Paper

On the Optimal Design of a Broadcast Data Dissemination System over VANET Providing V2V and V2I Communications "The Vision of Rome as a Smart City"

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Abstract—In different this paper we present the performance evaluation study of a simple broadcast data dissemination technique in new emerging Vehicular Ad hoc Networks (VANETs). Differently from the traditional Mobile Ad hoc NETworks (MANETs), VANETs require particular routing protocols, due to the high dynamism of the network topology, and to different traffic and mobility patterns. For safety and emergency message applications, broadcast data dissemination is an important key factor in VANETs. However, the design of optimal deployment of relay nodes in different network scenarios allows to enhance system performance. At this aim, this work analyzes vehicular network performances in terms of throughput and delays, for different traffic scenarios, exploiting both inter-vehicular communications, as well as the availability of fixed network infrastructure.

Keywords—broadcast protocol, IEEE 802.11, V2V, V2I, Vehicular Ad hoc Networks.

1. Introduction

Vehicular Ad hoc NETworks (VANETs) are a particular class of Mobile Ad hoc NETworks (MANETs), where mobile nodes are vehicles moving at different speeds and forming dynamic topology network scenarios [1]. VANETs provide data communications among nearby vehicles via Vehicle-to-Vehicle (V2V) protocol, in the support of Internet access (e.g., web browsing, instant messaging, online gaming, data sharing, etc.), as well as a large variety of safety applications (e.g., assisted braking, controlled safety distance, warning message delivery, etc.).

However, due to the variable nature of such networks, mainly due to dynamic vehicle speed and different mobility and traffic scenarios (e.g., urban, rural and highway), connectivity is time-varying and may cause intermittent and delayed packet delivery. Moreover, in totally-disconnected scenarios (i.e., in highways during nightly hours), data delivery has to rely on available network infrastructure (also called Road Side Units) or, in the case of no availability, on satellite connectivity links [1], [2].

Leveraging previous aspects, it is evident that connectivity issues still represent an open issue in vehicular networks [3]. Ongoing efforts are aimed at enabling inter-vehicle communications supported by existing network infrastructure, in order to provide seamless connectivity and efficient data propagation even in sparse-traffic scenarios. Intelligent Vehicular Ad hoc Networking (InVANET) has defined a smart novel way of using vehicular connectivity by integrating on multiple wireless technologies, such as 3G cellular systems, IEEE 802.11p, and IEEE 802.16e, for effective Vehicle-to-Infrastructure (V2I) communications [4]. Also, V2V and V2I communication technology has been developed as part of the Vehicle Infrastructure Integration initiative [5], which considers the network infrastructure as composed by several Road Side Units (RSUs), equipped with a 5.9 GHz Dedicated Short Range Communication (DSRC) transceiver (i.e., for communications between vehicles and RSUs), and a GPRS interface (i.e., to forward messages to the backbone networks).

In such heterogeneous network environments, protocols for data dissemination and delivery still represent a challenge. It is then evident that the decision on connectivity switching among different "short-lived" links[1] (i.e., V2V, and V2I) should be taken by each vehicle based on main vehicular parameters (i.e., speed, traffic, mobility, type of service, and so on). As an alternative, hybrid vehicular communication protocols (i.e., V2X) represent a viable solution to opportunistically exploit the nature of the vehicular network (i.e., traffic and mobility pattern, availability of fixed relay nodes, etc.) [6], [7].

In this paper, we provide a performance evaluation of a simple broadcast protocol for packet dissemination in VANETs, for different traffic and mobility patterns, ranging from highways with sparse traffic to a very congested traffic environment, where both V2V and V2I connectivity are provided. The main aim is addressed to evaluate the feasibility analysis of a vehicular network in a real highway scenario, considering a portion of highway in Rome (Italy). An effec-

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[1] In VANETs, the availability of connectivity links is affected by mobility and clusters formation. V2V and V2I links occur in unpredictable fashion, resulting as intermittent and short-lived. Opportunistic links are exploited for packet transmissions.

tive deployment of RSUs has been also investigated in order to enhance performance especially in low traffic density scenarios. Considerations on optimal RSUs deployment in the vehicular network are taken in order to maintain acceptable network performance, while limiting implementation costs.

This paper is organized as follows. In Section 2 we investigate previous related works on data dissemination protocols in VANETs. Section 3 introduces important issues related to broadcast routing for different scenarios, ranging from a sparse-traffic scenario, with lack of connectivity, to a fully congested scenario. Considering the most simple broadcast approach for data delivery in VANETs, in Section 4 we assess extensive simulation results for different traffic, mobility, and communication modes. Finally, conclusions are drawn in Section 5.

