DEVELOPMENT OF A COMMUNICATION PLATFORM FOR DRIVER AWARENESS AND ASSISTANCE FUNCTIONS BASED ON A CELLULAR NETWORK

Van Poppel, Suzanne; Perik, Harold; Wellens, Michiel; Rademakers, Erwin; Flanders’ DRIVE, Belgium;

KEYWORDS – V2I, driver assistance, cellular communication, femtocell, sensor fusion

ABSTRACT-
The application of cooperative driver awareness and assistance functions offers considerable potential to increase traffic safety. In such applications, traffic information is communicated to the driver to enable the latter to anticipate upcoming situations and, as a result, reduce the risk of accidents. This research project studies the possibilities to use existing cellular networks as communication channel. A second objective is to examine how information transmitted by vehicle sensors may help to improve the performance of such applications.

TECHNICAL PAPER-

INTRODUCTION

Cooperative driver awareness and assistance functions can be applied to increase traffic safety and traffic efficiency. The main functions of such applications are to provide drivers with information about the situation on the road so that they can anticipate and avoid accidents. Part of these systems makes use of information gathered by sensors integrated in the vehicle. These sensors detect an event, for instance a crossing pedestrian, in front of the vehicle and alert the driver. Other systems set up communication channels between different vehicles or between the vehicle and the infrastructure to exchange information. This paper describes the development of such a system and is based on the results of a study performed within the scope of the Flanders’ DRIVE Vision project.

This particular project focuses on situations that occur at junctions or on roundabouts. The objective is that information about the events at the junction, such as crossing pedestrians, the status of traffic lights, etc., is transmitted to the vehicle using a cellular communication link. In this way, a clearer picture of the potential of using existing cellular networks for V2I/I2V-applications is obtained. The system must be able to support functions that improve traffic efficiency and functions that increase safety at the junction. Scenarios that, in combination with the use of a cellular network, allow to improve traffic efficiency and traffic safety are the driving factors of the system design and requirements. These driving factors are described in the first part of this paper.

The developed system has 3 main subsystems. The first subsystem sets up cellular communication between infrastructure and vehicle. The second subsystem is installed on the infrastructure’s side. A traffic management server (TMS) gathers and processes information that it receives from road users and transmits data to the vehicle. The TMS receives the information about pedestrians and cyclists from infrastructure sensors. The third subsystem is installed in the vehicle itself. This in-vehicle system communicates with the infrastructural unit, processes the information and gives advice and warnings to the driver. Another function of this third subsystem is to use data from vehicle sensors in the designed applications. The complete architecture is described in the second part of this paper.

The developed system was used to test all defined scenarios on a specifically designed test track. In the final part of this paper, the results of these tests and the project conclusions and gained insights will be discussed.

DRIVING FACTORS OF THE SYSTEM DESIGN

Scenarios
One of the factors driving the system design and development are the scenarios in which the system improves traffic safety and traffic flow. The defined scenarios effect the system and component requirements. Two sets of scenarios have been defined. The first set concerns traffic efficiency scenarios that aim to improve the traffic flow on junctions. Here, the chosen scenario is the green wave scenario. In this scenario, drivers are given a
speed advice with which it should be possible to pass the green lights without having to stop before a red or orange light.

Figure 1: Green wave scenario

The second set concerns safety scenarios that focus on detecting and avoiding conflicts with other road users. These scenarios have been defined on the basis of safety statistics ([1], [2]) and represent the accidents that are most common or most fatal. In this group, scenarios with crossing pedestrians and cyclists in the blind spot of vehicles are the most important ones. Figure 2 shows the two scenarios of this group: on the left pedestrians crossing the street into which the vehicle turns and on the right the situation of a cyclist who is in the blind spot of a vehicle on a roundabout. This scenario has been defined because for cyclists a roundabout is more dangerous than an ordinary junction.

Figure 2: Safety scenarios

**Cellular Communication**

One of the main objectives of the project is to find out how cellular communication can be used for applications supporting cooperative driver awareness and assistance functions.

Thanks to technological evolutions and investments in the expansion of networks, affordable high-speed communication is available over large areas [3]. The wide-scale availability of an existing and well-maintained infrastructure is a first advantage of this type of network. Comparison of the 3G UMTS systems with the new 4th generation of cellular systems (LTE, 4G) shows that for the latter the bandwidths increase at lower latencies. Other advantages of cellular networks are that they have an inherent authentication process and support roaming.

Cellular networks also have disadvantages [4]. One disadvantage is that there are still areas without decent coverage, for instance in tunnels. Scalability is a second disadvantage. When many users are connected to one cell, congestion may occur. This leads to reduced data rates, lower bandwidths and higher latencies. Depending on cell activity the round-trip latency is in the range of 200–300+ ms range.

