3D ray launching simulation of urban vehicle-to-infrastructure radio propagation links

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Resumen—Las redes vehiculares ad-hoc (VANET) permiten la comunicación de vehículos inteligentes, y las ciudades inteligentes deben aprovechar sus aplicaciones y beneficios en las operaciones de transporte. En los entornos urbanos, la propagación multitrayecto de la señal de comunicación inalámbrica está relacionada con fenómenos como la reflexión, refracción, difracción y pérdida de transmisión. Este trabajo presenta algunas métricas de un enlace Vehículo a Infraestructura (V2I) como: atenuación de canal (path-loss), perfil de retardo potencia (power delay profile), ancho de banda de coherencia (Coherence Bandwidth) y mean excess delay, utilizando un algoritmo determinista de lanzamiento de Rayos 3D (3D-RL). Se presenta un análisis espacial que utiliza redes inalámbricas de sensores (WSN) a 868 MHz, 2.4 Ghz y 5.9 GHz. Los resultados muestran el impacto de factores como: geometría, propiedades dieléctricas y posición relativa de los obstáculos, ubicación de las antenas transmisoras y frecuencia del enlace V2I. La simulación 3D-RL muestra una mejor representación de los fenómenos de propagación en tipos especiales de intersecciones como redondeles cuando se compara con un modelo teórico, y destaca la importancia de consideraciones espaciales de distancia y segmentación del escenario para obtener resultados consistentes.

***Palabras Claves*—3D Ray Launching, Vehicular Ad-Hoc Networks (VANET), IEEE 802.11p, Vehicle-to-Infrastructure communication (V2I), Wireless Sensor Networks (WSN).**

Abstract—Vehicular ad hoc networks (VANETs) enable vehicles to communicate with each other as well as with roadside units (RSUs), and Smart Cities must be able to take advantage of its applications and benefits on transportation operations. In urban environments some propagation impairments as reflection from, diffraction around and transmission loss through objects gives rise temporal and spatial variation of path loss and multipath effects. This work evaluates some parameters of a Vehicle-to-Infrastructure (V2I) wireless channel link such as large-scale path loss and multipath metrics in an urban scenario, using a deterministic 3D Ray-Launching (3D-RL) algorithm. Spatial analysis using Wireless Sensor Networks (WSNs) at 868 MHz, 2.4 Ghz and 5.9 GHz is presented. Results show the impact of factors as: geometry, dielectric properties and relative position of the obstacles, placement of the RSU and frequency link, in the V2I communication. The 3D-RL simulation shows better representation of the propagation phenomena when compared with an analytical path loss model, mainly at special types of intersections as roundabouts and give insight of the importance of the spatial distance and scenario segmentation to get consistent results.

***Keywords*—3D Ray Launching, Vehicular Ad-Hoc Networks (VANET), IEEE 802.11p, Vehicle-to-Infrastructure communication (V2I), Wireless Sensor Networks (WSN).**

I. INTRODUCTION

Effective transport services will be a major challenge for future Smart Cities. In Latin America region's high urbanization and relatively high income call for fairly sophisticated urban transport systems [1]. Intelligent Transportations Systems (ITS) have the potential to harness the benefits that provide the Connected Vehicles (CV) in areas as safety, mobility, environment and data [2], which in turn will be boosted with the development of private initiatives [3], academic research and governmental projects [4] in the area of ITS where applications ranging from safe critical [5], up to on-car multimedia streaming [6]. The ongoing research of CV and its benefits currently is focused on light vehicles, freight, and transit, with limited applications for motorcyclists, bicyclists, and pedestrians.

CV research enables wireless communications and includes three major approaches for communications: vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and vehicle-to-pedestrian (V2P). Motorcyclists or bicyclists can carry mobile devices, allowing vehicles and infrastructure to communicate with other CV participants and vice versa known as vehicle-to-anything (V2X). In 1999, the U.S. Federal Communication Commission (FCC) allocated a 75 MHz of licensed spectrum at 5.9 GHz to be used as V2V and V2I communications known as Dedicated Short Range Communications (DSRC), and the IEEE 802.11p standard [7], was developed to operate at this band. In Europe the government have licensed the 5.9 GHz while in Japan have licensed the 5.8 GHz for vehicular communication. This dedicated network provides a low-latency wireless communications permitting fast and reliable data transmissions at high velocities, critical for safety applications in short-to-medium-range.

The vehicular communications in urban environments are challenged by the rapid changes in the radio propagation conditions where some propagation impairments as reflection from, diffraction around and transmission loss through objects, give rise to temporal and spatial variation of path loss and multipath effects from reflected and diffracted components of the wave. While stochastic and geometry-based stochastic could fail into characterize significant surrounding obstacles (foliage, lamppost, pedestrians, etc.) and V2I field test provides useful insight for specific in-situ scenarios [8], the deterministic Ray Launching simulators are suited for vehicular propagation analysis of electrical-large scenarios yielding a reasonable tradeoff between accuracy and computational cost. Although the literature includes many propagation models and channel simulators for V2X systems [9]–[12], there is a need for further studies to investigate V2I propagation using 3D deterministic tools in complex environments as the urban.

