

V2V Communication Quality: Measurements in a Cooperative Automotive Platooning Application

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ABSTRACT

This paper presents measurements on Vehicle to Vehicle (V2V) communication between participants in a platooning application. Platooning, according to the SARTRE concept, implies several vehicles travelling together in tight formation, with a manually driven heavy lead vehicle. The platoon being studied consists of five vehicles; two trucks in the lead and three passenger cars. The V2V-communication node in each vehicle contains an 802.11p radio at 5.9 GHz. It is used to send messages between vehicles to coordinate movements and maintain safety in the platoon. Another cooperative application that relies on V2V-communication is multiple UAVs flying in formation; as investigated in KARYON. This project also investigates cooperative autonomous vehicles. In both applications, V2V-communication is an enabling technology. Two metrics are studied to quantify the V2V-communication quality: system packet error rate and consecutive packet loss. These two metrics characterize the communication quality in the different tests (speed, antenna position and two tracks). The paper draws general conclusions on the performance of V2V-communication. The presented test results supports comparison of the tested antenna placements on the trucks and the communication quality related to speed and track.

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INTRODUCTION

In this paper we present measurements on Vehicle to Vehicle (V2V) communication for a cooperative application. In such an application, multiple entities cooperate to solve a common goal such as platooning in road vehicles or formation flying in airborne vehicles. Each individual vehicle has local sensors but must also share data from the sensors of other vehicles. This is because local sensors may be e.g. obscured by other vehicles or have limited range. Additionally, commands for coordination, such as joining or emergency brake, need to be exchanged. This is done with V2V-communication which hence becomes an enabling technology for cooperative systems. To design the cooperative function, the reliability and Performance of the V2V-communication must be known. The variability of communication quality should be quantified to understand how it will affect e.g. control algorithms of vehicle movements.

Two examples of cooperative application are SARTRE [1]: vehicle platooning on public roads; and KARYON [2]: Kernel-based architecture for cooperative vehicles promoting efficiency and safety.

This paper presents results of tests done on the V2V-communication system that was implemented in the SARTRE-project. The tests were performed at the APPLUS IDIADA facilities in Spain on multiple combinations of test tracks, platoon speed and antenna placements: Two different test tracks: a high speed oval circuit and a suburban general road track; three different top speeds: 50, 70 and 85 Km/h; and two different antenna placements on the trucks: Dual antennas on the cabin roof and antennas on both rear view mirrors (RVM). In the tests each vehicle communicates and measures the communication quality to each other vehicle. We study two metrics to quantify the V2V-communication quality: system

packet error rate and consecutive packet loss. These are studied at the system level, i.e. between the pair of communicating nodes. A sending or receiving node will be configured with either one or two radios (with antennas). Hence there are four possible pair configurations, i.e. systems. A measurement of communication quality, expressed in the two metrics, will apply to a particular system, i.e. the configuration of the communicating pair of nodes.

Several groups have, in recent years, studied different aspects of V2V-communications using IEEE 802.11p, as is also used here. In [3, 4, 5] communication is characterized in a mix of Line-Of-Sight and Non-Line-Of-Sight conditions focusing on parameters related to the physical layer. Examples of such parameters are channel gain, path loss, coherence time, power delay profile and Doppler spread. In [6] the focus is on channel measurements at street intersections for V2V safety applications. Paper [7] presents range measurements for vehicles driving towards or away from each other. A survey of V2V-communication is done in [8]. It is shown that the channel characteristics vary depending on the type of road: (highway, rural, suburban and urban). This can be explained by the different velocities, surroundings (number of and distance to scatterers differs in open areas versus small cities), traffic intensity etc. All these variations affect the multi path propagation environment for the radio waves which in turn affects the channel response. A measurement campaign that is similar to the one presented here, is found in [9]. Here, experiments involve two V2V-equipped vehicles and one antenna position. Each vehicle communicates with one radio (and antenna). Consecutive packet loss, round trip delay of packets and communication range is also investigated here.

