Performance Evaluation of H.264 Video Streaming over Inter-Vehicular 802.11 Ad Hoc Networks

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Abstract— **This paper evaluates the performance of video streaming in inter-vehicular environments using the 802.11 ad hoc network protocol. We performed transmission experiments while driving two cars equipped with 802.11b standard devices in urban and highway scenarios. Different sequences, bitrates and packetization policies have been tested. The experiments show that each scenario presents peculiar characteristics in terms of average link availability and SNR, which can be exploited to develop more efficient applications. In this paper we also determine the best packetization policies for the two scenarios, showing that large packets lead to better performance in the highway scenario and vice versa. Perceptual quality results indicate that the best packetization policy achieves consistent gains in terms of PSNR values (up to 5 dB), and reduced quality variations, with respect to a fixed-policy transmission technique.**

I. Introduction

The automotive industry is increasingly adopting wireless solutions to help the development of new applications and services. For instance, several cars already include an intra-vehicular wireless platform that allows easy integration of various devices, such as mobile phones, with the on-board systems.

Inter-vehicular wireless communications are also expected to gain popularity in the next few years, and many interesting research projects are being developed (e.g. [1]–[3]). Potential applications include, for instance, multi-vehicle-based visual processing of road information, multi-vehicle radar systems for obstacle avoidance and automatic driving. Inter-vehicular networks will also make a new class of applications possible, for instance 'swarm' communications among cars traveling along the same road, network gaming among passengers of adjacent cars and virtual meetings among coworkers traveling in different vehicles.

Several protocols for inter-vehicular communications have been proposed in recent years, e.g. WAVE and its ancestor DSRC [4]–[6]. However, these solutions require the development of new standards and devices, hence their deployment will take some time. In the meantime, several researchers are studying the applicability of currently available wireless networking protocols, such as the widely used 802.11 Wireless Local Area Network standard, to inter-vehicular communications.

Due to the relative novelty of the application, few efforts have been devoted so far to study and simulate 802.11 inter-vehicular networks. Some simulations have been performed to assess the performance of inter-vehicular transmissions compared with other access schemes such as UTRA TDD ad hoc [7]. Others addressed networking issues such as routing specifically for the inter-vehicular scenario [8].

However, few experimental results of 802.11-based inter-vehicular transmissions have been presented. Transmission experiments between two cars equipped with an external antenna have been presented in [9]; in this work, the performance of a generic UDP data transmission is evaluated by means of the Signal-to-Noise Ratio and throughput in different driving scenarios. Other works focused on vehicles communicating with a roadside access point [10].

The main contribution of this paper is to present results based on actual video transmission experiments between vehicles using the 802.11b wireless standard in different traffic conditions and scenarios. We monitored different performance metrics, such as the packet loss rate, the link availability and the received SNR, as well as the video quality of the real-time transmission, measured using the PSNR distortion measure. Moreover, we present a statistical analysis of the results, which highlights that the best transmission policy depends on the particular driving scenario.

This paper is organized as follows. Section II describes the 802.11 inter-vehicular transmission scenario, while Section III illustrates the codec setup for video streaming including the considered transmission policies. Section IV briefly describes the two experimental scenarios and Section V presents the results including a statistical analysis. Finally conclusions are drawn in Section VI.

II. 802.11 Ad-Hoc Inter-Vehicle Transmission Scenario

The tests have been performed while driving two vehicles through various environments, at various speeds and inter-vehicle distances. The first vehicle, a van (Figure 1) donated by

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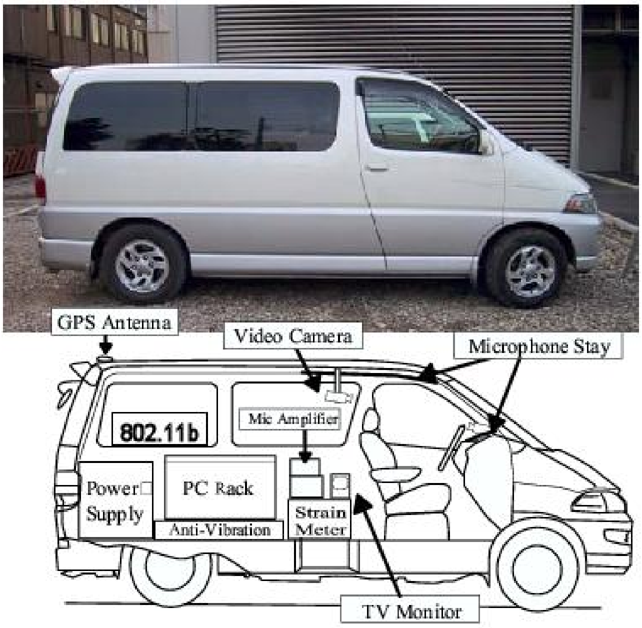

Fig. 1. Data collection vehicle used during the experiment.

