used when there are vehicles in the vicinity which have not yet formed any cluster. In this case the vehicles discover each other via HELLO messages and form a cluster followed by an election of the CH.

The second set of operations are used for cluster maintenance shown in Figure 2.2. Cluster joining operation shown in Figure 2.2a is used to add new members to the cluster. The request to join is initiated by the vehicle by sending the HELLO message. When the CH receives this message, it verifies if the vehicle is fit to join the cluster and then invites it using INVITE message. Cluster merging happens when two CH come in contact with each other as shown in Figure 2.2b. At this point the CHs
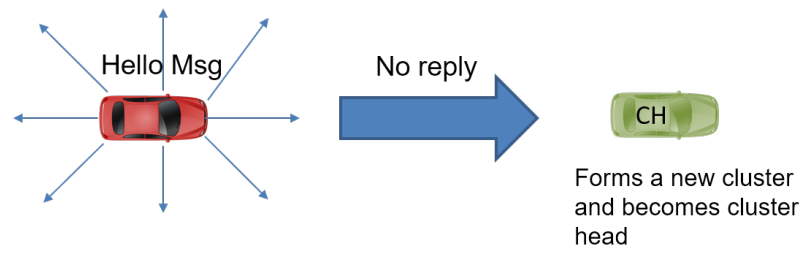
(a) Cluster creation with single vehicle
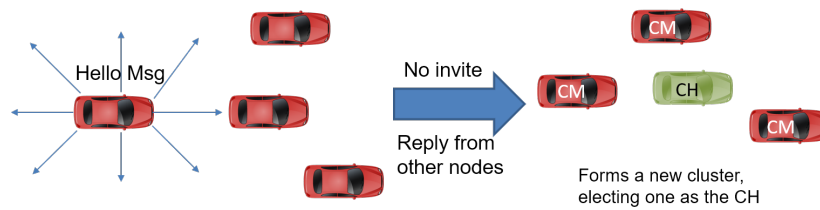
(b) Cluster creation with multiple vehicles

Figure 2.1 – Cluster creation operations

decide to merge the clusters if the current state of the two cluster is similar in terms of the cluster parameters. After merging, one of the existing CH becomes the new CH of the merged cluster and the other CH becomes a CM.

It should be noted that the actual implementation of these operations may change from one methodology to another depending upon the parameter and the use case for the clustering.

2.3 Methodologies

This section presents some of the methodologies which are popular and used as the basis for several algorithms designed for clustering in VANET.

2.3.1 Clustering using vehicular mobility

Vehicular mobility is one of the common and vastly used methodology for clustering. Relative velocity which can be used to differentiate the vehicles into different subgroups is used as one of the main parameters in such algorithms. The vehicle mobility is the main element affecting the network topology which the algorithms use to estimate dynamicity of the network and improve stability. Clustering algorithms presented by Arkian et al. [3], Dietzel, Balanici, and Kargl [4], and Morales, Hong, and Bang [5] use relative velocity as the main parameter to define the cluster joining and cluster head selection metrics.
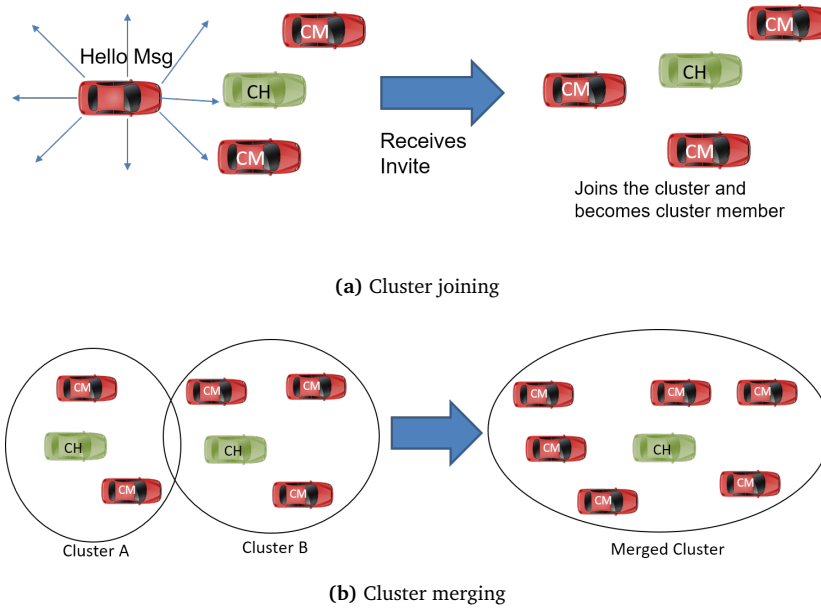
(a) Cluster joining