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In this work, the analysis of the V2I large-scale and small-scale signal propagation phenomena in a urban environment, has been carried out using an in-house 3D Ray-Launching (3D-RL) algorithm whose operating mode has been validated in intra-vehicle and transportation systems [13], [14]. Results show that factors as geometry, dielectric properties of the obstacles, placement of the RSU, and frequency link have significant impact in the V2I analysis. Factors as the spatial position of the obstacles respect to the transmitter (TX), and the scenario segmentation has been taken into account to obtain accurate and consistent results given that, the large-scale and small-scale parameters cannot be assumed constant due to the non-stationary nature of vehicular communications channel [15].

The remaining parts of the paper are organized as follow: Section II presents a brief explanation of the 3D-Ray Launching (3D-RL) technique. Section III describes the scenario characterization and simulation parameters. Section IV reports the large-scale and small-scale simulation results. Conclusions are summarized in Section V.

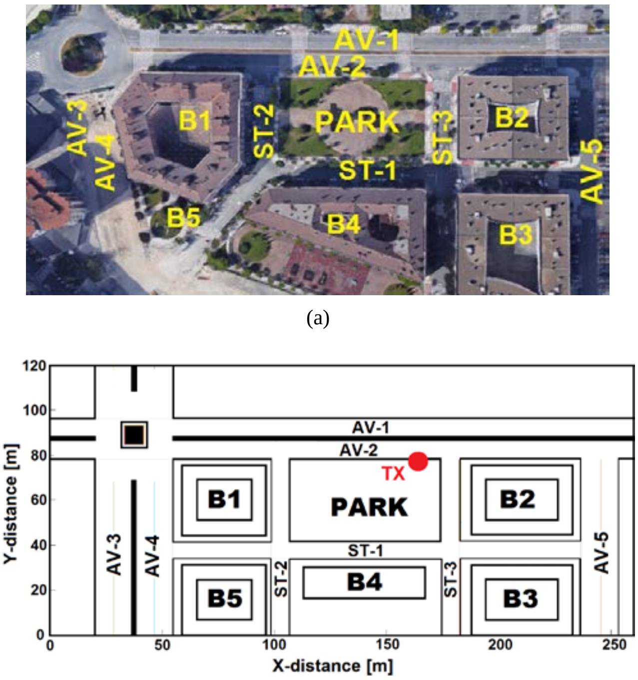
II. RAY LAUNCHING (RL) TECHNIQUE

A deterministic method based on an in-house developed 3-D Ray Launching (RL) code has been used to analyze the radio electric behavior of the considered scenario. The 3D RL algorithm is based on Geometrical Optics (GO) and Geometrical Theory of Diffraction (GTD). The main principle of the RL techniques is to identify a single point on the wave front of the radiated wave with a ray that propagates in the space following a combination of optic and electromagnetic theories. Each ray propagates in the space as a single optic ray. When the rays impact with an obstacle in its path, a reflected and a transmitted ray are created with new angles provided by Snell's law.

The RL algorithm is performed three-dimensionally, with angular resolution (horizontal and vertical planes) in a predefined solid angle that considers the radiation diagram of the transceivers sources. Spatial resolution is also defined by a uniform hexahedral mesh. Parameters such as frequency of operation, radiation patterns of the antennas, number of multipath reflections, separation angle between rays, and cuboid dimension can be taken into account. Besides, all the material properties for all the elements within the scenario can also be considered, given the dielectric constant and the loss tangent at the frequency range of operation of the system under analysis. When a ray impacts with an obstacle, reflection, refraction and diffraction will occur, depending on the geometry and the electric properties of the object.

III. SCENARIO REPRESENTATION

Fig. 1 shows the selected urban scenario where (a) correspond to its google-maps[1] aerial view and, (b) is an approximate 2D schematic representation. An exact representation of this particular scenario was not possible due to graphics limitations of the 3D-RL simulator, nonetheless, some spatial considerations and scenario segmentation were used to minimize the resulting errors for the propagation analysis. The Received Signal Threshold (RST) was chosen according as reported for commercial V2X radio-communication products [16]. The TX antenna is represented with a red circle.



(a)

(b)

Fig. 1. Represented urban scenario: (a) google-maps aerial-view, (b) 2D approximate schematic view.

The simulated area encompasses 624.000 m^3 and includes elements as vegetation, buildings, park-benches, lampposts, cars, pedestrians, avenues, streets and sidewalks. Simulation 3D-RL parameters are registered in Table I.

