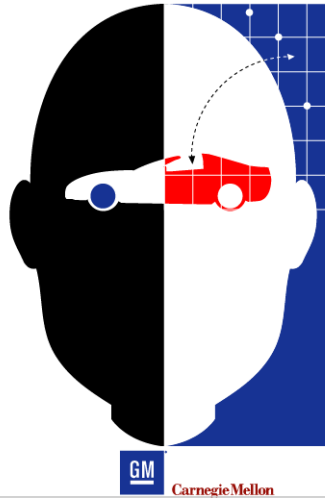


GrooveNet
Connected Vehicles. Connected People.



GrooveNet

Hybrid Simulator for Vehicular Networks

Rahul Mangharam, Daniel Weller, Prof. Raj Rajkumar
Carnegie Mellon University, Pittsburgh, U.S.A.

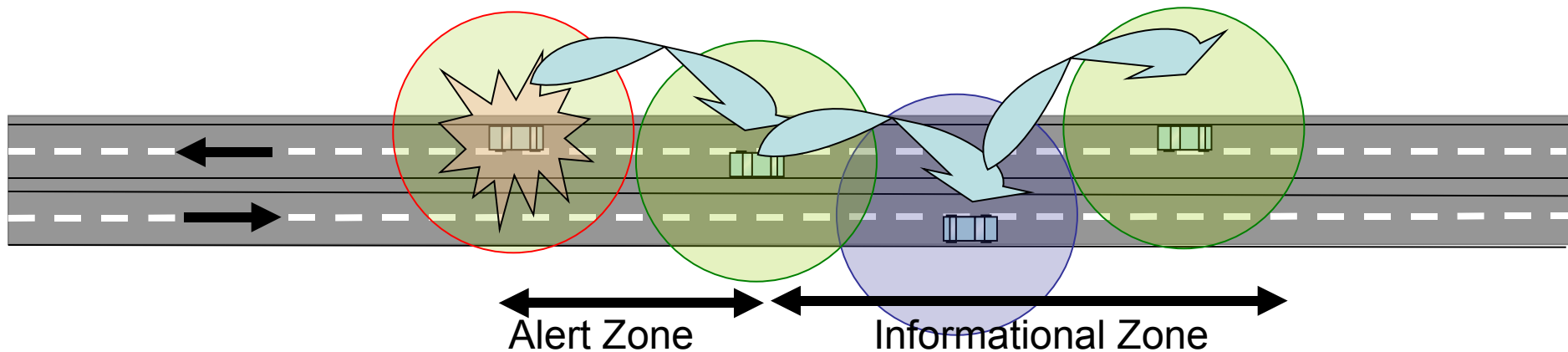
Priyantha Mudalige & Fan Bai
General Motors Research Center, Warren, U.S.A.

General Motors – Carnegie Mellon Collaborative Research Laboratory



- **5 GM Research Vehicles**
- **Multiple Inter-Disciplinary Projects**
 - V2V Network Protocols
 - Channel Modeling and Antenna Design
 - Navigation & User Interfaces
 - Autonomous Vehicles, AI and Computer Vision
 - Embedded Systems and bus design

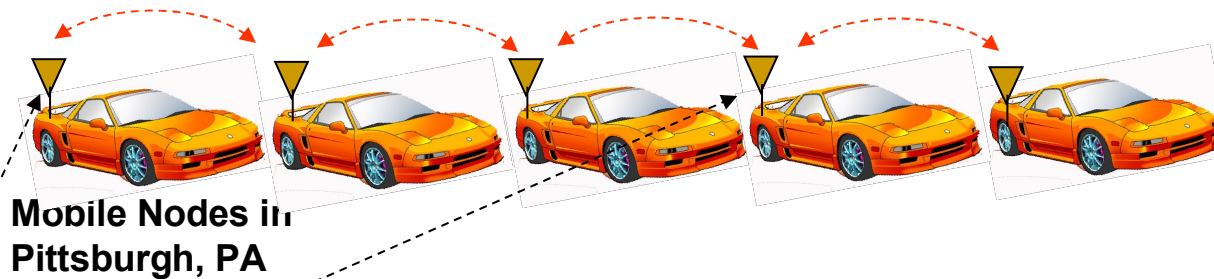
What are Vehicle-to-Vehicle Networks?



- **Vehicle-to-Vehicle Wireless Broadcast Protocols for:**
 - On-road Safety
 - Traffic Congestion Probing
- **The Key Questions:**
 - Market Penetration to make v2v useful?
 - Performance in urban, rural and highway?
 - What mix of mobile gateways, infrastructure and on-board wireless?
 - Which multi-hop protocols work best and under what conditions?

Experimental Multi-hop Vehicular Network Test-bed

5.9 GHz DSRC Dedicated Short Range Communications Between vehicles

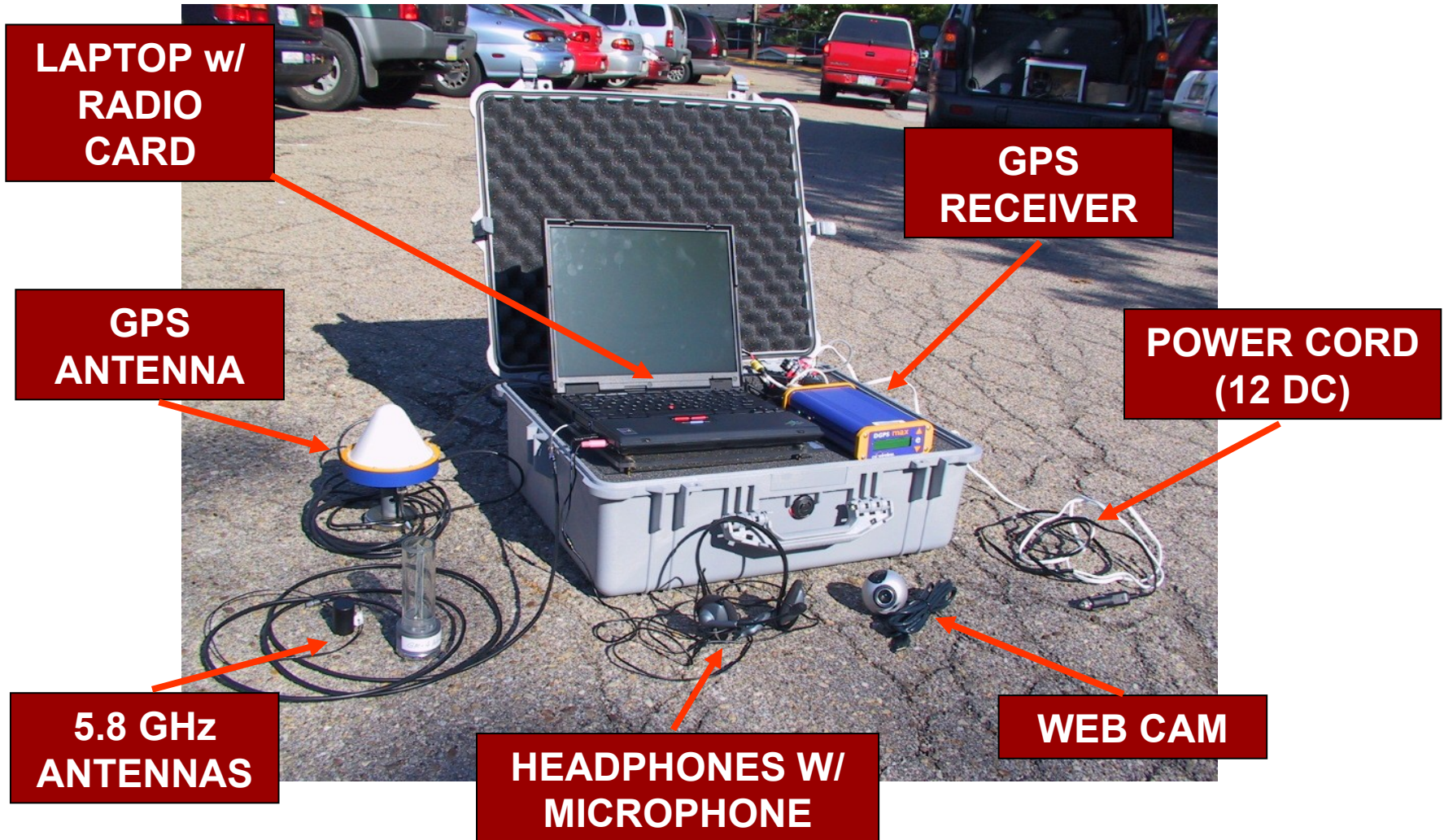


EVDO Cellular Network connects mobile gateway

Remote Monitoring of Experiment in Detroit, Michigan

- Vehicle-to-Vehicle Multi-hop
- Vehicle-to-Mobile Gateway
- Vehicle-to-Infrastructure

GrooveNet Test Kit

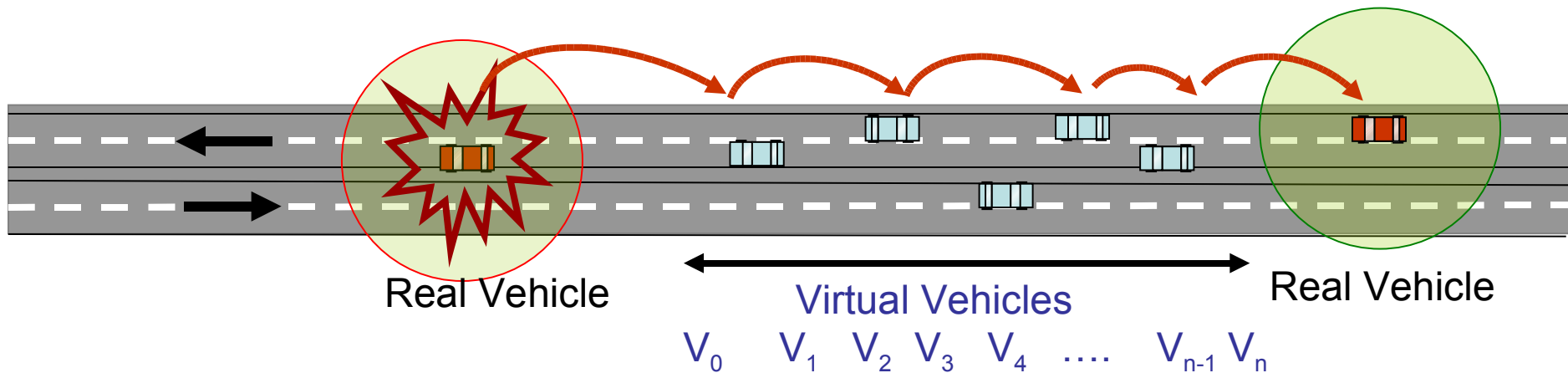


- Driven 5 vehicles over 400 miles – Urban, Rural and Highway Roads
- Over 625,000 link measurements

On-road Vehicular Networking Platform



Why do we need Hybrid Simulation?