TABLE I
MAIN CHARACTERISTICS OF THE WIRELESS NODES.

Device ID	#1	#2	#3
Function	Receiver	Transmitter	Monitor
Card interface	PCMCIA	PCMCIA	USB
Card type	802.11b	802.11b	802.11b
Manufacturer	Buffalo	Asus	D-Link
Model	Melco	WL-100	DWL-120
Driver name	Orinoco_cs	Linux_wlan_ng	Linux_wlan_ng

Toyota Corp. to Nagoya University for the CIAIR Project [11], is equipped with a GPS system, six video cameras to record the situation inside and outside the van and a laptop with one PCMCIA 802.11b card (device #1). The second vehicle is a car carrying another laptop equipped with two 802.11b wireless cards (#2 and #3).

Figure 2 shows our experimental video streaming testbed. Device #1 acts as the video receiver while Device #2 is the video transmitter. Device #3 is used to monitor the transmission between the two devices. This device has been configured to operate in monitor mode, thus it records all the traffic, including MAC acknowledgement packets, and it is useful to determine packet losses and SNR information. We used a third card for monitoring because enabling the monitor mode on Device #1 or #2 would prevent them from operating communications normally, hence the need to have a separate card. Both laptops run the Linux operating system version 2.4. The main characteristics of the wireless devices, including the drivers, are listed in Table I. All devices have been set to use the RTS/CTS mechanism. The MAC-level ARQ retry limit is set to 8.

No external antennas have been used, because we decided to test a scenario composed by portable devices which do not need complex set-up operations, such as placing an external antenna. For instance, they could be just a PDA equipped with a wireless network interface.

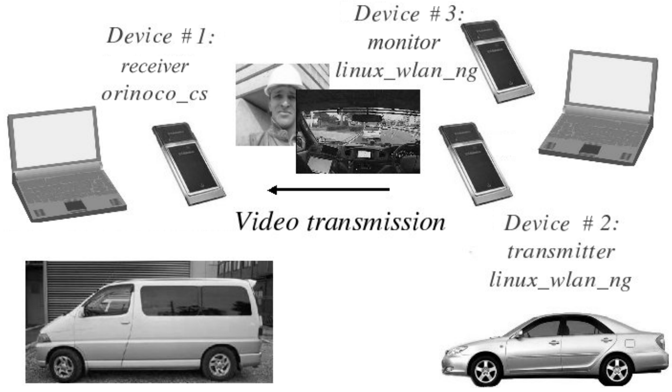

Fig. 2. The experimental testbed. The video flow is transmitted from the car to the van.

We used the software known as *ethereal*, which is based on the *libpcap* library, to monitor the wireless communications. All wireless devices used during the experiment are based on the Prism II chipset [12]. This chipset, with the appropriate kernel support [13], can also report the received signal quality for the captured packets. This required to enable the *raw dumping* and *prism header* features in the ethereal software, so that the signal quality could be read and stored. We measured the received SNR at both devices #1 and #3.

III. H.264 VIDEO STREAMING

We used the H.264 standard video coding software known as JM 6.1e [14], modified to be robust to packet losses. A temporal concealment has been implemented, so that the content corresponding to a lost packet is replaced with the same area in the previous frame, that is already stored in the decoder picture buffer. Packet losses can be detected at the decoder by means of the RTP sequence number. We coded the standard video sequences known as *foreman* (QCIF format) and *paris* (CIF format) using different bitrates and packet sizes, as shown in Table II. A total of six different RTP video flows have been generated, with different characteristics in terms of bitrate and packet size. The packet size was kept constant for each particular transmission experiment to simplify the interaction with the client/server software suite that we used to perform the transmission experiments. For this reason, sometimes the video encoder could not completely fill the packets. The amount of padding is shown in the last row of Table II.