2. Related Work

In the last years, several data dissemination techniques suitable for VANETs have been proposed. Routing algorithms are based on particular vehicular communication protocols (i.e. V2V, V2I and hybrid) and analyze how messages are propagating in VANETs (i.e., message propagation distance and end-to-end delivery delay). The main issue related to a vehicular network is that it lacks of connectivity due to quick disconnections, variable mobility of vehicles and rapidly changing network topology. VANETs suffer from a reliable data delivery specially in sparse-traffic, and totally disconnected scenarios, where vehicle density is very low, and null, respectively [8]. In these scenarios, there is a direct relationship between the amount of packets, which can be successfully received by a vehicle, and the traffic patterns and vehicle speed.

Data dissemination represents a challenge specially in commercial applications (e.g., Internet access, video-on-demand, advertising dissemination, etc.). In entertainment applications, where data flows are larger w.r.t safety applications, message dissemination should be efficient in order to reconstruct a whole data flow from a limited number of received messages. At this aim, the potentiality of network coding protocols for data dissemination has been largely exploited [9]–[12]. This approach can provide a rapid sharing of real-time messages, particularly suitable for comfort applications. As an instance, the use of Fountain codes has been demonstrated to provide efficient and reliable vehicular communications even in high dynamic networks [11], [12]. In [10] the authors propose VANETCODE, a content distribution scheme assuming the content as divided into smaller blocks, which are linearly encoded by vehicles.

The use of hybrid communication protocols has been considered by Cataldi *et al.* in [12]. The proposed scheme is I2V2V, where vehicles can communicate both with network infrastructure (i.e. I2V) and other neighboring vehicles (i.e. V2V), providing a cooperating approach between vehicles, since messages are delivered from the infrastructure to a set of relay vehicles, and then directly to the destination vehicles. This method improves the speed of data delivery in an end-to-end connection, also due to the use of rateless codes providing data reconstruction in a fast way with low overhead.

The use of multi-hop protocols has been exploited in many works for the analysis of message propagation in VANETs, and for a variety of communication modes (i.e., V2V, V2I and V2X). In [13], Resta et al. deal with multi-hop V2V emergency message dissemination through a probabilistic approach. The authors derive lower bounds on the probability that a vehicle correctly receives a message within a fixed time interval. Similarly, Jiang *et al.* [14] introduce an efficient alarm message broadcast routing protocol, and estimate the receipt probability of alarm messages sent to vehicles. Finally, the use of a vehicular grid together with an infrastructure has been largely discussed [15], [16], where benefits of using the opportunistic infrastructure placed on the roads are analyzed.

In this paper we focus on a traditional broadcast protocol in order to assess the feasibility analysis of a vehicular network, and validate network performance in real traffic scenarios. In this study, the vehicular environment is assumed to allow vehicles to communicate both in V2V and V2I modes.

3. Data Dissemination in VANET

Routing in VANETs is an emerging issue due to high mobility of nodes and the dynamic network topology. A VANET is characterized by very short-lived links and then lacks of knowledge about neighborhoods (i.e., vehicular density can change in different areas of the same network). Due to typical features of VANETs, traditional routing protocols designed for MANETs cannot always be suitable. In general, broadcast techniques are frequently used in VANETs for data sharing, traffic, weather and emergency applications. However, different traffic regimes[2] can have impact on data dissemination performances, as summarized as follows [8]:

- *Sparse* traffic condition (i.e., low vehicular density [veh./km]),
- *Dense* traffic condition (i.e., medium vehicular density [veh./km]),
- *Congested* traffic condition (i.e., high vehicular density [veh./km]).

The first scenario, which is very troublesome for conventional routing protocols, considers a limited number of vehicles on the road [8]. It is very typical of night hours, where the traffic density is very low and data dissemination from a source (i.e., a vehicle attempting to broadcast messages) to other relay vehicles is difficult to occur, due

[2] Notice that the traffic density varies heavily depending on the specific road, the time of day, etc. [17]

to the out of the transmission range of the source from the receiver node. Moreover, there might be no cars within the transmission range of the source in the opposite lane either. Under such circumstances, routing and broadcast techniques become a challenging task.

In the second scenario i.e., dense traffic regime, the vehicular density is not uniform in all the vehicular grid (i.e., some vehicles can have a low number of neighbors, while other nodes are moving in a high vehicular density area). The nodes inside the networks do not experience the same topology knowledge. In this case, some vehicles will have to apply a *broadcast suppression* algorithm[3], while some others will have to *store-carry-and-forward* the message in order to preserve the network connectivity.

The third case represents a congested scenario, that is when the vehicular traffic density is above a certain threshold (i.e., >70 veh./km). Several consecutive cars will share the same wireless medium leading to an excessive number of the same safety message, and then there will be a strong increase of packet collisions and medium contentions among vehicles attempting to communicate. This problem is also referred to as *broadcast storm problem*, which occurs when the traffic density is above a certain value (e.g., when vehicles are in congested traffic scenarios, like during a rush hour).

