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ELETTRONICA

WiFi-based intervehicle communications

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Riassunto. *L'industria automobilistica sta adottando in maniera sempre crescente soluzioni basate su dispositivi senza fili che facilitino lo sviluppo di nuove applicazioni e servizi, e in questa direzione si stanno sviluppando molti progetti di ricerca interessanti. Potenziali applicazioni includono, per esempio, sistemi radar basati su più veicoli per evitare gli ostacoli e per fornire una guida automatica, segnalazioni di emergenza e di avvertimento, pagamento pedaggi, informazioni sul traffico, e svariate applicazioni nel settore privato, quali controllo degli accessi, pagamento automatico dei posteggi, ecc.*

Negli anni recenti, diversi protocolli per comunicazioni interveicolari sono stati proposti, ma tutte queste soluzioni richiedono lo sviluppo di nuovi standard e dispositivi, per cui la loro messa in opera richiederà tempo. Nel frattempo, diversi ricercatori stanno studiando l'applicabilità dei procolli di comunicazione senza fili attualmente disponibili (es. 802.11) alle comunicazioni interveicolari.

A causa della relativa novità dell'applicazione, pochi risultati sperimentali di transmissioni interveicolari basate su 802.11 sono stati presentati in passato. Questo lavoro presenta i risultati di esperimenti reali di transmissione video tra veicoli utilizzando lo standard 802.11b in differenti scenari e situazioni di traffico. Sono state misurate diverse metriche prestazionali, quali la percentuale di pacchetti persi, la disponibilità del collegamento, e il rapporto segnale rumore, ed anche la qualità video della trasmissione in tempo reale. I risultati evidenziano come le caratteristiche della comunicazione dipendano fortemente dal particolare scenario di traffico, mostrando quindi che algoritmi di trasmissione adattativi sono necessari per ottenere le prestazioni migliori.

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Abstract. *The automotive industry is increasingly adopting wireless solutions to help the development of new applications and services, and many interesting research projects are being developed. Potential applications include, for instance, multi-vehicle radar systems for obstacle avoidance and automatic driving, emergency and warning signaling, toll collection, traffic information, and a number of applications in the private sector such as access control, drive-thru payment, parking lot payment etc.*

Several protocols for inter-vehicular communications have been proposed in recent years, but 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 (e.g. 802.11) to inter-vehicular communications.

Due to the relative novelty of the application, few experimental results of 802.11-based intervehicular transmissions have been presented. This work will present results based on actual video transmission experiments between vehicles using the 802.11b wireless standard in different traffic conditions and scenarios. Several 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 have been monitored. The results highlights that the characteristics of the communication strongly depend on the particular driving scenario, hence adaptive transmission algorithms are required to achieve the best performance. This work has been performed in collaboration with Nagoya University (Nagoya, Japan) which financially supported it in part.

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 intravehicular 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. 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.

In particular, a more detailed list of interesting applications for public safety follows: approaching emergency vehicle (warning) assistance, emergency vehicle signal preemption, road condition warning, low bridge warning, work zone warning, imminent collision warning, curve speed assistance (rollover warning), infrastructure based – stop light assistant, intersection collision warning/avoidance, highway/rail (railroad) collision avoidance, cooperative collision warning (for vehicle-to-vehicle communications), green light – optimal speed advisory, cooperative vehicle system – platooning, cooperative adaptive cruise control, vehicle based probe data collection, infrastructure based probe data collection, toll collection, traffic information, transit vehicle data transfer (gate), transit vehicle signal priority, emergency vehicle video relay, mainline screening, border clearance, on-board safety data transfer, vehicle safety inspection.

Potential applications in the private sector include access control, drive-thru payment, parking lot payment, data transfer / info fueling (diagnostic data, repair-service record, vehicle computer program updates, map and music data updates, video uploads), enhanced route planning and guidance, rental car processing, fleet management, transit vehicle refueling management, locomotive fuel monitoring.

Several protocols for inter-vehicular communications have been proposed in recent years, e.g. WAVE and its ancestor DSRC. 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 802.11Wireless 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 intervehicular 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. Others addressed networking issues such as routing specifically for the inter-vehicular scenario.

However, few experimental results of 802.11-based intervehicular transmissions have been presented. Transmission experiments between two cars equipped with an external antenna have been performed; in that 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.

This work will 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 work has been performed in collaboration with Nagoya University (Nagoya, Japan) which financially supported it in part.

1. Experimental Setup

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 Toyota Corp. to Nagoya University for the CIAIR Project, 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. 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.

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 . This chipset, with the appropriate kernel support, can also report the received signal quality for the captured packets. This required to enable the *raw dumping* and *prism*