TABLE I
3D SIMULATION PARAMETERS

TX: Power transmitted /Gain /Frequencies Polarization /Height	0dBm / 0dB / 868Mhz, 2.4 GHz, 5.9 GHz Omnidirectional / 3.5 m
RX: RST*/Gain /Frequencies Polarization /Height	-100 dBm / 0 dB / 868Mhz, 2.4 GHz, 5.9 GHz Omnidirectional / 1.5m
3D-RL: angular resolution / permitted reflections / cuboid segmentation	π/180 rad / 7 hops / 1m^3 (1 × 1 × 1) m
Urban scenario dimension	(260 ×120 × 20) m

IV. RESULTS

A. Large-Scale Path Loss

This large-scale spatial path loss subsection presents the Received Signal Strength (RSS) spatial representation as function of the Euclidean distance. The left (x-axis) distances from TX were prefixed with negative sign while right distances remain positive. The Line-of-Sight (LoS) regions had been identified. The RSS data generated by the 3D-RL simulator was fitted using Least Square (LS), which is robust to minimize the outliers effect, and could be used for comparison purposes with theoretical path loss models (PLM).

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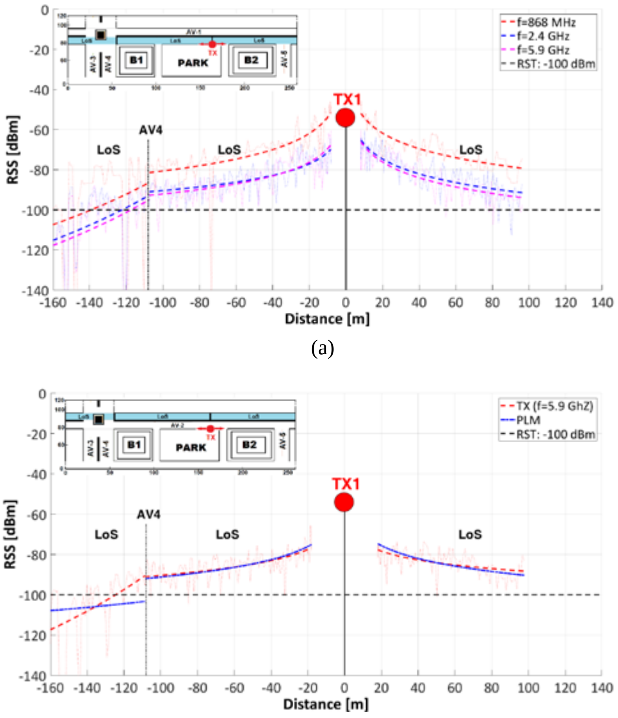
[1] http://www.google.com/maps (42°47'52.72N, 1°38'21.14W)



(a)

(b)

Fig. 2. Spatial Path Loss along: (a) AV-2, (b) AV-1

Fig. 2(a) depicts the path loss along AV-2 (light-blue colored in the upper leftmost picture) for 868 MHz, 2.4 GHz and 5.9 GHz frequencies and, Fig. 2(b) illustrates the path loss along AV-1 (light-blue colored in the upper leftmost picture) for 5.9 GHz and its comparison with a theoretical path loss model presented in [17].

Fig. 2(a) shows higher RSS values at 868MHz, while the higher multipath effects (data variability and dispersion) are related with 5.9 GHz. Fig. 2(b) presents good agreement between the 3D-RL and the theoretical PLM which can be explained for the LoS conditions, nonetheless, the roundabout which can be considered a special type of street intersection, causes marked decay and data variability in the RSS and this behavior cannot be accurately represented or predicted by the PLM. The Path Loss Exponent (PLE) was reported already 3.0 with Standard Deviation (STD) of 20.0 dB. Impairment factors as the roundabout may deteriorate the power signal irrespective of the TX-RX distance [18] and the V2I communication is significantly degraded or below the RST.

B. *Received Power*

Fig. 3 displays a surf plot of the RSS for 2.4 GHz. The buildings and roundabout cause significant RSS decay and data dispersion which is magnified at farthest distances.

