An Obstacle Model Implementation for Evaluating Radio Shadowing with *ns-3*

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Why is this research important?

- Obstacles (e.g., as buildings and trees) interfere with radio wave signal propagation by contributing fading and shadowing effects.
- Accurate simulation results require models that address the radio-interfering conditions that obstacle within real-world topologies present.
- The obstacle model for *ns-3* implements an empirically-validated, deterministic model [1] for propagation loss, suitable for VANET.
- Including realistic obstacle shadowing in simulation modeling improves performance assessment.

[1] Sommer, C., Eckhoff, D., German, R. and Dressler, F. A computationally inexpensive empirical model of IEEE 802.11 p radio shadowing in urban environments. In *Wireless On-Demand Network Systems and Services (WONS), 2011 Eighth International Conference on.* IEEE, 2011, 84-90.

Research Questions

- **RQ1**: Can fast fading and shadowing effects of obstacles, such as buildings, vehicles and trees, be modeled and efficiently simulated in *ns-3* ?
- **RQ2**: How does performance in a VANET compare between the deterministic obstacle shadowing model and other stochastic fading and shadowing models?

Main contributions

- An efficient implementation of an obstacle model based on computational geometry techniques was developed and offered to the *ns-3* network simulator community [2].
- Simulation results using obstacles compare quantitatively the effects of i) deterministic obstacle shadowing to ii) stochastic Nakagami-m fast fading and iii) no fading.

[2] https://codereview.appspot.com/201200043.

Agenda

[1] Background and Related Works

[2] Obstacle Shadowing Model

[3] Experimental Setup and Results

[4] Conclusions

[5] Future Work

Background and Related Work

Vehicular ad hoc Network (VANET)

- Goal: improve driving safety by allowing vehicles to communicate cooperatively using wireless technologies.
  - E.g., accident avoidance (safety apps), traffic congestion alert (info).
- Most-promising technologies in the U.S. are referred to as Dedicated Short Range Communications (DSRC)

<table>
<tr><td rowspan="2">Application</td><td colspan="5">Applications</td></tr>
<tr><td colspan="5">DSRC Message Set Dictionary SAE J2735</td></tr>
<tr><td>Transport</td><td rowspan="4">Management 1609.3</td><td>TCP</td><td>UDP</td><td rowspan="2">WSM 1609.3</td><td rowspan="4">Security 1609.2</td></tr>
<tr><td>Internet</td><td colspan="2">IPv6</td></tr>
<tr><td>Data Link</td><td colspan="3">LLC 802.2
MAC 802.11
1609.4</td></tr>
<tr><td>Physical</td><td colspan="3">PHY 802.11 (p)</td></tr>
</table>

This is not a VANET!

VANET vs. “normal” WiFi

- IEEE Std 802.11-2012 intended to address dynamic nature of fast-moving vehicles.
  - Allows a station (STA) that not a member of a Basic Service Set (BSS) to operate “outside the context of a BSS” (i.e., OCB).
  - Typ. 6 Mbps data rate using dedicated 10MHz channel in 5.9GHz range.
  - Every vehicle broadcasts an unacknowledged Basic Safety Message (BSM, defined by SAE J2725) at a nominal rate of 10 times per second.
    - BSM gives vehicles size, position, motion, braking status etc. and optionally vehicle events and path history/prediction.
  - May also utilize infrastructure, e.g., Roadside Unit (RSU) that provides connectivity to other infrastructure.
  - Communications range is approximately 15-1000m, with 400m limit being typical (in simulation, based on Tx power).

Radio Propagation Models (RPG)

- An RPG handles the effects of attenuation as signals move through free space (and obstacles) due to distance, multipath signal fading due to reflectors, and shadowing. E.g.,
  - Unit disk - direct LOS communications is limited to some radius
  - Two-Ray Ground – takes into account signal reflection from the ground
  - Stochastic – e.g., Rice, Raleigh, ***Nakagami-m***, lognormal, Weibull

$$f_{Nakagami-m}(r;m,\Omega) = \frac{2m^m r^{2m-1}}{\Omega^m \Gamma(m)} e^{-\frac{mr^2}{\Omega}},$$

where m is the Nakagami parameter (i.e., shape parameter), $\Gamma(m)$ is the gamma function, and Ω is the average power of multipath scatter field, which controls the distribution spread

