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Classification of Clustering Schemes in VANETs

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Abstract— **The emergence of Vehicular Ad-hoc Networks (VANETs) provides drivers and passengers with safer and more convenient services. However special characteristics of VANETs such as high mobility, movement constraint, and signal blocking hinder the wide propagation of it. One good way to alleviate those unique characteristics of VANETs is clustering. Even though there are many clustering techniques, few investigations to understand them are conducted. In this paper, we examine some cluster based approaches in VANETs carefully and classify them into two categories based on the property of cluster; that is, stationary cluster and mobile cluster. Finally, the advantages and disadvantages of both will be illustrated. We hope that researchers who design the new clustering mechanism in VANETs could facilitate this classification to make theirs more suitable for their purpose.**

Keywords—Clustering, classification, survey, VANETs, Computer Networks and Data Communication

I. Introduction

Vehicular Ad hoc Networks (VANETs) have received considerable attention since it can provide drivers and passengers with a lot of conveniences. Such conveniences could be estimation of car traffic on the road, notification of car accidents ahead, delivery of infotainment data, and so on [1]. These applications need communication between entities, e.g. vehicles, to achieve their objectives. Communications in here can be achieved by setting up routing protocol, which is the mutually established rule among entities for sending or receiving data.

In order to support communication in VANETs, people have tried to take advantage of the routing schemes from Mobile Ad hoc Networks (MANETs). Because VANET is one kind of MANETs, it seems proper to use already developed idea of MANET schemes to support VANETs' communication. However, it is necessary to take the special characteristics of VANETs into account.

The unique characteristics of VANETs can be high mobility, vehicles' restricted movement, and signal blocking by obstacles [1], [2]. First, nodes in VANETs have high mobility since the nodes are vehicles moving very fast. It causes frequent network partitions or merges which can prevent stable communication between cars when compared with MANETs. Second, the movement of nodes is constrained by the road. Nodes, vehicles in here, have to run along the road and are severely affected by the behavior of cars in front and road-traffic signals, especially in the city environment. It creates the problems of scalability, that is, the number of nodes in the network can vary to make the network very sparse or dense. Both situations are not desirable when designing routing protocol. Finally, signals can be easily blocked by obstacles such as buildings, or even pedestrians. So making packets follow the road would give the packets higher chances to be delivered to destination. This also enables us to consider the use of road map for more efficient decision of routing path for packets.

Although there were many classes of routing protocol, above difficulties in VANETs communication can be alleviated more easily by a clustering method [2]. Clustering is the action of grouping vehicles with similarity in VANETs. By clustering vehicles into groups with similar patterns, it would be possible to provide users with more reliable and efficient communication. And this can be directly connected to Quality of Service (QoS) for many applications [3]. However, clustering itself has many challenging issues such as forming clusters, electing proper cluster-heads, and maintaining clusters. Researchers have struggled to overcome these issues and introduced many ideas.

Even though there have been several surveys on topic of clustering in MANETs and Sensor Networks [4]-[6] to give comprehensive understanding of the subject, there is only one survey for the VANETs [7]. Unfortunately this survey only gives a brief overview of several clustering algorithms in VANETs, not the criterion for the classification.

In order to find the criterion to classify the clustering algorithms in VANETs, we observe several clustering schemes in VANETs and examine the properties of them. Based on the result of observation, we can classify clustering schemes in VANETs according to the property of clusters and provide advantages and disadvantages of them to help the better design of clustering algorithm for future researchers.

This paper is organized as follows. The section II suggests the classification of clustering schemes and shows two examples for each category. In section III, the comparison of each major category of clusters will be described. Finally, the paper concludes with summary in section IV.

II. Classification of Clustering schemes

Many clustering schemes, [8]-[11], [13] and ones from [7], have been proposed to provide VANETs with more stable communication. Those clustering algorithms can be categorized into two classes according to the property of cluster itself; one is fixed cluster and the other is moving cluster. In other words, cluster can move as the nodes changes their position or be fixed regardless of nodes' movement.

