GrooveNet
Connected Vehicles. Connected People.

GrooveNet

Hybrid Simulator for Vehicular Networks

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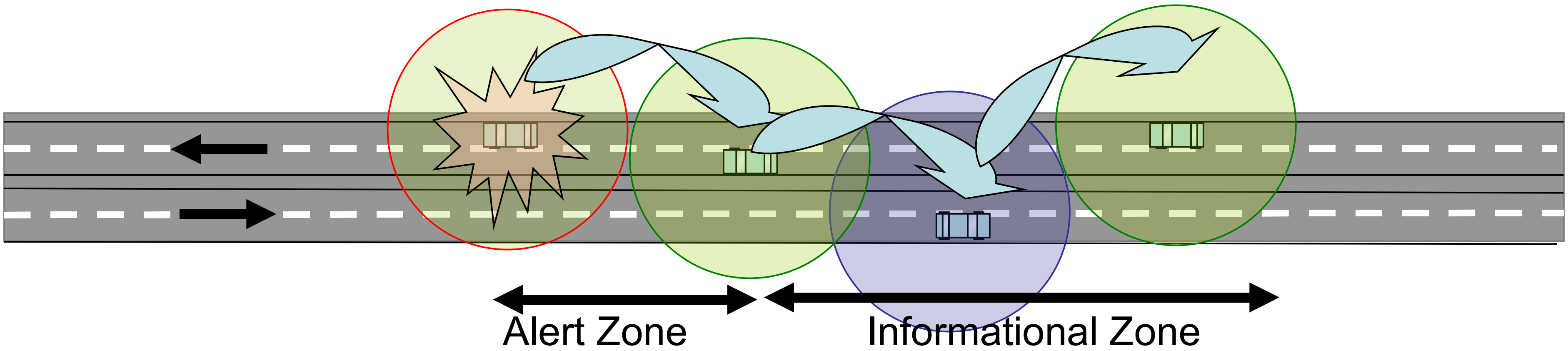
General Motors – Carnegie Mellon Collaborative Research Laboratory

- **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

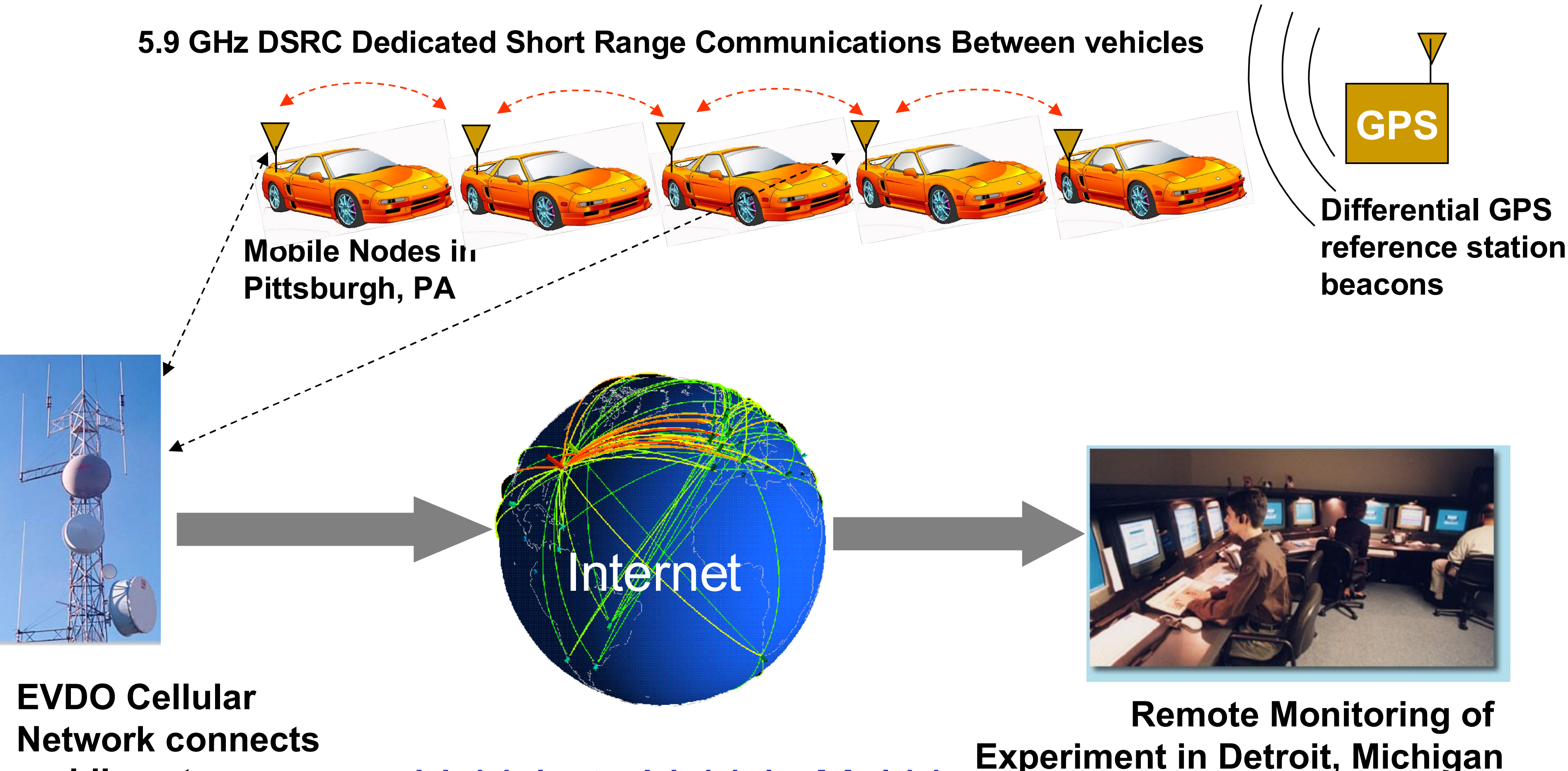
What are Vehicle-to-Vehicle Networks?



- **Vehicle-to-Vehicle Wireless Broadcast Protocols for:**
  - On-road Safety
  - Traffic Congestion Probing

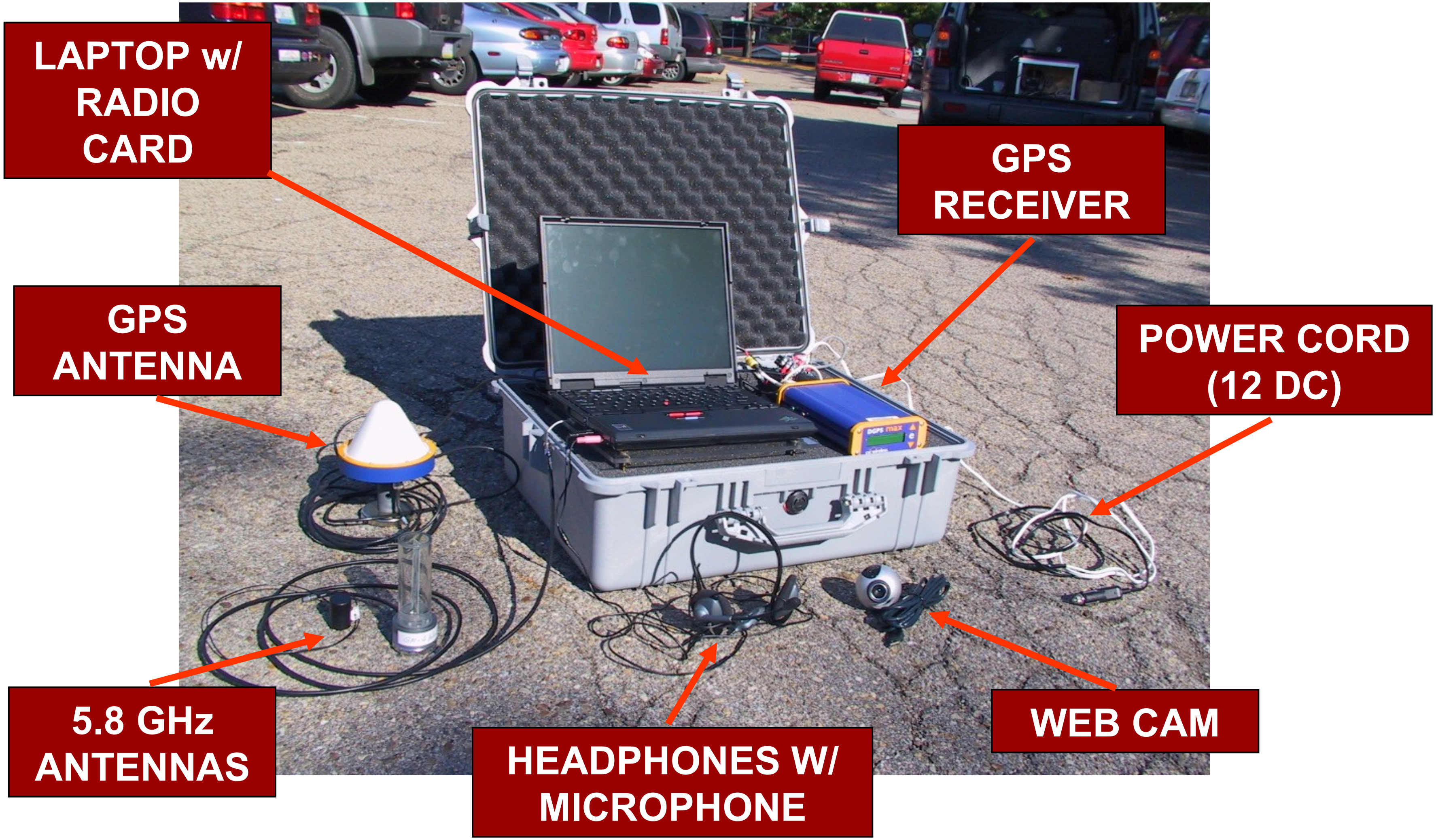
- **The Key Questions:**
  - Market Penetration to make v2v useful?
  - Performance in urban, rural and highway?
  - What mix of mobile gateways, infrastructure and on-board wireless?
  - Which multi-hop protocols work best and under what conditions?

Experimental Multi-hop Vehicular Network Test-bed



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

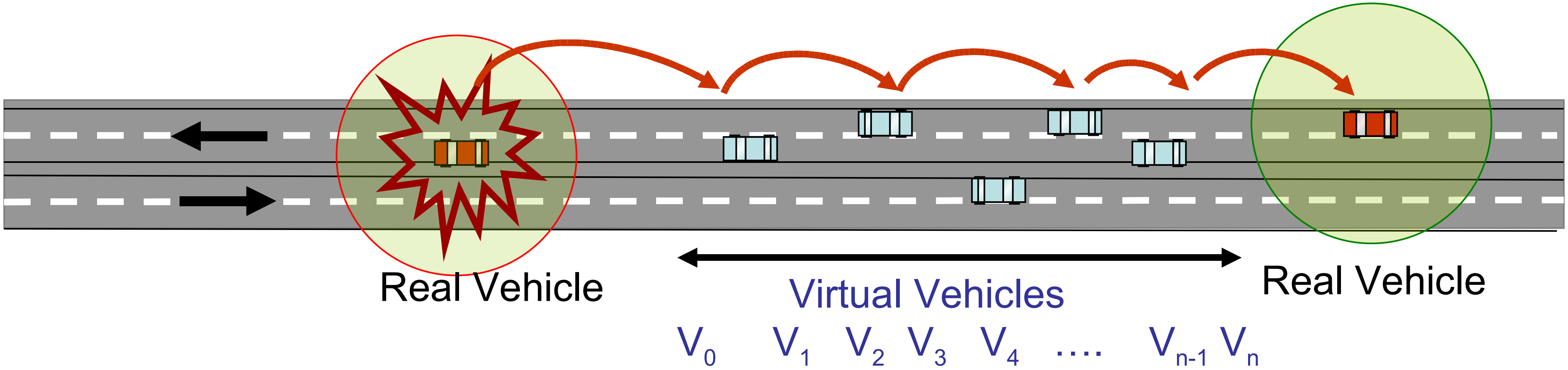
GrooveNet Test Kit



- 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?

