Using of beaconing for robust video transmission in overtaking assistance applications

Alexey Vinel, Evgeny Belyaev and Yevgeni Koucheryavy

Abstract— **Overtaking on rural roads often becomes dangerous when oncoming traffic is detected by the driver too late or its speed is underestimated. Up-to-date proposals for cooperative overtaking assistance systems rely either on the beaconing of status messages or on real-time video transmission. The beaconing-based system provides limited information to the driver about the upcoming traffic in the form of warnings. Introduction of the video-based system can extend the amount of driver information, thus, increasing the reliability of the assistance. However, when two platoons of vehicles are meeting each other, the quality of the video information can undergo significant degradation since a common multiple access communication channel is used.**

In this paper we demonstrate that the performance of a video-based overtaking assistant can be significantly improved if codec channel adaptation is undertaken by exploiting the information from the beacons about any forthcoming increase in the load of the multiple access channel used. The benefits of our approach are demonstrated in relation to the practical scenario of H.264/AVC video coding and IEEE 802.11p/WAVE inter-vehicle communication standards.

I. Introduction

Recently proposed cooperative overtaking assistance systems based on Vehicular Ad hoc NETworks (VANETs) rely either on real-time video transmission or on the exchange of status messages (beacons). In the first case, a video stream captured by a camera installed at the windshield of a vehicle is compressed and broadcast to the vehicles driving behind, where it is displayed to the driver. In the second case, beacons which include position, speed and direction are broadcast frequently by all the vehicles to ensure detection of oncoming traffic as early as possible and to issue a warning to the driver whenever needed.

The IEEE 802.11p/WAVE (Wireless Access in Vehicular Environments) standard has recently issued a set of physical (PHY) and medium access control (MAC) layer specifications to enable inter-vehicle communications [1]. In WAVE each vehicle periodically switches on a common control channel (CCH) to receive and transmit control and safety-related warning messages, and then tune into one of available service channels (SCHs) to exchange all the other information [2]. An IEEE 802.11p EDCA (Enhanced Distributed Channel Access) multiple access technique is used both in the CCH and the SCH. *Beacons* are the messages carrying the status information about the vehicle position, its speed and direction and they are periodically broadcast on the CCH and are used to announce the presence of a vehicle to its neighbors.

A. Vinel, E. Belyaev and Y. Koucheryavy are with Tampere University of Technology, Finland. alexey.vinel@tut.fi

Fig. 1. Video-based overtaking assistance [4]

The *beacons-based* overtaking assistance system is studied by simulation in [3], where it is shown that by setting up an adequate beaconing rate and properly choosing the IEEE 802.11p channel access priorities, the oncoming traffic can be detected early enough to issue a timely warning to the driver. The information from the overtaking assistant system can be even more relevant if it is presented as a *video stream* (Fig. 1). In [4] the implementation of video transmissions between the overtaken and overtaking vehicles is introduced. This allows the driver of the overtaking vehicle to have the same view of the road as that of the driver of the overtaken vehicle. However, [4] studies the ”ideal” scenario when there are only two vehicles in the network which is only valid in the early stages of WAVE penetration.

If some designated SCH is exploited for the video-streaming, then during a *short interval* of time when two platoons of vehicles are about to meet each other, the SCH load *rapidly increases*. Thus, the main challenge for a video-based overtaking assistance system with a high level of VANET-enabled vehicle penetration is to provide reliable operation in terms of visual quality during the approach of the oncoming platoon. In our work we demonstrate that the use of beaconing enables robust video streaming.

The paper is organized as follows. In Section II we describe our model for inter-vehicle communication. In Section III we model the influence of packet losses on video quality and we explain how to use the beacons in video compression. In Section IV we evaluate the joint beaconing and video-based overtaking assistance system.

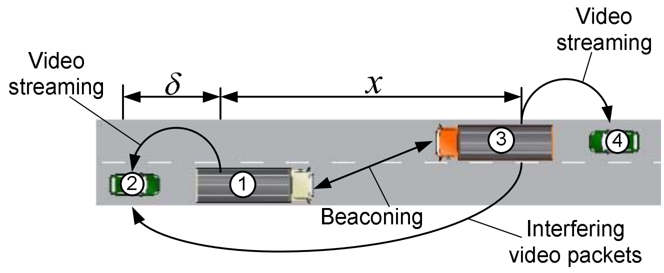

Fig. 2. The studied overtaking scenario

II. Analysis of inter-vehicle communication

A. System model

The operation of the studied system is illustrated in Fig. 2. Following the assumptions from [3] we consider a straight two-lane rural road with two platoons of IEEE 802.11p/WAVE-enabled vehicles driving in opposite directions with fixed velocity. Vehicle 1 is streaming real-time video to vehicle 2, while vehicle 3 is streaming to vehicle 4. The distance between vehicles 1 and 2 is denoted as δ and the one between vehicles 2 and 3 is denoted as x.

