FFI

RelCommH

Reliable Communication for Heavy vehicles

Project within Vinnova FFI, Fordonsutveckling - Möjliggörande elektronik.

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FFI

Content

FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which half is governmental funding. The background to the investment is that development within road transportation and Swedish automotive industry has big impact for growth. FFI will contribute to the following main goals: Reducing the environmental impact of transport, reducing the number killed and injured in traffic and Strengthening international competitiveness. Currently there are five collaboration programs: **Vehicle Development, Transport Efficiency, Vehicle and Traffic Safety, Energy & Environment and Sustainable Production Technology.**

For more information: www.vinnova.se/ffi

1. Executive summary

The overall aim of the project was to study and develop reliable over-the-air communication for road trains consisting of heavy vehicles. This was done by characterizing and improving reliability using smart communication and antenna solutions that conform to the European vehicle-to-vehicle communication standard ETSI ITS-G5. For road trains, reliable wireless communications are a prerequisite. Road trains will enable reduced energy consumption in heavy transport; improve safety and increase traffic efficiency, all of them important goals formulated by national and international political organs in the areas of transport, energy and environment.

The project was conducted as collaboration among project partners Scania, Volvo, SP, Kapsch and Qamcom.

The project has focused on, and built knowledge in, the areas of:

- Information sharing concepts of cooperative road trains.
- Antenna development and antenna placement for heavy vehicles.
- Antenna diversity on both the transmitting and the receiving sides and communication algorithms to counteract large-scale fading effects caused by trailers.
- System architecture and complex scenarios.
- Performance metrics enabling assessment of the reliability of ETSI ITS-G5 based wireless communications.
- The standardization work with respect to ETSI.

The project has strengthened cooperation between the project participants in the area of wireless communications in general and ETSI ITS-G5 related issues in particular. For example, the cooperation has enabled a common understanding of how standardized solutions for road trains can be designed.

2. Background

The traffic situation in the world will change drastically in the coming years. Increased traffic intensity, new environmental and safety requirements together introduce new demands on the transport sector. Increased traffic intensity also increases the probability of road traffic injuries, which already result in social and economic consequences. Therefore, there is a need for research and development of many different levels to meet these new requirements. One promising technique is to equip vehicles and road infrastructure with wireless communications equipment that enable the exchange of information in real time in order to increase road safety and traffic efficiency.

In order to exchange information, standards are required. In 2007, ETSI began to develop standards for vehicular communications in Eurpoe. A technical committee within intelligent transport systems (ITS TC) was formed which contained five working groups focusing on different aspects of the communication. The harmonized frequency band to be used for vehicular communication across Europe can now be found at 5.9 GHz, and US and Japan have similar frequency bands around 5.9 GHz. 5.9 GHz is a high carrier frequency, which in turn causes the antenna design and placement to have a major impact on the links between transmitters and receivers. Heavy vehicles are especially challenging due to their size and there is no obvious placement because the penetration of objects is low for this frequency band. For example, signals are completely blocked by the truck's trailer if it is made of conductive or absorbent material. Blocked signals result in dropped information, which in turn leads to delays and increased uncertainty in ITS applications. The reliability of the ITS-G5 standard can be addressed on several layers of the protocol stack but the most important is the physical layer which can be found at the bottom of the stack. This layer is already standardized in ITS-G5 and amendments and supplements to this part are very expensive and require a new radio chip. Therefore, the focus of this project was to improve reliability by developing customized antennas and to finding good antenna placements for heavy vehicles. In addition, by developing methods for antenna diversity (which can be used without modifications of the standard) and multi-hop algorithms that can be implemented further up in the protocol stack.

In Europe, many research resources have been invested in the development of applications based on the selected vehicle communication standard, see for example the EU projects CVIS, Safespot, Drive C2X and Sartre (which have implemented road trains). All projects have revealed problems with the reliability of the wireless link due to the high carrier frequency. If high reliability cannot be ensured it will be difficult to release versions of cooperative applications designed to improve road safety and increase traffic efficiency.

