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A Cooperative Intelligent Transportation System for Traffic Light Regulation Based on Mobile Devices as Floating Car Data (FCD)

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Abstract

This paper presents and analyzes a new Cooperative Intelligent Transportation System based on a simple concept: the use of information coming from the network of internet connected mobile devices to regulate traffic light systems. The new idea explored in this paper is a traffic light system with green cycles actuated by the information coming from mobile phone vehicle probes that would allow:

1) regulating traffic lights or offering information to drivers taking advantage of Floating Car Data (FCD);
2) convincing drivers to *accept this system as beneficial* and adopt it promptly and voluntarily becoming part of a successful cooperative system.

The idea presented in this paper is conceptually very simple: drivers interested in the service would install a mobile phone application on mobile devices with GNSS capabilities (such as GPS or Galileo system). This would allow the traffic light regulation system to know the position of subscribers and regulate traffic lights according to this. The fast and successful launch of the system would be guaranteed by the fact that, in the launch phase, the first drivers using the system would be given green priority on other drivers.

This paper carries on an analysis in a simulation framework to establish numerically what would happen at the launch of the system and when the subscriber base increases.

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It shows that after around 35% of subscribers would have joined, the system would operate more democratically and very efficiently in traffic regulation by estimating the position of all vehicles in the network using the subscriber base as a sample for the whole population of cars. An algorithm is proposed for the optimization of an isolated traffic light and for an isolated corridor. Micro-simulation has been used to make confrontations and estimation, in the analyzed scenarios, between the proposed system (using active mobile phone as sensors) and fixed time signal settings based on standard Highway Capacity Manual (HCM) procedure.

Numerical results are obtained that assess the proposed system from the point of view of both subscriber advantages and overall network travel time reduction depending on different subscriber rates in the driver population. Results have shown a great convenience of the system for low traffic flows and intersections not perfectly regulated. The proposed optimization algorithm can be extended to a whole network.

Keywords: Traffic theory; Adaptive traffic signals; Floating Car Data; ITS.

1. Introduction

According to European commission: “Congestion costs have been around EUR 50 billion per year or 0.5% of Community GDP. Everyday 7,500 km or 10% of the road networks are affected by traffic jams and severe congestion. In 2002 Road transport consumed 83% of the energy consumed by the whole transport sector representing more than 26% of the total energy consumption in the EU”. Cooperative Intelligent Transportation Systems (C-ITS) can be part of the solution and until now they have not sufficiently or effectively addressed the above problems as they have not yet been deployed on a large-scale.

This paper presents and analyzes a new Cooperative Intelligent Transportation System covered by patent [1], which is based on a simple concept: the use of information coming from the network of internet connected mobile devices to regulate traffic light systems.

Traffic control can take advantage of information obtained from road user mobile phones that can act as traffic probes. Floating car data (FCD) based on the collection of localization data, speed, direction of travel and time information from mobile phones in vehicles that are being driven can be an essential source for traffic information.

There have been many researches on obtaining traffic data from instrumented vehicles as traffic probes, among them: [2,3,4,5,6,7,8,9,10,11,12,13,14,15]. Some works have been investigating specifically traffic safety issues: [16,17,18, 19] .

Some other works have been based on the use of mobile phone applications to establish road pavement conditions:[20,21].

The possibility to use smartphones with satellite localization and wireless internet data transmission has been investigated with regards to the penetration rate necessary to achieve good results for traffic information systems in: [5,22]. Some researchers have been studying directly on the field combined GNSS and data transmission, examples are in the Mobile Century Project directed by Alex Bayen [23] and in [24,25].

The concept of establishing traffic parameters from the detection of mobile phone radio signals was proposed in the patent [4] in 2000 and has been implemented since 2008 using Bluetooth protocol. Results have been presented in [26,27]. More recent paper on the subject are [28,29,30].

Finally adaptive traffic signal systems have been investigated in [31,32,33]. The use of FCD as input for the regulation of traffic signals has been studied in [34] and also in the project Colombo [35,36].

