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Fast randomized algorithm for 2-hops clustering in vehicular ad-hoc networks ☆

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ABSTRACT

Vehicular Ad-Hoc Networks (VANETs) enable inter vehicle wireless communication as well as communication with road side equipment. Warning messages can be exchanged among nearby vehicles, helping to predict dangerous situations, and thus improving road safety. Such safety messages require fast delivery and minimal delay to local areas, in order for them to be effective. Therefore, a fast and efficient channel access scheme is required. A feasible solution, derived from the Mobile Ad-Hoc Networks (MANETs) field, groups nodes into smaller manageable sections called clusters. Such an approach can be beneficial for locally delivering messages under strict time constraints. In this paper, a Hierarchical Clustering Algorithm (HCA) is presented. HCA is a distributed randomized algorithm, which manages channel access by forming three hierarchy clusters. The proposed channel access scheme enables delay bounded reliable communication. Unlike other common clustering algorithm for VANETs, HCA does not require the knowledge of the vehicles' locations. This feature guarantees accurate operation even when localization systems such as GPS are not available. The running time and message complexity were analyzed and simulated. Simulation results show that the algorithm behaves well especially under realistic mobility patterns; therefore, it is a suitable solution for channel access scheme for VANETs.

1. Introduction

Vehicular Ad-Hoc Networks (VANETs) serve as the basis for Intelligent Transportation Systems (ITS) by utilizing Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) wireless communication. Dedicated hardware can be incorporated into vehicles and some roadside units, enabling V2V and V2I communication.

VANETs can be used for several purposes [1]: First, safety and warning messages can be used to alert drivers as to dangerous and unpredicted situations, and thus reduce the number of car accidents and their severity. In addition, such systems can improve road utilization by managing traffic flows. Traffic updates can be delivered in real time to allow time saving and lower fuel consumption. Finally, commercial and entertainment services can be distributed via these systems.

Therefore, research on VANETs has been receiving increasing interest in the last couple of years, both on the algorithmic aspects e.g., [2–6] as well as standardization efforts like the IEEE 802.11p and IEEE 1609 standards (named *WAVE* – Wireless Access in Vehicular Environments). The 802.11p standard handles the MAC and PHY layers for each individual channel, while IEEE 1609.x standards deal with upper layer protocols and multi-channel operation [7,8].

VANETs exhibit unique characteristics and requirements [9]. On one hand, safety applications require extremely low message delay in order for them to be effective. On the other hand, unlike some MANETs

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(Mobile-Ad-Hoc Networks), power and computational abilities are sufficient since the devices are carried by vehicles. Another key characteristic of V2V communication is the high relative velocity between the vehicles engaged in such communication, which results in short term sessions. Consequently, solutions based on the current packet radio communication protocols cannot guarantee the required quality of service (QoS). In addition, safety messages are required to be transmitted only in a small radius in order for them to be effective. Combining these two key requirements leads to the basic approach – clustering vehicles into groups [2–4] to ensure high QoS and fast propagation of messages in a limited area.

The clustering approach was initially suggested for MANETs [10–16]. These works include k-hops clusters in which the number of hops between any of the nodes in the cluster is at most k [13–15]. More recent works affiliate the clustering approach to VANETs. Examples include [2–6]; however, they are all based on a localization system such as GPS to improve their performance. This leads to undesirable dependence upon these systems. We elaborate more on this in the related works section.

Motivated by an industry-based collaboration with Mobilicom LTD [17], our goal was to create 4-hops clusters (where each node in the cluster is at most 2 hops from a *cluster head*) as fast as possible without the use of GPS or any other localization systems. The clustering algorithm should provide a comprehensive solution for wireless channel access in a mobile environment. In addition, it should guarantee a tight time delay bound for safety messages by selecting a set of leader nodes (i.e., cluster heads) that would synchronize and schedule channel access for the entire network.

Following the unique nature of VANETs expressed in short term sessions, a fast clustering algorithm is required. In this work we offer a fast randomized clustering and scheduling algorithm, to allow quick network setup. Our basic motivation was that 4-hops are sufficiently "local" for safety and other messages types, and that the initial setup time is more critical than the initial cluster quality. The initial setup, in turn, can be followed by a maintenance phase that improves the clusters structure. Therefore, the suggested algorithm creates hierarchical clusters in which the maximal distance between a ClusterHead (CH) vehicle and any other vehicle in the cluster is two hops. Additionally, unlike other k clustering algorithms such as [13–15], the algorithm does not assume any lower layer connectivity, and handles the channel access method and transmission scheduling within the cluster to avoid message collisions.

In order to evaluate the proposed algorithm prior to deployment and to examine its compatibility to vehicular networks, a designated simulator for VANETs was developed [18]. The suggested algorithm was simulated using the designated simulator in several scenarios and was compared to K-ConID algorithm [15]. Simulations show that the algorithm performs better under realistic mobility patterns and adapts to high velocities, which indicates that the algorithm suits VANETs. Furthermore, the algorithm's cluster formation process was studied analytically and simulated, showing that the algorithm creates clusters within $O(m \log \log m)$ time slots using $O(m)$ messages with m denoting the maximal cluster size in the network (of size n).

This paper is organized as follows. In Section 2 we discuss some related works regarding VANETs, and review clustering algorithms for MANETs and VANETs. Section 3 provides a detailed description of the suggested algorithm followed by Section 4 in which the algorithm is analytically analyzed. The scenarios that were used to evaluate the algorithm and the results that were obtained are presented in Section 5. This work concludes with the conclusions and future work section.

2. Related works

A 75 MHZ of Dedicated Short Range Communication (DSRC) spectrum were allocated in the US for vehicular communication for Intelligent Transportation Systems (ITS) with its primary goals being public safety and improvements of traffic flows. ITS require reliable data communication, and therefore an appropriate and mature technology must be used [19]. Several wireless technologies are reviewed in [19] including infrastructure and infrastructureless methods of connecting vehicles and road side units including cellular networks, WiMAX, WLAN, and DSRC/WAVE which will be further explained next.

Several standardization efforts were made in recent years, mostly led by the IEEE organization. The authors of [8] review the Wireless Access in Vehicular Environments (WAVE) protocol stack as defined by the IEEE. The lower layers (Physical and MAC) are covered by the 802.11p standard, while the Logical Link Control (LLC) layer and upper layers are covered by the IEEE 1609.x standards. The WAVE architecture supports two protocol stacks above the same Physical and MAC Layers. The first protocol stack is the IPv6 used for traditional communication, while the other is WAVE Short Message Protocol (WSMP) which handles high-priority, time-sensitive communications.

Clustering is a well known method used in Ad Hoc networks. The main advantages of using clustering schemes are presented in [10] and include: benefits in network management, introduction of QoS; efficient resource allocation and reduction of topology changes overhead. Some clustering algorithms include their own unique channel access method derived from the clustering process. In [10], the authors present a distributed one hop clustering algorithm for Ad-Hoc networks. First, the authors introduce a channel access scheme in a slotted system with nodes contending for transmission for a partial time-fraction of the slot. The channel access scheme is then analyzed in order to decrease the probability of collisions. The clustering algorithm is then presented; each node that does not belong to any cluster sets a random period of time and subsequently broadcasts a message declaring itself as a cluster head. Neighboring nodes that overhear this message join the cluster.

Some clustering algorithms [11,12] use different metrics (e.g., id, mobility) for the cluster formation process in order to form stable clusters. In [12], MOBIC, an algorithm for cluster formation and cluster head selection is