3. Objective

The overall objective of the project was to characterize the reliability of the wireless communication links of road trains consisting of heavy vehicles, and to then improve it by introducing smart communication and antenna solutions that do not violate the standard (ETSI ITS-G5) for wireless communication between vehicles and between vehicles and infrastructure. Road trains, as described in the background, are one way to approach the future goals of environmental friendly, safe and efficient transportation of goods.

The project has focused on the following objectives:

- Develop performance measures and metrics to assess the reliability of wireless communication based ETSI ITS-G5.
- Increase the reliability and performance of ITS applications using multiple antennas and thereby exploit transmit and receive diversity.

- Develop prototype antennas and antenna placements for heavy vehicles to enable reliable wireless communication.
- Study the system architecture for cost-effective solutions.
- Develop and evaluate algorithms for selecting the transmit antenna and multi-hop schedules.
- Define information sharing concepts for one or more road train applications and share the result with the standardization work of ETSI.
- Demonstrate a road train.

4. Project realization

The project was setup in seven work packages (AP) consisting of:

1. Project management
2. Information sharing ITS
3. System architecture
4. Antenna prototypes
5. Diversity communications
6. Tests
7. Demonstration

See the Gantt scheme according to figure 1, which visualizes the timing of the work packages and deliverables.

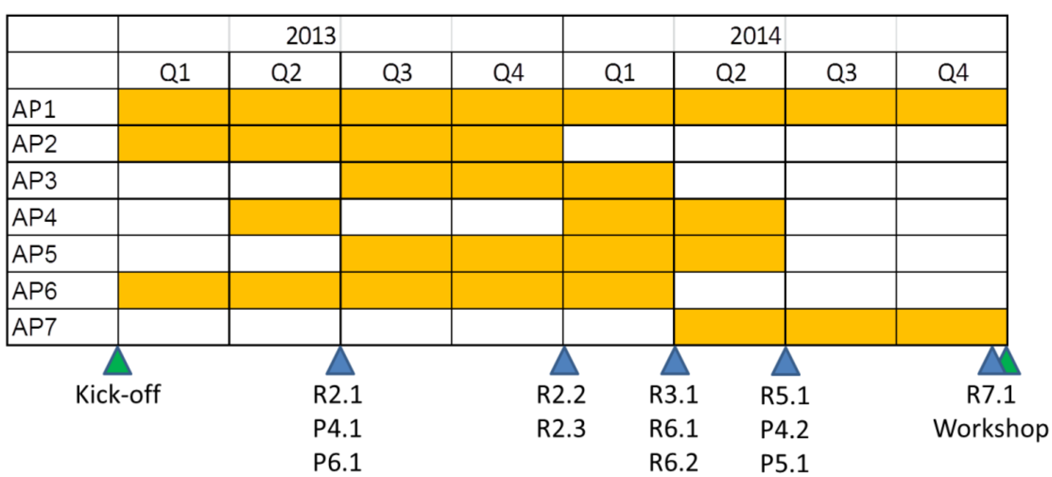

Figure 1. Gantt scheme with deliverables (the deliverables are described in the project plan).

5. Results and deliverables

The project started with the development of a *state-of-the-art* report and after that information sharing concepts for several variants of cooperative road train applications were defined. Variants which describe different levels of functionality based on how often and how much information shall be sent. Because the ETSI ITS-G5 has a very limited capacity (all communication is *ad hoc* with a *listen-before-talk* protocol implemented) trade-offs have been made between communication frequency (that is to say, update rates) and quantity of information (message length) on the side, compared to the functionality and reliability on the other side. These results are input to the standardization work of ETSI.

In the project we investigated antenna diversity and how to select transmit antenna based on the geometry of the road train and also on real-time estimations of the channel. On the receiver side, signals from multiple antennas were combined with different techniques (e.g. selection combining or maximum ratio combining) to enhance reliability. There are several different ways to implement antenna diversity on hardware (switches on the radio card, multiple radio nodes, etc.) and this has been studied in the project and the resulting performance has been weighed against practical and financial aspects in the analysis of system architecture.