Performance Metrics

- Network-level metrics:
  - Packet Delivery Ratio (PDR) - the percentage of broadcast packets that are successfully received by all vehicles within each transmitting vehicle's coverage range, *d.*
  - Packet Reception Ratio (PRR) - the percentage of nodes that successfully receive a packet from the sending node among the receivers being investigated at the moment that the packet is sent out.
  - Average Per-Packet Latency
- Application-level metrics
  - Awareness probability -the probability of receiving at least n packets in the tolerance time window, T_{Tol}

Obstacle Shadowing Model

Obstacle Model

- Wireless signals emitted by vehicles travelling through a (downtown, urban) scenario may encounter obstacles that affect signal propagation.
- Obstacles for VANET are modeled as two-dimensional polygons that represent obstacle boundaries.

Obstacle Model (2)

- Use Computational Geometry Algorithms Library (CGAL), the number of walls are counted as obstacle intersections and distances travelled through interior of obstacles.
- Values are then used for a deterministic calculation of obstacle shadowing loss (based on walls intersected and interior distances travelled).

Obstacle shadowing model enhancements to *ns-3*

ns-3 Source Code Modules	Existing Usage and Examples	Extensions for Obstacle Model
test		
helper	High-level wrappers for everything else aimed at scripting	
protocols, applications, devices, propagation, …	Friis, Two-Ray Ground, Nakagami-m loss	obstacle shadowing propagaion loss
internet, mobility	Mobility modules (static, random walk, etc.)	
network	Packets, Packet tags, Packet headers, Pcap/ASCII file writing Node class, NetDevice, Address types (IPv4, MAC, etc.), Queues, Sockets	
core	Smart pointers, Dynamic type system, Attributes, Callbacks, Tracing, Logging, Random variables, Events, Schedulers, Time arithmetic	obstacles, topology management

ns-3 Obstacle classes

- Three primary classes implemented:
  - Obstacle - represents an obstacle using a CGAL Polygon_2 object, and retains parameters that determine the fading effects through obstacle walls and interior space
  - Topology - loads buildings data from a file in the format as available through OpenStreetMap (OSM) and processed using Simulation for Urban Mobility (SUMO) Polyconvert utility
  - ObstacleShadowingPropagationLossModel – implements the obstacle shadowing loss model (described later)


```
<?xml version="1.0" encoding="UTF-8"?>
<!-- generated on 06/12/14 16:58:30 by SUMO polyconvert Version 0.19.0 <?xml version="1.0" encoding="UTF-8"?
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        type="building.yes" id="148163972"/>
```
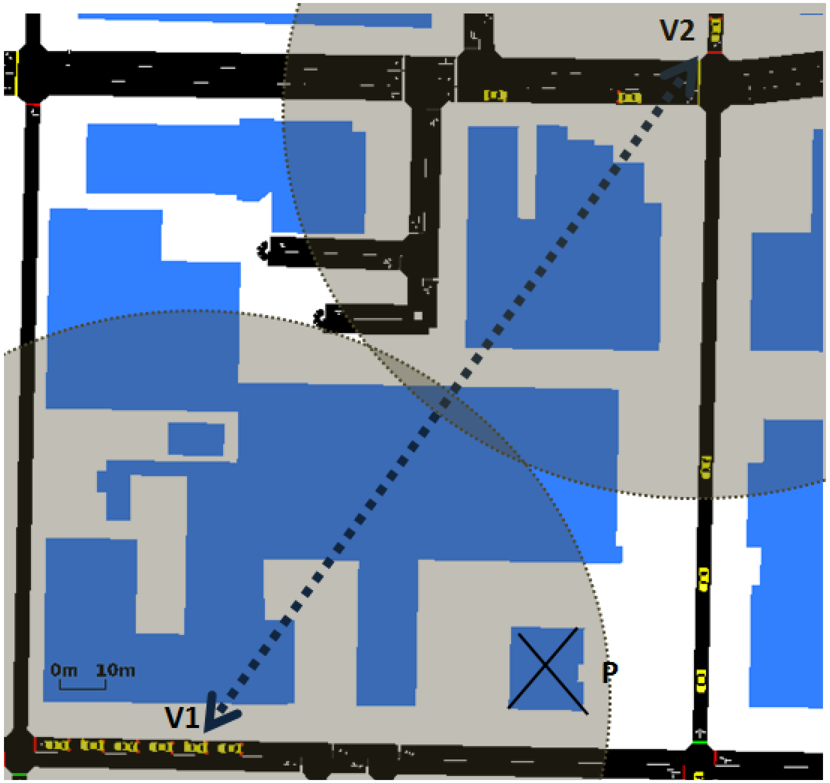