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Clustering process requires either coarse or fine efforts according to the property of cluster itself. For example, in case of stationary cluster, it usually uses simple broadcast message to form a cluster since the management of the cluster is not complex relatively. In contrary, mobile cluster requires sophisticated messages to make the cluster more stable because it is influenced by different behaviors of vehicles. Thus it can be told that this property of clusters can affect significantly on the design or selection of proper clustering scheme in different situation. Table I shows brief description of two categories of clustering schemes in VANETs.

TABLE I. DESCRIPTION OF TWO CLUSTERING CATEGORIES

Types	Description
Stationary cluster	Location of cluster is pre-defined. For example, a geographical area is divided into several fixed grids and cluster can be defined as the grid. Thus nodes may not need to do excessive or extra work to decide their cluster. In this type of cluster, Road-Side-Units (RSUs) sometimes take a role of cluster-head, but it is not necessary.
Mobile cluster	Cluster is moving along with the nodes. It may be necessary for every node to participate in the process of cluster-formation which makes clustering algorithm more complex. It also requires clustering algorithm to be effective so that it can form appropriate number of clusters.

A. *Stationary Cluster*

One class of cluster is stationary cluster as Fig. 1 shows. Cluster is usually the pre-defined grid of the geographical region. Sometimes, this type of cluster could involve with the Road-Side-Units (RSUs) which are fixed infrastructures providing connection to the outer network such as Internet. In this case, the range of a cluster can be equivalent to the transmission range of a RSU. Using RSUs could make the design of routing protocol easier since we do not have to consider multi-hop situation. But this would require additional costs for installing RSUs. Moreover, fixed RSUs could raise a problem of frequent re-affiliation that is the process of vehicles' moving out of a cluster and joining other cluster [12]. Frequent re-affiliation is not desirable because it can cause further cluster formation process of entire network.

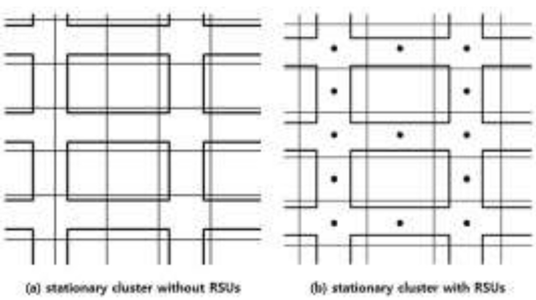

Figure 1. Stationary cluster examples – (a) stationary cluster without RSUs, (b) stationary cluster with RSUs

The stationary cluster has the advantage that it does not require complex process to form the cluster. The shape and location of clusters are pre-defined. In other words, vehicles only have to broadcast some information and determine the cluster-head in each cluster based on received information.

1) Luo's "A New Cluster Based Routing Protocol for VANET"

Yuyi Luo at el. [8] proposed cluster based routing scheme using vehicles' position. This scheme divides the geographic area into several square grids as shown in Fig. 2. Since each grid becomes cluster, nodes do not need to consider the range of cluster during cluster-formation process. The only thing nodes have to do is sending broadcast messages which embed its location to determine cluster-head. If cluster-head exists already, it will reply to the node to notify its existence. Otherwise, it tries to become a cluster-head for that cluster. Decision of being cluster-head is made by location of the node. When the node is closest to the center of that cluster, it can become a cluster-head. So the location of nodes is important for being a cluster-head in this algorithm.

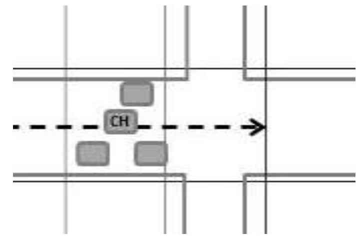

Figure 2. Stationary clustering technique used in Luo's scheme

There is definitely no complex procedure to determine the cluster-head since all nodes in the cluster only compare location of itself with the one of its neighbors. In other words, the computation complexity is low. In addition, the fixed range of cluster makes the overhead caused by the exchanged messages somewhat constrained though this algorithm does not clarify how much message-exchanging-rounds to make a decision about cluster-head it needs.