Key Benefits:

- Use same protocol implementation for Simulation and Prototype
- Observe effects of Network Scaling and Traffic Density
- Remote Monitoring of On-road Experiments
- Evaluate correctness of Physical, Link Layer and Vehicle Interaction Models

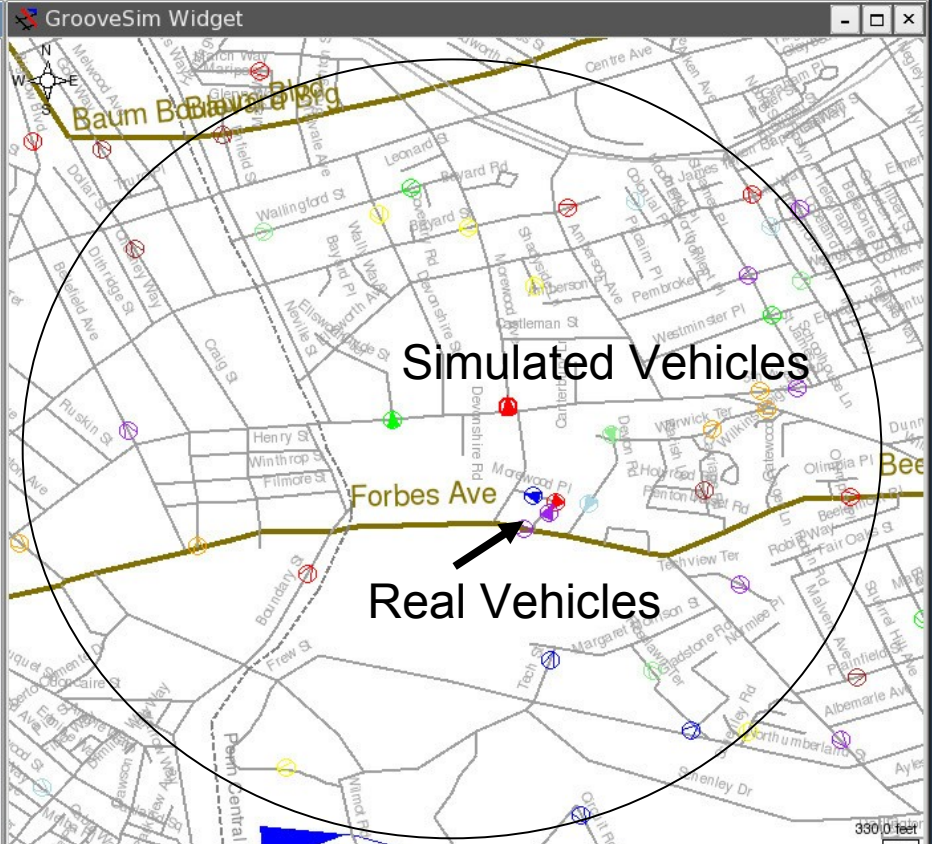
File Simulator Network Window

GrooveSim Widget

Vehicle	Type	Longitude	Latitude	Speed	Heading
192.168.1.82	Local/Simulated	-79.954209 °	40.444160 °	25 mph	130.24 °
192.168.1.83	Local/Simulated	-79.933996 °	40.441128 °	25 mph	71.57 °
192.168.1.84	Local/Simulated	-79.948152 °	40.438833 °	25 mph	-99.46 °
192.168.1.85	Local/Simulated	-79.940059 °	40.446695 °	25 mph	168.69 °
192.168.1.86	Local/Simulated	-79.927373 °	40.435799 °	25 mph	0.00 °
192.168.1.87	Local/Simulated	-79.936821 °	40.452889 °	25 mph	-33.69 °
192.168.1.88	Local/Simulated	-79.927684 °	40.443057 °	25 mph	-174.29 °
192.168.1.89	Local/Simulated	-79.936848 °	40.443189 °	25 mph	122.62 °
192.168.1.90	Local/Simulated	-79.936848 °	40.443189 °	25 mph	85.60 °
192.168.1.91	Local/Simulated	-79.936848 °	40.443189 °	25 mph	-83.66 °
192.168.1.92	Local/Simulated	-79.936848 °	40.443189 °	25 mph	-110.31 °
192.168.1.93	Local/Simulated	-79.928096 °	40.429347 °	25 mph	-82.11 °
192.168.1.94	Local/Simulated	-79.931711 °	40.444872 °	25 mph	68.20 °
192.168.1.95	Local/Simulated	-79.953997 °	40.453772 °	25 mph	163.14 °
192.168.1.96	Local/Simulated	-79.953841 °	40.429937 °	25 mph	135.00 °
192.168.1.97	Local/Simulated	-79.934435 °	40.439376 °	25 mph	138.37 °
192.168.1.98	Local/Simulated	-79.963582 °	40.453897 °	25 mph	56.31 °
192.168.1.99	Local/Simulated	-79.966349 °	40.439907 °	25 mph	-98.33 °
192.168.1.100	Local/Simulated	-79.942064 °	40.450700 °	25 mph	-24.10 °
192.168.1.101	Local/Simulated	-79.940780 °	40.445058 °	25 mph	-146.30 °
192.168.1.102	Local/Simulated	-79.929316 °	40.452525 °	25 mph	73.30 °
192.168.1.103	Local/Simulated	-79.940728 °	40.437519 °	25 mph	151.39 °
192.168.1.104	Local/Simulated	-79.942184 °	40.457106 °	25 mph	-60.64 °
192.168.1.1	Network	-79.936571 °	40.447486 °	25 mph	-105.26 °
192.168.1.2	Network				9.54 °
192.168.1.3	Network				48 °
192.168.1.4	Network				50 °
192.168.1.5	Network	-79.929210 °	40.445563 °	25 mph	111.80 °

