Vehicular Networks

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Background

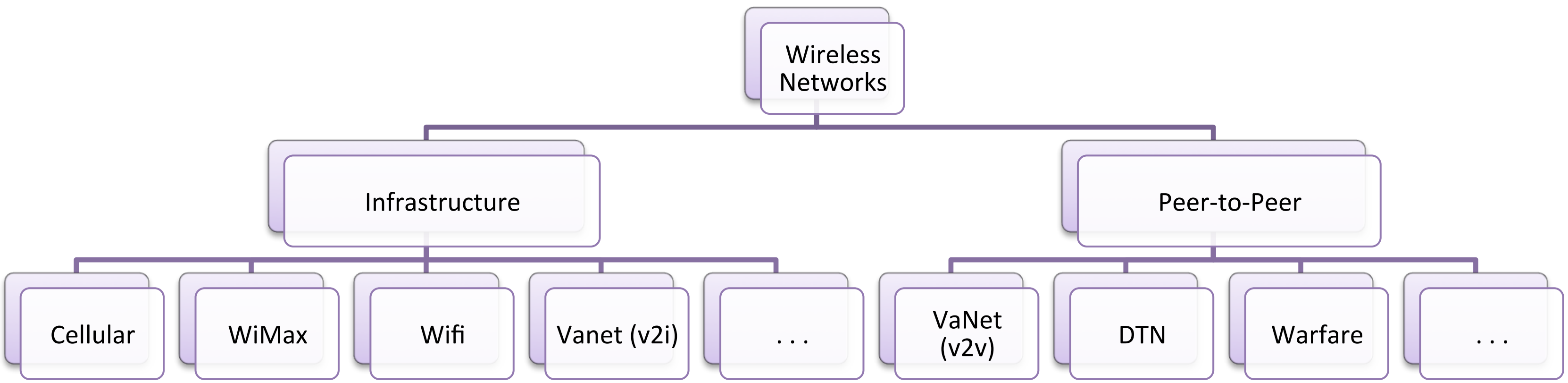
- What vehicles, bikes, busses, dolphins, zebra have in common?
- How they the items above are different from Cell-phones and what instead they have in common?
- What is the Major problem solved by TCP/IP and protocol Layering?

Background

- Intuitively what role play:
  - Mobility?
  - Physical Environment?

- What are the challenges?

