A Concept for a C2X-based Crossroad Assistant

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***Abstract*—In urban crossroad areas the traffic flow is commonly not efficient. This results in an unnecessary high traffic density within cities and a resulting environmental pollution by the waste of fuel. To improve this situation, the driver should be enabled to better slow down, to better accelerate, to better decide, to better come in and to better follow within crossroads. This can be achieved by a C2X-based crossroads assistant that brings information about crossroads with lanes and traffic lights on time to the driver to decide on a convenient crossing strategy. Within this paper we introduce our concept for such a crossroads assistant that is based on newly standardized C2X message types. We have developed a novel graphical user interface for interpreting this new information sources in an intuitive, informative but not distractive way to the driver. A first prototype is already implemented and under test.**

***Keywords*—C2X, crossroads, driver assistance**

I. INTRODUCTION

A global trend of urbanization can be observed since several years and this trend is also predicted for the next decade [1]. As side effect this trend implies also an increase in the amount of cars in cities that entails an increase of the traffic density. Especially crossroads with traffic lights are and potentially remain bottom neck of city traffic. In addition crossroads are accident black spots [2].

To overcome these issues several techniques have been developed. Inductive loops are often used to detect waiting cars at traffic lights. This information is used to dynamically adapt the green phases to reduce waiting times and improve the traffic flow. Some cities have also prioritization systems at traffic lights for public transport or emergency vehicles, e.g., ambulance or police cars. Such systems can be realized by radio signals, transmitted from the vehicles or a central traffic control. However, these systems are still limited in their effect and penetration. So the increasing amount of traffic in big cities rises the need for further improvements.

On the other side communication technology improved a lot and especially in the automotive domain the interest of bringing more communication capabilities to the cars is very high. A lot of research projects during the last years had a focus on Car-to-Car (C2C) and Car-to-Infrastructure (C2I) communication, or Car-to-X (C2x) as generalization. Until now this technology is not yet deployed in real operation but will come within the next years. Large scale tests have already been conducted, e.g., within the project SimTD [3]. Many important standards and protocols are already defined by now and thus the foundation is available to develop systems beyond [4]. Especially message types to describe traffic light signaling and crossroads topography are already defines and currently under standardization by the European Telecommunications Standards Institute (ETSI) and the Comité Européen de Normalisation (CEN). In consequence the idea is to use existing technologies validated by former research projects such as simTD to build an approach and implementation of a cooperative crossroads assistant. The considered application scenario focuses on inner cities crossroads with traffic lights that are equipped with road side units for C2X communication. For the development we take over the five goals defined by the project UR:BAN [5]:

- Better stop and better wait: Driving tactics for long red phase and advanced start-stop.
- Better come in: Optimizing the come in to crossroads and the adaptation of green waves.
- Better decide: Provide an extended horizon for local traffic and obstacles, e.g., for selection of the driving direction.
- Better start: Raising the drivers awareness for optimized starting.
- Better follow: Proactive following by a situation-specific approach strategy.

By obtaining these goals the crossroads assistant should help to increase the efficiency at crossroads and help to decrease the fuel consumption and thus the respective emissions.

Different C2X messages with an extensive and feature rich amount of information have been introduced over the last years. This rises the question: How to present this extensive amount of data in an informative, but by no means distracting, way to the driver? In the work at hand, we present a prototype of a novel graphical user interface (GUI) for representing the complex static and dynamic data for intersections in an intuitive, informative as well as not distractive way. The main contribution is the core functionality that can be used in a cascade between the communication unit (CCU) and the infotainment system and thus allows automakers in the future to extend their systems with this functionality. Our prototype implementation is a first step to a new generation of driver information and assistance systems.

The remainder of this paper is structured as follows: We provide an overview of related work in Section II. In Section III, we sketch our technical concept and present our application concept in Section IV. Section V describes our conducted system test. We summarize our work and provide an outlook on future work in Section VI.

II. RELATED WORK

The german project SimTD, ended in 2013, focused on the technical implementation and testing of C2X communication

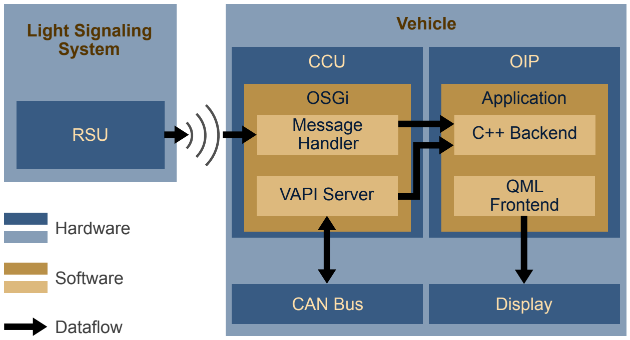

Figure 1. System integration of the C2X-based crossroads assistant.

systems and applications [3]. Project objectives were to increase traffic safety, enhance traffic efficiency and value-added services such as infotainment. Furthermore, implementation scenarios and operating models for C2X communication were developed.

