Audio Communication in Multicast 802.11 Vehicular Ad Hoc Networks for Safety Applications

Paolo Bucciol Federico Ridolfo Juan Carlos De Martin
Dipartimento di Automatica e Informatica
Politecnico di Torino, corso Duca degli Abruzzi, 24, I-10129 Torino, Italy
Phone: +39-011-090-7065, fax: +39-011-090-7198
[paolo.bucciol | federico.ridolfo | demartin]@polito.it

ABSTRACT

In this paper we analyze the performance of multimedia communication in a Vehicular Ad hoc Network (VANET). We focus on the multicast transmission of multimedia signals (MP3 streams) between a static and a mobile node. We examine different solutions to guarantee vehicle-to-infrastructure connectivity via both omni-directional and directional antennas. An optimized client-server streaming software suite has been developed and tested with various safety messages in a real-world network testbed. Results are presented in terms of both network layer (such as packet loss rate) and application layer (Mean Opinion Score) metrics. Results show that the network and application layer QoS are strictly related to the specific context of the experiment (environmental conditions, selected hardware). Results also show that a reasoned choice of the hardware makes possible to transmit multicast safety messages in urban context using the standard 802.11b protocol.

Categories and Subject Descriptors

C.4 [**Performance of Systems**]: Reliability, availability, and serviceability

General Terms

Measurement, Performance, Reliability

Keywords

Inter-vehicle Networks; Multicast; Ad Hoc; Open Source; Audio streaming; Safety; Directional Antennas.

1. INTRODUCTION

The automotive industry is increasingly adopting wireless solutions for inter-vehicle communication in the context of Intelligent Transportation Systems (ITS). While price of portable, 802.11-enabled devices is always lowering, many car manufacturers already ship vehicles with built-in wireless platforms. Vehicles equipped with a wireless interface can establish a communication channel with an external infrastructure statically configured (infrastructured fashion) or dynamically, with both mobile and non-mobile nodes (ad hoc fashion). Vehicles connecting in ad hoc fashion create a particular Mobile Ad hoc NET (MANET), called Vehicular Ad hoc Network (VANET). Potential applications include, for instance, safety applications, such as broadcasting of emergency notifications in cases of accidents, vocal messages for intelligent traffic routing and automatic driving. Other possible applications include value-added services such as VoIP, gaming, and generic infotainment applications.

Several protocols for inter-vehicular communications have been proposed in recent years, e.g. WAVE and its ancestor DSRC [1], [2]. However, we focus on the 802.11b Wireless Local Area Network Standard, since the 802.11p standard is expected to be ratified in 2009, and deployment of standard compliant solutions will take some time.

The rest of this paper is organized as follows. In Section 2 we consider the challenges of transmitting multimedia data in a VANET. Section 3 describes the simulation scenario. Performance evaluation in terms of network-level and application-level metrics is presented in Section 4. Finally, Section 5 concludes the paper.

2. CHALLENGES

The peculiar characteristics of inter-vehicle ad hoc networks, such as high mobility and presence of interference and multipath effects, make the problem of data transmission even more challenging than in ordinary MANETs [10][13]. Among the key factors which have to be considered when evaluating the performance of an application in a VANET, particular care shall be taken in considering the target scenario [17] and node mobility [4][11].

Environmental conditions and context can significantly impact on the quality of the wireless communication [20][22]. A non-ideal context such as the presence of concurrent transmissions and high node density and mobility, which lead to increased interference and multipath effects, does not allow high quality communication. Standard solutions as retry limit adaptation are unable to solve this problem [12]. Use of IPv6 [5] and dynamic routing algorithms [8] to solve the issues of automatic node configuration and packet routing issue in high density VANETs are very promising approaches which, however, will not be discussed here since they fall outside of the scope of this paper. On the other side, in an ideal context where there are no concurrent transmissions and nodes are sparse, high node mobility does not impair significantly the transmission quality [19]. In our analysis we jointly consider the impact of context and node mobility on the quality of the wireless communication.

