Connectivity Improvement in Urban Intersections Obstructed by Buildings using RSUs

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Abstract

Vehicular collision avoidance systems can improve road safety by means of periodic exchange of status information between neighbouring vehicles. At urban intersections, the effect of shadowing caused by buildings has a severe impact on the communication links, leading to a connectivity performance degradation due to attenuation of the radio signal. A solution to the shadowing problem is to use vehicles or dedicated Road-Side Units (RSUs) as relay nodes, in urban intersections obstructed by buildings. In this paper, we analyze how an RSU improves connectivity in scenarios where vehicles are approaching over perpendicular roads on an intersection with obstructing buildings. We evaluate the connectivity provided by the system in terms of the notification position, number of beacons received, and link life time. The simulation results show that using an RSU in this scenario significantly improves connectivity, hence, providing better conditions for the operation of road safety-oriented applications.

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1 Introduction

Modern vehicles are equipped with detection technologies like ultrasonic sensors used for parking assistance systems, video cameras employed to monitor the lane or detect pedestrians, and radars used to detect and measure the distance from a vehicle to nearby obstacles [Cai+14]. However, the proper performance of these detection technologies can be affected by natural factors such as snow, rain, and non-line of sight, which are very common in vehicular environments. Fortunately, these problems can be overcome with vehicle-to-vehicle (V2V) communication.

V2V communication offers a platform for the deployment of cooperative road safety and traffic efficiency applications. The goal of safety applications is to alert drivers about potentially hazardous situations with sufficient time to take proper actions. Road safety can be increased by means of periodic exchange of status messages, called "beacons" [ETS14], which contain data such as the position, speed, acceleration, and direction of transmitting vehicle, among others. With the information provided by the beacons, the vehicles create a map of their surroundings, which is used by safety applications for a variety of purposes.

Drivers are vulnerable to traffic in intersections. Without a clear map of the vehicles located in the nearby area, they may be not aware of the danger coming from vehicles driving in the perpendicular direction, resulting in a high possibility of car crashes [GCG17]. In this urban scenarios, the line of sight between vehicles is often affected by obstacles such as buildings, and parked or moving vehicles [SED14]. At the moment when the vehicles have communication or line of sight between them, it might be very late because due to the speed of the vehicle, the safety distance could be surpassed and an accident could take place. At intersections, the effect of shadowing caused by buildings affects drastically the communication range of vehicles. This issue impacts negatively on the capacity of road safety systems to detect neighbours that approach to the intersection [MKH11]. In [SED14], the authors examined the use of parked vehicles as relay nodes for improving cooperative awareness and road traffic safety in urban and suburban environments. The authors showed the use of parked vehicles as relay nodes to be effective and to improve the cooperative awareness among all nearby nodes if the node density is high. This, however, requires both a high traffic density and a high percentage of equipped vehicles (i.e., substantial market penetration of DSRC devices). A possible solution to the low percentage of DSRC-equipped vehicles, as well as the shadowing problem at the intersection, is to use dedicated Road-Side Units (RSUs) as relay nodes. Placing an RSU at a strategic position can strengthen the connectivity between vehicles traveling on perpendicular roads of an obstructed intersection (see Figure 1). In this work, we analyze how an RSU can improve connectivity at urban intersections blocked by a building. We use a realistic simulation framework to evaluate the connectivity provided by the system in terms of the following performance metrics: notification position, number of beacons received, and link life time. We focus on the worst case scenario, which considers that a building totally obstructs the communication link between vehicles. Further, we study the impact of using different values of the path loss exponent for direct line of connectivity. We aim at demonstrating that, by improving connectivity, we also improve the operation conditions of road-safety applications, hence, providing an increase in road safety for the participant vehicles.

2 Experimentation

We conducted the experiments using the Veins framework [SGD11], which bidirectionally couples the OMNeT++ network simulator and the SUMO road traffic simulator. We have employed as test scenario an urban intersection located on the following streets: Beauchef with Blanco Encalada, in Santiago, Chile.

This intersection is obstructed by a building, which can be noted inspecting Fig. 2. The scenario seen from Google Earth and SUMO traffic simulator is illustrated in Fig. 2a and Fig. 2b, respectively. At this intersection, we have designed two experiments. In the first one, two vehicles are moving on perpendicular roads blocked by a building, as shown in Fig. 2c. In the second one, we placed an RSU on the intersection to retransmit the beacons received from Node 1, as shown in Fig. 2d. In these experiments