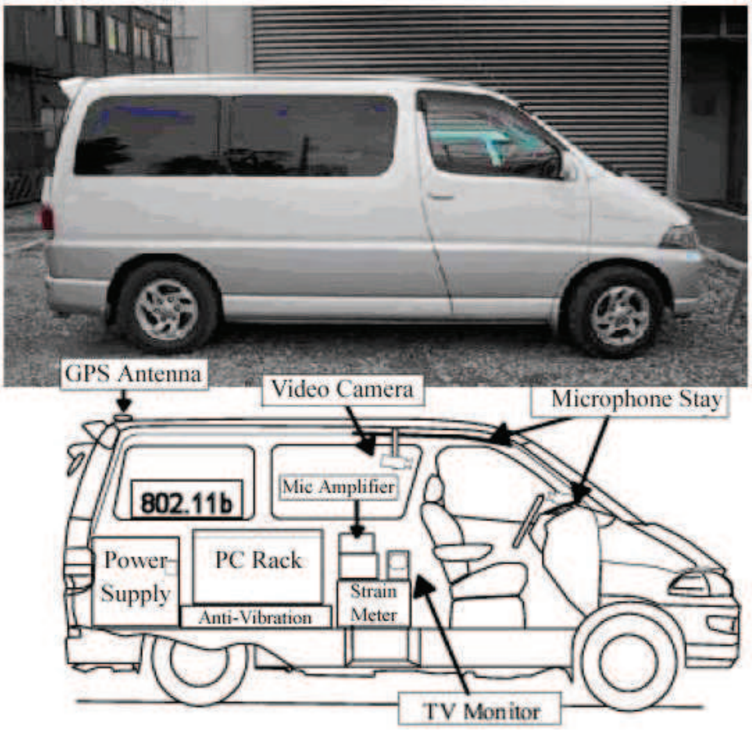


Illustration 1: Data collection vehicle used during the experiments.

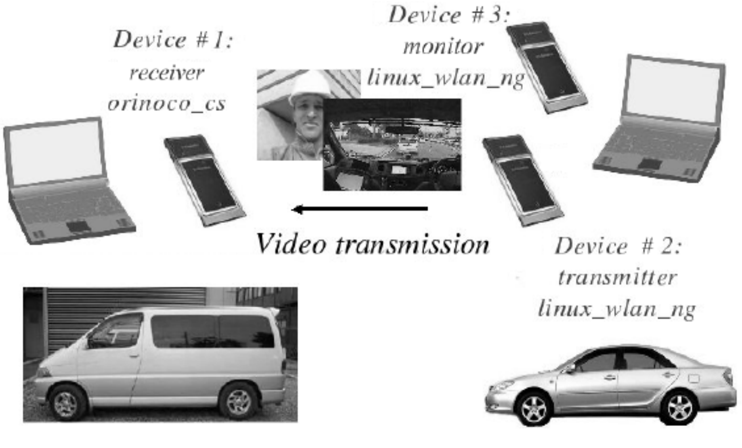


Illustration 2: The experimental testbed.

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.

We used the H.264 standard video coding software known as JM 6.1e, 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. 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. To perform the transmission experiments we used the *rude/crude* packet generation suite, which is a complete and open-source client/server solution to generate customized UDP streams. Several flows 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 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 presented results.

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.

2. 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.

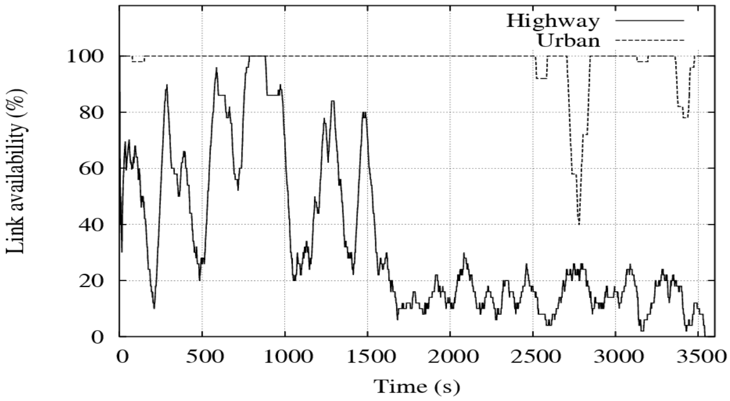


Illustration 3: Link availability as a function of time for both the highway and urban scenarios. Values are averaged on a ten-second window.

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.

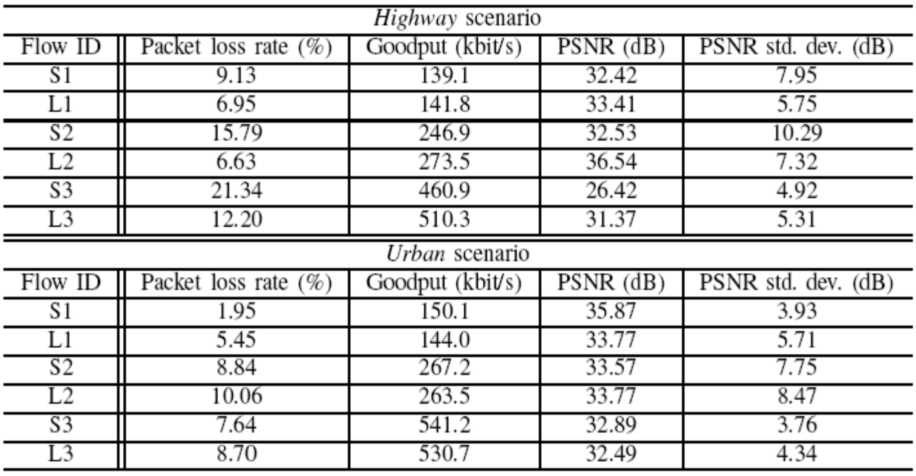
In the urban scenario devices #1 and #2 can communicate for over 97 % of the time, because the cars are next to each other and proceed at low speed. In the highway scenario, instead, link is available for less than half of the time. This is mostly due the to higher average distance between the two vehicles. To this regard, an external antenna could considerably increase the communication range of the wireless devices.

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.

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 take advantage of the different bit error probability 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.

Table 1 presents the values of packet loss rate measured when transmitting the six flows in the two considered scenarios, after discarding outliers. The packet loss rate and goodput values in Table 1 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.



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

Table 1: Packet loss rate, goodput and perceptual quality for all flows.

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 1. Gains up to 5 dB in perceived video quality are possible in the highway scenario if the best 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.

3. 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.