IEEE 802.11p Vehicle to Infrastructure Communications in Urban Environments

J. Gozalvez, M. Sepulcre and R. Bauza

ABSTRACT

The future exploitation of cooperative vehicular services in urban environments, generally characterized by challenging propagation conditions, will require an efficient deployment of roadside units. This article presents the results of an extensive field testing campaign aimed at analyzing the impact of urban characteristics, RSU deployment conditions, and communication settings on the quality of IEEE 802.11p vehicle-to-infrastructure communications. The reported results show that the streets' layout, urban environment, traffic density, presence of heavy vehicles, trees, and terrain elevation have an effect on V2I communications, and should be taken into account to adequately deploy and configure urban RSUs.

INTRODUCTION

Cooperative vehicular systems are being developed to improve traffic safety and efficiency through to the wireless exchange of information between vehicles, and between vehicles and infrastructure units or roadside units (RSUs). The deployment of RSUs will facilitate the implementation of future cooperative applications, in addition to providing a communications gateway for road traffic management authorities and infotainment service providers. The effectiveness of cooperative systems using RSUs for vehicle-to-infrastructure (V2I) communications will strongly depend on how efficiently RSUs are being deployed. Such deployment should take into account important aspects such as the cooperative applications to be provided, mobility patterns, budget restrictions, and operating and propagation conditions. These conditions can be particularly challenging in urban environments where the presence of numerous obstacles (building, trees, etc.) can strongly influence the received signal levels at the 5.9 GHz frequency band, and thereby the effectiveness of cooperative applications.

In this context, this article presents the results of an extensive field testing campaign conducted to investigate the impact of operating and propagation conditions on IEEE 802.11p V2I communications [1]. Based on the conducted tests, a set of RSU deployment guidelines are presented to assist stakeholders in deploying RSUs and maximizing the efficiency of cooperative applications. The campaign has been conducted within the city of Bologna as part of the European FP7 iTETRIS project [2, 3]. The mobility (GPS data) and IEEE 802.11p V2I communication traces obtained during the field tests, and that have been used to conduct the study reported in this article, are openly released to the research community to facilitate future cooperative vehicular research activities. The traces can be downloaded from [4].

V2I AND V2V COMMUNICATION FIELD TESTS

Several IEEE 802.11p vehicular communications field studies have already been reported in the literature. The work presented in [5] was one of the first extensive measurement campaigns that analyzed the performance of vehicle-to-vehicle (V2V) and V2I communications based on the IEEE 802.11p standard in highway scenarios. The study investigated their performance for various transmission parameters (power and data-rate), number of antennas, and operating conditions. The obtained results revealed that a sustained V2I communications range beyond 1000m could be obtained under line of sight (LOS) propagation conditions. However, non-LOS (NLOS) conditions provoked by large blocking vehicles complicate maintaining reliable and stable links at 5.9GHz. The study reported in [6] investigates the impact of parameters such as the packet length, data rate and vehicle speed on the IEEE 802.11p V2I communications range in highway scenarios. The study showed that increasing the data rate can notably reduce the communications range. In this context, the optimum data rate with respect to the volume of data that could be exchanged between an onboard unit (OBU) and RSU was found to be