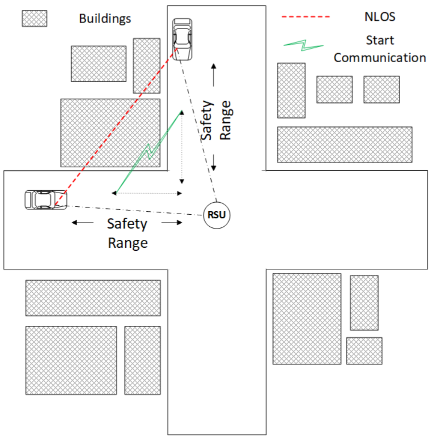


Figure 1: Utilization of RSU as relay nodes can increase cooperative awareness in vehicular security applications. Building blocks safety messages and reduce the safety range between vehicles.

only Node 1 regularly broadcast beacons. The idea is to evaluate the capacity of Node 1 to notify its presence to Node 0 without and with an RSU. Both vehicles and RSU employ the IEEE 802.11p EDCA model [ES12] of the Veins framework to represent the MAC/PHY layer. This is an open source implementation, which fully captures the distinctive properties of IEEE 802.11p radio access technology. Node 1 broadcast beacons to the communication channel using a rate of 10 beacon/s. The radio signal propagation is simulated using the Simple-Obstacle Shadowing model [Som+11]. With the Simple-Obstacle Shadowing model, the building obstructs the communication link between vehicles until they arrive at intersection.

Table 1: Simulation Parameters

Parameter	Value
CCH center frequency	5.890 GHz
Channel bandwidth	10 MHz
Transmission power	20 dBm
Beacon rate	10 beacon/s
Beacon size	250 bytes
CW	(3, 7)
AIFSN	2
Path Loss Exponent	$(2.8, 3.0, 3.5)$
Receiver sensitivity	- 90 dBm
Thermal noise	- 110 dBm
Data rate	6 Mbps
Antenna type	Omnidirectional

The path loss exponent values $\alpha = \{2.8, 3.0, 3.5\}$ were selected according to [Fer+14]. The communications are established on control channel (CCH) without considering the effect caused by multi-channel operation. The beacons' size is 250 bytes and are transmitted with a priority corresponding to voice access category (AC_VO). Each vehicle is 5 m long, 2 m wide, and has maximum acceleration of 0.8 m/s^2, maximum

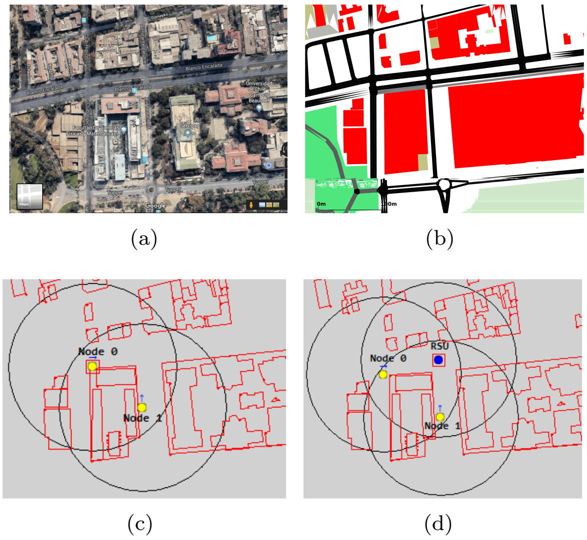


Figure 2: Evaluation scenario seen from: a) Google Earth, b) SUMO, c) OMNeT++ without RSU, d) OMNeT++ with RSU.

deceleration of 4.5 m/s^2, and maximum speed of 50 km/h. The antenna height of vehicles is 1.5 m, whereas the height of the dedicate RSU is 2.2 m. Table 1 includes the additional simulation parameters.

3 Simulation Results

In order to evaluate the connectivity provided by the system without and with RSU, we computed in Node 0 the following metrics:

- Number of Beacons Received (NBR): The NBR is directly related with the knowledge collected by the vehicle when approaching to the intersection.
- Beacon reception time (BRT): The BRT register the times at which beacons are received for the duration of the link.
- Link Life Time (LLT): The LLT related with BRT; it and corresponds to the time duration for a link between two vehicles.

Negative values of the notification position mean that the vehicle has not arrived at the intersection, whereas zero means that the node is at the intersection, and positive values mean that the vehicle passed the intersection.

Figure 3 shows the potential benefits of using an RSU on obstructed intersection in terms of NBR by Node 0. Without an RSU, the building blocks direct transmissions between vehicles, reducing drastically their communication range. In this situation, the connectivity is only possible when the vehicles are very close from intersection. In fact, the Node 0 is aware of the presence of Node 1 when it is located at 15.61 m from the crossing point. This notification position may not be sufficient to react to potentially dangerous situations. Note that the path loss exponent does not have an impact in this case. However, the notification position increases significantly with the presence of an RSU. Fig. 3a shows that Node 0 receives the first beacon from Node 1 when it is located at 155.43 m from the crossing point for $\alpha = 2.8$. Moreover, with a poor reception (i.e., α=3.5) the notification position is still twice in comparison to the situation without the RSU, as shown in Fig. 3c.