Downside of this algorithm is that there would be very frequent events of updating cluster members including cluster-head, which could degrade the performance of routing protocol based on the algorithm.

2) Maslekar's Direction Based Clustering Algorithm

Maslekar *et al.* [13] pronounced the clustering algorithm based on the direction of the vehicles at the intersection. Their object is to help in the traffic management at the intersection by measuring density of vehicles. The sequence of this algorithm is similar with [8]. Geographical area is divided into fixed grids and they act as clusters. Each vehicle entering grid determines cluster-head by broadcasting its direction information. If there is no reply within a certain amount of time, it declares itself as a cluster-head.

The main advantage of this scheme is that the consideration of direction during clustering process helps each vehicle to reduce the number of messages to be handled. This means that direction information filters unnecessary messages. This filtering will save the bandwidth by restricting the indiscreet response to all broadcasts. Like the other stationary clustering algorithm, this scheme also has low computation complexity.

The disadvantage is same with the one of other stationary cluster. The resulting clusters can be very unstable since it does not consider any other factors than direction. In addition to the property of stationary cluster, this will lead to the frequent re-clustering or re-affiliation.

B. *Mobile Cluster*

The other class is mobile cluster. In this kind of scheme, it looks more suitable to support the mobile characteristics of VANETs since clusters are moving along with vehicles. This mobile cluster or mobile backbone concept can help us to construct more stable clusters than the stationary cluster. However, it spends additional time and bandwidth, which is unavoidable, to calculate eligibility of cluster-head and exchange the results. In other words, the performance of mobile cluster can suffer from the clustering procedure. Every vehicle might have to conduct complex calculation and then exchange the result several times. Since suitability of cluster-head determines the stability and efficiency of the cluster, a lot of factors and calculation methods have been considered.

Consequently, algorithm for mobile cluster tends to be more sophisticated to reflect different and variable characteristics of vehicle. Fig. 3 illustrates an example of mobile cluster.

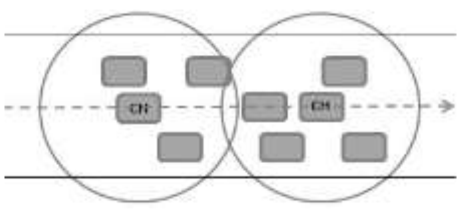

Figure 3. Mobile cluster example

1) Luo's Bus-based moving cluster

Jie Luo et al. [9] showed interesting idea using buses as cluster-head. This scheme exploits the type of vehicles like in [14] so as to differentiate them as buses and normal cars. As we can see from Fig. 4, normal cars attach themselves to nearby bus to communicate each other. Cluster-heads, i.e. buses, are connected each other by using interface with longer transmission range. Initially, bus sends periodical broadcast messages containing its location and velocity to neighbor nodes to from clusters. Upon receiving this message from near bus, vehicles calculate their expected connection time to the bus, which is based on the distance between bus and itself, velocity of bus and itself, and transmission range of itself. And then each normal vehicle can calculate score value for each bus nearby itself based on the expected connection time. This procedure reflects the similarity of vehicles to form cluster and thus helps to form more reliable cluster.

The advantage of this scheme is that it fixes cluster-head as bus so that cluster-head election procedure becomes simpler. The procedure of electing cluster-head usually requires much time or complex computation since it determines the performance of the cluster. By making the bus as default cluster-head, Luo's solution could save time or reduce complexity that is necessary for the election of cluster-head.

However, it has obvious problems such as *blind-spot* and *out-of-service*. *Blind-spot* problem arises because bus lines do not cover the entire area. The area where any buses do not operate cannot be served by cluster. *Out-of-service* problem also comes from the limited bus operation time. For example, cluster does not exist while the bus is out of service.