To perform the transmission experiments we used the *rude/crude* packet generation suite [15], which is a complete and open-source client/server solution to generate customized UDP streams. Several flows, whose characteristics are reported in Table II, have been transmitted during the experiments. The transmission of each flow has been repeated 50 times to achieve statistically significant results.

For each target bitrate, two different packetization policies have been used. The flows denoted by S are characterized by

TABLE II

MAIN CHARACTERISTICS OF THE TEST VIDEO SEQUENCES.

Sequence	*foreman*		*foreman*		*paris*	
Resolution	QCIF (176×144)		QCIF (176×144)		CIF (352×288)	
Frame rate (fps)	10		15		20	
Target bitrate (kbit/s)	150		300		600	
Flow ID	**S1**	**L1**	**S2**	**L2**	**S3**	**L3**
Maximum packet size (bytes)	560	750	560	750	750	1200
PSNR (Y) (dB)	37.51	37.54	40.78	40.66	35.68	35.68
Actual bitrate (kbit/s)	148.5	151.2	304.5	300.8	607.2	594.0
Total number of packets	1050	780	2010	1500	1050	780
Packet frequency (packets/s)	35	26	67	50	100	62
Amount of padding (%)	17.94	23.31	13.04	18.43	13.84	13.63

a small maximum packet size and consequently a relatively high packet rate, and vice versa for the other flows (denoted by L). We decided to use two different packetization policies because we expect that the performance of the transmission will noticeable vary depending on the driving scenario, as confirmed by the results in Section V.

IV. EXPERIMENTAL SETUP

Measurements have been conducted in two traffic scenarios, characterized by different vehicular mobility and traffic density. The two scenarios are called *highway* and *urban*.

In the *highway* scenario the speed limit is 55 mph. Stops are not frequent and are caused only by traffic lights. We did not experience any traffic jam. During this part of the experiment, we drove out of Nagoya city, heading to Motoyama and back, at moderate speed, and stopping infrequently. In this scenario sometimes the wireless devices could not communicate with each other, due to the high distance between the two cars.

In the *urban* scenario the average speed is low, less than 15 mph. Stop caused by traffic jams and traffic lights are frequent, while the distance between the two cars is on average smaller than in the previous case. In this part of the experiment we drove downtown Nagoya at low speed and with many cars around and between the wireless devices. Communication problems happened when the two cars were at opposite sides of an intersection or other cars were located between the two.

V. RESULTS

The first result is that the two scenarios differ in terms of link availability and SNR at the receiver. In particular the main difference between the two scenarios is given by the different amount of time in which the link is available. The link availability is determined by means of the beacon frames. We set each device to transmit one beacon frame every second. We compute the link availability as the ratio between the number of received beacon frames over the number of transmitted ones for a given temporal window. Figure 3 shows the link availability as a function of time for the two scenarios. Table III summarizes the average values of link availability. In the urban scenario devices #1 and #2 can communicate for over 97% of the time, because the cars are next to each other and proceed at low speed. In the highway scenario, instead, link is available for less than half of the time. This is mostly due the to higher average distance between the two vehicles.

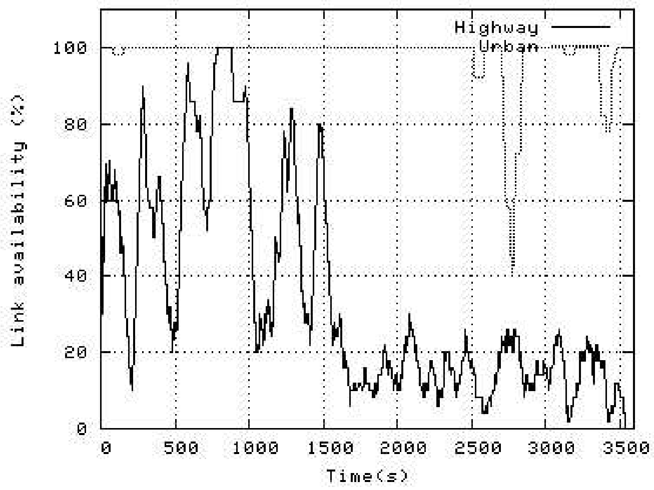

Fig. 3. Link availability as a function of time for both the *highway* and *urban* scenarios. Values are averaged on a ten-second window.