In order to alleviate this problem, several solutions have been proposed [18], [19], mainly based on decisions for packet (re)-transmission i.e., when and how a safety message should be (repeated) delivered. As a solution, selective broadcast or multicast strategies seem more applicable than either unicast routing or flooding, for the requirement of limitation of broadcast storm problem. Indeed, broadcasting to selected vehicles provides a high overhead without increasing the success rate substantially. Several solutions have been made to introduce intelligence to the basic broadcast concept and make it more selective and, thus, more efficient in its resource usage.

In this paper we consider a broadcast data dissemination technique for all three different traffic regimes, assuming vehicles are moving in a real highway scenario. Extensive simulation results will highlight the design of a vehicular network, providing effective network performance, expressed in terms of throughput and packet delay.

4. Simulation Results

In this section we describe our simulation scenario, where vehicles can communicate via V2V, as well as V2I, for different traffic conditions. The aim of the following tests is to analyze how the increase of vehicles as well as the presence of RSUs in the same area, can affect the network performance, in terms of throughput and delay. In fact, if there is a large gap between two vehicles[4], a packet could be lost or discarded. At this aim, the number of received packets can be increased by exploiting the presence of fixed nodes (i.e., RSUs), which are able of relaying packets inside the vehicular network and then, enlarging the coverage area. We remind that RSUs may generally be either stand-alone devices that communicate only with vehicles via wireless communication, or may be interconnected via a backbone network, or via a mesh network of RSUs [17]. Figure 1 depict the schematic of the use of RSUs to extend the network coverage. In Fig. 1(a) a source vehicle attempts to transmit a packet forward along the route. Packet loss occurs due to a large inter-vehicular gap w.r.t the source transmission range, and no RSU can act as relay node toward a destination vehicle. In Fig. 1(b) the source vehicle transmits a packet to a RSU acting as relay node. The packet is received by the destination vehicle, due to the presence of a RSU along the route, which extends the source vehicle's transmission range.

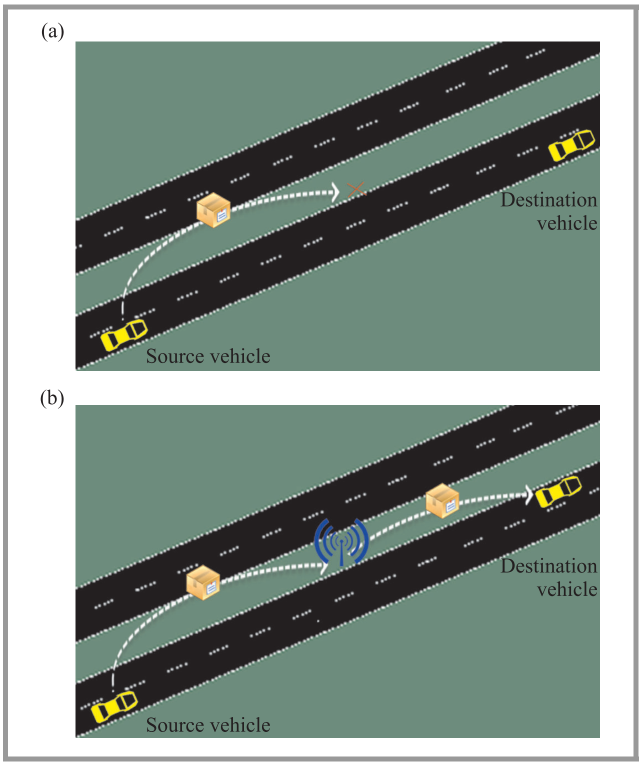

Fig. 1. Schematic of the use of RSUs in a vehicular network to avoid packet losses: (a) packet loss, (b) effective reception.

The network model has been simulated using ns2 [20], and the mobility traces have been generated by SUMO tool [21]. In particular, the used mobility trace is based on a existing highway map from the city of Rome (Italy). Figure 2 depicts the portion of a very well known highway in Rome, called GRA (Grande Raccordo Anulare)[5], which has been used for our simulations.

Different environment configurations have been simulated, varying the mobility traffic level (i.e., from sparse to dense

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[3] A broadcast suppression algorithm is used for limiting the number of copies of a message, which can be rebroadcast several times.

[4] The inter-vehicle distance is higher than the source transmission range (i.e., typically >125 m, depending on the technology.)

[5] Literally, "Great Ring Junction" that is a toll-free, ring-shaped orbital motorway, encircling the city of Rome.

Fig. 2. Map of a portion of GRA highway in Rome (Italy).

traffic scenarios), and the presence of network infrastructure (i.e., RSUs positioned near the routes). Two sets of simulations have been performed, such as:

- *V2V-oriented*, which is aimed to evaluate V2V communications only, and no RSU is considered;
- *V2I-oriented*, which is aimed to evaluate not only V2V, but also V2I communications, due to the increasing number of RSUs.