Simulated Vehicles

Real Vehicles in vicinity



Simulated Vehicles

Real Vehicles

Vehicle/Simulator: 192.168.1.2

- 192.168.1.1
- 192.168.1.2
- 192.168.1.3
- 192.168.1.4
- 192.168.1.5

Network Connections with Real Vehicles

Reconnect ▾ Disconnect Reinitialize

Denso Client

TCP Client

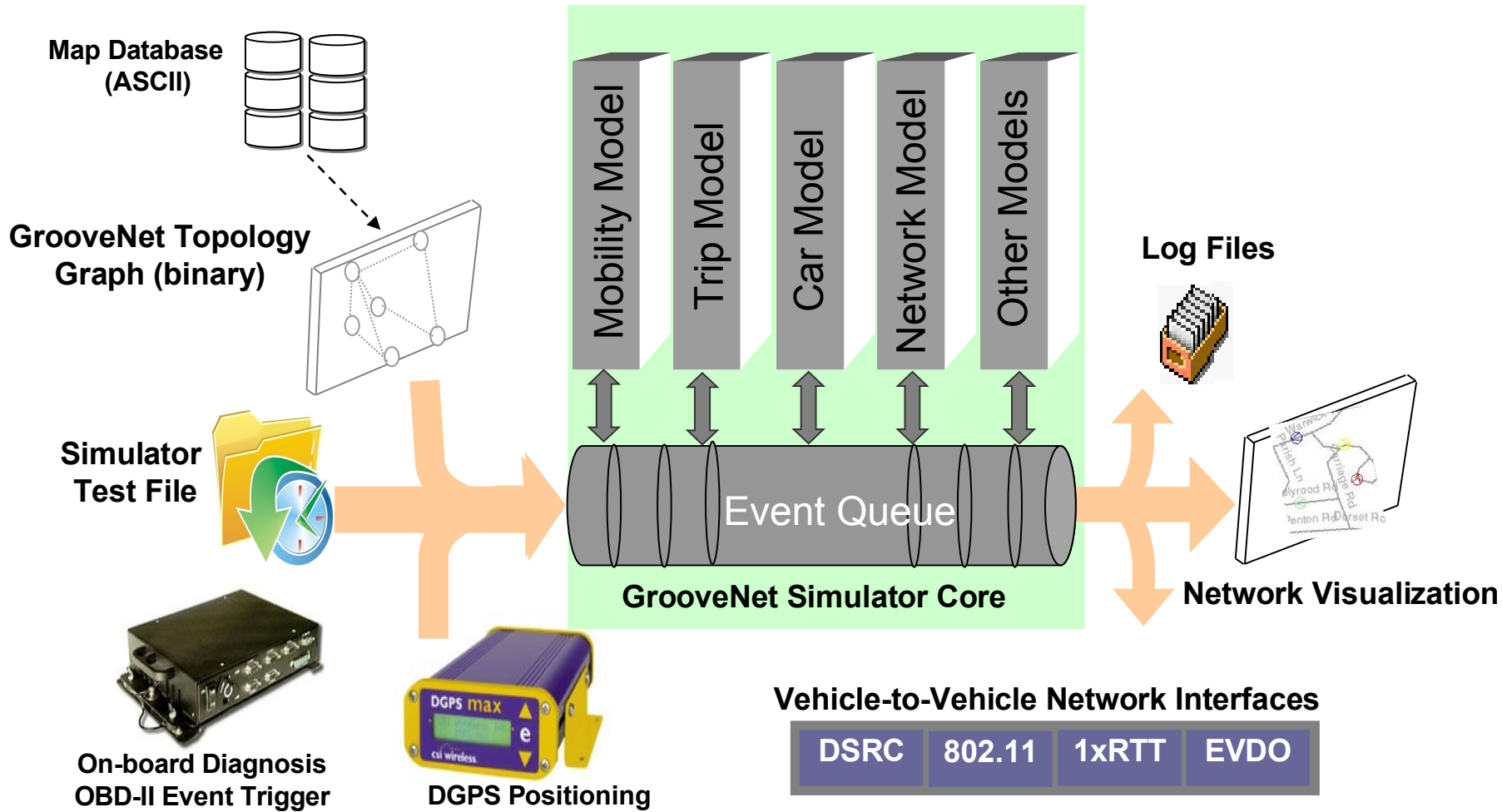
UDP Client

Close

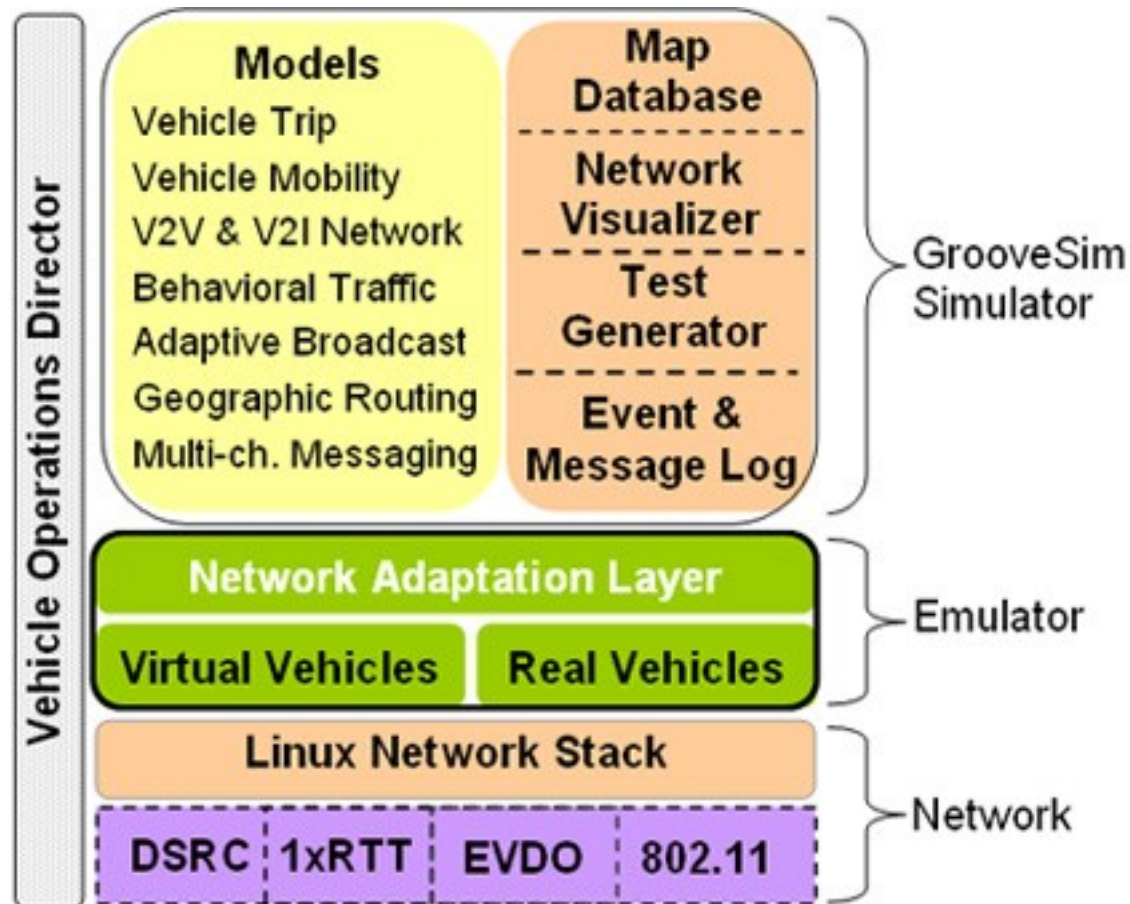
Stop Server

Real Network Connectivity

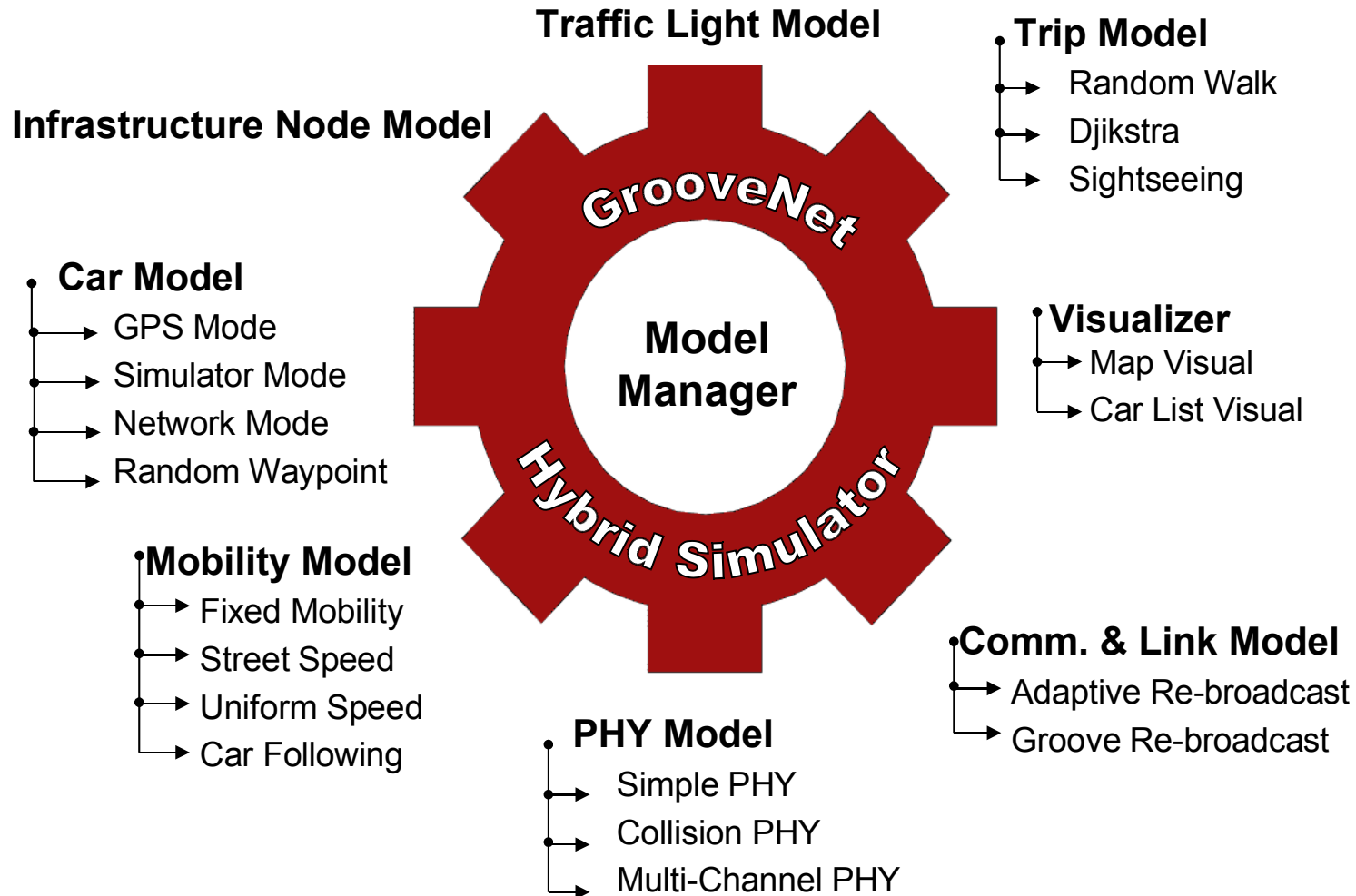
GrooveNet Hybrid Simulator Design



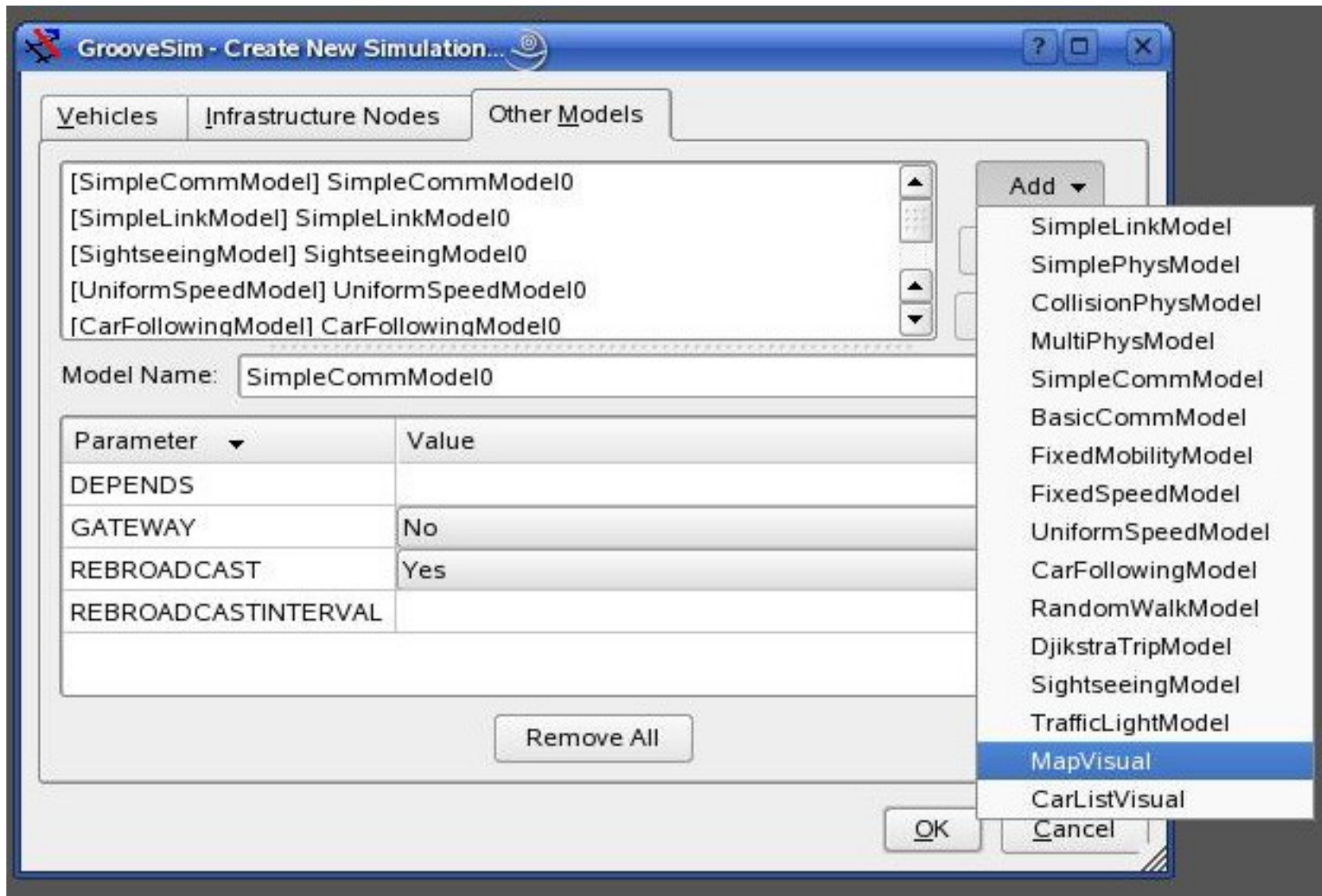
Modular Architecture



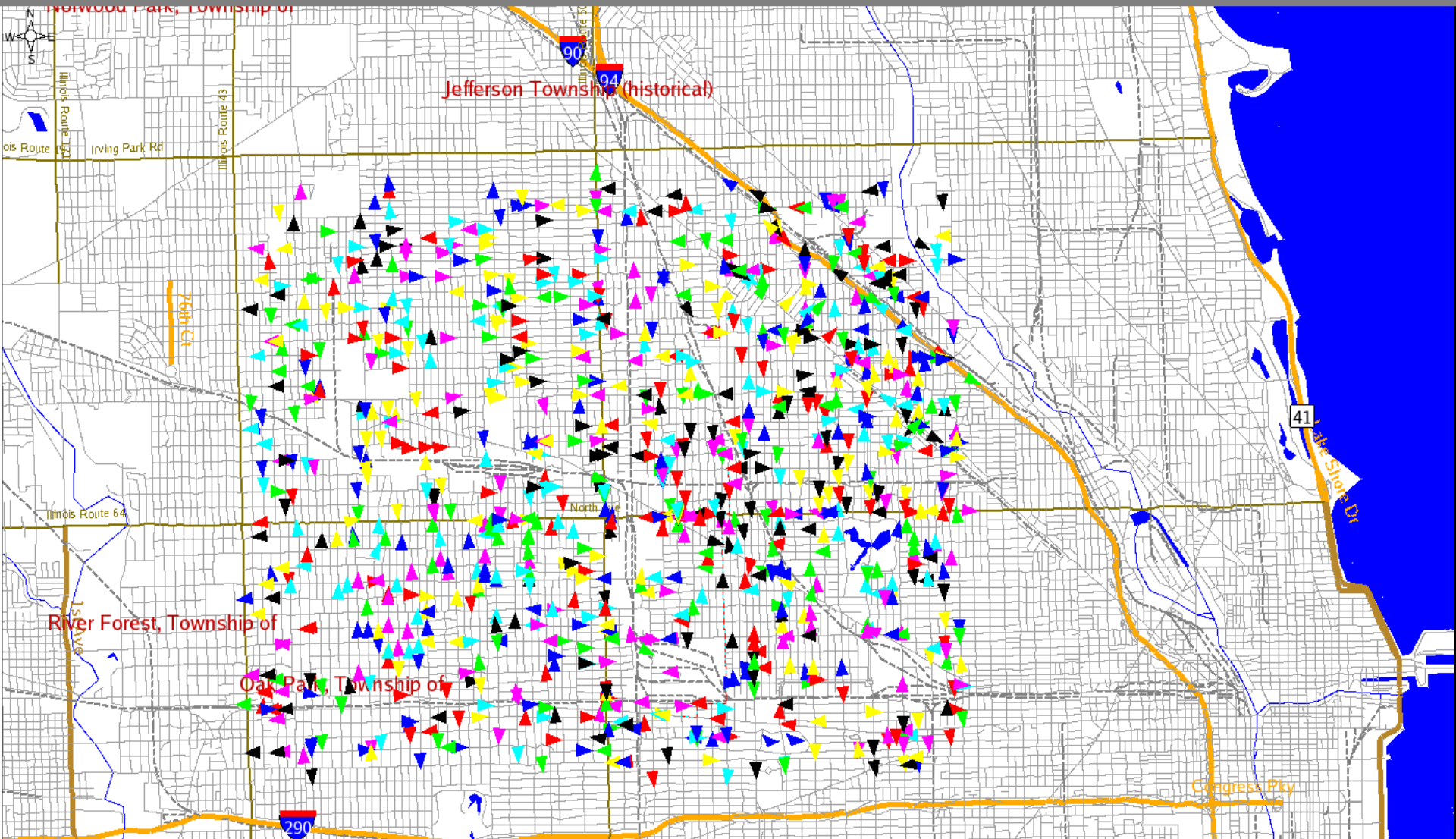
Modular Architecture (2)



