Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 177 (2020) 474–479

Procedia Computer Science

www.elsevier.com/locate/procedia

The 4th International Workshop on Connected & Intelligent Mobility
(CIM 2020)
November 2-5, 2020, Madeira, Portugal

The Computer System Architecture of our first real-time real-world experiment of adaptive traffic signals with "connected" vehicles

Vittorio Astarita[a*], Vincenzo Pasquale Giofrè[a], Giuseppe Guido[a] and Alessandro Vitale[a]

[a]*Department of Civil Engineering, University of Calabria, Arcavacata di Rende (CS) 87036, Italy*

Abstract

Connected vehicles can transmit real-time information to traffic control management systems. Despite the recent technical advances of telecommunication networks and mobile computing there have been no real-time adaptive traffic signal control experiments with connected vehicles. Most of the research in this field has been carried out only with simulations. In this work we present the computer system that was adopted to regulate traffic signals in real-time with "smartphone-connected" vehicles as the only source of information. We introduce the description of the computer system architecture that was deployed in an experiment of a Floating Car Data (FCD)-based adaptive traffic signal in which a traffic signal has been regulated in real-time with 100% "smartphone-connected" vehicles. The description of the system based on commonly-used technologies could help others to develop and deploy new traffic signal management systems in new "connected" intersections.

Keywords: adaptive traffic signals; Intelligent Transportation Systems (ITS); Floating Car Data (FCD); traffic management; connected and autonomous vehicles.

1. Introduction

Both connected vehicles and connected traffic signals are poisoned to become an important part of the forthcoming Internet of Things (IoT) and of Intelligent Transportation Systems (ITS).

* Corresponding author. Tel.: +39-0984-496780;
E-mail address: vittorio.astarita@unical.it

1877-0509
10.1016/j.procs.2020.10.065

Connected vehicles may help to manage and control road traffic in many new ways. Classic road traffic engineering practice was founded on efforts to allocate demand on transit systems [1] and on better road traffic control by adopting tools such as: traffic simulation [2–7] dynamic network loading equilibrium and dynamic models [8–11] and the implementation of efforts to influence user route choice [12–16].

There have been no practical advances in traffic signal regulation in the last years and traffic signals are very often controlled with prefixed signal settings that are not always appropriate for the always-changing traffic flows. This can cause traffic congestion that is a serious problem in cities and also a great cause of air pollution.

The use of inductive loops for real-time traffic signal control is the current standard and its limitation lies in the expensive infrastructure and maintenance resources that are necessary to keep them working.

Existing technologies such as smartphones can contribute to creating cheap "smartphone-connected" vehicles that can act as floating probe vehicles [17,18] (Floating Car Data: FCD), or the use of dedicated local wireless networks can create a dedicated vehicle to infrastructure (V2I) communication systems.

By combining smart-phones with existing wireless mobile phone data networks and Satellite localization systems, ITS can be deployed at a very low cost compared with ad hoc developed wireless systems that would bring higher costs.

The first research efforts on smart-phone-based FCD did not benefit from satellite positioning systems, nowadays, mobile phones can obtain position data and transmit this information; thus it is possible to evaluate travel times and speeds [19,20]. An assessment of some safety issues is also possible [21]. with assistance for a safer driving [22]. The estimation of fuel consumption [23–26], the measurement of road pavement problems [27,28], and route choice behavior-based research are also possible with smart-phones.

FCD was also used with the idea to help to keep a better driving approach at traffic signals and research has been carried on connected vehicles approaching traffic signals in real-time [29–32]. The only systems that were applied in the field, so far, have been systems in which the information coming from the traffic signal is used to adjust driving patterns. The reason for this might be that is easier to develop a helping driver interface than modifying traffic signal control [33] in a system such as the one presented in this paper.

In this paper, we describe the architecture of the computer system that was deployed in our experiment where a traffic signal was regulated by FCD of 100% of smartphone-connected vehicles. To the best of our knowledge, this is the first contribution on such kind of experiment with 100% connected vehicles.

2. Materials and methods

The general structure of the computer system, which was experimented in July 2019, is presented in Fig. 1, where the following physical parts are depicted:

- *The* traffic *signal:* the traffic signal that was used and was activated by a local controller;
- *The local signal control unit:* the local electronic controller (a Raspberry microcomputer see Fig. 2) was connected to the internet by Ethernet cable and was operating as a web server able to receive outside commands that would directly regulate the traffic signals. This webserver was based on an open-source software architecture running apache and a PHP script. This web server commanded the signal lights accordingly to a binary string received by the central control server described in the following. In detail, the Raspberry decides which General Purpose Input/Output (GPIO) to activate or deactivate that corresponds to different 9 relays. Three relays are used to control the lights corresponding to each of the three lanes of the intersection controlled with the traffic light. An exchange of information, through an Ethernet internet connection, is established between the local controller and the server only when the traffic signal has to change phase.