In both cases, the following three scenarios, depicting real vehicular traffic, have been simulated:

- *Smooth-flowing – sparse – traffic scenario*, where traffic is assumed to be disconnected, as typical of night hours. In particular, we simulate 90 vehicles driving at variable speed, as typical of highway environments.
- *Dense traffic scenario*, i.e. the inter-vehicle distance is almost small, but connectivity is not always guaranteed. Basically, we simulate a high number of vehicles up to 180.
- *Rush hours scenario*, i.e. with high vehicular density (i.e., 300 vehicles moving inside the vehicular area), as typical of rush traffic hours.

Figure 3 depicts the three simulated traffic conditions. We assume that each vehicle is equipped with IEEE 802.11n transceivers, allowing to act as a mobile relay node, and a GPS receiver, allowing information on vehicle's localization. More in detail, in our simulations we consider the design specifications of RSUs and the on-board equipment for V2I and V2V communications, according to Savari Networks [22]. We consider the Savari MobiWAVE On Board Equipment (OBE), which is mounted on-board and is comprised of the main devices for safety applications (e.g., the Vehicle Awareness Device, the Automotive Safety Device, and more others), and the StreetWAVE RSU that is a fixed wireless gateway that can be mounted on a road side traffic pole, working according to ITS applications. Figure 4 (a) and (b) depict the Savari MobiWAVE OBE, and the StreetWAVE RSU, respectively [22].

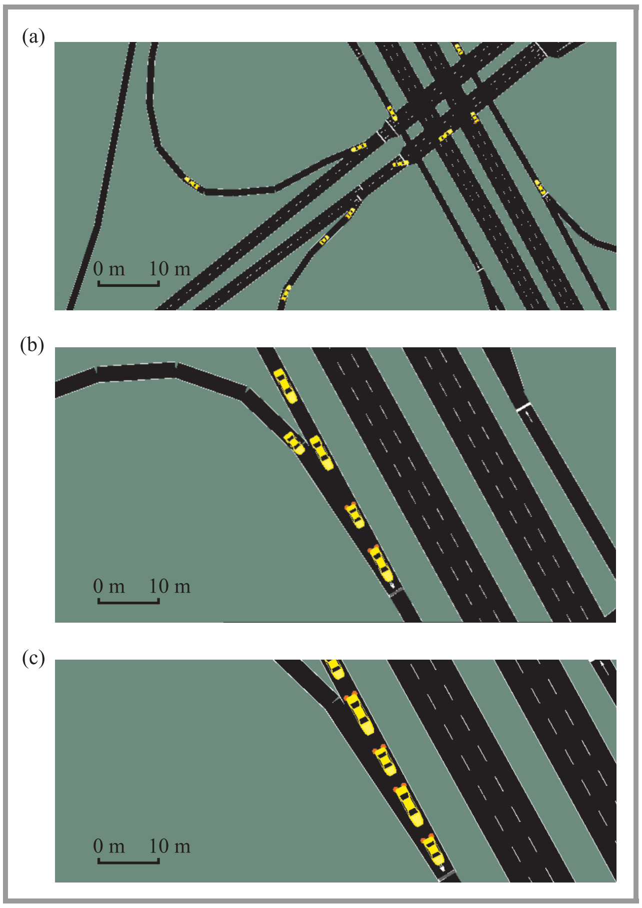

Fig. 3. The three typical simulated traffic conditions inside the vehicular network. (a) Case 1: smooth-flowing traffic scenario, (b) Case 2: dense traffic scenario, and (c) Case 3: congested traffic scenario.

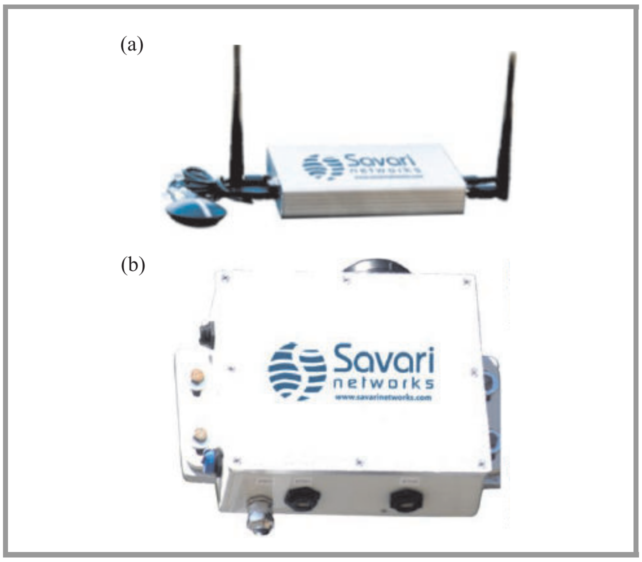

Fig. 4. Savari devices for RSU and on-board unit, [22]. (a) Savari MobiWAVE OBE, and (b) StreetWAVE RSU.

All vehicles are equipped with the Savari MobiWAVE OBE, featuring of a IEEE 802.11p network interface card, a highly accurate GPS receiver and a 5.9 GHz DSRC radio. Packets are generated with a constant generation rate, and are transmitted according to a fixed data rate.

