Attenuation Caused by Obstructing Vehicles in VANETs

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Abstract

The connectivity among vehicles is affected by obstructions either static (e.g., buildings, vegetation, hills) or mobile (other vehicles on the road). The low height of antennas onboard the vehicles implies that the optical line of sight (LOS) can be obstructed by the obstructions, in particular by the mobile obstructions causing disconnection among vehicles even within the single hop transmission range. In this work, the channel modeling for vehicular communication scenario is investigated in detail. Multiple knife-edge diffraction is proposed to account for attenuation caused by vehicle along the propagation path. The vehicular communication scenario is simulated in the ns-3 network simulator with four categories of vehicles and the attenuation loss is calculated. The simulation results confirm that vehicles as obstructions can be a major source of signal attenuation and a single vehicle can cause attenuation up to 20 dB in the road scenario.

Keywords: Signal attenuation, received signal strength, Line-of-sight communication, Multiple-knife edge diffraction, Channel modeling.

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INTRODUCTION

While investigating the reliability of message broadcast, the phenomenon of transmission holes in the broadcast range has been recently considered as a potential cause of message loss in VANETs. In (Tonguz et al. 2007, Boban et al. 2011). conduct extensive experiments to prove the presence of reception holes in the transmission range. The authors report mobile obstacles (i.e., vehicles), primarily in the LOS, as a major cause of loss in the signal strength, resulting in some portions of the broadcast region being completely uncovered. The studies show that a single obstacle can cause an RSS drop of over 20 dB when two cars communicate at a distance of 10 m; while in NLOS conditions the chances of a successful communication become 90% (Ros et al. 2012, Santos et al. 2004).

Coverage of nodes located in the transmission holes is a challenging problem in any wireless scenario. The nodes located in the transmission holes are completely oblivious of the activity in the wireless channel. Consequently, the detection of a packet loss becomes challenging considering the limitation of the use of a feedback mechanism in a broadcast scenario. The proposed attenuation and detection model employs constant observation of the immediate neighborhood by each vehicle. RSS is estimated using the angle between the given receiver (immediate neighbor) and the sender (verifier node is aware of the original sender node and its respective location). Any node in the direct LOS path between sender and receiver is counted as obstacle with its impact on the signal loss depending on the its vehicle type (Tonguz et al. 2007, Boban et al. 2011). Loss caused by road surroundings and road geometry can also be included for additional accuracy in RSS estimation (e.g., the propositions of (Laouiti et al. 2009, Otto et al. 2009).

The proposed received-signal-strength estimation technique uses a topological map of the one-hop neighborhood. Each vehicle along the LOS path between the sender and the receiver is counted as a source of signal attenuation. The accumulated signal attenuation is the sum of attenuation caused by each vehicle along the LOS path. Multiple knife-edge diffraction model is used to account for the loss with each obstructing vehicle counted as a source of diffraction. The simulation results show that the attenuation strictly depends on the angle of the obstacle with the sender and the receiver nodes. A single vehicle as obstacle can cause a received signal strength drop between 2 to 20dB.

ATTENUATION CAUSED BY VEHICLES

Determining the vehicles obstructing the line of sight

Each vehicle maintains the geographical topology of the one-hop neighborhood. The topology is maintained in the form of rectangles representing vehicles on a plane in R^2. The length and width of a vehicle is exchanged in the beacon messages, along with the height of a vehicle. The height of a vehicle will be considered while computing the signal loss using knife-edge diffraction. A vehicle causing obstruction in the line of sight between the sender and the receiver is determined by testing if an intersection exists between the line segment (joining the sender and the receiver) and the rectangle representing the vehicle in the path.

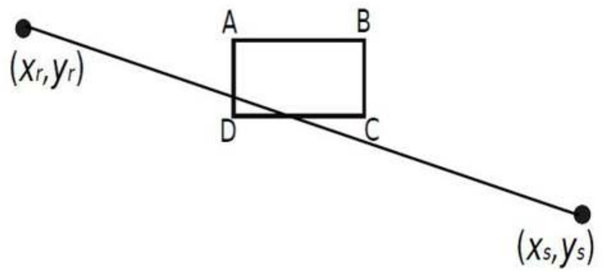

Figure 1: Determining the intersection between a line segment and a rectangle.

