COLOMBO: Investigating the Potential of V2X for Traffic Management Purposes assuming low penetration Rates

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Abstract

After the Vehicular Communication (V2X) technology roll out in 2015, the number of equipped vehicles is assumed to increase slowly. While many Day One V2X applications are related to traffic safety and require a high penetration rate and communication reliability, traffic management applications could still benefit from even few equipped vehicles. Considering local V2X-based traffic surveillance based on a low rate of V2X technology, traffic light control could dynamically adapt priorities depending on traffic flows and volumes. In order to mitigate the low rate of V2X technology, already deployed solutions for wireless ad-hoc communications, such as WiFi-direct, available on most smartphones (often on-board of regular vehicles), should be investigated and exploited as complementary source of information, with full awareness of their strong reliability and performance limitations. The COLOMBO project, which is co-funded by the European Commission and presented within this report, focuses on such use of information either from a small subset of V2X-equipped vehicles only, or complementary to other wireless ad-hoc technologies and tries to exploit this information for traffic surveillance and an adaptive, optimized control of traffic lights.

Keywords:

Vehicular communication, V2X, traffic surveillance, traffic lights control, simulation, optimization, open source.

Introduction

In European context, the deployment of vehicular communication (vehicle-to-vehicle /

vehicle-to-infrastructure communication or V2X – vehicle-to-anything-communication) has been pushed by national and European authorities in the last decade. A dedicated communication channel was allocated by the European Commission in the 5.9GHz band in August 2008. Most of the needed communications parts were standardised by ETSI and a roll-out is scheduled for 2015. Besides the communication framework, ETSI standardisation documents also cover the applications to be deployed, so called “day one applications”. Most of them target on vehicular safety, supporting the driver with additional information, while only few of them are related to traffic efficiency. We expect a gradual but slow increase of the penetration rate of vehicles equipped with V2X technology. However, safety-related applications require a large number of V2X equipped vehicles, as most of these applications need a direct communication between two of such.

It is interesting to note, that the infrastructure is not foreseen to gain information from passing vehicles within “day one” applications, despite the case of community services. This is in so far peculiar, as modern traffic management is known to rely on data and a possibility to obtain new data should make the deployment of road side units more attractive to the authorities responsible for traffic management. One explanation may be the concentration on measuring vehicle flows, as already possible using conventional detectors, such as inductive loops or cameras. Measuring the flow directly is, however, difficult if the percentage of counted vehicles is very low.

The idea behind the COLOMBO project [2] is to investigate the potential of V2X-enabled vehicles assuming only a low percentage of equipped vehicles. COLOMBO targets on two major fields of traffic management: traffic surveillance and traffic lights control. To compensate the low penetration rate of V2X technologies, the COLOMBO project evaluates the benefits in terms of traffic monitoring and communications from smartphones and personal digital assistants (PDAs), which have a largely higher penetration ratio and are also capable of sensing motion and exchanging data.

The remainder of this report is structured as follows: At first, the basic ideas behind the developed traffic management solutions, namely traffic surveillance and traffic light control are given. Then, the tools used and extended within COLOMBO are described. Next, a short description of set of scenarios for traffic lights evaluation is given. This report ends with a summary.

Surveillance Systems

Conventional traffic detection systems are mainly based on inductive loop detectors, which are able to measure the number of passing vehicles at a particular cross section of a road. Although reliable, their deployment and maintenance requires opening the road surface, raising high costs and disturbing traffic. In some cases, the speed of the passing vehicles can also be measured. Currently under investigation are systems which allow to recognize and to classify vehicles by their inductive signature.

Passive infrared sensors are mounted above the road surface and measure vehicles' speeds and lengths or the volume/occupancy of a road at a road's cross-sections by observing changes in the recognized temperature. Passive acoustic sensors use the noise emitted by vehicles for the same purpose. Both are known to loose accuracy under certain weather conditions. Active detectors, infrared, microwave, or ultrasonic, emit a signal, which is reflected by passing vehicles, allowing their detection. They are assumed to deliver values in a quality similar to inductive loops. Even if their usage tends to significantly decrease the costs associated to road works, they are still too expensive to allow a massive and widespread adoption in large-scale deployment environments.

To overcome the costly obstacles of conventional traffic detection, V2X communication is merging into the field of traffic surveillance. The main hindrance of V2X based traffic detection remains the low penetration rates of equipped traffic participants. Within the COLOMBO project, possibilities to exploit information sent by a low percentage of equipped vehicles will be designed and evaluated by the means of simulation. The deployment of traffic surveillance based on V2X communications and on-board sensing/communication devices promises the possibility to determine the state around an intersection at a low cost – as only one stationary receiver has to be deployed. Additionally, being placed above the road for connectivity reasons, the maintenance costs of such a receiver would be much lower than the replacement of an inductive loop.