Although transmission of data flows over VANETs is already a challenging issue by itself [6][21], transmission of multimedia data is even more critical [16][23], due to hard timing constraints and high bitrates. In critical traffic conditions, the standard 802.11b infrastructured mode is unable to guarantee acceptable QoS [18], and multimedia applications can be successfully run only over ad hoc topologies [9].

However, connection quality in ad hoc networks significantly degrades when the number of concurrent transmissions increases [7]. When the same information has to be propagated among various nodes of the network, multicasting or broadcasting techniques are foreseen to increase network efficiency. The standard 802.11 Medium Access Control layer can be used without modifications if the information is broadcasted at moderate bitrate [3]. In this context, use of directional antennas can further increase the network scalability, increment the propagation range and thus reduce network design issues and complexity [14][15]. For instance, we can send different information messages to the various branches of a given intersection.

3. EXPERIMENTAL SCENARIO

We consider a typical urban scenario, focusing on an intersection controlled by a traffic light. The server, a multicast transmitter, is placed next to the selected intersection. Information is sent by using the standard 802.11b protocol, in ad hoc mode. Our vision is depicted in Figure 1.

From the client point of view, a 802.11b-enabled handheld device is placed in a car. On this device we have installed our client software. It runs for the whole duration of the experiments, which consist in passing through the intersection with the car and examine how changing a given set of parameters can influence the transmission. The parameter set includes the transmitter antenna, the car speed, the handheld device and the transmitted message.

The real experiments have been conducted in an urban context, next to a traffic light controlled intersection, in the center of Turin, Italy. Two different scenarios have been examined: a *day scenario* and a *night scenario*. The day scenario is characterized by frequent traffic jams and by many cars parked at both sides of the roads. The night scenario, on the other hand, is characterized by low traffic density and almost no car parked at the side of the streets. We now proceed by describing the software suite and the wireless devices that used in the experiments. Next, we detail the characteristics of the transmitted multimedia flows. Finally, we analyze the antennas we have selected for the transmission.

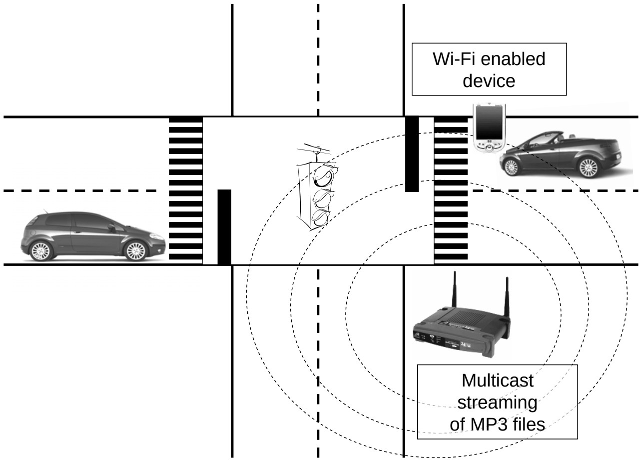

Figure 1. Our experimental scenario.

3.1 Software Suite

The client-server software suite used during the experiments has been developed in the context of the LScube project [27]. It has been released following the open source paradigm. Source code, as well as pre-compiled images for handheld devices, can be downloaded from the WiSafety Project site [26].

The server is compliant with the standard RTP/UDP/IP protocol stack and has been designed to send MPEG-1 Layer 3 (MP3) files in multicast. It takes a MP3 file in input – allowed bitrate ranges from 64 to 192 Kbps – and encapsulates one MP3 frame for each data packet. In this context, then, the terms *packet* and *MP3 frame* are equivalent. Packets are then sent in real-time. The client has been designed to run with different sound output modules, suitable for different architectures, and contains a small output buffer with some optimizations for the specific scenario, like packet reordering.

