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A System for Traffic Light Control Optimisation and Automated Vehicle Guidance Using the V2X Communication Technology

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ABSTRACT

The vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication for the increasing of traffic safety, traffic efficiency and driving comfort is a relatively new field of intelligent transport systems. In this paper a cooperative system for urban transport – which has been developed within the German research project KOLINE – is presented. It uses the communication between vehicles and traffic lights via the wireless communication standard IEEE 802.11p with the aim to avoid stops at traffic lights in order to reduce noise and pollutant emissions. The traffic lights provide information about the future signal changes and the local traffic state to the vehicles. The vehicles use this data to calculate the optimal approach strategy. In addition, the signal programs of the traffic lights are coordinated throughout the network and recalculated every 15 minutes according to the traffic volume. The article focuses on the architecture of the cooperative system and the communication between vehicles and traffic lights.

KEYWORDS: traffic light control, V2X communication

1. Introduction

Acceleration and deceleration of motor vehicles at traffic lights significantly influences the level of noise and pollutant emissions. The fewer stops for each vehicle are required and the more uniform traffic in urban networks flows, the lower the negative impact on the environment. If the number of stops on the road network can be decreased through a proper coordination of traffic lights and by an appropriate communication between vehicles and infrastructure, the waiting times of motor vehicles and the emission scan significantly be reduced.

In this context, the German research project KOLINE was running from 2009 to 2012 with the main goal to avoid stops of vehicles at traffic lights in order to reduce noise and pollutant emissions by using (a) the communication between vehicles and traffic light systems via the wireless communication standard IEEE 802.11p, (b) an automatic vehicle speed control and (c) a traffic volume dependent adjustment and coordination of the traffic lights within the observed road network.

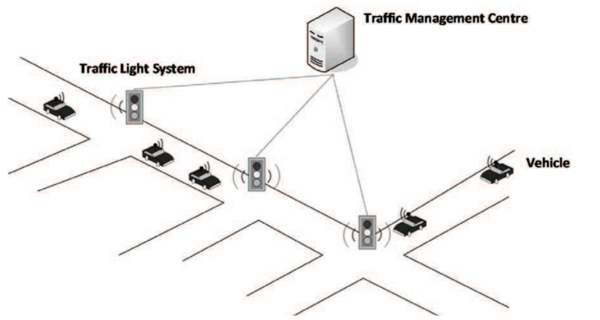

Fig.1. Overview of the KOLINE system

An overview of the KOLINE system is given in Fig 1. The traffic light system provides information about the upcoming signal changes and the local traffic state to the vehicles via wireless communication. The vehicles use this information to calculate the optimal approach strategy. In addition, the signal programs of the traffic signal systems are coordinated throughout the network and recalculated every 15 minutes according to the traffic volume. For the first time, a mutual optimisation of both traffic lights and vehicles is performed.

After providing some basics of vehicular communication systems in Section 2, the subsystems and components of the KOLINE system will be explained in more detail in Section 3.

2. Vehicular Communication Systems

Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication (also called V2X) is understood as the capability of vehicles to communicate with each other as well as the infrastructure directly. Many research projects have dealt with the topics of vehicular communication so far. In Europe, some of the most important have been PReVENT, SAFESPOT, COOPERS, DRIVEC2X, COMeSafety and sim^{TD}. The main motivation for vehicular communication systems is increasing traffic safety, traffic efficiency and driving comfort.

The frequency bands in Europe for vehicular communication are located at 5.9 GHz[1]. Two categories of draft standards provide outlines for vehicular communication. These standards constitute a category of IEEE standards for a special mode of operation of IEEE 802.11 for vehicular networks called Wireless Access in Vehicular Environments (WAVE). 802.11p extends the 802.11 Wireless LAN medium access layer (MAC) and physical layer (PHY) specification. 802.11p aims to provide specifications needed for MAC and PHY layers for specific needs of vehicular networks[2]. The wireless communication should still working at a speed of 200 km/h and a range of 1000 m [3]. IEEE 1609 is a family of standards for the higher layers of the ISO/OSI protocol stack. These standards deal with issues such as management and security of the network [4].

3. Architecture of the KOLINE System

The architecture of the KOLINE system is provided in Fig. 2. The KOLINE system consists of the following subsystems and components:

The **Vehicle** is equipped with an IEEE 802.11p compatible communication device. By using topology information, current and future signal states as well as tailback length, the vehicle's **Assistant System** computes the optimal strategy for passing the intersection, which means preferably not to stop under certain constraints (e.g.a minimum and a maximum speed). The strategy is implemented by the vehicle, so that the speed of the vehicle is controlled automatically without operation of the driver. The vehicle provides information about its speed and location to the traffic light system via IEEE 802.11p.