(b) Cluster merging

Figure 2.2 – Cluster maintenance operations

2.3.2 Clustering using direction and destination

It has been identified that vehicles which travel in same direction or to same destination are supposed to be benefited most if they share information to each other. This makes the direction of travel and destination based clustering other important parameters used for clustering. This methodology requires the vehicles to be equipped with Global Positioning System (GPS) devices to get accurate location information. There can be variations based on the calculation and comparison of the routes of the vehicles. The methodology presented by Kanemaru et al. [6] uses trajectory tables to store position information which is then shared and compared by the vehicles to check the direction and route of travel whereas methodology presented by Maslekar et al. [7] calculates the direction at intersection points based on the turn the vehicles are going to take. Mohammad and Michele [8] has proposed a method which uses lane based information to decide the direction and cluster the vehicles.

2.3.3 Clustering using vehicular density

Density of the vehicles varies based on the environment considered. This is often utilized by the clustering algorithm as an important parameter to define different communication methodologies for dense network in city vs sparse network on highways. Aim of such algorithms is to reduce network congestion in cities by avoiding unnecessary flooding and provide longer network coverage on highways

using long range communication. Kuklinski and Wolny [9] discusses one such algorithm which uses density based clustering to define different communication model based on connectivity and link quality estimates.

2.3.4 Hybrid clustering

Some application may require use of more than one parameter to make decision. Clustering algorithms defined for such application are complex and use multiple parameters in combination to each other. The clustering scheme proposed in [5] uses a combination of location, vehicular velocity and destination information to build up clusters which can adapt with changes in any of the parameters. Such methods are always complex and require a lot of communication between the vehicles to share real-time information.

2.3.5 Multi-hop clustering

The methodologies summarized till now, relies on one hop communication i.e. direct communication between the CH and the CM. The one hop based communication clusters face the problem of frequent handoffs between the clusters for members with high mobility. Multi-hop clustering methods try to address this issue by including N-hop members to the cluster. As shown in Figure 2.3b and Figure 2.3c, the multi-hop members communicate to the CH via the intermediate members and can be located a maximum of N-hop distance away from the CH. In a multi-hop clustering methodology, the HELLO messages contain additionally the number of current hops and are re-broadcasted by a node after adding themselves as an intermediate node. This forms the basis for identifying routes to the N-hop nodes after clustering. Zhang, Boukerche, and Pazzi [10] and Ucar, Ergen, and Ozkasap [11] present clustering methods based on multi-hop schemes along with vehicular mobility.
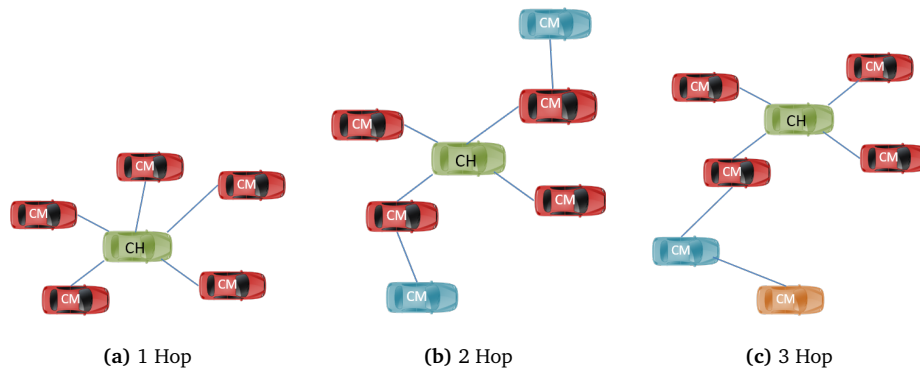

(a) 1 Hop   **(b)** 2 Hop   **(c)** 3 Hop

Figure 2.3 – Multi-hop clustering (based on [11, Figure 1])

Chapter 3

Evaluation and analysis techniques

Implementing a proposed solution for VANET with real vehicles for testing is not straight forward. It always requires availability of various equipment and testing environment to implement a prototype system which would be suitable for evaluating the proposed method. Due to this, most of the authors of the proposed solution use simulation as the main method of evaluation and producing data for evaluation. This chapter will discuss some of the important tools and techniques used for evaluation of clustering methodologies for VANET and present the common metrics derived from the simulation data for comparison.