At the moment in applications already deployed on the field most all of the real time information obtained from “instrumented” vehicles as traffic probes comes from the mobile phone data network and GNSS systems. This real time information has been used to give back to user traffic information and give road guidance in systems such as Tom Tom, Google Maps, Here Maps, iGO, Ovi Maps and Waze. Insurance companies have used this information to asses driving risks associated with distance traveled and other parameters obtained by the GNSS tracks of subscribers. This kind of information, though, has not been widely used to implement traffic control operations since the information in most cases is not in the hands of city and other road administrations, and since where such information was obtained by city administrations there has not yet been an enough and consistent diffusion of this mobile “city” phones application in the public. For example cities like Santander have started to experiment with dedicated mobile phone applications and the experiment has shown that still one of the problem is to reach a large scale diffusion of such dedicated mobile phone applications.

This paper presents a new mobile phone application as the core of a new invention (details can be found in the patent [1]), the invention consists in an advanced system for the dynamic and real-time management of traffic lights. This system can be a valid alternative to traditional methods for the development of adaptive traffic light systems and represents a valuable tool to support traffic flow management of a road network, allowing the detection of traffic volumes and informing transport system users of travel times at intersections. Traditional systems for the regulation of traffic light phases are based on vehicle flows detected in one or more points with traditional survey systems (electromagnetic coils and other systems able to detect traffic flow, density and vehicle speeds). In this system traffic lights are regulated on the basis of position and speed data provided by vehicles "instrumented" with fixed or mobile devices: "instrumented" vehicles are vehicles that have on board a detection system of satellite-location (GPS type receivers, GLONASS, Galileo, etc.) coupled to a wireless communication device on the internet cellular data network or over a local network. It must be noted that a common smartphone already has all this features built in.

2. General description the proposed Cooperative Intelligent Transportation System for traffic light regulation based on mobile devices as FCD

The system is composed of the following modules also indicated in Figure 1:

- the first module (A), are the traffic lights of one or more intersections;
- the second module (B), is the electronic controller that regulates the traffic lights and the circuit for the data connection (the traffic light control algorithm characterizing the invention is described below);

- the third module (C), is the central server for data collection and processing;
- the fourth module (D), are the "instrumented" vehicles circulating in normal road traffic with smart-phones and a dedicated application.