Finding Obstacles

- Only consider obstacles that lie less than 500m from a vehicle
  - Obstacles at greater distances tend to entirely block residual radio wave energy.
  - Candidate obstacles are found by searching a Binary Space Partition (BSP) of obstacle centers (i.e., midpoint of obstacle's bounding box).
  - Inter-vehicle obstacle obstructions are cached and assumed identical for vehicles that have not moved more than 0.1m.



Propagation Loss

- Obstacle shadowing loss is modeled as an additive loss using *ns-3*'s propagation loss chaining model
  - E.g., two-ray ground loss PLUS obstacle shadowing
- Obstacle shadowing path loss, $L_{s,o}$, is dependent on both per-wall-attenuation and per-meter-attenuation as:

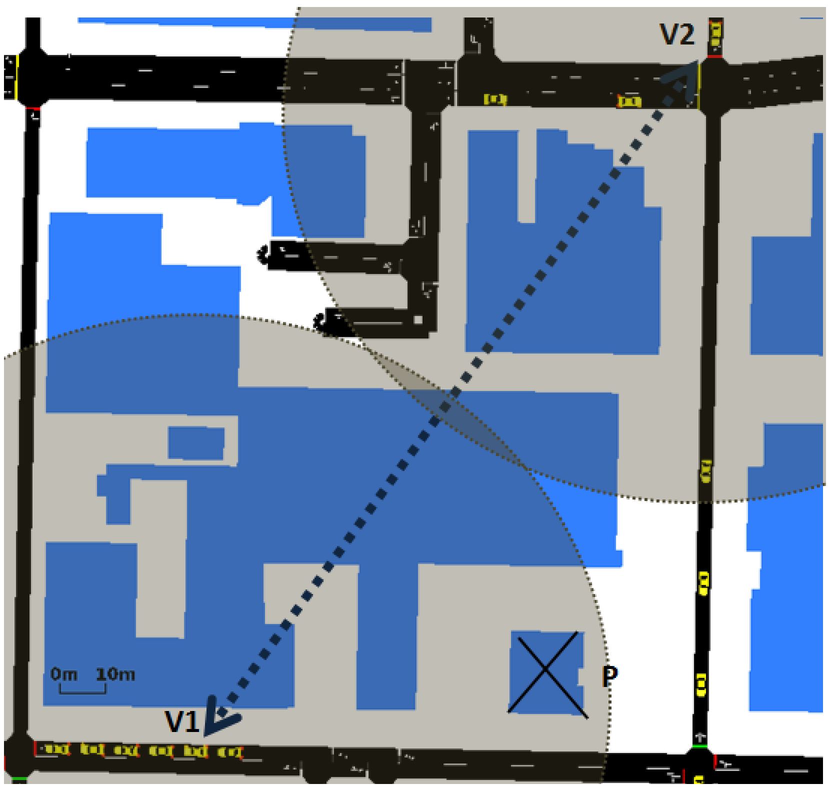
$$L_{s,o} = \alpha n + \beta d_o,$$

  - where α is the attenuation per wall, in decibels (dB), n is the number of walls penetrated, β is the attenuation per meter, in dB, and d_o is the distance, in meters, traveled through obstacles.
- Default values as per of α = 9 dBm and β = 0.9 dB / m are used.
  - Example: n=6 walls and an interior distance of d_O = 32m yields

$$L_{S,O} = 6 \times 10 + 0.9 \times 32 = 88.8\ dB$$

  - Configurable "per object"

Algorithm Pseudo-code



Algorithm GETOBSTRUCTEDDISTANCEBETWEEN (p_1, p_2, B)

Input. Locations, p_1 and p_2, of two vehicles and a pre-determined binary search partition (BSP), B, of obstacles.

Output. The total obstructed distance, m_o, and the number of obstacle edge intersections, n.