Vehicles 1 and 3 exchange beacons in CCH to warn each other about the approaching. In one common SCH (which is selected for the video-assistance application) only the leading vehicles transmit video streams at equal video bit rates of R_v, which are dependent on the SCH conditions. Packets of equal size L_v and data rate C_v are used for the video streaming.

IEEE 802.11p/WAVE EDCA carrier-sense multiple access protocol is adopted. Video packets are broadcast without any acknowledgment and random backoff delay is introduced prior to each packet transmission. Vehicles air interfaces reception is modeled as in [6]. Three power thresholds are considered:

- *carrier-sense threshold* (CSTh): if received signal power is lower than CSTh, then the packet is assumed to be dropped without any influence on the receiver; otherwise the signal is sensed and prevents an interface from transmission;
- *reception threshold* (RxTh): if there only one transmission and received signal power is more than RxTh, then the packet is successfully received;
- *capture threshold* (CpTh): if there are two concurrent transmissions, then the packet is successfully received only if its power is larger than RxTh and the difference between this power and the power of interfering packet exceeds CpTh.

Let us consider the transmission of video packets from vehicle 1 to vehicle 2 and from vehicle 3 to vehicle 4. Transmissions of vehicle 3 influence the decisions of vehicle 1 to access the SCH channel. Receiving signals powers from vehicle 1 and from vehicle 3 at vehicle 2 are denoted as P_1 and P_3 accordingly, then the following events in CCH and SCH occur:

- *Event A*: Vehicle 1 and vehicle 3 transmit simultaneously, $P_1 \geq$ RxTh, $P_3 \geq$ CSTh and P_1 exceeds P_3 of CpTh. This event will be treated at vehicle 2 as a collision;
- *Event B*: Vehicle 3 transmits and vehicle 1 senses the SCH, CSTh $\leq P_3 <$ RxTh. This event corresponds to the case when vehicle 1 senses some transmission in the SCH and treats it as a collision;
- *Event C*: Vehicle 3 transmits and vehicle 1 senses the SCH, $P_3 \geq$ RxTh. This event corresponds to the case when vehicle 1 senses some transmission in the SCH and treats it as a success;
- *Event D*: Vehicle 3 transmits a beacon in CCH and it is successfully received by vehicle 1.

Let us denote the probabilities of the above events as $P_A(\delta, x)$, $P_B(x)$, $P_C(x)$ and $P_D(x)$, respectively. These probabilities depend on the distances between the vehicles (δ, x), transmission powers, reception model thresholds (CSTh, RxTh, CpTh) and assumed signal propagation model (see the calculation details in [5]). In this paper we use Nakagami-m model propagation model with fading intensity m, which is typically applied in inter-vehicle communication analysis [6].

B. Analysis of channel throughput

Assuming an approach similar to [7] we find that for the saturation conditions the SCH is divided into "virtual" slots of different durations and vehicles 1 and 3 are accessing the SCH in every slot with a constant probability $\pi = \frac{2}{W_v+1}$, where W_v is the minimum contention window of IEEE 802.11p. The mean duration of the virtual slot can be computed as follows:

$$T_{vs}(\delta,x) = (1-\pi)^2\sigma + \pi T_s + (1-\pi)\pi P_B(x) T_c + \\ +(1-\pi)\pi P_C(x) T_s + (1-\pi)\pi(1-P_B(x))\sigma,$$

where $T_s = T_h + L_v/C_v + AIFS$, $T_c = T_h + L_v/C_v + EIFS$, T_h is the duration of the physical layer convergence protocol preamble and header, $AIFS$ and $EIFS$ is an arbitrary and extended inter-frame space and σ is a $aSlotTime$ defined by [1].

Then the average number of virtual slots per the SCH is $\frac{T}{T_{vs}}$ and the mean number of video packets from vehicle 1 successfully received at vehicle 2 is:

$$X(\delta,x) = \left(\pi^2(1-P_A(\delta,x)) + \pi(1-\pi)\right)\frac{T}{T_{vs}(\delta,x)}, \quad (1)$$

where $T = T_{SCH} - T_g - T_h - L_v/C_v$ is the useful duration of the SCH interval, which can be found by applying the reasoning from [8], T_g is the WAVE guard interval and T_{SCH} is the duration of the SCH interval.

