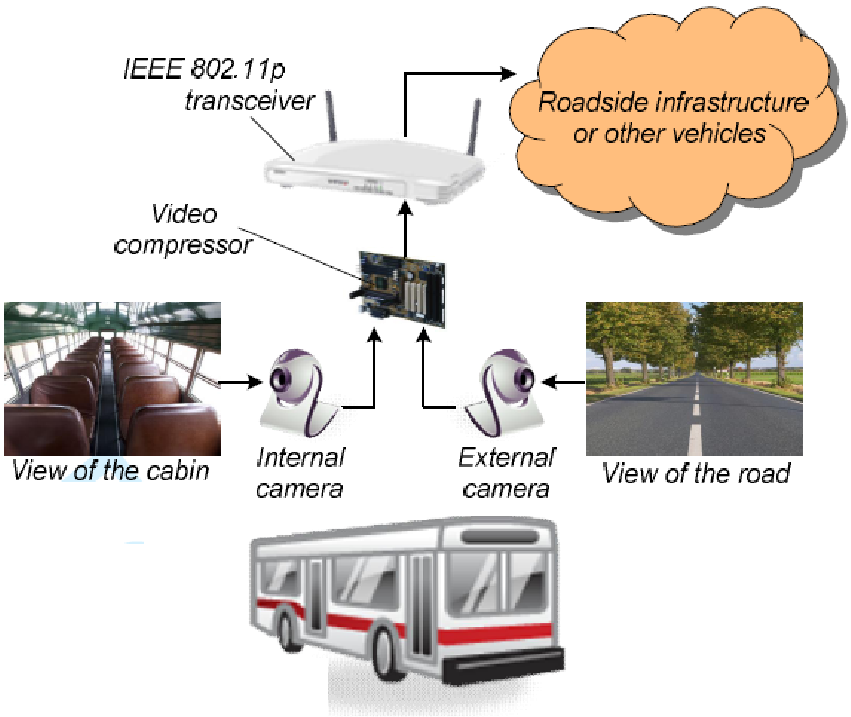
Pre-study: Real-time video streaming over VANETs for increased road traffic efficiency and safety



Project within FFI Transport Efficiency

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FFI

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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.**
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1. Executive summary

This pre-study has identified research questions and opportunities for providing real-time video streaming in vehicular ad hoc networks to increase road traffic safety and road traffic efficiency. Further, a list of possible use cases for real-time video streaming in vehicular networks has been compiled. A frequency band at 5.9 GHz has been allocated for cooperative intelligent transport systems (C-ITS), where the short-range wireless standard IEEE 802.11p has been selected as the communication technology directly between vehicles. C-ITS applications range from road traffic safety to value-added services passing by road traffic efficiency. C-ITS can utilize different wireless technologies for different applications depending on requirements and information dissemination area. In this pre-study, we assume the usage of the short-range wireless communication standard IEEE 802.11p, which provides the possibility to disseminate information locally around the vehicle in an ad hoc mode without any detour around an access point or base station. The advantage with ad hoc communication is that no extra infrastructure is needed to be installed in order to run C-ITS applications.

However, since there is no central controller in 802.11p based networks, this implies that applications and algorithms must be self-organizing, scalable and decentralized. Video streaming has traditionally been carried out in centralized wired networks (backbone) where only the last mile delivery to the user is represented by wireless networks. Video streaming is bandwidth consuming and the 802.11p network does not have endless resources. To efficiently distribute real-time video in vehicular networks several research questions have been identified. New ways of performing statistical multiplexing of multiple video streams need to be addressed for the vehicular environment since all research up to date is assuming a central controller in the network. Further, research on enhanced encoding schemes of video streams also need to be performed due to the high mobility of vehicles causing packet loss patterns that differs from traditional distribution of video streams to for example our homes.

The pre-study has resulted in presentations at workshops, two scientific papers and it has facilitated new collaboration in the area of video streaming.