Let be the line segment representing the line of sight between the sender and the receiver, and ABC D be the rectangle representing the vehicle in the propagation path. If the endpoints of the line segment are (x_s, y_s) and (x_r, y_r), then a point (x, y) is on the same straight line if

$u.x + v.y + w = 0$ with $u = y_r - y_s$, $v = x_s - x_r$, and $w = x_s y_r - x_r y_s$. The two half planes defined by the line are $u.x + v.y + w > 0$ and $u.x + v.y + w < 0$.

Additionally, it is also ensured that the vehicle (rectangle) lies within the segment of the line between the sender and the receiver, and not at a point on the line beyond the sender or the receiver. To ensure this condition, the and ABC D intersection verification is performed after the following conditions holds true: ($x_{ob} > x_r$ and $x_{ob} < x_s$) or ($x_{ob} < x_r$ and $x_{ob} > x_s$) or ($y_{ob} > y_r$ and $y_{ob} < y_s$) or ($y_{ob} < y_r$ and $y_{ob} > y_s$), where (x_{ob}, y_{ob}) is the location of the obstacle.

Thus, if u.v + v.y + w > 0, ABC D; or if u.v + v.y + w < 0, ABC D, there exists no intersection between the line segment and the rectangle ABCD. Therefore, the given vehicle does not obstruct the line-of-sight path between the sender node and the receiver node. The given vehicle is considered as an obstruction otherwise.

Estimating the Attenuation Caused by Vehicles

After determining that a given vehicle lies in the line of sight between the send and the receiver, the impact of the vehicle on the signal loss is estimated. The attenuation in the radio link increases as vehicles obstruct 60% of the first Fresnel zone between the sender and the receiver. The attenuation is due to the diffraction that depends on the obstruction level, the carrier frequency, the shape of the obstruction, and the amount of the obstruction in the path between the sender and the receiver. We use the multiple knife-edge diffraction model to estimate the effect of vehicles as obstructions. The prerequisite for the applicability of the knife-edge diffraction model is that the wavelength should be significantly smaller than the size of the obstacle. Therefore, the application of the model in the VANET scenario is reasonable because the DSRC frequency of 5.9 GHz has a wavelength of approximately 5 cm, which is significantly smaller than the size of a vehicle.

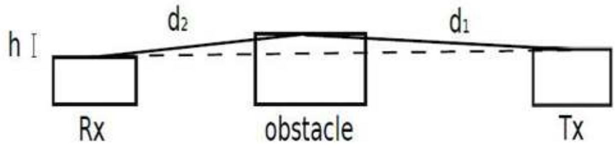

Figure 2: Single knife-edge diffraction between vehicles

The attenuation is estimated using the knife-edge diffraction model described in the ITU-R recom- mendation (Piorkowski et al. 2012). The scenario is depicted in Figure 2. The obstacle is viewed perpendicular to the radio link between the sender and the receiver vehicles. The approximation of the attenuation (in dB) caused by a single knife-edge obstacle L can be obtained using the following equation:

$$L = \begin{cases} 6.9 + 20log[\sqrt{(v-0.1)^2+1} + v - 0.1], & v > -0.78 \\ 0, & otherwise, \end{cases} \quad (1)$$

where

$$v = h\sqrt{\frac{2}{\lambda}\left[\frac{1}{d_1} + \frac{1}{d_2}\right]}. \quad (2)$$

The extension of the single knife-edge diffraction model to multiple edge obstacles is not immedi- ate. We follow the ITU-R method, where correction factors are added to the attenuation to improve the approximation. The method consists of applying single knife-edge diffraction successively to multiple obstacles, with the top of the preceding obstacle acting as a source of diffraction for the following obstacle. The case of multiple obstructions in the line of sight is depicted in Figure 3. The total attenuation caused by multiple vehicles, following the multiple knife-edge diffraction model, is given by

$$L_t = \sum_{i=1}^{N} L_i + 20\,log\,C_N, \quad (3)$$

where L_i is the diffraction loss over the ith vehicle, assuming the source to be at the edge of the $(i-1)$th vehicle. The function C_N is a correction factor dependent on the parameters shown in Figure 3. The correction factor is given by

$$C_N = \sqrt{\frac{P_a}{P_b}}, \quad (4)$$

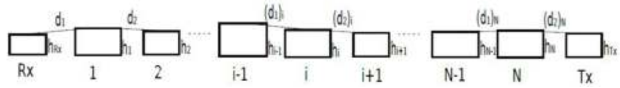

Figure 3: Multiple knife-edge diffraction between vehicles

where

$$P_a = d_1 \prod_{i=1}^{N} [(d_2)_i] \left(d_1 + \sum_{j=1}^{N} [(d_2)_j] \right), \quad (5)$$