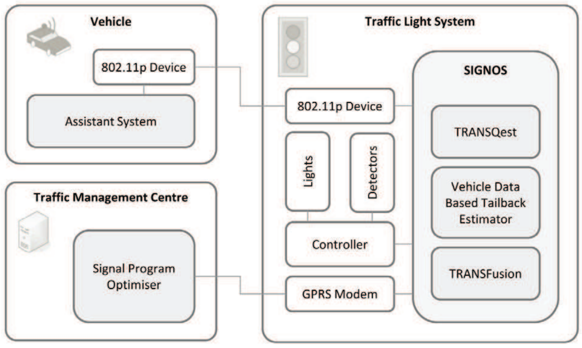

Fig.2. Architecture of the KOLINE system

The **Signal Program Optimiser** running in the **Traffic Management Centre** continuously computes signal programs for all traffic light systems of the considered network for a period of 15 minutes. The calculation bases (a) on the collected traffic volumes measured by stationary detectors within the last period and (b) on the predicted traffic demand. The signal programs are coordinated to each other for the respective optimisation period. The signal programs are sent to the traffic light systems for operation.

The **Traffic Light System** is connected to the signal program optimiser in the traffic management centre via GPRS and to the vehicles via the IEEE 802.11p compatible communication device. The heart of the traffic light system is **SIGNOS** – an interoperable system for traffic light control developed in the research project with the same name[5]. SIGNOS processes the signal programs which are calculated by the signal program optimiser. It is connected to the stationary detectors and can aggregate their raw occupancy data to traffic volumes, time gaps and occupancy periods etc. The **Controller** links SIGNOS with the lights and detectors. The other main task of the controller is to preserve the traffic lights from unsafe states (e. g. intergreen times violation).The local traffic state is calculated by the following three components:

1. **TRANSQest** estimates the tailback lengths on lanes by stationary detectors (one detector for each lane). It bases on the method described in[6].
2. The Vehicle Data Based Tailback Estimator estimates the tailbacks on lanes by speed and location data sent by the vehicles via IEEE 802.11p.
3. **TRANSFusion** merges the estimated tailbacks provided by TRANSQest and the vehicle data based tailback estimator. The result is a set of future tailback lengths with equidistant times (see Section 6).

4. Communication Protocols and Messages

Within the KOLINE system, the subsystems vehicle and traffic light system communicate via V2X communication technology. The subsystems traffic light system and traffic management centre communicate via mobile internet using the General Packet Radio

Service (GPRS).Fig. 3 gives an overview of the communication technologies used. This Section explains details about the protocols and messages.

4.1. V2X Communication

All messages to be send base on the SAE J2735 Dedicated Short Range Communications (DSRC) Message Set Dictionary[7]. They have been slightly adapted by the sim^{TD} research project[8]. All messages are defined with the Abstract Syntax Notation One [9].

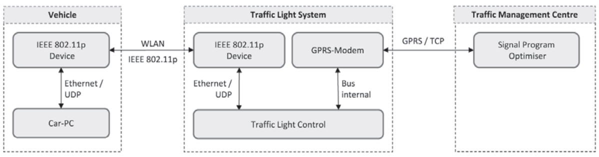

Fig.3. Communication technologies within the KOLINE system

The traffic light system sends the following messages to the vehicles every second:

- Topology (TOPO): The traces of all lanes and the position of the stop lines.
- SignalPhaseAndTimingData (SPAT): The current and future signal states of all signal groups related to the lanes defined in TOPO.
- AppSpecificData(ASD) with TrafficState: The estimated current and future tailback lengths of all lanes (see also Section 6).