2. Background

Real-time wireless communication between vehicles in the automotive environment is a one out of several key enablers to decrease the number of accidents and increase road traffic efficiency, thus focusing on the objectives of the FFI program. Vehicles will exchange information wirelessly to cooperatively avoid dangerous situations and enhance the overall road traffic situation, i.e., cooperative intelligent transport systems (C-ITS). For realizing C-ITS IEEE 802.11p and its European counterpart ITS-G5 has been selected as the short-range wireless communication technology facilitating information dissemination locally around the vehicle. In both US and in Europe a frequency band at 5.9 GHz has been set aside for C-ITS applications. This has been divided into several 10 MHz frequency channels (i.e., service and control channels). The control channel will carry two important messages directly related to road traffic safety, namely, position messages and event-driven hazard warnings. The former message will always be present and broadcasted by all vehicles with 1-10 Hz depending on driving context. It will contain speed, heading, position, etc., of the transmitting vehicle that will be used by the receiving vehicle to predict potential dangerous situations in the near future. The event-triggered hazard warnings are triggered based on some in-vehicle sensor such as when the vehicle is braking heavily. Those messages will only be present temporarily and as long as the detected event is alive. So far, only the control channel in Europe has been allocated specific data traffic, there is still room for utilizing service channels for other types of data traffic that can contribute to a better road traffic environment in the future.

One C-ITS application that has a huge potential in better utilization of present roads as well as saving the environment with reducing $CO2$ emissions is platooning (a.k.a. road trains). However, there are still many open issues to address before platooning is a reality on public roads such as policy, liability, and acceptance. The driver acceptance of joining a platoon where vehicles will have a time gap of 0.5 seconds in the future is maybe an issue. For a passenger car following a truck with only 10 meters in-between the vehicles can be perceived as uncomfortable. Video streaming between the vehicles could be one way of increasing the acceptance. For example, the platoon leader could have a camera in its windshield distributing the platoon leader's view on the road ahead currently to all other vehicles in the platoon. Video streaming between vehicles in the platoon for entertainment is also a possibility. Further, the video streaming could also be used for safe overtaking of trucks in rural areas. Trucks could be equipped with cameras showing the road ahead for other vehicles approaching from behind and a more safe overtake could be performed.

These were only two examples of what video streaming could be used for. Video camera capability has been standard in premium cars and in certain special vehicles such as garbage trucks for some years to increase the awareness horizon for the drivers. Now, it is time to take this a step further: share what the video camera produces and distribute it to the vehicles in their neighbourhood in real-time to enable new C-ITS applications that can increase road traffic efficiency, safety and public security (see the figure on the cover page). In this pre-study, we take a closer look on the possibilities to use real-time video streaming between vehicles to enhance the road traffic environment. We outline challenges and possibilities with video streaming in vehicular networks.

3. Objective

This pre-study is aiming for investigating the potential of and identification of research questions when using real-time video streaming in vehicular networks for increased traffic safety and efficiency.

4. Project realization

This is a small pre-study, which has mainly been performing a literature study together with some experiments. Also dissemination at relevant workshops to gather opinions and comments regarding the ideas of video streaming in vehicular networks has been conducted. The pre-study has also facilitated fruitful collaboration with Dr. Evgeny Belyaev at Tampere University of Technology in Finland. He has contributed to the outcome of this pre-study with his deep knowledge and practical experience on video coding and transmission.

5. Results and deliverables

Three main results can be outlined:

- Possible IEEE 802.11p-enabled video applications have been identified.
- Preliminary experimental results of inter-vehicular video-streaming have been obtained.
- Multiplexing of live video-flows in the IEEE 802.11p channel has been identified as one of the key research questions for future study.

Live video streaming has become an everyday life feature and applications such as the built-in FaceTime for iPhones enable new ways to interact with the environment. Very often the ”last mile” for delivery of real-time video streams is based on the ubiquitous wireless local area network standard IEEE 802.11, which is the basis for IEEE 802.11p. However, a plethora of new applications, which are briefly explained in Table 1, have been identified during this pre-study, based on providing video streaming both in vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) modes and by combining the live video streams with position messages and hazard warnings that are already in place.

Table 1. Identified IEEE 802.11p-enabled video applications for the vehicular environment.

Application	Objective	Mode	Idea
Pedestrian crossing detour assistance	Urban mobility safety	V2V	Live video is exchanged between the vehicles approaching a pedestrian crossing.
Public transport detour assistance	Public transportation road safety	V2V	Live video is delivered from the bus at the stop to the vehicles passing by.
In-vehicle video surveillance	Public security	V2I	Public transport is monitored in real-time by the control center to help counteract terrorism, vandalism and other crimes.
Traffic conditions video surveillance	Traffic control	V2I	The current situation at a given road section, an intersection or even a lane is transmitted from the nearest vehicle to the management center.
Overtaking assistance	Rural roads safety	V2V	Live video information is delivered from the truck vehicle to the vehicles behind on rural roads.
Video conferencing in platoons	Infotainment	V2V	Group video conferencing is organized between vehicles in a platoon for a pleasant journey.
Police assistance at a crime scene	Public Security	V2V V2I	Live video is exchanged between the emergency vehicles at the crime scene.