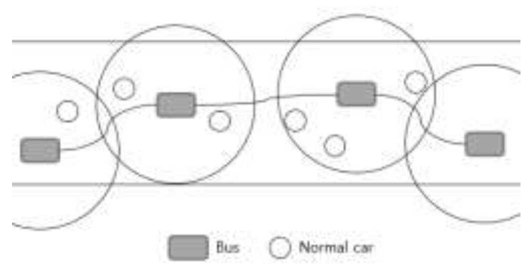

Figure 4. Bus-based mobile cluster

2) Rawshdeh's strongly connected clustering algorithm

Rawshdeh et al. [15], [16] tried to make more reliable cluster. During cluster formation procedure, they considered speed difference among vehicles in addition to location and direction of vehicles to reflect more similar behavior of nodes. According to this algorithm, each node maintains two sets of vehicles whose relative speed is greater and less than itself. A node with the empty set of vehicles whose relative speed is less than itself is called as cluster originating node (COV). Only COVs can initiate clustering process to avoid the collision of clustering initiation messages and the creation of excessive number of clusters. When receiving the message from COV, vehicles calculate its suitability of being a cluster-head based on average location difference, speed difference, and the degree of connectivity among its neighbors. After comparing suitability with others, a node with the highest suitability finally becomes a cluster-head. One possible result of clustering process is shown in Fig. 5.

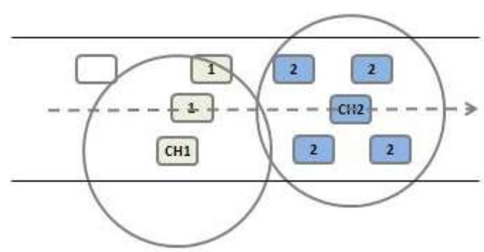

Figure 5. Rawshdeh's strongly connected cluster

By considering relative speed among vehicles, the chance for any nodes in a cluster to move out of that cluster could be greatly reduced. As a result, the clustering scheme could reduce re-affiliation so that it would have high chance to avoid re-clustering in whole network which can cause excessive message exchange. However, this obviously leads to relatively high computation complexity. To compute suitability, vehicles need to measure or get other vehicle's speed and location first. And then they have to calculate their suitability and compare it with others by exchanging several messages. This effort-requiring process could degrade the performance of clustering algorithm.

III. Comparison between Stationary and Mobile cluster

With the careful observation, clusters can be categorized into stationary and mobile cluster. As the examples of each type show, each cluster has their own characteristics. They show differences in the aspects such as the range of cluster, complexity of computation, strength of connection, and frequency of re-affiliation. Table II summarizes characteristics of stationary and mobile cluster.

TABLE II. COMPARISON BETWEEN STATIONARY AND MOBILE CLUSTER

Type	Cluster range	Computation complexity	Connection strength	Re-affiliation occurrence
Stationary	Fixed	Low	Weak	High
Mobile	Fixed or variable	High	Strong	Low

First, stationary cluster has the fixed range since it divides the target area into fixed grids and set them as clusters. On the other hand, the range of cluster in mobile concept can be variable because the range of cluster is analogous to the transmission range of a cluster-head. Second, computation complexity for stationary cluster is very low due to the simple clustering procedure whereas the one for mobile cluster is quite a bit complex due to the variety of relevant factors. Third, connection strength is relatively weak for stationary cluster. This is because the scheme does not consider stability of cluster. However, connection is usually very tight for the mobile cluster since it considers a lot of factors to make the network stable. Finally, stationary cluster suffers from the frequent re-affiliation due to the instability of cluster. Considerations for the stability of cluster in mobile cluster help it to decrease the rate of re-affiliation.

IV. Conclusion

In order to provide more reliable services in VANET applications, it is necessary to establish more stable routing protocols to deliver data packets to destination. Clustering algorithm is one of good solutions to support the special characteristics of VANETs such as high mobility, movement constraint, and signal blocking. However, it might be difficult for developers of routing protocol to select proper clustering techniques for their needs.

In this article, we classify clustering techniques into two categories; one is stationary and the other is mobile. We show some representative examples from each category to describe their pros and cons. Through these examples and descriptions for each scheme, we provide the concept and features of clustering schemes regarding computation complexity, limitation of transmission range, and cluster structure stability. Due to the difference of their natural property, there will be no clustering method that is the best option for all situations. Thus, we hope that the proposed classification would give clear principle for designers of clustering algorithm to decide which type fits to their objectives.

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