Results with measurements and tests of a V2V-system for a platooning application, including a comparison of antenna placement, have been published [10]. A similar V2V-setup as in this paper is used, e.g. the truck communicated with two radios (and antennas). In this paper we contribute further to the understanding of how to design a reliable V2V-system for platooning. More realistic scenarios are used and more configurations are tested in this paper.

The rest of the paper is organized as follows: a presentation of cooperative applications which use V2V-communication is presented in the next section. This is followed by a description of the measurement setup. Then the results of the test are presented and finally conclusions and reflections are made.

At the time of measurements the main author, Carl Bergenheim, was employed at SP - Technical Research Institute of Sweden.

COOPERATIVE APPLICATIONS

Cooperative applications involve multiple entities that cooperate to solve a common goal. The entities can be vehicles and the goal can be a specific task such as platooning (road vehicles) or formation flying (airborne). The cooperative aspect of the application necessitates wireless communication

among the participants of the application. In addition to vehicles, entities that participate in the application may also be road-side units that e.g. provide external information and high-level control. An example is traffic control that provides information on road condition and congestion.

The vehicles involved in a cooperative application can be equipped with local sensors which provide data to the application. Through cooperation with other entities external data is also received, see [Figure 1](#). Sensor fusion is used to meld the data from the two sources. Local data is mostly more trustworthy than external. Also external data is attributed different levels of trust depending on the source e.g. from a vehicle that is participating in the application or is unknown. However, external data can describe the environment from a standpoint that is e.g. obscured to local sensors such as the speed of the vehicle in front of the preceding vehicle in a platoon. Local sensors can also be limited e.g. in range or field of vision. Weighting of the data sources according to trust and data quality is typically used in sensor fusion algorithms. External data is sent with V2V-communication from the source, e.g. other participants, and is received at the local vehicle. Data can be periodically sent (time-triggered) or sent only when an event occurs (event-triggered).

Two examples of cooperative application are given below; platooning according to SARTRE and formation flying of UAVs as studied in KARYON. A brief survey of other vehicle platooning systems is given in [11].

The SARTRE Platooning Application

SARTRE (SAfe Road TRain for the Environment) was a project (2009 - 2012) that developed technology for platooning [1]. It was a European Commission Co-Funded FP7 project that sought to support a step change in transport utilization. The project vision was to develop and integrate solutions that allow vehicles to drive in platoons. SARTRE defined a platoon (or road train) as a collection of vehicles led by a manually driven heavy lead vehicle. The following vehicles (trucks and passenger cars) follow the lead vehicle automatically; both laterally and longitudinally. Vehicles may join or leave the platoon dynamically e.g. leave on arrival at the desired destination. The demonstrator consisted of platooning with five vehicles: Two trucks and three passenger cars. SARTRE aimed to explore technology for platooning on roads without changes to the infrastructure and that was safe enough to allow mixing with other users of public roads. Advantages of platooning included a reduction in fuel consumption, increased safety and increased driver convenience and comfort.

The technical challenges in the project were many and interesting such as the design of control algorithm and sensor-fusion. Another challenge is the V2V-communication system. The V2V node is a wireless gateway between the network in the local vehicle to the networks in the other vehicles. The V2V-node allows sharing of local vehicle signals, maps and sensor data among the vehicles in the platoon. The shared

signals are used in the control algorithms of the platoon. The platoon forms a cooperative system where sensing, control algorithm and actuation are distributed throughout the platoon and data is communicated between vehicles (V2V). Automatic control over an individual following vehicle is partly external from the lead vehicle and partly internal from the systems in the following vehicle itself. The following vehicles automatically strive to maintain the specified gap to the vehicle in front, and the trajectory as specified by the lead vehicle. The local systems in the following vehicle can also take over in emergency situations and during loss of communication.