$$P_b = (d_1)_1 (d_2)_N \prod_{i=1}^{N} [(d_1)_i (d_2)_i]. \quad (6)$$

Using the correction factor, the total attenuation caused by the vehicles in the line of sight path is calculated from Equation 43. The attenuation L_t, along with the free-space propagation loss, gives the total path loss between the sender vehicle to the receiver vehicle. The estimated received signal strength becomes

$$RSS = P_{Tx} + G_{Tx} - L_{ld} - L_t + G_{Rx}, \quad (7)$$

where P_{Tx} is the transmitted output power of the transmitter, G_{Tx} is the transmitter antenna gain, L_{ls} is the log-distance path loss, L_t is the diffraction loss in the propagation path, and G_{Rx} is the receiver antenna gain. The vehicle is considered to be located in a coverage hole when the sensitivity threshold is $RSS < -98\,dBm$ (U. technology. 2012).

Simulation analysis

Simulation Setup: To analyze the performance of the proposed RSS estimation technique, the algorithm is fully implemented along with the UMB scheme and the SB scheme in the ns-3 simulator (The ns-3 2011). The traffic mobility is generated using the VanetMobiSim tool (Haerri et al. 2006). The common simulation parameters are summarized in Table I. The ns-3 simulator lacks the multi-knife diffrac- tion model, and as part of this work, we have implemented a generic multi-knife edge diffraction for ns-3. The code is in the process of review for submission to the upcoming version 3.16

of the ns-3 simulator. The simulation implements the three dimensional propagation scenario in detail. Each vehicle is considered with its three dimensions information of height, width, and length. Four different vehicle categories are used with vehicle dimensions as described in Table II. The simulation uses a four-kilometers of road-length with unidirectional roads in two lanes. Six different vehicle densities are tested with densities from five to 30 nodes per 300 meters length of the road (i.e., the one-hop distance). Vehicles are assigned Gaussian-random speed with a mean of 50 miles per hour and a standard deviation of three miles per hour. The minimum safe headway between the vehicles is kept as 1.5 seconds. Log-distance path-loss model is used with path loss exponent equal to 3 (Blaszczyszyn et al. 2009). The physical channel is characterized in detail using the multi-knife diffraction loss model. The propagation is followed along the entire path between the sender and the receiver. The effect of each vehicle as obstacle along the path is considered. Each vehicle along the path is first evaluated using the obstruction detection technique described the attenuation caused by the vehicle is estimated using the knife-edge diffraction model.

Table I
SIMULATION PARAMETERS FOR NSN-H EVALUATION.

Description	Value
Transmission range	300 meters
Data rate	3 Mbps
Message payload size	100 Bytes
Protocol overhead	14 bytes
MAC header size	34 bytes
PHY header size	26 bytes
RTB, CTB, ACK, NACK	20, 14, 12, 10 bytes
Time slot, DIFS, SIFS	20, 50,10 μs
Road length	4 km (2 lanes, unidirectional)
Vehicle density	2-30 vehicles/300 meters
Vehicle speed	50 miles/h (mean)
Message generation rate	0.01-1 message per vehicle/second
Path loss model	Log-distance path loss model
Diffraction model	Multiple knife-edge diffraction model
Simulation time	100 seconds (each run)

Table II
DIMENSIONS OF VEHICLES.

Vehicle	Dimensions (meters)		
	Height	Width	Length
Lincoln LS	1.453	1.59	4.925
Pontiac Vibe	1.547	1.763	4.371
Ford E-250	2.085	2.029	5.04
General trailer truck	4.25	2.5	20

RESULTS AND DISCUSSION

In Figure 4, the proportion of vehicles with the LOS and NLOS communication is depicted for one-hop neighborhood. The figure shows the average number of vehicles in the line of sight or non-line of sight to the sender with varying distance from the sender. The result depicted in the figure represents the average based on evaluation over varying vehicle density between five nodes and 30 nodes per 300-meter distance of the road. In the figure, it is noticed that the ratio of vehicles with unobstructed and obstructed line of sight increases with increasing distance between the sender and the receivers. At a distance of 50 meters, most of the vehicles are in line of sight with the transmitter, and the propagation loss is only affected by the attenuation in the free-space. However, at a distance of 100 meters and beyond, the majority of the receivers are in non-line of sight with the transmitter, which can incur excessive diffraction loss due to vehicles along the path. Therefore, characterizing the physical channel of the vehicular scenario by considering the free-space and the road surrounding objects as the only parameters affecting the propagation can result in inaccurate coverage estimation. Moreover, the non-line of sight path for majority of receivers at farther distances has high likelihood of coverage holes, where a given vehicle fails to receive the safety message.

