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Clustering in Vehicular Ad Hoc Networks using Affinity Propagation

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ABSTRACT

The need for an effective clustering algorithm for Vehicular Ad Hoc Networks (VANETs) is motivated by the recent research in cluster-based MAC and routing schemes. VANETs are highly dynamic and have harsh channel conditions, thus a suitable clustering algorithm must be robust to channel error and must consider node mobility during cluster formation. This work presents a novel, mobility-based clustering scheme for Vehicular Ad hoc Networks, which forms clusters using the Affinity Propagation algorithm in a distributed manner. This proposed algorithm considers node mobility during cluster formation and produces clusters with high stability. Cluster performance was measured in terms of average clusterhead duration, average cluster member duration, average rate of clusterhead change, and average number of clusters. The proposed algorithm is also robust to channel error and exhibits reasonable overhead. Simulation results confirm the superior performance, when compared to other mobility-based clustering techniques.

1. Introduction

Vehicular Ad Hoc Networks (VANETs) are an emerging field of research that will help improve road safety, navigation, and congestion. VANETs will enhance driver safety and reduce traffic deaths and injuries by implementing collision avoidance and warning systems. In addition, VANETs will enable the dissemination of traffic and road condition. This will aid in navigation and relieve traffic congestion by providing a driver with live routes that avoid road hazards and bottleneck areas. The vast sensor network that VANETs will create, is inciting countless other applications, and making VANETs a hot topic in ad hoc networking today.

The VANET environment contains many challenges for communication, many of which can be addressed by a clustered network. As highlighted in [1], VANETs suffer from high mobility and high node-density, which lead to channel congestion and the hidden terminal problem. VANETs have a highly-mobile environment with a rapidly changing network topology. Clustering the vehicles into groups of similar mobility will reduce the relative mobility between communicating neighbor nodes, and simplify routing. VANETs demand a high frequency of broadcast messages to keep the surrounding vehicles updated on position and safety information. These broadcasts lead to the “broadcast storm problem” [2], which describes the resulting congestion in the network. Both [2,3] recommend a clustered topology to effectively alleviate this congestion. In addition, both delay-sensitive (e.g. safety messages) and delay-tolerant (e.g. road/weather information) data will need to be transmitted, necessitating Quality-of-Service (QoS) requirements. Clustering the network will aid in supporting these QoS requirements as shown in [4].

There has been much research on cluster-based VANETs in the recent literature, most of which has focused on developing cluster-based MAC protocols, as in [5–11] and cluster-based routing protocols, as in [12,13]. In [6,11], the clusterhead (CH) takes on a managerial role and

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facilitates intra-cluster communication by providing a TDMA schedule to its cluster members. In [11], adjacent clusters are assigned different CDMA codes to avoid interference between clusters. The work in [11] shows a substantial reduction in probability of message delivery failure, when compared to traditional 802.11 MAC.

By introducing clustering we create a hierarchy in the network. The communication can be divided into cluster member to clusterhead and clusterhead to clusterhead communications. By allocating different channels to different clusters, the effect of interference and hidden node terminals can be reduced. Using clustering, a local infrastructure-based network is formed in which a clusterhead acts as an access point for cluster members. The clusterhead can then coordinate the transmissions in order to reduce packet collisions and to maximize the throughput.

The recent research in cluster-based MAC and routing protocols for VANETs motivates the need for an effective VANET clustering scheme. The clustering algorithms suggested in this research have low complexity and take advantage of node mobility more effectively. For highly-mobile networks, mobility must be considered during the clustering process in order to ensure cluster stability. Since the clusters provide the foundation for cluster-based MAC and routing schemes, cluster stability is vital for achieving reliable communication.

In addition to stability, an effective clustering algorithm must be robust to the harsh channel conditions present in the VANET environment. As discussed in [1], VANETs have unreliable radio channel characteristics. The high mobility of the environment and numerous reflective obstacles lead to shadowing and multipath fading. It is thus important to evaluate the robustness of the algorithm when channel error is present.

In this paper, we propose a distributed mobility-based clustering algorithm for VANETs called APROVE. The proposed algorithm possesses excellent cluster stability, where stability is defined by long clusterhead duration, long cluster member duration, and low rate of clusterhead change. In addition, our algorithm is robust to channel error and exhibits a reasonable overhead. We achieve this algorithm by utilizing Affinity Propagation (AP) [14]. Our clustering scheme uses vehicles' position (provided by GPS) and velocity information to form clusters with low relative mobility between the clusterheads and their cluster members.

An earlier version of APROVE was first introduced in [15]. In [15] we presented a preliminary version of the algorithm with basic simulation results where we compared the clustering performance with MOBIC [16], a well stablished clustering algorithm in mobile ad hoc networks. In this work, we propose a revised version of APROVE to improve and extend the our work as follows:

- Asynchronous APROVE is proposed. There is no synchronization overhead which is an obvious advantage particularly when there is congestion.
- An aggregated message passing algorithm is proposed in which responsibility and availability messages are aggregated into a single HELLO message.
- A cluster head contention subroutine is introduced to reduce the number of clusters being produced.
- Analysis of overhead, convergence, and channel error is presented. Furthermore, new simulation results are added to observe the effect of channel error and to characterize the overhead.
- In addition to MOBIC, performance comparisons are made with two recent clustering algorithms for vehicular networks: Aggregate Local Mobility (ALM) clustering [17] and Position-based Prioritized Clustering (PPC) [18].

The rest of this paper is organized as follows. Section 2 discusses the related work in VANET and MANET clustering. Section 3 presents the Affinity Propagation algorithm. Section 4 introduces the APROVE clustering algorithm, and the algorithm's operation is analysed and discussed in Section 5. Section 6 presents the simulation results, and finally Section 7 concludes the paper.

2. Related work

Much of the recent VANET research discussing cluster-based MACs and routing schemes, also present a low-maintenance clustering algorithm. Each of these algorithms works essentially the same way, whereby nodes periodically transmit HELLO beacons to indicate their present state. States can be one of the following: Undecided, Clusterhead, Cluster Member, and sometimes Gateway. An undecided node will join the first CH that it hears a HELLO beacon from (or join all CHs if Gateway nodes are allowed). If the node does not hear from a CH within a given time period, it will become a CH itself. In addition, protocols are introduced to deal with colliding clusters, which occurs when two clusterheads come within range of one another. During a cluster collision, one clusterhead decides to give up its status to the other. This technique is used by [11,13] without regard for mobility. In [6], mobility is addressed during cluster collision, whereby the winning clusterhead is the one with both lower relative mobility and closer proximity to its members. Alternatively, [10] addresses mobility by first classifying nodes into speed groups, such that nodes will only join a clusterhead of similar velocity.

The above clustering techniques offer low complexity, but in the highly mobile VANET environment, they are lacking in cluster stability. The algorithms do not have a proactive approach to cluster stability, in that they make no attempt to select a stable CH during initial clusterhead election. Node mobility must be taken into consideration in order to achieve stability, however many of the proposed techniques ignore it. Mobility is considered in [6] as a reactive measure, in that it is only considered after two clusters collide. The use of cluster speed groups in [10] may improve stability, but the large variations in the predefined speed groups (e.g. 60–110 km/h) will still allow high relative mobility inside the clusters.

In order to achieve the necessary cluster stability, mobility should play an integral role in initial cluster formation. A well-known and effective mobility-based