III. Analysis of video transmission

A. Influence of packet losses on video quality

Let us assume that each video frame is separated into non-overlapping *slices* which are compressed independently. Each slice is placed in one packet of length L_v and transmitted over the SCH with data rate R_v. The expected end-to-end distortion $E[D_n^{(k)}]$ for the slice k in the frame n is then defined as [9]:

$$E[D_n^{(k)}] = (1-p_n^{(k)})D(\Delta_n^{(k)}) + p_n^{(k)}E[D_{loss}], \quad (2)$$

where $p_n^{(k)}$ is the loss probability for the slice k in the frame n, $D(\Delta_n^{(k)})$ is the distortion caused by the quantization with step $\Delta_n^{(k)}$ on the encoder side and D_{loss} is distortion caused by the packet losses and error concealment algorithm on the decoder side (see [5]).

For simplification, let the video decoder use the following error concealment algorithm. If the slice k from the frame n is not received then the decoder plays back the slice from the previous reconstructed frame $n-1$ with the same coordinates. Let us define the distortion in this case as $\hat{D}_{n-1}^{(k)}$. If the corresponding slice in the frame $n-1$ is also not received, then the decoder plays back the slice from the frame $n-2$ with the distortion $\hat{D}_{n-2}^{(k)}$ and so on. Taking into account these assumptions $E[D_{loss}]$ can be written as:

$$E[D_{loss}] = (1-p_{n-1}^{(k)})\hat{D}_{n-1}^{(k)} + p_{n-1}^{(k)}(1-p_{n-2}^{(k)})\hat{D}_{n-2}^{(k)} + ...$$

In the application considered, video frames are captured from a fast moving vehicle. Thus, the neighboring frames are not the same and the $E[D_{loss}]$ can be approximated as

$$E[D_{loss}] \approx (1-p_{n-1}^{(k)})\hat{D}_{n-1}^{(k)} + p_{n-1}^{(k)}\hat{D}_{\max},$$

where $\hat{D}_{\max}$ is the maximum possible distortion.

B. *Using of beacons in video compression*

We propose to use beacons for robust video transmission in the following way. Using the information received in CCH from other vehicles, the beaconing system computes the maximum number of video packets $X(\delta, x)$ using formula (1), which can be transmitted in the SCH. Therefore, video system has an up-to-date information about the channel state, can easily adapt to channel conditions by using video rate controller with required bit rate:

$$R_v(\Delta_n^{(k)}) = \frac{X(\delta, x)L_v}{T_{SI}}. \quad (3)$$

Therefore, information about the oncoming traffic obtained from the beacons and received on the CCH to provide video transmission with acceptable visual quality during the time period when the platoons are approaching.

IV. Numerical results and conclusions

In our experiments we use the test video sequence "Highway" [10], which contains captured video from a moving vehicle on the road, to illustrate the efficiency of the proposed approach. The parameters of the end-to-end video distortion model (2) were estimated in the case of compression of this sequence using JM reference software [11] and the H.264/AVC video coding standard [12]. The intra-frame coding mode was used to achieve independent slice compression. As the visual quality metric we use the well known Expected peak signal-to-noise ratio for luma (Y) component, which is calculated as

$$E[Y-PSNR] = 10\lg\frac{255^2}{E[D_n^{(k)}]}.$$

Transmission power and receiver thresholds (CSTh, RxTh, CpTh) are selected in accordance with [6] for $C_v = 3$ Mbit/s. The distance δ between vehicles 1 and 2 is fixed to 50 meters. The distance x between vehicles 2 and 3 varies from 2000 to 0 meters. IEEE 802.11p/WAVE MAC protocol parameters are taken from [8].

In figures below we demonstrate the changes of multiple access channel state, throughput at the receiving vehicle 2 and visual quality during the approaching of the platoons for two fading intensities, which parameterize Nakagami-m model: $m = 1$ and $m = 7$.

Probabilities of events A, B, C and D depending on distance x are shown in Fig. 3 and Fig. 6. These figures demonstrate that if vehicles 1 and 3 are approaching each other at the speed of 180 km/hours and a vehicle generate 10 beacons per second, then the successful exchange of beacons between vehicles 1 and 3 will occur early enough to maintain acceptable visual quality of video system (see Event D).