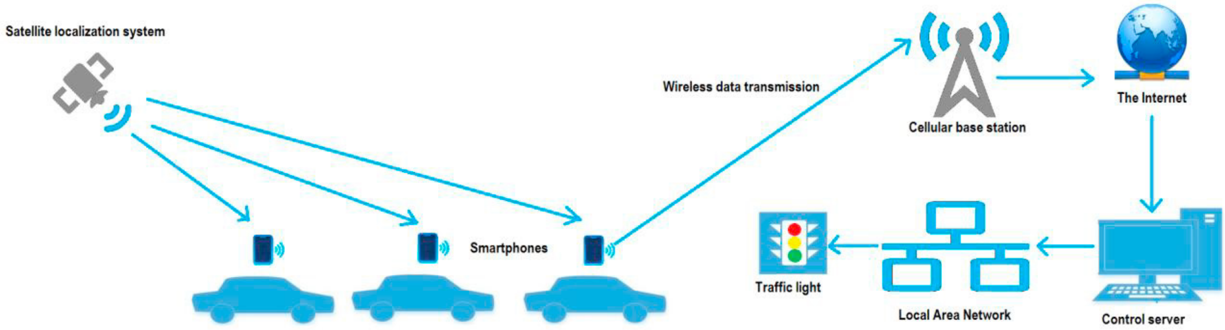

Fig. 1. The complete architecture of the system.

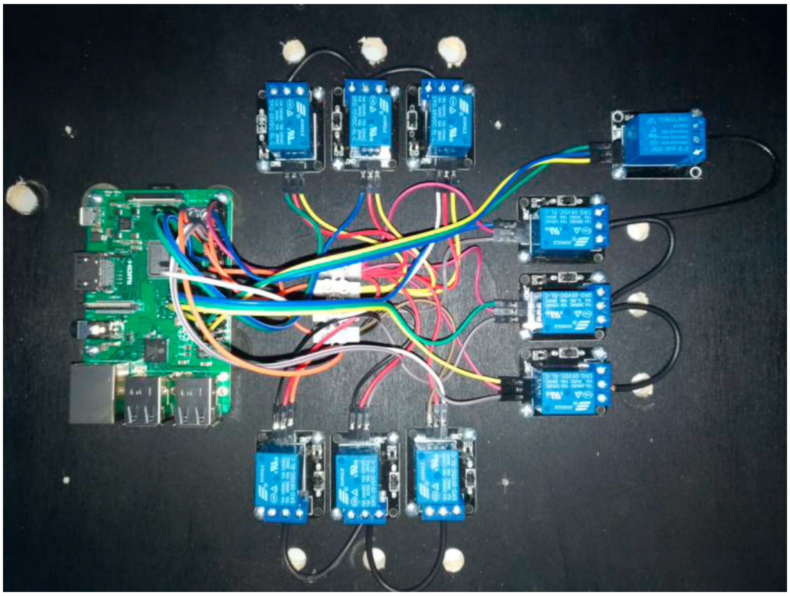

Fig. 2. The local signal control unit: on the left the Raspberry microcomputer that is connected to the 9 traffic light relays. An additional control Relay is switched on when the web-server software is active on the Raspberry (up on the right).

- *The central server:* a central server which was the "brain" of the traffic regulation algorithm by collecting data from "connected" vehicles" and establishing the optimal traffic signal timings. Timings were established according to a greedy algorithm that evaluates the quantity of "connected" vehicles on every intersection approach and assigns green time to the approach that has the longest queue. The queue estimation procedure is similar to that applied in [34]. More details on the implementation of this greedy algorithm are in [35] and in [36]. The central control system was a standard computer, namely a Dell PowerEdge 2650 with a 2.8 GHz Intel® Xeon ™ processor with 32bit technology, 512 MB ECC DDR SDRAM and 5 HDD 146 GB. It was connected to the Internet on the University 1000 GHz optical fiber link. We believe that any standard ADSL internet connection would have served the purpose. It is worthwhile noting that potentially the server could be located on the other side of the world since a lag in the order of the milliseconds would not impact the control system. The server was running Microsoft Windows Server 2008 system, MySQL database. Delphi language package was used to compile and implement the server code. The implemented code was able to collect the positions of the connected vehicles, estimate the queues, implement the control algorithm, and send the control requests to the local traffic signal control unit. We set the server to repeat this procedure every second. Every second the server would decide to prolong the green of the active phase or to grant the green to another phase. Once the server established a change of phase the information was sent via the internet to the signal control unit using the GET / POST protocol in the form of a 9-bit binary string. Each new phase was introduced: 1) for the previous green approach, with the sequence: green -> yellow -> all red -> red; 2) for the new green approach, with the sequence red-> all red > green; 3) for the red approaches, with the sequence: red-> all red -> red.