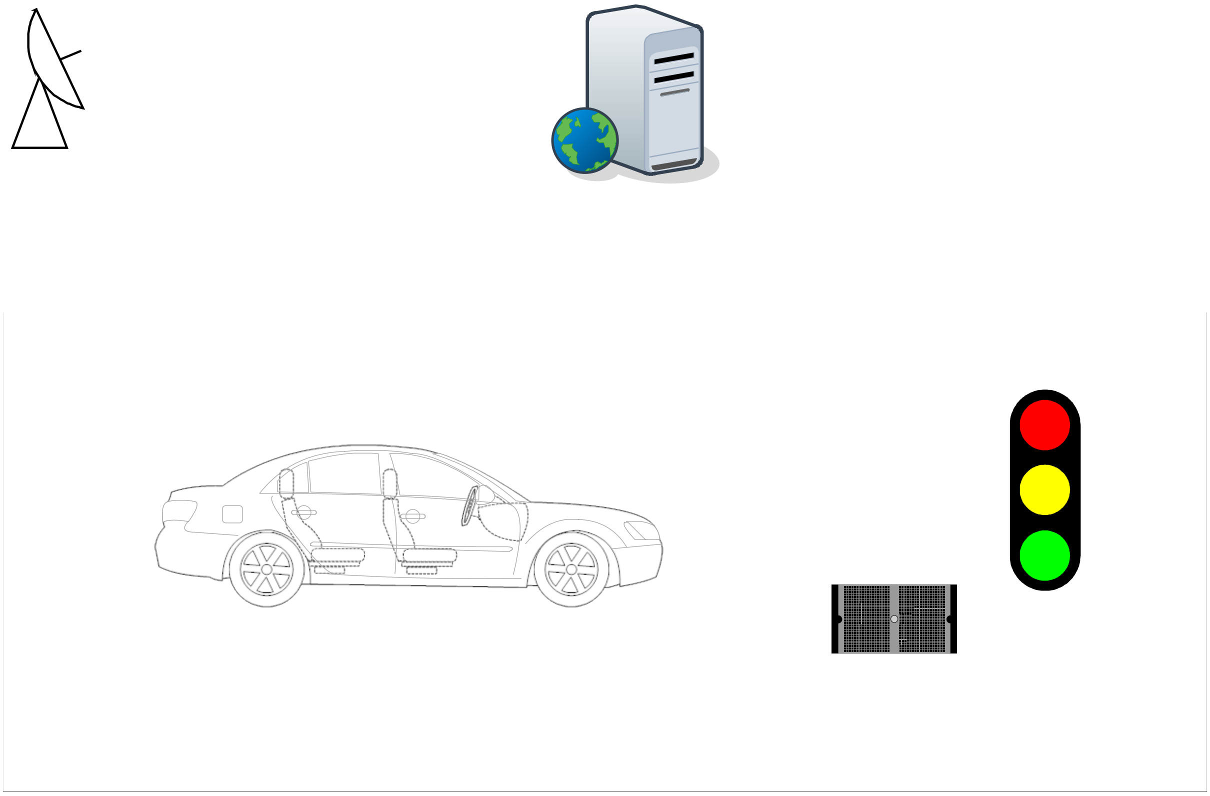

Figure 1: General structure of the proposed system

The operation of the traffic light control logic is conceptually different from that of any other of the traffic light control system implemented by the traffic as it is based on the acquisition of the sequence of positions and velocities obtained from satellite positioning receivers of only instrumented vehicles. It must be noted that the control system only considers the presence of "instrumented" vehicles in the logic for the assignment of green at the traffic-light phases.

The "instrumented" vehicles (D) circulating detect their positions and speeds (through the satellite receiver) and instantaneously communicate such data to the central server (C) via wireless Internet data connection. The central server processes the "instrumented" data of the vehicles circulating on the network and determines dynamically in time, according to a control logic based on the minimization of the "instrumented" vehicles travel times. These data are transmitted to the individual controller units of the traffic lights (B). The controllers actuate the various traffic lights (A).

The system can give priority over all other traffic flows to an emergency vehicle based on the real position of the vehicle.

The system allows traffic operators to provide a service in which the circulation of "instrumented" vehicles is favored in the selection of the green times to be assigned to traffic lights. As an example: in the presence of a single "instrumented" vehicle approaching a regulated intersection, the system will tend to provide the green to the "instrumented" vehicle as soon as possible (minimum green times for every phase will always be guaranteed). If several vehicles are "instrumented" the system will tend to provide the Green to "instrumented" vehicles in order to minimize the "instrumented" vehicle delays.

In the ideal situation in which all vehicles are "instrumented" the implementation system of the traffic light cycle will have available all the positions of all the vehicles and the relative speed on the network allowing for an optimal traffic signal regulation which would never be possible with the traditional systems Such a system may operate by its nature with innumerable rules of green allocation. In the event that the "instrumented" vehicles are only part of the total of vehicles in the system it will operate on the basis of an estimate of the parameters needed to traffic regulation based on the methodology described in Astarita et al. (2006). The traffic measurements thus obtained are, in fact, an estimate of total traffic whose accuracy depends of course, by the ratio between the number of "instrumented" vehicles and the total of vehicles.

3. System for forecasting and traffic control

The measures obtained from this mobile phone application system, based on the techniques described, allow to estimate in real-time traffic with an amount of data not otherwise available. It would be possible to pair these measures with the simulation of real-time traffic to predict traffic evolution and operate control strategies and feedback information to users. Such information can be provided in various ways, moreover, the system will be able to provide a driving assistance to increase safety and facilitate a smoother ride. Drivers can in fact be informed on driving style to be taken to arrive at signalized intersections saving time and fuel. In practice, the system not only receives position and speed data from instrumented vehicles, but transmits in the opposite direction (from the central server to the smart-phones of drivers) information which can take into account the traffic lights setting at intersections.

The system does not affect in any way the laws of privacy since information from "instrumented" vehicles would be processed just to regulate traffic signal and once sensitive data are erased they can be processed and returned to users in aggregate and anonymous form, for example: general traffic information, information on flows, on average speeds, routes and travel times etc.