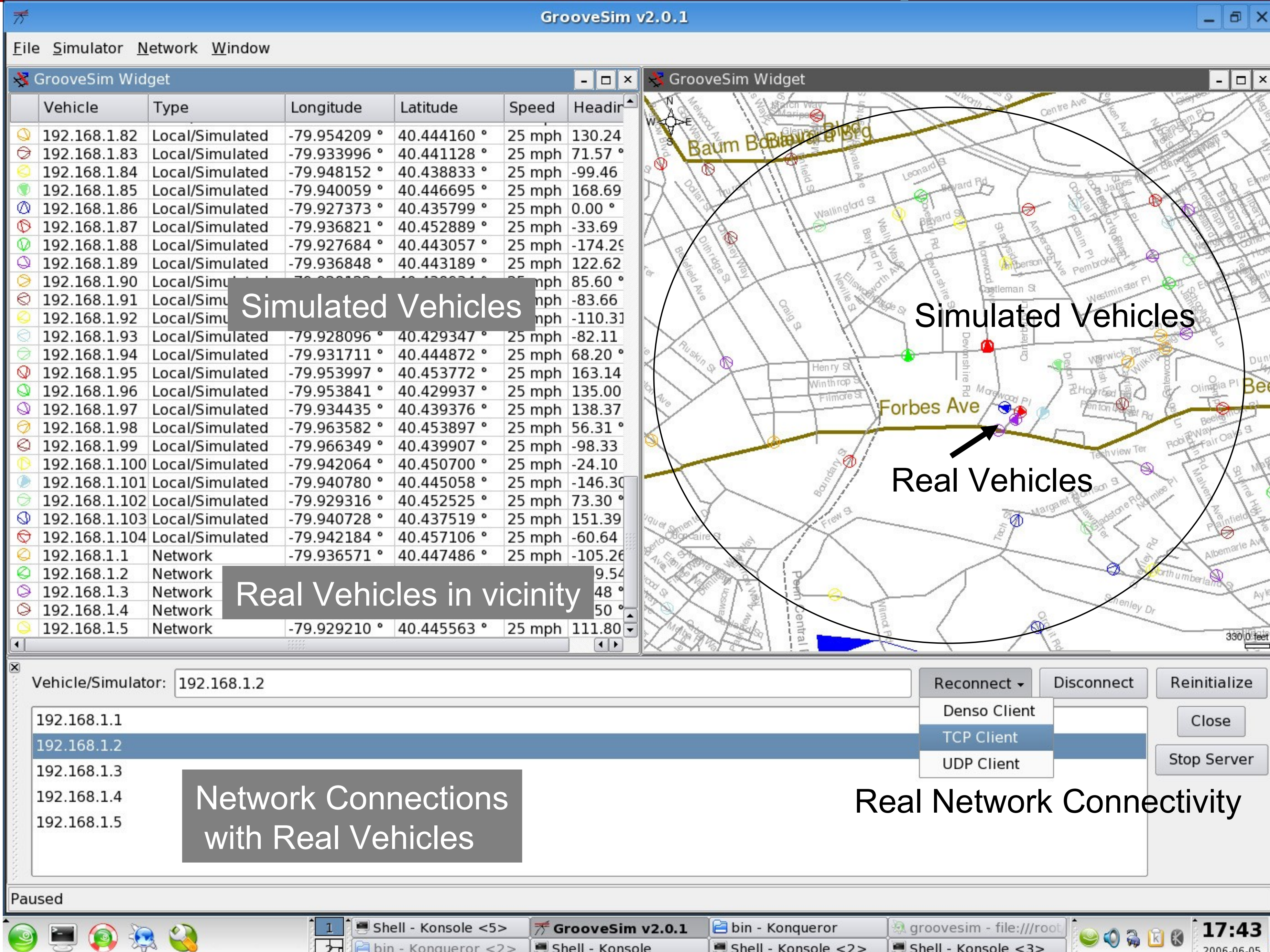


Key Benefits:

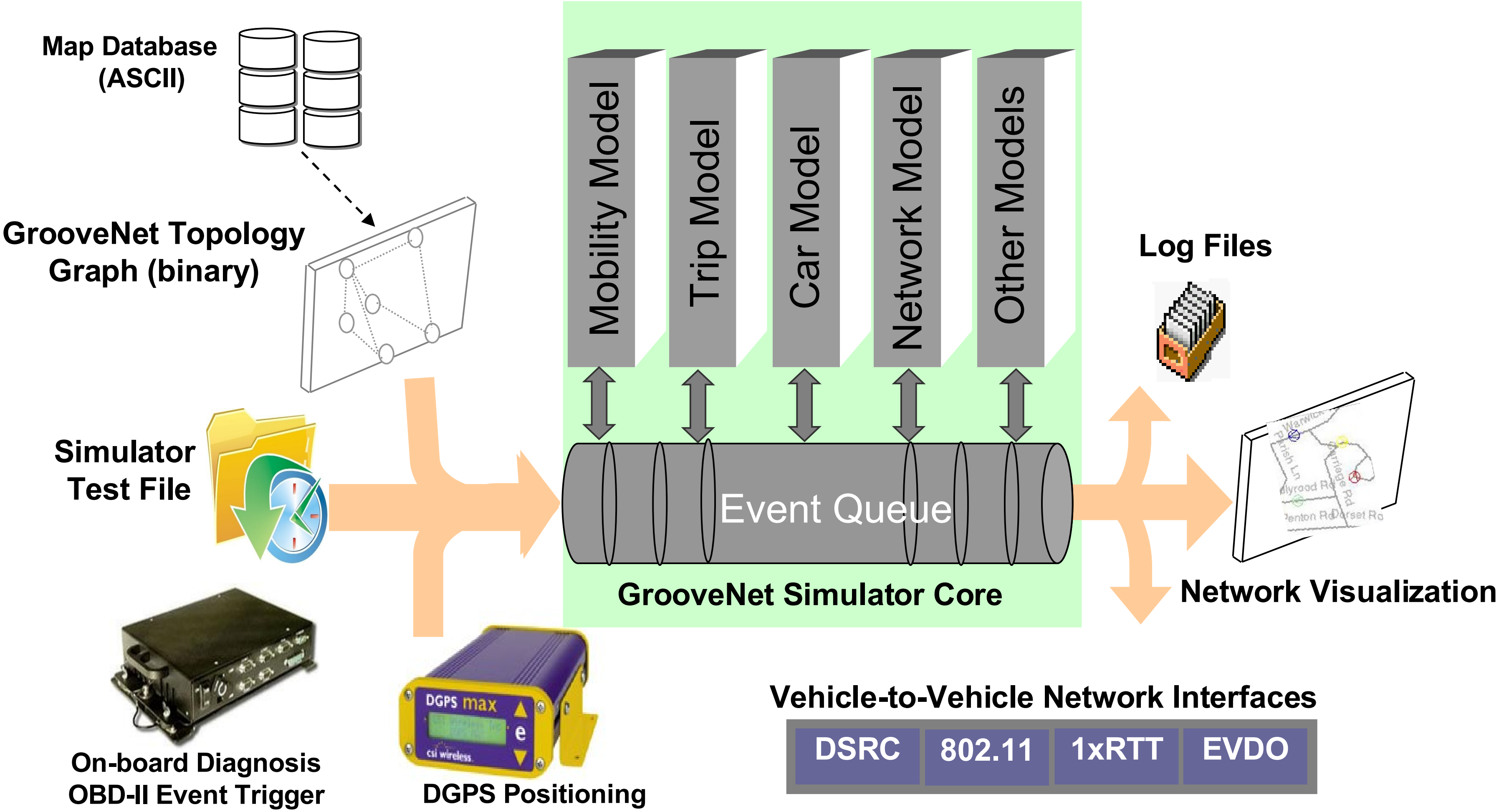
- Use same protocol implementation for Simulation and Prototype
- Observe effects of Network Scaling and Traffic Density
- Remote Monitoring of On-road Experiments
- Evaluate correctness of Physical, Link Layer and Vehicle Interaction Models

GM-CMU Collaborative Research Laboratory

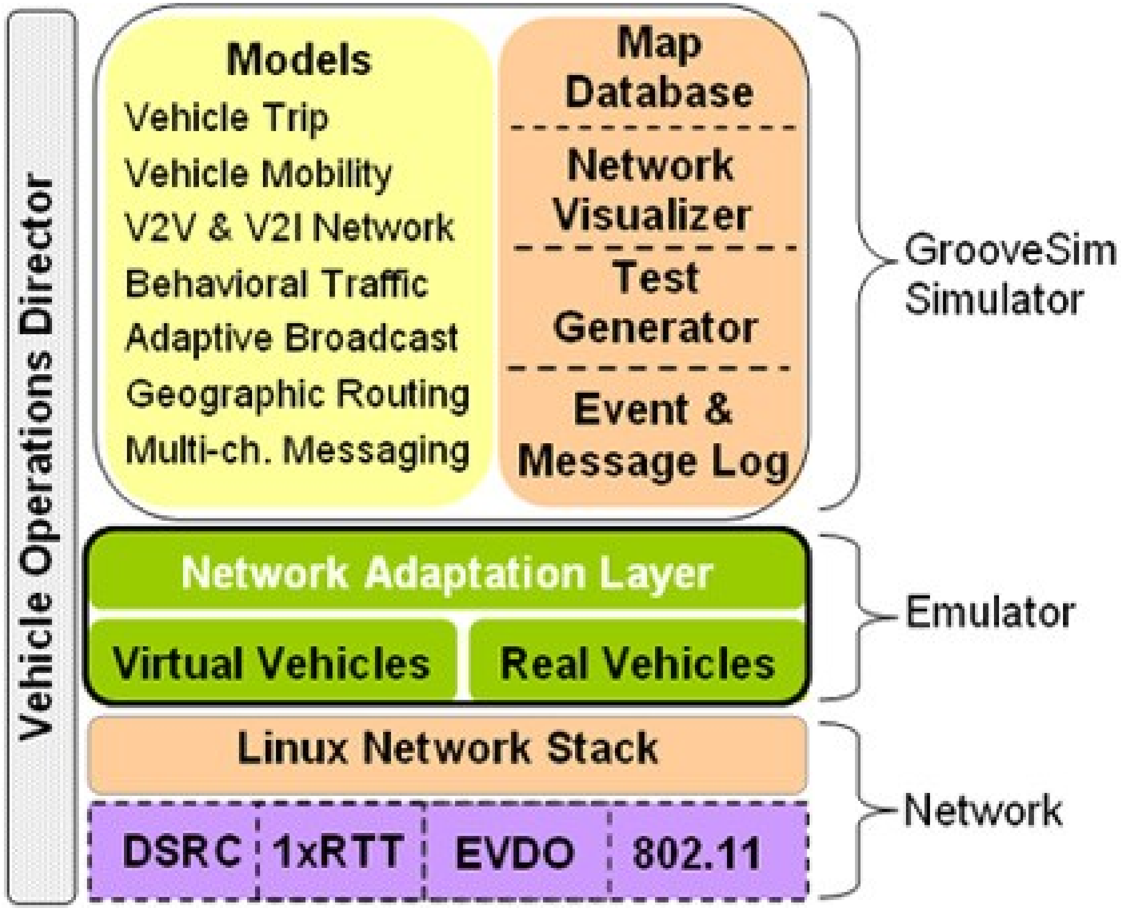
Carnegie Mellon



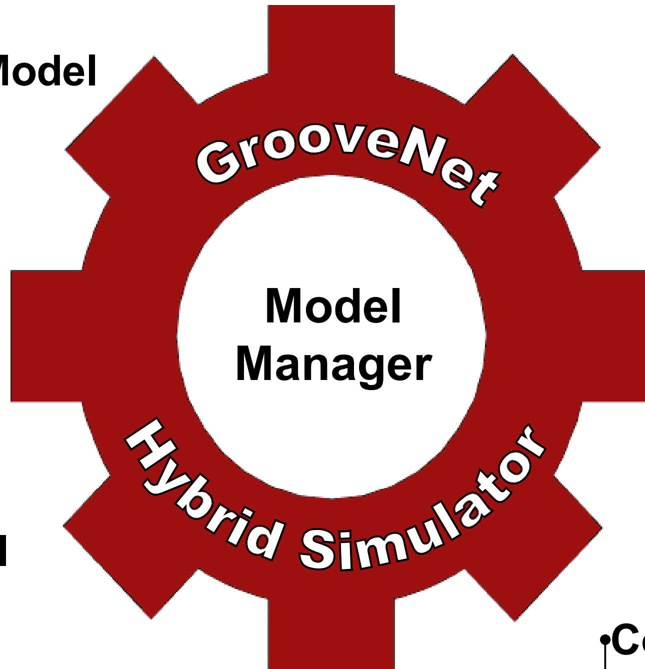
GrooveNet Hybrid Simulator Design



Modular Architecture



Modular Architecture (2)



