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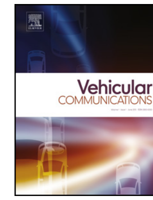

Supporting augmented floating car data through smartphone-based crowd-sensing

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ABSTRACT

Over the last few years, academia, governmental agencies, automotive and electronic industries have increased their interest in Intelligent Transportation Systems (ITS) and services. The leading European ITS stakeholders are pushing to start a few "day-one" applications in 2015. Among them, the collection of Floating Car Data (FCD) generated by moving vehicles is expected to support many practical use cases in a near future, such as road safety provision, in-vehicle diagnostics, and traffic monitoring. This paper shows that *consumer devices on the mass market* (such as smartphones) *and available networking technologies* (such as Wi-Fi and cellular) can compensate for the current lack of dedicated equipment and mature vehicular communication technologies.

The proposed SmartCar (*SMARTphone-based floating CAR data collection*) platform gives a twofold contribution to the efficient support of early ITS applications on a *large-scale* through: (*i*) an intelligent use of smartphones to collect "augmented" FCD from in-vehicle telematics and external sensors (e.g., pollution detectors for urban sensing), and (*ii*) the adoption of an *offloading* strategy that leverages Wi-Fi hotspots to alleviate the burden on the cellular network due to the massive generation of "augmented" data. The technological feasibility of SmartCar for augmented FCD gathering and remote transfer is demonstrated through a prototype, preliminarily experimented on board the vehicle and based on *low-cost off-the-shelf hardware* and *open-source software*. Results from preliminary field trials are collected, whereas the effectiveness of offloading at a large-scale is further assessed by a simulation campaign under realistic settings.

1. Introduction

A wide range of Intelligent Transportation Systems (ITS) services, including safety applications, traffic efficiency, predictive maintenance, infotainment, smart green mobility, and pervasive sensing, can be provided by letting vehicles exchange data with each other and with the road infrastructure.

The following "day-one" vehicular applications have been selected for deployment by the leading European ITS stakeholders starting in 2015: in-vehicle signage, floating car data (FCD), intersection safety/green wave, road works warning, traffic information, strategic routing, hazardous location warning [1]. Among them, especially FCD-related services have the potential to support many practical applications for safety, vehicle diagnostics and road traffic monitoring.

FCD refers to the collection of vehicles' position and kinematics data (e.g., speed, direction of travel) to get traffic information for ITS applications. Furthermore, thanks to the advancements in in-vehicle telematics, FCD can also include reports about the status of microprocessor-based electronic control units networked within the vehicle through the Controller Area Network (CAN) bus. Environmental sensors (like pollution detectors) can be easily brought into the picture to augment the scope of FCD-enabled applications towards urban sensing operations, so that vehicles can be integrated in the future smart-city infrastructure [2]. Henceforth, we will refer to the resulting set of collected data as "*augmented" FCD*.

These augmented data can be processed by remote control centers for multiple purposes, e.g., to monitor road traffic conditions and prevent congestion [3,4], to inform fleets of vehicles cooperatively driving [3], to detect possible in-vehicle malfunctions, to collect traffic statistics, to get car maintenance tips and service information. Depending on the purpose of the FCD collection, data may have different time validity (time interval during which the information is relevant for the service) and accuracy demand. For

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example, if extracted traffic-related data are used for traffic signs adaptation, then a few seconds validity is reasonable, whereas long-term road traffic statistics may tolerate longer validity times, up to some minutes, and a lower number of samples; finally, data pertaining to long-term car maintenance can be stored for days on the vehicle before transmission.

Despite the wide range of services potentially enabled by *augmented* FCD and the surging interest within standardization bodies, such as 3GPP (Third Generation Partnership Project) [3], ETSI (European Telecommunications Standards Institute) [4], and SAE (Society of Automotive Engineers) International [5], the deployment of standard communication technologies and protocols for the remote transfer of FCD is still underway. Stakeholders worldwide are struggling to finalize standards to allow specialized wireless on-board units (OBUs) to *directly* interact with the CAN bus and to communicate with other OBUs and with roadside units, under any propagation condition, intermittent connectivity, and traffic density [6].

Nonetheless, both technical (harsh vehicular environment) and economic barriers slow down the large-scale deployment and market penetration of Vehicular Ad hoc NETworks (VANETs) and OBU-equipped cars. Such factors challenge the capability of the automotive industry and standardization process to be fast enough in developing and pushing the new technology before the current consumer electronics and network technologies available in the market offer valuable alternative solutions.