COLOMBO will follow different approaches to gain representations of the traffic state at low penetration rates of V2X technology. Three approaches are outlined in the following.

The first assumption states that collecting information included in cooperative awareness messages (CAMs) from a sample of vehicles passing a road side unit (RSU) may yield a good representation of the overall traffic state, if the collected indicators are chosen well. Different indicators, such as the number of vehicles passing a detection point, their average velocity, or the queue length in front of an intersection are supposed to have different sensibility to the size of the sample. Additionally, historical data can be collected and used for a traffic state representation of a quality that increases over time. Earlier evaluation of floating car data (FCD) [3][4] as well as of traffic surveillance methods based on vehicular communications [5], show that sparse data may be transferred into usable information.

Furthermore, besides V2X-heartbeats, other sources of information can be taken into account, such as smart phones or similar devices (named PDA in the following) carried by on-board passengers. Such devices usually have built-in sensors, albeit with a limited precision/accuracy, such as GPS, accelerometer, etc., and can exchange messages with nearby vehicles and road side units (RSUs) by exploiting their local wireless communication interfaces over WiFi-DIRECT. Even if less accurate, they can help in improving traffic surveillance. In COLOMBO three different classes of vehicles and one RSU class will be considered:

- Class A: passive vehicles that do not participate to traffic surveillance and communication exchanges, because they do not host on-board sensors, wireless communication interfaces, or processing functionality;
- Class B: vehicles with on-board PDAs that participate to traffic surveillance via their low-precision PDA sensors, and communicating via their PDA-based wireless connectivity. They typically offer limited data processing/storage for traffic surveillance, also in order to limit local battery consumption;
- Class C: vehicles with full sensing capabilities, full communication capabilities (V2X-equipped vehicles), and good availability of local resources for data processing;
- Road Side Units (RSUs): Communication Infrastructures with improved sensing, processing and dissemination capabilities deployed in key areas to help traffic surveillance.

From the point of view of sensed data processing, Class B and Class C vehicles, as well as RSUs can autonomously eliminate duplicates, which is the simplest processing operation. First-step processing will be operated only by Class C vehicles and RSUs: in Class C, it will include fusion of Class B data and historical data fusion from other Class C cars; in RSUs, it will include fusion of sensed data from both Class B and Class C vehicles. Finally, RSUs will be the only responsible entities for second-step processing, which relates to the extraction and determination of the traffic-related indicators to be used in the control system.

Conventional stationary detectors, such as inductive loops or cameras can be taken into account if available. The inclusion of different sources of information by RSUs is assumed to allow a complete representation of the state of an intersection over time, requiring advanced data fusion techniques to merge data that have different levels of accuracy.

The collected and generated information about the traffic state are not only used by the developed traffic lights (see next section) but also by the vehicles, mainly for self-tuning their monitoring and communication operations, together with the adaptation of their local processing algorithms. On top of a local traffic state representation, additional, model based and domain specific monitoring solutions can be implemented.

The obtained indicators will be compared to those usually used by nowadays' traffic control facilities for determining whether conventional detectors can be replaced by the COLOMBO surveillance system. This will include a comparison of the quality of collected data and of installation and replacement costs.

Self-Organising Adaptive Traffic Light Algorithms

In COLOMBO a traffic light control system directly inspired from research in swarm intelligence will be developed. Swarm intelligence is a discipline that studies natural and artificial systems that are composed of a large number of (typically identical or very similar) individuals ("agents"), which coordinate using decentralized control and self-organization. In

Swarm Intelligence, agents follow simple local rules and although there is no centralized control structure dictating how individual agents should behave, local interactions between agents lead to the emergence of "intelligent" global behaviour that is complex and adaptive, unknown to the individual agents. The global behaviour provides both positive and negative feedback respectively reinforcing or dampening the local relationships thus achieving a learning capability of the system based on past experience.

Prior research [6] has shown that the principles underlying many natural swarm intelligence systems can be exploited to engineer artificial swarm intelligence systems that show many desirable properties and effective solutions. Traffic management is a domain where Swarm Intelligence can be directly applied. For the purposes of the COLOMBO project, the set of traffic signals that together control one intersection can be seen as one agent whose activity is determined by a set of policies that are chosen in dependence of the current traffic situation. The system works, as depicted in Figure 1, in a continuous loop like every classic control system: sensing, evaluation, action. In particular, information is acquired from distributed monitoring (performing sensing and elaboration) and used to feed stimulus functions that probabilistically select one policy to be executed from a set of rule-based policies, which are specifically defined for different traffic conditions. The chosen policy is then executed for the next time span and evaluated to provide feedback for the next policy selection.

