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Vehicle-to-Vehicle Communication for a Platooning System

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Abstract

This paper describes a vehicle-to-vehicle (V2V) communication system that is developed in the SARTRE project. The project vision is to develop and integrate technology that enables vehicles to drive in platoons. SARTRE defines a platoon (or road train) as a collection of vehicles where a manually driven heavy lead vehicle is followed by several automatically controlled (both laterally and longitudinally) following trucks and/or passenger cars. The V2V communication system enables forwarding of messages between vehicles to share data such as vehicle speed. In this paper, we present performance measurements of a first prototype of the V2V system. This is an important part of the platooning demonstrator that is being developed in the SARTRE project. We evaluate two antenna placements on the lead vehicle; in front on the driver cabin and in the rear on top of the container. Our results show that the rear placement provides superior results, especially for distances above 70 meters.

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"Keywords: Vehicle to vehicle communication; vehicular communication; 802.11p; ITS; platooning; road train;"

1. Introduction

This paper describes a vehicle-to-vehicle (V2V) communication system that is developed in the SARTRE project (1). SARTRE is a European Commission Co-Funded FP7 project that seeks to support a step change in transport utilization. The project vision is to develop and integrate solutions that allow vehicles to drive in platoons. According to SARTRE, a platoon (or road train) is a collection of vehicles led by a manually driven heavy lead vehicle where several following vehicles (trucks and passenger cars) follow the lead vehicle automatically; both laterally and longitudinally. Control over an individual following vehicle is partly external, i.e. it is partly controlled from the lead vehicle. Vehicles may join or leave the platoon dynamically e.g. leave on arrival at the desired destination. The V2V communication system is used in a platooning demonstrator that is developed in the project.

The platoon forms a cooperative system where the participating vehicles are sub-systems. In such a system sensing, control algorithm and actuation is distributed throughout the platoon and data is communicated between vehicles (V2V). Using V2V communication in addition to local sensors in each vehicle is essential for avoiding lateral and longitudinal instability in the platoon. This is caused by accumulated delays and errors when measuring platoon movements from the perspective of the local vehicle. Local sensor measurements are only based on the adjacent vehicle, i.e. there is no “look ahead” in a platoon without V2V communication. By using V2V communication the lead vehicle can directly inform following vehicles of any movement and commands. For the safety of the platoon, it is important to make sure that V2V communication is reliable, for example that all following vehicles are in contact with the lead vehicle and that they receive the same information. Careful antenna placement, which is examined in this paper, contributes to the reliability of the communication system.

SARTRE aims to explore technology for platooning on roads without changes to the infrastructure and to investigate if it is safe to allow mixing platoons with other users of public roads. Expected advantages of platooning include a reduction in fuel consumption, increased safety and increased driver convenience. An example of the latter is being able to legally operate a mobile phone. The technologies developed will be demonstrated in a prototype platoon with up to five vehicles (trucks and passenger cars). The technical challenges in the project are many and interesting such as the design of control algorithms and sensor-fusion. Another challenge is the V2V communication system. In this paper we give an overview of the V2V system that has been used for the first tests in SARTRE, and describe its function.

Controller–area network (CAN or CAN bus) is a common wired communication bus standard designed to allow microcontrollers and devices in vehicles (also called nodes or ECUs) to communicate with each other within a vehicle. A vehicle may contain several CAN buses for different functional areas such as powertrain or body functions. A dedicated SARTRE CAN bus is added in the SARTRE prototype vehicles to interconnect a cluster of computer nodes. These nodes are responsible for separate tasks of the platooning application such as control algorithms, HMI, sensor fusion and V2V. The V2V node acts as wireless gateway to the CAN bus of the other vehicles. This allows sharing of local vehicle signals such as speed and sensor data among vehicles in the platoon. The shared signals are used in the control algorithms of the platoon. The V2V communication system uses IEEE 802.11p (8) for wireless communication.

The paper also present results of measurements that were made on the first prototype of the V2V communication system. The measurements compare communication range with real vehicles in a platoon with respect to two different antenna placements on the lead vehicle.