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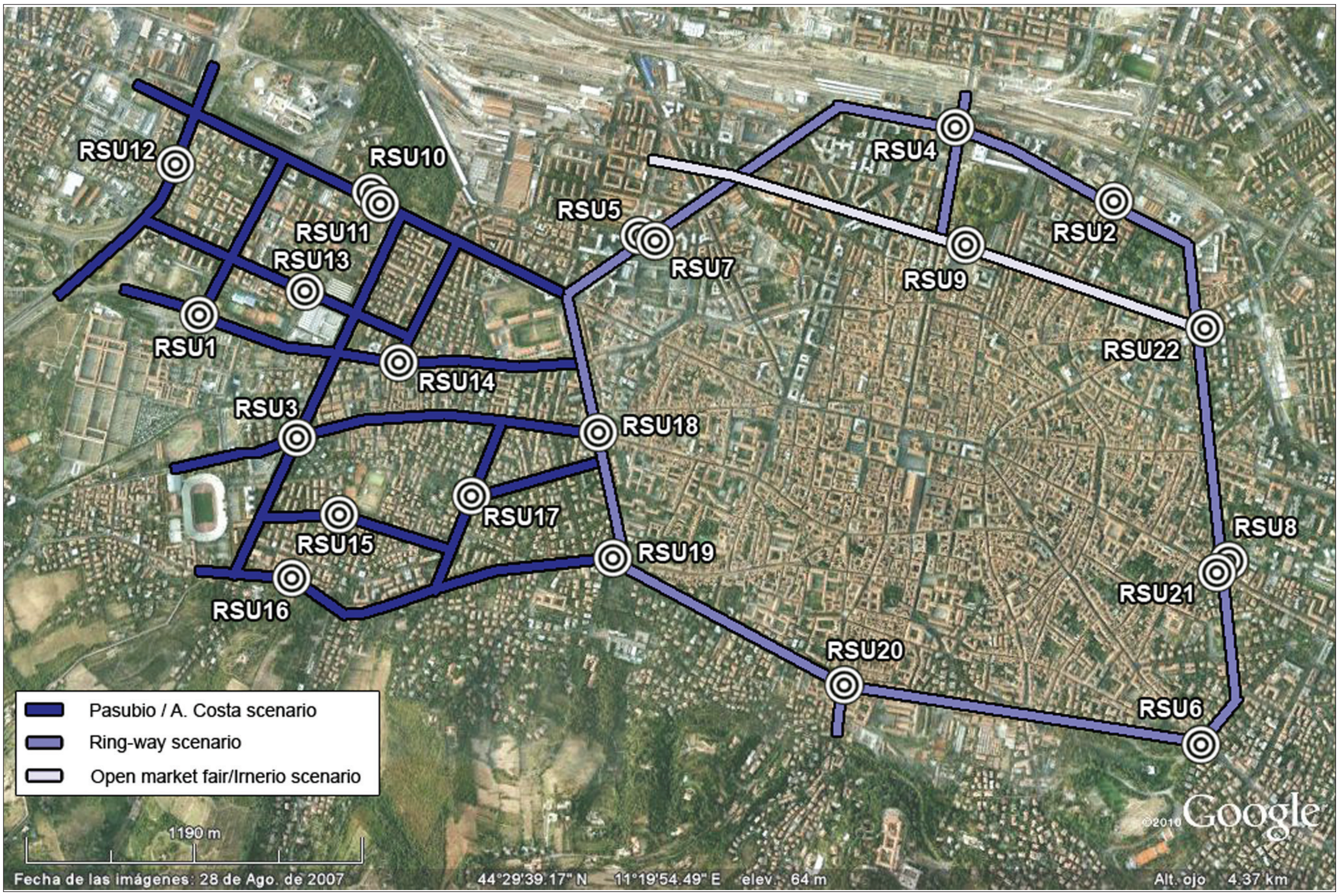

Figure 1. *Bologna's urban scenarios, RSU locations, and V2I radio traces.*

in the range of 6 to 9 Mb/s. The conducted experiments did not find any influence of the vehicle's speed on the communications range. On the other hand, increasing the packet length was shown to increase the link's variability, although a decrease in the communications range was not observed. The authors extended their field study in [7], and analyzed the potential impact of road traffic on V2I communications in highway scenarios. One of the first V2I field studies in urban environments was presented in [8]. The article evaluated the performance of IEEE 802.11p V2I communications in terms of round-trip times, transaction times, and jitter. The study was conducted in an urban intersection, and showed significant dependence of the performance on transmission parameters (packet transmission intervals, data rates, and packet sizes).

Although this article is focused on V2I communications, it is also worthwhile summarizing some of the main conclusions obtained in V2V field tests. In [9], the authors analyze the impact of obstructing elements on the V2V communications range in parking lot (static), highway, suburban and urban environments. The obtained results show that vehicles blocking the line of sight can significantly attenuate V2V signals and reduce the communications range. A related study can be found in [10] for highway, urban, and rural environments, in which the high degradation of V2V connectivity under NLOS propagation conditions is demonstrated. Finally, an interesting study is reported in [11] where the authors analyze the IEEE 802.11p V2V communications performance in highway environments from the applications perspective, and show that adequate reliability levels can be ensured to deploy future cooperative applications, such as forward collision warning and lane change applications.

The studies reviewed have provided valuable information about propagation and V2V/V2I communications performance. However, most of these studies focus on highway scenarios, and their validity under urban environments needs yet to be certified given the limited number of reported V2I urban studies. In this context, this article extensively analyses V2I communications performance in urban environments, and discusses how to efficiently and reliably deploy RSUs.

Measurement Campaign: Scenario and Setup

Urban Scenario

The field testing campaign has been conducted as part of the iTETRIS project, a European research initiative to develop a standard compliant, modular and open source traffic and wireless simulation platform to investigate the effectiveness of cooperative applications over large-scale scenarios [2]. To this aim, iTETRIS selected the city of Bologna as its testing envi-

Figure 2. *RSU equipment and deployment.*

ronment, and identified four key scenarios (three urban and one highway) that could benefit from the future deployment of cooperative applications. The field testing campaign focused on the three urban scenarios: *Pasubio/A. Costa*, *ring-way* and *Open Market Fair/Irnerio*. Figure 1 depicts Bologna's city centre, and identifies the three urban scenarios selected within the iTETRIS project.

The *Pasubio/A. Costa* scenario includes the city's stadium, hospital and cemetery. This scenario is prone to high traffic flow variations as a result of specific events. Consequently, cooperative traffic management applications such as dynamic management of bus lanes, prioritization of emergency vehicles, or notification of traffic conditions and alternative routes to the drivers, could provide valuable tools to improve traffic management and avoid congestions. The ring-way and Open Market Fair/Irnerio scenarios include the inner city ring-way, which can be covered clockwise or anti-clockwise, and Irnerio street, an important avenue that shortcuts the ring-way, has important public transportation traffic and an open market fair at weekends. The scenario offers adequate conditions to test cooperative applications such as regulatory/contextual speed limits notification, traffic light optimal speed advisory, and enhanced cooperative route guidance and navigation (e.g. using the ring-way shortcut, or driving clockwise or anti-clockwise in the ring-way based on traffic conditions and travel times).