Different types of antennas and antenna placements have been evaluated through measurements in the lab and in the field (Figure 2). This has resulted in much knowledge about the radio channel (in the context of heavy vehicles) used in ITS-G5 communications. Seven different antennas have been developed and verified in the project. This development also resulted in a patent application.

In parallel with the above, to be able to assess reliability of ETSI ITS-G5 based wireless communications, performance metrics and measurement methods were developed. The project developed special measurement software (Figure 3) and a test software for both SISO (Single Input Single Output) and MIMO (Multiple Input Multiple Output) radio nodes. The latter was developed by Kapsch based on specifications developed in RelCommH in cooperation with the FFI project WCAE.

At the end of the project a road train was demonstrated with two different communication protocols: one according to ETSI ITS-G5 and another one according to an improved protocol developed in the project. The demonstration was held at the AstaZero test site and showed how the standard solution (ETSI ITS-G5) would sometimes result in a (simulated) collision during hard braking events when the distances were short between the leading vehicle and the following vehicles in a road train. With the improved communication protocol the subsequent vehicles initiated retardation immediately and stopped at a safe distance.

The project has also created a framework for specification and analysis of complex scenarios for road trains.

Furthermore, the theoretical concept of data age has been defined and used to evaluate measured data and algorithms. Existing algorithms have been evaluated and new ones have been developed (to increase reliability and reduce the data age) using simulations based on both theoretical radio channel models as well as on data measured in field on real road trains.

Taken together, all these activities helped to increase the reliability of the ITS-G5 communications.

Figure 2. Example of antennas developed in the project (left) and an antenna integrated in a rear view mirror (right).

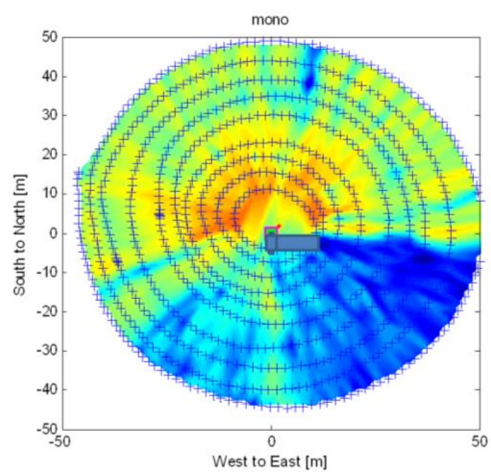

Figure 3. Rigid truck placed for measurement of radiation pattern (left) and resulting radiation pattern (right).

5.1 Delivery to FFI-goals

Climate and environment are key factors that impact future road transport. Today, research is under way in a number of areas to reduce negative impacts, where road trains are one of the methods possible for reducing fuel consumption of heavy transport by up to 20%. In RelCommH we have studied road trains with a focus on radio communications and information sharing, both of which are key components for enabling secure and energy-efficient road trains. In this project, methods of measurement, hardware and methods to improve the reliability of communication were developed, and the results can in turn be used to safely reduce the distances between the vehicles in the road trains. The opposite (low reliability) necessitates either longer distances (and thus reduced fuel savings) or road trains with shorter distances between the vehicles that are not safe, introducing risk of both material and personal injuries.

Compared with ACC (adaptive cruise control - a system that use only local sensors in one vehicle), a road train vehicle gains at least one second of reaction time by receiving a brake message from the vehicle in front. Information from other vehicles in the road train further ahead is also received over the wireless link and this is information that an ACC system cannot deliver. A cooperative road train application accommodates a variety of communications related to vehicle dynamics and events. By picturing a control loop and the simple example of a braking message one can realize both the advantages and importance of reliable wireless communication for road trains.

More specifically, the project has contributed to:

- Methods to measure and assess the reliability of the ITS-G5 communication between heavy vehicles.
- Methods to improve the reliability of the ITS-G5 communication between heavy vehicles.
- Development and evaluation of products for increased reliability in the ITS-G5 communication between heavy vehicles.
- Information sharing concept for road train applications for heavy vehicles, which contributes to future standardization work in this area. The project participants thereby have possibilities to affect development of road trains within the standardization organizations.
- Volvo and Scania have gained a competitive advantage by early study and realize the importance of transmit and receive diversity for vehicular communications.
- In the extension of the project, cost-efficient and environmentally friendly transports are enabled.
- The project has moved the TRL level for road trains from TRL4 to TRL5.