Click to Add Model

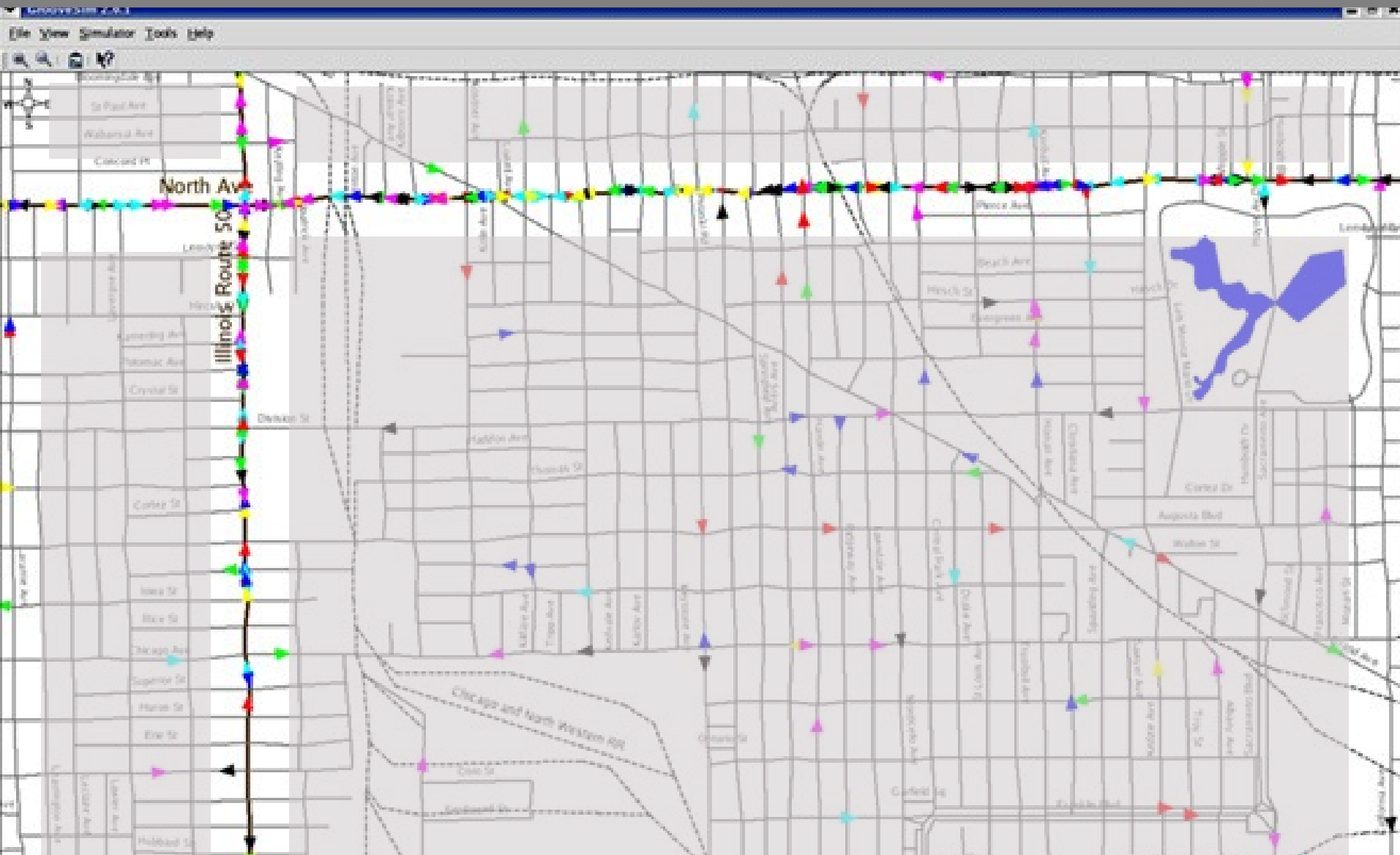


1,000 Vehicles in Chicago, IL suburb



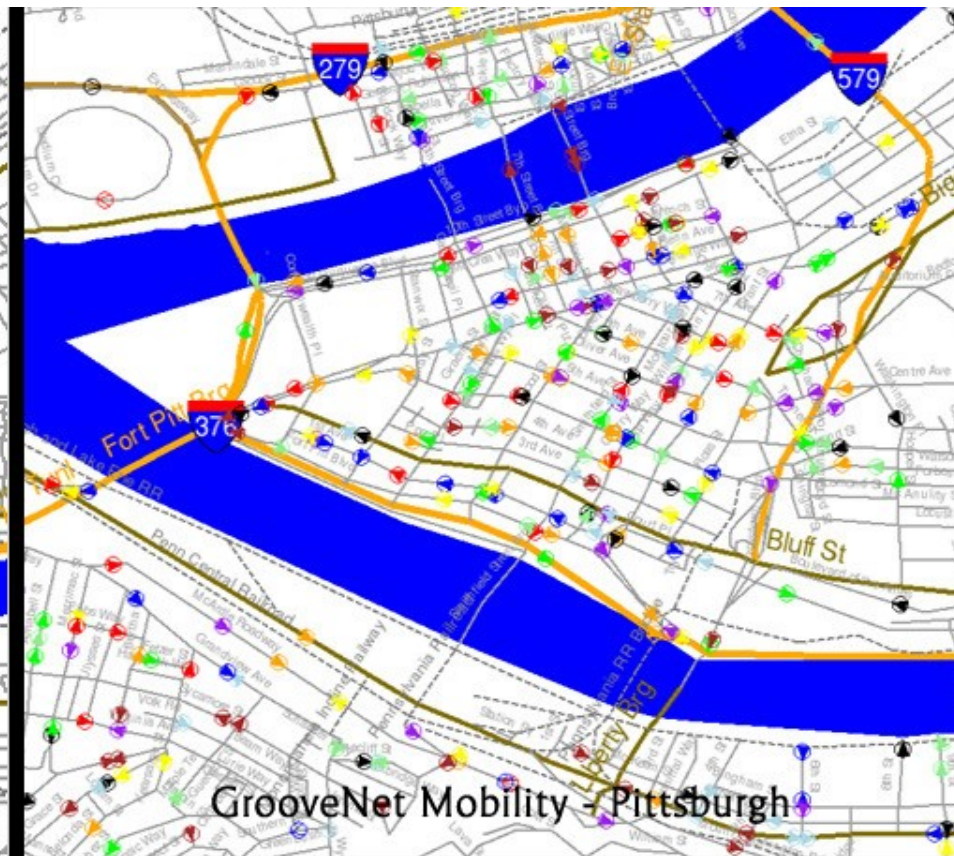
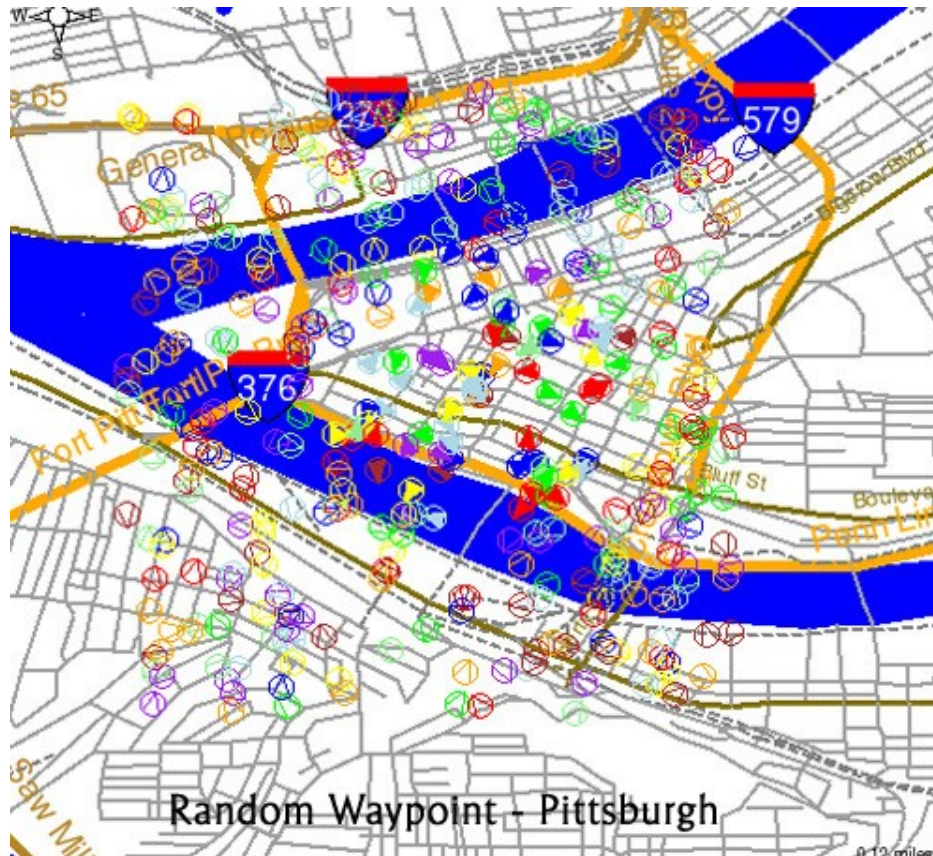
Routed with Minimum Cost Routing