TABLE III

AVERAGE LINK AVAILABILITY AND SNR.

Scenario	Average link availability	Average SNR when link is available
Highway	33.98 %	22.49 dB
Urban	97.78 %	19.14 dB

To this regard, an external antenna could considerably increase the communication range of the wireless devices.

Table III also reports the SNR values when the link is available. The average SNR when the link is available in the highway scenario is about 22.5 dB, more than 3 dB compared to the urban scenario. This fact can be explained as follows. In the highway scenario cars cause very little communication problems because they are not close as in the urban scenario. Moreover, potentially interfering devices (e.g. access points) are not as frequent as in the urban scenario. When driving in the urban scenario, instead, the number of interfering objects increases. Thus we expect that the average SNR of the communication channel is lower, as confirmed by the value in Table III.

The strong variations experienced, in terms of link availability and SNR, suggest that the optimal packetization policy should be different when environmental changes happen, to

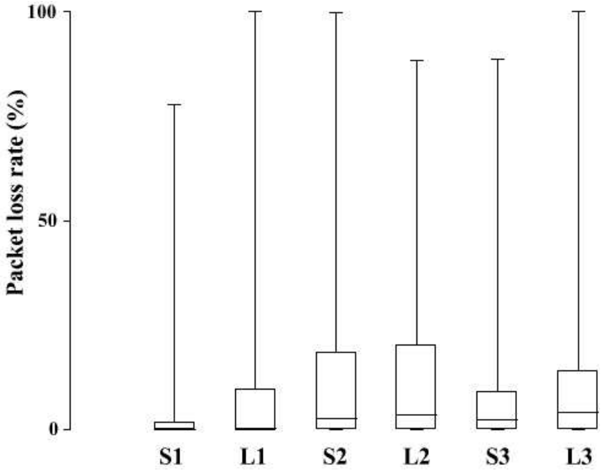

Fig. 4. Raw packet loss rate data for urban scenario presented with box-plots. The line in the middle of the box indicates the median value, the upper and lower bounds of the box indicate the third and first quartile respectively (Q_3 and Q_1) and the external lines extend until the adjacent values.

take advantage of the different bit error probability [16] which depends on the SNR at the receiver. In particular, in the urban scenario we expect that a transmission policy which privileges small packet sizes (S) results in lower error rates compared with the opposite policy L (large packet size). In the highway scenario, instead, we expect that the transmission policy L performs better for the opposite reasons. Despite the lower link availability, in fact, the relatively high SNR value allows the error-free transmission of larger packets, leading to a greater throughput when the link is available. Moreover, it is better to exploit the channel as much as possible when the link is available because the devices can communicate for less than 34% of the time (see Table III).

A. Statistical Analysis

In this section we present a statistical analysis of the collected data. In Figure 4 the packet loss rate of each transmission experiment in the urban scenario is presented using box-plots, which are useful to analyze the statistical distribution of the data. Each box-plot represents the distribution of packet loss rate obtained with 50 transmission experiments of the same flow. The line in the middle of the box indicates the median value, the upper and lower bounds of the box indicate the third and first quartile respectively (Q_3 and Q_1), that is, 50% of the values lay inside the box. The external lines extend until the adjacent values (as defined in [17]) and they denote the distance between the upper adjacent value and Q_3 (upper line) and between the lower adjacent value and Q_1 (lower line). The upper adjacent value (AV_u) is the largest observed value which satisfies the inequality $AV_u \leq Q_3 + 1.5r$ where $r = Q_3 - Q_1$ is the inter-quartile difference. Analogously, the lower adjacent value (AV_l) is the smallest observed value which satisfies the inequality $AV_l \geq Q_1 - 1.5r$.

A commonly accepted empirical rule, first proposed by Tukey [17], has been used to check if potential outliers are present. If the length of the lines external to the box is more than 1.5 times the inter-quartile range (i.e. the height of the box) outliers probably exist. Figure 4 therefore shows that most of the samples whose packet loss rate is about 100% are potential outliers.

