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Clustering in vehicular ad hoc networks: Taxonomy, challenges and solutions

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ABSTRACT

Over the last few years, Vehicular Ad Hoc Networks (VANETs) have emerged as a new class of efficient information dissemination technology among communities of users mainly because of their wide range of applications such as Intelligent Transport Systems (ITS), Safety applications, and entertainment during the mobility of the vehicles. Vehicles in VANETs act as an intelligent machine, which provides various resources to the end users with/without the aid of the existing infrastructure. But due to the high mobility and sparse distribution of the vehicles on the road, it is a challenging task to route the messages to their final destination in VANETs. To address this issue, clustering has been widely used in various existing proposals in literature. Clustering is a mechanism of grouping of vehicles based upon some predefined metrics such as density, velocity, and geographical locations of the vehicles. Motivated from these factors, in this paper, we have analyzed various challenges and existing solutions used for clustering in VANETs. Our contributions in this paper are summarized as follows: Firstly, a complete taxonomy on clustering in VANETs has been provided based upon various parameters. Based upon this categorization, a detailed discussion is provided for each category of clustering which includes challenges, existing solutions and future directions. Finally, a comprehensive analysis of all the existing proposals in literature is provided with respect to number of parameters such as topology selected, additional infrastructure requirements, road scenario, node mobility, data handled, and relative direction, density of the nodes, relative speed, communication mode, and communication overhead. The analysis provided for various existing proposals allows different users working in this domain to select one of the proposals with respect to its merits over the others.

1. Introduction

Vehicular Ad Hoc Networks (VANETs) consist of Vehicles/Mobile nodes communicating with each other over wired/wireless links with/without existing infrastructure [1]. Vehicles have the capability to communicate directly with other vehicles in Peer-to-Peer (P2P) manner or indirectly using the existing infrastructure alongside the road. Vehicles and roadside infrastructure need to be equipped with dedicated hardware for providing safety and security to the passengers sitting on board. Standardization of wireless communication technology is required for providing entertainment to the passengers. Therefore research on VANETs has been receiving increasing interest in the last couple of years, both in the algorithmic aspects as well as standardization efforts like IEEE 802.11 p & IEEE 1609 standards. In a clustering structure, the mobile nodes are divided into a number of virtual groups based on certain rules. These virtual groups are called clusters. Under a cluster structure, mobile nodes may be assigned a different status or function, such as cluster-head, cluster-gateway, or cluster-member. A cluster-head normally serves as a local coordinator for its cluster, performing intra-cluster transmission arrangement, data forwarding etc. A cluster-gateway is a non-cluster-head node with inter-cluster links, so it can access neighboring clusters and forward the information between clusters. A cluster-member is usually called as an ordinary node, which is a non-cluster-head node without any inter-cluster links.

The notion of cluster organization has been used for Mobile Ad Hoc Networks (MANETs) in number of issues such as routing, security, Quality of Service (QoS) etc. [1,2]. However due to the characteristics of VANETs such as high speed, variable density of the nodes, clustering schemes which are proposed for conventional MANETs may not be suitable for VANETs. Due to time taken

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for cluster formation and maintenance, clustering requires additional control overhead. Thus a good clustering algorithm should not only focus on forming minimum number of clusters but also dynamically maintain the cluster structure without increasing a high communication overhead over the network. Thus clustering allows the formation of a virtual communication backbone that supports efficient data delivery in VANETs and it also improves the consumption of scarce resource such as bandwidth. A low cost clustering method should be able to partition a VANET in a short time with little overhead of control message broadcasting. Hence, VANETs must follow a tight set of constraints as compared with MANETs and therefore require specialized clustering scheme.

Also, the developed clustering algorithm should be distributed, with no central coordinator. The algorithm should also handle the locality properly, i.e., single topology change should have less impact on the overall topology and should be able to detect and react to topology changes. Because of the high degree of mobility, a clustering algorithm should converge fast and should have a reduced overhead to minimize the time lost in the clustering process.