The receiver devices commonly used for mobile communications are small and portable. Their main drawback is little computational power and autonomy. Moreover, most of the computational power is used to perform high priority tasks, like wireless connection management, output buffer management, multimedia stream decoding and playback. All these tasks are computationally intensive for those devices, due to hardware limitations, such as lack of Floating Point Unit in many of the currently sold handheld devices. Keeping in mind those (hard) constraints, our efforts in the development of the client application were targeted to two main goals, both aimed at increasing the user's perceived quality: error concealment and reduction of glitches. Error concealment also plays a crucial role in avoiding decoder crashes. To reach this goal, two simple and low-complexity error concealment techniques have been implemented in the decoder.

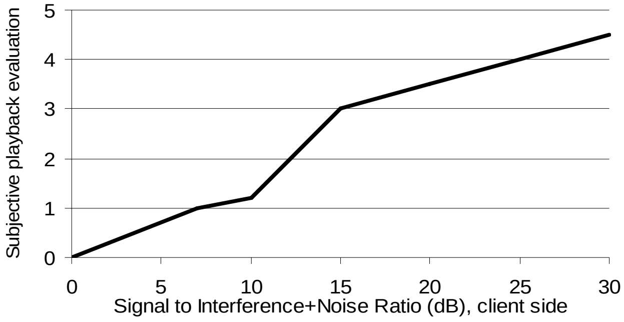

Figure 2. Impact of interference and noise on the quality of the received MP3 stream.

Table 1. Characteristics of the handheld devices used in the experiments (Sharp Zaurus, HP iPAQ).

Name	CPU	OS	Wireless
HP iPAQ h5550	Intel PXA 255 @400MHz	Linux Familiar	Integrated Atheros
Sharp Zaurus SL-C3200	Intel PXA 270 @416MHz	Open Zaurus	D-Link DCF-660W

More sophisticated techniques which, for instance, exploit the correlation between the various packets to increase the perceived quality, are outside of the scope of this paper. However, the client software has been designed to ease the implementation of customized error concealment algorithms by third parties.

Each of the two implemented techniques creates a fake packet every time the decoder should decode a packet which has not been received. The first technique (zero copy) consists in feeding the decoder with a packet filled with zeros. It can be used as lower bound for more sophisticated techniques. The second technique (frame copy) consists in feeding the decoder with the content of the last frame which had previously been correctly received. Since frame copy constantly outperforms the basic zero copy technique, application layer results will be implicitly presented by means of frame copy technique.

The second optimization made at the client consists in avoiding playback if the Signal to Interference+Noise Ratio (SINR) is low. As detailed in Section 2, background noise and interference are dramatically high in VANETs. SINR can easily be obtained by using the command-line interface of the Wireless Tools [24]. Multicast transmission does not retransmit packets, thus it performs poorly in VANETs. The resulting high packet loss rates then induce annoying scratches and anomalies of the decoded MP3 stream, which are commonly referred to as "glitches". We evaluated how the SINR determines the presence of glitches in the playback of the received stream by means of a subjective evaluation made by four different testers under different SINR levels. Results are shown in Figure 2. The four testers evaluated the playback with a score ranging from zero (nothing is played) to five (excellent playback). Scores under 2.5 correspond to almost incomprehensible messages and were classified as "very annoying". In this specific context, a "very annoying" playback corresponds to a SINR<15dB. This value can be used as a threshold to stop the playback in situations where the message would not be understood.

Table 2. Antennas used for transmission – details.

Device n.	Characteristics			
	Gain (dBi)	Beam Width	Front to Back Ratio (dB)	Price (USD)
1	24	12°	>30	180
2	18	30°	26	95
3	8	omni	-	15

3.2 Receivers

The performance of our transmission suite has been tested with two different handheld receivers, whose characteristics are detailed in Table 1. The first receiver, an HP iPAQ h5550, has been configured with a Linux Familiar 0.8.2 distribution, based on the Linux 2.4 kernel, while the second, a Sharp Zaurus SL-C 3200, has been configured with the OpenZaurus 3.5.4.1 distribution, based on the Linux 2.6 kernel.