By deploying small cells (pico- or femtocells), the coverage problems of existing cellular networks can be eliminated. With these small cells, a local network can be set up to which users can connect. Networks of small cells can be installed in busy areas, for instance at large junctions in the centre of town. These small-cell-based networks also offer solutions for areas where there is no coverage or where only a weak signal is available. However, every small cell must be connected to the operator’s mobile core via the public internet. This internet connection is a drawback of this type of network.

The main advantage of small cell-based networks is that latency is lower than with cellular networks. There are two main reasons for this. The first reason is lower congestion. Fewer users will be connected to one small cell. For situations in which the number of users increases, the number of small cells can be increased as well. The second reason is the possibility to set up a Local Brake-Out (LBO). Once the user is connected to the LBO, data are communicated via a local network. By communicating data locally and not through the global network, the latter is also off-loaded. For small-cell networks, round trip latency is in the range of 60–80ms [4].

Figure 3 shows the connection to cellular communication with a normal cellular network on the one hand and with a local network of femtocells on the other [3]. For the purposes of this project, the UMTS modem is installed in the vehicle; it must set up a communication link with the traffic application server, which is installed on the infrastructure’s side. The traffic application server is connected to the public internet and to a local network (router connection).
For setting up a connection with the normal cellular network, the blue flow is followed. The UMTS connects to the operator’s mobile core through the network. In the mobile core, an authentication process checks the secured keys of the SIM-card. From the mobile core, routing continues over the public internet. As the traffic application server is connected to the public internet, communication between both devices can be set up.

When communication is based on the local network of femtocells, the UMTS-modem is directly connected to the femtocell. Once this connection between UMTS-modem and femtocell has been established, connection is made with the operator’s mobile core for executing the authentication process (magenta line). This connection can be a dedicated connection between femtocell and mobile core or the public internet can be used for this (lower left in figure 3). Once the authentication process has been executed, the data connection can be locally re-routed to connect the UMTS with the traffic application server (green flow). The data between both devices are communicated over the local network only, off-loading the main internet connection of the operator’s network.

![Figure 3: Communication paths between UMTS modem and traffic application server [3]](image)

**SYSTEM ARCHITECTURE**

Figure 4 gives a schematic overview of the overall system architecture. The system consists of 3 subsystems. The first subsystem sets up the communication link between vehicle and infrastructure. The second subsystem is installed on the infrastructure’s side and is designed to gather information from road users, process that information and transmit useful information to the vehicle. The final subsystem is installed in the vehicle; it communicates with the infrastructure and gives information to the driver. In the following sections, the 3 subsystems will be explained in more detail.

**Communication Link**

Between the vehicle and infrastructure unit a communication link based on a cellular network is set up. In the project, two types of cellular networks are tested, namely the 2.5G Edge cellular network, which is the network normally available on the test track, and a 3G femtocell-based network supporting the 3GPP rel. 10 specification, which includes support of 4G Local Break-Out (LBO) capability inside a 3G network. Test track coverage was achieved by the installation of 4 femtocells alongside the track.
On the infrastructure side the traffic management system (TMS) is placed. The TMS gathers all the information about the different road users. For the detection of the pedestrian and bicycles infrastructure sensors of Traficon (FLIR) are used [5]. For the pedestrian who crosses the street a 2D vision based sensor is used. This sensor detects only the presence of a crossing pedestrian in a defined area. Parameters like speed, direction or position in the area are not given nor the number of pedestrians. The detection of cyclist with a vision based system is more complex. The contours of cyclists are hard to detect because they ride closely to vehicles in the same lane. The difficulty increases when they are driving in shadows or at night. To overcome these problems thermal video detection is used for this detection. The warmth profile of a cyclist is different from the vehicle and can be detected in the dark. The sensors are placed on telescopic masts to allow flexible use of the sensors.

Another function of the TMS is to control the traffic lights at the junction. The communication between the TMS and the traffic lights is executed as a one-way Zigbee channel from TMS to controller. The wireless connection makes it easy to adjust the configuration of the traffic lights when needed.

The third main function is the V2I-I2V functionality, which is responsible for receiving information from and sending information to the vehicle. The in-vehicle system transmits information about its speed, heading and position towards the TMS. The TMS uses this information together with all information about the situation at the junction to transmit the relevant information to each single vehicle (e.g. light sequence of upcoming traffic light). Figure 5 shows a diagram of the overall system architecture of the infrastructure unit.
In-Vehicle System

The in-vehicle system is designed such so as to meet the following requirements:

1. Communication with traffic management system (TMS) via cellular communication
2. Measuring of vehicle parameters such as speed, position and heading
3. Processing of data from TMS and vehicle to detect possible conflicts between the vehicle and other road users and to calculate the speed range for the green wave scenario
4. Transmission of information to the driver
5. The use of more accurate vehicle sensors as input for enhanced vehicle parameters.