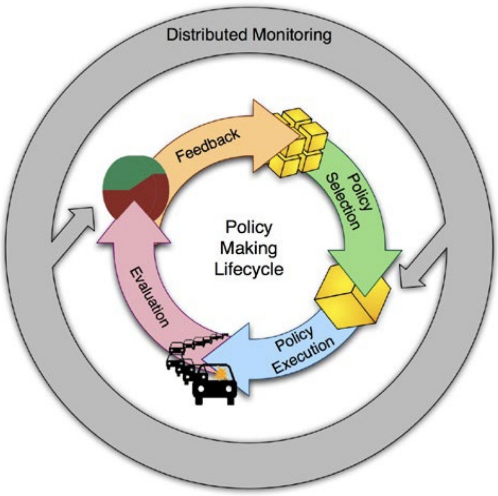

Figure 1 - The continuous loop of policy making

In the simplest case, each agent that controls an intersection acts on the basis of local information and does not explicitly communicate with neighbouring intersections. Neighbours then communicate indirectly through “stigmergy”, a mechanism of indirect coordination between agents through modifications of the physical environment. Stigmergy is a form of self-organization. It can produce complex, seemingly intelligent structures, without a need for any explicit planning, external control, or direct communication between the agents. As such it supports efficient collaboration between simple agents that lack any memory, planning capabilities or even awareness of each other.

Besides private vehicles, the traffic light control policies defined in the COLOMBO project will explicitly take into account environmental-friendly modes:

- public transport will be considered with the aim of defining policies that are aware of it and aim at improving its efficiency, mainly in terms of reducing travel time.
- bicycles and pedestrians: their consideration greatly affects traffic-light logics. Specific policies for their smooth accommodation will be considered and integrated in the system to maximize cyclists and pedestrians' safety.

Tool Set

The developed algorithms for traffic surveillance and traffic lights control will be evaluated within COLOMBO using simulations. COLOMBO will use existing solutions, mainly open source applications, and will extend them for the needed purposes. The involved tools will be joined into a single execution system using the iCS application, developed within the iTETRIS project [10][11]. Originally, iCS was designed to couple the traffic simulation SUMO [12][13] and the communication simulation ns3 [14], as well as a traffic management application to evaluate. The developed solutions for traffic surveillance and traffic lights control will act as V2X-applications in the context of iCS. An additional interface will be implemented in SUMO for an on-line interaction with the vehicular emissions model PHEM. A further tool will be used to optimise the application's performance. The currently assumed architecture of the COLOMBO system is depicted in Figure 2, the tools will be described in a larger detail in the following subsections.

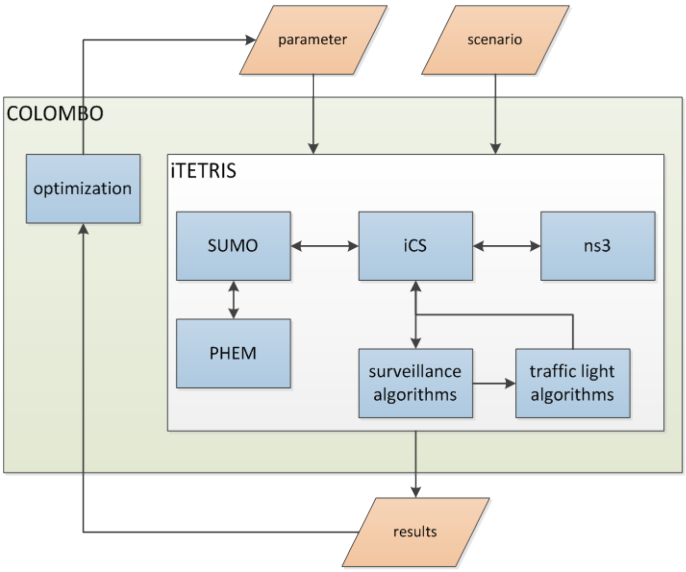

Figure 2 - The preliminary architecture of the complete COLOMBO system

Optimization Tool Kit

A common topic among traffic light controllers and, in general, any algorithmic approach to such and similar problems is the setting and the adaptation of their parameters. Within the COLOMBO project, leading-edge automatic algorithm configuration and tuning techniques will be used and further improved with the goal of defining appropriate rule-based policies, the setting of parameters for the policies as well as within the policy selection algorithm of the developed traffic lights.