On the RSUs' deployment in the vehicular network, four configurations have been considered. In the first case, no RSUs have been included in the scenario; in the second configuration, a dense deployment of RSUs has been introduced (i.e., with a non-uniform RSUs gap), while in the third and fourth cases, RSUs are separated respectively at 1 and 2 km each other. In Table 1, we summarize the main parameters used for all the scenarios.

Table 1
Simulation parameters setup

Parameter	Value
Network Simulator	NS2
Traffic Simulator	SUMO
Number of vehicles	$[90, 300]$
Vehicular area	14 km^2
Simulation time	300 s
Vehicle and RSU MAC	IEEE 802.11p
RSU range	$[1000, 2000]$ m
Data Transmission Flow	UDP
Transmission range	300 m
Data rate	6 Mbit/s
Propagation model	Free Space

The simulation results have been compared in all the scenarios, in terms of network performance through the following metrics:

- *Throughput*, as the total amount of data transmitted from the source to destinations in a unit period of time,
- *End-to-end delay*, as the total latency experienced by a packet routed from a source vehicle to a destination node inside the network.

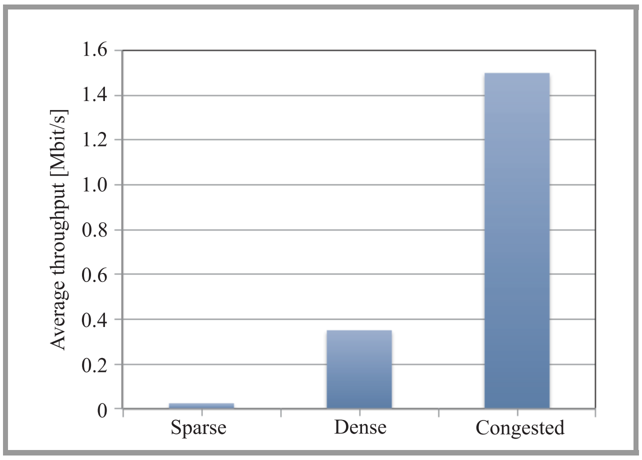

Fig. 5. Comparison of average throughput experienced by vehicles communicating via V2V only, in different traffic scenarios (i.e., sparse, dense and congested).

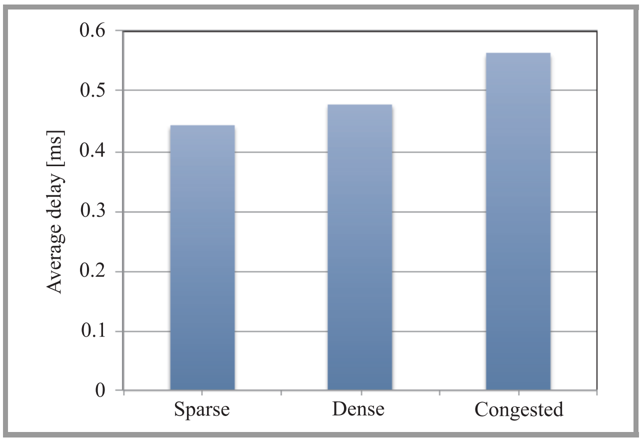

Fig. 6. Comparison of average delay experienced by vehicles communicating via V2V only, in different traffic scenarios, (i.e., sparse, dense and congested).

