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An integrated VANET-based data dissemination and collection protocol for complex urban scenarios

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ABSTRACT

Data dissemination and data collection to/from vehicles traveling on city roads are key features to fully enable the advent of Intelligent Transport Systems and Autonomous vehicles. Both Road Side Units and On Board Units need to disseminate different kind of data to vehicles or to collect data sensed by the vehicles themselves and transfer them to road monitoring and control centers. In this work we propose a protocol, named DISCOVER, that disseminates and collects the data of interest in a quite large city area efficiently and timely by using a single network structure, i.e., a multi-hop backbone made up only of vehicles nodes. DISCOVER is distributed and adaptive to the different traffic conditions, i.e., to the different levels of vehicular traffic density. Several numerical results show that it attains very good performance in different type of city maps (New York, Paris, Madrid and Rome) when compared with baseline approaches as well as when compared with a theoretical bound.

1. Introduction

Intelligent Transportation Systems (ITS) integrate Information and Communications Technology (ICT) with transportation engineering methods to get an improved knowledge of current and future states of the transportation system and, possibly, to react to unexpected perturbations in order to keep the system near a desired state of safety, efficiency and comfort. The transportation system is traditionally represented through the interactions between its elementary components: travelers, vehicles, and infrastructure. These interactions affect and, at the same time, are affected by the external environment, both at monadic level - that is, the single vehicle - and at aggregate level, represented by the traffic system. ITS applications enhance efficiency and effectiveness of these interactions thanks to a set of sensors that monitor the surrounding environment up to a certain extent, and a set of actuators that put in practice predetermined control rules.

Two key enablers of ITS services that can be supported by the Vehicular Ad-Hoc Network (VANET) technology are the data dissemination and the data collection from vehicles on the road. Data dissemination can be achieved through the use of vehicle-to-vehicle multi-hop communications, enabling the extension of the road span covered by the Road Side Units (RSUs) or On Board Units (OBUs) generating the data. This dissemination function is of interest for both safety and infotainment applications [1]. Another interesting function is the collection of data from vehicles, through the VANET. Vehicles can be used as sensors that monitor traffic, roads, the environment and send their data to a collection center. In opposition to the dissemination, data collection aims at gathering data, relevant to safety, traffic information, infotainment, over a given area of interest.

This article is an extension of our preliminary paper [2], in which we propose DISCOVER, a protocol for VANETs, that can be used both for data dissemination and collection in a complex urban scenario. Since data collection in real time from vehicles is a qualifying new aspect of our proposal, we focus on this aspect in this paper. Nevertheless, the protocol we propose merges the dissemination and collection functionalities in a modular way, so that the amount of information to be disseminated and/or collected and the repetition rate of the procedure can be tailored to any vehicular application environment. The proposed protocol design induces a self-organized VANET backbone structure, with no prior knowledge of the road map or of the intersection positions and no need for any special networking equipment. The VANET backbone is composed on relay nodes that can be used flexibly both to disseminate data and to collect FCD from roaming vehicles in the target area. The flexible composition of the dissemination and collection functions in a single protocol is a distinctive feature of DISCOVER.

The major contribution of this work are as follows:

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(i) The definition of an integrated protocol to disseminate and collect data in real time, based on a self-organized VANET.
(ii) The evaluation of the protocol performance as for real time FCD collection with a set of realistic simulation scenarios, based on the urban maps of New York, Rome, Madrid and Paris.
(iii) The definition of bounding benchmarks to qualify the performance achieved by the proposed protocol: on one side, we define a theoretical lower bound of the amount of overhead required to collect the data from the vehicles roaming in the Region of Interest (RoI) through the VANET; on the other side, we show results for two baseline approaches, RANDOM and FLOODING, that provide a gauge of the gap between ideal performance as predicted by the theoretical bound and of easily achievable performance with baseline strategies.

The rest of the paper is structured as follows. Section 2 provides an overview of the related work. Section 3 defines the theoretical performance bound. Section 4 describes our proposed protocol. Section 5 presents the performance analysis and the comparison with other solutions, while conclusions are drawn in Section 6.

2. Related work

Many research projects are in progress aiming at creating new and efficient data dissemination and collection schemes based on the VANET. The most widespread techniques to disseminate and collect data are broadcast-based, because of the advantage given by eliminating the complexity of route discovery, address resolution and topology management. The most of the proposed schemes that we find in the literature focus either on data dissemination, or on data collection.