From Table 1, it is clear that there are C-ITS applications that would benefit from real-time video streaming between vehicles and between vehicles and infrastructure for increasing both road traffic safety and road traffic efficiency. IEEE 802.11p offers eight different transfer rates (3, 4.5, 6, 9, 12, 18, 24, and 27 Mbps), which are achieved by squeezing more and more bits into every Hertz. By squeezing in more bits there is a need for having higher received signal strength to decode the packet successfully, i.e., the highest transfer rate needs a stronger received signal strength compared to the lowest transfer rate given the same distance between sender and receiver and the same output power. Thus, at longer distances a lower transfer rate must be used that is more robust against channel impairments. For position messages and event-trigger hazard warnings a default transfer rate of 6 Mbps has been selected.

The vehicular network based on IEEE 802.11p will not use any centralized infrastructure for delivery of messages, i.e., there exists no base station or access point regulating access to the shared communication channel. This implies that algorithms must be designed for being self-organizing, scalable and ad hoc. The responsibility for sharing the scarce communication resources must be distributed fairly among the vehicles needing channel capacity. The number of vehicles within communication range can drastically change from very few into hundreds (e.g., accident on a multilane highway) and these rapid changes in vehicle density have forced the standardization community to develop an algorithm for avoiding to overload the channel with data from many vehicles. In an overloaded situation, the number of successfully received packets will decrease drastically affecting the C-ITS applications. To avoid ending up in an overloaded situation, standardization in Europe (i.e., ETSI) has developed a framework called decentralized congestion control (DCC). The aim with this framework is to provide an algorithm that avoids an overloaded network situation regardless of the number of vehicles in the vicinity. The algorithm is providing the allowed number of messages per second that the vehicle is currently allowed to transmit given how busy the channel is for the moment. This DCC algorithm must be accounted for when developing C-ITS applications using video streams because in certain situations DCC will restrict the video streams. DCC is a mandatory component of IEEE 802.11p in Europe when using the frequency band at 5.9 GHz.

Video streaming is a resource-intensive application and research on video streaming has up until now mainly been conducted for wired networks, where the capacity problem is of another character compared to the wireless network ("Do we need more bandwidth? Yes, let's add another cable."). In traditional video streaming applications such as showing YouTube clip on a laptop or television broadcast, the wireless network has mainly been represented as the last mile delivery in homes. This last mile delivery is relying on other parts of the 802.11 standard, which has evolved offering much higher transfer rates for short distances between sender and receiver (e.g., access point and laptop) than compared to the 802.11p network. Recently, research on video streaming in vehicular ad hoc networks using 802.11p for communication has been initiated [1].

Preliminary experimental results of video streaming between two vehicles reported in [2] have demonstrated that good visual quality can be achieved when the inter-vehicle distance is less than 300–400 meters. However, in this experimental set-up there was one video stream transferred only in one direction. Hence, not two concurrent video streams were utilizing the communication channel. From the experimental set-up an important research question for video delivery in vehicular environments was identified, namely how to deliver efficiently numerous concurrent flows.

A method called statistical multiplexing of video sources is needed when two or more video streams should be transmitted over the commonly shared communication channel. The problem of statistical multiplexing has so far only been addressed in the literature for video broadcasting in systems such as wireless digital video broadcasting (DVB) or new broadband wireless infrastructure networks (LTE). In such types of systems there exist some kind of common rate controller (e.g., installed at the base station), which allocates the channel bandwidth between different video streams in a centralized manner. In the simplest case, the channel bandwidth can be allocated equally between the transmitted video sources. But, taking into account that statistical properties of the sources can be significantly different (e.g., news programs with low motion level or sport programs with high motion level), some videos will have very good visual quality, while others will have unacceptably low visual quality (e.g., sport programs). Therefore, the channel bandwidth should be allocated unequally using some fairness-based visual quality criterion. Two well-known criteria of this type are the maximization of the overall video broadcast quality [3] and the second one is maximization of the minimum video quality per program. The following problems have been identified for using statistical multiplexing in vehicular networks that need to be addressed:

1. High computation complexity caused by multi-pass coding [4] which is needed for calculation of bit rate and quality for each video program. The encoding complexity can be reduced by using pre-encoded scalable video stream [5] which allow to avoid multi-pass coding, but it cannot be used for real-time applications (such as video surveillance or video conferencing), where the pre-encoding is not possible.

