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VEHICULAR AD-HOC NETWORKS TO AVOID SURPRISE EFFECTS ON SPARSELY TRAFFICKED, RURAL ROADS

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Abstract

This paper summarizes the main results from a project focusing on the development and evaluation of communication protocols for inter-vehicle communication on sparsely trafficked, rural roads, ensuring the reliable and timely delivery of safety-critical data. The project is motivated by traffic safety applications, especially warning systems to avoid surprise effects of unexpected vehicle encounters on sparsely-trafficked, rural roads. The key issue in such an application is to make sure that the vehicles become aware of each other's existence by the help of communication as soon as possible. The driver can then be warned in time to avoid a possible accident. The challenge is to gain high probabilities of successful delivery in time, especially when having to cope with bad communication performance caused by e.g. crests.

1. Introduction

After the success of passive safety features like the airbag or the three-point safety belt, research and resources in the area of Intelligent Transport Systems (ITS) are now focused on active traffic safety. The goal is to increase the driver's awareness horizon by introducing wireless communication technology and thereby provide him/her with the necessary information to avoid or react to dangerous traffic situations in time. The introduction of communication technology has great potential to reduce the number of fatalities and financial loss of traffic accidents (figure 1). Information on e.g. a vehicle's geographical position, speed and status is exchanged with other traffic participants and used to build a more complete picture of the actual traffic situation and to send warnings to the driver. This data has of course to be fresh and long delays due to the communication process are not only unacceptable, but potentially dangerous.

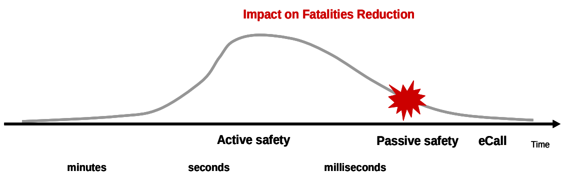

Figure 1: Schematic visualization of the impact of ITS safety applications on fatalities reduction.

Figure 2: A type scenario of a sparsely trafficked, rural road.

A system warning for e.g. on-coming traffic has the potential of saving many lives on rural roads. Due to the relatively high speed and lack of physical counter measures (e.g. lack of guardrails), rural roads account for a majority of the fatal traffic accidents today [1]. On sparsely trafficked roads in rural areas, it is rather the radio environment than the volume of vehicles that challenges the communication technology. Dense vegetation or steep road cuts on the road side limit a vehicle's transmission range and thereby its ability to detect other vehicles and make its own presence known to others. Vehicles on both sides of steep crests and narrow curves can experience similar difficulties (figure 2), which must be dealt with.

This paper summarizes the main results from a project focusing on the development and evaluation of communication protocols for inter-vehicle communication on sparsely trafficked, rural roads, ensuring the reliable and timely delivery of safety-critical data. The focus is on traffic safety applications, especially warning systems to avoid surprise effects of unexpected vehicle encounters on sparsely-trafficked, rural roads. By the help of communication, the vehicles become aware of each other's existence as soon as possible and the driver is then warned in time to avoid a possible accident.

We have measured the communication capabilities of the new IEEE 802.11p standard [2] (taken summer 2010) by field measurements, showing limitations and forming valuable input when developing simulation models [3]. We have used equipment developed in the

European CVIS project [4] for the measurements. Especially at steep crests, the range is limited and timely communication is crucial to warn drivers in opposite direction in time. In that way, this cooperative safety application can be viewed as a “virtual guard rail” where the installation of a physical guard rail, keeping the driving directions separate, is not feasible.

Communication protocols and methods have been developed to improve the real-time communication performance, both using infrastructure [5] and pure ad hoc network solutions [6]. We have, e.g., investigated how to adapt the transmission period of periodic alert messages depending on the situation and role of the vehicle. By giving the leading vehicle of a queue of vehicles a higher priority compared to other vehicles, the performance can be improved. Still, there is an upper limit where the nature of the random access MAC protocol will lead to a saturated network. Our simulation experiments made in the project include evaluation of both single-hop and multi-hop performance. This is especially important when a vehicle is behind another vehicle and has reduced sight, both visually and by radio. If the vehicle starts overtaking, the risk of collision with a vehicle in opposite direction is obvious. The communication is very time-critical and different methods to increase the probability of successful warnings have been investigated.