- The *vehicles:* the "connected" vehicles equipped with a smart-phone that can elaborate GPS data and send them to the central server (using common-standard wireless phone 3G-4G networks).

In other words, for this very first experiment, every connected vehicle had computing capabilities, the traffic signal had a local computer controller and a central server was gathering all information and deciding control strategies. That is one way to decline the concept of IoT. In the future, each operating entity (in this case each vehicle) and each infrastructure or service will have their computational capabilities, they will be connected to the internet and able to exchange information directly or make transactions through a central server. In some cases, such as our case (or for example in the case of a monetary transaction with a bank a central server), a ruling authority will also participate in the information exchange.

3. Results

The results of the experiment went beyond expectations. Before the experiment, we performed a microscopic traffic simulation of the traffic scenario and we were expecting positive results (see Fig. 3). In the actual experiment, we did have no hardware technical issues and the traffic dynamics were improved more than in the simulations (only one software issue with one among the different control algorithms we tested). Two drones were used to generate traffic videos, the videos were then elaborated to extract traffic parameters, more details on the traffic flow dynamics in the experiment can be found at [36].

Fig. 3. on the left the real traffic scenery of the experiment filmed with a drone on the right the simulated reality.

The mobile phones that we used in the experiment were all normal smartphones with standard wireless voice and data plans. Earlier works as the Finnish work of Kummala [37] or Rose [38] suggested that the usage of mobile phones as probes for dynamic traffic signals might not be practical. These results are outdated since the implementation of 4G and 5G as wireless data transmission standards make now possible to easily transfer all the necessary data. Moreover, the satellite localization module of modern smartphones has improved notably in time. More satellite constellations have been added to GPS such as GLONASS (Russian Federation), Beidou (China), and Galileo (European Union).

The accuracy of smartphone positioning has extremely improved in the last years and with our experiment, we demonstrate that the actual level of accuracy is enough to perform smart-phone based signal control optimization when there is limited sky occlusion. Of course in the presence of specific urban canyons, the same positive results may not be easily obtained but we believe on the base of our experience that most urban intersections in sparse urbanized areas can be easily dealt with (see also [39]).

The experiment demonstrated that with current technologies it is possible to implement adaptive traffic signals with "snartphone-connected" vehicles. There is no need for improvement of "hardware" elements:

- hardware computational capabilities and satellite localization accuracy that are necessary for this task are adequately met with standard mobile phones and cheap computer hardware;
- wireless data communication between connected vehicles and control unit can be easily performed on standard mobile phone data networks.

4. Discussion

The main obstacle that stands in the way of a city implementation of such traffic signal control systems is mainly the awareness of the politicians, the public, and the media on the feasibility of such systems. Scientific literature in general is proposing complicated ad hoc systems that are assessed only in simulation and that are far away from a real implementation. This paper possibly can help to demonstrate that solutions such as the one here presented, and experimented for the first time on the field, can be easily implemented in our cities. It is just necessary to empower people that have specific knowledge, with sufficient economic resources, to allow them to develop all practical improvements that the smart cities and smart traffic light signal deployment requires.

References

[1] Marzano,V., Tocchi,D., Papola,A., Aponte,D., Simonelli,F. and Cascetta,E. (2018) Incentives to freight railway undertakings compensating for infrastructural gaps: Methodology and practical application to Italy. *Transportation Research Part A: Policy and Practice*,. https://doi.org/10.1016/j.tra.2018.01.040

[2] Astarita,V., Florian,M. and Musolino,G. (2001) A microscopic traffic simulation model for the evaluation of toll station systems. *IEEE Conference on Intelligent Transportation Systems, Proceedings, ITSC*,.