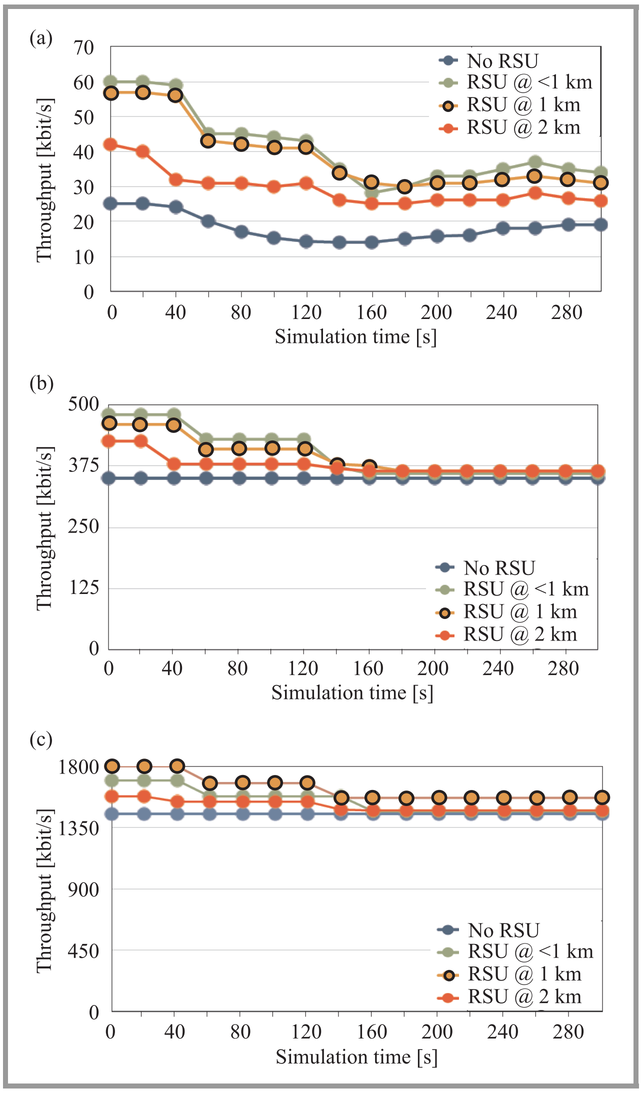

Fig. 7. Throughput [kbit/s] vs. simulation time in different scenarios, i.e., (a) *Smooth-flowing traffic scenario*, (b) *dense traffic scenario*, and (c) *congested traffic scenario*. Notice an increase of performance in all the configurations, mainly due to a higher vehicular traffic density.

In Fig. 5 and Fig. 6, throughput and delay are evaluated in different traffic scenarios, for the case of V2V-oriented simulations. We notice how, on one side, throughput performance increases for higher number of vehicles available to communicate each others and in the other side, the average delay increases due to collisions and congestions. This aspect shows also the influence of market penetration of smart vehicles enabling for inter-vehicle communications.

The most interesting results are when connectivity is supported both by V2V and V2I communications (i.e., V2I-oriented). This represents the most expected scenario configuration for future envision of *smart cities*, where mobility and communications in vehicular environments are supported by vehicles as well as existing network infrastructure. In Fig. 7(a), we show the throughput performance for different values of the number of RSUs; increasing the number of RSUs provides an increasing trend of throughput, reaching up to 60 kbit/s. However, also considering RSU at 1 km of distance each other has a positive impact on throughput. On the other hand, performances get worse when the distance among RSUs increases, as shows the throughput trend for RSUs at 2 km.

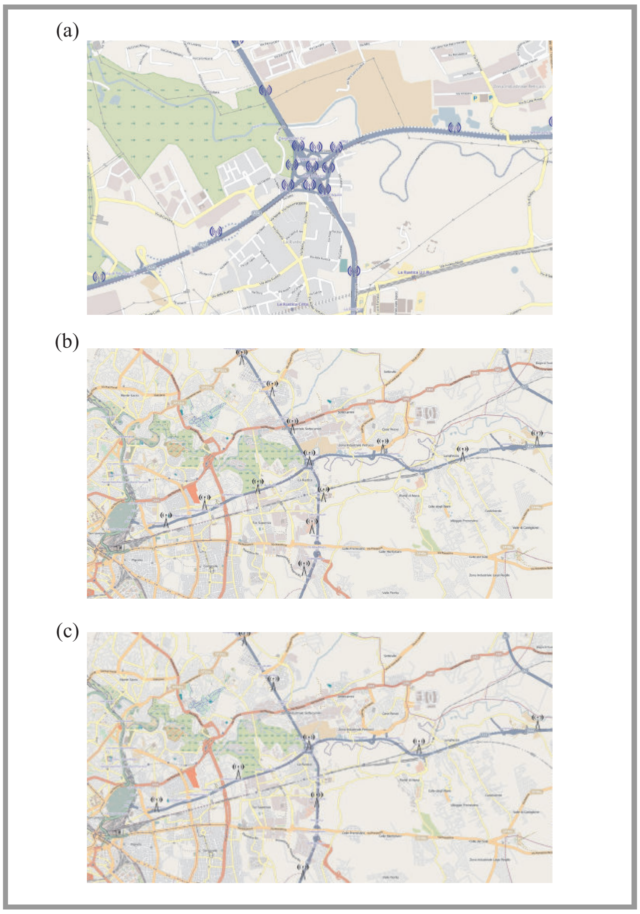

Fig. 8. Variable RSUs deployment in different scenarios. (a) Dense RSUs deployment in the center and near the ramps of the GRA, while low RSU density in highway, (b) 13 RSUs in a dense configuration, deployed at 1 km each other, and (c) 9 RSUs in a sparse configuration, deployed at 2 km each other.

In Fig. 7(b), network performance are evaluated in terms of throughput for the dense traffic case. In this case, the density of vehicles is increased; this leads to an improvement of performances, and all the curves are converging towards the same value. Notice how performances increase for a dense deployment of RSUs in the vehicular network; this also implies that throughput is stable at 350 kbit/s. A variation of performances can be seen at the beginning of the simulation when the vehicles are starting to move before they create dense traffic scenario. Finally, in Fig. 7(c), the obtained throughput when considering a congested network is illustrated. Also for this scenario, an increasing trend of the throughput is obtained when RSUs are at 1 km of distance each other. Notice how performances increase in all the configuration; this can impact on the number of rebroadcast packets, causing network congestions.