Traffic Light Model

Infrastructure Node Model

Trip Model
- Random Walk
- Djikstra
- Sightseeing

Car Model
- GPS Mode
- Simulator Mode
- Network Mode
- Random Waypoint

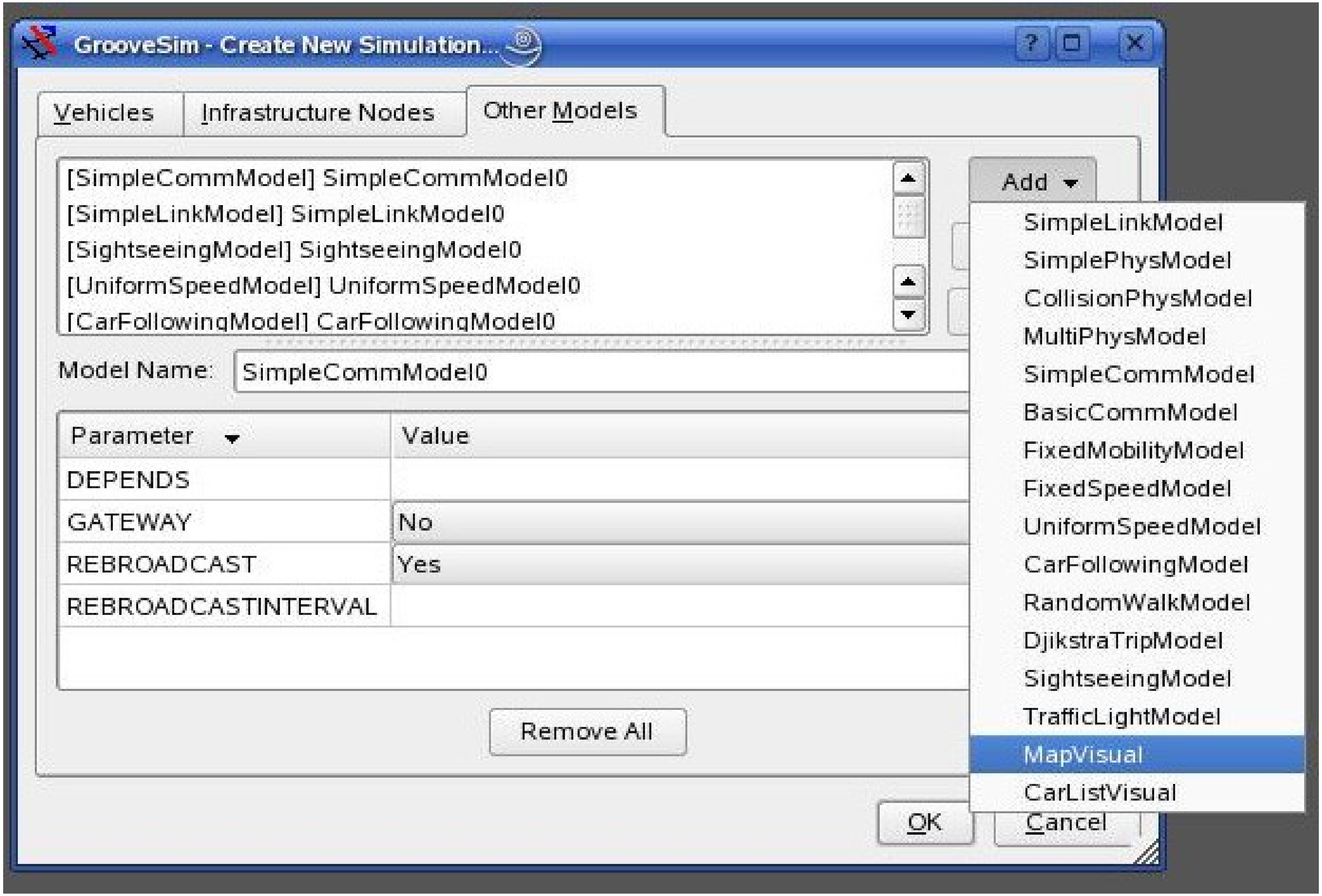
Visualizer
- Map Visual
- Car List Visual

Mobility Model
- Fixed Mobility
- Street Speed
- Uniform Speed
- Car Following

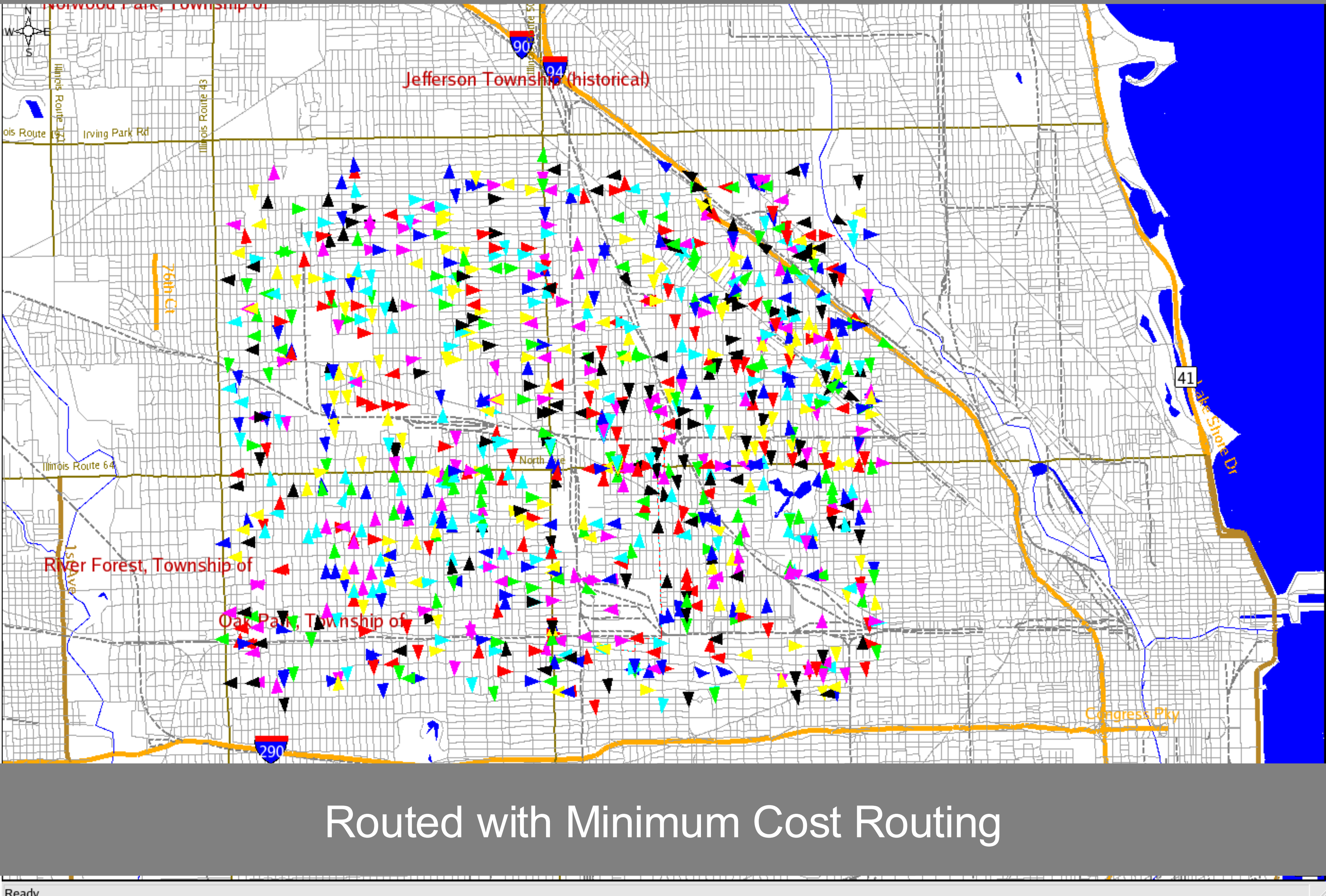
Comm. & Link Model
- Adaptive Re-broadcast
- Groove Re-broadcast