[3] Astarita,V., Giofré,V., Guido,G. and Vitale,A. (2011) Investigating road safety issues through a microsimulation model. *Procedia - Social and Behavioral Sciences*, **20**, 226–35. https://doi.org/10.1016/j.sbspro.2011.08.028

[4] Young,W., Sobhani,A., Lenné,M.G. and Sarvi,M. (2014) Simulation of safety: A review of the state of the art in road safety simulation modelling. *Accident Analysis and Prevention*,. https://doi.org/10.1016/j.aap.2014.01.008

[5] Astarita,V. and Giofré,V.P. (2019) From traffic conflict simulation to traffic crash simulation: Introducing traffic safety indicators based on the explicit simulation of potential driver errors. *Simulation Modelling Practice and Theory*, Elsevier. **94**, 215–36. https://doi.org/10.1016/j.simpat.2019.03.003

[6] Osorio,C. and Punzo,V. (2019) Efficient calibration of microscopic car-following models for large-scale stochastic network simulators. *Transportation Research Part B: Methodological*,. https://doi.org/10.1016/j.trb.2018.09.005

[7] Martinez,F.J., Toh,C.K., Cano,J.C., Calafate,C.T. and Manzoni,P. (2011) A survey and comparative study of simulators for vehicular ad hoc networks (VANETs). *Wireless Communications and Mobile Computing*,. https://doi.org/10.1002/wcm.859

[8] Gentile,G. (2018) New formulations of the stochastic user equilibrium with logit route choice as an extension of the deterministic model. *Transportation Science*,. https://doi.org/10.1287/trsc.2018.0839

[9] Gentile,G. (2016) Solving a Dynamic User Equilibrium model based on splitting rates with Gradient Projection algorithms. *Transportation Research Part B: Methodological*,. https://doi.org/10.1016/j.trb.2016.02.005

[10] Cantarella,G.E., Di Febbraro,A., Di Gangi,M. and Giannattasio,O. (2019) Stochastic Multi-Vehicle Assignment to Urban Transportation Networks. *MT-ITS 2019 - 6th International Conference on Models and Technologies for Intelligent Transportation Systems*,.

[11] Cantarella,G.E. and Watling,D.P. (2016) A general stochastic process for day-to-day dynamic traffic assignment: Formulation, asymptotic behaviour, and stability analysis. *Transportation Research Part B: Methodological*,. https://doi.org/10.1016/j.trb.2016.05.005

[12] Trozzi,V., Gentile,G., Kaparias,I. and Bell,M.G.H. (2015) Effects of Countdown Displays in Public Transport Route Choice Under Severe Overcrowding. *Networks and Spatial Economics*,. https://doi.org/10.1007/s11067-013-9207-5

[13] Kucharski,R. and Gentile,G. (2018) Simulation of rerouting phenomena in Dynamic Traffic Assignment with the Information Comply Model. *Transportation Research Part B: Methodological*,. https://doi.org/10.1016/j.trb.2018.12.001

[14] Marzano,V., Papola,A., Simonelli,F. and Papageorgiou,M. (2018) A Kalman Filter for Quasi-Dynamic o-d Flow Estimation/Updating. *IEEE Transactions on Intelligent Transportation Systems*,. https://doi.org/10.1109/TITS.2018.2865610

[15] Papola,A., Tinessa,F. and Marzano,V. (2018) Application of the Combination of Random Utility Models (CoRUM) to route choice. *Transportation Research Part B: Methodological*,. https://doi.org/10.1016/j.trb.2018.03.014

