Journal of Network and Computer Applications 34 (2011) 207–222

Contents lists available at ScienceDirect

Journal of Network and Computer Applications

journal homepage: www.elsevier.com/locate/jnca

VWCA: An efficient clustering algorithm in vehicular ad hoc networks

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ARTICLE INFO

Article history:
Received 25 June 2009
Received in revised form
21 July 2010
Accepted 26 July 2010

Keywords:
Vehicular ad hoc networks
Clustering
Dynamic transmission range
Connectivity
Monitoring
Attackers

ABSTRACT

Vehicular ad hoc networks (VANETs) are appropriate networks that can be used in intelligent transportation systems. Among challenges in VANET, scalability is a critical issue for a network designer. Clustering is one solution for the scalability problem and is vital for efficient resource consumption and load balancing in large scale networks. As our first algorithm, we propose a novel clustering algorithm, vehicular clustering based on the weighted clustering algorithm (VWCA) that takes into consideration the number of neighbors based on dynamic transmission range, the direction of vehicles, the entropy, and the distrust value parameters. These parameters can increase stability and connectivity and can reduce overhead in network. On the other hand, transmission range of a vehicle is important for forwarding and receiving messages. When a fixed transmission range mechanism is used in VANET, it is likely that vehicles are not located in the range of their neighbors. This is because of the high-rate topology changes and high variability in vehicles density. Thus, we propose an adaptive allocation of transmission range (AATR) technique as our second algorithm, where hello messages and density of traffic around vehicles are used to adaptively adjust the transmission range among them. Finally, we propose a monitoring of malicious vehicle (MMV) algorithm as our third algorithm to determine a distrust value for each vehicle used in the VWCA. The effectiveness of the proposed algorithms is illustrated in a highway scenario.

1. Introduction

Communication among vehicles is an important field of study for transportation systems. Vehicular ad hoc networks (VANETs) are appropriate networks that can be applied to intelligent transportation systems (Nadeem and shankar, 2006). VANET is based on short-range wireless communication among vehicles. VANETs are built on-the-fly and do not need any investment, except the wireless network interface that will be a standard feature in the next generation of vehicles. The Federal Communications Commission (US FCC) has allocated 75 MHz of spectrum in the 5.9 GHz band for the Dedicated Short Range Communication Standard (DSRC) for VANET communications. The purpose of DSRC is to enhance bandwidth and to reduce latency for vehicle-to-vehicle and vehicle-to-infrastructure communications (Abdulhamid et al., 2007).

Scalability is a critical issue among many challenges running for VANET technology. In practice, when a flat-topology network contains a large number of vehicles, a large percentage of limited wireless bandwidths should be used for the control of overhead such as routing packets. Without using dedicated communication hardware such as routers, the development of a hierarchical clustering system within the network is a possible method to optimize communication within the network (Fan et al., 2007). Clustering is vital for efficient resource consumption and load balancing in large scale networks. Routing based on clustering is appropriate for vehicular networks because vehicles may be formed as clusters in roads. The advantages of clustering can be summarized as follows (Liu et al., 2007): (1) clustering can facilitate the reuse of resources and then can improve the capacity of VANET, (2) clustering can decrease the amount of information that is used to store the network state, (3) the amount of routing information propagated in the network can be reduced in cluster-based routing, (4) a cluster-head (CH) can gather the status of its members and build an overview of its cluster condition, and (5) distant vehicles outside a cluster usually do not need to know the details of specific events occurring inside the cluster.

In clustering, vehicles are located inside clusters, where each cluster has one cluster-head, and one or more members. Vehicles that form a cluster are coordinated by the relevant cluster-head. Vehicles in one cluster communicate together directly, but vehicles that are located in two different clusters can communicate together via cluster-heads. Each vehicle can play three roles: cluster-head, gateway, and member. If one vehicle is located within two or more clusters, it is called a gateway.

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doi:10.1016/j.jnca.2010.07.016

Cluster-heads maintain information about their members and gateways. In this approach, data and control packets are sent via cluster-heads and gateways. In order to prevent interference among inter and intra-clustering transmission, each cluster-head communicates with two different frequencies. One frequency is used to communicate among cluster-heads and another frequency is allocated to communicate between each cluster-head and its members (Varadharajan et al., 2004).

When a vehicle moves out of its cluster, it will firstly check whether it can be a member of other clusters. If such a cluster exists, it will separate itself from current cluster and join to the new one. The process of joining to a new cluster is known as re-affiliation (Wang and Bao, 2007). One disadvantage of common clustering algorithms is high re-affiliation frequency when network topology changes very fast. High frequency of re-affiliation will increase re-calculations of determining cluster-heads, and consequently will increase the communication overhead in network (Wang and Bao, 2007). Thus, reducing the number of re-affiliations is necessary in VANETs. Therefore, a good VANET clustering algorithm should reduce the number of cluster swaps and increase stability of network (Fan et al., 2007).