PHY Model
- Simple PHY
- Collision PHY
- Multi-Channel PHY

Click to Add Model

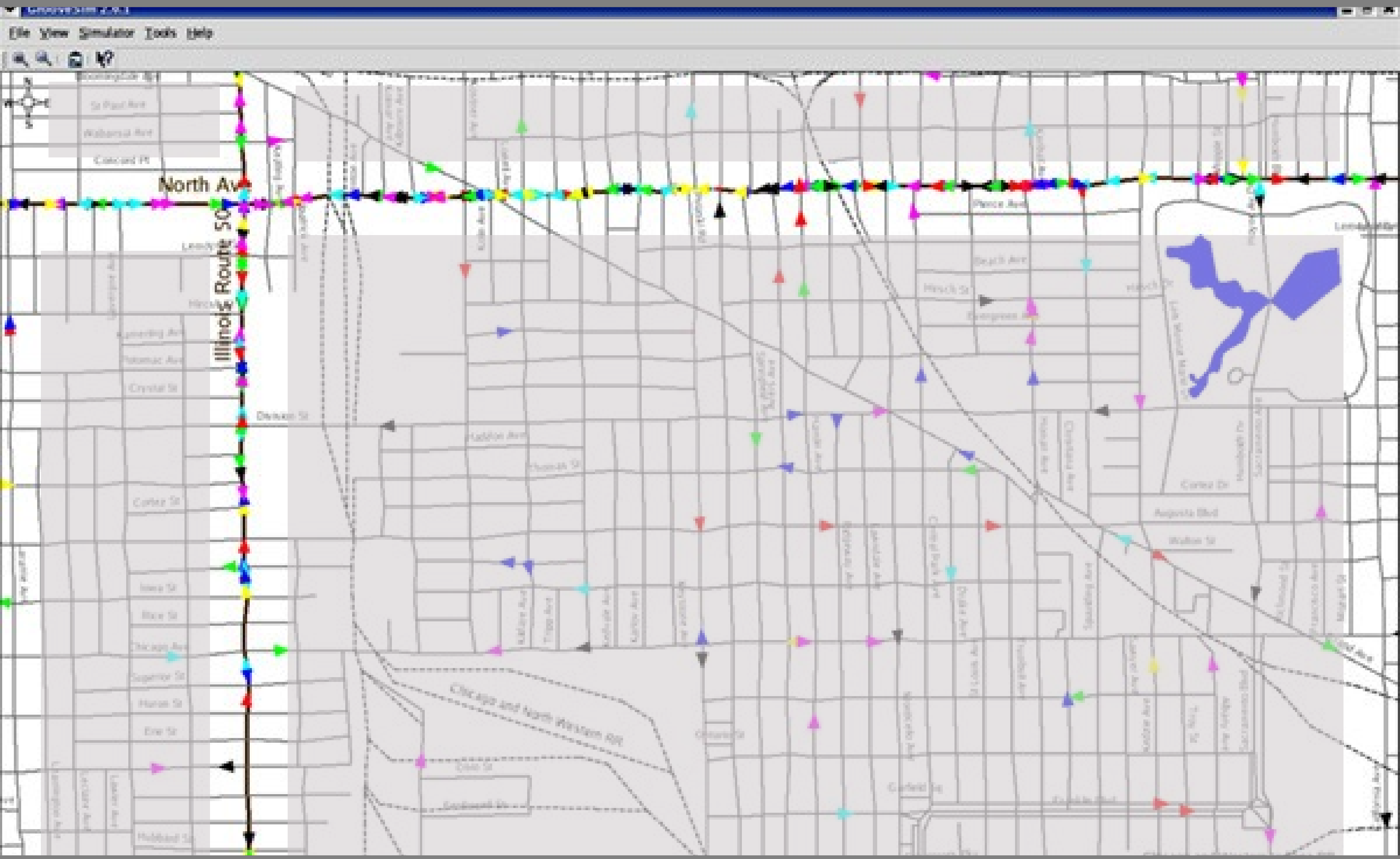


1,000 Vehicles in Chicago, IL suburb



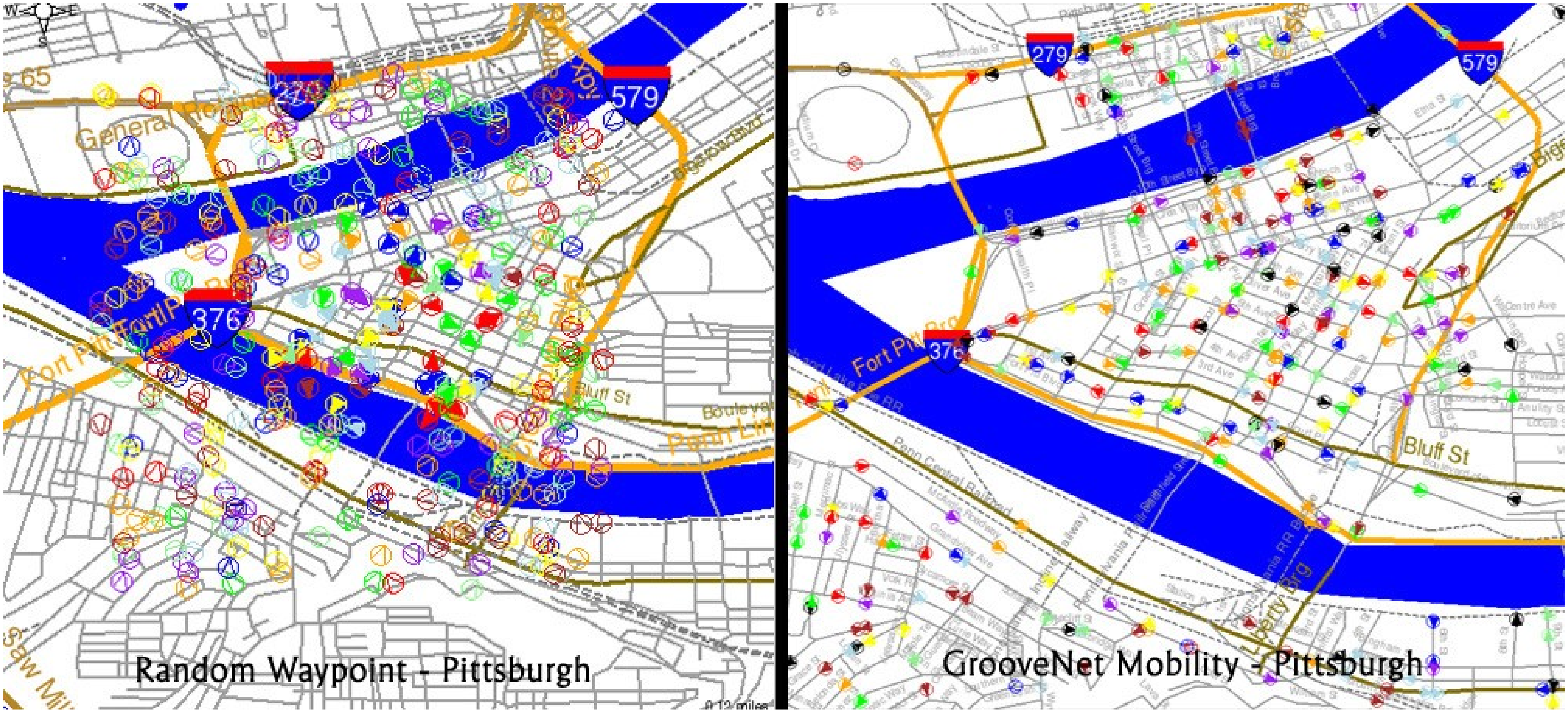
Routed with Minimum Cost Routing

Minimum Weight Routing

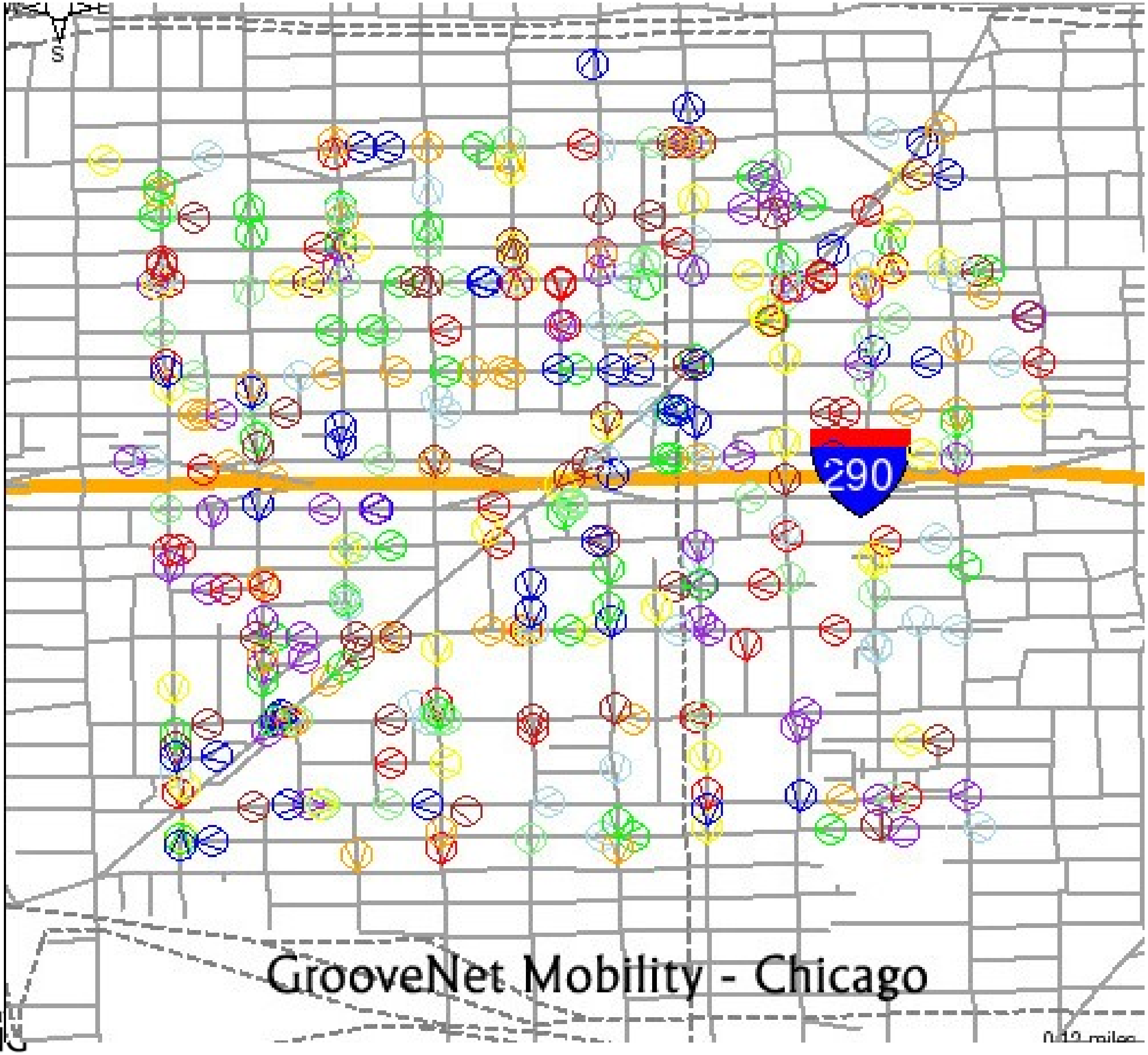


Vehicles migrate to roads with higher speed limits

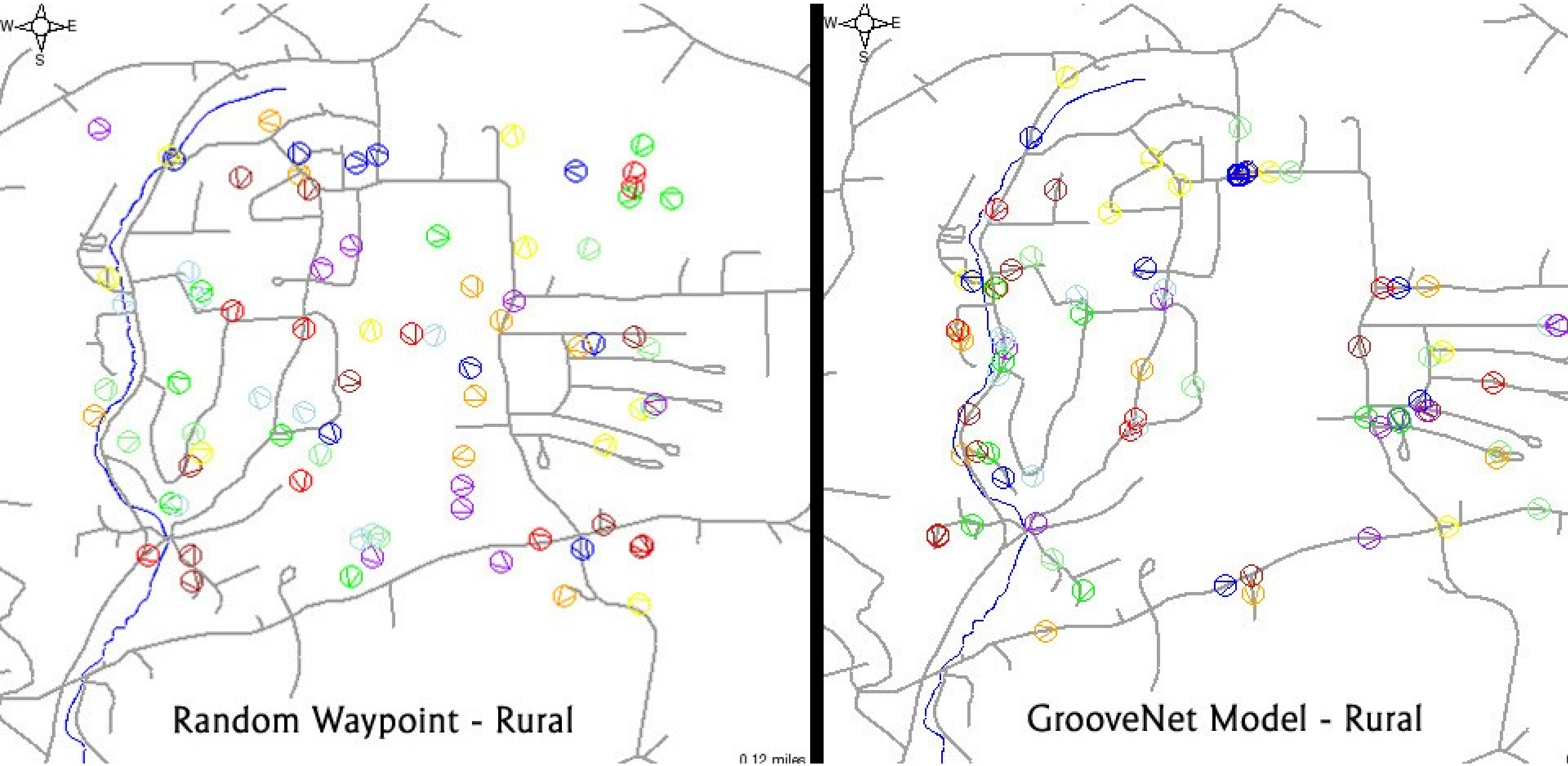
Why do we need GrooveNet?