The system involves the use of satellite location detection technology (localization) GNSS (type of Receivers: GPS, Glonass, Galileo, etc.). In particular, the adaptive traffic light system acquires and processes a sequence of positions and velocities obtained from the GNSS chips mounted on mobile devices of instrumented vehicles. In this way, unlike other systems, it is not a fixed infrastructure to detect vehicles, but it is the vehicle to localize itself and send and receive information via radio. The kinematic data and position of instrumented vehicles are transmitted, for the processing phase, from the fixed or mobile instrumentation to a server, via radio connection: 2G, GPRS, 3G or UMTS, 4G. In road intersections where mobile phone signal is poor Wi-Fi antennas or other local system for data broadcasting via short-range radio can be used. Among the many possible fields of use, the system also allows to benefit certain categories of users giving them a specific green phase and at the same time allows to send information to all drivers regarding the traffic signal phases provided.

The idea presented in this paper is conceptually very simple: drivers interested in the service would install a mobile phone application on mobile devices with GNSS capabilities (such as: GPS and Galileo). This would allow the traffic light regulation system to know the position of subscribers and regulate traffic lights according to this.

4. A simple greedy optimization algorithm for adaptive traffic signals from FCD

The operating logic (and the instruments) used by the traffic light control are different from that of any other existing traffic light control system because the system is based on the acquisition and processing of the sequence of positions and velocities obtained from the satellite positioning receivers of instrumented vehicles. The system, in fact, can not only allow to give priority to some categories of users in the allocation of green times, it can also send driving instructions to drivers according to the foreseen green times provided by the system.

An algorithm has been developed and applied for the optimization of an isolated traffic light given this new kind of information. The algorithm evaluates the number of instrumented vehicles that are on every approaching street and assigns green to the approaches with priority to the approach that has more instrumented vehicles the green time assigned to every approach depends on the evaluated length of the queue which is established on the base of the position of the last instrumented vehicle in queue and considering also the number of vehicles that may be arrived since the moment this last vehicles has stopped.

Having evaluated the length of the queue as dmax the following equation is applied [37]:

$$Lenght_{green} = 0.135\ d_{max} + 2.274 = [s] \quad (1)$$

If there is no instrumented vehicle the algorithm falls back into fixed time cycle. In any case the algorithm assigns a minimum green of 4 seconds for every phase. It must be noted that the proposed optimization algorithm can be extended to a whole network.

5. Simulation tests

The control algorithm has been tested using Micro-simulation, on a single intersection, making confrontations between the proposed system (using mobile phones as sensors) and traditional fixed time signal cycles traffic systems. Tritone microscopic traffic simulator [38] has been used with a dedicated module for post-processing of vehicles trajectories and positions. This module has been developed to introduce the GNSS error in the estimation of positions that would be met in a real environment. The positions with random errors have then been analyzed with a map matching algorithm obtaining estimates that have been fed into the adaptive traffic signal algorithm.

Numerical results have been obtained after 50 repetitions of every different scenario. Scenarios have been estimated from the point of view of both subscriber advantages and overall network travel time reduction as a function of different subscriber rates in the driver population.

Results have shown a great convenience of the system for low traffic flows and when traffic lights might not be regulated at the optimal fixed time plan.

The following two graphs show total travel time of all vehicles both instrumented and not instrumented with varying percentage of "instrumented vehicles". The scenario is that that of a road intersection regulated by traffic lights with a single lane and a single phase for each access. The four total green phases share the total time according to HCM optimized pre-fixed time plan when the optimization algorithm is not applied. The algorithm is not applied when the percentage of "instrumented" vehicles is equal to zero or when no "instrumented" vehicle is approaching the intersection.

In Figure 1 it is depicted the total travel time for an intersection with total traffic flow at around 50% of intersection capacity and a good fixed signal plan fixed according to HCM procedure, the different lines show different traffic flows repartition for the two main directions. Traffic 50/50 means that northbound/southbound traffic is equal to eastbound/westbound traffic.

