Impact of Vehicles as Obstacles in Vehicular Ad Hoc Networks

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Outline

1. Vehicular Communications
2. Impact of Vehicles as Obstacles
3. Results
4. Conclusions
Vehicular Ad Hoc Networks (VANET)

Network with two kind of nodes
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- Network with two kind of nodes
  - Vehicles (as expected)
Network with two kind of nodes
- Vehicles (as expected)
- Roadside Units.
Main Motivations

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- The overall cost (based on wasted fuel and lost productivity) reached USD 87.2 billion - more than USD 750 for every U.S. traveler.
- Data from Autoridade Nacional de Segurança Rodoviária: In 2007, traffic related accidents killed 854 people and injured 43202. And in 2008, there were 772 fatalities e 40745 injuries.
Vehicular Communications: Potential Applications

- Safety
- Road Work Ahead
Vehicular Communications: Potential Applications

- Safety
- Weather Conditions
Vehicular Communications: Potential Applications

- Mobility
- Traffic Information
Vehicular Communications: Potential Applications

- Mobility
  - Dynamic Route Guidance
VANET Simulation

- Provides feedback from extremely complex scenarios
- Enable insights, identify critical problems, and test solutions.
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- Realistic propagation models (e.g., ray tracing): computationally expensive
- Mobile obstacles increase the complexity even further.
- Simplified stochastic radio models (Shadowing): rely on the statistical properties of the chosen environment and do not account for the specific obstacles in the region of interest
- Do not provide satisfying accuracy for typical VANET scenarios.
Desired VANET Propagation Model

- Realistic
  - Modeling both static and dynamic obstacles
    - Static: buildings, trees, overpasses, hills, parked vehicles, ...
    - Mobile: other vehicles on the road
- As topology/location independent as possible
- Computationally manageable
  - Propagation model is only one of several simulated models in VANETs (mobility, MAC, routing, application, ...)
  - Modeling vehicles is only one part of propagation modeling
  - Has to execute within certain time, otherwise is not useful
Model for evaluating the impact of vehicles

- Impact on line of sight (LOS)
- Impact on signal propagation
- Time complexity of the model
Problem Setup

- Spatial characteristics of vehicular networks that are of interest:
  - Exact position of each vehicle and the inter-vehicle spacing
  - Vehicle dimensions (height, width, length)
  - Speed distribution of vehicles
  - To obtain these data, we used stereoscopic aerial photography
  - Data from A28 and A3 collected by FCUP group.
  - 404 vehicles on a 12 km highway strip and 55 vehicles over 7.5 km respectively.
Stereoscopic Aerial Photos
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- Widths and heights of vehicles?
  - Automotive Association of Portugal
  - 18 brands comprising 92% of vehicles
  - Both H & W normally distributed
Impact of Vehicles as Obstacles

Speed Distribution A28

Cumulative Distribution Function

Speed of vehicles on A28
Best normal fit
99% confidence bounds

- Speed of vehicles on A28
- Best normal fit
- 99% confidence bounds
Inter-vehicle spacing A28
How do we evaluate probability of LOS?

(a) Stereoscopic aerial photography

(b) Abstracted model showing possible connections

LOS not obstructed
LOS potentially obstructed

60% of First Fresnel Ellipsoid
How do we evaluate probability of LOS?

- Per-link probability of LOS → Average probability of LOS for a given vehicle → Macroscopic probability of LOS behavior.
Effect on Received Signal Power

- Obstructing vehicles are approximated as knife-edge obstacles;
- Additional attenuation due to multiple knife-edge obstacle calculation.
Computational Complexity

- The described model can be regarded as a special case of geometric intersection problem.
- Well known problem in computational geometry.
- Red-Blue intersection problem:
  - Given a set of red line segments $r$ and blue line segments $b$ in the plane, report all $K$ intersections of red with blue segments.
  - Time complexity of the algorithm: $O(N^{4/3} \log N + K)$
  - $N = r + b$
  - Additional time for multiple knife-edge: $O(K)$
  - Overall $O(N^{4/3} \log N + K)$
Results: Probability of LOS

- Macroscopic probability of LOS.
- A28: 32.3 vehicles/km, A3: 7.3 vehicles/km.

<table>
<thead>
<tr>
<th>Highway</th>
<th>Transmission Range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100</td>
</tr>
<tr>
<td>A3</td>
<td>0.8445</td>
</tr>
<tr>
<td>A28</td>
<td>0.8213</td>
</tr>
</tbody>
</table>
Results: Obstructed Neighbors

- Neighbors with unobstructed and obstructed LOS
- Half of the neighbors will not have LOS due to vehicles only at 500 m of observed range.
Stationarity of Poisson Process

- Stationarity of the generating Poisson process
- Important for characterizing the moving network (i.e., over time)
- Important for determining the refresh rate for vehicles-as-obstacles model

<table>
<thead>
<tr>
<th>Time offset</th>
<th>$\Delta P(LOS)_i$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 5%</td>
</tr>
<tr>
<td>1ms</td>
<td>100%</td>
</tr>
<tr>
<td>10ms</td>
<td>99%</td>
</tr>
<tr>
<td>100ms</td>
<td>82%</td>
</tr>
<tr>
<td>1s</td>
<td>35%</td>
</tr>
<tr>
<td>2s</td>
<td>31%</td>
</tr>
</tbody>
</table>
Results: Received Signal Power

\[ P_T = 20 \text{ dBm}, \ G_T = G_R = 1 \text{ dBi}, \ Tx \ Range = 750 \text{ m}. \]
Results: Packet Reception

Transmission Range (m)

Packet success rate

- 3Mb/s – obstacles
- 3Mb/s – free space
- 6Mb/s – obstacles
- 6Mb/s – free space
- 12Mb/s – obstacles
- 12Mb/s – free space
Results: Measurement Campaign in Pittsburgh, PA
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Impact of Obstruction

Loss of Signal due to the Obstructing Bus

RSSI (dB)

TIME (sec)

Receiver

00:00:41 sec

Receiver (behind the bus)

00:00:46 sec
Conclusions

- PHY layer effect: RSS is optimistic

- Link layer effects:
  - Overestimation of contention
  - Overestimation of network reachability

- Network layer effects:
  - Overly optimistic hop count
  - End-to-end delay incorrectly calculated

Credibility of simulation results

5 dB attenuation and 20% packet loss on average are far from negligible!

If vehicles are not accounted for, optimistic results are obtained. In reality, routing protocols will behave worse, network reachability will be reduced, delay will be incorrect.
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Thank You!

- Questions?
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