For rural roads, we mostly assume V2V communication, i.e. direct communication between vehicles. On a particularly accident-prone road section, the deployment of a fixed access point on the road side (Road Side Unit – RSU) might be reasonable. This RSU can than be integrated into an overall communication system, increasing the real-time properties and reliability of the system. We have especially investigated methods to efficiently support connection-setup of new vehicles, including efficient handover from nearby RSUs [5] [7].

A demonstrator showing the potential in field operation has been developed and demonstrated. The demonstrator plays a sound, warning the driver, when a new vehicle is discovered via wireless communication.

The rest of the paper is organized as follows. Section 2 discusses the challenges and limitations of IEEE 802.11p-based communication, including the presentation of selected results from our field measurements. Section 3 presents selected results on our flexible vehicle prioritization scheme, while Section 4 concludes the paper.

2. Challenges and limitations of IEEE 802.11p-based communication

In this section, we shortly introduce the challenges and limitations of the MAC (Medium Access Control) protocol of the recently accepted IEEE 802.11p standard for medium range inter-vehicle communication. Real-world measurements lead us to the conclusion, that the range of realistic V2V-based applications for rural roads is limited and/or needs support from road side infrastructure or communication protocol adaptations.

2.1 Medium Access Control in IEEE 802.11p

One challenge when using IEEE 802.11p for ITS safety applications arises from its MAC method. 802.11p uses a contention-based MAC protocol (CSMA/CA – Carrier Sense Multiple Access with Collision Avoidance), which means that a vehicle competes for access to the common frequency channel with all other vehicles (and/or road side infrastructure) within its transmission range. When two transmitters send at the same time, a data collision occurs and a new attempt must be started, leading to an unpredictable delay until a data packet can successfully be sent. For high numbers of nodes, as e.g. on densely-trafficked highways, this poses a real problem to safety-critical applications, where timing is crucial [8]. (A centralized MAC protocol providing guaranteed channel access for a highway entrance scenario based on V2I (vehicle-to-infrastructure) was proposed in [9] [10].) On sparsely trafficked rural roads, the number of communicating vehicles is usually not high enough to cause such concerns as the probability of data collision in CSMA/CA decreases with the number of channel access attempts and therefore with the number of vehicles.

2.2 Communication in the 5.9GHz frequency band

The choice of the 5.9GHz frequency band for ITS safety communication has severe implications on the connectivity of a vehicular network. In [3], the results of real world measurements of 5.9 GHz 802.11p-based V2V communication in various road settings were presented and evaluated. From our tests with two cars equipped with 802.11p-enabled prototypes we concluded that connectivity is almost immediately lost with the loss of LOS (Line of Sight). This limits the range of safety applications that can be built around 802.11p-based inter-vehicle communication considerably as it is not always possible to warn a driver of e.g. on-coming traffic before LOS between the vehicles is established and the driver is (theoretically) able to visually detect the other vehicle.

A transmission range of about 500m was achieved for two vehicles with free LOS (figure 1), whereas figure 2 shows a quick loss of connectivity when e.g. dense vegetation in a curve limits the radio contact. This has severe implications on the choice of ITS safety applications that can be built on this technology.

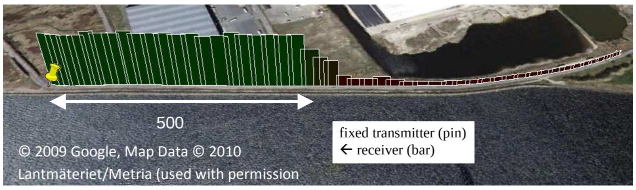

Figure 3: Measurement results for stationary transmitter and mobile receiver. Achieved transmission range at full LOS. (Google Earth visualization).

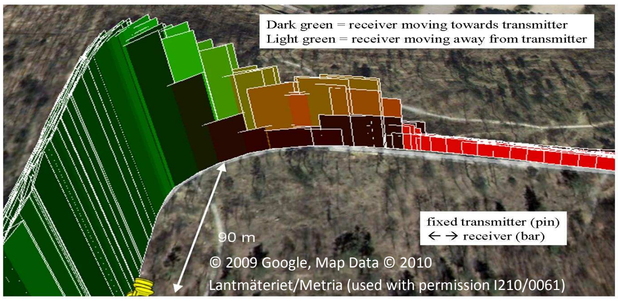

Figure 4: Measurement results for stationary transmitter and mobile receiver. Achieved transmission range at limited LOS around a vegetated curve. (Google Earth visualization).