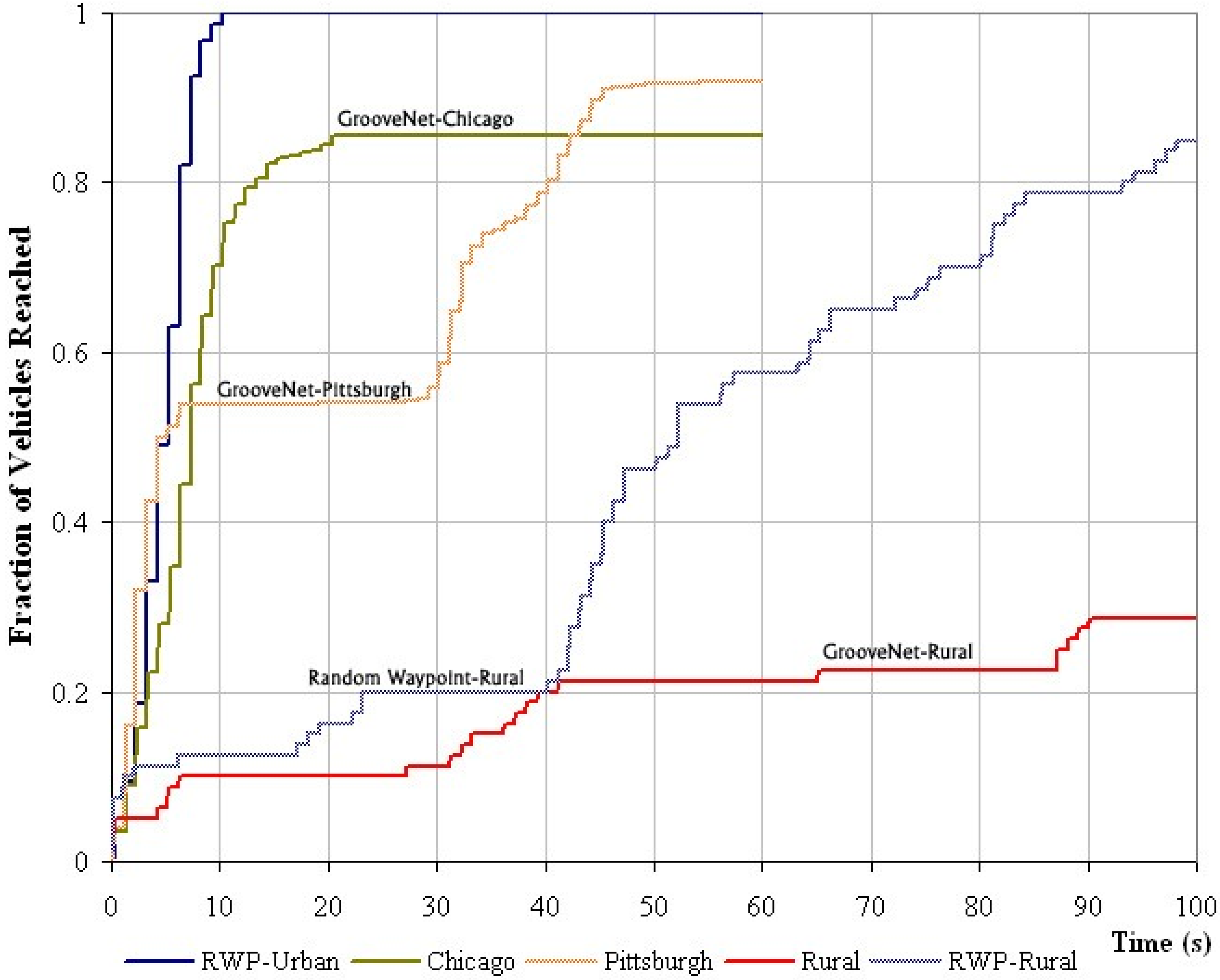
Uniform Urban Distribution



Rural Area: Rnd Waypoint Vs GrooveNet Topology-Mobility Models

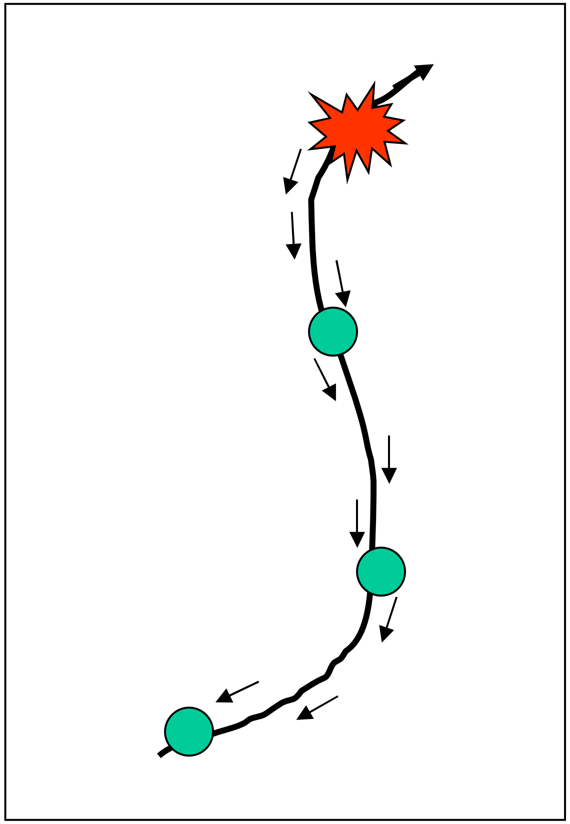


Message Propagation Rate

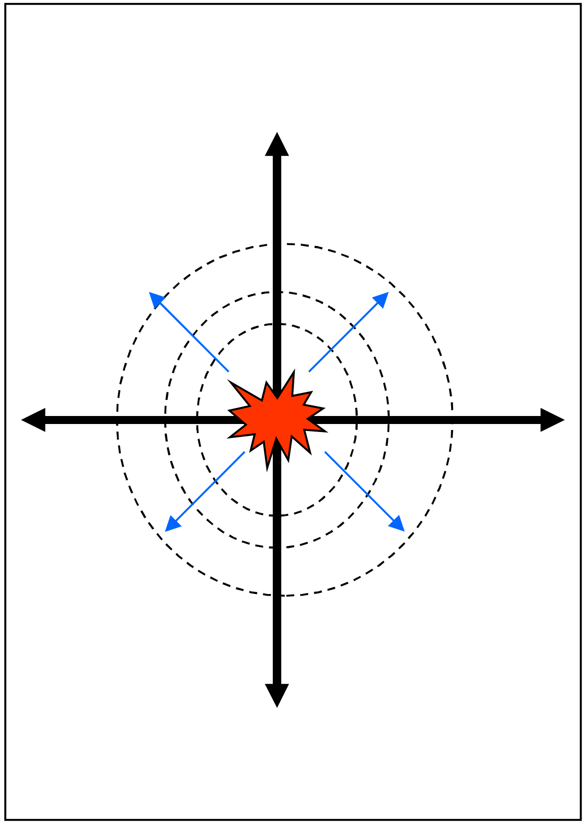


GeoRoute: Broadcast Scenarios

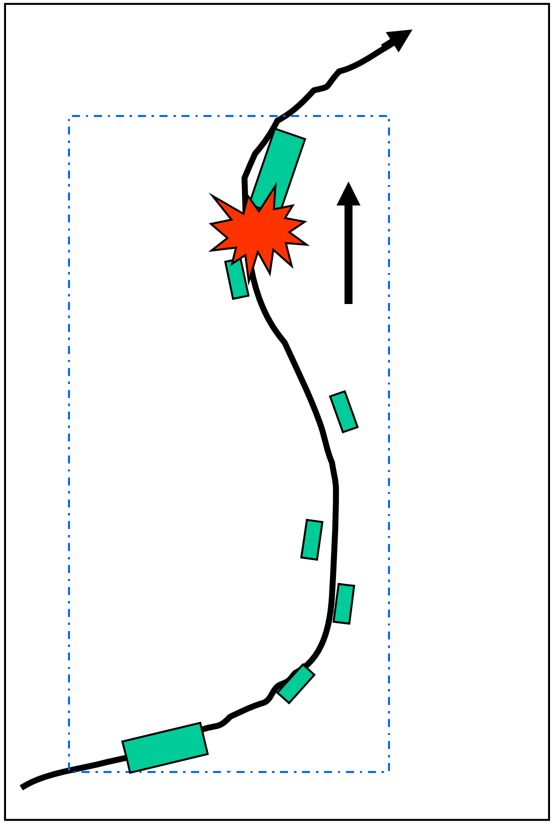
Highway Driving



City Driving



Rural Driving

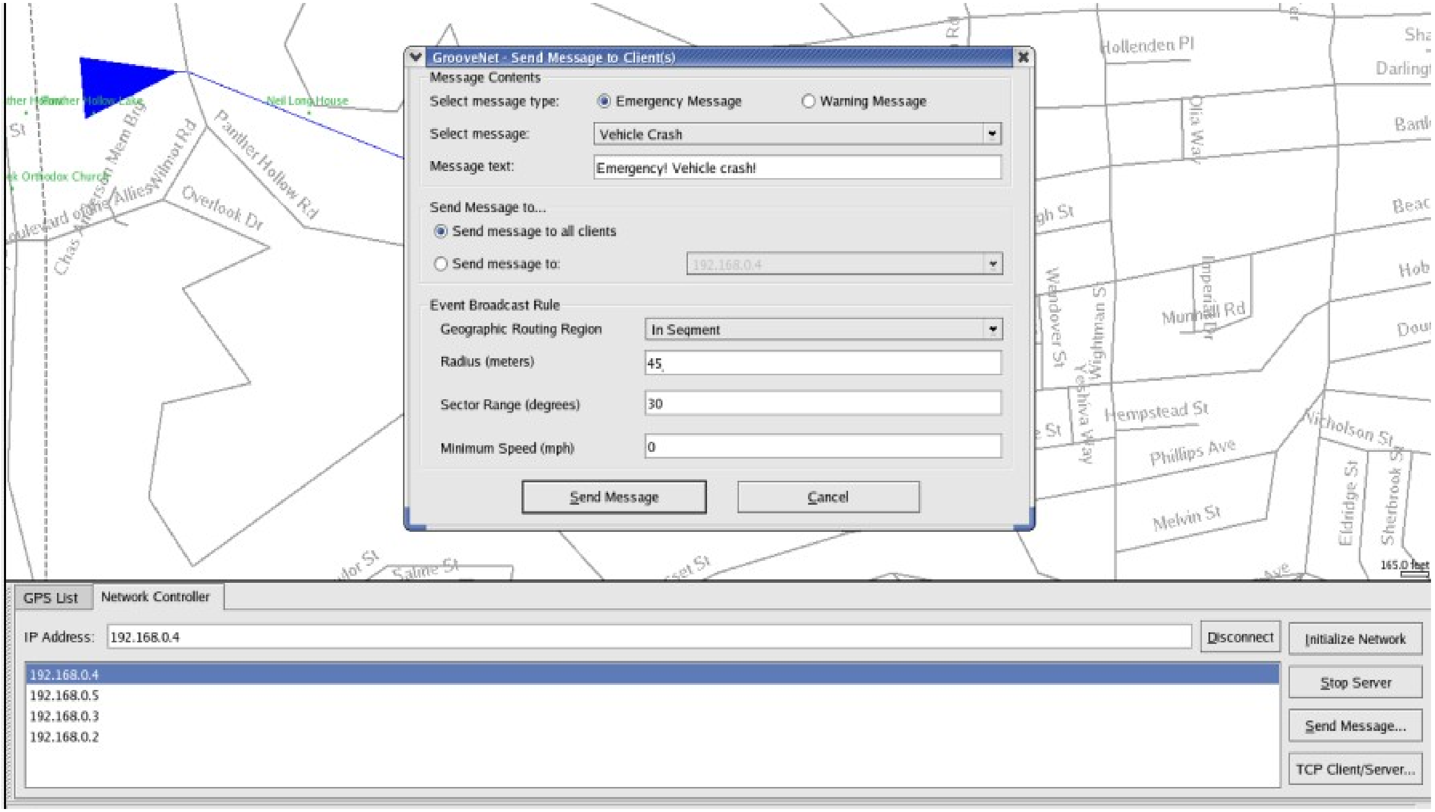


- Path with Intermediate points