The wireless cards of both devices support the 802.11b standard. On the iPAQ we used the integrated Atheros wireless chipset. On the Zaurus, since no wireless card was present, we chose an external D-Link DCF-660W card (Compact Flash). We chose not to use external antennas at the receiver side because we were interested in setting up an easy-to-replicate environment, without the need of setting up anything more than a car cradle on the windscreen of the vehicle. Our vision is that our suite can be easily set up at the client side by just installing a freely available software program on any of the most common handheld devices with support to Linux OS (for instance, many models manufactured by Sharp, HP, Dell, Asus support Linux).

3.3 Transmitted Data

Several MP3 files containing safety messages have been transmitted during the experiments. Ten different generic safety messages have been recoded in four different combinations (English Male, English Female, Italian Male, Spanish Female).

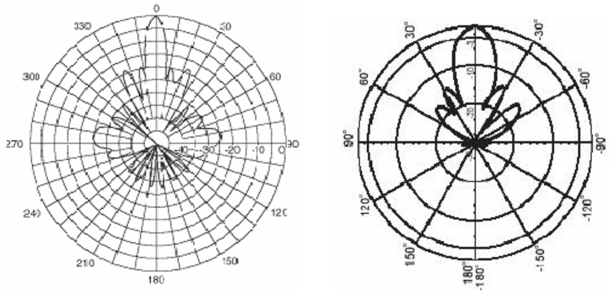

Figure 3. Irradiation patterns of the directional antennas (device n.1: left, device n.2: right).

Table 3. Tested combinations of antenna gain and car speed, in [Day (D), Night (N)] scenario.

Car Speed (Km/h)	Antenna gain (dBi)		
	8	18	24
40	N	N	D
50	DN	DN	D
70		DN	D

Two different voices, a male and a female one, and three different languages, Italian, English, and Spanish, have been considered. The four combinations related to the same safety message, although expressed in different languages and from people of different gender, have the same duration of about two seconds. All messages have been encoded at 192Kbit/s using the MPEG-1 Layer 3 encoder.

A single test consists in driving the car with the handheld device through the selected intersection. We define as a *transmission cycle* all the data successfully received during this test from the handheld device, starting from the moment at which the receiver starts receiving packets and ending when the car has passed the intersection. In case of directional antennas, the handheld device automatically stops receiving packets after crossing the intersection. Some packets can still be received, though, due to secondary lobes or reflections. In case of omni-directional antennas, the playback is stopped as soon as we move away from the intersection and the SINR falls below the threshold value of 15dB.

3.4 Antennas

At transmitted side we used both directional and omni-directional antennas, whose details are shown in Table 2. We used a single omni-directional antenna with 8dBi gain, and two directional antennas, with different characteristics (and cost); one highly directional grid antenna with 24dBi gain and one panel antenna with 18dBi gain, whose H-plane irradiation patterns, taken from the respective data sheets, are presented in Figure 3.

4. RESULTS

We have considered three different car speeds, namely 40, 50, and 70 Km/h (equal to 25, 31 and 43 Mph respectively). All tests have been repeated for both day and night scenario, with green or flashing yellow light and a constant speed. All tested combinations of antenna gain and car speed for each scenario are shown in Table 3.

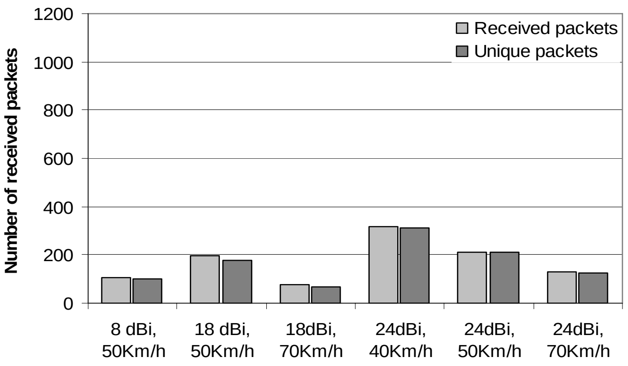

Figure 4. Received packets, day scenario.