The network performances have also been evaluated in terms of end-to-end delay. The end-to-end delay represents an important issue when dealing with vehicular communication systems (e.g., a safety message should be received in a very short time). In this paper, the end-to-end delay is evaluated considering the inter-RSU distance inside the network. In fact, the propagation delay should decrease as the distance of RSUs decreases. For the performance analysis only the smooth-flowing case is taken into account, and the reason lies since for dense or congested traffic scenario there is no lost of connectivity. The end-to-end delay has been evaluated according to previous configurations, i.e., RSUs in a dense deployment (i.e., at < 1 km inter-RSU distance), RSUs laying at 1 km each other, and RSUs laying at 2 km each other. Figure 8 depicts the different scenarios with varying RSUs deployment.

Figure 9 depicts the comparison of end-to-end delays[6] for the three different configurations of RSUs' deployment, in the case of smooth-flowing traffic since this represents the most challenging scenario for packet transmission delay. It is possible to note that, as expected, small increases of delay occur as the inter-RSU distance increases.

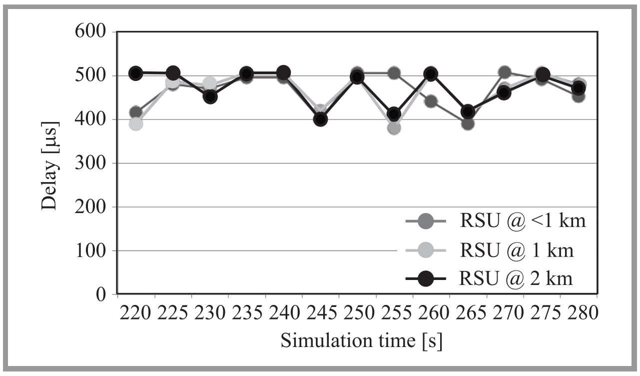

Fig. 9. Packet delay [μs] for a given vehicle vs. simulation time, for different RSUs deployments in the vehicular network. Large gaps between RSUs affect packet delivery delay.

[6] The end-to-end delay is for a reference vehicle only, chosen randomly among all the vehicles in the network. In this particular case, the packet delay exists for $t \geq 220$ s.

Table 2
Performance and cost comparison among different RSUs' deployment configurations within the portion of GRA in Rome

Number of RSUs	Max Throughput in:			Cost [kUSD]
	Smooth-flowing traffic scenario [kbit/s]	Dense traffic scenario [kbit/s]	Congested traffic scenario [Mbit/s]	
0	30	30	1.5	0
18	60	490	1.8	180
13	57	400	1.7	130
9	44	360	1.6	90

Finally, we provide some considerations on the optimal configuration to adopt for the deployment of RSUs, in order to maximize network performance, while keeping low the economic requirements. By considering the installation costs of Savari MobiWAVE OBE, and StreetWAVE RSU, (i.e., 4 and 10 kUSD, respectively), the following Table 2 compares the different configurations of RSUs (i.e., from the absence of RSUs up to 13 RSUs that is the maximum number of RSUs assumed in our simulations). Considering the maximum achievable throughput and the costs, we can conclude that the optimal configuration is for 13 RSUs. Indeed, the differences of maximum achievable throughput in different scenarios are comparable (i.e., only 3 kbit/s low in the smooth-flowing traffic scenario, and around 100 kbit/s in other scenarios). On the other hand, with this configuration we obtain a cost saving of 50 kUSD. This demonstrates that the deployment of a large number of RSUs does not necessary provide a significant enhancement in network performance, but also can have a negative impact on the energy consumption.

5. Conclusion

In this paper, a performance evaluation of broadcast routing protocol in a VANET has been analyzed and discussed, also taking into account the deployment of RSUs inside the vehicular network. The performance analysis has been evaluated in a most realistic scenario (i.e., a selected portion of GRA in Rome) shown that for increasing vehicular densities we obtain high values of throughput.

By including several RSUs along the vehicular network, the end-to-end packet delay – evaluated for a given vehicle – decreases and at the same time, the network throughput shows a better trend. On the other side, an extended number of RSUs has a negative impact on energy and costs consumption in the VANET. A trade-off among an increased throughput and decreased end-to-end delay, and an increased energy/cost consumption is necessary to design an effective vehicular network.

Acknowledgements

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References

[1] S. Olariu and M. C. Weigle (Eds.), *Vehicular Networks: From Theory to Practice*. CRC Press, Taylor & Francis,2009.

[2] A. M. Vegni, C. Vegni, and T. D. C. Little, "Opportunistic vehicular networks by satellite links for safety applications," in *Proc. Fully Netw. Car Worksh.*, Geneva, Switzerland, 2010.