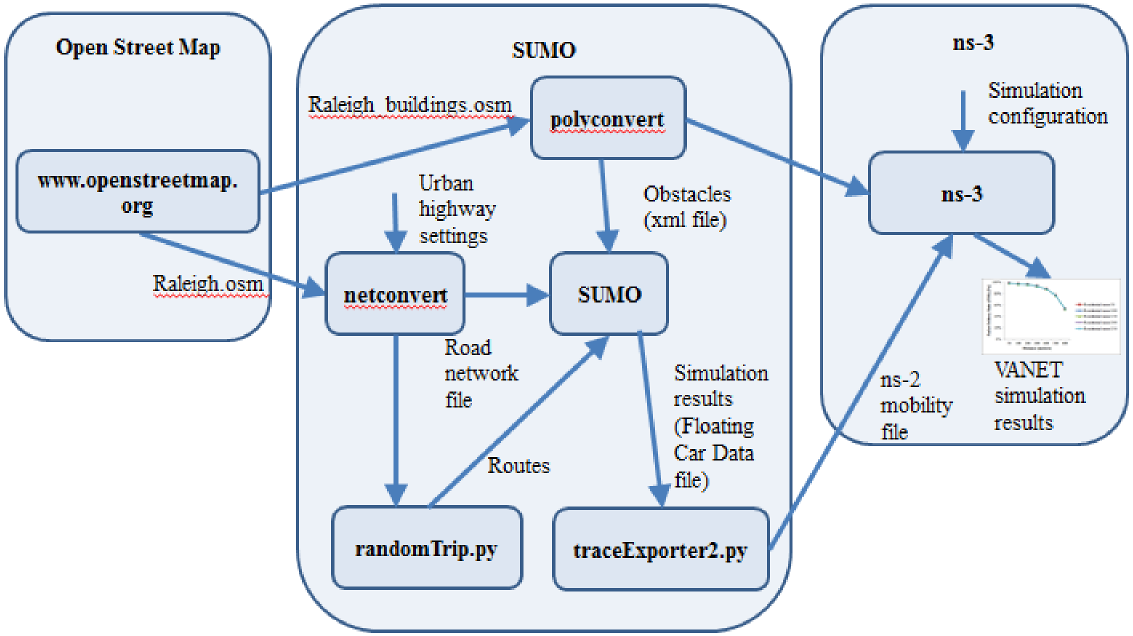
1. $m_o \leftarrow 0$; $n \leftarrow 0$
2. Initialize a maximum range, r, the distance from either point p_1 or p_2 to an obstacle center-point, that is used to filter the set of obstacles to the subset which are sufficiently nearby for calculation purposes (i.e., for optimization, exclude far-away obstacles).
3. Create a bounding box, b, for p_1 and p_2 and extend in all directions by r.
4. Get the set of potential obstacles, O. $O \leftarrow$ the range search of b within B.
5. For every obstacle $o \in O$, do:
6. if the distance from p_1 or $p2$ to the obstacle center is within range, r, then
7. for each edge $s \in o$,
8. if s intersects a ray from p_1 to p_2
9. $n \leftarrow n + 1$ (i.e., found an obstructing wall)
10. save the min. and max. distances from $\{p_1, p_2\}$ to the intersection pt. (i.e., to find spanning interior distance among the edges of o)
11. $m_o \leftarrow m_o$ + distance between min., max. values in step 10 (i.e., spanning interior obstructed distance)
12. return m_o and n

https://codereview.appspot.com/201200043

Experimental Setup

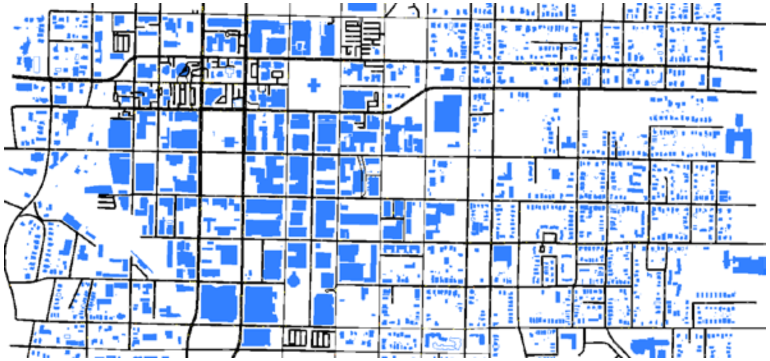
Buildings Data and Simulation Setup

- Obtain buildings data from OpenStreetMap (OSM).
- Convert through SUMO Polyconvert
- Load into SUMO, generate vehicular trace files, export to ns-2 mobility trace files
- Playback ns-2 mobility trace files in ns-3 using ns2MoblityHelper
- Run ns-3 script, such as vanet-routing-compare