The project UR:BAN, running until 2015, focuses on user oriented driver assistance and information systems and traffic management in urban areas. The project UR:BAN is divided into 3 areas *cognitive assistant*, *networked transport system* and *human in transport*. Common objectives are to increase traffic efficiency and safety as well as to reduce emissions through cooperative traffic systems.

The Car-To-Car Communication Consortium analyzes in their report *Manifesto* several possible application scenarios that could benefit by C2X-based information exchange [6]. They highlight the optimization of green phases to increase the traffic flow and fuel economy. This describes the basic concept that is conducted within this work.

Gradinescu et al. introduce a C2X communication based adaptive traffic light. Their system mainly adjusts the beginning and duration of a green phase in order to reduce intersection triggered congestions [7]. Simulations have shown that an improvement of the traffic flow and thus a reduction of emissions is possible. Röglinger et al. highlight the accident risks on urban roads and name a crossroad assistant as possible solution [8].

Bernais and Lotz analyze C2X messages within crossroads [4]. They describe topology specification (TOPO) as well as signal phase and time (SPAT) messages, which are mainly send by intersections [9]. Furthermore, they highlight possible assistance functions in the context of crossroads that could be enabled by cooperative systems. We continue these findings by developing a crossroad assistant system, which is capable of giving the today's driver a powerful, intuitive and not distracting decision aid.

In summary, to the best of our knowledge, our work is the first description of a cooperative C2X-based crossroads assistant that makes use of the previously mentioned message types *TOPO* and *SPAT*.

III. Technical Concept

In the former project SimTD [3] a set of hardware and software components to realize cooperative C2X systems has been defined. This includes the delivery of different message types over Wi-Fi according to the standard IEEE 802.11p [10].This is a dedicated Wi-Fi standard for wireless access in vehicular environments (WAVE) for cooperative systems and uses packet oriented, connectionless data transmission.

Our technical concept is based on the outcome of the SimTD project and makes use of some of the therein developed components, e.g. the C2X message stack for *TOPO* and *SPAT*. The *TOPO* messages contain information about the exact topology of a crossroads, i.e., the topology of all single lanes, and allow a complete virtual reconstruction of the crossroads. Furthermore the *TOPO* message contains the unique identifier of the crossroads and the exact geographical position on base of a reference point. These messages are dispatched periodically by the light signaling system that are equipped with a communication unit within cooperative traffic systems. An example for such a TOPO message is given in Listing 1. The structure of a *TOPO* message is as follows: Each intersection has an unique id number and a geographical reference point (refPoint) that allows following nodes to reference. Additionally, each intersection has several approaches. In this context the term approach refers to a lane that arrives at one side of an intersection. Therefore, most common intersections need four *approaches* data fields, whereas each of them can define incoming (approach) and outgoing (egress) lanes in a more detailed manner. This is done with the description of driving lanes, which consists of a lane id, lane width and particular features described in a bit representation (e.g., a lane that is reserved for bus traffic). The location and pathway of a lane can be described by nodes, whereas the first node is relative to the reference point and each following node description is relative to the node defined straight before. Lanes can be connected to other lanes with the connectTo attribute, which consists of the number of the lane to be connected and the needed maneuver to do so (e.g., 0x00 for a U-turn). The combination of this data leads to a flexible and expressive representation of the topology of an intersection.

The *SPAT* messages contain information about signal phase and timing of traffic lights. These messages contain information about the current light phase and switching times for each lane of a crossroads. Additionally the *SPAT* messages contain the unique identifier of the respective crossroads to allow an unambiguous matching. Equally to the *TOPO* messages, these messages are also dispatched periodically by the light signaling system. An example of a *SPAT* message is given in Listing 2. A *SPAT* message has also an unique identifier, which corresponds with the unique identifier of the applied intersection. Different states can be represented with a status bit description (e.g., a yellow blinking traffic light in the night). A state represents an amount of lanes for which a specific traffic light applies and defines the actual states of the light as well as the timing of different phases (e.g., green phase). Different types of traffic categories (e.g., rail) can be specified with the category bit representation. The lineRef variable contains information about public transport lines whereas the laneSet value contains all lanes by id for which this state definitions is applicable. The relevantManeuver value describes the direction of the specific move this light is for (e.g., turn right). The temporal progress of the light is given in the nextChanges field. Therefore a *SPAT* message can be understood as a holistic description of the static and dynamic influence properties of a traffic light.