The vehicles send the Cooperate Awareness Message (CAM) to the traffic light system every second. The root element of all messages sent between the traffic light system and the vehicles is C2XAppPayload:

Part of the ASN.1 Definition of C2XAppPayload[10]

C2XAppPayload::= SEQUENCE {
protocolMsg CHOICE {
appSpecificData [APPLICATION 1] AppSpecificData,
coopAwareness [APPLICATION 2] CoopAwareness,
decEnvNotification [APPLICATION 3]
DecEnvNotification,
probeVehicleData [APPLICATION 4] ProbeVehicleData,
destinationData [APPLICATION 5] DestinationData,
intersectionData [APPLICATION 6] Intersection,
trafficRegulationData [APPLICATION 7]
TrafficRegulationData,
signalPhaseAndTimingData [APPLICATION 8]
SignalPhaseAndTimingData,
sotisData [APPLICATION 9] SotisData,
trafficListData [APPLICATION 10] TrafficListData,
textAnnounceementData [APPLICATION 11]
TextAnnouncementData,
}
}

The ASN.1 definition is compiled with an ASN.1 compiler [11]. It generates classes which can be used together with a runtime library provided by the ASN.1 compiler for encoding and decoding the messages. Within the KOLINE project, the packet encoding rules (PER) were applied. A special case is the traffic state message. Because the Message Set Dictionary did not provide an appropriate message definition, a KOLINE specific ASN.1 definition was built, which is packed into the AppSpecificData frame.

Within the KOLINE project, the model LinkBird MX by the manufacturer Renesas Electronics (former NEC)[12]is used as the V2X communication device. By using the software development kit of the V2X communication device, Single Hop Broadcast Messages (SHBMessage) are created and sent to the V2C communication device via the User Datagram Protocol (UDP) with the above mentioned messages as payload. The V2X communication device broadcasts the messages via IEEE 802.11p.

4.2. Communication between Traffic Lights and Management Centre

Fig. 4 provides the steps of collecting local traffic volume data, calculating the signal program for the next interval at the traffic management centre and operating the calculated signal program at the traffic light system.

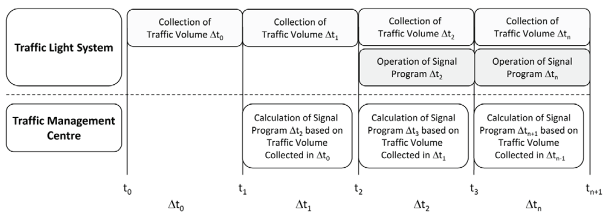

Fig.4. Steps of collecting traffic volume followed by calculating and operating of signal programs

The messages sent by the traffic management centre are the periods of the current and the next optimisation intervals and the calculated signal programs. The traffic light systems provide the collected traffic volumes of the just expired interval to the traffic management centre. The messages are encoded in a binary format (no usage of ASN.1). For transmitting the messages, the Transmission Control Protocol (TCP)is used.

5. Field Operational Test

Field operational tests were performed on a non-public site and on a public road section. The part of the vehicles was taken by the KOLINE partners Volkswagen AG and Institute of Control Engineering at the Technische Universität Braunschweig, Germany. The two test sites differ in some technical aspects which are described in this Section.

5.1. Technical Validation Site

The technical validation site is a former military barracks area. It was equipped with three signal controlled intersections. The correct technical functioning of the whole KOLINE system has been proofed there. All subsystems and components are identically to the description in Section 3. The controller deTRAplex as announced in [13] was used as a component of the traffic light system.

5.2. Demonstration Site

Three signal controlled intersections within the public road network in Braunschweig, Germany, have been selected for the demonstration site. Compared to the technical validation site, the hardware equipment at the demonstration site is from third parties. The main difference is the missing feasibility for SIGNOS to take the main control by sending the signals to be shown to the controller. From several reasons, it is not possible for the controllers used in Braunschweig to process the SIGNOS commands. Instead, the controller provides the current and the first subsequent signal state of all signal groups to SIGNOS. With this information SIGNOS recognises the current signal program running on the controller calculates the signal changes carried out within a short time and provides them to the vehicles and the tailback estimator components. Because of the missing link between SIGNOS and the Controller the signal programs calculated within the signal program optimiser are not operated.

6. Conclusion

This article has described the architecture and the technical components as well as communication aspects of the KOLINE system for the co-operative optimisation of traffic lights and vehicle guidance. There are two other related papers being published on the TST Conference 2012 which reports from the KOLINE project. One article with the title "Multi-Criteria and Monetizing Evaluation of Microsimulated V2X Technology for Traffic Light Optimisation" by Wolfgang Niebel et al. deals with the impact of the KOLINE system on the traffic flow, the noise and the pollutant emissions. The other article with the title "Improvement of Traffic State Estimation at Signal Controlled Intersections by Merging Induction Loop Data with V2X Data" by Oliver Bley et al. discusses the tailback estimation part of the KOLINE system in much more detail. Details to the signal program optimisation were published in [14].

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