The dark blue, light blue, and white traces used in Fig. 1 are not only used to identify the Bologna urban scenarios, but also highlight the 20km of urban road network over which V2I radio measurements have been obtained during the field testing campaign reported in this article. The campaign included 22 different RSU locations (Fig. 1) carefully selected to study the impact of various operating and propagation conditions on V2I communications. The campaign analyzed more than 70 RSU deployment configurations (combination of RSU location, transmission power, antenna height and type of mast). For each configuration, the OBU performed multiple test-drives to/from the RSU to provide valuable indications on the quality of V2I communications. More than 700 test-drives were conducted in total, with around 950 km of testing distance traveled during more than 35 hours of wireless measurement tests being recorded.

Equipment

The field testing campaign used one OBU in a vehicle and two portable RSUs, all of them equipped with an IEEE 802.11p DENSO WSU (Wireless Safety Unit) prototype controlled by a standard laptop. The OBU used a Nippon omni-directional antenna with 0 dBi gain, placed on the roof of the vehicle and connected with an LMR240 antenna cable of 3 m length and approximately 3 dB cable loss. The OBU employed two Novatel SMART-V1-2US-PVT GPS receivers to improve the GPS signal availability and accurately track the vehicle's position in urban environments. To this aim, one of the GPS receivers was configured using a PDP (Pseudorange/Delta-Phase) filter specifically designed to improve the GPS signal availability in urban environments, and the positions obtained with the two GPS receivers was combined. The RSU used an ECO12-5800 omni-directional antenna with 12 dBi gain, placed on top of a portable pneumatic telescopic mast with a maximum height of 11 m, and connected with an LMR400 antenna cable of 14 m length and approximately 5 dB cable loss. Considering P as the output transmission power of the IEEE 802.11p prototype, the equivalent isotropically radiated power (EIRP) for the RSU and OBU can be estimated based on the antenna gains and cable losses: $EIRP_{OBU}$ = P – 3, and $EIRP_{RSU}$ = P + 7. To emulate possible RSU deployments, antenna heights of h = 3 m (RSU antenna deployed on top of a traffic signal), h = 6.5m (traffic light) and h = 10.5 m (street light) have been tested. The tests also included the deployment of different type of masts as shown in the center and right photo of Fig. 2, which depicts the RSU equipment deployed during the tests.

The RSUs and OBU were configured to periodically transmit (with a 10Hz frequency) a broadcast packet on the IEEE 802.11p control channel, 5.895-5.905 GHz in Europe, using the default 6Mb/s data rate (1/2 QPSK). The transmitted packets (126 bytes including headers) included a timestamp, a packet ID for post-processing, the transmitter's ID, and the transmitter's latitude, longitude, heading and speed. All the information related to every single transmitted and received packet was logged at each node (OBU and RSU). The logged data for each packet included also its received signal strength indicator (RSSI) and local positioning information (number of detected GPS satellites and estimated positioning errors).

V2I Communications Experimental Results

This section presents and discusses the V2I communications performance measured during the field tests. The performance was analyzed under different operating conditions in order to identify those effects that have a major influence. The communications performance was measured in terms of the packet delivery ratio (PDR) as a function of the distance of the OBU to the communicating RSU. However, in order to better summarize the obtained results and facilitate their comparison under different testing conditions, two additional performance indicators have been defined. In particular, this article defines the Reliable Connectivity Range (RCR) as the distance to the RSU up to which the experienced PDR is above 0.7. Consequently, the RCR represents the range over which high quality V2I communications can be established as multipath fading effects are mitigated. The unreliable connectivity range (UCR) is defined as the distance to the RSU from which the experienced PDR is below 0.1, and only very sporadic and low quality V2I transmissions can take place. Figure 3 illustrates an example of the PDR measured during the Bologna field testing campaign (with more than 30 samples or packets per PDR data point), and how the RCR and UCR performance indicators are obtained. This figure compares the V2I performance when transmitting at two different power levels (*P* equal to 10 and 20 dBm), and the OBU drives away from RSU1 (Fig. 1) to the North in Marzabotto street under low traffic density conditions. The RSU antenna height was fixed to h = 6.5 m. The obtained results show that the use of high transmission power levels can significantly increase the RCR and UCR distances in straight streets without significant obstacles.