Listing 1. Example of a TOPO message. Based on [4], [9].

```
Intersection {
  id = 47
  refPoint {
    longitude = 105360082
    latitude = 522755554
    elevation = 0
  }

  approaches[0] {
    laneWidth = 300
    approach {
      drivingLanes[0] {
        laneNumber = 101
        laneWidth = 300
        laneAttributes = 0x28 0x00 00000xxx
        nodeList {
          nodes[0] {
            xOffset = -4484
            yOffset = 2209
          }
          nodes[1] {
            xOffset = -324
            yOffset = 935
          }
        }
        connectsTo[0] {
          lane = 104
          maneuver = 0x00
        }
        speedLimit = 30
      }
    }
    egress {
      drivingLanes[0] {
        laneNumber = 104
        laneWidth = 300
        laneAttributes = 0x10 0x00 00000xxx
        nodeList {
          nodes[0] {
            xOffset = -3355
            yOffset = 2352
          }
          nodes[1] {
            xOffset = -315
            yOffset = 935
          }
        }
        speedLimit = 30
      }
    }
  }
}
```

On the hardware side our concept is based on the *Communication Control Unit* (CCU) developed by the SimTD project. The purpose of the CCU is the information exchange via several communication channels, e.g., cellular networks or automotive Wi-Fi. Furthermore, the CCU consists of a GPS receiver for localisation and time synchronization.

The system architecture and integration of our concept is depicted in Figure 1. The light signaling systems as well as the vehicles are both equipped with a communication unit which may be exactly of the same type. However, we will use the term Road Side Unit (RSU) for the light signalizing system for a better distinction. The RSU is dispatching *TOPO* and *SPAT* messages periodically. At the vehicle side these messages are received by the CCU and directed to the message handler. Another software component executed on the vehicle CCU is the vehicle application programming interface (VAPI) server that provides an interface to the vehicle sensors' via CAN bus. This information is forwarded to the Open Infotainment Platform (OIP), a development platform for Continental's infotainment product . Data encoding on the OIP is achieved by a C++ backend component and immediately forwarded to the core logic of our assistant system. The logic of the application uses a QML-based description to generate the GUI that is displayed on a screen.

IV. Application Concept

The developed application consists of two main components to provide the driver with all necessary information. The GUI of our developed application is depicted in Figure 2. The left side consists of the map view of the crossroads under consideration. This view is generated out of the information received in the *TOPO* messages and illustrates the particular traffic lanes of every crossroad branch. The map view can be switched between oriented to the north or to the actual heading in order to fit the driver's needs. An intuitive and dynamic illustration of complex *SPAT* messages were developed and is shown on the right of Figure 2. We developed different approaches for showing *SPAT* messages interactively and chose the presented one as the best trade off between intuitive recognition, information content and inferior distraction. It depicts three lanes that symbolize the three directions between a driver has to choose at crossroads, namely left, straight ahead and right. The actual position is shown by a symbolic vehicle that is placed on the corresponding lane. It moves towards the upper edge corresponding to its actual speed. In order to predict the right lane the car is on, we read out the actual position of the turn indicator blinker through the vehicles' CAN bus respectively the VAPI. The three shown lanes are animated in red and green color corresponding to the actual and following light phase. As an example, Figure 2 describes that the left and straight ahead lane is actual in green phase. As time goes on, the color pattern of each lane is moving

Listing 2. Example of a SPAT message. Based on [4], [9].

```
SignalPhaseAndTimingData {
  id = 47
  status = 0x00 000000xx

  states[0] {
    movementId = 1
    category = 10000xxx
    lineRef = 101
    laneSet[0] = 101
    currState = 0010xxxx
    relevantManeuver = 0x04

    nextChanges[0] {
      minTimeToChange = 30
      maxTimeToChange = 40
      likelyTimeToChange = 35
      confidence = 5
      passState = TRUE
      predCnt = 5
    }
  }
}
```