- Systematic analysis of complex scenarios in road trains.

6. Dissemination and publications

6.1 Knowledge and results dissemination

Knowledge about the measurement methods that have been developed has already been adopted by the companies and used in other in-house projects. The project has also devised and investigated novel and improved antenna positions for heavy vehicles in combination with ITS-G5 communications and these are now used by the participating OEMs. In addition, the specific benefits of both transmitter and receiver diversity for heavy vehicles in combination with ITS-G5 communication have been demonstrated in the project. In all these areas (methods of measurement, antenna placement, antenna, diversity), the project has already had an impact.

ETSI has recently opened a Work Item for platooning (road trains) and reports (which are made public) from the project will be a great contribution to this sub workgroup. Project participants from Kapsch and Volvo AB are members of this group and can transfer knowledge.

The project organized a two-day activity for researchers and others active in the field, at AstaZero, October 22-23, 2014. The first day consisted of project presentations from RelCommH and a demonstration on AstaZeros rural road. On the second day other research projects related to vehicular communication presented their objectives and results. The projects presented include (in addition RelCommH) EMCCOM, Chase V2X, WCAE, Companion and ACDC. The presentations were followed by discussions. The first day was attended by about 60 people and the second day by about 35. The arrangement received many positive comments. For press release and schedule see Appendix A and B.

In addition, the project has been presented at the "Elektronik i fordon” conference and at the FFI program conference on November 6, 2014.

6.2 Publications

RelCommH will publish at least ten conference papers:

1. K. Karlsson, J. Carlsson, M. Olbäck, T. Vukusic, R. Whiton, S. Wickstrom, G. Ledfelt, J. Rogö, "Utilizing two-ray interference in Vehicle-to-Vehicle Communications," Antennas and Propagation (EUCAP), 2014 8th European Conference on, vol., no., pp.2544,2547 6-11 April 2014.
2. C. Bergenhem, E. Coelingh, R. Johansson, "Measurements on V2V Communication Quality in the Vehicle platooning Application," 7th International

Workshop on Multiple Access Communications (Macom), 27-28 August 2014, Halmstad, Sweden.
3. C. Bergenhem, A. Soltani Tehrani, E. Coelingh, R. Johansson, "V2V communication quality: measurements in a co-operative automotive platooning application," SAE 2014 World Congress, Detroit, MI, USA, Apr. 8-10, 2014, 2014-01-0302.
4. K. Karlsson, J. Carlsson, T. Andersson, M. Olbäck, L. Strandberg, M. Hellgren, "Distance Dependent Radiation Patterns in Vehicle-to-Vehicle Communications," SP Report 2015: 07, ISBN 978-91 -88001-36-8, ISSN 0284-5172, Borås 2013-12-15.
5. K. Karlsson, M. Larsson, S. Wickstrom, G. Ledfelt, M. Olbäck, R. Whiton, J. Rogö, "On the Effect of Vertical Spatial Diversity on V2V Communication for Three Different platooning Scenarios," Accepted for presentation at Antennas and Propagation (EUCAP), 9th European Conference on, Lisbon, Portugal, April 12-17, 2015.
6. M. Larsson, M. Jonsson, K. Karlsson, C. Bergenhem and T. Larsson, "Curvature-based Antenna Selection Method Evaluated Using the Computer Age, Metric and V2V Measurements," Accepted for publication at IEEE ICC 2015 - Workshop on Dependable Vehicular Communications (DVC), London, England, June 8-12, 2015.

Publications not yet submitted:

7. Channel measurements of road trains for transmitting and Receive Diversity.
8. A Framework for Complex Scenarios for Vehicle platoons
9. Concepts for Multi-hop algorithms.
10. ITS Information sharing concept for Platooning and CACC.

7. Conclusions and future research

The project has come up with several appropriate antennas and antenna placements. A patent application has also been developed in the field of antennas, which was an unexpected but positive project outcome.