Figure 4 represents the RCR and UCR parameters measured during the tests conducted to analyze the impact of different operating conditions on V2I communications. Each test (*Tx*) is identified as *RSU*[*a*] – [*b*, *c*] – *P*[*d*] – *h*[*e*], where RSU[*a*] is the ID of the RSU in Fig. 1, [*b*] denotes if the OBU approaches (A) or drives away (D) from the RSU during the test, and [*c*] represents the cardinal point (N, S, E, W) from which the OBU approaches the RSU or to which the OBU drives away from the RSU. *P*[*d*] and *h*[*e*] represent the transmission power (dBm) and the RSU antenna height (meters). To illustrate the measured V2I communications link variability, each of the bars plotted in Fig. 4 represents a vertical line every time the PDR crosses the 0.5 threshold. While a single line indicates that the PDR decreases from the RCR to the UCR without significant oscillations, multiple lines indicates that the PDR experiences high variations between RCR and UCR. The representation of results shown in Fig. 4 has been chosen to concisely summarize the large number of conducted field tests, and more clearly identify those conditions that most significantly influence V2I communications. The results reported in Fig. 4 correspond to RSU to OBU communications, although no significant difference was found between the quality observed in V2I and I2V transmissions. Interested readers can have access in [4] to the PDR figures for all the tests concisely reported in Fig. 4, and to photographs of the testing conditions in which every test was conducted.

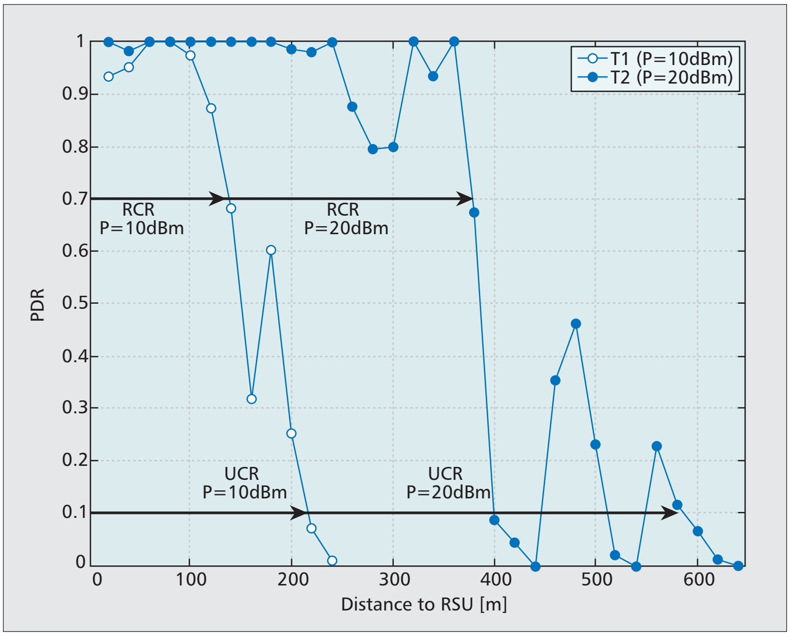

Figure 3. *Effect of changing the transmission power on the PDR as a function of the distance to RSU1 (*h = *6.5 m).*

NLOS Conditions

Urban environments are typically characterized by streets with multiple intersections and curves that can provoke NLOS propagation conditions between OBUs and RSUs. The impact of such conditions was first analyzed during the T3 and T4 tests using different transmission power levels (10 and 20 dBm). The tests were conducted at Bologna's ringway (Carlo Berti Pichat Avenue) under low traffic density conditions (the OBU approaches RSU2 from the east), and a 6.5 m RSU antenna height. There is a sharp curve at 340 m from the RSU, and at higher distances the OBU and RSU do not have direct visibility. Compared to the results depicted in Fig. 3, increasing the transmission power (T4 compared to T3) does not significantly augment the RCR and UCR distances due to the strong NLOS conditions experienced after the curve. In fact, the RCR distance measured in T4 is equal to the distance between the RSU and the curve, and the difference between RCR and UCR is significantly reduced as a result of the sudden loss of connectivity after the curve. The same effect was observed in additional tests conducted around RSU6, RSU16, and RSU22.

Other scenarios such as A. Costa Avenue were characterized by lighter NLOS conditions after smooth curves with buildings at both sides of the road. To analyze their impact, tests T5 and T6 were conducted under low traffic density conditions, with the OBU driving away from RSU3 to the East. In this scenario, there are two smooth curves at around 250 and 530 m from the RSU that provoke NLOS conditions. The two tests were performed with an RSU antenna height of h = 6.5 m and different transmission power levels (10 and 20 dBm). The results depicted in Fig. 4 show that the presence of smooth curves does not result in a sudden decrease of the link connectivity, with differences between RCR and UCR close to 150 m.