Scenario Topology

		Scenario		
		Open highway	Residential neighborhood	Urban downtown
Latitude	N	35.8855	35.8758	35.7828
	S	35.8420	35.8650	35.7714
Longitude	W	-78.8858	-78.6770	-78.6506
	E	-78.7785	-78.6502	-78.6237
Approx. Area (sq. mi.)		39.17	1.68	2.01
Buildings		348	1440	1776
Traffic lights		7	5	75
Vehicles, routes		50-250	50-250	50-250
Car-following model		Krauss	Krauss	Krauss



Network Simulation

- Using src/wave/examples/vanet-routing-compare.cc

Parameter	Value	*ns-3* commnd line argument
BSM size	200 bytes	`--bsm=200`
BSM rate	10 Hz	`--interval=0.1`
Transmit power	20 dBm	`--txp=20`
Frequency	5.9 GHz	`(N/A - value hard-coded)`
Channel bandwidth	10 MHz	`--phyMode=OfdmRate6MbpsBW10MHz`
Channel access	802.11p OCB	`--80211Mode=1`
Tx range	50 - 2000 m	`--txdist[n]=[d]`
Sync time accuracy	1-10 µs (uniform)	`--gpsaccuracy=10000`
Encoding	OFDM	`--phyMode=OfdmRate6MbpsBW10MHz`
Rate	6 Mbps	`--phyMode=OfdmRate6MbpsBW10MHz`
Propagation loss model	Two-ray ground	`--lossModel=3`
Simulation time	2000 s	`--totaltime=2000`
Fading Model	Obstacle Shadowing	`--buildings=1`