- Static Source Routing

- Radial Broadcast

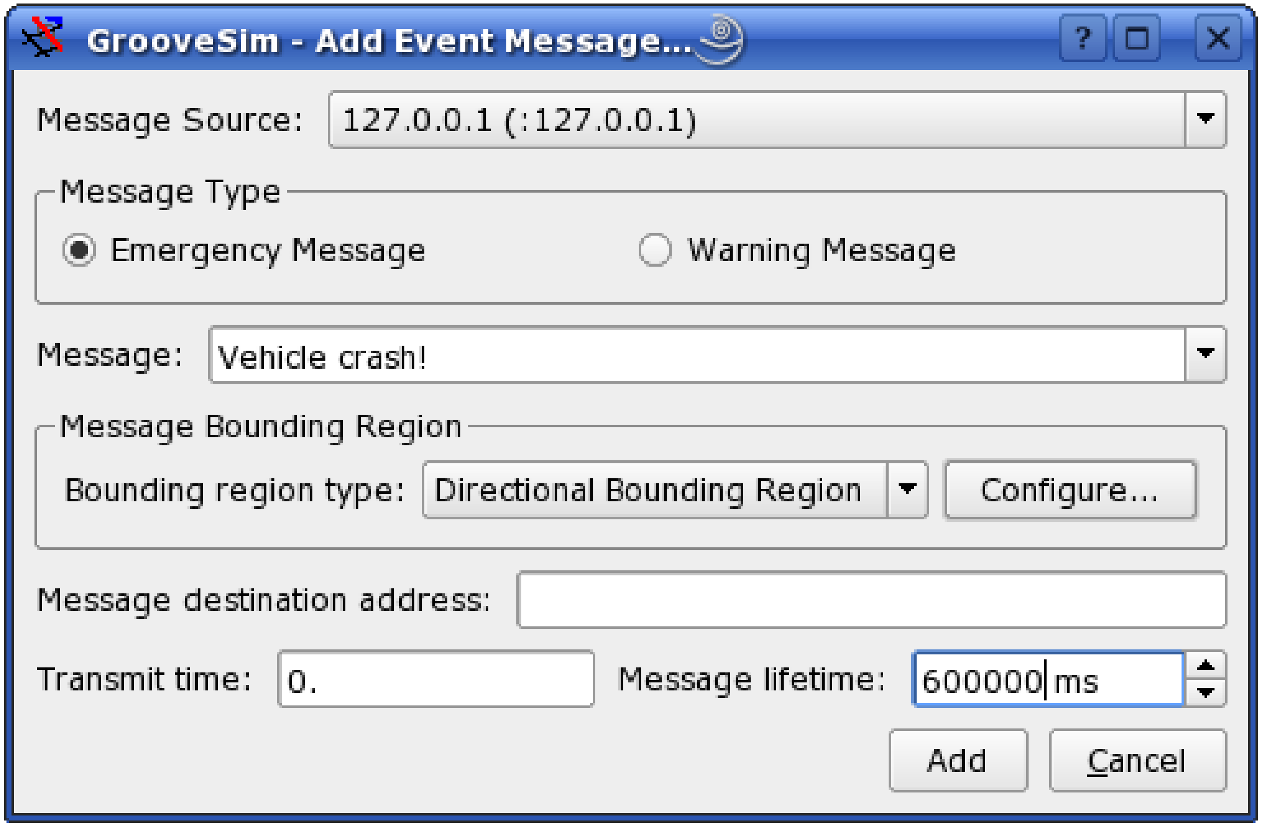
- Bounding Box
- Controlled Flooding

GrooveSim – On-Road Alerts (1)

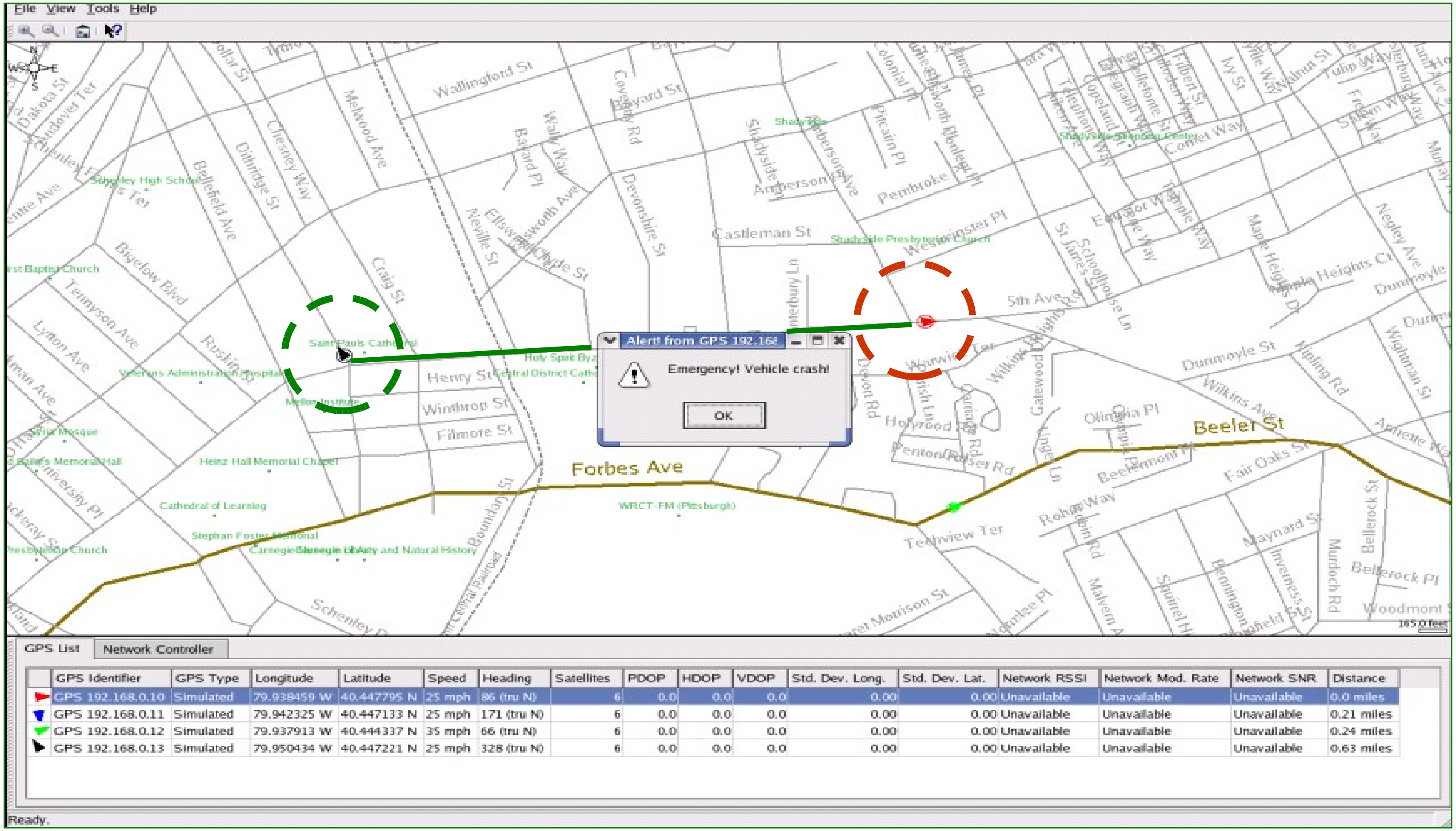


- Broadcast Safety Alerts to all vehicles in the vicinity
- Messages are valid in a specific geographic region
- Regions are determined by position, speed and direction

GrooveSim – On-Road Alerts (2)



GrooveSim – On-Road Alerts (3)