From Fig. 4 and Fig. 7 one can conclude that SCH throughput rapidly decreases with the decrease of distance x. Therefore, the delivery of beacons is critical to inform the video systems about the change of channel conditions. To illustrate this, visual quality at vehicle 2 for the cases when beacons from vehicle 3 are successfully received by vehicle 1 as well as without beaconing information are shown in Fig. 5 and Fig. 8. One can see that when beaconing information is not used the video quality becomes unacceptably low. If the beacons are available, then the video rate is adapted according to the channel throughput early enough, what guarantees acceptable quality during the overall time period of the platoons approaching.

References

[1] "IEEE 802.11p, WAVE," Jul. 2010.

[2] "IEEE 1609.4-2010, IEEE Standard for Wireless Access in Vehicular Environments (WAVE) - Multi-channel Operation," Feb. 2011.

[3] A. Böhm, M. Jonsson, E. Uhlemann, "Adaptive Cooperative Awareness Messaging for Enhanced Overtaking Assistance on Rural Roads," *4th International Symposium on Wireless Vehicular Communications (WIVEC 2011)*, San Francisco, Sep. 2011.

[4] C. Olaverri-Monreal, P. Gomes, R. Fernandes, F. Vieira, M. Ferreira, "The See-Through System: A VANET-enabled assistant for overtaking maneuvers," *Intelligent Vehicles Symposium*, Jun. 2010.

[5] A. Vinel, E. Belyaev, K. Egiazarian, and Y. Koucheryavy,"An overtaking assistance system based on joint beaconing and real-time video transmission," *IEEE Transactions on Vehicular Techonology*, accepted for publication, DOI 10.1109/TVT.2012.2192301.

[6] M. Torrent-Moreno, J. Mittag, P. Santi, H. Hartenstein, "Vehicle-to-Vehicle Communication: Fair Transmit Power Control for Safety-Critical Information," *IEEE Transactions on Vehicular Technology*, Vol. 58(7), pp. 3684-3707, 2009.

[7] G. Bianchi, "Performance Analysis of the IEEE 802.11 Distributed Coordination Function", *IEEE Journal on Selected Areas in Communications*, Vol. 18, pp. 535–547, 2000.

[8] C. Campolo, A. Vinel, A. Molinaro, Y. Koucheryavy, "Modeling Broadcasting in IEEE 802.11p/WAVE Vehicular Networks," *IEEE Communications Letters*, Vol. 15(2), pp. 199–201, 2011.

[9] F. Zhai, Y. Eisenberg, T.N. Pappas, R. Berry, A.K. Katsaggelos, "Rate-distortion optimized hybrid error control for real-time packetized video transmission", *IEEE Transactions on Image Processing*, vol. 15, pp. 40–53, 2004.

[10] Xiph.org Test Media, `http://media.xiph.org/video/derf/`

[11] H.264/AVC JM Reference Software, http://iphome.hhi.de/suehring/tml/

[12] Advanced video coding for generic audiovisual services, *ITU-T Recommendation H.264 and ISO/IEC 14496-10 (AVC)*, 2009.

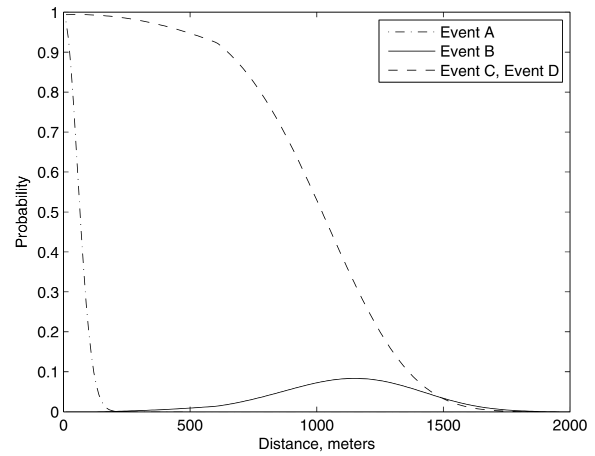

Fig. 3. Probabilities of events A, B, C and D depending on distance for fading intensity $m = 1$

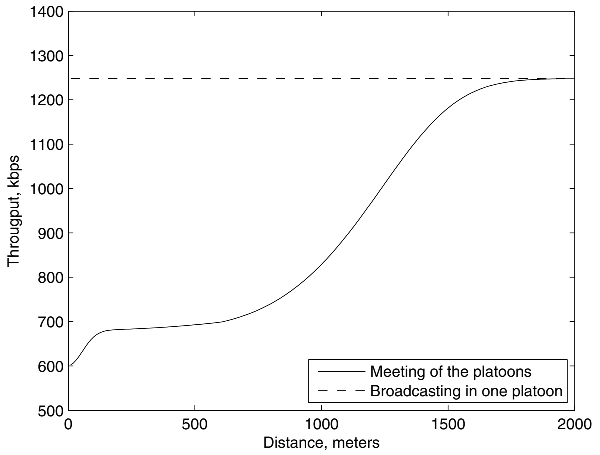

Fig. 4. Multiple access channel throughput depending on distance for fading intensity $m = 1$