The platooning application requires that V2V-communication is used in addition to local sensors in each vehicle. Using V2V-communication implies that data can be sent directly from the source rather than being indirectly measured locally with sensors. Detecting platoon movements via only local sensors is prone to lag and to accumulate errors. This is because local sensor measurements are only based on the adjacent vehicle, i.e. there is no “look ahead” e.g. of intended movements. For example the lead vehicle can directly send requested acceleration as measured at the pedal rather than having a following vehicle measure the acceleration with its local sensors. With local vehicle sensors a change in acceleration has to “propagate” through the platoon from the lead vehicle to each of the following vehicles and be detected. This affects, for example, the minimum gap size that can be safely achieved.

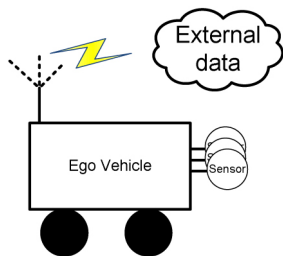


Figure 1. An ego vehicle view of the cooperative application

Without V2V-communication, the gap between vehicles has to be larger to allow for the slower response. Using only local sensors can lead to lateral and longitudinal instability, increased oscillations, and unsafe behavior of the platoon.

The goals of longitudinal control, e.g. the speed of the following vehicles, are to make coordinated movements that are accurate and adequately safe. Two examples are keeping a fixed gap between vehicles and being able to perform an evasive maneuver such as emergency brake or lane change. Lateral control (steering) has similar goals, solutions and also faces similar challenges.

The local and V2V-data is combined by sensor fusion. The default weight of each source is decided offline; The weighting is adapted during operation e.g. with regard to operating conditions such as speed of the platoon. V2V-data is more prone to transient communication failure compared to the local sensor data. Sensor fusion is therefore used and is adaptive

according to the condition of data. The on-line reliability of V2V-data is assessed with timestamps. The sender of a message adds a timestamp with the current time. The receiver can hence detect that the signals in the message have not been updated as expected and are hence old and less credible.

When V2V-data is not sufficiently updated a fall-back strategy aims to gracefully degrade platoon operation while maintaining safety. A possible strategy can have four operational classes. Each class implies gradual loss of service that depends on the length time since the last update, i.e. due to a consecutive packet loss. This denoted BOP (“black-out” period).

1. If BOP is shorter than 100 ms, nothing is done;
2. If BOP is between 100 ms and shorter than 500 ms, modified control parameters are used based on the last valid V2V data. Safe assumptions are made e.g. about acceleration until V2V communication is resumed;
3. If BOP is between 500 ms and two seconds, the inter vehicle gap is smoothly increased;
4. Eventually, after two seconds BOP dissolution of the platoon is initiated. Platoon dissolution implies manual take over by the drivers in the following vehicles.

The fall-back scheme and time parameters given above are examples and reasonable assumptions. Actual times will depend on the control algorithm and environment and need to be investigated in each case. Characterization of V2V-Performance, as in this paper, contributes to the reliability of the platooning system since e.g. control algorithms can be designed appropriately by taking into account the properties of the V2V-Performance.

KARYON

KARYON (Kernel-based ARchitecture for safetY-critical cONtrol) [2] is an on-going project investigating how to solve the paradox of getting cooperative vehicles that are functionally safe without sacrificing Performance or price. It is co-funded by EU FP7 and consists of partners from academia and from automotive and avionic industry, respectively. The scenarios address several possible cooperative functions in the automotive domain (platooning, coordinated lane change, coordinated intersection) and in the avionics domain (coordinated common trajectory traffic, coordinated level crossing trajectories and coordinated flight level change).

The problem addressed in KARYON is that proving that cooperative functions are functional safe, for 100% of the mission time might, become very costly and/or restrictive to the functional Performance. The proposed route forward is to move part of the safety assessment from design-time to runtime. Each cooperative function is defined as a number of different levels of Performance - each having an associated Hazard analysis and Risk assessment. This implies that depending on which level of Performance a function is in, different safety