The remainder of the paper is organised as follows: Related work is presented in Section 2. Platooning definitions are presented in Section 3. The V2V communication system is presented in Section 4, the test setup for the communication system is described in Section 5 and the results are presented in Section 6. Finally conclusions are drawn in Section 7.

2. Related work

Platooning and related issues have been researched in several projects so far. PROMOTE CHAUFFEUR I+II (2) (3) was a European project where truck platooning and driver assistant functions were explored. KONVOI (4) was a German national project where the focus was on platoons consisting of only trucks. The PATH project (5) in the USA requires changes to the infrastructure where as SARTRE does not. For example; PATH vehicles follow transponders that are embedded in the road or use dedicated lanes. These projects were focusing mainly on the technical feasibility of the concept.

A University competition, known as the Grand Cooperative Driving Challenge (GCDC), has taken place during 2011 to develop platooning technology (6). The current scope of GCDC is on longitudinal cooperative driving where as SARTRE also includes lateral control.

Related measurement on V2V communication with 802.11p is described in (7). In that paper field measurements with vehicles were also performed. During the measurements the vehicles were moving and there were moving obstacles located between the transmitting and receiving nodes creating a Non-Line-of-Sight (NLOS) environment. During the test distance, speed and type of obstacle were varied. These results are not directly comparable since different antennas, vehicles and software was used compared to SARTRE.

The V2V node uses IEEE 802.11p as the main main communication channel. This is an amendment to the IEEE 802.11 standard to add Wireless Access in Vehicular Environments (WAVE). The amendment implies small modifications to the PHY and MAC layer in order to achieve a robust connection and a fast setup for moving vehicles. Communication with this standard is ad-hoc based, i.e. communication is direct between nodes and no intermediate base station is needed. ETSI ITS-G5 (8) is a European profile of IEEE 802.11p and transmits in the licensed band of 5.9 GHz. This frequency band is reserved for ITS-applications i.e. Intelligent Transport System. An overview of ITS communication (Intelligent Transport Systems) and the various involved European standards such as ETSI ITS-G5 is given in (9).

3. Definitions in SARTRE

Concept	Description
BO (Back office)	Back office is an infrastructure unit supporting the platooning concept.
FV (Following Vehicle)	A vehicle (truck, bus or car) in a platoon behind an LV. FV is controlled without driver involvement while in highly automated driving mode: Both lateral and longitudinal automated control.
LV (Lead Vehicle)	LV is the lead vehicle of a platoon and is a truck or bus. LV is manually controlled by a trained professional driver.
OV (Other Vehicle)	A vehicle that lacks necessary equipment and cannot join a platoon but may affect it.
PFV (Potential Following Vehicle)	A PFV is not currently platooning, but may do so. When in a platoon this vehicle is an FV.
Platoon	A platoon is a number of vehicles that are travelling together and electronically connected (e.g. via wireless communication). There is one LV and one or more FVs.
PLV (Potential Lead Vehicle)	A PLV is not currently leading a platoon, but may do so.
PPV (Potential Platoon Vehicle)	A vehicle that may be included in a platoon. PPV is controlled manually. A PPV in a platoon is either an FV or LV.
PV (Platoon Vehicle)	LV or FV. In the case of FV it is controlled with high automation.
SARTRE CAN	CAN bus dedicated for communication between nodes involved in platooning.
V2I	Communication between vehicle and BO. V2I is a logical entity and independent of technology used for communication.
V2V	Communication between vehicles. V2V is a logical entity and independent of technology used for communication.

contains a selection of definitions and acronyms that are used in SARTRE. The definitions concern driver vehicle interaction, terminology, prerequisites and assumptions. Further definitions used on SARTRE are given in (10).

Table 1: Definitions for SARTRE platooning

Concept	Description
BO (Back office)	Back office is an infrastructure unit supporting the platooning concept.