Minimum Weight Routing

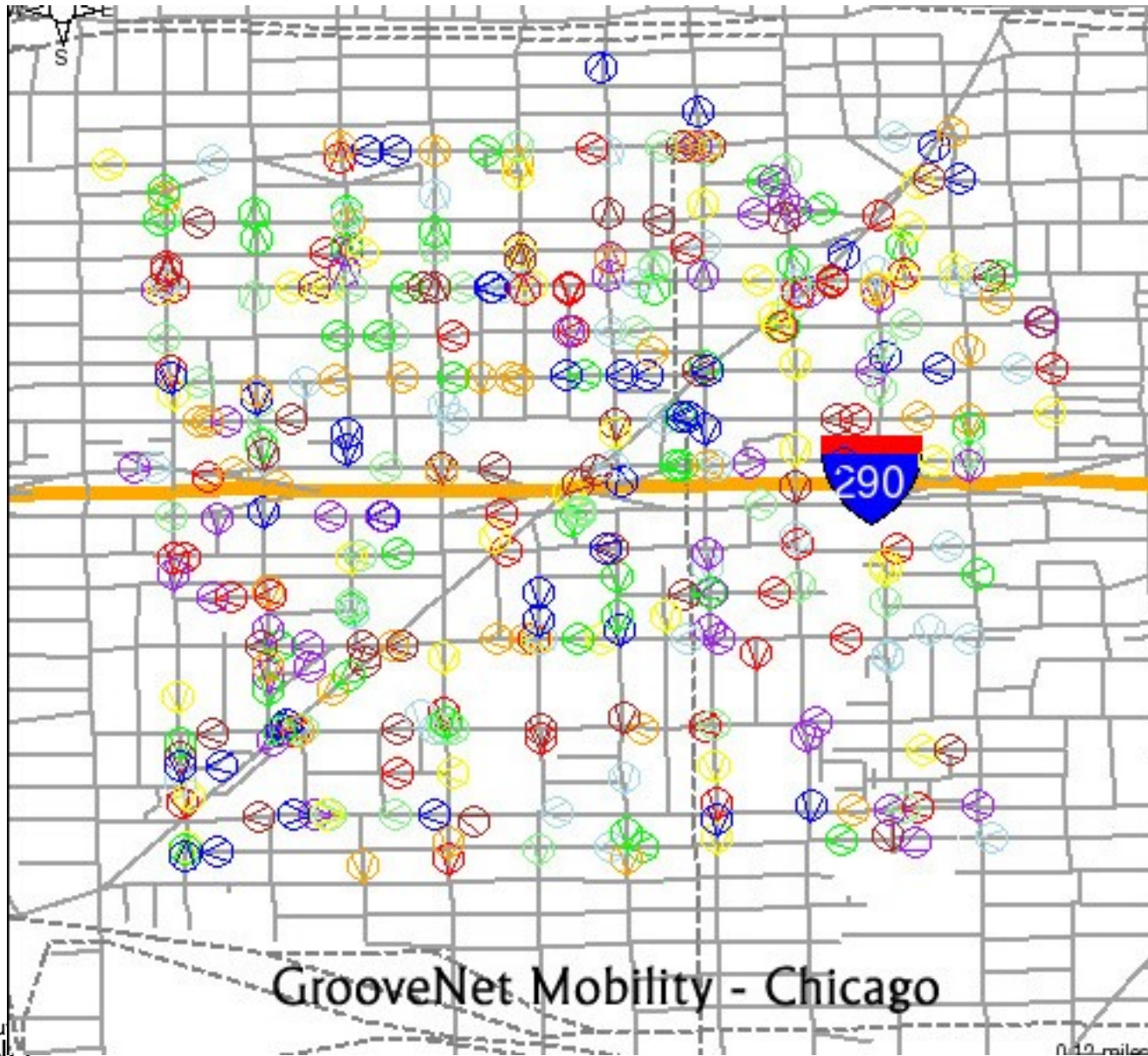


Vehicles migrate to roads with higher speed limits

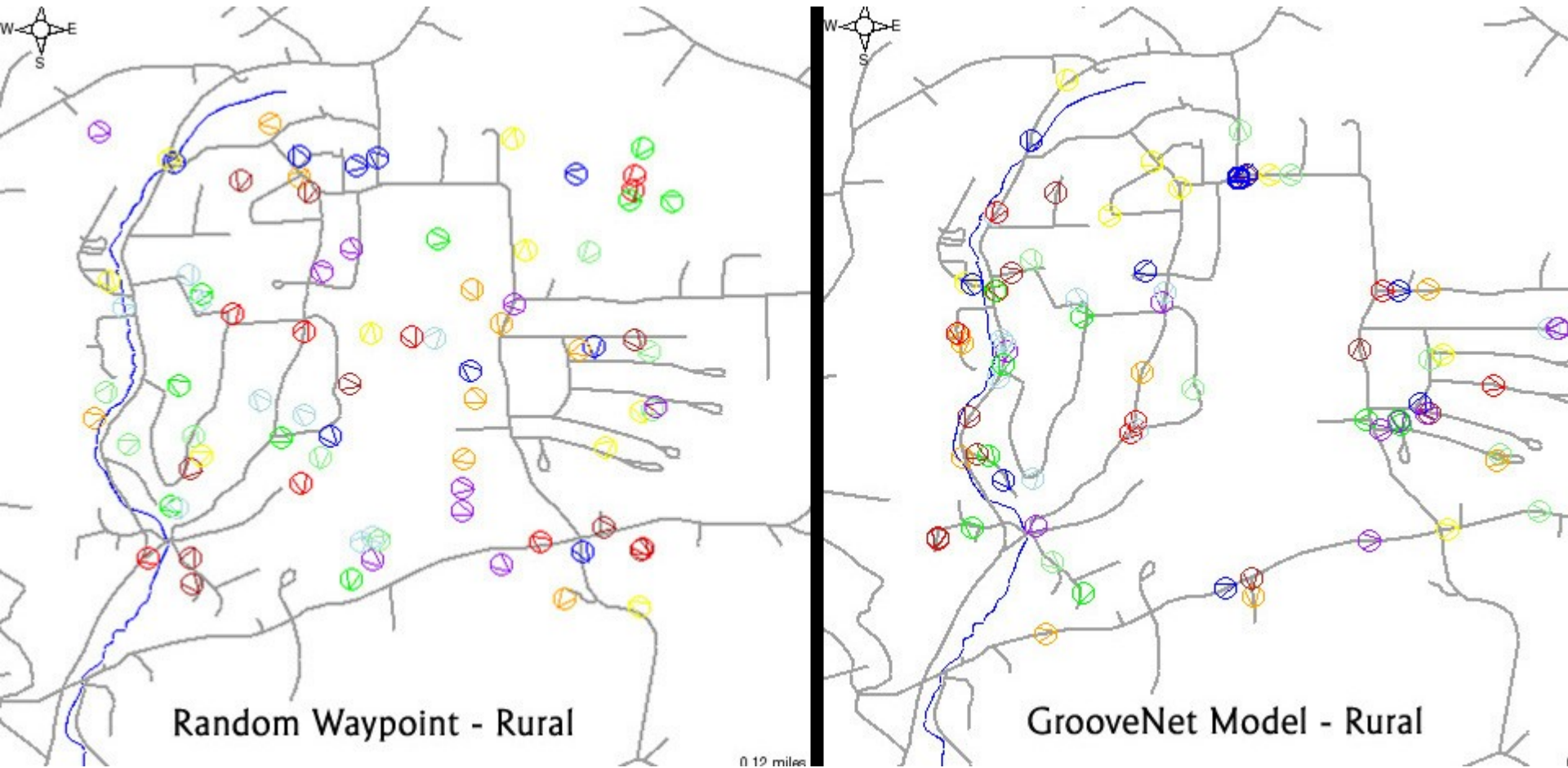
Why do we need GrooveNet?