3. Flexible vehicle prioritization

The standard assumes that each vehicle sends out a CAM (cooperative awareness message) [11] at a rate of 2 Hz, i.e. every 500 ms, in order to inform the surrounding vehicles (and/or RSUs) of its position, speed and heading. In that way each vehicle can build a fairly recent and accurate picture of the current traffic situation. 2 Hz might be a reasonable update frequency for densely trafficked roads, where a higher update frequency would overload the channel and lead to packet collisions and unwanted delay. In the sparsely trafficked case of a rural road, however, the bandwidth is not optimally exploited with a CAM update frequency of only 2 Hz.

Several studies consider the CAM report rate (a.k.a. beacon rate) in vehicular networks. In [12], Vinel et al. suggest an analytical method to study the successful beacon delivery and mean beacon transmission delay. This approach does not consider the assignment of different roles and report rates to individual vehicles to improve the performance of specific applications. The focus of [13] lies on adapting the report rate based on vehicle speed and density and the position accuracy required by the application, but it does not, however, evaluate or propose methods to deal with application specific delay requirements.

We assume the standard IEEE 802.11p MAC protocol but introduce a flexible prioritization scheme to make better use of the offered bandwidth. The 802.11p MAC method offers several QoS (Quality of Service) levels, where a predefined set of waiting and back-off times determine how long a node has to wait before trying to access the common channel or before retrying to send a packet after a packet collision.

We use these QoS level to distinguish between vehicles that need to communicate more frequently in order to speed up the warning message distribution and vehicles that do not need to send out packets as often. In the overtaking warning scenario studied in our simulations, we distinguish between “leading vehicles” (the first vehicle in a queue) and “non-leading vehicles” (the 2nd to last vehicle in a queue) in the following way:

Leading vehicle:

- A vehicle at a distance larger than the LOS transmission range from the vehicle in front.
- Leading vehicles use the parameters of the highest priority data traffic class provided by 802.11p.
- Leading vehicles send their messages with a higher update frequency (e.g. 10 or 20 Hz) than non-leading vehicles.

Non-leading vehicle:

- A vehicle at a distance less than the LOS transmission range from the vehicle in front.
- Non-leading vehicles use the parameters of the lowest priority data traffic class provided by 802.11p.
- Non-leading vehicles send their messages with the regular update frequency of 2 Hz.

As the standard’s 2 Hz update frequency was chosen with densely trafficked highway and urban scenarios in mind, the available bandwidth is not used properly by the relatively low number of communicating vehicles on a rural road. This margin of unused bandwidth can be exploited by increasing the update rate at which a prioritized (in our case, leading) vehicle sends out its data packets. In order to evaluate the performance of an 802.11p-based overtaking warning system (with and without the flexible prioritization scheme), we implemented a simulator in MatLab. Our simulation results show what can be gained from this adaptation in terms of warning dissemination delay.

For the simulations presented in this paper, we have chosen a straight road with full LOS between the leading vehicles. An overtaking warning can only be viewed as successful if it reaches the driver in time to react properly. We assume a reaction time of 1,5 s (which is realistic for a sudden and unexpected warning) and do not add any time for breaking, as a warning should only prevent a driver from starting an overtaking maneuver or, in case he/she has already started it, to aboard the maneuver, not to bring the vehicle to a stand still. In other words, an overtaking warning to any vehicle in the queue must be issued at least 1.5 s before the on-coming traffic passes it by.

We assume realistic vehicle speeds normally distributed around 90 km/h. Furthermore, we assume that all vehicles are equipped with 802.11p-enabled communication technology and a higher packet error probability (i.e. a decrease in connectivity) the further the communication vehicles are away from each other. The increase in packer error probability in respect to distance follows the findings for free LOS (Figure 3).

We studied four cases to show the improvements achieved by the flexible prioritization scheme, always treating the leading vehicle as the highest QoS class of the 802.11p standard and with various send rates:

Case A:

- Send rate non-leading vehicle: 2 Hz
- Send rate leading vehicle: 2 Hz

Case B:

- Send rate non-leading vehicle: 2 Hz
- Send rate leading vehicle: 10 Hz

Case C:

- Send rate non-leading vehicle: 2 Hz
- Send rate leading vehicle: 20 Hz

Case D:

- Send rate non-leading vehicle: 10 Hz
- Send rate leading vehicle: 20 Hz

Figures 5-8 show the results of about 2000 vehicle meetings (meetings of 2 queues in opposite directions) at full LOS and a constant transmission range of 600m. The x-axis shows the number of seconds left for the leading vehicle in one lane until it meets up with the leading vehicle in the on-coming traffic when it receives a warning message. The y-axis shows the number of meters this vehicle and the on-coming traffic are apart (when keeping a constant speed). Figure 5 provides the results for case A, Figure 6 for case B, Figure 7 for case C and Figure 8 for case D, where each dot in the figures represents a successful reception of a warning message from the on-coming traffic.