FV (Following Vehicle)	A vehicle (truck, bus or car) in a platoon behind an LV. FV is controlled without driver involvement while in highly automated driving mode: Both lateral and longitudinal automated control.
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OV (Other Vehicle)	A vehicle that lacks necessary equipment and cannot join a platoon but may affect it.
PFV (Potential Following Vehicle)	A PFV is not currently platooning, but may do so. When in a platoon this vehicle is an FV.
Platoon	A platoon is a number of vehicles that are travelling together and electronically connected (e.g. via wireless communication). There is one LV and one or more FVs.
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4. The V2V Communication System

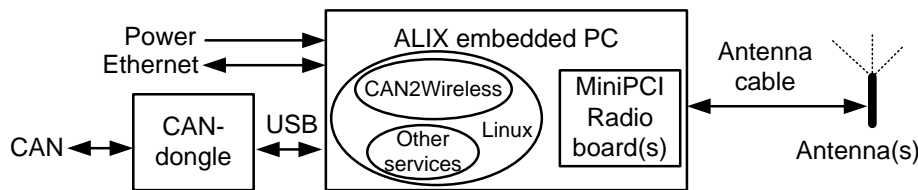


Figure 1: The main components (both hardware and software) of the SARTRE V2V communication system

The main task of the V2V communication system is to forward selected messages from the local SARTRE CAN in one platoon vehicle to the SARTRE CAN of another platoon vehicle. The V2V system enables communication between all platoon vehicles although the majority of communication is information being broadcasted from the LV to FVs. Each CAN message contains numerous signals, such as vehicles status, speed, trajectory, user input to HMI, etc. A schematic overview of the V2V system is given in Figure 1. The forwarding task is coordinated with software called CAN2Wireless. Other services from the node include e.g. clock synchronization between vehicles.

V2V is defined as communication between vehicles independent of communication technology. However, a goal of SARTRE also states that requirements on or changes to the infrastructure be avoided. Therefore communication technologies such as UMTS or LTE (3G, 4G) are avoided due to the dependence on a base station. Also the current deployment of LTE is low. The main inter-vehicle communication channel uses the IEEE 802.11p standard using the 5.9 GHz frequency band. Our tests have shown that communication with IEEE 802.11p is adversely affected by non line-of-sight conditions. This finding is confirmed in (13). In platooning non line-of-sight conditions will occur due to different sizes of vehicles and environmental conditions. This implies that careful antenna placement is needed.



Figure 2: The V2V communication node

4.1. V2V Hardware

We use an ALIX 3D3 embedded x86 PC (11) for the V2V system hardware, see Figure 2. It is based on a 500 MHz AMD Geode LX800 CPU and contains 256 MB DRAM and 8 GB flash storage on a removable compact-flash card. The Ethernet port is used for communicating directly with the V2V system. It is used e.g. for programming, maintenance, and updating the V2V software, but is not used for the platooning function.

The ALIX embedded PC can be equipped with one or two radio boards; currently one is used. The radio board (from Q-Free) connects to the ALIX PC with a miniPCI socket and is based on the Atheros AR5414 chipset. Each V2V node connects to the SARTRE CAN bus using a CAN dongle. The Kvaser Leaf Light HS CAN to USB dongle is used because a Linux API is provided. The SARTRE CAN bus in each vehicle is run at 500kbit/s.

In the current prototype the V2V nodes use 5.9 GHz antennas that are connected to the radio cards. These antennas are manufactured by Mobile Mark, have a magnetic base and a 9 dBi gain (12). The same antenna is used for both trucks and cars. The placement of the antennas on the vehicles is further described in Section 5.

4.2. V2V Software

The V2V node runs Linux. We have developed software called CAN2Wireless for communication between V2V nodes. The function of the software is selective forwarding of CAN messages from the SARTRE CAN bus in one vehicle to the SARTRE CAN bus in another vehicle. It uses UDP/IP messages for transport over the wireless link. CAN2Wireless reads a configuration file that dictates communication parameters. CAN2Wireless can be configured to randomly drop a percentage of forwarded messages. This can be used to test the robustness of e.g. platooning control algorithms.

A SARTRE CAN database states which messages that are to be shared with the V2V system. These messages are picked up by the V2V node while other messages are ignored. In the current SARTRE platooning prototype each vehicle sends in the order of 10 CAN messages every 25ms. These messages are broadcasted so that all V2V shared messages are available in all vehicles. The V2V node buffers the CAN messages received during 25 ms (default value but can be changed in a configuration file) and sends them in one UDP/IP message over the wireless interface. This causes less overhead compared to sending individual CAN messages immediately upon reception.