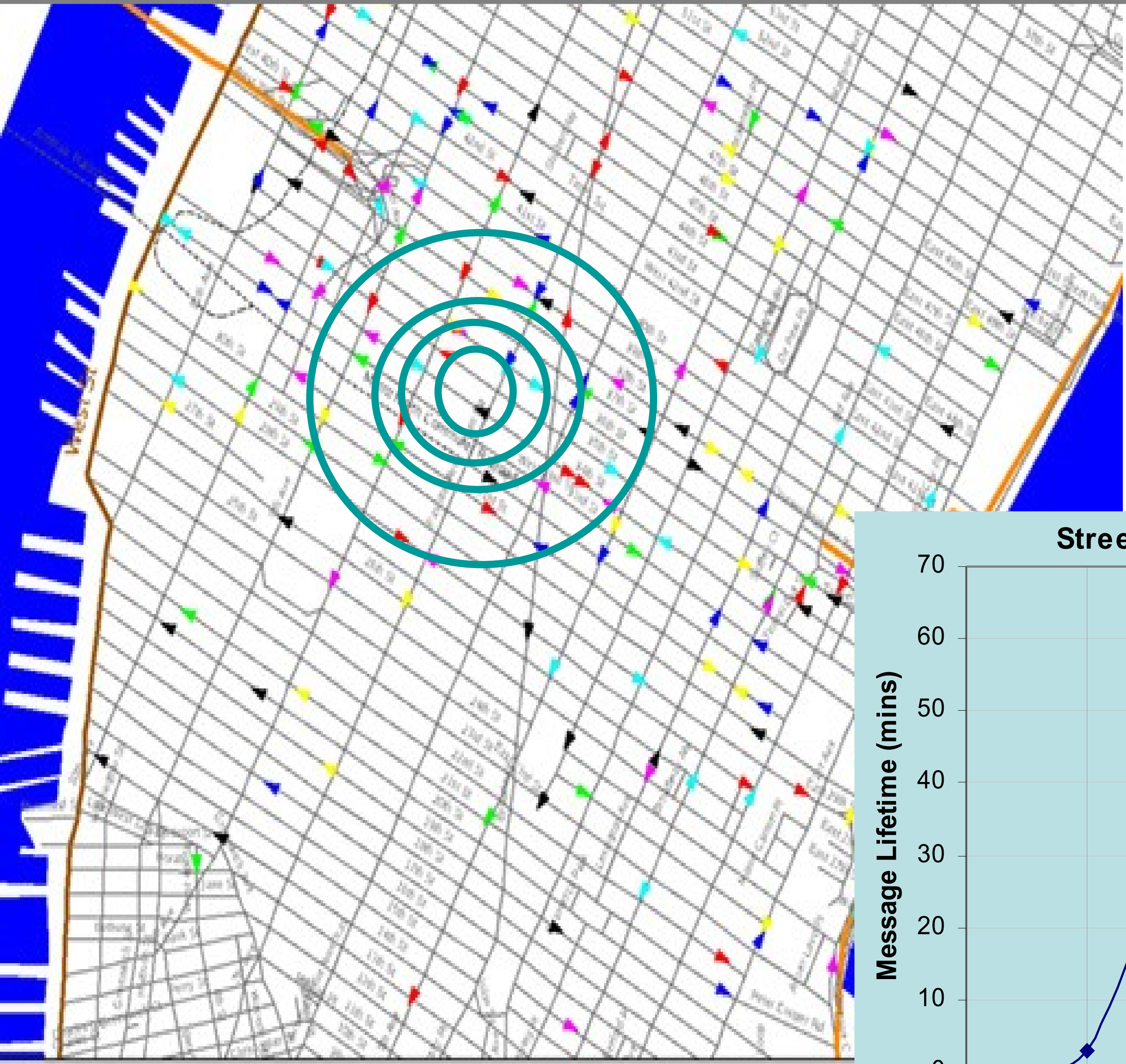


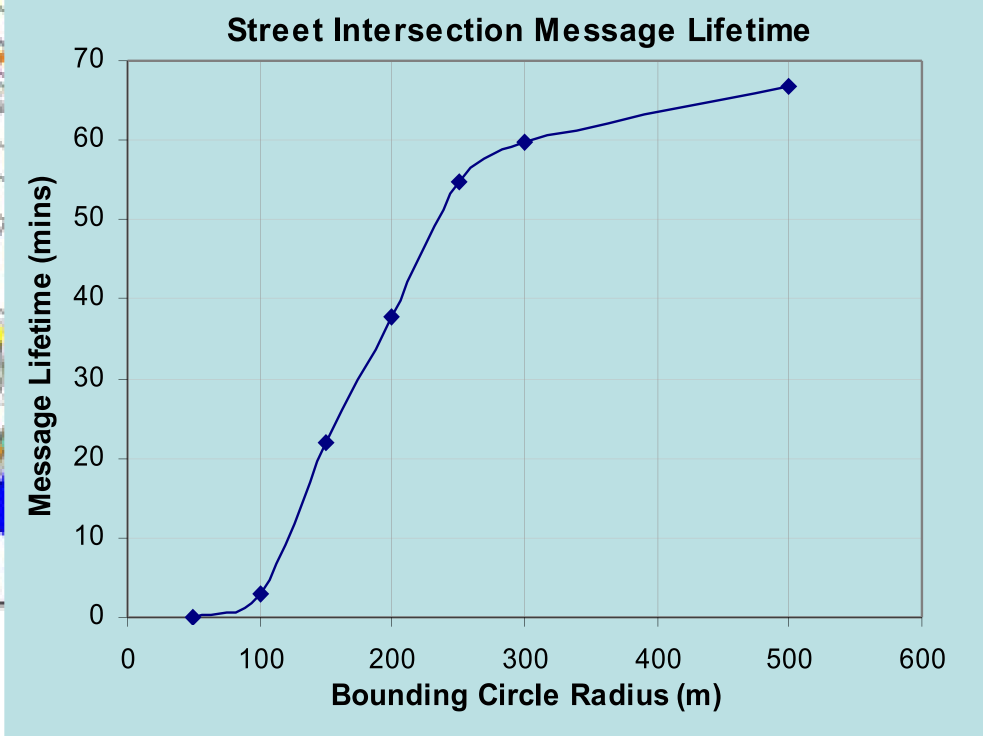
- Only vehicles in the relevant geographic region receive alerts

Performance: Message Delay

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

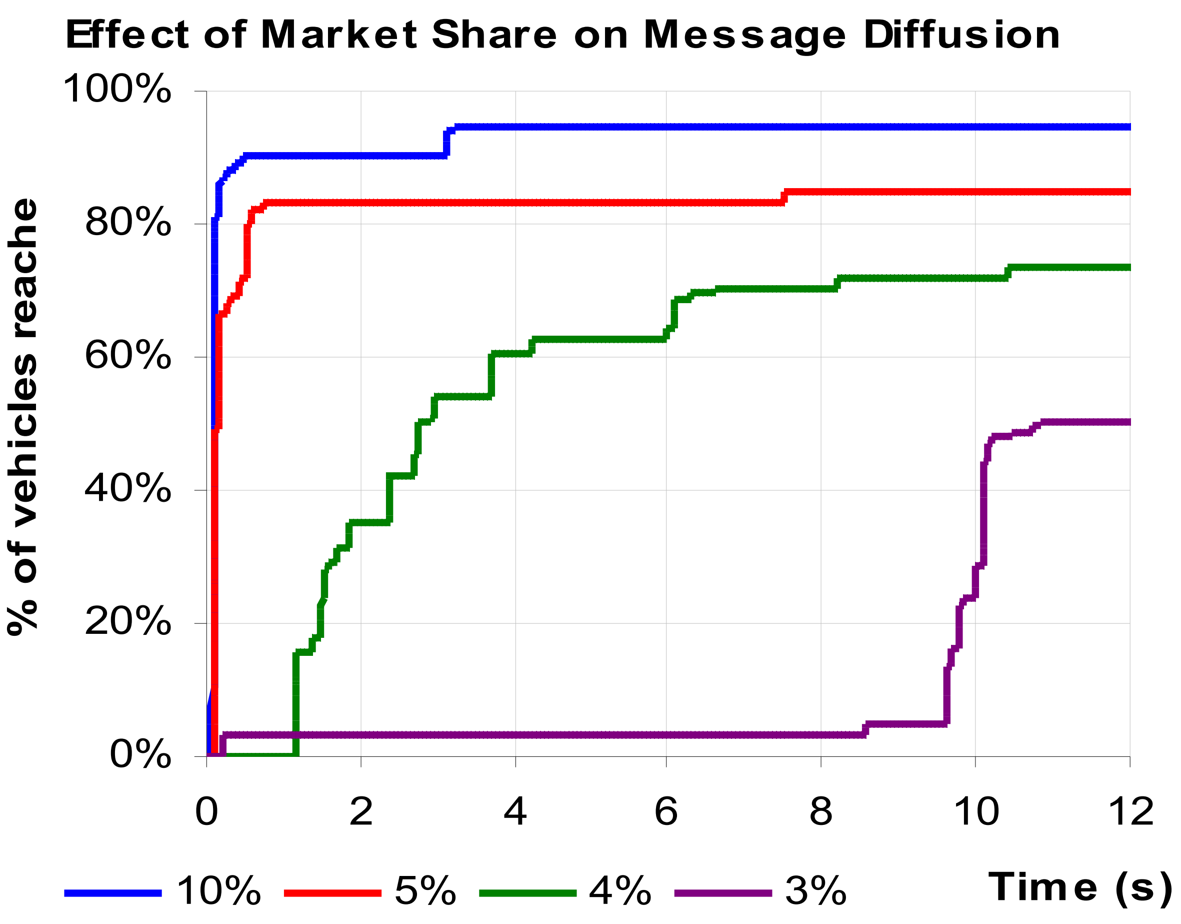
Performance: Message Lifetime



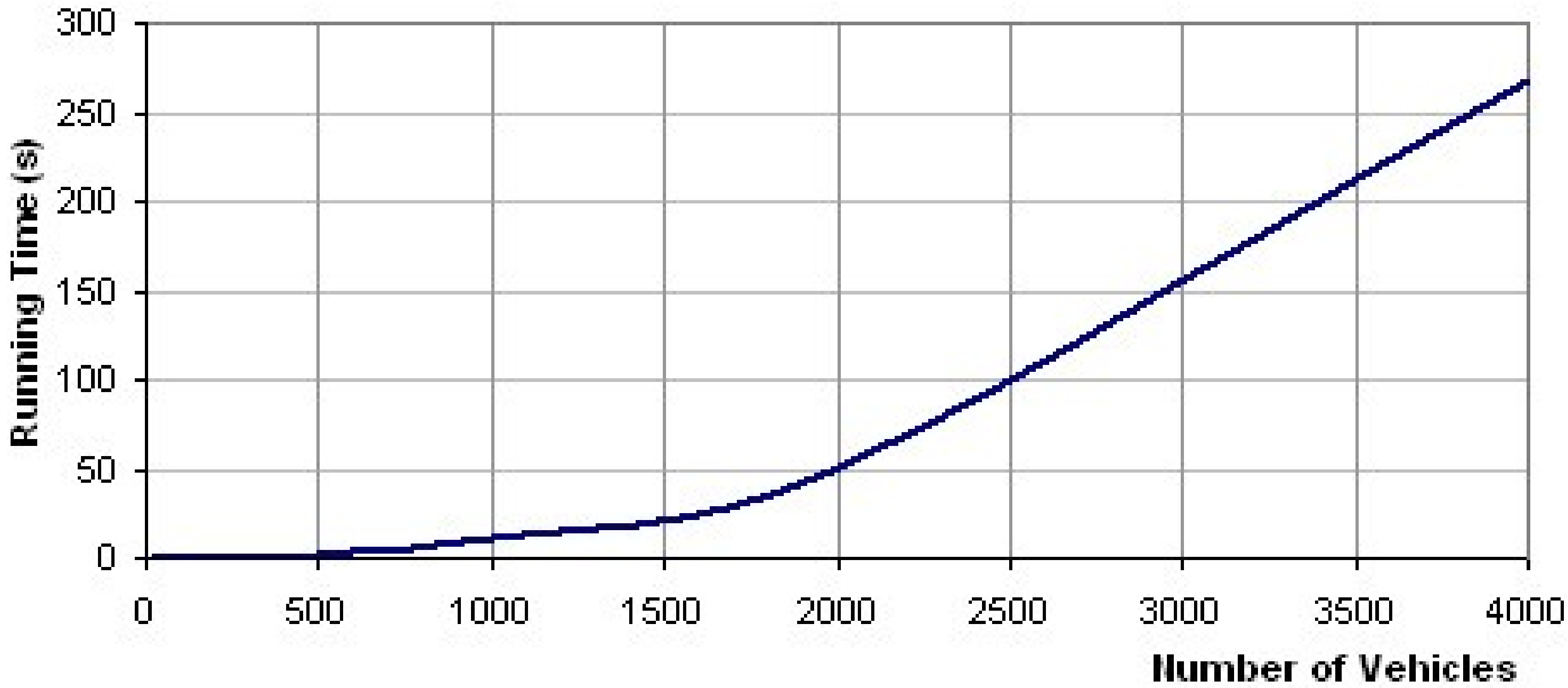


How close are we to V2V?