For each combination of antenna and car speed, at least six transmission cycles have been made with all combinations of each safety message. Tests have been repeated for both client devices. The combinations which haven't been tested wouldn't have added useful information, as explained in the "Results" section.

In particular, as will be clarified later in this section, during the day high gain antennas and at medium-high speeds perform better. Thus, combination of low gain antennas and low speeds have not been tested, apart from the combination [8 dBi, 50Km/h], useful to perform comparisons with the night scenario. During the night, on the other hand, the reduced environmental noise (interference, multipath) and traffic allowed good communication also with lower gain antennas and at all considered speeds. Thus, the adoption of more expensive, high gain antennas (according to Table 2) is unnecessary in this scenario.

4.1 Network layer results

All results shown later on are the average of the performance obtained by the two different client devices (which had almost the same performance in all considered metrics during the tests).

Figure 4 and Figure 5 show the number of received packets as a function of the antenna gain and car speed for day and night scenario respectively. In Figure 7 the performance comparison between the two scenarios in terms of packet loss rate and percentage of duplicated packets is presented, while in Figure 6 the comparison is made by means of the received stream length. All the experiments performed in the day scenario suffer from high packet losses. In the worst case, that is, when using the 8dBi omni-directional antenna, percentage of lost packets exceeds 20%. On the other hand, with the 24 dBi directional antenna packet losses remain around 10%.

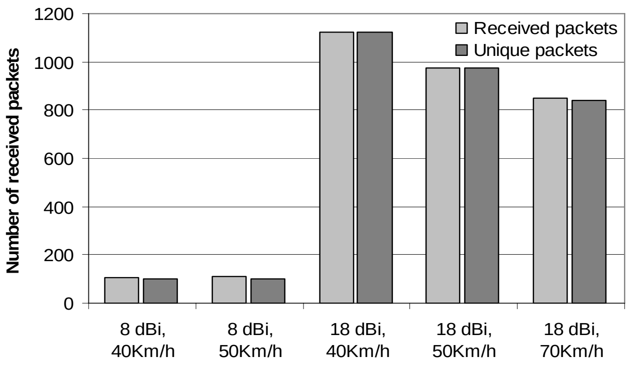

Figure 5. Received packets, night scenario.

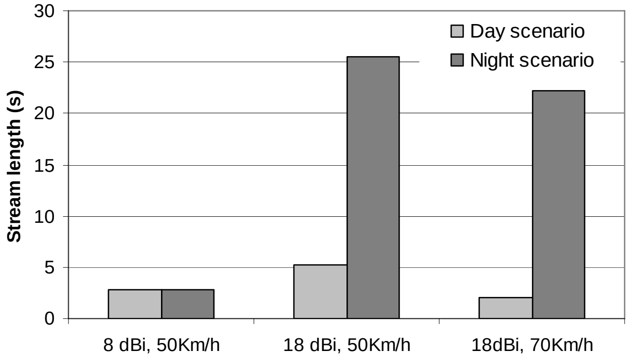

Figure 6. Average length of the received streams as a function of antenna gain and car speed.

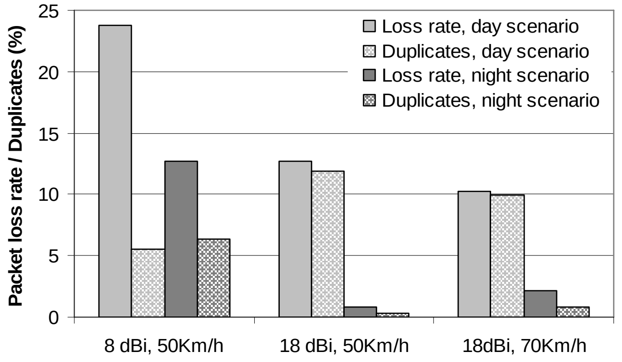

Figure 7. Packet loss rate and duplicated packets as a function of antenna gain and car speed.