A recent survey on dissemination protocols in vehicular networks is provided in [3]. One of the most used technique to implement an efficient data dissemination scheme is to identify only a small subset of vehicles responsible for re-broadcasting the information. We can find this idea in [4], where a new dissemination protocol, named Vehicular Backbone Network (VBN), has been proposed. Here the messages sent out by the RSU are forwarded only by those vehicles that are situated closest to *nominal relaying positions*, that are spaced out by a range *D*. The distance *D* is chosen so as to provide each receiving relay node with a SINR level that can support the intended packet transmission rate. Since VBN was designed especially for disseminating data in highways, we extended this protocol in order to disseminate and collect data in urban scenarios. In [5] Viriyasitavat et al. face the problem of data dissemination in urban scenarios in the presence of disconnected networks. They propose UV-CAST (Urban Vehicular Broadcast), a completely distributed protocol which utilizes both direct relays through multi-hop transmissions and indirect packet relays through the *store-carry-forward* (SCF) mechanism.

A number of researches and implementation efforts have been spent to investigate data collection schemes. In [6] Brik et al. propose a Token-based Clustered Data Gathering Protocol (TCDGP). This protocol divides the interested road in two types of segments: Collection Segments (CS), where the vehicle-to-vehicle (V2V) communication is allowed, and Silent Segments (SS), where V2V communication is prohibited in order to avoid collisions between adjacent segments. A Cluster Head (CH) vehicle is elected for every CS, considering the vehicles distance from the center of the CS and the time traveled on the middle lane, which is in charge of collecting data inside the CS. This solution was designed to collect data on highways, while our protocol aims at collecting data in urban environments. A similar approach can be found in [7], where Chang et al. propose TrafficGather. This protocol also divides the road into a series of contiguous clusters and for each cluster it elects a Cluster-head Vehicle (CV). Once the clusters are created, each vehicle sends its information to its own CV according to a TDMA Access Control Algorithm (TACA) proposed by the authors, in order to avoid collisions. In the data retrieval phase the CVs send their collected data towards the initiating vehicle using a flooding strategy, which generates a very large overhead.

A different approach for data collection is found in [8], where the authors propose ADOPEL (Adaptive Data Collection Protocol using Reinforcement Learning). It is a data collection technique designed to collect data on highways while making the collection operation more reactive to nodes mobility and topology changes. The protocol is based on a distributed Qlearning technique where a reward function is provided and defined to take into account the delay and the number of packets to aggregate. The collect operation is periodically started by a randomly selected node called *initiator*, which has to collect the traffic data from vehicles and deliver it to a Traffic Control Center (TCC). The selection of the best next relay is based on the Qvalue, determined by the Qlearning algorithm. Zhang and He [9] proposed a two-way data collection scheme for VANET. Their algorithm is completely stateless, thus vehicles neither store neighbor information locally nor detect neighbors change. The algorithm is divided in two phases: the dissemination phase and the collection phase. The process starts with a request message from BS (Base Station), which is further disseminated possibly to all vehicles using broadcasting. In order to deal with the broadcast storm problem [10], the authors propose two mechanisms: *Rebroadcast filtering* and *Duty Cycled Execution*. The first mechanism tries to reduce the redundant rebroadcasts by filtering the received messages: only on receiving a message for the first time vehicles have to rebroadcast. The second tries to reduce the contention and collision by restricting the transmission frequency: vehicles are allowed to broadcast once in a fixed duty cycle. As for the data collection phase, the authors propose to use the same algorithm adopted for data dissemination phase. In particular, once a vehicle receives a request message, besides continuing the dissemination process, it also sends back a reply message containing the requested information. Vehicles in charge of returning the reply message back to the BS are selected based on their geographical proximity to the BS itself. Since this protocol basically uses a flooding approach to collect data, it induces a large overhead due to multiple re-broadcasting of messages. The problem of delay-constrained data aggregation in VANETs is faced in [11] by Zhu et al. They propose a two version (centralized and distributed) approach called *aTree*, which first constructs a data aggregation tree using a *flooding* approach, and then assigns a waiting time budget for each node on the tree. Their basic idea is to assign larger waiting timers to nodes closer to the collection node, in this way allowing child nodes to send their information earlier. Nodes aggregate all the data received from their child nodes in the tree before transmitting it towards the collection node.

A more recent trend in vehicular networking focuses on data dissemination and collection using a hybrid approach: vehicles use VANETs for V2V communication, and cellular networks for vehicle-to-infrastructure (V2I) communication. For example, the authors in [12] present a mechanism for information dissemination based on virtual infrastructure selection in combination with multiple communication technologies. They aim at increasing the penetration of information by defining an optimal dissimilarity relation among vehicles elected as virtual infrastructure. Salhi et al. [13] propose CGP (Clustered Gathering Protocol), a cross-layered gathering, dissemination and aggregation protocol. The idea of the protocol is to divide the road in virtual segments with the same length. In each segment a Cluster Head (CH) is elected, that gathers data from all nodes in its segment and aggregates them, before sending this result to the next segment or to the base station. Another framework