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TMA: Trajectory-based Multi-Anycast forwarding for efficient multicast data delivery in vehicular networks

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ABSTRACT

This paper describes Trajectory-based Multi-Anycast forwarding (TMA), tailored and optimized for the efficient multicast data delivery in vehicular networks in terms of transmission cost. To our knowledge, this is the first attempt to investigate the efficient multicast data delivery in vehicle networks, based on the trajectories of vehicles in the multicast group. Due to the privacy concern, we assume only a central server knows the trajectory of each vehicle and the estimated current location of the vehicle. Therefore, after receiving a request of multicast data delivery from a source vehicle, the central server has to figure out how the data has to be delivered to the moving vehicles in the multicast group. For each target vehicle in the multicast group, multiple packet-and-vehicle rendezvous points are computed as a set of relay nodes to temporarily hold the data, considering the vehicle's trajectory. This set of rendezvous points can be considered an Anycast set for the target vehicle. We have formulated the multicast data delivery as the data delivery to the anycast sets of the multicast group vehicles. Through theoretical analysis and extensive simulation, it is shown that our design provides an efficient multicast for moving vehicles under a variety of vehicular traffic conditions.

1. Introduction

Vehicular Ad Hoc Networks (VANETs) have become one of key components in Vehicular Cyber-Physical Systems for Intelligent Transportation Systems (ITSs) [1–5]. This is because VANET can support the *in situ delivery* of data messages for emergency information dissemination (e.g., accidents and driving hazards), real-time traffic estimation for trip planning, and mobile Internet services. Espectially, for the driving safety (e.g., collision warning message delivery), VANET is more prompt and reliable than cellular networks (e.g., 3G and 4G-LTE) having an additional delay due to data relay via base stations. Also, to support various road network services with cellular networks while servicing the data and voice traffic generated by cellular phones and smartphones, the service providers of the cellular networks will have to spend significant expenses for the infrastructure expansion and service maintenance due to those additional road network services. Based on these observations, VANET is considered worthy of specialized wireless networks for road network services.

For a varity of road network services for the driving safety and efficiency, VANET can leverage the wireless communications for up-to-date data sharing among vehicles having common interests, such as the images or video clips of driving hazard spots, congested areas, and street parking lots. This will be realized through (i) the standardization of Dedicated Short Range Communications (DSRC) [6] for vehicular communications, (ii) the popular demand of GPS navigation systems [7] for the efficient driving, and (iii) the participatory sensing through smartphones or computer vision devices for vehicle safety (e.g., Mobileye

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[8]). Therefore, with this trend, we can raise one natural research question of how to take advantage of these GPS-guided driving paths (called *vehicle trajectories*) to efficiently share data in vehicular networks in terms of minimal wireless communication cost.

In this paper, we take advantage of *vehicle trajectories* to efficiently dispatch messages or data to a group of vehicles (defined as *multicast group vehicles*) that have common interests (e.g., road conditions along the driving paths and street parking scenes in urban areas). For examples, we envision that (i) intelligent driving guidance and (ii) location-based service are viable applications. First of all, it is assumed that some of vehicles or smartphone users (as participatory sensors) report regularly their sensing information (e.g., road conditions and environments) collected from their various sensors (e.g., accelerometer [9] and mono-camera [8]) to Traffic Control Center (TCC) [10]; note that TCC is a central server maintaining the vehicle trajectories for the location management for the data delivery toward mobile vehicles like Mobile IP. First, for the intelligent driving guidance, when a road segment is congested, TCC is aware of cars that will go through this segment, based on their trajectories. TCC can notify these cars of this congestion along with the video clip, image or statistics of this congested road segment in the multicast data delivery so that they can select another better moving path beforehand. Second, a location-based service is a targeted information sharing through the up-to-date photos including the gas prices of gas stations among vehicles that may go through the nearby region. It is desirable for this information to reach those relevant vehicles earlier for their possible visit in a wireless-network-bandwidth efficient way, such as multicasting. Note that both applications have to be aware of vehicle trajectories and it is overkill to use broadcast radio to target a fixed set of vehicles having common interests instead of the DSRC communications [6]. On the other hand, the current multicast approaches [11,12] for vehicular networks are not fully addressing this important property of vehicle trajectory to support our target applications for the efficient utilization of wireless channel.