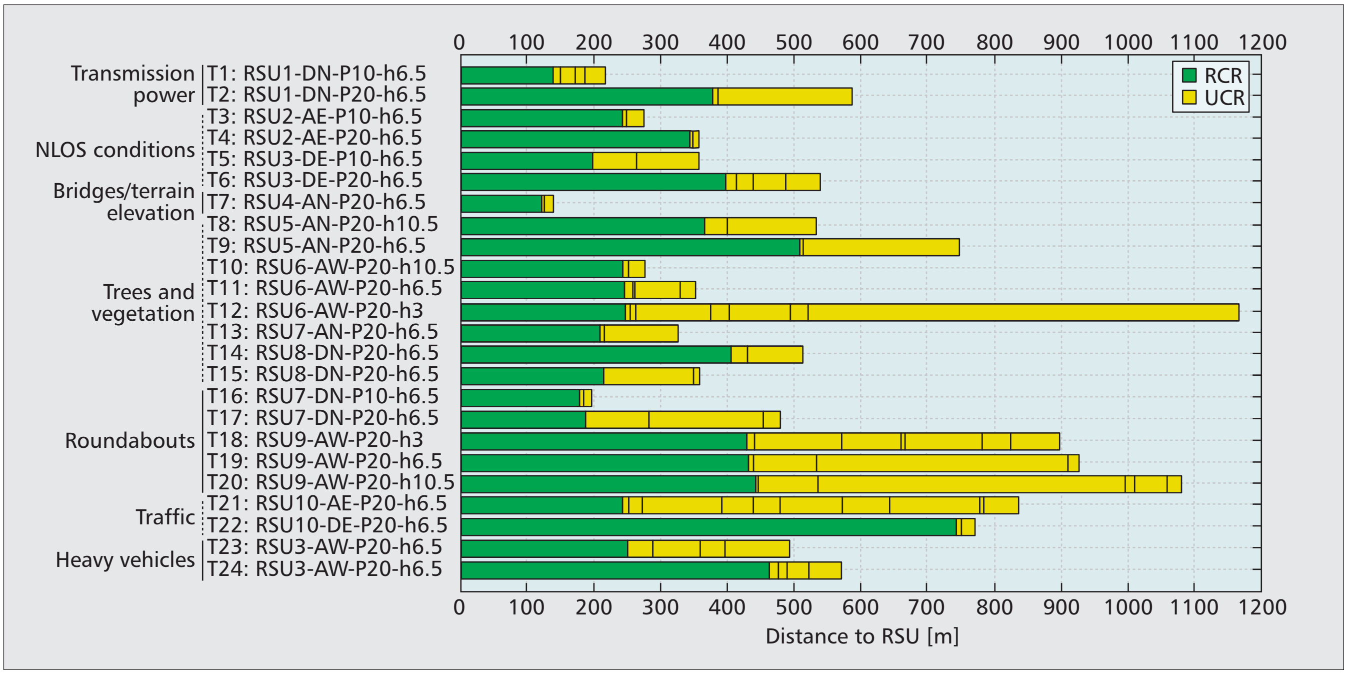

Figure 4. *RCR and UCR parameters for the most significant tests (Tx). Notation* RSU[a] – [b][c] – P[d] – h[e]: RSU[a] *is the ID of the RSU,* [b] *denotes if the OBU approaches (A) or drives away (D) from the RSU,* [c] *represents the cardinal point (N, S, E, W) from which the OBU approaches the RSU or to which the OBU drives away from the RSU,* P[d] *is the transmission power (dBm), and* h[e] *the RSU antenna height (meters).*

While the connectivity is lost 100 m after the first curve for T5 (P = 10 dBm), the higher transmission power in T6 (P = 20 dBm) increases RCR, and allows reaching the second curve with a low connectivity level.

Bridges/Terrain Elevation

The presence of bridges or changes in the terrain elevation can also influence the visibility conditions between OBU and RSU, and thereby their link connectivity. This effect was evaluated in T7 where RSU4 (h = 6.5 m) was located close to an arch bridge (intersection between Giacomo Matteotti street and the ring-way). As shown in Fig. 4, the connectivity is lost after reaching the top of the bridge (at a distance of about 140 m from the RSU, and an elevation above the sea level 5m higher than the elevation at the RSU location), with a rapid decrease of the link performance (small difference between RCR and UCR) as it was observed with sharp curves resulting in strong NLOS conditions (e.g. T4).

Trees and Vegetation

The presence of trees is also quite common in urban environments, but their effect on V2I communications has not been usually taken into account. To analyze their impact, tests T8 and T9 were conducted in Bologna's ring-way (Silvani Avenue, three lanes in each direction), where tall and dense trees in the median partially cover the avenue. The tests were conducted under medium traffic density conditions, with the OBU approaching RSU5 from the North and the RSU deployed in the same direction as the vehicle was driving through. The tests considered a transmission power of P = 20 dBm and different RSU antenna heights. The results depicted in Fig. 4 show that the V2I communications are improved with lower antenna heights due to the presence of large and dense trees (in this case, their crown started at around 3–4 m from the ground). In particular, the RCR and UCR distances increased by 150 m and more than 200 m, respectively, when the antenna height was reduced from h = 10.5 m (T8) to h = 6.5 m (T9). Similar tests were conducted at Giovanni Gozzadini Avenue (T10, T11, and T12), also located in the ringway, and with tall and dense trees at both sides of the road. In these tests, the OBU approached RSU6 from the West under similar (medium) traffic density conditions. In this case, decreasing the RSU antenna height did not improve the RCR, but notably increased the UCR from less than 300 m with h = 10.5 m (T10) to more than 1100 m with h = 3 m (T12). The improvement measured during T12 was due to the possibility of reducing the impact of the tree's foliage (started at around 4–5 m from the ground) through the use of low antenna heights. However, reducing the antenna height to 3 m significantly increased the link's variability due to the higher obstruction caused by surrounding vehicles.