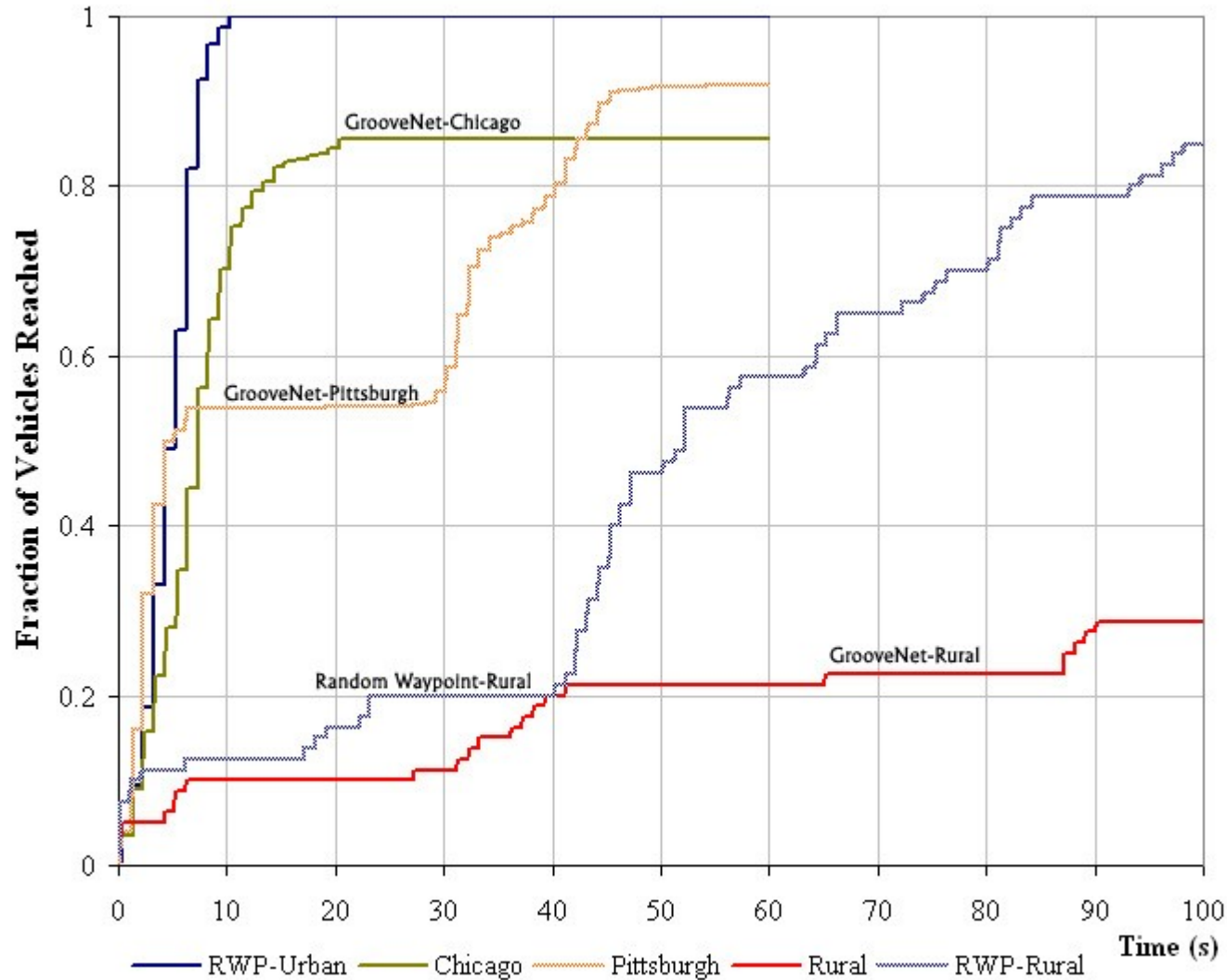
Uniform Urban Distribution



Rural Area: Rnd Waypoint Vs GrooveNet Topology-Mobility Models

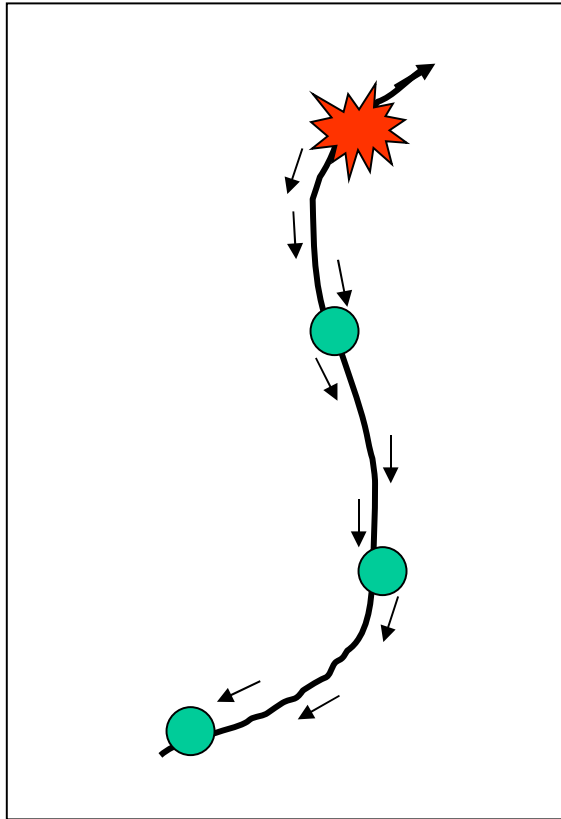


Message Propagation Rate



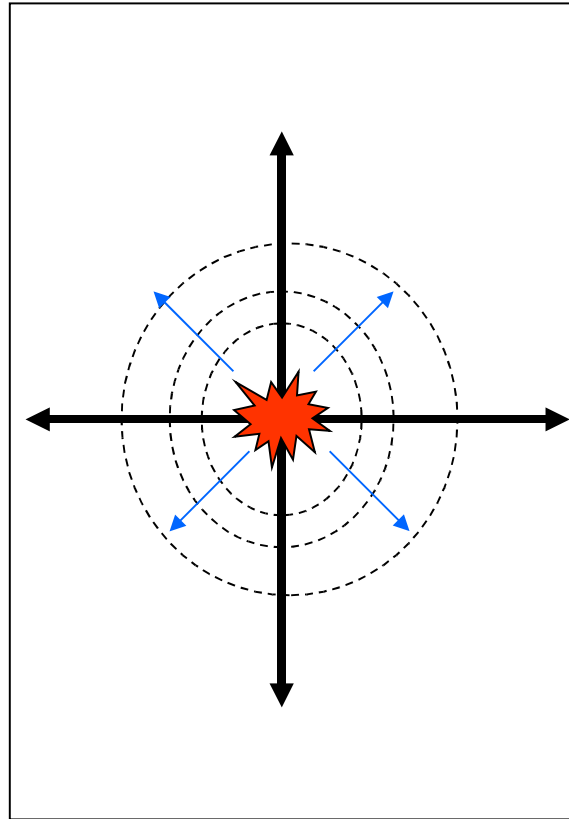
GeoRoute: Broadcast Scenarios

Highway Driving



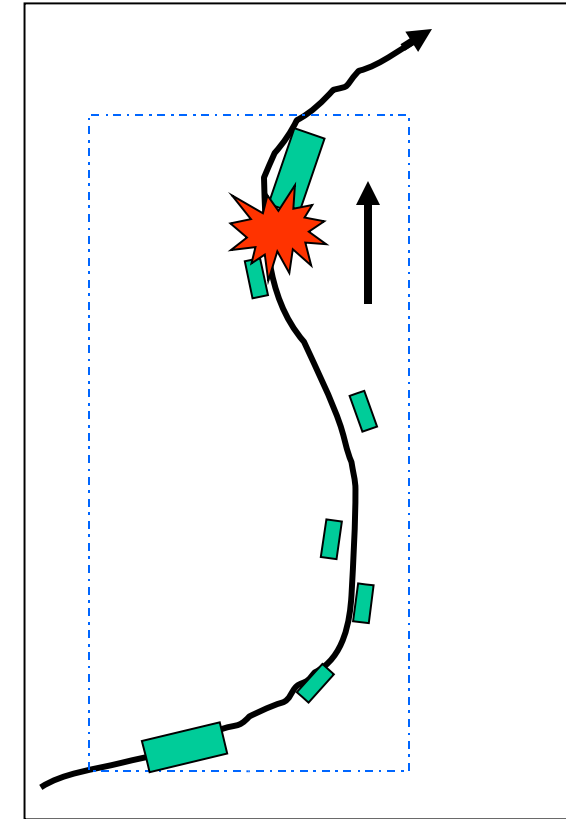
- Path with Intermediate points
- Static Source Routing

City Driving



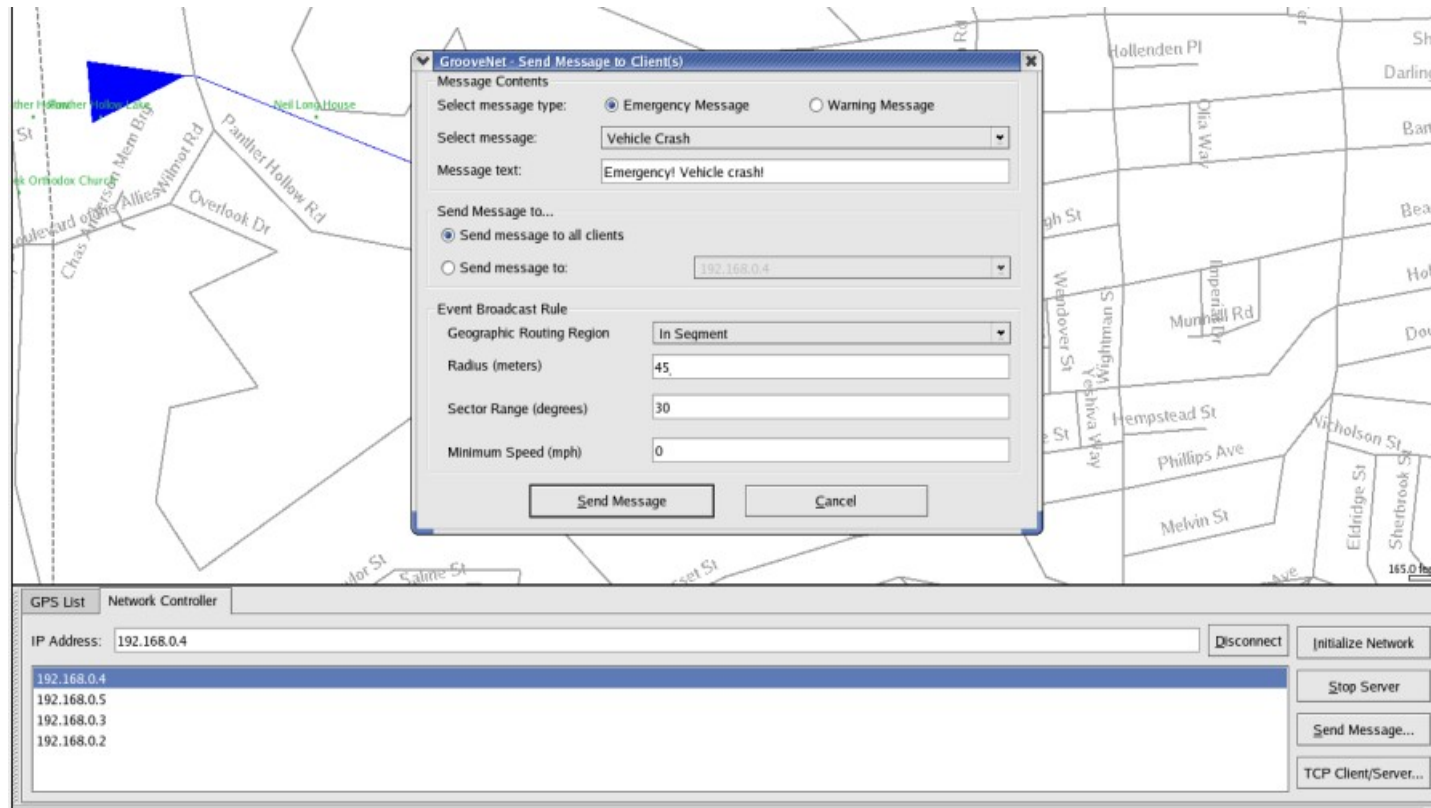
- Radial Broadcast

Rural Driving



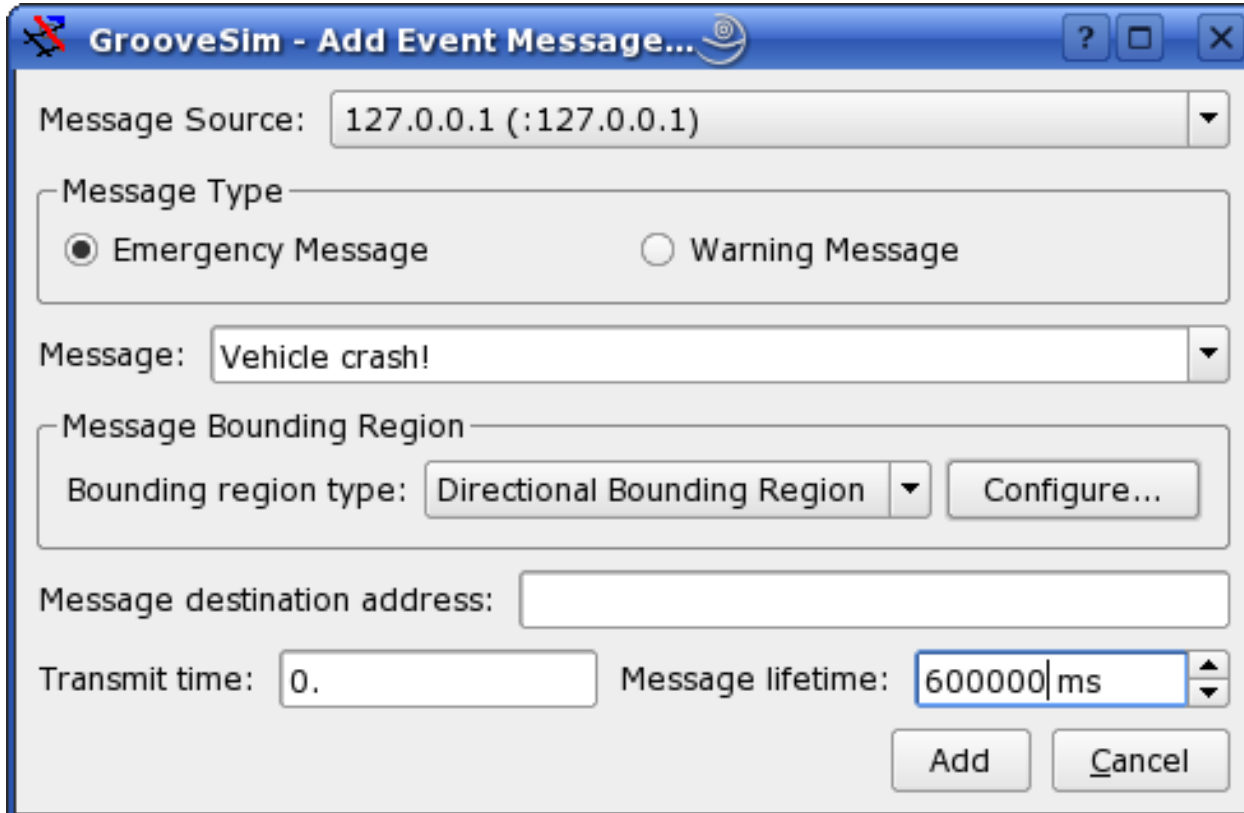
- Bounding Box
- Controlled Flooding

GrooveSim – On-Road Alerts (1)



- Broadcast Safety Alerts to all vehicles in the vicinity
- Messages are valid in a specific geographic region
- Regions are determined by position, speed and direction