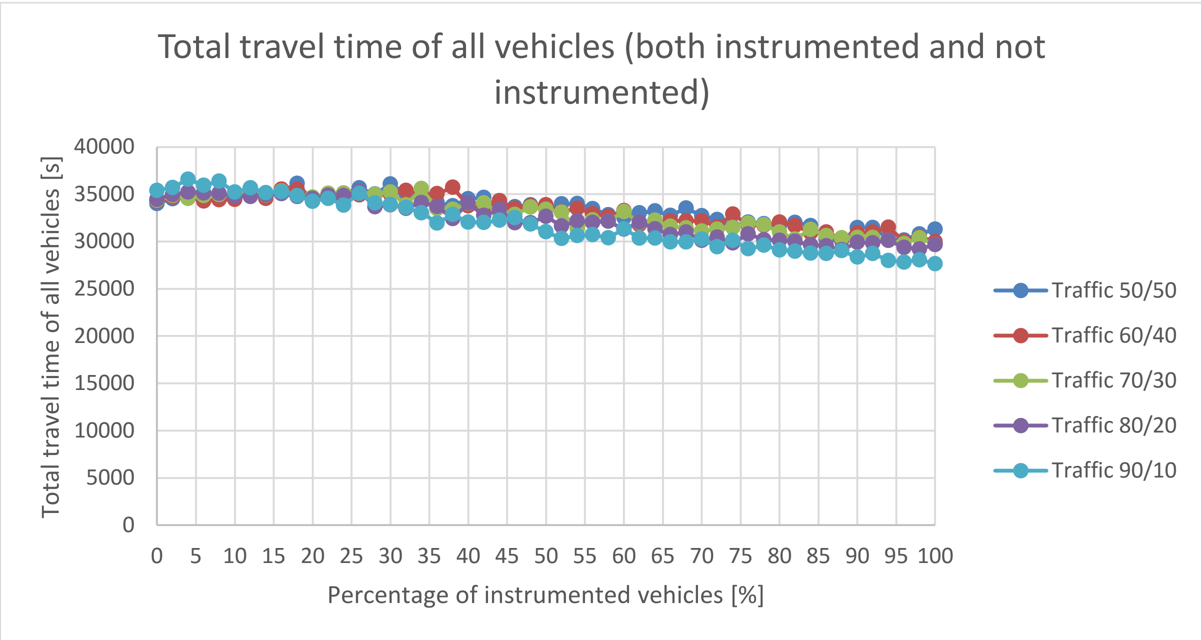

Figure 1: total travel time of all vehicles (both instrumented and not instrumented) as a function of the percentage of instrumented vehicles on a well regulated intersection.

In figure 2 it is depicted the total travel time for an intersection with total traffic flow at around 50% of intersection capacity and a fixed signal plan which has a longer cycle (wrong cycle) established as if the intersection was nearly to saturation.

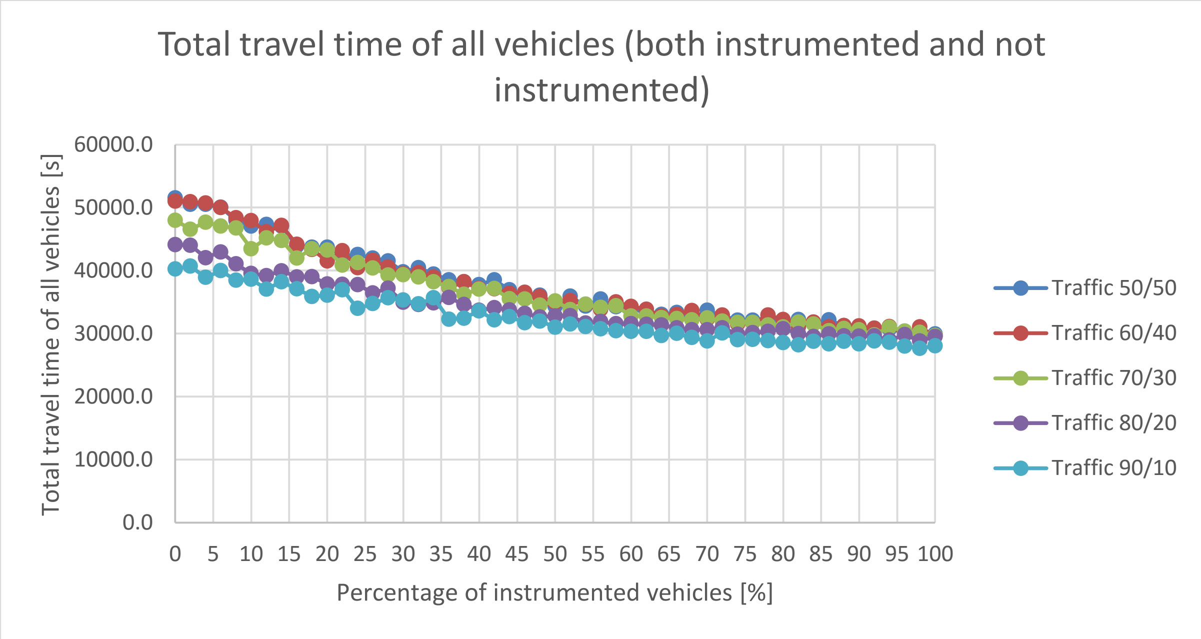

Figure 2: total travel time of all vehicles (both instrumented and not instrumented) as a function of the percentage of instrumented vehicles on a badly regulated intersection.

6. What would happen at the official launch of the smartphone application and when customer base reaches around 35-40%

At the launch of the system users of the system would find reduced travel times in a road network where traffic lights are regulated according to fixed time signal plans. Travel time would be reduced considerably for first users cause they would not only take advantage of the actuated phases with regard to fixed time signals, they would also be given green priority on other drivers. Other drivers would find themselves penalized by the system when the percentage of instrumented vehicles is low. For this reasons since the official launch the presented mobile phone application presents itself with a great potential for attracting drivers and establishing quickly an extended new customer base. Users not willing to use the system may protest again the introduction of this system yet in the following it will be shown how when the customer base extends to reach 35-40% of circulating vehicles, all vehicles would take advantage of the introduction of this system.

Simulations, in fact, showed that in all cases when the customer base extends to reach 35-40% of circulating vehicles then the overall travel time is reduced for both instrumented and not instrumented vehicles. In other words the simulations established that when a threshold of 35% of customer base is reached there would be benefit also for drivers that are not using the system.

7. Conclusions

The system presented in this paper would allow the following new results:

- regulating traffic lights or offering information to drivers taking advantage of FCD data [1, 2, 3, 4];

- convincing drivers to *accept the proposed system as beneficial* and adopt it promptly and voluntarily becoming part of a successful cooperative system.

The fast launch of the system and driver acceptance would be guaranteed by the fact that, in the launch phase, the first drivers using the system would be given green priority on other drivers.

The fast and successful launch of the system would be guaranteed by the fact that, in the launch phase, the first drivers using the system would be given green priority on other drivers. When around 35% of subscribers would have joined, the system would operate more democratically and very efficiently in traffic regulation by estimating the position of all vehicles in the network using the subscriber base as a sample for the whole population of cars.

It is not the scope of the paper to discuss the moral or political convenience of making such a system a payment system or to suggest different payment options and/or green priorities for different users. Though it has to be noted that technically the system would allow prioritizing of vehicles. This would allow vehicles such as ambulances to move faster on the network comparing to other vehicles. Instead in this paper a technical and theoretical analysis of the system advantages and performances (also depending on subscriber rate) has been carried on. In this paper it has been considered only the advantages obtained by the traffic light regulating system and it must be noted that the possibility of managing such a great amount of vehicle trajectories information can also be useful in many other ways for example just by providing traffic or detailed driving information to driver mobile devices.

Moreover this paper is a first introduction to the problem and presents the proposed system just in general terms. It must be noted that the intersection analyzed is a simple intersection with one single lane for each approach. More complicated algorithms must be applied for more complicated intersections. Further research work will be devoted to investigate more complicated intersection layouts and the control algorithms that can be applied in all possible intersection layouts and signal phase plans.

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