T13 was conducted using the same configuration as T9, except that RSU7 was located in the opposite direction to the vehicle's movement. In this context, the communications link between the OBU and RSU (h = 6.5 m) was fully obstructed by the trees located in the median. Both tests (T9 and T13) were conducted at the same time with the two RSUs simultaneously active (the communications load was sufficiently low to avoid packet collisions). The results depicted in Fig. 4 show that the presence of trees in the median (T13) reduces the RCR and

UCR distances by 50 percent compared to the RSU deployment in T9.

T14 was conducted placing the RSU antenna at the end of a 3 m horizontal stick fixed on top of the mast (right photo in Fig. 2). The stick was used in order to separate the transmitting antenna from nearby obstacles (in this case, trees on the same side of the street) and improve the propagation conditions. The test was conducted around RSU8, with the vehicle driving away to the North, P = 20 dBm, and h = 6.5 m. T15 was conducted under the same conditions as T14, except that the stick was not used (center photo in Fig. 2), and the antenna was thereby closer to nearby obstacles. In this case, the RCR decreased by around 200 m (50 percent reduction), which emphasizes the importance of avoiding nearby obstacles when deploying RSUs.

Roundabouts

The impact of roundabouts was evaluated at Silvani avenue (T16 and T17). During the conducted tests, the OBU drives away from RSU7 to the North under low traffic density conditions. The OBU enters a roundabout at around 190 m from the RSU, and returns to the ringway at approximately 280 m from the RSU. Surrounding buildings (including a monument placed at the center of the roundabout) block the visibility conditions when the OBU enters the roundabout. The results reported in Fig. 4 show that, independently of the transmission power, the RCR is approximately equal to the distance between the RSU and the beginning of the roundabout. The PDR for tests T16 and T17 (Fig. 5) show a sudden decrease of the link connectivity due to the experienced NLOS conditions when the OBU enters the roundabout. However, the use of higher transmission power levels allows recovering the link connectivity after the vehicle leaves the roundabout. Similar tests (T18, T19, and T20) were conducted in Irnerio street under low traffic density conditions. In these tests, the OBU approaches RSU9 from the West, and enters the roundabout at around 550m from the RSU, and returns to Irnerio street at around 440m from the RSU. In this case, the roundabout does not have any monument, but surrounding buildings still block the visibility conditions when the OBU enters the roundabout. These tests used the higher transmission power (P = 20 dBm) and varied the antenna height. Figure 4 shows that the RCR remains constant and equal to the distance from the RSU to the roundabout independently of the RSU antenna height. However, increasing the antenna height helps better recovering the link connectivity when the vehicle leaves the roundabout (UCR augments, and the link variability is reduced). Finally, it is worth highlighting that the link connectivity could not be recovered, independently of the transmission configuration, if no direct visibility conditions between OBU and RSU could be restored after leaving the roundabout (additional tests conducted around RSU1 and RSU12).

Traffic

Tests T21 and T22 have been conducted in the East part of Aurelio Saffi avenue (RSU10, P = 20 dBm and h = 6.5 m) to analyze the impact of traffic conditions on V2I communications. In T21, the OBU approaches RSU10 from the East under high traffic density conditions and heavy machinery/trucks due to road works on the opposite side of the road. T22 was conducted driving away from RSU10 to the East, and under low traffic density conditions. The results depicted in Fig. 4 and Fig. 6 demonstrate the important impact of traffic conditions in V2I communications. In particular, high traffic density conditions significantly reduce the RCR and increase the communications link variability.

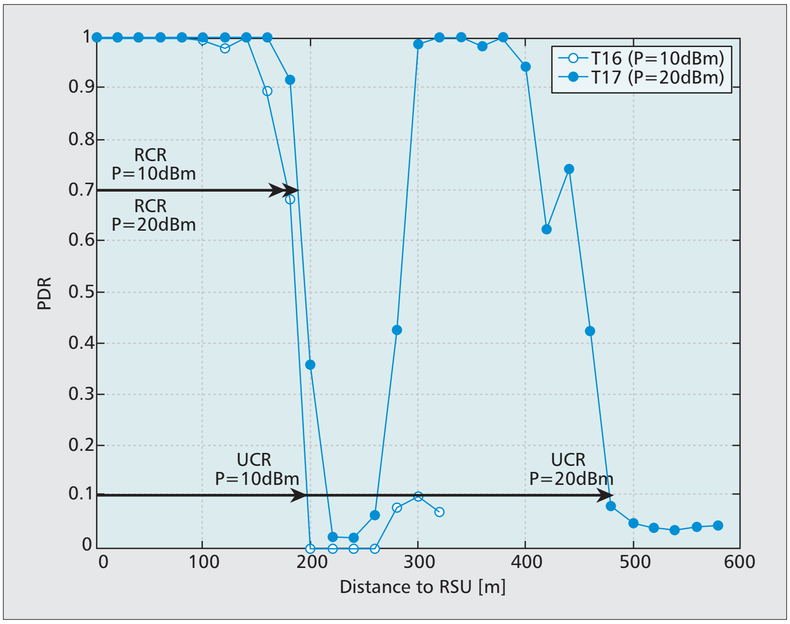

Figure 5. *Effect of changing the transmission power on the PDR as a function of the distance to RSU7, with a roundabout at around 250m from the RSU* (h *= 6.5m).*