The CAN communication protocol uses messages IDs for addressing rather than source-destination pairs as in e.g. the Ethernet protocol. To be able to identify the source, e.g. the LV, of a message that is shared via V2V the V2V node translates CAN IDs with an offset. Without this scheme it is not possible to discriminate the source of a V2V message; e.g. whether it originates from the LV or FV1 etc. The position in the platoon of the vehicle that sent the message (the source) gives the offset that is added to the CAN ID, i.e. the CAN ID translation. A V2V message hence occurs with several offset in the CAN database. In the database the ID of a message from the LV will always end with 1 while the ID of a message sent from FV1 will end with 2 and so on. The ID of a non-translated message always ends with 0. Such a message has a local source and has not been forwarded by the V2V system. The same CAN database is used in all SARTRE platoon vehicles.

PTP (13) is used to synchronize the clocks in V2V nodes to achieve a common notion of time. It is possible to reach time precision in the millisecond range (14). The synchronized time is transmitted on the local SARTRE CAN every second to allow other SARTRE nodes in the vehicle (e.g. sensor-, control-nodes) to synchronize their internal time. A common notion of time can be used e.g. for comparing the age of data.

The V2V system has a service to measure the V2V communication quality. The quality is transmitted in a message on the local SARTRE CAN every 25 ms. The service gives a measure of the communication quality between the own V2V node and the nodes in the other platoon vehicle. It can be used by other nodes in each vehicle that perform e.g. control function to adapt their algorithms. For example: With low communication quality an alternative control strategy can be chosen such as increasing the gap between vehicles to increase safety.

5. Communication test setup

Communication tests were done with a three vehicle platoon to compare antenna positions with respect to communication range and packet loss. The LV in the platoon was a truck, followed by a second truck as FV1 and car as FV2. The LV and FV2 car is depicted in Figure 3. The FV1 truck is not depicted in the figure but has the same geometry as the LV. The LV was equipped with two V2V nodes with antennas to be able to compare reliability of communication to the FV2. The antenna of one node was placed on the top of the cabin roof (3,8 meters from the ground). The antenna of the other node was placed at the far rear on top of the container (4 meters from the ground). The latter solution has drawbacks in that the

container is removable and that the overall height of the vehicle is increased by the height of the antenna (37cm).

No V2V equipment was installed in the FV1 truck. The FV2 car had one V2V node with the antenna placed on the roof (1,5 meters from the ground). The LV and FV2 car were equipped with GPS receivers to be able to log position during the tests. The order of the vehicles during the tests was always LV – FV1 – FV2.

For the communication tests the V2V nodes ran a test program, not the CAN2Wireless program. No platooning application was actually running since the goal was to evaluate antenna placement with respect to range and packet lost. The test program consists of a client and a server part. The function of the server is only to receive and send back messages from a client. The client sends periodic probe messages at 10 Hz to the server. The client logs the sent and received message identification number, message size, round trip delay, RSSI (Received signal strength indication), position, date and time. Front and rear V2V nodes in the truck ran the client program.

The server program logs the sent and received message identification number, message size, position and date and time. The FV2 car ran the server program and hence served both clients in the truck. The messages received from the front and the rear V2V nodes in the truck were logged in the same file but was split afterwards to separate communication between the two nodes.

Time in the nodes was synchronized with the PTP protocol as described in Section 4.2. This simplified handling the log-files from the tests since events, such as message sending and reception in two nodes, can be easily compared.

The rolling communication test were performed on a highway in an industrial area around Lindholmen in Gothenburg, Sweden. The speed varied between 0 km/h at traffic lights and 80 km/h. The weather was clear with some clouds and around 20°C. The test lasted 19 min and the distance travelled was about 10 km.





Figure 3. The LV (above) with one V2V antenna on the cabin and one at the rear of the container (circled). FV2 car (below) had the V2V node antenna placed on the roof.

6. Results of communication range tests

The results from tests with front and rear antenna placement are presented in Table 2.

Table 2. Results from rolling test with front and rear antenna placement in LV communicating to FV2 car with another truck in between.