2. Packet losses and their influence to the video quality are not taken into account during the multiplexing. For such types of losses, the rate controller should use probabilistic average of visual quality as optimization criterion. In [6] the min-max expected video distortion criterion is proposed, but in this work the authors deal with a single video source and do not consider the statistical multiplication of the video programs.

3. In all previously described works, the video multiplexing operate in one central device which is installed on a broadcast base station. In other words, only centralized video multiplexing is considered. There are no papers, which the authors are aware of, which consider video multiplexing in decentralized wireless networks which uses random multiple access for transmission over the shared channel such as in IEEE 802.11p based vehicular networks. We have preliminary results on the real-time video delivery in a platooning application [7] for a case of two simultaneously transmitting vehicles.

For video compression and robust transmission we plan to use a video codec based on the three-dimensional discrete wavelet transform (3-D DWT) developed by Dr. Evgeny Belyaev [8]. In comparison to traditional video coding standards such as MPEG-2 or H.264/AVC, the video stream generated by the 3-D DWT codec is much less sensitive to packet losses and has significantly less computational complexity [9]. That makes it very attractive for video transmission over highly unreliable wireless channels as well as for real-time software implementation on low-power devices.

To optimize the performance and make efficient use of the scarce shared spectrum at 5.9 GHz for real-time video streaming applications, new ways of sharing the bandwidth among the vehicles must be explored as well as further research must be conducted on how the encoding can be made more efficiently to save bandwidth. Up until now, statistical multiplexing of video streams has been assuming a central coordinator of the resources, which is lacking in the vehicular environment. Further, the DCC must be taken into account when designing C-ITS applications using real-time video streaming.

5.1 Delivery to FFI-goals

Real-time video streaming in vehicular networks contributes to increased road traffic safety both for C-ITS equipped vehicles but also for non C-ITS equipped vehicles, vulnerable road users and other motorists, since cameras are introduced. Real-time video streaming will contribute to the acceptance of platooning since vehicles following the platoon leader can still get a glimpse of what is happening in front of the platoon leader and platooning itself will reduce CO_2 emissions and contribute to road traffic efficiency. With real-time video streaming the driver's awareness horizon increases, implying that incidents and accidents can be avoided and thereby road traffic efficiency is indirectly affected.

6. Dissemination and publications

Measurements using real-time video streaming between two vehicles have been conducted together with Tampere University of Technology [2] and the outcome of this work was presented at IEEE International Conference on Communication in Budapest, Hungary, June 2013.

Results from the pre-study have been presented by Alexey Vinel at the following seminars:

- EIS Information Technology Open Day 13-11-2013 (Halmstad University)
- ITS mini-workshop 21-11-2013 (University of Twente, the Netherlands)
- ITS postgraduate school retreat 28-11-2013 (Norrköping)
- Research seminar 03-12-2013 (NEC Laboratories Europe, Heidelberg, Germany)

A demonstration paper is under preparation for submission to 33rd Annual IEEE International Conference on Computer Communications in 2014 (deadline for submission in mid-December 2013).

7. Conclusions and future research

This pre-study facilitated a literature study and identification of exciting research questions for providing real-time video streams in vehicular networks without central coordination. The selected wireless technology IEEE 802.11p has its bandwidth limitations but also the DCC described earlier put requirements on the development of resource-efficient and fair real-time video distribution algorithms for the vehicular environment. Further, the high mobility of vehicles in certain use cases imposes extra challenges due to temporarily high number of packet losses, which will lower the video quality. The packet loss pattern due to the high mobility and usage of 802.11p looks different from other types of networks traditionally used for real-time video distribution. Therefore, the two identified main research questions, assuming the restrictions and requirements stemming from 802.11p and DCC, are:

- How to provide fair resource allocation using statistical multiplexing in the vehicular environment?
- How to find new efficient encoding of video streams that is suitable for a high-speed mobility environment?

8. References

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