Automatic configuration and parameter tuning techniques have been shown in various contexts to lead to substantial performance improvements when compared to traditionally used, manual parameter setting approaches. In addition, beyond pure performance improvements, these techniques lead to a substantial reduction of human effort and allow researchers and engineers to focus on their main strength: higher-level system design. They also lead to an increased flexibility and reusability of the system because specific design and parameter choices can be left open until the system is to be deployed in a new environment.

Emission Models

COLOMBO puts a strong focus on developing solutions that reduce pollutant emissions generated by traffic. Within COLOMBO, the model PHEM (Passenger Car and Heavy Duty Emission Model) will be applied to compute vehicular emissions, since it offers some advantages against other existing instantaneous pollutant emission models:

- PHEM is based on an extensive European set of vehicle measurements and covers passenger cars, light duty vehicles and heavy duty vehicles from city buses up to 40 ton semi-trailers. For all vehicle categories predefined model input data is available from the actual update of the HBEFA [7].
- PHEM has already a validated interface to micro scale traffic models from former projects [7][8][9].
- PHEM also provides the emission values for the traffic situations in the HBEFA and also feeds the model COPERT with emission factors. Thus all results will be compatible with European macroscopic emission modelling approaches in terms of absolute emission levels (e.g. to evaluate emission reduction potentials).

PHEM is developed at TU Graz since 1999. PHEM calculates the fuel consumption and emissions of vehicles based on the vehicle longitudinal dynamics and on engine emission maps. Since the vehicle longitudinal dynamics model calculates the engine power output and speed from physical interrelationships, any imaginable driving condition can be illustrated by this approach. Figure 3 shows the configuration of PHEM with the different modules.

This approach allows PHEM to simulate all possible combinations of speed course, road gradients, vehicle loadings and drivers gear shift behaviour. When combined with traffic models, PHEM is used to calculate modal emissions for all vehicles in the traffic network defined in the traffic model. The vehicle speed data is used as simulated by the traffic model. The required vehicle and engine data is taken from the existing PHEM database on average vehicles automatically, according to a user defined or a default fleet composition. If information about the simulated road network is available (i.e. geo-coded street networks) PHEM can assign the calculated emissions to road segments as input for emission dispersion models if required.

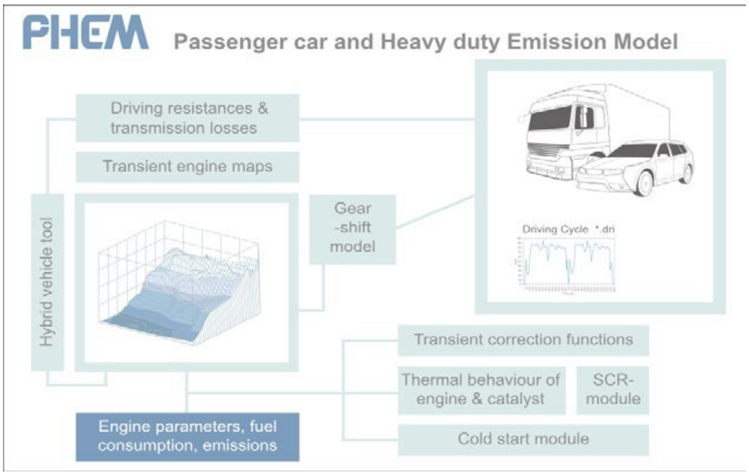

Figure 3 - Modules of the PHEM emission model

A shortcoming in the existing interfaces between traffic models and emission models is the fact, that the traffic models do not consider physical limits on the possible vehicle acceleration levels, yet. PHEM includes a driver model, which shifts gears of the vehicles virtually. Depending on the actual vehicle, the engine full load curve and the actual engaged gear, the vehicle acceleration is limited by the actual available engine torque. PHEM automatically limits the acceleration to full load. Today’s traffic models, however, do not take these limitations into consideration. Since V2I communication and intelligent traffic light control can be used for influencing the driver behaviour (e.g. towards more steady flow and Eco-Drive behaviour), a feedback from PHEM to the traffic model on reasonable acceleration levels for each vehicle would improve the usability of the coupled traffic and emission model significantly. This shortcoming will be eliminated in the interface between SUMO and PHEM during the project.

Traffic Simulation

Even though commercial traffic simulation suppliers offer cheap academic licences, academic research often builds upon own simulation models. Such simulations are mostly developed for one project only and the reuse rate is low. The open (GPL-licenced) microscopic traffic flow simulation suite SUMO allows using a continuously developed and improved traffic simulation for free. Meeting the academic needs, SUMO is portable, and can be executed from the command line, allowing to be embedded in a loop which optimizes the simulated system's parameters, for example. SUMO's high execution speed and small memory footprint allows a fast simulation of large areas and makes it highly usable for optimization tasks. SUMO has been used by different organisations in several projects co-funded by the European Commission, mainly iTETRIS, SOCRATES, and DRIVE C2X, as well as in national projects on vehicular communication, such as simTD.