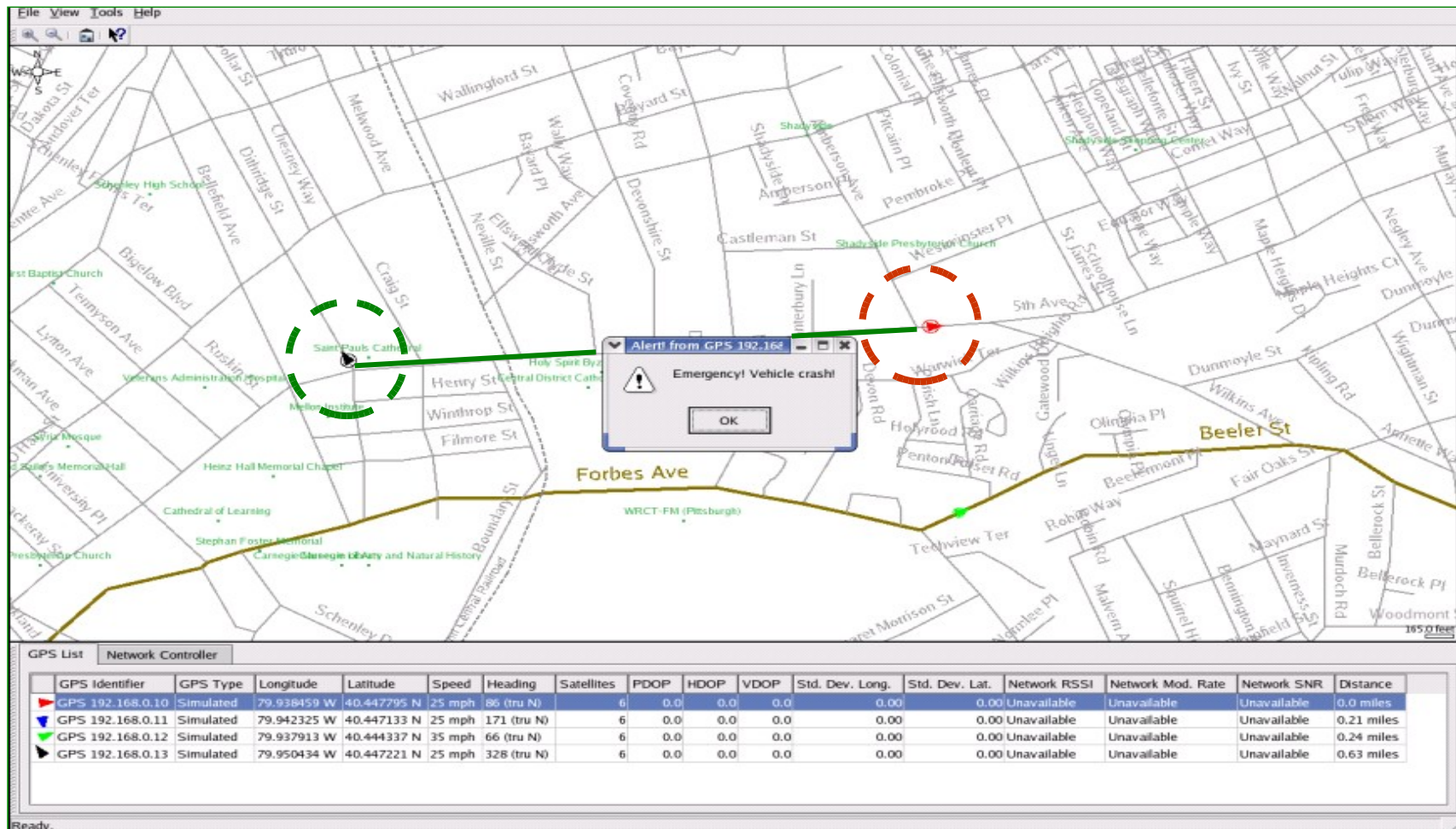
GrooveSim – On-Road Alerts (2)



The image shows a screenshot of a software dialog box titled "GrooveSim - Add Event Message...". The dialog box contains the following fields and controls:

- Message Source:** A text box containing "127.0.0.1 (:127.0.0.1)".
- Message Type:** A group box containing two radio buttons: "Emergency Message" (selected) and "Warning Message".
- Message:** A text box containing "Vehicle crash!".
- Message Bounding Region:** A group box containing a "Bounding region type:" label, a dropdown menu set to "Directional Bounding Region", and a "Configure..." button.
- Message destination address:** An empty text box.
- Transmit time:** A text box containing "0.".
- Message lifetime:** A text box containing "600000" with "ms" to its right.
- Buttons:** "Add" and "Cancel" buttons at the bottom right.

GrooveSim – On-Road Alerts (3)



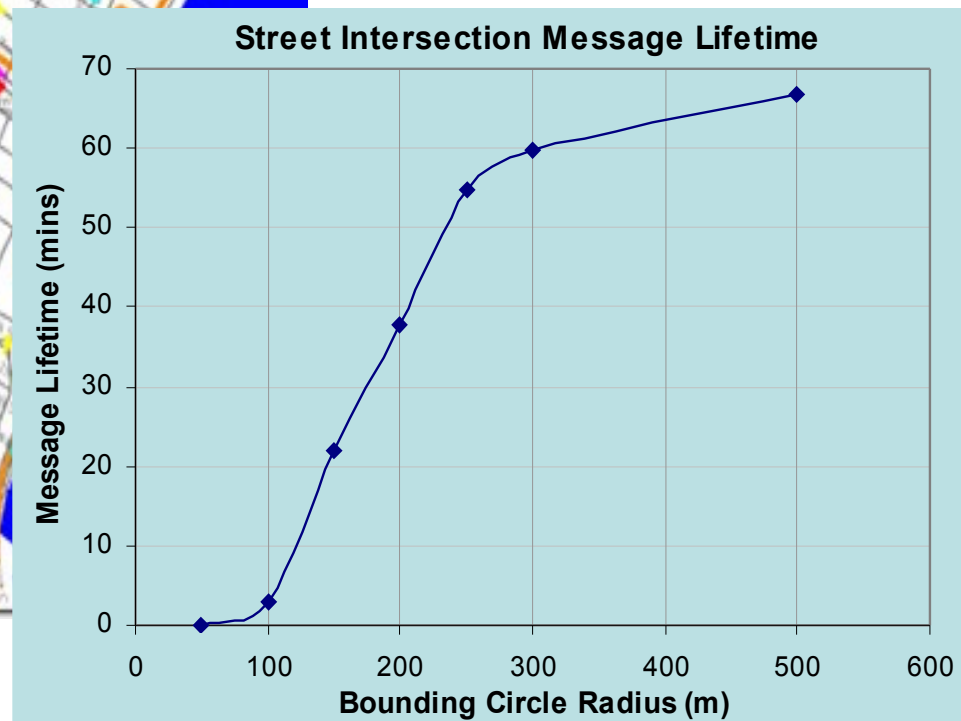
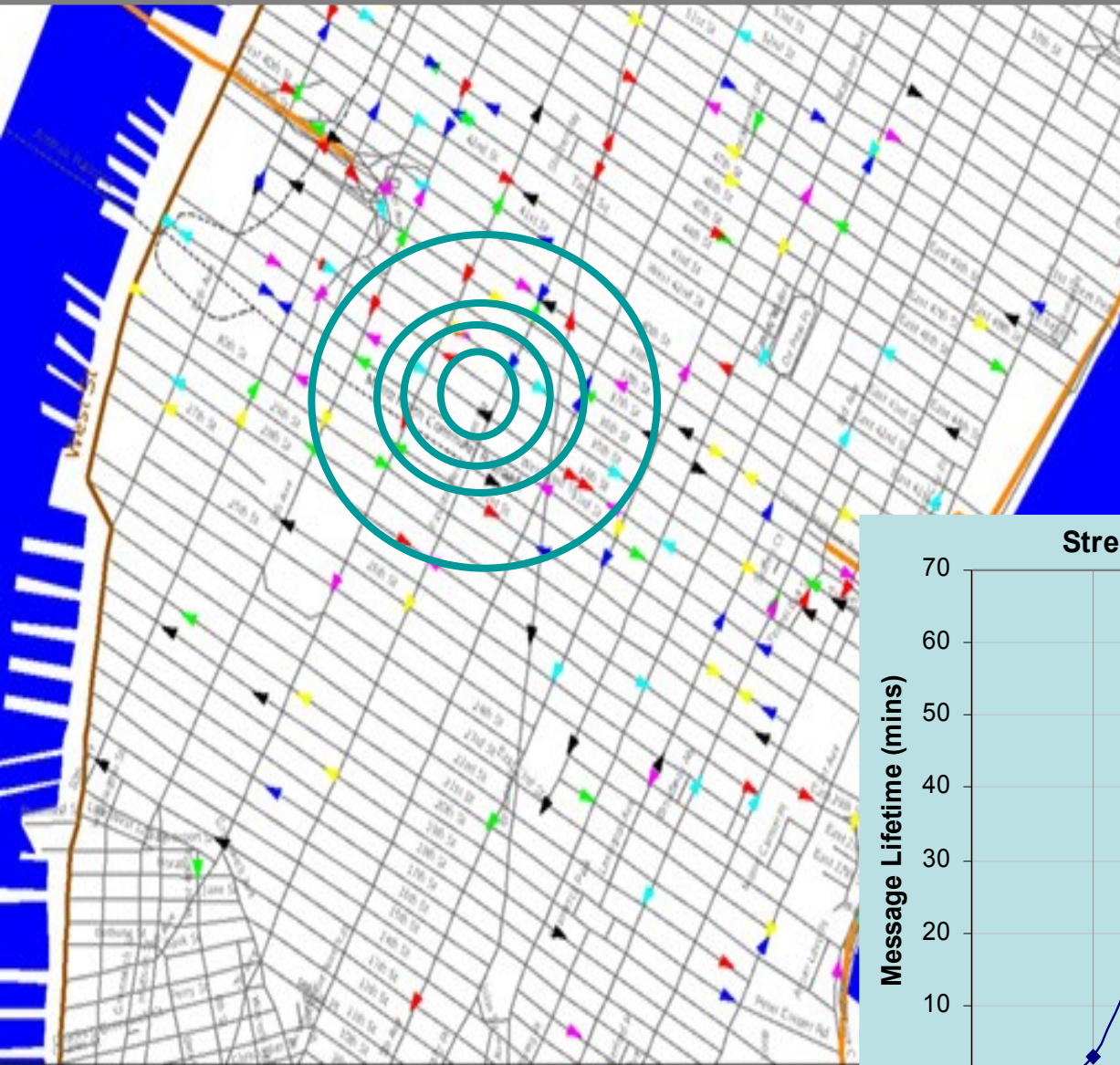
- Only vehicles in the relevant geographic region receive alerts