Heavy Vehicles

Specific tests have also been conducted to analyze the effect of large or heavy vehicles. To this aim, tests T23 and T24 were conducted in A. Costa street where the OBU approaches RSU3 from the West (P = 20 dBm and h = 6.5 m). The only difference between these two tests was that during T23 the OBU was positioned immediately behind a bus blocking the radio signal between OBU and RSU under worst-case propagation conditions. The results depicted in Fig. 4 show that the presence of a bus can decrease the RCR by more than 200 m (40 percent reduction), while only slightly decreasing the UCR (less than 100m). Tests were also conducted to try overcoming the negative effect of the bus by increasing the antenna height. However, the presence of large trees in the area avoided the possible benefits of using an antenna height of 10.5m.

Cooperative RSU Deployment Guidelines

The obtained results have demonstrated that V2I communications are highly influenced by the environment (presence of obstacles, road can strongly impact the V2I connectivity. This effect has been shown for the case of bridges, but could also be extended to other scenarios with significant terrain elevation variations. Such variations need to be taken into account to maximize the V2I coverage with the deployed RSUs.

- The optimum RSU antenna height in terms of maximum radio coverage heavily depends on the presence of trees and vegetation, and their characteristics. The conducted tests have shown that high antenna heights can increase the communications range when no vegetation is present. However, when high dense trees partially reduce the visibility conditions, the conducted experiments have shown that reducing the RSU antenna height can help overcome the propagation losses resulting from the tree's foliage at the expense of a higher V2I link's variability under high traffic density conditions.
- High traffic density conditions have been shown to increase the V2I communications link variability. This effect can be partially overcome through the use of high antenna masts. Despite the degradation observed in terms of links variability, the conducted experiments also showed that high traffic density conditions do not significantly reduce the unreliable communications range.
- Heavy vehicles such as buses, trucks or heavy machinery have been shown to considerably reduce the communications range when obstructing the visibility between OBUs and RSUs. The deployment of RSUs with high masts can help overcome this negative effect, although their benefit depends on the surrounding presence of high and dense trees that also influence the visibility conditions between OBUs and RSUs.

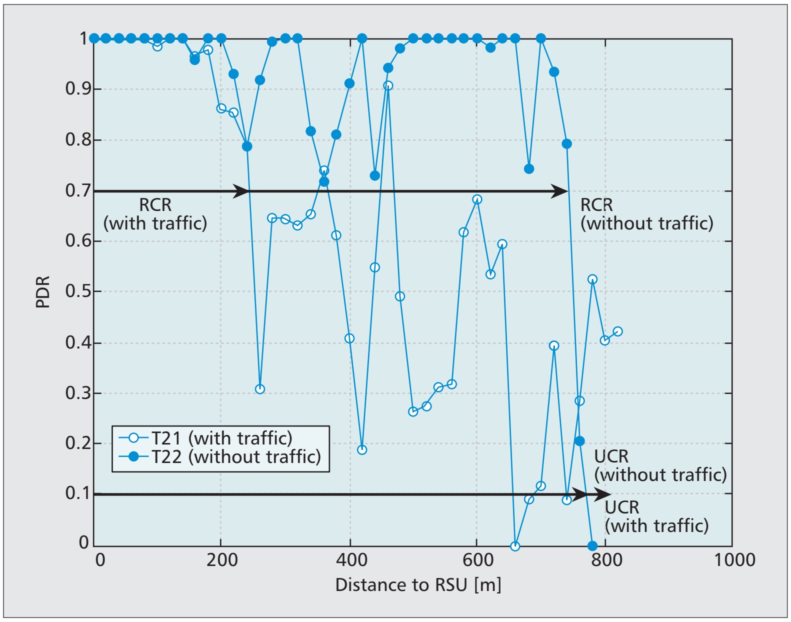

Figure 6. *Effect of traffic on the PDR as a function of the distance to RSU10 (*P = *20dBm,* h = *6.5m).*

topology, traffic density), the RSU deployment conditions (location, antenna height, and type of mast), and the communications settings (transmission power). Based on the conducted field tests and the observations previously reported, a set of guidelines for deploying cooperative RSUs in urban environments can be derived.