In order to meet these requirements, two types of platforms have been designed (Figure 6). The first platform is an ‘Android-based Smartphone platform’ and is the central part of the in-vehicle system. The Smartphone platform is not only used for setting up communication with the TMS but also as a computing platform that measures the vehicle parameters and processes all data and as a user interface. The combination of all these functions on the Smartphone platform shows that the Smartphone is a complete platform for driving assistance functionalities. Without extra technology within the vehicle itself, drivers can already benefit from the information gathered from the infrastructure.

The last functional requirement from the above list cannot be fulfilled by the Smartphone. For this, a second platform, which is able to retrieve information from the sensors, is designed. This platform is the ‘Vehicle Sensor Fusion Platform’ (VSFP).

The following paragraphs give more detailed information on both platforms and their functionalities. The corresponding user interface that has been developed, is described in the third paragraph.

Android-based Smartphone
An off-the-shelf Smartphone was chosen because it has the required functional requirements. To set up the communication link with the traffic management server the Smartphone needs the IP-address of the TMS. The sensors on the Smartphone can be used to retrieve the necessary vehicle data. The vehicle data and the data received from the TMS are processed by three Smartphone applications. The first application supports the green wave functionality. Taking into account the maximum speed, the vehicle-to-traffic lights distance and the subsequent statuses of the traffic lights, it calculates a range of vehicle speeds that the driver can follow to pass the green light. Both other applications support the safety scenarios: one gathers the junction information from the TMS, the other checks if there is a conflict between the vehicle and other road users. If there is such a conflict, it will transmit information to the user interface to warn the driver.

Vehicle Sensor Fusion Platform
The second platform is the ‘Vehicle Sensor Fusion Platform’ (VSFP) (Figure 7). It is designed to investigate how information from the vehicle sensors can help to improve the performance of the different scenarios. This platform is a Beckoff industrial PC, connected on one side to the vehicle CAN and to an external GPS sensor which is more accurate than a Smartphone GPS. Via the vehicle CAN, information about wheel speeds, accelerations and steering is collected. These data are combined with the position and heading of the GPS sensor to obtain accurate vehicle speed, position and heading data. On the other side, the VSFP is connected to the in-vehicle network router to be able to set up a wireless communication link with the Smartphone. The Smartphone itself is connected via WiFi with the in-vehicle network router. Through this link it can retrieve the more accurate vehicle data.
Figure 7: Vehicle Sensor Fusion Platform and connection with Smartphone platform

HMI for speed advice
Figure 8 shows the HMI that has been developed for the green wave application. This interface shows a speed range depicted as a green area on the speedometer instead of one single speed. The driver only has to keep his speed within this range to pass the green light. If he drives at a speed indicated in red, he will have to stop before a red or orange light. This speed range interface was perceived by drivers as more intuitive and easier to use than having to maintain one specific speed.

Figure 8: HMI interface for the green wave application

HMI for conflict indication
When the application for the safety scenarios detects a potential conflict with another road user, a warning sign above the speedometer will light up. The position of this warning sign depends on where the conflict is situated in relation to the vehicle. If the conflict is situated to the right of the vehicle, the sign will appear in the right-hand corner to direct the driver’s attention towards the conflict. For a conflict situated centrally or to the left of the vehicle, the sign will appear in the middle or in the left-hand corner respectively. For these scenarios an add-on to the Smartphone user interface has been developed. This add-on consists of 3 LED bars mounted below the windshield of the vehicle and is controlled by the ‘LED bar controller’ (Figure 9). Analogous to the warning signs above the speedometer, the LED bar corresponding with the location of the conflict will light up. For instance, the right-hand LED bar will light up when a cyclist is detected in the vehicle’s blind spot. The LED bar controller receives the corresponding information from the Smartphone application. The wireless communication link is a BlueTooth link.

Figure 9: Depiction of the LED bar controller
RESULTS

The different scenarios were tested on a specifically designed test track consisting of a normal junction for testing the green wave application and scenarios with pedestrians and of a roundabout for testing the cyclist scenario. All tests were performed under controlled circumstances to test the software and the communication set-up. In the test, only one vehicle was connected with the TMS. The communication set-up was tested at a maximum speed of 70 km/h. The designed system flexibilities regarding cellular communication configurations and the use of different platforms inside the vehicle make it possible to test and compare the different system configurations.

At the test track, a 2.5G network was available. This type of cellular network has a higher latency than the new generation of cellular networks. Once the communication link is set up, all data are sent and received correctly by both vehicle and TMS. The higher latency on the 2.5G doesn’t affect the execution of the green wave scenario. This is however not the case for the safety scenarios. The 3G femtocell network with the 4G Local Brake Out functionality proved to be a good addition to the 2.5G network. The lower latencies (60–80ms) that can be achieved by 3G-LBO (or LTE) will allow to communicate time-critical information.