Moreover, as we could expect from highly directional antennas, with the 24dBi antenna the number of duplicated packets remains quite low. This is due to many reasons. Among them, we see a clear relationship between the number of duplicates and the cars parked at the sides of the road. The wider the antenna beam, the stronger the possibility of interferences, such as multipath effects. Thus, the use of highly directional, high gain antennas is highly recommended in day scenario, since the performance of the omni-directional 8 dBi antenna is unacceptable with respect to all considered metrics. On the other side, the good performance of the directional 18 dBi antenna in night scenario makes the adoption of the 24dBi antenna unnecessary in this context. In fact, the 18 dBi antenna allows the playback of more than 20 seconds of the safety message, while packet loss rate and number of duplicates remains almost negligible. Thus, we recommend the use of directional, moderate gain antennas in this context, since the duration of the received stream is long enough to allow transmission of detailed messages or implementation of more sophisticated buffering techniques.

For all scenarios, the number of received packets is strictly related to the speed of the mobile node, decreasing noticeably when the speed increases. This reflects also in a smaller length of the received stream (Figure 6). However, this decrease is more noticeable in the day scenario. When using the 18 dBi directional antenna, in fact, received packets decrease by 60% when passing from 50 to 70 Km/h (198 and 78, respectively). In the night scenario, under the same conditions (antenna, speeds), received packets only decrease by 13% (976 packets received versus 849).

4.2 Application layer results

The algorithm used to measure the perceptual quality of the received stream is the ITU-T implementation of the PESQ algorithm [25]. The received MP3 stream is decoded and resampled at 16 KHz, mono, 16 bits per sample. The resulting score is then mapped to a MOS scale following the ITU-T P.862.1 recommendation [28], in order to make the results independent of the implementation of the PESQ algorithm. MOS scale ranges from 1 (worst) to 5 (best).

The overall perceptual results (average of the four combinations language-gender) are presented in Figure 8. Results obtained with the 8 dBi antenna are unacceptable also when considering the perceived quality of the transmitted stream. It is worth noting that, while in the night scenario the quality slightly decreases when speed increases (higher the speed, lower the SINR), in the day scenario the trend is reversed. We related such behavior to lower interference levels caused by other moving cars when speed is higher. Probably this effect wouldn't be noticeable when all cars travel at the same speed. Moreover, the perceived quality experienced in the day scenario increases when passing from 50 to 70 Km/h with the 18 dBi antenna, even if the number of received packets decreases. The burst of received packets lasts less but its quality is higher. Last, the low variance obtained throughout the whole experiment (<0.4 in MOS scale for each set of [car speed, antenna gain, scenario]) makes us confident on the reliability of the presented results.

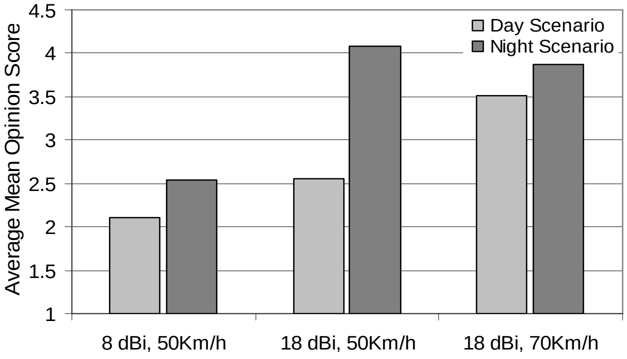

Figure 8. Average MOS as a function of antenna gain and car speed.

5. CONCLUSIONS AND FUTURE WORK

In this paper we analyzed the performance of multimedia communication in a Vehicular Ad hoc Network (VANET). We focused on the multicast transmission of safety messages via MP3 streams in a typical urban context. We examined different solutions for guaranteeing vehicle-to-infrastructure connectivity via both omni-directional and directional antennas. To reach this goal, we developed an optimized client-server streaming software suite and tested it in a real-world network testbed by streaming safety messages recorded in different combinations [language, gender]. Results showed that the plain 802.11b standard can be used for successfully transmitting safety messages in multicast with acceptable levels of both network and application layer QoS. Results also showed that quality of the communication strongly relies on environmental conditions.