To further quantify the existence of vehicles as obstacles in the propagation path, the average number of obstacles is depicted against the distance from the transmitter in Figure 5. The average number of obstacles along the propagation path are shown for three different node densities. In the figure, the propagation path is mostly a direct LOS at a distance close to the transmitter. However, with increasing distance, in addition to the path being mostly obstructed by the surrounding vehicles, the number of obstructing vehicles also increases. Similarly, increasing the density of traffic has a direct affect on the number of obstructing vehicles. Therefore, at a distance of beyond 200 meters from the transmitter and at a density of 30 nodes per 300 meters, the average number of vehicles acting as obstacles in the propagation path for a given receiver is over eight vehicles. Considering the potential attenuation caused by an obstructing vehicle (depending on the type of the vehicle), there is a high likelihood that a given receiver does not receive the safety message due to excessive attenuation along the path. It is also noted that the effect may be dominant at a farther distance from the transmitter, however, coverage at a closer distance of 100 meters can potentially be effected by excessive attenuation due to vehicles as obstacles. At a close of distance of 100 meters, even though the number of vehicles as obstacles can be four or less, however, larger obstructing vehicles (e.g., a trailer truck) can result in acute attenuation of up to 18 dB per vehicle. Thus, vehicles located at a closer distance to the transmitter are also susceptible to being located in the coverage holes.

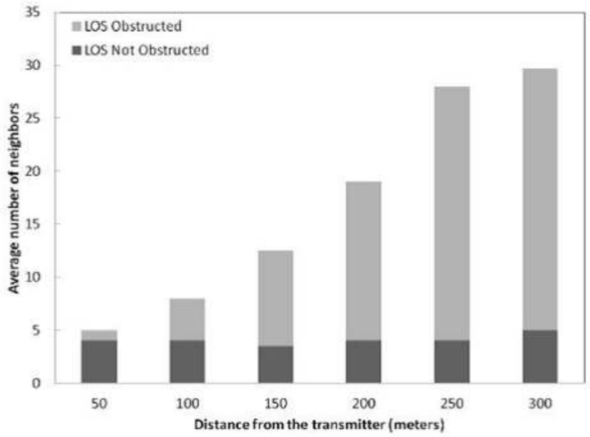

Figure 4: Average number of neighbors with obstructed and unobstructed line of sight.

In Figure 6, a thorough comparison is presented for the signal reception in the line of sight and non-line of sight path. In the figure, line of sight represents the case where the vehicles are not considered to be causing obstruction and attenuation, while the obstructed case accounts for the average received signal strength (RSS) where the attenuation caused by each vehicle along the propagation path is considered. Since the number of obstacles in the close vicinity of the transmitter are near negligible, the average RSS is almost equal for the two cases in the close vicinity of the transmitter. However, the attenuation due to obstacles is pronounced over farther distances and the difference in the measured signal for the two paths increases with distance. Note that the figure also illustrates the minimum measured RSS for the obstructed path that clearly confirms the notion of holes being present all across the one-hop neighborhood. In other words, even at close distances, there are instances where the attenuation caused by vehicles is strong enough to prevent coverage of a particular location in the path. The reason for such an effect, as stated previously, is the type of vehicles obstructing the path. For example, a combination of a trailer truck and smaller vehicles can cause high attenuation even with a few number of vehicles as obstacles in the propagation path. The existence of holes in the broadcast range results in some vehicles being oblivious of a safety message broadcast, and not performing the necessary safety maneuver. Therefore, it becomes indispensable to cover nodes being located in the coverage holes to ensure the critical VANET requisite of reliability of the delivery of the safety message.