The vehicle parameters can be obtained from the Smartphone standalone and be enhanced via the Vehicle Sensor Fusion Platform. The heading and position data from both platforms are measured and compared. The heading data from the external GPS-sensor connected with the VSFP are improved by data from the vehicle. The heading data from the Smartphone showed inaccuracies, particularly at lower speeds. The heading is an important factor in the detection of potential conflicts with other road users. As the heading improves, detection accuracy will increase. The GPS-sensor used in the VSFP is more accurate and is needed for functions where position errors must remain minimal (<10m). For other system functionalities, the position of the Smartphone is sufficient.

The vehicle speed calculated on the VSFP is based on wheel speeds, accelerations and steering angle. This way, the accuracy of this vehicle speed is considerably improved, particularly at lower speeds and in situations where wheels are slipping or blocking. The optimized vehicle speed is communicated to the Smartphone. When using this speed for the green wave scenario instead of the speed measured by Smartphone, the following main improvements are visible to the driver.

1. Accurate speeds at standstill or at low speeds.
   
   The Smartphone speed switches between values and doesn’t indicate a standstill. The reason for this switching between speeds is that the Smartphone speed is based on the GPS-position. When the vehicle is standing still, the Smartphone’s GPS doesn’t always measure the same position. These differences in position result in speed calculations when, in fact, the vehicle is standing still. Based on the vehicle data, the VSFP does recognize a standstill and so it will give the correct speed of 0 km/h. As for lower speeds, the VFSP uses the vehicle acceleration and wheel speed data to calculate a reliable value.

2. No lagging of vehicle speed during acceleration and deceleration.
   
   As mentioned before, the Smartphone speed is based on differences in position of the vehicle. When the driver accelerates or decelerates, this increase or decrease in speed is calculated as soon as a new position measurement is performed. This delay in speed changes is also reflected on the speedometer of the user interface and affects the ease with which the driver can control speed. The VSFP on the other uses the measured wheel speeds as input for calculating the vehicle speed. These wheel speeds will be increased or decreased immediately whenever the driver accelerates or decelerates. Accordingly, the VSFP speed does not suffer from any delay and tests show that this speed is easier to control for drivers.

During the project and especially during the tests, the differences between the traffic flow scenario and safety scenarios became visible. First of all, data for the traffic flow scenario are less time-critical. A delay of 200-300ms on the communication link is acceptable. Also, for this scenario the error tolerance with regard to the vehicle’s absolute position amounts to about 15m. Things are different in the safety scenarios. Information on the presence of another road user close to the vehicle is more time-critical. Besides, the vehicle’s relative position and the distance between the vehicle and the detected road user are more important here than the absolute position of the vehicle. Extra sensors are needed to obtain this information.

CONCLUSIONS

The purpose of this project was to study the possibility to use existing cellular networks as communication channel between vehicle and infrastructure in cooperative driver awareness and assistance applications. The results show that it is possible to use the 2.5G network but the latency on the communication link is too high for
time-critical applications. To decrease latency, the use of networks with Local Break-Out (LBO) capability and small cell-based networks for reducing congestion is studied. In this project, the LBO is set up using a network of 3G femtocells with 3GPP rel. 10 specification. The 4G cellular network also offers LBO capability and thus shows considerable potential for use in ITS applications. By using femtocells, congestion decreases leading to a lower latency. Note that femtocell-based networks with many users can also have congestion problems.

The off-the-shelf Smartphone used for the project is a central part of the in-vehicle system. It fulfils all the functional requirements needed for driver assistance functions. With such highly available platform, drivers can have easy access to ITS applications. When the Smartphone receives information from the vehicle sensors, the performance of the application improves resulting in a better user experience.

The test results showed the potential and advantages of this type of system but also identified points that are capable of improvement or require additional research:
- The accurate calculation of the vehicle’s relative position in relation to other road users
- Research into ways to obtain more detailed information about pedestrians and cyclists
- The tests were performed in a very controlled environment and at speeds not exceeding 70km/h. The further development of this platform requires more random tests and also performance tests are needed.

ACKNOWLEDGEMENT

This research is part of the project “VISION”, which is supported financially by the Flemish government (IWT). The following project partners participate in the project: Alcatel-Lucent, Flanders’ DRIVE, Lommel Proving Ground, LMS, Melexis, Mobistar, NXP, Tenneco, Tomtom and Traficon. Furthermore, we want to thank Luc Beysen, Frank Dautzenberg, André Nieuwland, Jef de Busser, Michiel Gijbels and Hans Burm for their support.

REFERENCES