Possible extensions to our work include performing the same experiments in different contexts (for instance, highway scenarios), and transmitting different kinds of multimedia streams.

6. ACKNOWLEDGMENTS

The authors wish to thank Maria Teresa Medina Quintana and Dr. Fabio De Vito from Politecnico di Torino, Italy, for their precious help during the experiments.

7. REFERENCES

[1] IEEE Task Group TGp. Status of Project IEEE 802.11p. URL: http://grouper.ieee.org/groups/802/11/Reports/ tgp_update.htm.

[2] H. Oh, C. Yae, D. Ahn and H. Cho. 5.8 GHz DSRC Packet Communication System for ITS Services. In *Proc. IEEE Vehicular Technology Conference* (VTC 1999 Fall). Vol. 4, pp. 2223–2227.

[3] R. M. Yadumurthy, A. Chimalakonda, M. Sadashivaiah and R. Makanaboyina. Reliable MAC broadcast protocol in directional and omni-directional transmissions for vehicular ad hoc networks. In *Proc. ACM Workshop on Vehicular Ad Hoc Networks* (VANET 2005) (Colonia, Germany, Sept. 2005), pp. 10-19.

[4] M.L. Sim, M. Nekovee and Y.F. Ko. Throughput analysis of Wi-Fi based broadband access for mobile users on the highway. In *Proc. IEEE International Conerence on Communications* (ICC 2005) (Seoul, Korea, May 2005), vol. 1, pp. 21-26.

[5] M. Bechler and L. Wolf. Mobility Management for vehicular ad hoc networks. In *Proc. IEEE Vehicular Technology Conference* (VTC 2005 Spring) (Stockholm, Sweden, May 2005), vol. 4, pp. 2294-2298.

[6] W. Sun, H. Yamaguchi and S. Kusumoto. A study on performance evaluation of real-time data transmission on vehicular ad hoc networks. In *Proc. IEEE Mobile Data Management* (MDM'06) (Nara, Japan, May 2006), pp. 126-130.

[7] Y. Günter and H.P. Groβmann. Usage of wireless LAN for inter-vehicle communication. In *Proc. IEEE Intelligent Transportation Systems* (ITS 2005) (Vienna, Austria, Sept. 2005), pp. 296-301.

[8] P. Beckman, S. Verna and R. Rao. Use of mobile mesh networks for inter-vehicular communication. In *Proc. IEEE Vehicular Technology Conference* (VTC 2003 Fall) (Orlando, Florida, USA, Oct. 2003), vol. 4, pp. 2712-2715.

[9] T. Osafune, K. Monden, S. Fukuzawa and S. Matsui. Performance measurement of mobile ad hoc network for application to Internet-ITS (Intelligent Transportation System). In *Proc. IEEE International Symposium on Applications and the Internet* (SAINT'04) (Tokyo, Japan, Jan. 2004), pp. 25-30.

[10] J.J. Blum, A. Eskandarian and L.J. Hoffman. Challenges of intervehicle ad hoc networks. In *IEEE Trans. On Intelligent Transportation Systems* (Dec. 2004), vol. 5, no. 4, pp. 347-351.

[11] G. Ravikirian and S. Singh. Influence of mobility models on the performance of routing protocolsin ad-hoc wireless networks. In *Proc. IEEE Vehicular Technology Conference* (VTC 2004 Spring) (Milan, Italy, May 2004), vol. 4, pp. 2185-2189.

[12] Y. Wang, Y. Liu and H. Zhang. Effects of MAC retransmission on TCP performance in IEEE 802.11-based ad-hoc networks. In *Proc. IEEE Vehicular Technology Conference* (VTC 2004 Spring) (Milan, Italy, May 2004), vol. 4, pp. 2205-2209.

[13] M. Möske, H. Füβlet, H. Hartenstein and W. Franz. Performance measurements of a vehicular ad hoc network. In *Proc. IEEE Vehicular Technology Conference* (VTC 2004 Spring) (Milan, Italy, May 2004), vol. 4, pp. 2116-2120.