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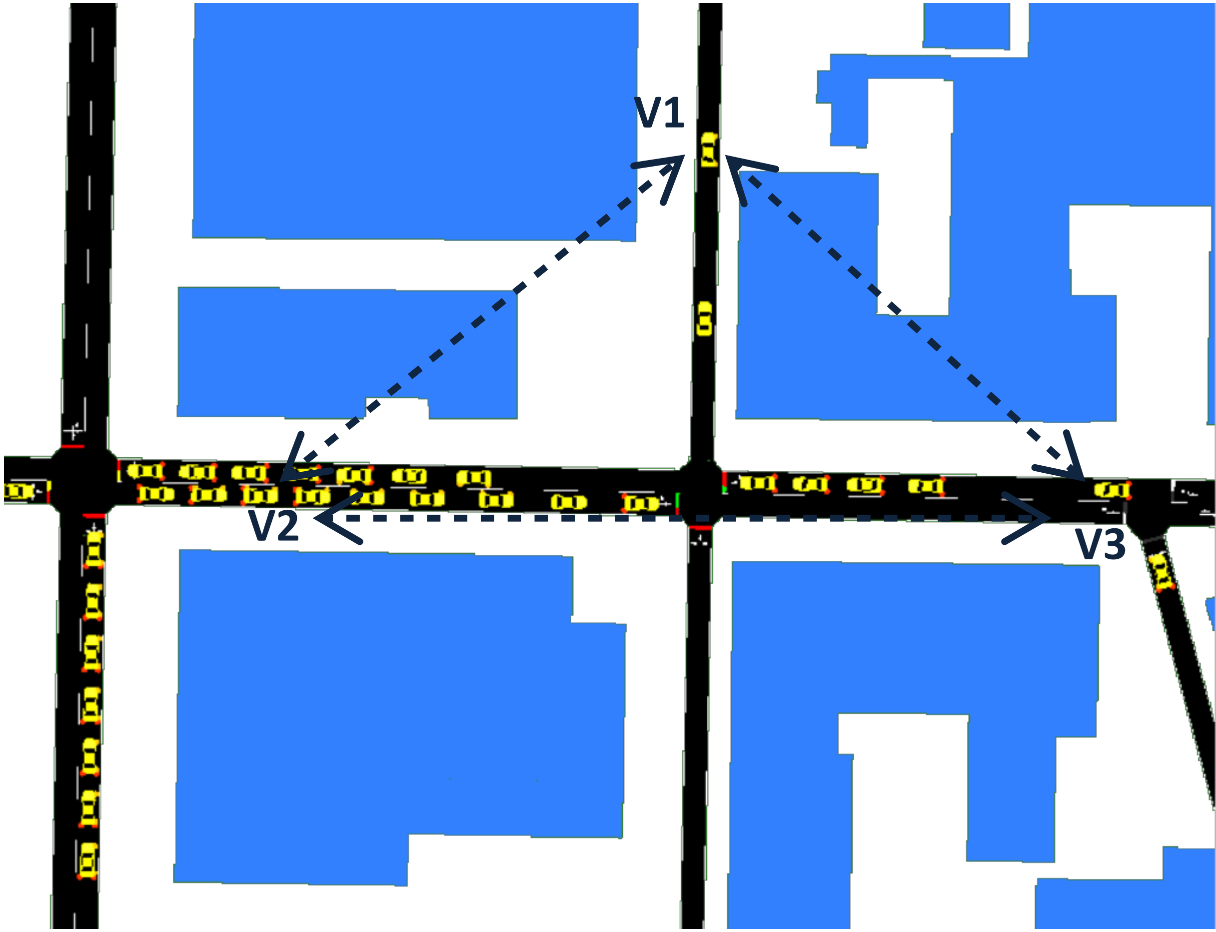
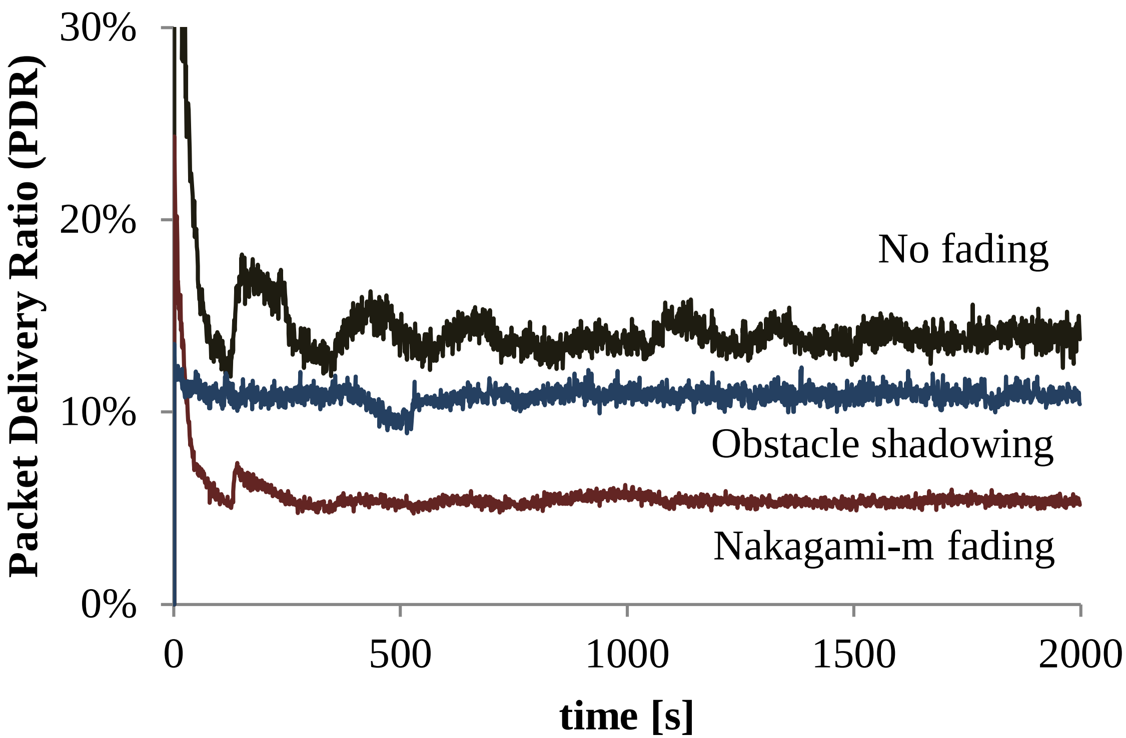
Results and Discussion

- Effects of propagation loss models:
  - Shadowing effects are different for deterministic vs. stochastic evaluations.