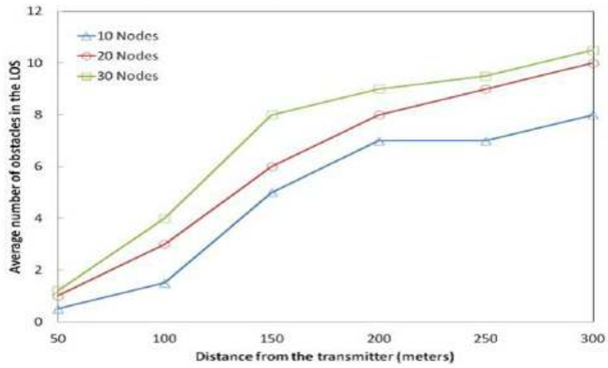

Figure 5: Average number of vehicles as obstacles in the line of sight.

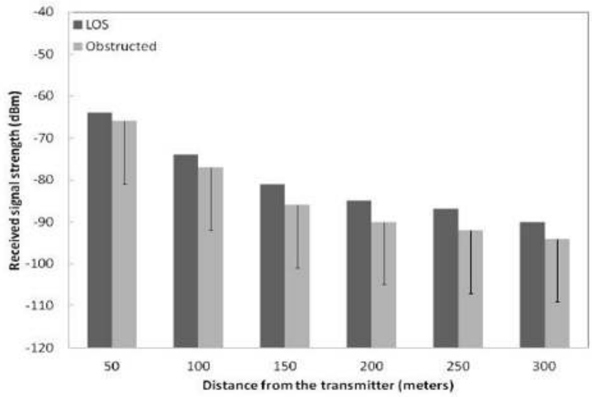

Figure 6: Average received signal strength for the obstructed and unobstructed line of sight.

CONCLUSION

In this work, the attenuation caused by vehicles is investigated in vehicular communication sce- nario. Received signal strength estimation is proposed that uses multiple-knife edge diffraction to calculate the loss caused by each vehicle along the propagation path. The vehicular communication scenario is thoroughly simulated in the ns-3 network simulator with four categories of vehicular traffic. Three dimensional ray-tracing technique has been used to detect vehicles as obstacles along the path. The investigation reveals that a single vehicle can cause an RSS drop of about 2 to 20dB depending upon the dimensions of the vehicle and the angle of the obstacle with respect to the sender and receiver. Further investigation may be conducted to account for the loss caused by surrounding vegetation and structures along the propagation path.

REFERENCES

- Blaszczyszyn, Muhlethaler P and Toor T. (2009). “Performance of mac protocols in linear vanets under different attenuation and fading conditions,” in 12th International IEEE Conference on Intelligent Transportation Systems, pp. 1 –6.
- Boban M, Vinhoza T, Ferreira M,Barros J, and Tonguz O. (2011). “Impact of vehicles as obstacles in vehicular ad hoc networks,” IEEE Journal on Selected Areas in Communications. 29:15 –28.
- Fethi HF and Bonnet. (2006). “VanetMobiSim: generating realistic mobility patterns for VANETs.” http://vanet.eurecom.fr/.
- Lugo PR, Grossglauser P and Hubaux. (2012). “Propagation by diffraction).” Recommendation ITU-R P. 526-12.
- Muhlethaler LP and Toor Y. (2009). “Reliable opportunistic broadcast in vanets (r-ob-van),” in 9th International Conference on Intelligent Transport Systems Telecommunications,(ITST), pp. 382 –387.
- Otto J, Bustamante F and Berry R. (2009). “Down the block and around the corner the impact of radio propagation on inter-vehicle wireless communication,” in 29th IEEE International Conference on Distributed Computing Systems, pp. 605 –614.
- Ros FJ, Ruiz PM and Stojmenovic I. (2012). “Acknowledgment-based broadcast protocol for reliable and efficient data dissemination in vehicular ad hoc networks,” IEEE Transactions on Mobile Computing. 11:33 –46.
- Santos R, Edwards R, Edwards A and Belis D. (2004). “A novel cluster-based location routing algorithm for inter-vehicular communication,” in 15th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications. 2:1032 – 1036.
- Tonguz O, Wisitpongphan N, Bai F, Mudalige P and Sadekar V. (2007). “Broadcasting in vanet,” in Mobile Networking for Vehicular Environments, pp. 7 –12.
- U. technology corporation. (2012). “802.11p dsrc communication unit by unex corporation - data sheet.” OBE-102 data sheet, 2012.
- “The ns-3 network simulator (ns-3.9). (2011). ” http://www.nsnam.org/.