Simulation for VANET involves two aspects, first is modelling the vehicular mobility and second is modelling the network communication between the vehicles. Another major challenge is to define the interlink between these models to build a realistic simulation environment. Some of the popular network simulators used are OMNET++[1], ns3[2] and VanetMobiSim [12]. Vehicular mobility can be defined by SUMO [13] which is most popular tool capable of managing vehicular mobility via predefined traffic scenarios or some specific mobility model. Sommer, German, and Dressler [14] presented Vehicles in Network Simulation (VEINS) which defines extensions to interconnect OMNET++ and SUMO. A combination of these tools is used to provide simulation environments for evaluating the clustering methodologies.

3.1   Important parameters for evaluation

Choosing correct simulation parameters is important for producing data which is suitable to derive metrics for evaluation. It mostly depends on the characteristics of the simulated model which in this case is clustering methods so mostly depends on the parameters Table 2.1 chosen for clustering and some typical networking and

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[1] https://www.omnetpp.org/
[2] https://www.nsnam.org/

vehicular mobility characteristics. Table 3.1 lists down some of the parameters along with their typical values in simulation environment.

Parameter	values	
Simulation Time	120 s - 400 s	
Route length	3 km - 10 km	
Average speed of Vehicles	10 m/s - 40 m/s	
Transmission rate	6 Mbps - 27 Mbps	
Communication range	100 m - 400 m	
Size of messages	100 B - 150 B	
No. of vehicles/Flow rate	1800 vehicles/h	-
	3600 vehicles/h	

Table 3.1 – Typical simulation parameters

3.2   Analysis of results

Once the data is captured using the simulation of the target clustering methods, it should be used for analysis against some metrics which allows comparative evaluation of the proposed schemes. Some of the important metrics which are used to compare the performance of the clustering algorithms for VANET are as follows.

- **Cluster head duration/Cluster lifetime**: Most important metrics used to measure the stability of clusters. Longer duration of CH is resultant of stable clusters which can perform better in a dynamic environment.

- **Number of clusters**: This metric gives quality of formation of the clusters. Higher number of clusters would lead to cluster merging and increased cluster formation overhead whereas smaller number means large cluster sizes which would result in cluster division due communication failures in high mobile environment.

- **Cluster member duration/Connectivity**: Longer member duration are important for stability and effective communication. Member duration is also a measure of connectivity and the link quality achieved by the clustering method which directly affects the network communication between the nodes.

Chapter 4

Conclusion

This thesis introduces the reader with the requirements for clustering in vehicular networks along with various terminologies and methodologies proposed in literature by various researchers. It also gives a brief overview of tools and metrics which are important for the evaluation of methodologies in VANET systems. The methodologies mentioned in this thesis only provides a brief introduction to the main ideas for clustering in vehicular networks to the reader.

Currently, there is a huge advancement being made in the wireless communication technologies which will open various new opportunities for improving the communication environment for VANETs in the future. Improved communication mechanisms for Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication would provide more stable and reliable communication channels. Thus, providing basis for improving existing clustering methodologies by extending them to use new technology and design new methodologies to achieve better performance in terms of stability and networking connectivity.

I believe this thesis should be a good starting point for introducing the concept of clustering in vehicular network and highlighting the major areas which the reader can further explore based on their needs.

List of Abbreviations

CH	Cluster Head
CM	Cluster Member
GPS	Global Positioning System
MANET	Mobile Ad Hoc Network
RSU	Road Side Unit
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VANET	Vehicular Ad Hoc Network
VEINS	Vehicles in Network Simulation
WANET	Wireless Ad Hoc Network

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