In addition, it is important to forward correctly messages in VANET. However, the messages may be damaged by attacker nodes. Attackers may perform in several ways with different objectives (Picconi et al., 2006) such as eavesdropping the communication between vehicles, dropping, changing, or injecting packets into the network. Therefore, with respect to the lack of coordinator unit in VANET, vehicles should cooperate together to enhance security performance of VANET. Note that security at routing level is very important because protocol layers on top of the network layer would not work properly when routing fails.

Network connectivity is an important criterion for organizing VANET (Lee, 2008). When the inter-vehicle network has low interconnection, it must ensure that information is disseminated to and within a targeted area (Adler, 2006). It means that connectivity shows the probability that a vehicle can make a connection to exchange information with another vehicle. However, vehicles may even leave a certain area without having met another network vehicle to communicate with each other. There are factors that affect the network connectivity such as the density of vehicles, the distribution of vehicle positions, the geographical characteristics, and the transmission range (Lee, 2008). However, the transmission range is a very critical factor to the connectivity in VANETs. In VANET, a static transmission range cannot maintain the network's connectivity because of the non-uniform distribution of vehicles and rapid change of traffic conditions (Artimy, 2007). Therefore, a dynamic transmission range is required to maintain a good connectivity in non-uniform networks.

The contributions of this paper are the proposal of three algorithms suitable for highway scenario as: (1) to propose the vehicular clustering based on weighted clustering (VWCA) technique that uses different parameters to select cluster-heads so that the stability, connectivity, and security performances of VANET can be improved; (2) to design an adaptive allocation of transmission range (AATR) technique that uses hello messages and considers the density of traffic around vehicles. This technique can guarantee connectivity and ensure that other vehicles can receive messages. Moreover, AATR is a useful technique for VANET clustering; and (3) to provide a monitoring of malicious vehicle (MMV) algorithm to monitor behavior of vehicles in the network in order detect abnormal vehicles in the system.

The organization of this paper is as follows. Related works are reviewed in Section 2. In Section 3, definitions, equipments, and network model are mentioned. The VWCA algorithm is stated in Section 4. In Section 5, we detail the AATR algorithm. The MMV algorithm is described in Section 6. Performance evaluations of the new algorithms are showed in Section 7. Section 8 provides a brief conclusion.

2. Related work

In order to elect a cluster-head, several heuristic techniques have been proposed such as highest-degree heuristic (Lin and Gerla, 1997; Gerla and Tsai, 1995), lowest-ID heuristic (Lin and Gerla, 1997; Baker and Ephremides, 1981), and weighted clustering algorithm (WCA) (Chatterjee et al., 2002). WCA gets the advantages of other algorithms, where it considers the degree of a vehicle, average speed, and distance as input parameters. One disadvantage of WCA (Chatterjee et al., 2002) is its high re-affiliation frequency when network changes very fast. However, some characteristics of VANET cause that the traditional approaches proposed for MANET cannot be appropriate for clustering of VANET. For example, high dynamic mobility of vehicles and high change of network topology in VANET reduce the stability of cluster formation when using MANET approaches. In Fan et al. (2005), two D-HD and D-LID methods have been suggested to improve the stability of the highest degree and lowest-ID algorithms for VANET. A clustering for open inter-vehicle communication networks (COIN) algorithm (Blum et al., 2003) has been proposed in which a cluster-head is selected based on vehicular dynamics and driver intentions, instead of ID or relative mobility in classical clustering methods. COIN can improve the stability compared to the Lowest-ID. A reactive location based routing algorithm (Santos et al., 2005) has been presented that uses cluster-based flooding for VANETs, called location-based routing algorithm with cluster-based flooding. However, LORA-CBF increases routing overhead, general overhead and routing load. A direction-based clustering (Fan et al., 2007) has been suggested for VANETs that takes into consideration the moving direction of vehicles and leadership of cluster-heads. An improved compound clustering algorithm has been introduced in Fan et al. (2006) which takes into account the degree, the position, the velocity, and the acceleration of vehicles. The stability of VANET can be improved by Fan et al. (2007, 2006), but without considering the behavior of vehicles. Therefore, an abnormal vehicle may be selected as a cluster-head.

To maintain connectivity, some algorithms are introduced. The neighbor-based approach is based on maintaining the number of neighbors that can be reached by a vehicle within certain thresholds by adjusting transmission power (Liu and Li, 2002). This approach is simple but does not guarantee connectivity. In Li et al. (2005), it has been showed that the network connectivity can be guaranteed if there exists at least one neighbor in each cone of a certain angle centered at the vehicle. The fair power adjustment for vehicular algorithm (Monero et al., 2005) has proposed a power control algorithm to find the optimum transmission range of every vehicle in which the minimum transmission range for all vehicles is maximized in a synchronized approach. Then, a maximum transmission range is achieved for all vehicles individually, while satisfying the condition of keeping the channel load under a certain limit (Monero et al., 2005). Moreover, there is a dynamic transmission range algorithm (Chatterjee et al., 2002), which is closely related to a class of topology control algorithms that control a vehicle's degree by adjusting the transmission power. This algorithm depends on the mobility of vehicles and local density is estimated locally.

There are several proposed algorithms for security purposes and detecting attacker nodes in VANET. Existing works on VANET security (Raya and Hubaux, 2007; Yan et al., 2008; Guo et al.,