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Vehicular Ad-Hoc Networks sampling protocols for traffic monitoring and incident detection in Intelligent Transportation Systems

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ABSTRACT

Vehicular Ad-Hoc Networks (VANETs) are an emerging technology soon to be brought to everyday life. Many Intelligent Transport Systems (ITS) services that are nowadays performed with expensive infrastructure, like reliable traffic monitoring and car accident detection, can be enhanced and even entirely provided through this technology. In this paper, we propose and assess how to use VANETs for collecting vehicular traffic measurements. We provide two VANET sampling protocols, named SAME and TOME, and we design and implement an application for one of them, to perform real time incident detection. The proposed framework is validated through simulations of both vehicular micro-mobility and communications on the 68 km highway that surrounds Rome, Italy. Vehicular traffic is generated based on a large real GPS traces set measured on the same highway, involving about ten thousand vehicles over many days. We show that the sampling monitoring protocol, SAME, collects data in few seconds with relative errors less than 10%, whereas the exhaustive protocol TOME allows almost fully accurate estimates within few tens of seconds. We also investigate the effect of a limited deployment of the VANET technology on board of vehicles. Both traffic monitoring and incident detection are shown to still be feasible with just 50% of equipped vehicles.

1. Introduction

Intelligent Transportation Systems (ITSs) integrate Information and Communications Systems (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. ITSs enhance efficiency and effectiveness of the interactions among different components of the transport system (vehicles, road, drivers) thanks to a set of sensors that monitor the near and the far environment, and a set of actuators that put in practice predetermined control rules.

Vehicular Ad-Hoc Networks (VANETs) allow Dedicated Short Range Communications (DSRC) of vehicles in the 5.9 GHz band, through the IEEE 802.11p standard. They support ITS with both Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications for applications in both near and far environment; in such a way, VANETs are a

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technology that enables a unified framework for integrating traditional ITS applications, Advanced Driver Assistance Systems (ADAS), Advanced Traveller Information Systems (ATIS), and Advanced Traffic Management Systems (ATMS).

Applications of V2V/V2I communications to ATIS and ATMS provide these systems with a monitoring subsystem that exploits equipped vehicles as probes in the traffic stream and, at the same time, with a communication system that allows vehicles exchanging information with each other regarding current traffic speed or any other useful message on traffic conditions. ATIS and ATMS can be effectively integrated in order to have a unique platform that controls regulation devices such as traffic signals and provides users with updated proactive information in a consistent way. Not only traffic monitoring and communication tasks are transferred to vehicle communication devices; also a significant part of data processing can be distributed and conveyed to the vehicle communication network, since on-board devices can apply transmission protocols that process data exchanged between vehicles without requiring transmission and processing of data by a traffic control center.

Effectiveness of VANET applications on ATIS/ATMS is significantly affected by the penetration rate of equipped vehicles, which impacts primarily on the communication network reliability. It is worth noticing that, even if information transmission can be ensured, penetration rate determines the sample of vehicles tracked and then the accuracy of traffic state estimates, thus affecting the reliability and effectiveness of the system.

In this work we look at a perspective where the majority of vehicles are equipped with standardized VANET On Board Units (OBU) and we explore the potential of VANETs in the collection of Floating Car Data (FCD) over urban highways. Specifically, we aim at assessing the effectiveness of FCD collection through VANET multi-hop communications in order to minimize the required fixed infra-structure. We made a preliminary investigation of this problem in De Felice et al. (2014). Here we provide a more formal description of the VANET protocols and an in-depth performance evaluation of an incident detection algorithm on top of the VANET based monitoring system. The algorithm is shown to be quite effective, in spite of the simplicity of the VANET system and of the light load it imposes on the VANET (0.08 kbps for the sampled FCD collection and 40–50 kbps for the exhaustive collection).

We test the algorithm by setting up incident scenarios on an urban highway ring about 70 km long, around Rome, Italy. Micro-mobility is simulated with SUMO (e.g., see Behrisch et al. (2011)) and the communication process by means of NS2 (e.g., see Fall and Varadhan (2000)). Vehicular traffic generation is tuned by means of massive GPS real data collected from vehicles monitored on the same highway. We investigate the impact of the penetration rate of VANET equipment on traffic monitoring and incident detection capabilities. Our approach still works when not all the vehicles are equipped with DSRC devices.

To sum up, the major contributions of this work are: (i) definition of two practical, lightweight protocols for vehicular traffic monitoring based on VANET; (ii) detailed, integrated simulations of micro-mobility and communications, trained by real vehicular data; (iii) definition and evaluation of a real time incident detection algorithm exploiting the traffic data collected by the VANET based protocol.

The rest of the paper is so organized. The related literature is reviewed in Section 2. The VANET data collection protocols are presented in Section 3. Section 4 outlines the simulation scenario used to test the protocol performance, based on a real highway and driven by vehicular traffic generated from real data. A performance evaluation analysis is presented in Section 5. Conclusions are drawn in Section 6.

2. Related work

In the last years, a broad literature arose concerning VANET applications to different ITS subsystems, ranging from ADAS (specifically, cooperative collision warning), to ATMS (as far as virtual traffic lights, traffic monitoring, incident detection) and ATIS (regarding advanced speed control, route guidance). Traditional traffic monitoring systems are based on fixed sensors, like inductive loops or video image processors, which detect traffic state variables, such as occupancy, flow and sometimes speed, and process the collected data to detect possible incidents or predict future traffic conditions in the short term.

A comprehensive overview of the vast literature on this field is out of the scope of this paper. The interested reader can refer to Vlahogianni et al. (2014) for an updated critical review of the recent literature. We just focus here on incident detection algorithms, which provide a partial but significant example of diagnostic models.

Incident detection algorithms developed in the 70s, like California of Payne and Tignor (1978), were based on occupancy measures at fixed road sections and tried to recognize anomalous conditions by comparing upstream and downstream traffic density measures; that is, by observing the effects of the incident on traffic flow. Statistical algorithms detect significant differences between observed data and traffic characteristics predicted by prior probabilities, as done by Dudek et al. (1974), or by time-series and filtering analysis, as in Ahmed and Cook (1982), Stephanedes and Chassiakos (1993).

McMaster algorithm applied the Catastrophe theory to recognize an abrupt interruption of the regular pattern in the flow-speed-occupancy space (Persaud et al., 1990). Then, several different methods were introduced that apply artificial intelligence techniques, including neural networks (Stephanedes and Liu, 1995; Adeli and Samant, 2000), fuzzy logic (Lin and Chang, 1998), and a combination of these two techniques, as in Hsiao et al. (1994), Ishak and Al-Deek (1998).

The performances of the aforementioned algorithms depend on the balance of the thresholds chosen for incident identification. If thresholds that provide false alarm lower than 2% are chosen, the mean time to detect an incident ranges from about 1 min to 6–8 min (Mahmassani et al., 1998).