- Obstacles that reduce the visibility conditions between OBUs and RSUs can significantly impact the communication capabilities. Strong NLOS conditions (e.g., due to sharp curves or the presence of buildings) have been shown to drastically reduce the communications range and quality, with the connectivity being lost only a few meters after these conditions are met irrespectively of the RSU settings (transmission power and antenna height). On the other hand, weak NLOS conditions can be partially overcome through the use of high transmission power levels that increase the communications range. The deployment of RSUs in urban environments should then first take into account the road topology or street layout, together with the position and size of buildings and other large static obstacles that could cause NLOS. High transmission power levels should only be considered under weak NLOS conditions, and avoided under strong NLOS conditions due to their inefficiency. An adequate selection of the deployed type of mast can also help overcome the NLOS conditions partially caused by trees or buildings along a street.
- The conducted tests have shown that *temporal* strong NLOS conditions are experienced when a vehicle enters a roundabout. Although the use of high transmission power levels and antenna heights cannot improve the effect of such temporal NLOS conditions, they can help recover the link connectivity once the OBU leaves the roundabout and recovers LOS conditions with the RSU.
- Significant variations in terrain elevation

Conclusions

The introduction of cooperative vehicular services in urban environments requires efficiently deploying infrastructure nodes. Such deployment should not only take into account the type of services to be provided and possible budget restrictions, but also the impact of urban environments on V2I communications. To assist potential stakeholders in the future deployment of urban RSUs, this article presents the results of a very extensive IEEE 802.11p V2I field testing campaign conducted in the city of Bologna. The campaign was aimed at analyzing the impact of the urban environment, RSU deployment conditions, and communications settings on the quality of IEEE 802.11p V2I communications. The conducted tests have shown that the streets' layout, terrain elevation, traffic density, presence of heavy vehicles, trees and vegetation should all be taken into account to adequately deploy and configure, both radio and physically, urban RSUs. The wireless and GPS traces obtained during the field testing campaign are openly released to the community to further facilitate research activities in cooperative vehicular communications.

Acknowledgments

This work was supported in part by the European Commission through FP7 ICT Project iTETRIS: An Integrated Wireless and Traffic

Platform for Real-Time Road Traffic Management Solutions (no. FP7 224644), and by the Spanish *Ministerio de Industria, Turismo y Comercio* through INTELVIA: *Sistema Integral de Control*, *Señalización y Comunicación para la Gestión Operacional Segura e Inteligente del Tráfico en Servicios e Infraestructuras* project (TSI-020302-2009-90).

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BIOGRAPHIES

JAVIER GOZALVEZ (j.gozalvez@umh.es) received an electronics engineering degree from the Engineering School ENSEIRB (Bordeaux, France), and a Ph.D. in mobile communications from the University of Strathclyde, Glasgow, United Kingdom. Since October 2002, he is with the University Miguel Hernandez of Elche, Spain, where he is currently an associate professor and director of the Uwicore Laboratory. At Uwicore, he is leading research activities in the areas of wireless vehicular communications, radio resource management, heterogeneous wireless systems, and wireless system design and optimization. He currently serves as Mobile Radio Senior Editor of *IEEE Vehicular Technology Magazine*, and previously served as Associate Editor of *IEEE Communication Letters*. He was TPC Co-Chair of the 2011 IEEE Vehicular Technology Conference-Fall, TPC Co-Chair of the 2009 IEEE Vehicular Technology Conference-Spring, and General Co-Chair of the 3rd ISWCS 2006. He is also the founder and General Co-Chair of the IEEE International Symposium on Wireless Vehicular communications (WiVeC) in its 2007, 2008, and 2010 editions. He has been elected to the Board of Governors of the IEEE Vehicular Technology Society (2011–2013), and to the IEEE Distinguished Lecturers program of the IEEE Vehicular Technology Society.

MIGUEL SEPULCRE (msepulcre@umh.es) received a telecommunications engineering degree in 2004 and a Ph.D. in communications technologies in 2010, both from the University Miguel Hernandez of Elche (UMH), Spain. In 2004, he spent six months at the European Space Agency (ESA) in Noordwijk (The Netherlands) working on the communications physical layer of earth exploration satellites. He then joined in 2005 the University Miguel Hernandez of Elche as a networks manager and teaching assistant. In March 2006, he obtained a Ph.D. fellowship from the Valencian regional government and joined the Uwicore Laboratory to conduct his Ph.D. on cooperative vehicular communications. He is currently a research fellow at the Uwicore Laboratory of UMH, working on cooperative vehicular communications and wireless industrial communications.

RAMON BAUZA received a telecommunications engineering degree from the University Miguel Hernandez of Elche (UMH), Spain, in 2008. He then joined the Uwicore Laboratory as a research engineer working initially on the development of GIS-assisted wireless planning tools. He then worked in the European FP7 iTETRIS project which investigated the impact and benefits of cooperative vehicular communications for road traffic management. As part of iTETRIS, he was responsible for the iTETRIS ns3 wireless communications implementation, the development of novel cooperative networking protocols, and the design of cooperative traffic congestion detection applications. He was also involved in the INTELVIA project that is working towards the development of innovative and advanced ITS road signaling solutions based on cooperative vehicular communications.

The conducted tests have shown that the streets' layout, terrain elevation, traffic density, presence of heavy vehicles, trees, and vegetation should all be taken into account to adequately deploy and configure, both radio and physically, urban RSUs.