The project has investigated the importance of diversity for road trains with heavy vehicles. This has resulted in the knowledge that diversity in this case is a necessity for reliable communication.

Various multi-hop strategies have been tested and verified. Existing multi-hop strategies are evaluated on measured data from real road trains and new multi-hop algorithms have been developed.

Among the project participants, it has always been a positive and constructive spirit and contacts for future collaboration have been established. A continuation project

(RelCommH2) has been planned but, due to internal company resources, postponed. Contact regarding this matter shall be resumed Q3 2015.

For road trains we see the following needs for continued research:

- An ecosystem for road trains; handshaking, events that create, dissolve road trains etc. must be explored and defined
- Security (encryption, authentication)
- Functional Safety in cooperative applications
- Certification
- Information sharing, standardization, protocols and multi-hop algorithms
- Measurement methods

8. Participating parties and contact persons

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Appendix A - Article included in SP customer magazine Technology;research #1 2015

Truck road trains save a lot of fuel

An automotive project that ended at the AstaZero test facility in Borås has studied the potential from intelligent transport systems where vehicles communicate with one another.

AUTOMOTIVE The project came up with solutions that improve information transmission between trucks and that can therefore make transport both safer and more efficient.

"Up to 20 per cent of fuel consumption in heavy vehicles can be saved with the help of interacting intelligent transport systems that exploit new communication technology based on wireless communication," says SP scientist Kristian Karlsson.

In the RelCommH (Reliable Communication for Heavy vehicles) project this technology was used to drive heavy vehicles in road trains with a gap of no more than ten metres between each truck. This requires the construction of robust wireless communication links between the vehicles, and it was this that was studied and demonstrated in the project. The results from the project will contribute to future standardisation of road trains.

PHOTO NIKLAS ARABÄCK, SP

A lot of fuel can be saved with the help of new communication technology.

RelCommH was financed by Vinnova as part of the FFI programme's vehicle development project. SP participated together with SP, Volvo Group, Scania, Kapsch TrafficCom and Qamcom Research & Technology.

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Appendix B - RelCommH demonstration and workshop program

RelCommH

October 22-23, 2014
AstaZero, Sweden

Presentations and demonstration of RelCommH project

Wednesday, October 22

9.30 Registration and coffee

10.00 AstaZero information, Mikael Blomqvist, AstaZero

10.10 RelCommH presentations

10.10 *RelCommH overview*
Kristian Karlsson, SP Technical Research Institute of Sweden

10.20 *Project partner presentations*
Scania, Volvo, Kapsch, Qamcom

11.00 *Field measurements and antenna development*
Kristian Karlsson, SP Technical Research Institute of Sweden

11.30 Coffee break

11.50 *Complex scenarios and system architecture*
Lars Strandén, SP Technical Research Institute of Sweden

12.10 *Information sharing concept for platooning applications*
Carl Bergenhem, Qamcom

12.30 *Data age concept - simulations and measurements*
Marcus Larsson, Qamcom

12.45 *Introduction to the demonstration*
Samuel Wickström, Scania and Magnus Olbäck, Volvo

13:00 Lunch, demonstration and mini exhibition

17.00 Closing

Welcome!

RelCommH project team

SP your Science Partner qamcom kapsch >>> SCANIA VOLVO VINNOVA

Appendix B - RelCommH demonstration and workshop program

RelCommH

October 22-23, 2014
AstaZero, Sweden

Workshop on Swedish & EU V2X project interactions

Thursday, October 23

9.30 Registration and coffee

10.00 Project presentations

10.00 *EMCCOM*
Björn Bergqvist, Volvo Cars

10.30 *Chase V2X*
Erik Ström, Chalmers

11.00 Coffee break

11.30 *WCAE*
Mikael Nilsson, Volvo Cars

12.00 *Companion*
Henrik Pettersson, Scania

12.30 Lunch

13.30 Project presentations cont.

13.30 *ACDC*
Annette Böhm, Högskolan i Halmstad

14.00 *RelCommH*
Kristian Karlsson, SP Technical Research Institute of Sweden

14.15 Conclusions and discussions

15.00 Closing

Welcome!

RelCommH project team