It is the authors' convincement that the current need for *augmented* FCD could be satisfied by using *mass-market users' devices, such as smartphones, and available technologies, such as cellular and Wi-Fi networks*. This convincement is shared with the scientific community [7] and many running initiatives are pushing towards enabling users' portable devices, such as tablets and phones, to access in-vehicle telematics [8] and to monitor in-vehicles services through low-cost devices and open-source software [9,10]. In addition, several solutions have been proposed that leverage smartphones in the automotive context, e.g., for safety [11,12] and traffic management purposes [13,14], or to collect driving habits [15–17]. Finally, the Open Automotive Alliance (OAA), a group of leading automotive manufacturers and technology companies [18], also argues for a close alignment of consumer and automotive technologies and pushes towards bringing the *Android* platform to the car, to make in-car technology safer and more intuitive for everyone.

Although the use of smartphones is a timely solution to offer automotive services with a *short-time-to-market*, some issues needs to be addressed when considering FCD-based services. Specifically, the amount of uploaded data from a large number of contributing vehicles with a frequency of seconds risks burdening the cellular network and drain the smartphone's battery. Consequently, either traditional cellular traffic (e.g., voice) could be penalized or FCD applications could achieve poor performance being unable to meet time delivery and integrity requirements. Solutions in the literature, targeting to solve such an issue and alleviate the cellular network load, either leverage the upcoming IEEE 802.11p technology to collect data to be aggregated and remotely delivered [19, 20], or probabilistically select a subset of cars to take part in the process [21] by assuring only partially accurate data retrieval.

The work in this paper addresses the support of FCD services in a more comprehensive way, with the design and demonstration of a solution encompassing smartphones for (*i*) efficient data collection from a wide set of heterogeneous (in-vehicle and external) sensors to effectively provide *augmented FCD services*, and (*ii*) opportunistic data delivery through a simple cellular traffic *offloading* technique designed to exploit on-the-road Wi-Fi connectivity by leveraging the built-in smartphone's Wi-Fi network interface card (Fig. 1).

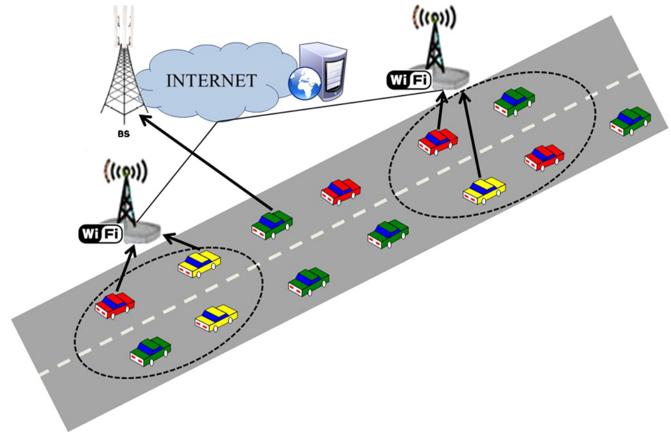

Fig. 1. Reference scenario: vehicles transmit augmented FCD traffic to either the cellular network or a Wi-Fi hotspot.

Cellular network offloading may significantly reduce costs for cellular operators to tackle increasing traffic demands, by avoiding the deployment of additional base stations or the upgrading of the existing ones. Unlike previous literature on offloading techniques, typically focusing on *downlink data transfers* in *low-mobility scenarios* [22], our work addresses *uplink data packets offload in vehicular environments*. Indeed, in [23] vehicular Wi-Fi offloading is preliminarily debated as a promising research direction, provided that some issues uniquely arising in vehicular environment (i.e., short and intermittent connectivity, fast fluctuating wireless channels) are properly overstepped. Some of those concerns may hinder the effectiveness of offloading in the presence of bulky contents [23], but are deadened in case of *small packets*.

An early version of the SmartCar (*SMARTphone-based floating CAR data collection*) design [24] and its preliminary demonstrator [25] are extended in this paper with further functionalities to specifically target *augmented* FCD applications. The prototype deployed on board the vehicle leverages *low-cost off-the-shelf* hardware and *open source* software (e.g., *Arduino* platform [26] and Android [27]), which give to the designed solution the potentiality to be an effective mobile crowd-sensing tool.

The rest of the paper is organized as follows. Section 2 describes the set of services enabled by FCD and the issues raised by the evolution towards *participatory* FCD. Section 3 discusses the role of the smartphone in the SmartCar platform, whose main components are presented in Section 4 along with a rough cost analysis. Section 5 discusses the rationale behind design choices of the conceived platform. In Section 6 first field trials are introduced. Section 7 provides quantitative insights into the performance of the offloading technique through simulations conducted under realistic settings for the roads topology, the vehicular mobility patterns, the deployment of Wi-Fi access points, and the smartphone's parameters. Section 8 concludes the paper, providing hints about future work.

2. Floating car data: a day-one ITS application

2.1. FCD services

FCD enables a wide range of services, ranging from *traffic management* to *vehicle diagnosis* and *fleet management*, serving both the individual commuter and the community, and generating potentially high revenues for the stakeholders. In addition, FCD services are among the main representative use cases of a very hot topic, i.e., machine-to-machine (M2M) communications [3,4], considered as the foundation layer for the future world of smart objects, smart homes, smart cities.