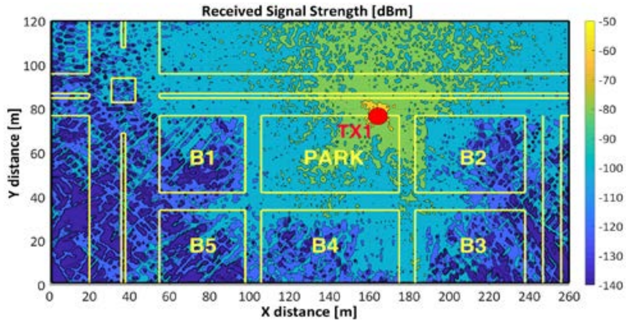
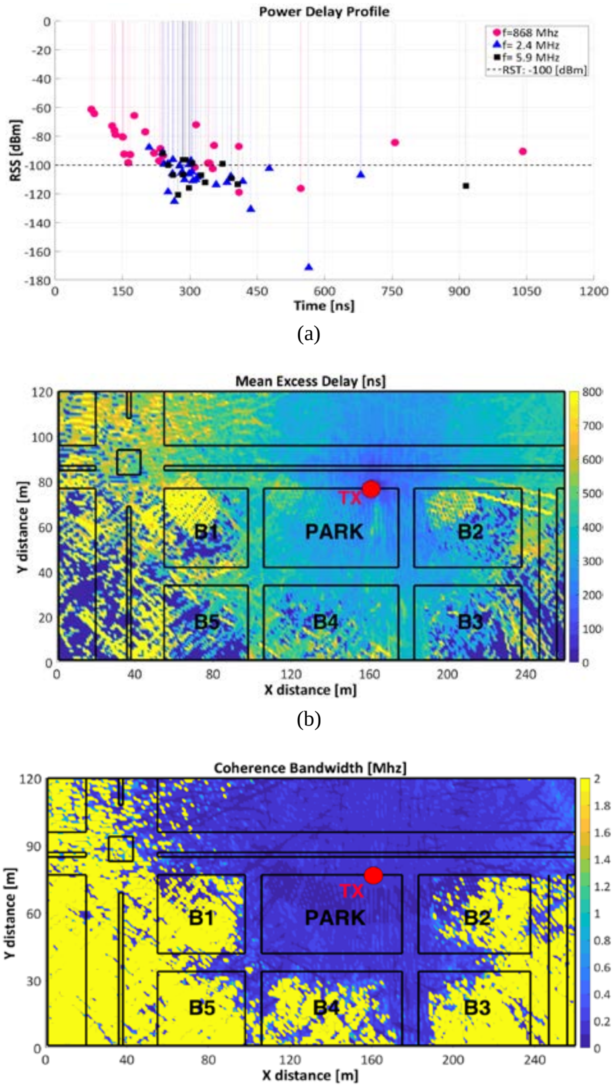


Fig. 3. Received Signal Strength (2.4GHz)

The waveguide effect is present in some areas of ST-1, ST-2 and ST-3 where TX rays impact upon the lining walls of the buildings; factors as the width and length of the streets and the incidence angle of the transmitted rays, define the magnitude of the waveguide effect. The NLoS caused by buildings generate high path loss and severe fluctuations in the RSS at AV-3, AV-4 and AV-5.



(a)

(b)

(c)

Fig. 4. Multipath metrics: (a) PDP, (b) Mean Excess Delay (2.4 GHz), (c) CB (2.4 GHz).

C. *Multipath metrics*

The analysis of multipath metrics must be understood and determined to develop a proper scheme for wireless communications. The Power Delay Profile (PDP) quantifies the number and severity of power rays, the Mean Excess Delay quantify the time dispersive properties of multipath channels and, the Coherence Bandwidth (CB) is the range of frequencies over which two frequency components have a strong potential for amplitude correlation [17].

Fig. 4 depicts some multipath metrics where: (a) is the PDP for 868 MHz, 2.4 GHz and 5.9 GHz, (b) is the mean Excess delay (2.4 GHz) and (c) is the CB (2.4 GHz, and frequency correlation of 0.9). The PDP shows a large number of power rays in a time span of 0 to 1050ns with higher RSS values for 868 MHz; the multipath effects are more severe for 5.9 GHz. The Mean Excess Delay is increased in the extent of the amplitudes of the reflected signals relative to the direct path TX-RX become larger. Low CB values are an indicator of high channel occupancy and its analysis must be complementary with the large-scale path loss (subsection A) and received power (subsection B). This metrics help to understand the high dispersive nature of this urban environment. Based on the aforementioned results, at least 4 TX are suggested to provide complete scenario coverage: two for the park area (opposite configuration), one for the roundabout area and one for the AV-5.

V. CONCLUSIONS

A deterministic 3D-RL tool was used to estimate some V2I large-scale and small-scale propagation parameters for different frequencies in an urban scenario, opening a path for the analysis of issues as channel models, packet error performance, scalability, heterogeneous network operation, etc. The Path Loss analysis show good agreement with a PLM, however, the 3D-RL results are more accurate, mainly in areas as roundabouts where the RSS values undergo significant decay and PLE and STD values experiment sensitive increment, irrespective of the distance. Multipath effects are more severe for high frequencies. High CB values are related with channel availability for other frequency links, useful for the analysis of cognitive radio applications. Factors as geometry and relative position of the obstacles, placement of the TX and frequency link, have significant impact in the V2I communication. These results are oriented to be useful in the early stages of the radio-planning phase of WSNs for urban V2I deployments.

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