Figure 4 -Two screenshots of a simulation of the city of Brunswick, Germany (left: complete simulated area, right: zoom at a single intersection)

SUMO is microscopic, time-discrete, and continuous in space. SUMO simulates multi-lane traffic, allows restricting lane usage to certain vehicle classes, and handles different types of intersections, such as uncontrolled intersections with right-before-left rules or prioritised intersections as well as intersections controlled by traffic lights. Besides vehicles, single persons with trip chains may be simulated, where a trip chain may consist of rides using different modes of transport. SUMO's default longitudinal model is based on the model developed by Krauß [15], the lane-changing model was developed within the work on the application and is described in [16]. While "SUMO" is the name of the simulator application itself, the complete "SUMO" package includes further tools for network building, route computation, visualisation (see Figure 4), etc.

Currently, simulated pedestrians may "walk" along roads, "wait" at bus stops or roads, "wait" while performing an action, or use a public or private vehicle. As pedestrian and bicycle traffic have a strong influence on traffic light performance and could also be used as additional communication support, SUMO will be extended by the ability to simulate these modes of traffic within the work on the COLOMBO project. The work will include the extension of the network model by additional pathways along the streets for pedestrians and bicycles, as well as their crossings over the streets.

Communication Simulation

Two different approaches will be taken in the field of simulating vehicular communication within the COLOMBO project. The first is to re-use the ns3 communication simulator which was extended within the iTETRIS project by models for ETSI ITS G5 and GeoNetworking stack. Further extensions will be necessary, here, for simulating additional opportunistic communication protocols for vehicle-to-vehicle and vehicle-to-RSU communication, dynamically adaptive depending on the estimated penetration rate of Class A, Class B, and Class C vehicles. Heterogeneous wireless technologies, such as Class C on-board wireless interfaces and smartphone WiFi-direct cards on Class B vehicles will be jointly considered, as well as differentiated vehicle-local processing techniques to reduce the payload of vehicle-to-vehicle and vehicle-to-RSUs communications

The work on large-scale scenarios has shown that the high execution time of ns3 makes an in-depth evaluation of an application's parameters almost impossible. Due to this, the second approach is to develop a fast, coarse model of vehicular simulations, which will exploit some simulation evaluations made on ns3 under simplifying assumptions (typically smaller scale) as concise configuration parameters for the second step of evaluation.

Middleware

The iTETRIS Control System (iCS) used by COLOMBO joins a network simulator, a traffic simulator, and a V2X application to simulate into a single execution system. Within COLOMBO the development and extension of the iTETRIS platform will be continued. COLOMBO will perform several extensions needed despite the fact that the traffic surveillance and traffic control algorithms developed in COLOMBO can be treated as – rather complex – applications and can be used by the iCS without major changes. The work will include a) opening the iCS for enabling its usage in a loop, controlled by the offline configuration tool, b) implementation of interfaces for allowing complete interactions with the COLOMBO traffic management solutions, and c) incorporating faster communication simulators for reducing the time needed to perform a simulation.

Scenarios

The benefit of new traffic light control systems is usually proofed using simulations. But every report uses own scenarios that range from very basic four-arm intersections up to complex multi-intersection real-world scenarios. We state that such heterogeneity is a major burden to the comparability of traffic lights control algorithms. Hence within COLOMBO, a set of "standard" traffic light evaluation scenarios will be generated, based on evaluation of scenarios used in past research. The COLOMBO scenarios are strived to be portable to other traffic simulators.

Summary

A description on the work planned to be performed within the COLOMBO project was presented. The project is based on the idea to exploit the information retrievable from a small number of vehicles equipped with vehicular communication systems for traffic management purposes, additionally taking into account on-board devices carried by the driver or the passengers. Two traffic management topics are covered within COLOMBO: traffic surveillance and traffic lights control. The developed solutions are meant have lower costs than conventional ones, raising the attractiveness of V2X-based solutions. The additional incorporation of already available technologies, such as the usage of sensors of PDAs carried by the drivers and/or passengers, is assumed to increase the quality of the traffic state representation and to compensate the lack of a needed number a V2X-equipped vehicles.

COLOMBO will rely on simulations for developing these solutions. For this purpose, a comprehensive tool set will be implemented, mainly by re-using already available open source solutions. Besides making the extensions on these software packages available for the community, the project will also deliver a set of scenarios for evaluating own traffic light control methods.

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