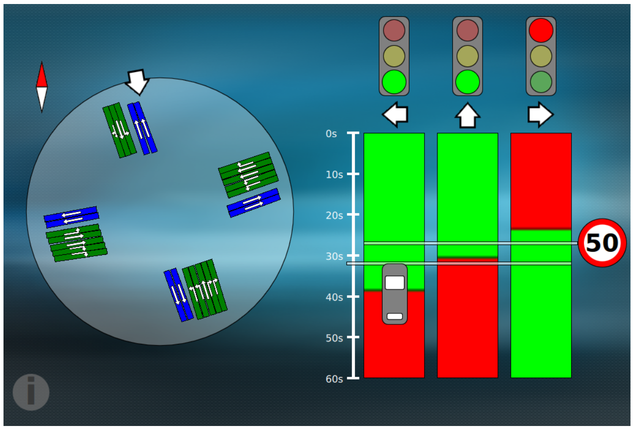

Figure 2. The developed graphical application interface.

from bottom to top. The red area reaches the upper edge in a time synchronous manner related to the end of the real green phase of the respective traffic light. Additionally, there are two indicators shown horizontally that also move to the upper edge. The lower indicator line corresponds to the predicted arrival phase related to the actual driving speed. In this example, the driver actually arrives the intersection in a green phase if he maintains his actual speed. The upper indicator line is tagged with the speed limit sign of the currently allowed maximum speed on the right. This line is illustrating the arrival at the traffic light of the crossroads with maximum allowed speed. In the example depicted in Figure 2 this is for the *straight ahead* and the *turn left* lanes. In this example the car is driving on the *turn left* lane and will arrive the crossroads in a green phase by driving the maximum allowed speed but also by continuing driving with the current speed. For the *straight ahead* lane the current speed would not be sufficient to arrive within the green phase. However, accelerating to the maximum allowed speed would also be sufficient for the *straight ahead* lane to reach the crossroads within the current green phase. The selected design is an informative, intuitive and not distracting representation of the huge amount of received data and can be used by the driver to adapt his road behavior in order to support a better traffic flow. In addition to that, the driver itself is able to reduce fuel consumption as well as exhausting stop and go. The intention was to not give a recommendation of accelerating or decelerating to the driver. This information based approach allows the driver to decide early to remove the foot from the gas pedal and to roll out. This allows to reduce fuel consumption, to avoid hard breaking, and smooth the traffic flow. Furthermore the information about the exact remaining time of the red phase allows early to prepare for accelerating and thus to speed up the take off.

V. System Test

We have integrated the functionality on the target hardware, the CCU and the OIP, and conducted functional tests in a hybrid environment with communication over the air and simulated drive. These tests have proven the overall system functionality. Extensive tests and evaluation are planned for 2015 as part of the UR:BAN project under real traffic and communication conditions at a dedicated test site of the project UR:BAN in Germany.

VI. Conclusion

In this work we have introduced the concept of a crossroads assistant based on C2X communication. Our assistance application is focused on extending the information horizon of the drivers so that a predictive driving strategy could be taken and unnecessary acceleration and brake could be avoided.. The introduced concept is already implemented and has passed functional tests. The implementation is ready to be integrated into the UR:BAN project and will be tested and evaluated in the next future.

The required functionality in form of driver information based on data provided by light signaling systems, transferred by C2X messages is in this first prototype already achieved. The GUI of the crossroad assistant presents the traffic light phase information in conjunction with the ego-vehicle movement. The application GUI provides all necessary information in a compact way so that the driver is able to achieve a quick and accurate perception and interpretation of the situation and to take then a predictive crossroads strategy. . Before being deployed in real operation, the C2X-based crossroad assistants have to be validated and further improved following extensive user studies and large scale, long term field test.

For operational success of the crossroad assistants as presented in this paper the first step is frankly to establish the necessary infrastructure. However, wherever the infrastructure implementation is on place, every equipped vehicle will profit from the system. In this case, it is not necessary to have a 2-digits percentage of C2X-penetration as predicted for many other C2X applications. Most probably this will be the case at important crossroads in bigger cities within the next years.

It is also straightforward that the C2I communication will occur in bi-direction, i.e. every equipped vehicle will submit its own moving data, of course under strict protection of privacy, to the road side units so that the dynamic traffic control, especially traffic light control, could be optimized. This is of particular interest, if the vehicle data is then combined with the existing measurement devices at the crossroads. In this way we expect mutual impulses for the improvements of both adaptive traffic controls and in-vehicle assistants.

A further interesting aspect is the involvement of pedestrians and cyclists in the cooperative systems in crossroad areas, e.g. based on stationary detecting equipments and mobile devices.

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