[14] S. Roy, D. Saha, S. Bandyopadhyay, T. Ueda and S. Tanaka. Service differentiation in multi-hop inter-vehicular communication using directional antenna. In *Proc. IEEE Vehicular Technology Conference* (VTC 2004 Spring) (Milan, Italy, May 2004), vol. 4, pp. 2176-2180.

[15] M.M. Artimy, W. Robertson and W.J. Phillips. Connectivity in inter-vehicle ad hoc networks. In *Proc. IEEE Canadian Conference on Electrical and Computer Engineering* (CCECE 2004) (Niagara Falls, Ontario, Canada, May 2005), pp. 293-298.

[16] M. Guo, M.H. Ammar and E.W. Zegura. V3: a vehicle-to-vehicle live video streaming architecture. In *Proc. IEEE International Conference on Pervasive Computing and Communications* (PerCom 2005) (Kauai, Hawaii, Mar. 2005), pp. 171-180.

[17] S.Y. Wang. On the intermittence of routing paths in vehicle-formed mobile ad hoc networks on highways. In *Proc. IEEE Intelligent Transportation Systems* (ITS 2004) (Washington, D.C., USA, Oct. 2004), pp. 803-809.

[18] H. Rohling, A. Ebner and L. Wischhof. Performance of UTRA TDD ad hoc and IEEE 802.11b in vehicular environments. In *Proc. IEEE Vehicular Technology Conference* (VTC 2003 Spring) (Jeju, Korea, Apr. 2003), vol. 2, pp. 960-964.

[19] R.A. Santos, R.M. Edwards and N.L. Seed. Inter vehicular data exchange between fast moving road traffic using an ad-hoc cluster-based location routing algorithm and 802.11b Direct Sequence Spread Spectrum radio. *PostGraduate Networking Conference* (PGNet 2003) (Liverpool, UK, June 2003).

[20] J.P. Singh, N. Bambos, B. Srinivasan and D. Clawin. Wireless LAN performance under varied stress conditions in vehicular traffic Scenarios. In *Proc. IEEE Vehicular Technology Conference* (VTC 2002 Fall) (Vancouver, B.C., Canada, Sept. 2002), vol. 2, pp. 743-747.

[21] J. Ott and D. Kutscher. Drive-thru Internet: IEEE 802.11b for "Automobile" users. In *Proc. of the* 23rd *annual IEEE Conference on Computer Communications* (INFOCOM 2004) (Hong Kong, Mar. 2004).

[22] P. Bucciol, E. Masala and J.C. De Martin. Dynamic Packet Size Selection for 802.11 Inter-Vehicular Video Communications. In *Proc. of Vehicle to Vehicle Communications Workshop* (V2VCOM 2005) (San Diego, CA, USA, July 2005), pp. 365-372.

[23] P. Bucciol, E. Masala, N. Kawaguchi, K. Takeda and J.C. De Martin. Performance Evaluation of H.264 Video Streaming over Inter-Vehicular 802.11 Ad Hoc Networks. In *Proc. IEEE International Symposium on Personal, Indoor and Mobile Radio Communications* (PIMRC 2005) (Berlin, Germany, Sept. 2005).

[24] Jean Tourrilhes. Linux Wireless Tools. URL: http://www.hpl.hp.com/personal/Jean_Tourrilhes/Linux/Tools.html.

[25] ITU-T Recommendation P. 862. Perceptual Evaluation of Speech Quality (PESQ) and objective method for end-to-end speech quality assessment of 3.1 kHz handset telephony (narrow-band) networks and speech codecs (Feb. 2001).

[26] Paolo Bucciol. WiSafety project homepage. URL: http://media.polito.it/WiSafety.

[27] LScube Project. URL: http://live.polito.it/.

[28] International Telecommunication Union (ITU-T) Recommendation P.862.1. Mapping function for transforming P.862 raw result scores to MOS-LQO (Geneva, Switzerland, Nov. 2003).