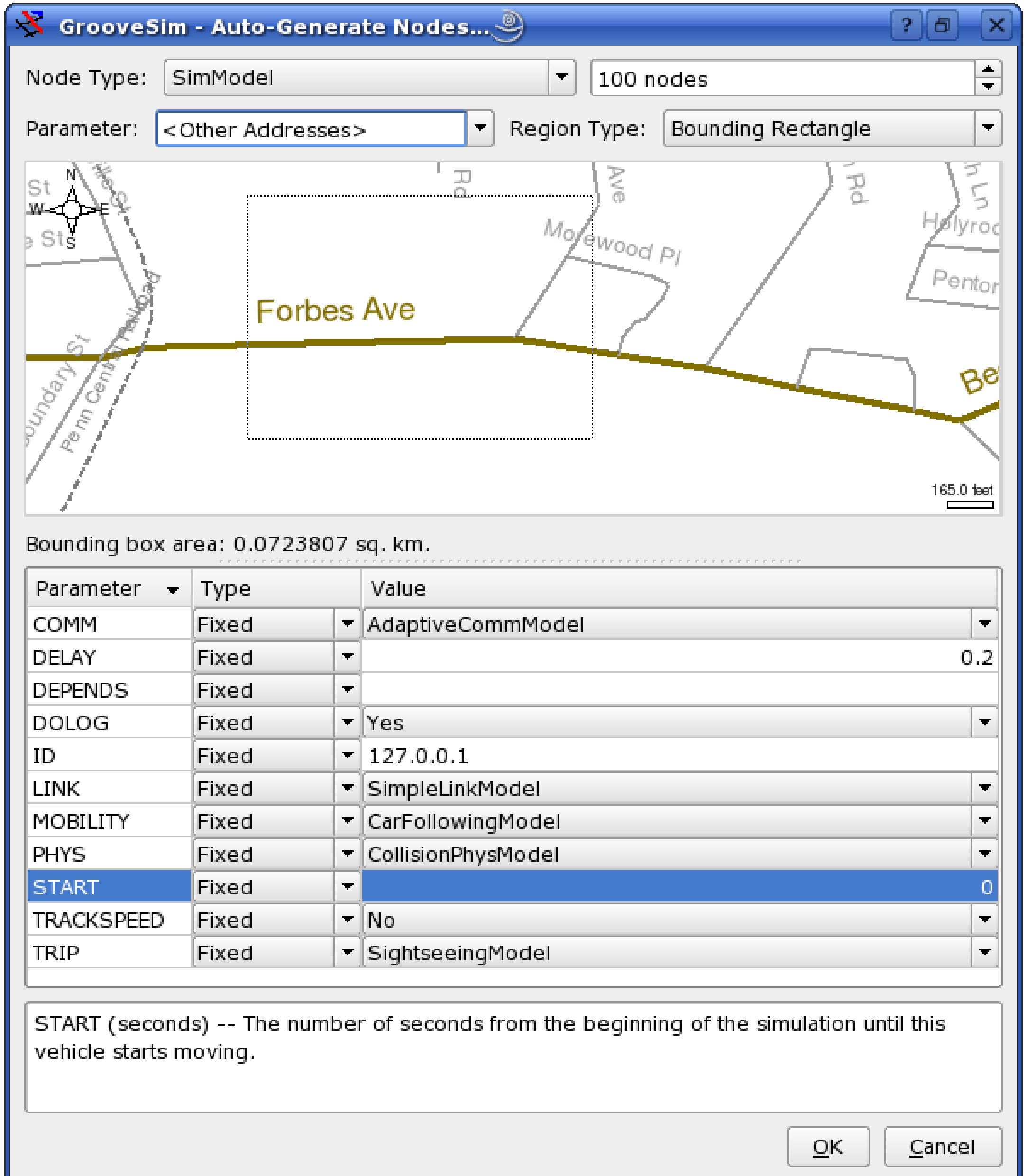
V2V Market Share



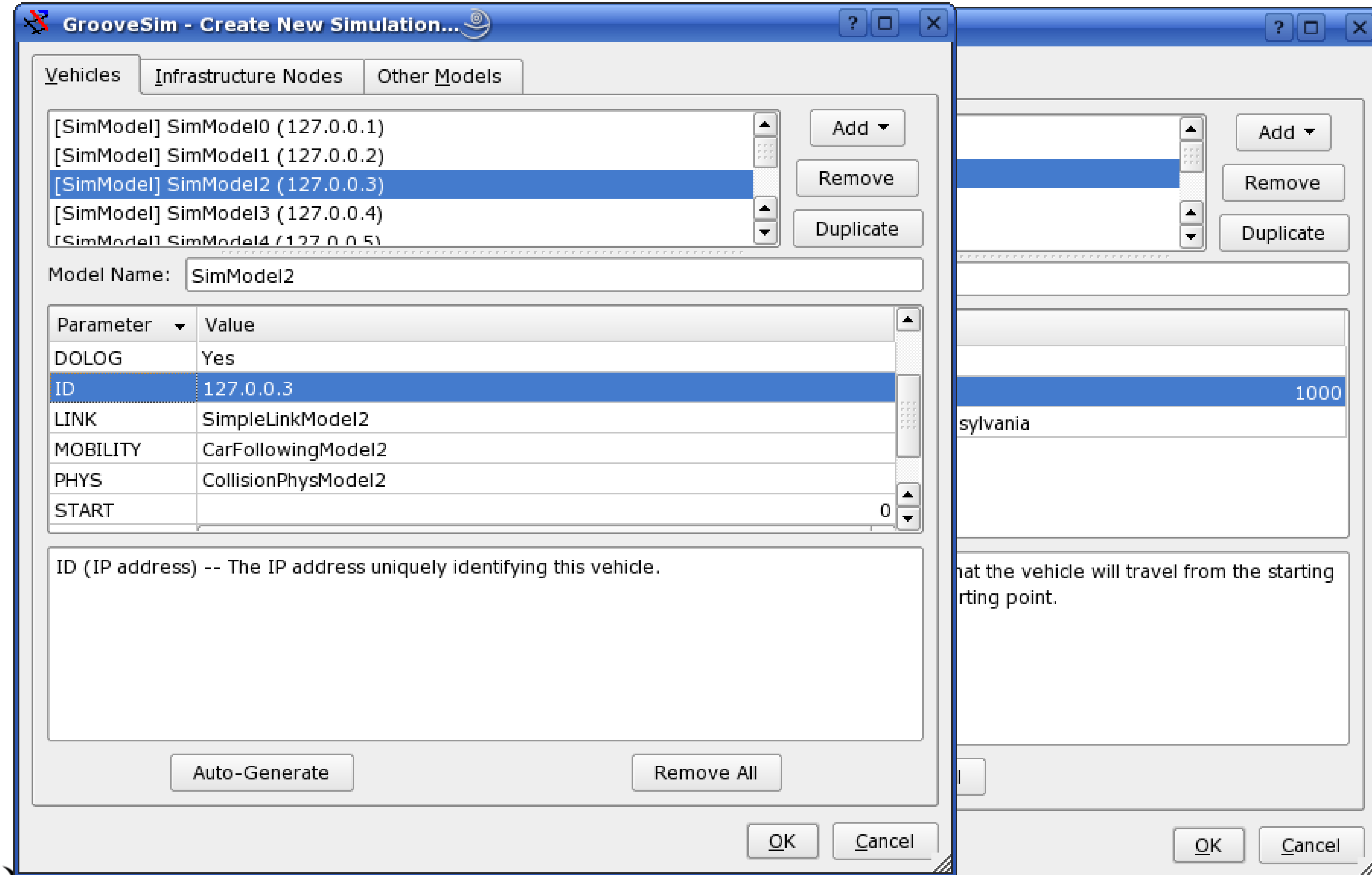
Simulator Scalability



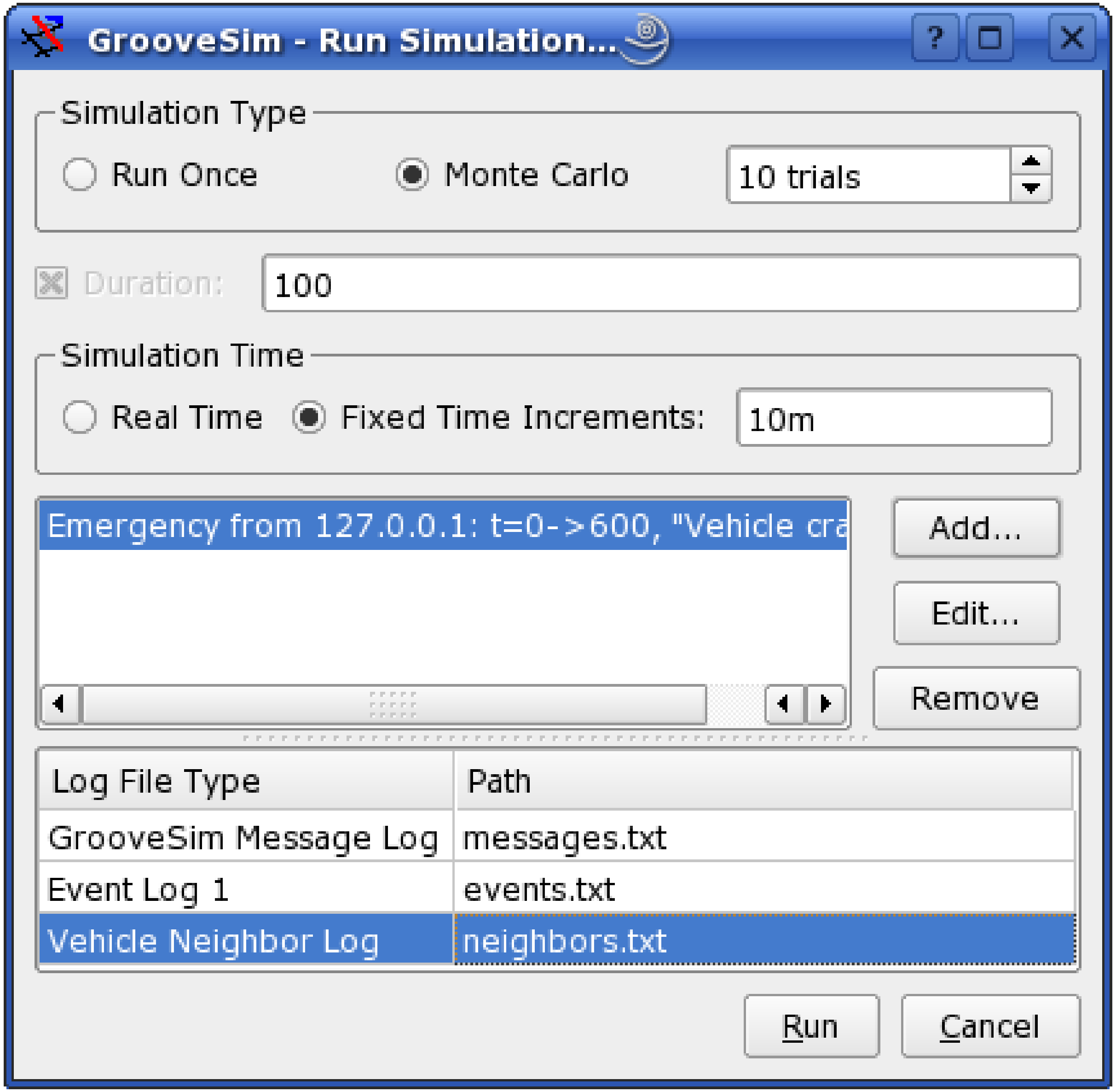
Simulation Setup – 1000s of vehicles



Simulation Test Setup is Easy



Running the Simulation test



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

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"That's all Folks!"

Infrastructure Nodes