[16] Papola,A. (2016) A new random utility model with flexible correlation pattern and closed-form covariance expression: The CoRUM. *Transportation Research Part B: Methodological*,. https://doi.org/10.1016/j.trb.2016.09.008
[17] Astarita,V., Festa,D.C. and Giofrè,V.P. (2018) Mobile Systems applied to Traffic Management and Safety: a state of the art. *Procedia Computer Science*, **134**, 407–14. https://doi.org/10.1016/j.procs.2018.07.191
[18] Wahlstrom,J., Skog,I. and Handel,P. (2017) Smartphone-Based Vehicle Telematics: A Ten-Year Anniversary. IEEE Trans. Intell. Transp. Syst. https://doi.org/10.1109/TITS.2017.2680468
[19] Guido,G., Vitale,A., Saccomanno,F.F., Carmine,F.D., Astarita,V., Rogano,D. et al. (2013) Using smartphones as a tool to capture road traffic attributes. Appl. Mech. Mater. https://doi.org/10.4028/www.scientific.net/AMM.432.513
[20] Guido,G., Saccomanno,F.F., Vitale,A., Gallelli,V., Festa,D.C., Astarita,V. et al. (2013) Extracting vehicle tracking data from smartphone sensors. *Proceedings of the 92th Annual Meeting of Transportation Research Board*,.
[21] Astarita,V., Giofré,V., Guido,G. and Vitale,A. (2012) Calibration of a new microsimulation package for the evaluation of traffic safety performances. *EWGT 2012 - Compendium of Papers*,.
[22] Vaiana,R., Iuele,T., Astarita,V., Caruso,M.V., Tassitani,A., Zaffino,C. et al. (2014) Driving behavior and traffic safety: An acceleration-based safety evaluation procedure for smartphones. *Modern Applied Science*, **8**. https://doi.org/10.5539/mas.v8n1p88
[23] Astarita,V., Guido,G., Mongelli,D. and Giofrè,V.P. (2015) A co-operative methodology to estimate car fuel consumption by using smartphone sensors. *Transport*, **30**. https://doi.org/10.3846/16484142.2015.1081280
[24] Astarita,V., Guido,G., Mongelli,D.W.E. and Giofrè,V.P. (2014) Ecosmart and TutorDrive: Tools for fuel consumption reduction. *Proceedings of 2014 IEEE International Conference on Service Operations and Logistics, and Informatics, SOLI 2014*,. https://doi.org/10.1109/SOLI.2014.6960716
[25] Astarita,V., Festa,D.C. and Mongelli,D.W.E. (2014) EcoSmart: An application for smartphones for monitoring driving economy. Adv. Mater. Res. https://doi.org/10.4028/www.scientific.net/AMR.827.360
[26] Astarita,V., Festa,D.C., Mongelli,D.W.E., Mongelli,N., Ruffolo,O. and Servino,A. (2014) EcoSmart: A survey and sector analysis of mobile phone application market for fuel consumption reduction. Appl. Mech. Mater. https://doi.org/10.4028/www.scientific.net/AMM.519-520.1544
[27] Astarita,V., Caruso,M.V., Danieli,G., Festa,D.C., Giofrè,V.P., Iuele,T. et al. (2012) A Mobile Application for Road Surface Quality Control: UNIquALroad. *Procedia - Social and Behavioral Sciences*,. https://doi.org/10.1016/j.sbspro.2012.09.828
[28] Astarita,V., Festa,D., Giofrè,V., Guido,G., Saccomanno,F. and Vitale,A. (2013) Investigating safety issues in two-way rural highways. *External Costs of Transportation Systems: Theory and Applications (Selected Papers)*, FrancoAngeli, MILANO. p. 36–52.
[29] Astarita,V., Giofrè,V.P., Guido,G. and Vitale,A. (2019) Game theory and cooperative-competitive performances in real time traffic signal settings based on floating car data. *6th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems, MT-ITS 2019- Proceedings*, p. 6.
[30] Astarita,V., Festa,D.C. and Vincenzo,G. (2018) Cooperative-competitive paradigm in traffic signal synchronization based on floating car data. *2018 IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe)*, IEEE.
[31] Giofre',V.P. and Astarita,V. (2017) TRITONE: Un microsimulatore per l'inquinamento acustico. *STRADE & AUTOSTRADE*, **122**, 124–6.
[32] Sharma,S., Lubmann,J. and So,J. (2019) Controller Independent Software-in-the-Loop Approach to Evaluate Rule-Based Traffic Signal Retiming Strategy by Utilizing Floating Car Data. *IEEE Transactions on Intelligent Transportation Systems*,. https://doi.org/10.1109/TITS.2018.2877585
[33] Guo,Q., Li,L. and (Jeff) Ban,X. (2019) Urban traffic signal control with connected and automated vehicles: A survey. Transp. Res. Part C Emerg. Technol. https://doi.org/10.1016/j.trc.2019.01.026
[34] Ekeila,W., Sayed,T. and El Esawey,M. (2009) Development of Dynamic Transit Signal Priority Strategy. *Transportation Research Record: Journal of the Transportation Research Board*,. https://doi.org/10.3141/2111-01
[35] Astarita,V., Giofrè,V.P., Guido,G. and Vitale,A. (2017) The Use of Adaptive Traffic Signal Systems Based on Floating Car Data. *Wireless Communications and Mobile Computing*, Hindawi. **2017**, 1–13. https://doi.org/10.1155/2017/4617451
[36] Astarita,V., Giofré,V.P., Festa,D.C., Guido,G. and Vitale,A. (2020) Floating car data adaptive traffic signals: A description of the first real-time experiment with "connected" vehicles. *Electronics (Switzerland)*,. https://doi.org/10.3390/electronics9010114
[37] Kummala,J. (2002) Travel Time Service Utilising Mobile Phones, Finnish Road Administration Report Vol. 55, Helsinki.
[38] Rose,G. (2006) Mobile phones as traffic probes: Practices, prospects and issues. Transp. Rev. https://doi.org/10.1080/01441640500361108
[39] Giofre,V.P., Astarita,V., Guido,G. and Vitale,A. (2017) Localization issues in the use of ITS. *5th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems, MT-ITS 2017 - Proceedings*,. https://doi.org/10.1109/MTITS.2017.8005710