[3] A. M. Vegni, C. Campolo, A. Molinaro, and T. D. C. Little, *Modeling of Intermittent Connectivity in Opportunistic Network: The Case of Vehicular Ad hoc Networks in Routing in Opportunistic Networks*. Springer, 2013 (in press).

[4] H. Moustafa and Y. Zhang (Eds.), *Vehicular Networks: Techniques, Standards and Applications*. Auerbach publishers, Taylor & Francis, 2009.

[5] X. Dong, K. Li, J. Misener, P. Varayia, and W. Zhang, "Expediting vehicle infrastructure integration (EVII)", Tech. rep., California PATH Research Report, UCB-ITS-PRR-2006-20, 2006.

[6] A. M. Vegni and T. D. C. Little, "Hybrid Vehicular Communications based on V2V-V2I Protocol Switching", *Int. J. Veh. Inform. Commun. Sys. (IJVICS)*, vol. 2, no. 3/4, pp. 213–231, 2010.

[7] A. Mostafa, A. M. Vegni, T. Oliveira, T. D. C. Little, and D. P. Agrawal, "QoSHVCP: Hybrid Vehicular Communications Protocol with QoS Priorization for Safety Applications", *ISRN Commun. Netw.*, vol. 2012, p. 14, 2012.

[8] O. Tonguz, N. Wisitpongphan, F. Bai, P. Mudalige, and V. Sadekar, "Broadcasting in VANET", in *Proc. Mob. Netwo. Veh. Environ.*, Anchorage, AK, USA, 2007, pp. 7–12.

[9] S. Yousefi, T. Chahed, M. Moosavi, and K. Zayer, "Comfort Applications in Vehicular Ad Hoc Networks Based on Fountain Coding", in *Proc. 3rd IEEE Int. Symp. Wirel. Veh. Commun. WiVEC 2010*, Taipei, Taiwan, 2010.

[10] S. Ahmed and S. Kanhere, "VANETCODE: Network Coding to Enhance Cooperative Downloading in Vehicular Ad-hoc Networks", in *Proc. Int. Conf. Wirel. Commun. Mob. Comput. IWCMC 2006*, Vancouver, Canada, 2006.

[11] V. Palma, E. Mammi, A. M. Vegni, and A. Neri, "A Fountain Codes-based Data Dissemination technique in Vehicular Ad-hoc Networks", in *Proc. 11th Int. Conf. ITS Telecommun. ITST 2011*, Saint-Petersburg, Russia, 2011, pp. 750–755.

[12] P. Cataldi, A. Tomatis, G. Grilli, and M. Gerla, "A novel data dissemination method for vehicular networks with Rateless Codes", in *Proc. IEEE Wirel. Commun. Netw.*, Budapest, Hungary, 2009.

[13] G. Resta, P. Santi, and J. Simon, "Analysis of multi-hop emergency message propagation in vehicular ad hoc networks", in *Proc. 8th ACM Int. Symp. Mob. Ad Hoc Netw. Comput. MobiHoc'07*, Montreal, Canada, 2007, pp. 140–149.

[14] H. Jiang, H. Guo, and L. Chen, "Reliable and efficient alarm message routing in VANET", in *Proc. 28th Int. Conf. Distrib. Comput. Syst. Worksh.*, Beijing, China, 2008, pp. 186–191.

[15] M. Gerla, B. Zhou, Y.-Z. Lee, F. Soldo, U. Lee, and G. Marfia, "Vehicular grid communications: the role of the internet infrastructure", in *Proc. 2nd Ann. Int. Worksh. Wirel. Internet WICON'06*, Boston, MA, USA, 2006.

[16] G. Marfia, G. Pau, E. De Sena, E. Giordano, and M. Gerla, "Evaluating vehicle network strategies for downtown portland: opportunistic infrastructure and the importance of realistic mobility models", in *Proc. 1st Int. MobiSys Worksh. Mobile Opport. Netw. MobiOpp'07*, Puerto Rico, USA, 2007, pp. 47–51.

[17] H. Hartenstein and K. P. Laberteaux, *VANET: Vehicular Applications and Inter-Networking Technologies*. Wiley, 2010.

[18] A. M. Vegni, A. Stramacci, and E. Natalizio, "SRB: A Selective Reliable Broadcast Protocol for Safety Applications in VANETs", in *Proc. Int. Conf. Selec. Topics Mob. Wirel. Netw. iCOST 2012*, Avignon, France, 2012.

[19] H. Juang, H. Guo, and L. Chen, "Reliable and Efficient alarm message routing in VANET", in *Proc. 28th Int. Conf. Distrib. Comput. Syst. Worksh.*, Beijing, China, 2008.

[20] "Network Simulator 2" [Online]. Available: www.isi.edu/nsnam/ns

[21] "Sumo-simulation of urban mobility" [Online]. Available: http://sumo.sourceforge.net/

[22] "Savari networks" [Online]. Available: http://www.savarinetworks.com/

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