Description	LV front node – FV2 car	LV rear node – FV2 car
Total number of sent messages	11373	11377
Number of successful round trip messages	9633	10955
Number of failed round trip messages	1740	422
Percent successful round trip messages	84.7%	96.3%

Two aerial views of the path travelled in the test run show the differences between front and rear antenna placement in LV. The environment was a highway in an industrial area in Gothenburg, Sweden. The paths in the figure are augmented with red bars to indicate lost messages during the test run. Figure 4 show the lost messages from the front and rear V2V node in LV respectively. During the test run the distance between the vehicles varied between 20m and 170m, see Figure 5. In Figure 4 the distance between LV and FV2 car is approximately 140 meters (indicated with blue arrowheads).

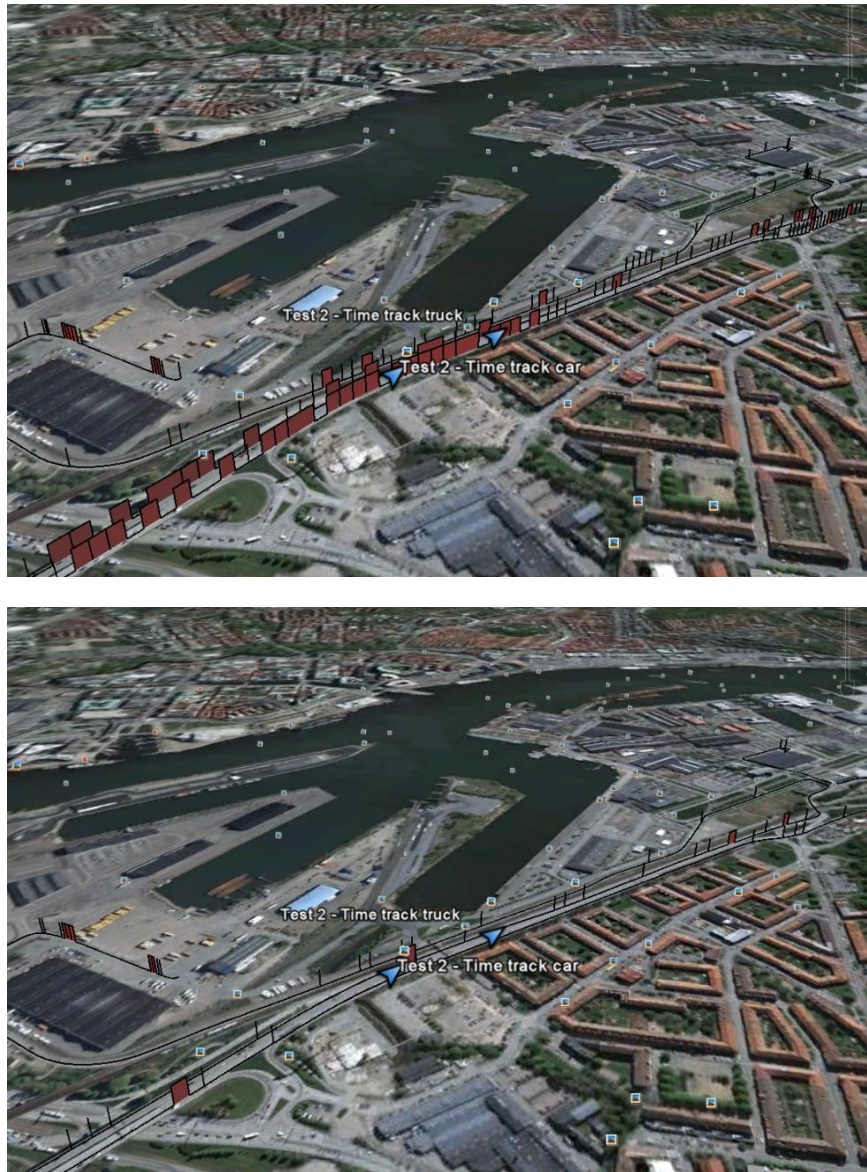


Figure 4. Lost messages between the front (above) and rear (below) V2V node in the LV and the FV2 car are indicated by red bars. The distance between LV and car (arrows) is about 140 meters.