The reduction in delay to get a warning message is reduced significantly when changing from 2 Hz send rate for all vehicles to the prioritized send rate of 10 Hz for the leading vehicles. A further increase to 20 Hz gives only limited further improvement. Also increasing the send rate for the non-leading vehicles, to 10 Hz, decreases the performance instead because of the congested medium and the characteristics of the CSMA based protocol.

4. Conclusions

In this paper, we have presented both simulation results and real measurements showing the possibilities and limitations of using IEEE 802.11p in a warning system to avoid surprise effects of unexpected vehicle encounters on sparsely-trafficked, rural roads. We have shown how our flexible vehicle prioritization scheme improves the performance and thereby the chances to save life.

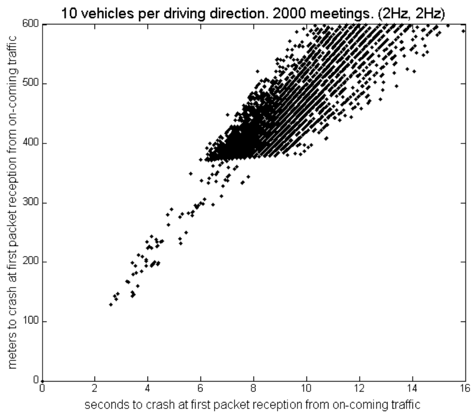

Figure 5: Simulation results when having 2 Hz send rate of both leading vehicles and non-leading vehicles.

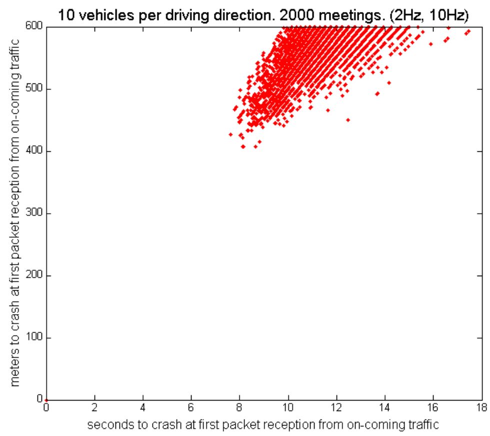

Figure 6: Simulation results when having 2 Hz send rate of leading vehicles and 10 Hz of non-leading vehicles.

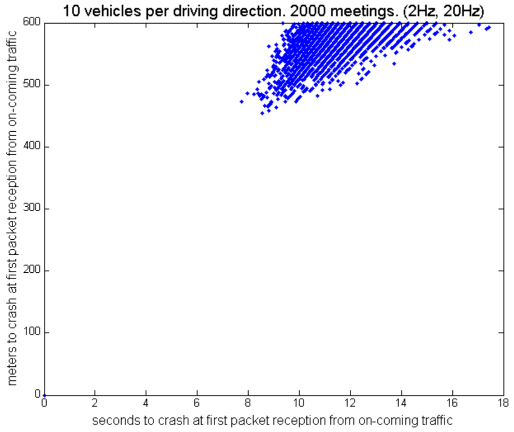

Figure 7: Simulation results when having 2 Hz send rate of leading vehicles and 20 Hz of non-leading vehicles.

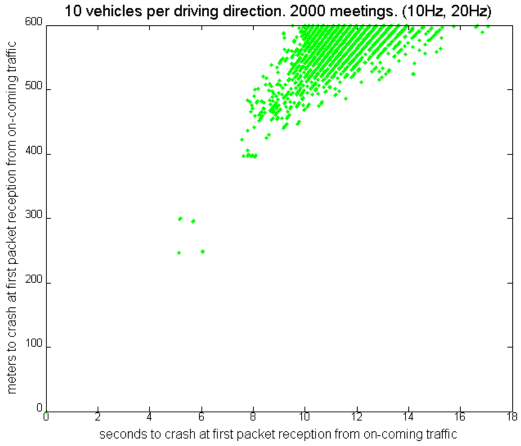

Figure 8: Simulation results when having 10 Hz send rate of leading vehicles and 20 Hz of non-leading vehicles.

5. Acknowledgements

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