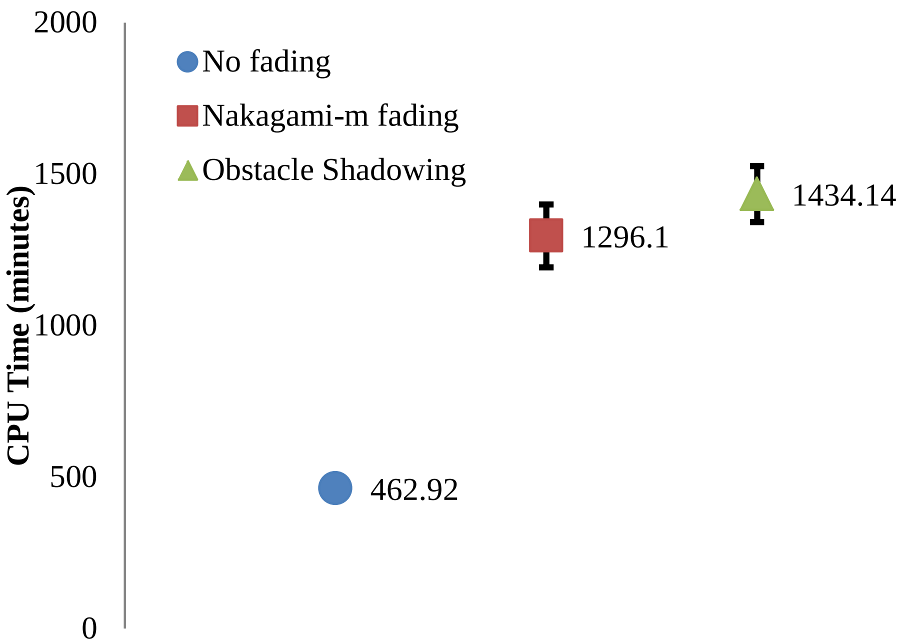
Packet Delivery Ratio (PDR)

Model	Mean	σ
No fading	14.38%	2.48%
Nakagami-m fading	5.60%	1.35%
Obstacle shadowing	10.85%	0.56%



Performance

- 30 trials each of 50-750 vehicles in open highway, residential neighborhood, and urban downtown settings, with all nodes transmitting 10 BSMs per second for 2000 seconds.
- Wall-clock times captured to compare simulation overhead of different models
  - Obstacle shadowing model is on the order of time complexity of stochastic models such as Nakagami-m



Conclusions

- An obstacle model and a fading model that uses it has been implemented and offered to the open source *ns-3* network simulator community.
  - The models are shown to execute efficiently with simulation overhead on the time complexity order of the stochastic Nakagami-m fading model.
- Deterministic obstacle shadowing can greatly degrade PDR and compares differently than stochastic Nakagami-m fading.
  - Failing to account for the effects of obstacles can therefore inaccurately or even greatly overstate the performance of VANET scenarios.
- Including realistic obstacle shadowing in VANET simulation modeling improves VANET assessment

Future Work

- It remains unclear if the model implemented is, in fact, the best model for obstacle shadowing.
  - Evaluate a small, but real-world example
- Identify additional “real-world” buildings data.
  - Extend to 3D data.
  - Identify data sources that allow the model to be tuned based on building composition materials (e.g., brick, or wood)
  - Build an ns-3 utility to assist with buildings data extraction (i.e., from OSM? Or other source(s)???)
- Extend the obstacle shadowing model to other ns-3 wireless models
  - LTE, LR-WPAN, Wimax
  - Modeling needs may vary, but may use common geometrical techniques, i.e, found in CGAL

Thanks to...

- Junling Bu, for the ns-3 IEEE 1609/WAVE implementation.
- Konstantinos Katsaros, for leading VANET training as WNS3-2015.
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- The entire ns-3 community for work contributions that make a most-excellent network simulator!

https://codereview.appspot.com/201200043

Q&A