Figure 4 shows the BRT computed by Node 0, which implicitly includes the LLT of the vehicles while approaching the obstructed intersection. The RSU significantly increases LLT and reduces the distance between the point the first beacon was received respect to the intersection, especially for lower path loss exponents. Fig. 4a shows an increase in LLT of 17 s when the RSU is used as a relay node for $\alpha = 2.8$. With the most aggressive path loss exponent $\alpha = 3.5$, the RSU still provides a gain of 5 s in LLT, and the first notification is realized 3 s in advance. This time of anticipation is vital for the performance of vehicle collision avoidance systems, which need to alert drivers with sufficient time and distance to take proper actions. Table 2 shows a summary of the metrics studied for the different path loss exponents.

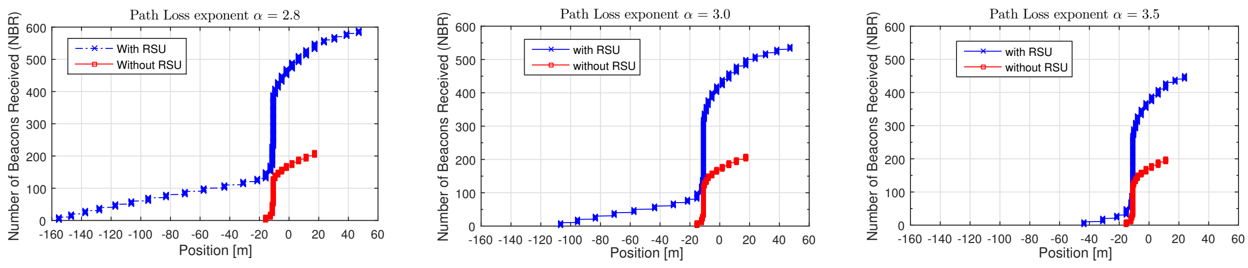
Table 2: Vehicles' Connectivity Metrics

Obstructed Urban Intersection						
	Without RSU			**With RSU**		
Metrics	$\alpha = 2.8$	3.0	3.5	$\boldsymbol{\alpha = 2.8}$	**3.0**	**3.5**
NBR	210	210	200	**590**	**540**	**450**
LLT [s]	20.9	20.9	19.9	**37.9**	**32.9**	**24.9**
Notification Position [m]	-15.61	-15.61	-15.61	**-155.43**	**-100.64**	**-43.91**

4 Future Work

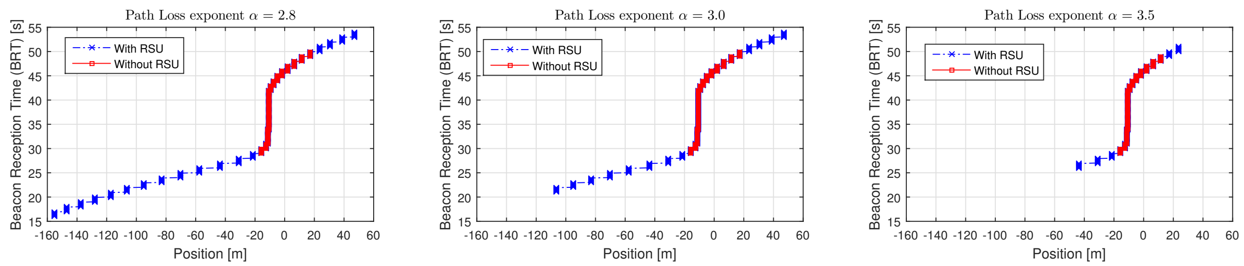
As future work, we will aim to present a specific relay strategy scheme. Intelligent algorithms need to be applied in these solutions to control the moment that the RSU should participate as a relay node or stay silent for safety applications at intersection. Define an efficient procolo to enable the relays in the obstruction zones, is not only permitted improvement the use and channel load but to the the benefits of improving communication distance and link life time for the security applications and so these parameters of the offered reaction extends to the drivers or the vehicles directly.

We plan to evaluate the performance of the radio signal propagation in obstructed intersections with a high density of vehicles. Experimental validation in real conditions will be carried out by installing OBUs in vehicles. The experimental results will be compared with data obtained by simulations.



(a) (b) (c)

Figure 3: Number of beacons received (NBR) by Node 0 as a function of position from the intersection for different path loss exponents: a) $\alpha = 2.8$, b) $\alpha = 3.0$, c) $\alpha = 3.5$.



(a) (b) (c)

Figure 4: Beacon reception time (BRT) computed by Node 0 as a function of position from intersection for different path loss exponents: a) $\alpha = 2.8$, b) $\alpha = 3.0$, c) $\alpha = 3.5$.

Acknowledgements

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