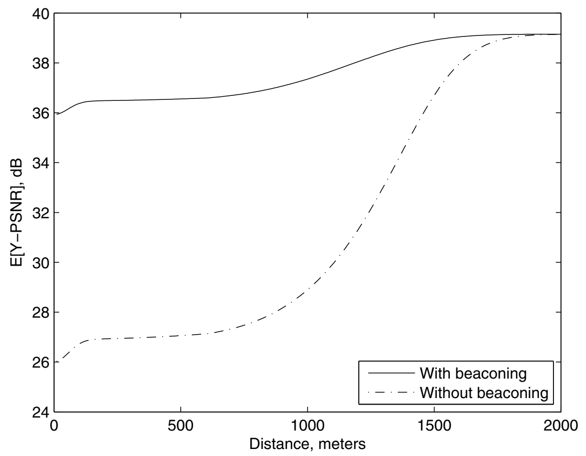

Fig. 5. Expected distortion with and without using of beaconing information for fading intensity $m = 1$

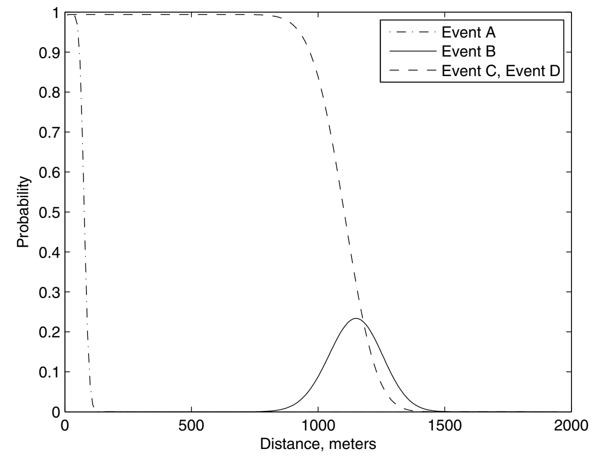

Fig. 6. Probabilities of events A, B, C and D depending on distance for fading intensity $m = 7$

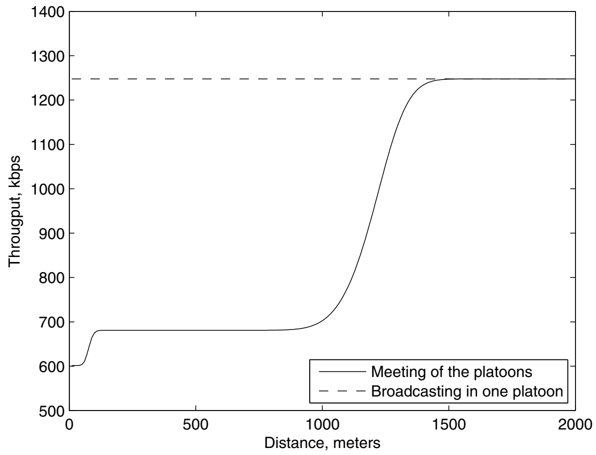

Fig. 7. Multiple access channel throughput depending on distance for fading intensity $m = 7$

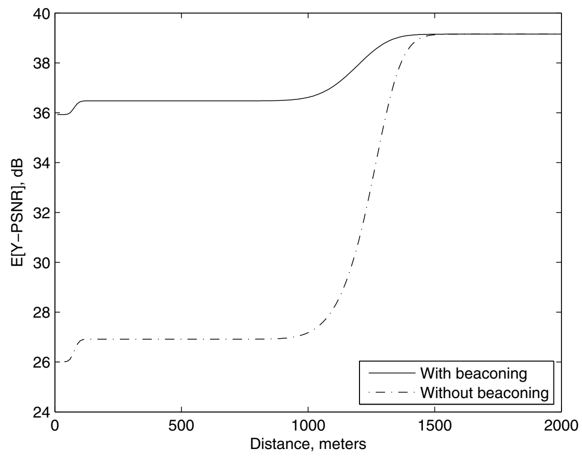

Fig. 8. Expected distortion with and without using of beaconing information for fading intensity $m = 7$