Figure 5 presents successful round-trip messages sent from front and rear node in the LV to FV2 car. Note that the number of sent messages is not the same for all distances. The data in the figure is therefore only used for comparing between front and rear placement.

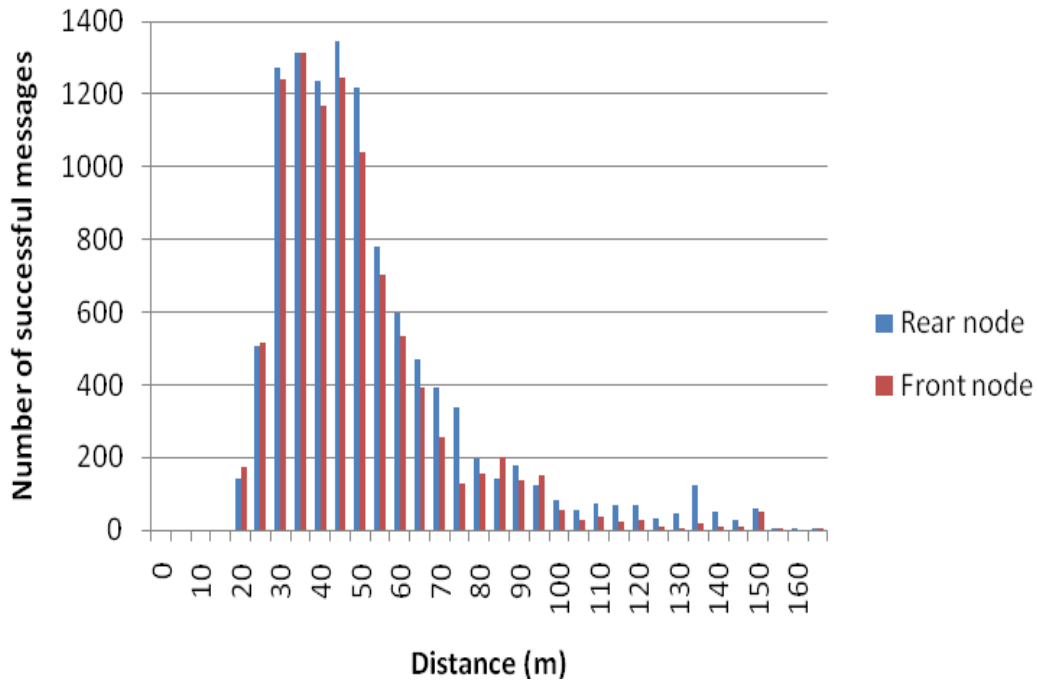


Figure 5. Successful communication at different distances between LV and FV2 car.

Three different range bins are presented in Table 3. In this table statistics on successful round-trip messages at different distances are presented. The advantage (in %) of using the rear antenna over the front is given in the third column in the table.

Table 3. Successful round-trip messages from front and rear V2V node in LV to FV2 at different distances between vehicles.

Distance LV-FV2	LV front node – FV2 car	LV rear node – FV2 car	Advantage
< 70 meters	8332	8892	7%
≥ 70 meters	1301	2063	59%
≥ 100 meters	276	693	151%

7. Conclusions

The paper describes SARTRE, a European Commission Co-Funded FP7 project that seeks to support a step change in transport utilization. The project vision is to develop and integrate solutions that allow vehicles to drive in platoons with a reduction in fuel consumption, improvement in safety and increased driver convenience. A platoon according to SARTRE is a manually controlled lead vehicle with a number of automatically controlled (both longitudinally and laterally) following vehicles.

To achieve the goal of platooning there are a number of technical challenges that include vehicle-to-vehicle (V2V) communication. A V2V communication system prototype is proposed and described. The main communication channel is based on IEEE 802.11p which operates at 5.9 GHz. We describe the function of the software in the V2V system, which is to forward CAN messages between vehicles. In this way signals such as vehicle speed can be shared among vehicles in the platoon.

Measurements of performance of the prototype V2V system are presented. We show that the performance of the V2V is affected by Line of Sight and thoughtful placement of the antenna is needed. Two antenna placements on the LV were tested; in front on the driver cabin and in the rear on top of the container. The rear placement displayed superior results, especially for distances above 70 meters.

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