Our paper proposes Trajectory-based Multi-Anycast forwarding (TMA), tailored and optimized for the efficient multicast data delivery in vehicular networks in terms of transmission cost (i.e., the number of transmissions). To the best of our knowledge, our TMA is the first attempt to investigate the vehicle trajectory for the efficient multicast data delivery.

For an efficient multicast, we have the following two challenges. The first challenge is how to select packet-and-vehicle rendezvous points for multicasting. With the vehicle travel delay and packet delivery delay distributions, our TMA algorithm determines multiple rendezvous points (a set of relay nodes to temporarily hold data packets) of the destination vehicle and the packet. These rendezvous points are called *target points* in this paper and can be considered an Anycast set for the destination vehicle. Thus, we formulate the multicast data delivery to multiple destination vehicles in the multicast group as to deliver data to any target points in the anycast sets of those destination vehicles.

The second challenge is how to connect these anycast sets by selecting one target point per anycast set (called representative target point) into a multicast tree, guaranteeing a given data delivery ratio. Our TMA algorithm constructs a Delivery-Ratio Constrained Minimum Steiner Tree with the representative target points for a multicast tree with a minimum channel utilization [13]. Once the multicast tree is constructed, a packet with the multicast tree encoded is source-routed to the target points corresponding to the relay nodes that will hold and deliver the packet to the multicast group vehicles.

Our intellectual contributions are as follows:

- **A multicast data delivery architecture in vehicular networks.** The architecture supports a macro-scoped multicast for multicast group vehicles moving on the different road segments of a target road network.
- **An optimal target point selection algorithm for a multicast group.** This algorithm minimizes the number of target points for the multiple destination vehicles in the multicast group, while guaranteeing the user-required data delivery ratio.
- **A multicast tree construction algorithm for a target optimization goal.** With the selected target points, a multicast tree per packet is constructed to minimize the overall multicast delivery cost or delivery delay, considering the mobility of the multicast group vehicles at the packet transmission time.

The rest of this paper is organized as follows: Section 2 summarizes the related work. Section 3 describes the problem formulation. Section 4 explains the packet and vehicle delay models. Section 5 explains our TMA design. Section 6 explains our TMA protocol. Section 7 evaluates our design. Finally, this paper is concluded with future work in Section 8.

2. Related work

Recently, the VANET research has put a lot of attention on the data forwarding for vehicle-to-vehicle or vehicle-to-infrastructure communications [2–5,14,15]. Most of them are focused on the unicast data forwarding in vehicular networks.

Many data forwarding schemes (e.g., *VADD* [2], Delay Bounded Routing [3], and *SADV* [16]) are investigating the layout of road network and vehicular traffic statistics for the multihop Vehicle-to-Infrastructure (V2I) data delivery. *VADD* [2] investigates the data forwarding based on a stochastic model to achieve the *lowest delivery delay* from vehicle to AP. On the other hand, Delay Bounded Routing [3] proposes data forwarding schemes to satisfy the *user-defined delay bound* rather than the *lowest delivery delay*, while minimizing the channel utilization. *SADV* [16] first proposes a forwarding structure leveraging relay nodes for reliable data delivery. *TBD* [17] utilizes vehicle trajectory information along with vehicular traffic statistics for shorter delivery delay and better delivery probability for multihop vehicle-to-infrastructure data delivery. *TSF* [18] first supports the forwarding for multihop Infrastructure-to-Vehicle (I2V) data delivery, based on vehicle trajectory.