To unveil possible outliers, we used the well-known Tchebyshev's inequality. By using this method we do not make any specific assumption on the statistical distribution of the data. Tchebyshev's inequality states that the probability Π_s for any sample s to be more than ι times σ far away from the mean is

$$\Pi_s < \frac{1}{\iota^2} \qquad (1)$$

We used an interval of 95%, which is a reasonable value for experimental statistics, to decide which samples will be discarded, that is, the probability of the sample is less than $\overline{\Pi}_s$, where

$$\overline{\Pi}_s = \frac{100 - 95}{100} \cdot \frac{1}{2}. \qquad (2)$$

The factor 1/2 is due to the symmetry of the Tchebyshev's distribution. Let ι_{cr} be the *critical value* of ι, that is, the value which satisfies Equation (1) for the chosen $\overline{\Pi}_s$. The critical value ι_{cr} is equal to 6.32. Samples whose standard deviation is greater than $\iota_{cr}\sigma$ have been discarded.

B. Experimental Results

Table IV presents the values of packet loss rate measured when transmitting the six flows in the two considered scenarios, after discarding the outliers with the previously described method. The packet loss rate and goodput values in Table IV show that the packetization policy S (small packets) experiences lower error rates than the policy L (large packets) in the urban scenario and vice versa for the highway scenario. Clearly, the goodput values present the same behavior. Note that the goodput shown in the table is defined as the amount of useful information correctly received, excluding retransmissions. The different behavior of the two packetization policies is clearer in the highway scenario, where switching from policy S to L increases the goodput up to 10%. In this scenario the low link availability causes packet dropping at the transmitter due to MAC-level timeout expiration. Therefore, given a certain amount of data to transmit as in the case of a constant-bit-rate real-time transmission, it is better to create a lower number of large packets than a high number of small packets. In the urban scenario, instead, the nearly constant availability of the channel leads to lower packet loss rates because the loss rate due to MAC-level timeout expiration is negligible. Given a certain SNR, therefore, the packet loss rate is only function of the number of bits in the packet. This leads to smaller differences in goodput (about 2%).

We also evaluated the perceptual quality experienced by the user at the receiver, in terms of PSNR. Although the PSNR may not be the best estimator of the users' mean opinion, it is a widely accepted measure and it facilitates comparisons with other works. Results are presented in the last two columns of Table IV. Gains up to 5 dB in perceived video quality are possible in the highway scenario if the best

TABLE IV

PACKET LOSS RATE, GOODPUT AND PERCEPTUAL QUALITY VALUES FOR ALL FLOWS.

Highway scenario				
Flow ID	Packet loss rate (%)	Goodput (kbit/s)	PSNR (dB)	PSNR std. dev. (dB)
S1	9.13	139.1	32.42	7.95
L1	6.95	141.8	33.41	5.75
S2	15.79	246.9	32.53	10.29
L2	6.63	273.5	36.54	7.32
S3	21.34	460.9	26.42	4.92
L3	12.20	510.3	31.37	5.31
Urban scenario				
Flow ID	Packet loss rate (%)	Goodput (kbit/s)	PSNR (dB)	PSNR std. dev. (dB)
S1	1.95	150.1	35.87	3.93
L1	5.45	144.0	33.77	5.71
S2	8.84	267.2	33.57	7.75
L2	10.06	263.5	33.77	8.47
S3	7.64	541.2	32.89	3.76
L3	8.70	530.7	32.49	4.34

packetization policy L (large packets) is chosen (see flows S3 and L3). In the urban scenario, as previously explained, the best packetization policy consists in sending small packets, but in this scenario the differences between the two transmission policies, although they can be significant (more than 2 dB transmitting at 150 kbit/s), are generally smaller due to the lower average packet loss rate. It is also worth noting that, regardless of the scenario, the standard deviation values are always lower if the best packetization policy is chosen, thus PSNR values are more consistent, with positive effects on the overall quality perceived by the user.

VI. CONCLUSIONS

In this paper we presented the results of inter-vehicular transmission experiments using an 802.11b ad hoc network in two typical driving scenarios, urban and highway. The tests showed that each scenario presents peculiar characteristics in terms of link availability and SNR, which can be used to help in developing efficient applications. In our work we showed that those differences can be exploited to improve the performance of the video transmission, for instance using a different maximum packet size. Perceptual quality results showed that consistent gains in terms of PSNR value (up to 5 dB) can be achieved with respect to a scenario-unaware transmission technique.

VII. ACKNOWLEDGEMENTS

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