1.1. Motivation and challenges

As VANETs have been used in various applications whose ultimate goal is to provide safety and comfort to the passengers sitting in the vehicles, hence there is a requirement of optimized solutions for clustering in VANETs. But due to large number of nodes and lack of routers, a flat network scheme may cause serious scalability and hidden terminal problems. A possible solution to above problems is the use of an efficient clustering algorithm. As for efficient communication among the vehicles on the road, Dedicated Short Range Communications (DSRC) is used, so it would be a good idea to divide the vehicles in clusters so that vehicles within the same cluster may communicate using DSRC standards. These facts motivate us to categorize various clustering techniques in VANETs based upon predefined criteria. But on the other hand, there are number of challenges that need well designed solutions for clustering of vehicles. Some of the challenges are high mobility of the vehicles, sparse connectivity in some regions, and security.

Due to large number of parameters which have been considered in different clustering, it was difficult to consider some parameters as standard for evaluation of reviewed protocols. To accommodate this diversity, all the parameters were analyzed and then synthesized into eight standard categories in this paper. These eight parameters have been broadly categorized into vehicle density and vehicle speed; which characterize the efficiency of clustering protocol; cluster stability, cluster dynamics, cluster convergence and cluster connect time; transmission efficiency and transmission overhead. This standardization will help us to provide a comparative analysis of all the reviewed clustering protocols.

Some of the above described parameters are illustrated as follows. Vehicle Density which is one of the most important parameters defines the average number of vehicles in terms of vehicles per kilometer (km) or vehicles per lane. For urban scenarios high value of vehicle density is considered compared to highways. Vehicle speed is the range of speeds considered for simulation by a particular protocol in terms of m/s or km/h. A speed range that varies realistically indicates better adaptability. Transmission efficiency is described as average number of messages or packets that are transmitted or received by a cluster member during a time duration. High transmission efficiency shows that a clustering scheme is more effective in data dissemination. Transmission overhead is the average communication or control overhead required by a clustering scheme for cluster formation and maintenance in terms of number of packets. A clustering scheme that has lower transmission overhead is desired. Cluster stability is the average life-time of a cluster. A high value of cluster stability indicates a better clustering protocol. The parameter cluster dynamics describes the average number of status changes per vehicle defined in terms of average number of cluster changes or cluster head changes in terms of total number of vehicles. A low value of cluster dynamics is more suitable. Cluster connect time refers to percentage time duration that a vehicle stays connected to a single cluster. A high value of cluster connect time indicates higher suitability of a protocol. Cluster Convergence refers to the duration required for all the nodes to join a cluster at the initiation of a clustering scheme. The suitability of a clustering scheme for VANETs is more when it exhibits low clustering convergence.

1.2. Main contributions

Based upon the above discussion, the main contributions of this paper are summarized as follows:

- A complete taxonomy for clustering in VANETs has been provided which categorizes clustering based upon various key parameters.
- A detailed description of the protocols in each category has been provided in the text. Moreover, an analysis of the protocols of each category is provided by careful selection of various parameters.
- Finally, a detailed comparison and discussion of various approaches and protocols have been provided with respect to various parameters. Also, open issues and future directions in this newly emergent area are highlighted in the text, which guides various users to select a particular solution based upon its merits over the others.

1.3. Taxonomy of the clustering in VANETs

For efficient communication among the nodes in the network, stable clustering is required. In this direction, many researchers have used various techniques to form a stable cluster among the nodes. Some of these techniques consist of the use of signal strength received, position of the node from the cluster head, velocity of the nodes, direction and destination of node. Keeping in view of the above issues, the detailed taxonomy of various clustering algorithm is described in Fig. 1.

1.4. Organization

Rest of the paper is organized as follows. Section 2 provides the description about the Predictive clustering. Section 3 describes about the Backbone Clustering. Section 4 describes the MAC based clustering. Section 5 discusses about the Traditional clustering techniques. Section 6 explores on Hybrid clustering. Section 7 describes the Secure Clustering. Section 8 provides the comparative analysis with respect to various parameters. Section 9 explores on the open research issues and challenges. Finally, Section 10 concludes the article and gives the future directions on the topic.

2. Predictive clustering

In predictive clustering, the cluster structure is determined by the current geographic position of vehicles and its future behaviour. This vehicle traffic information helps to associate priorities which then assist in cluster formation. The future position and the intended destinations of vehicles have been used in the literature to form clusters in VANETs. Some of these protocols are classified as position based and destination based as follows: