# Implementation of road safety and traffic management applications over mobile opportunistic systems

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*Abstract:* - Road safety, air pollution and traffic management are three problems that the residents of urban centers around the world have to face promptly given the radical growth in cities' population worldwide. Intelligent Transportation Systems (ITS) aim to contribute in this direction through automated fusion of information and by collecting, processing and communicating the real-time data that enables either the citizens or the authorities to make efficient decisions. The common denominator of the realization of these systems is the effective opportunistic communication between vehicles and between vehicles and infrastructure so as to collect and disseminate the information in a distributed way, yet delivering the right piece of information in time and at the right location. While initial attempts assumed WLAN communication, as this is not efficiently supporting high speeds, IEEE has standardized the 802.11p protocol to match the requirements of this networking environment. In this paper, we present the design and implementation of indicative traffic management applications. For our development, we have used the NEC Linkbird platform, which supports communication based on 802.11p. We exploit the functionality that the 802.11p standard offers to build these applications and discuss practical implementation issues.

*Key-Words:* - Wireless Sensor Networks, Intelligent transportation systems, Vehicle-to-vehicle networking

## 1 Introduction

Road safety, air pollution and traffic management are three major concerns that the residents of urban centers around the world have to face promptly given the radical growth in cities' population worldwide. Road traffic accident mortality is high among young people with transport accidents causing 8 % of all loss below 65 years in the EU-27 [1], more than any disease. Across EU, transport is most dangerous in regions in Portugal, Lithuania, Latvia, Corsica, Greece and Poland. On the other hand, air pollution is tightly related to traffic management and plays a substantial role to the climate change while burdening the commitment of Europe to decrease the $CO_2$ emissions. In urban areas, an increase in average speed may dramatically reduce fuel consumption, while traffic signal synchronization has the potential to increase intersection throughput for private traffic by 15%. Guiding traffic (e.g. through route advisory systems) away from problematic areas may lead to up to 8% less emissions [2]. Today, 30% of energy is consumed for human and goods transportation [3] and circa 18% of the $CO_2$ emissions from combustion come from road transportation [4]. Although the broadening of the road infrastructures increases their capacity, it cannot keep up with the pace of the increase in urban populations worldwide, due to cost and time reasons, leading the city authorities to pursue "soft" measures to solve the problem.

To tackle these problems, the design and development of Intelligent Transportation Systems (ITS) has been pursued the last decade. These systems rely on intelligent collection and processing of information which enables decision making and information/decision dissemination to enhance the citizen's experiences either through enhancing transportation efficiency or safety. They can be classified in advanced public transport systems, advanced traveler information systems, advanced Traffic Management Systems, incident management systems, electronic toll collection systems, Vehicle Information and Communications System and Video Transmission Systems for road surveillance.

In this paper, we consider a generic architecture where mobile nodes (on board units) with sensing capabilities are opportunistically connected to each

other and to static nodes located at the road side (road side units) using the IEEE 802.11p standard. We present applications that can be designed and implemented on this architecture towards enhancing the road safety and traffic management efficiency.
The rest of the paper is organized as follows: in section 2 we present the considered Vehicle to vehicle and vehicle to infrastructure communication architecture, while in section 3 we briefly outline the 802.11p functionality which will be exploited for the application development. In section 4 we design application capitalizing on this architecture related to the city traffic cycle. Finally, conclusions are drawn in section 5.

## 2 Network infrastructure supporting mobile opportunistic communications

The system architecture we consider is depicted in Figure 1. Vehicles with and without "on board units" travel on the road. The "on board units" (called hereafter OBUs) consist of a system equipped with sensing devices (e.g. humidity sensor, temperature sensor, accelerometer, gyroscope, $CO_2$ sensor) and with a device capable of communicating either with other vehicles or with devices installed in the road (infrastructure) side. The "Road Side Unit" (called hereafter RSU) is capable of communicating (apart from the vehicles in their transmission range) with an application server located at the premises of the traffic control center or road operation authorities through any legacy wired or wireless communication technology. We consider that such devices can be attached to traffic light posts or posts carrying either lights or cameras in highways.
For the communication between the vehicles and between the vehicles and the infrastructure we rely on the IEEE 802.11p protocol which supports wireless communication between nodes moving at high speed. Short-range wireless communication based on IEEE 802.11p is characterized by low cost, availability and wide deployment. The wireless technology enables a fully distributed vehicular communication network based on self-organization and self-coordination of the network nodes which is mandatory for car-to-car and car-to-infrastructure communication (called Car-2-x or shortly C2X by NEC in [5]). The transmission occurs in the 5.9GHz unlicensed band for both EU and USA with a maximum transmission range of 1000m with 200μs latency and a data rate between 6-27Mb/s.

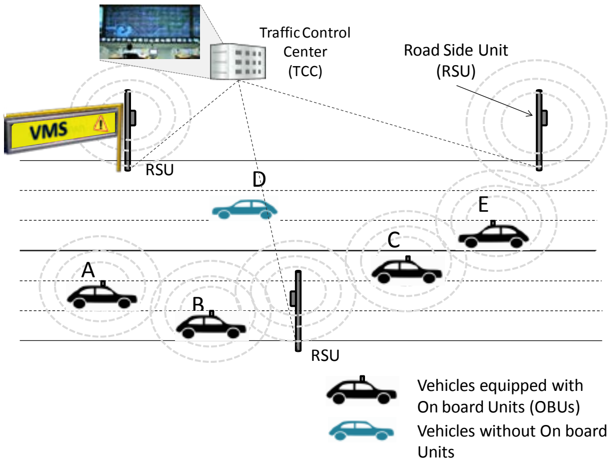


Fig. 1: The system architecture

While car manufacturers install more and more sensors on the vehicles and offer more and more communication interfaces (e.g. Bluetooth, USB), they are reluctant to disseminate the sensor readings (even for a very limited subset of the available sensors). On the other hand, the cost of sensors decreases rapidly as the production volumes constantly increases. Already car industries produce vehicles equipped with a various set of sensors and display units. So, an additional 802.11p interface could easily and economically upgrade a common car with C2X capabilities. Statistics show that European citizens are highly interested in safety when buying a car and thus it is highly likely for them to be also interested in buying a device that supports safety applications. In the future leveraging technology consolidation, market adoption and mature (potentially open) interfaces, such a device could be combined /embedded with devices offered by highway operation authorities for electronic toll payment (e.g. e-pass) or automotive control systems. These devices could also support entertainment applications which may offer further incentives for installing such a device in the vehicle even for young drivers who may underestimate safety or traffic management benefits. For example, offering instant messaging with passengers of nearby cars for free could strengthen the incentives.
In this paper, we consider the case where OBUs integrate a microprocessor and memory elements with the following limited set of sensors:

- GPS, necessary for the support of 802.11p standard which implements geographical routing assuming the device location is known.

- accelerometer, to detect sudden direction or speed changes that may cause accidents or reveal abnormal conditions
- humidity and temperature sensors, to enable the detection of severe environmental conditions that may need specific action taking.
- Peripheral devices for informing the driver (e.g. display or audio peripherals)

For experimental purposes, such an OBU device can be developed using the NEC linkbird device and connecting to it the sensors through USB interfaces.

For the RSU, it is important to support 802.11p functionality to communicate with the vehicles and another communication technology (wireless or wired) to connect to a server that is capable of processing real-time information and implement intelligent decision making schemes. RSUs execute a multitude of functions including forwarding of data (to increase the coverage of the ad hoc network), transmission and reception of application data from the vehicles (e.g. collecting measurements and disseminating warnings or decisions made at the Traffic Control Center - TCC), communication with the road operation authorities and traffic control center and Internet access support to cars. Furthermore, the RSU could be equipped with sensors (e.g. for weather or $CO_2$ emissions monitoring) and deliver the readings to decision making applications.

Exploiting the above architecture, the drivers of all the vehicles, the pedestrians and the road operation authorities can benefit from the sensed data. This architecture comprises a distributed sensing infrastructure (sensing overlay) since the vehicles are capable of detecting events and through their opportunistic communication with the RSU, the sensed data can arrive at the road operator and/or traffic management authorities. This distributed infrastructure senses the whole road network, even neighbourhoods or areas where the traffic does not justify investment on monitoring infrastructure. On the other hand, the routing instructions and traffic information can be disseminated towards both pedestrians and drivers through a variety of means which includes (except the OBU), variable message signs and mobile phones to reach a wider audience.

# 3 The IEEE 802.11p networking framework and protocol stack

The requirements imposed by vehicular communication for support of highly mobile vehicles, frequent topology changes, and scalability with potentially very large number of nodes dictated the adoption of geographical routing principles [6], which can be secured [7] with limited node resource consumption and has been proven to have good performance not only on simulated but also in realistic environments [8]. Therefore, the 802.11p Task Group of IEEE has chosen the so-called Geocast routing protocol as the core networking protocol for vehicular communication. 802.11p is an approved amendment to the IEEE 802.11 standard promoted by the Car-to-Car Communication Consortium (C2C-CC) in Europe, the major European industry consortium for vehicular communication. This protocol supports opportunistic communication as well as multi-hop communication supporting both a) the forwarding of data towards the geographical position of a single destination node for unicast communication and b) the distribution of data in a geographical region.

The Geocast is an ad hoc routing protocol utilizing geographical positions for data transfer. It is assumed that each vehicle is aware of its geographical position via e.g. GPS and periodically advertises this information to its neighboring vehicles (in the so called beacon messages). Hence, an 802.11p enabled device is informed about all other 802.11p devices located within its direct communication range (one hop neighbours) and maintains a so called neighbor table in soft state containing all known neighbours IDs and their geographical positions.

Geocast supports point-to-point and point-to-multipoint communication. Leveraging the capabilities to distribute information based on geographical routing, enables innovative applications mainly by exploiting the protocol capabilities for selective addressing of geographical areas as target of data packets. Thus, a vehicle can specify a well delimited geographic area to which the messages should be delivered/broadcasted. Intermediate vehicles serve only as message relays and only the vehicles located within the target area terminate messages at the application layer conveying related information to the driver as appropriate. In this way, the vehicles that are actually affected by a dangerous situation or a traffic-related event are notified, whereas vehicles unaffected by the event are not targeted. The geographical area can be rectangular, circular or ellipsoidal. To this end the following forwarding types of Geocast can be used:

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- GeoUnicast, which is a unidirectional data transport service from a single source node (S) to a single destination node (D). (Figure 2a). Node S forwards data packets to the one-hop neighbour relay node (F) that is closest to the destination, which in turn forwards them along the path until they reach the destination node D.
- Geographically-Scoped Broadcast (GBC), which is used to transport data from a single node to all nodes within an area defined by a geometric region (either via unicast as shown in Figure 2c or other forwarding methods like the Contention-Based Forwarding CBF).

- Topologically-scoped broadcast (TSB), which provides rebroadcasting of a data packet from a source to all nodes in a limited N-hop neighborhood (Figure 2b). Single-hop broadcast is a specific case of TSB which is used to send periodic messages (beacons or heartbeats), while setting N large enough so as the whole ad hoc network can be reached. TSB shall be used very rarely since it may cause congestion in the network.

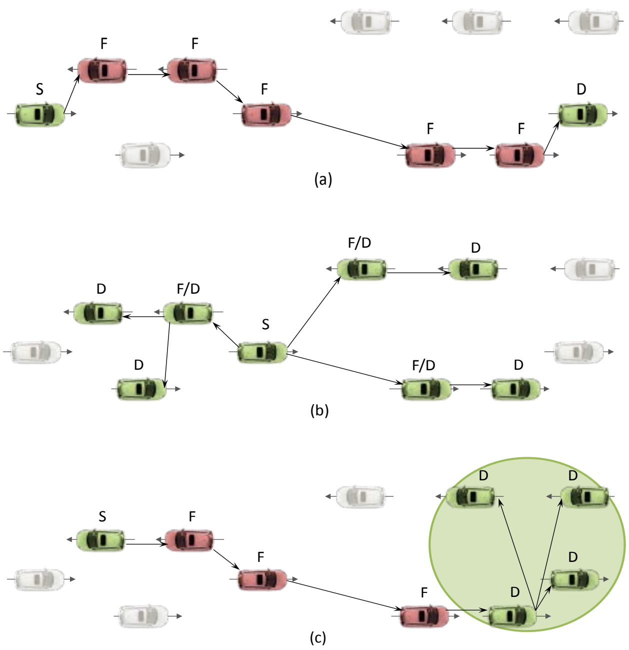


Fig. 2: The routing schemes supported by 802.11p routing protocol (a) Geographical Unicast, (b) Geographical Broadcast, (c) Topologically-Scoped Broadcast

# 4 City Traffic management based on distributed sensing

Leveraging the IEEE802.11p mechanisms for realizing efficient communication between mobile nodes and between mobile and static nodes (C2X communication), the next step is the design and implementation of intelligent applications which enhance road safety and assist traffic management. In the sequel, we present indicative applications that capitalize on the considered architecture. The applications we implemented exploit the communication network described above comprising the in-vehicle, ad hoc, and infrastructure domains. The ad hoc domain is composed of vehicles equipped with OBUs and stationary RSUs that can be attached to fixed locations. Most prominent locations for RSUs include traffic lights and Variable Message Signs (VMS). RSUs are responsible for interconnection between the ad hoc and the infrastructure domain. Thus, OBUs can directly communicate if direct wireless connectivity exists. In case of no direct connectivity, multi-hop communication is used, where data is forwarded from one OBU to another, potentially via RSUs, until it reaches its destination. By deploying this kind of ITS infrastructure prototype fixed service-based cooperative information systems have been developed and tested.

The traffic lights consist a key element in traffic management within a city. The coordinated traffic flow control implementing the "green wave" concept was initially proposed to minimize the vehicle stops to red traffic lights within the city. The rationale is that reducing unnecessary stops and increasing the average transportation speed of vehicles reduces both the travel time and the $CO_2$ emissions at the same time. This "wave" is generally enforced in a more or less static manner. Further to static coordination, we describe in this section how sophisticated applications exploiting mobile opportunistic communications can enhance efficiency, without necessarily introducing high complexity or unbearable implementation cost.

## 4.1 Dynamic traffic light cycle definition

The dynamic adaptation of the traffic light cycles according to traffic conditions has been recognized as a means to achieve the same benefits with the green wave: reduced vehicle stops for shorter travel time and lower $CO_2$ emissions. This adaptation requires the detection of the traffic conditions which is currently realized through infrastructure-based systems (e.g. cameras, LIDAR systems, etc.) and the communication with the city traffic management authorities for global city traffic management decision making. Mainly due to cost reasons, such a

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traffic monitoring infrastructure has not been installed in all intersections across cities.
The same effect in a more efficient manner and capable of handling a wealth of information can be achieved by placing RSUs on the traffic light posts where electric power and internet connectivity is available, as shown in Figure 3. Cycle adaptation can exploit the IEEE 802.11p operation which foresees that OBUs periodically transmit beacon messages including their geographical position and heading (in other words their direction). The 802.11p protocol stack at the RSU side located on the traffic light post receives the beacon messages from all the vehicles within its reception range. The RSU based on the received beacon messages should be able to detect the lane, side of the crossroad and direction of each vehicle passing by and maintain counters for each direction. Performing measurement based estimation of the load of each traffic flow based on moving averages light cycle adaptation can be efficiently implemented. Short term statistics and status information can be forwarded to the TCC for processing to perform longer-term estimations, data-base maintenance and status visualization.

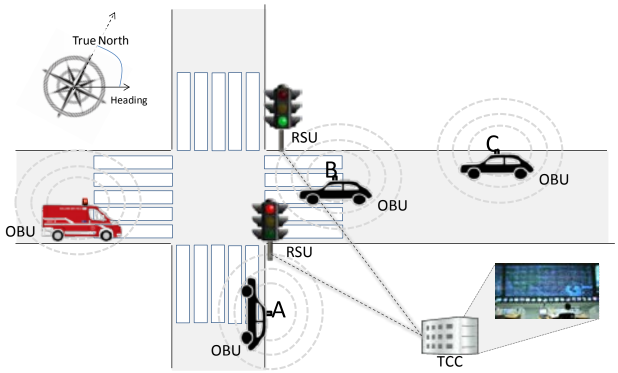


Fig. 3: Exploiting OBU and RSU for dynamic traffic light cycle adaptation

The message flow is shown in Figure 4. Statistics collection can be a locally executed application for the dynamic adaptation of the traffic light cycle to the traffic conditions but usually it is expected to reside at the premises of traffic management authorities (state-of-the-art traffic lights already support TCP/IP connectivity for configuration and control) allowing coordination of traffic lights to achieve global traffic control benefits. Beacon messages from OBUs denoted as “MStatus Report” are collected and processed as described above to produce “SStatus Report”. “Event report” messages report local geographical traffic events to TTC and facilitate the applications discussed in following section.

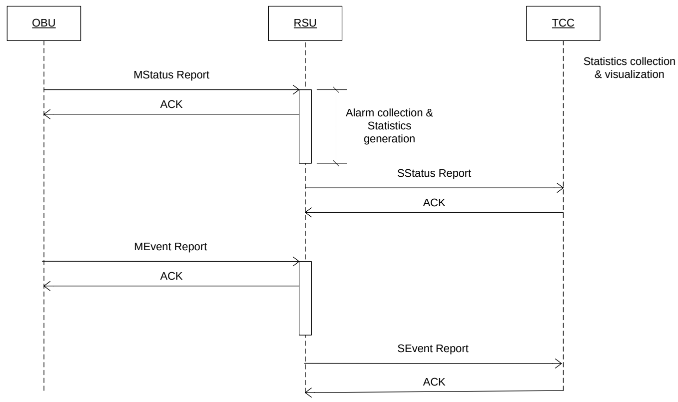


Fig. 4: The message flow between the OBU, the RSU on the traffic light posts and the application center.

### 4.1.2 Traffic light as sink for sensed data

As OBUs are usually equipped with sensors monitoring environmental conditions and the vehicles speed and direction, they are capable of detecting rain (humidity above a certain threshold), ice (a function of humidity and temperature thresholds) or slippery conditions at any location it passes by. With very low complexity, it can store this information in order to transmit it to the first available RSU it will be occasionally find within range. The OBU is capable of discriminating other OBUs from RSUs based on the addressing scheme of the 802.11p standard with discrete address ranges for different types of devices, based on information transmitted through Beacon messages. Based on this communication scheme, road conditions across all locations can be monitored by traffic management authorities. Subsequently this information can be used to inform drivers and also provide routing advice through VMS or other means. The information gathered at the central application can be visualized using a Graphical User Interface (GUI) as shown in figure 5 and figure 6. Namely, in figure 5, the available crossroads and highways can be listed. Choosing among them, the status of the traffic light is shown in real-time along with information about the weather and traffic conditions and a list of detected events reported by vehicles passing by. Figure 6 shows the real-time evolution of traffic based on data received by the RSUs located at the traffic lights.

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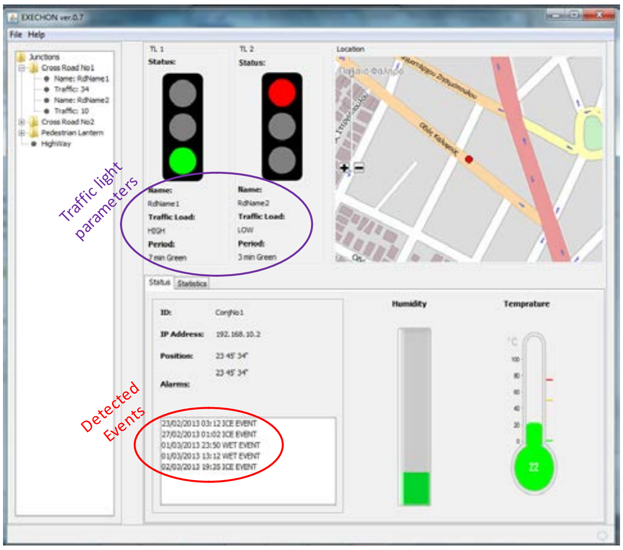


Fig. 5: Graphical Representation of the sensed data at the city traffic management center (traffic light parameter and detected events)


Fig. 6: Graphical Representation of the sensed data at the city traffic management center (traffic load evolution with time)

## 5 Conclusions

The rapid developments in the networking towards the realisation of the vision of the Internet of Things in combination with the significance of both the safety and environmental friendliness of transportation for the modern societies have pushed forward the development of relatively low cost applications that contribute towards these directions. In this work, we have discussed how current technologies and protocols facilitate the development of such applications and indicatively presented the design of two applications targeting the efficient traffic management within a city.

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