Performance: Message Delay



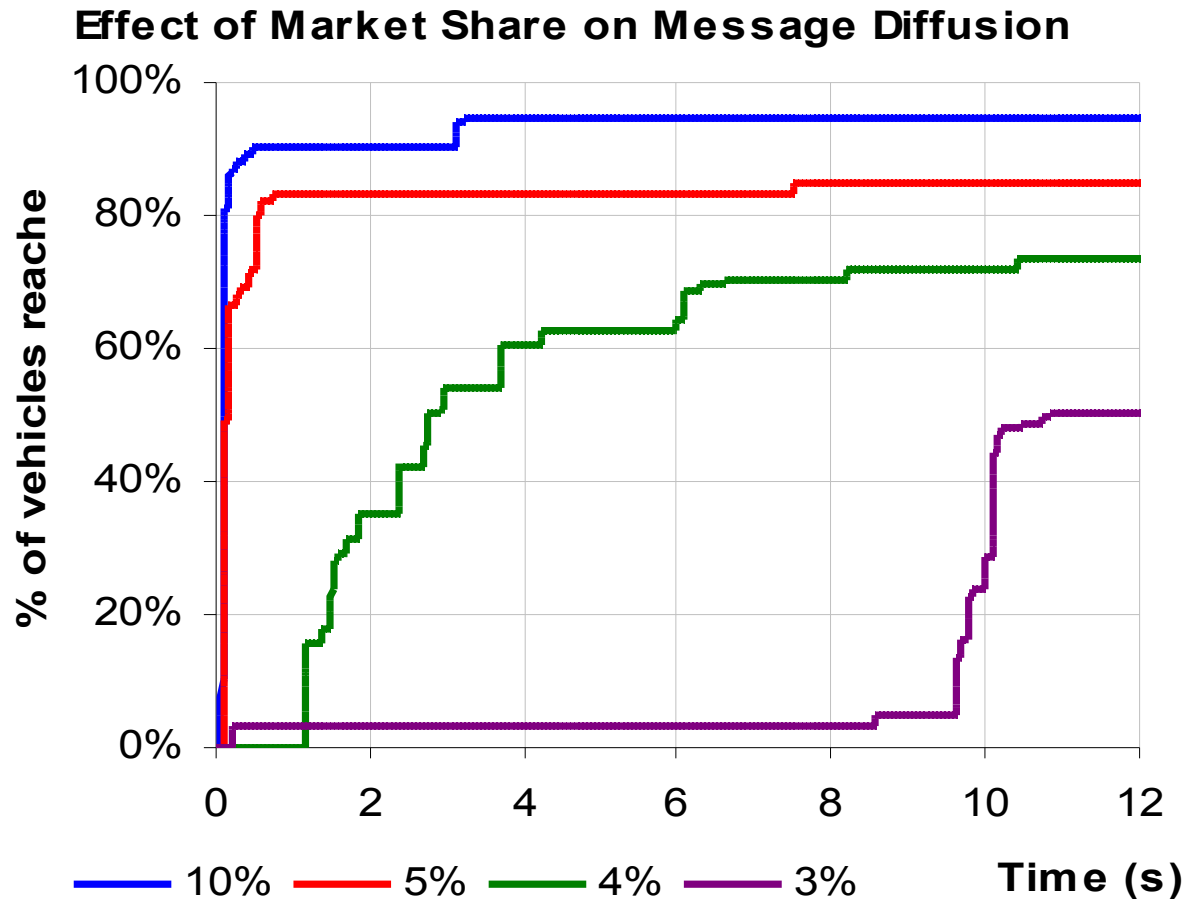
Bounding Box Size	# Active Vehicles	Message Delay (sec)
0	1	192
1	138	40.4
2	150	19
3	162	11

Performance: Message Lifetime

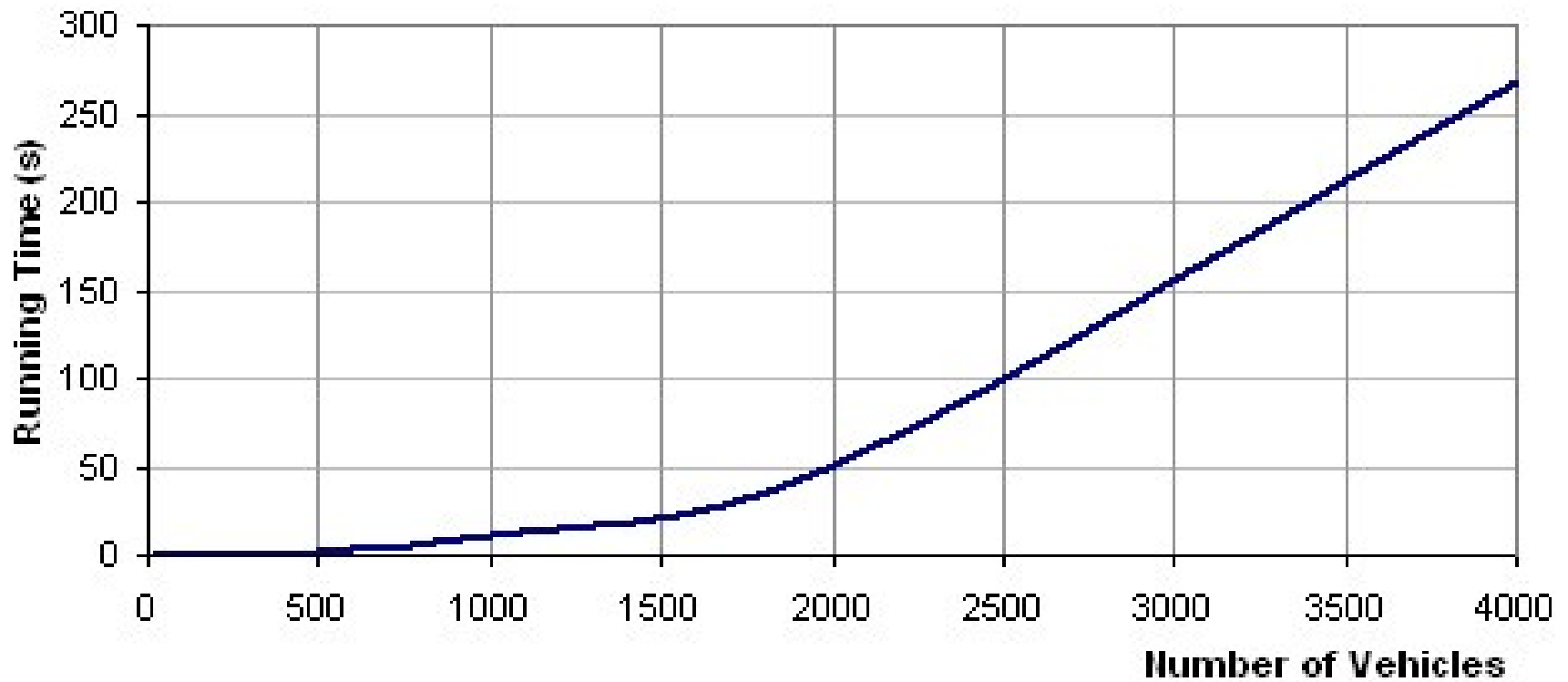


How close are we to V2V?

V2V Market Share



Simulator Scalability




Simulation Setup – 1000s of vehicles

GrooveSim - Auto-Generate Nodes...

Node Type: SimModel 100 nodes

Parameter: <Other Addresses> Region Type: Bounding Rectangle



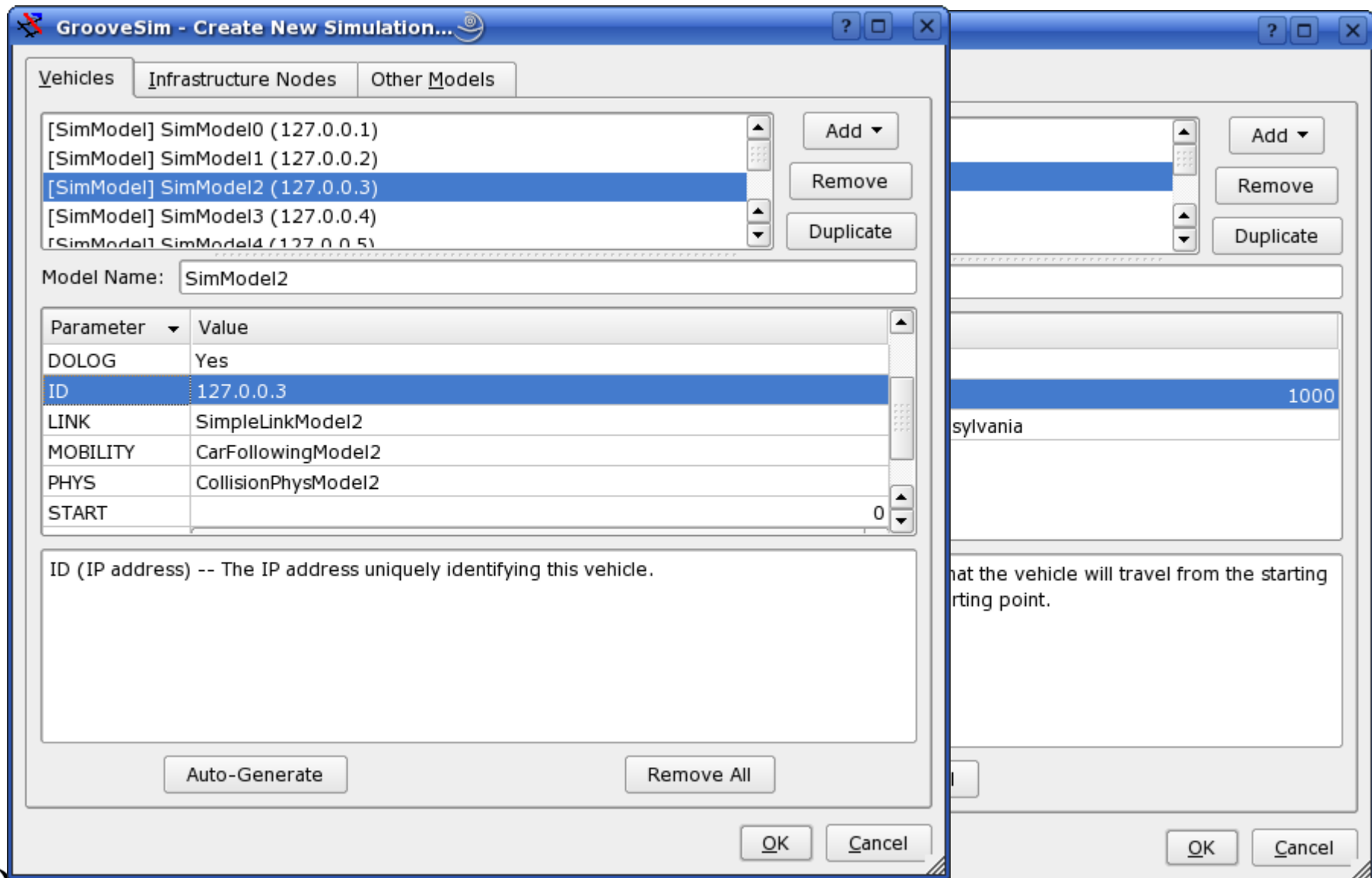
Bounding box area: 0.0723807 sq. km.

Parameter	Type	Value
COMM	Fixed	AdaptiveCommModel
DELAY	Fixed	0.2
DEPENDS	Fixed	
DOLOG	Fixed	Yes
ID	Fixed	127.0.0.1
LINK	Fixed	SimpleLinkModel
MOBILITY	Fixed	CarFollowingModel
PHYS	Fixed	CollisionPhysModel
START	Fixed	0
TRACKSPEED	Fixed	No
TRIP	Fixed	SightseeingModel

START (seconds) -- The number of seconds from the beginning of the simulation until this vehicle starts moving.

OK Cancel

Simulation Test Setup is Easy



Running the Simulation test

GrooveSim - Run Simulation...

Simulation Type

Run Once Monte Carlo

Duration:

Simulation Time

Real Time Fixed Time Increments:

Emergency from 127.0.0.1: t=0->600, "Vehicle cra

Add...
Edit...
Remove

Log File Type	Path
GrooveSim Message Log	messages.txt
Event Log 1	events.txt
Vehicle Neighbor Log	neighbors.txt

Run Cancel

Easy to Add New Models

```
int CarFollowingModel::Init()
{
    . . . . .
}

int CarFollowingModel::PreRun()
{
    . . . . .
}

int CarFollowingModel::ProcessEvent(SimEvent & event)
{
    . . . . .
}

int CarFollowingModel::PostRun()
{
    . . . . .
}

int CarFollowingModel::Cleanup()
{
    . . . . .
}
```

What's Next?

- Develop an Embedded in-vehicle platform
- General Motors to deploy 50 vehicles
- Congestion Probe and Stream Protocols
- GrooveNet is Free for academic use
Email: Rahul (rahul@cmu.edu)



That's all Folks!

Infrastructure Nodes