A Taxonomy by Architecture



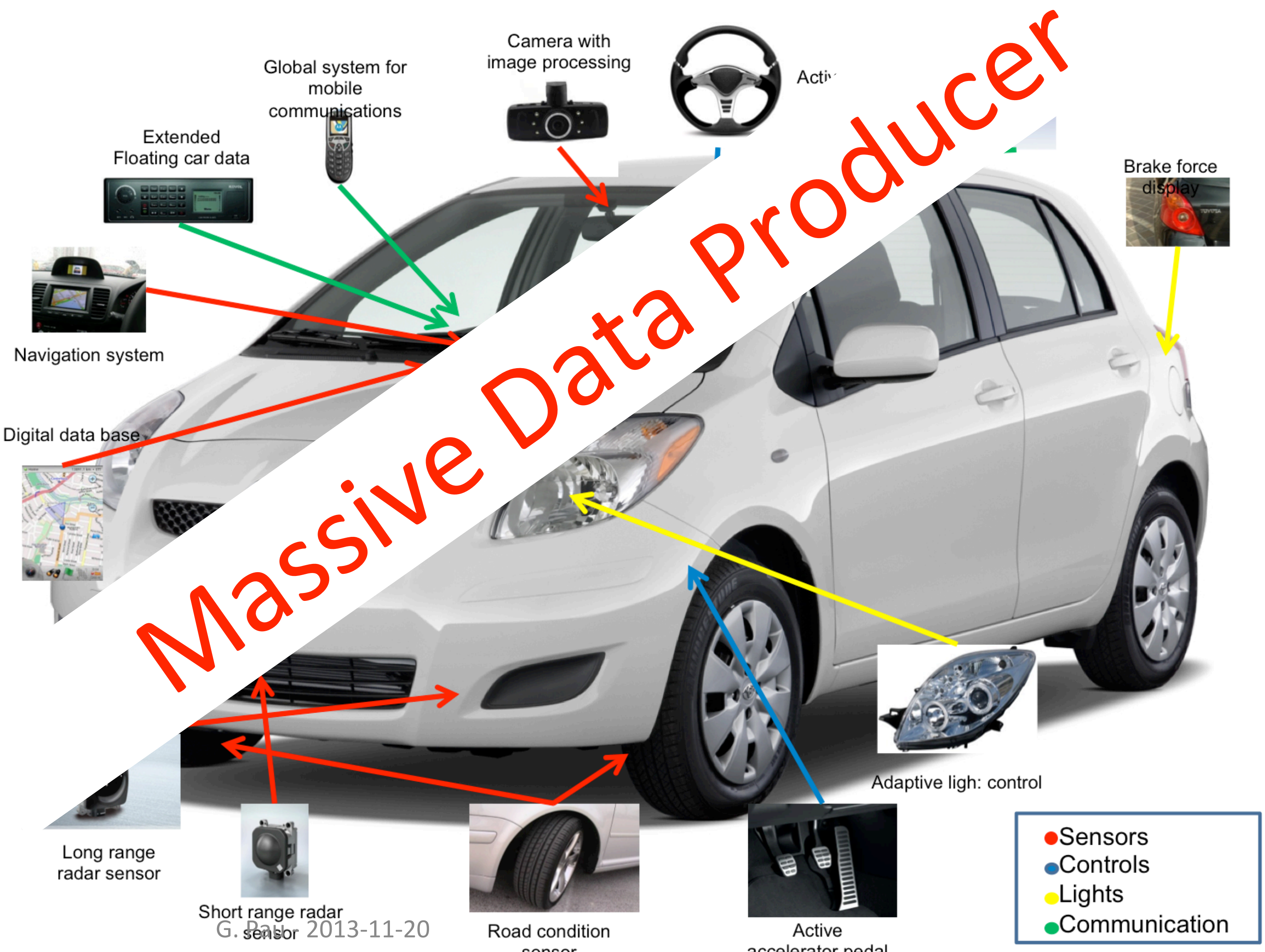
Vehicular Networks

… Cars …

- They are present in large numbers
  - China and India being the largest growing population of Cars
  - With a penetration rate of about 70% in most developed countries.
- Have virtually no energy constrains
  - When the engine is ON energy is produced by the alternator
  - When Parked energy can be harvested from the Battery (some energy issues here)
- Can exploit mobility
  - Principal duty of vehicles is transportation of goods and people. It is possible to see public vehicles as a mean to build an urban sensor netowrk.
- Can carry relatively large loads
  - Can be instrumented with sensors, communication devices and computing units.
  - Many Manufacturers are exploring connected vehicles to provide advanced services and

- In essence can they are the ideal candidates as nodes of a wireless mobile network.

… Cars …



Camera with image processing
Global system for mobile communications
Extended Floating car data
Navigation system
Digital data base
Brake force display
Adaptive ligh: control
Long range radar sensor
Short range radar sensor
Road condition sensor
Active accelerator pedal
Sensors
Controls
Lights
Communication
Massive Data Producer

New Vehicular Apps

- Safe navigation:
  - Vehicle & Vehicle, Vehicle & Roadway communications
    - This will be essential in autonomous driving
  - Forward Collision Warning, Blind Spot Warning, Intersection Collision Warning
  - In-Vehicle Advisories from CAN sensors
    - “Ice on bridge”, “Congestion ahead”,….
- Entertainment
  - Share location critical multimedia files
  - Exchange local ad information
  - Support passenger to passenger internet games
- Smart City Applications
  - Monitor Pollution and optimize traffic flow
  - Smart Navigation Services
  - Smart Grid nodes (with electric vehicles)
  - Urban Surveillance
- Data Mules
  - Vehicles can carry large amounts of data between points (i.e. large backups)

Vanets in a Nutshell

- Vehicular networks are opportunistic by design to cope with the effects of mobility and propagation.
- Mobility: Causes disruption due to rapid changes in the underneath topology.
- Propagation: Disruptive multipath fading and Obstructions create frequently link disruptions

- In short a dynamically partitioning network, the ability tolerate disruption is essential in the application design as well as at the network layer.

Vehicular Paradigms

- Vehicle to Vehicle (V2V): presents the challenges typical of an ad hoc network in addition to a very high speed mobility and an intermittent connectivity
- Vehicle to Infrastructure (V2I): Protocol design is challenged by intermittent connectivity and short communication windows.
- Opportunistic: V2V for a limited number of hops until is possible to connect to the Infrastructure.

  – Note: infrastructure is also a neighbors' 3G.

Challenges

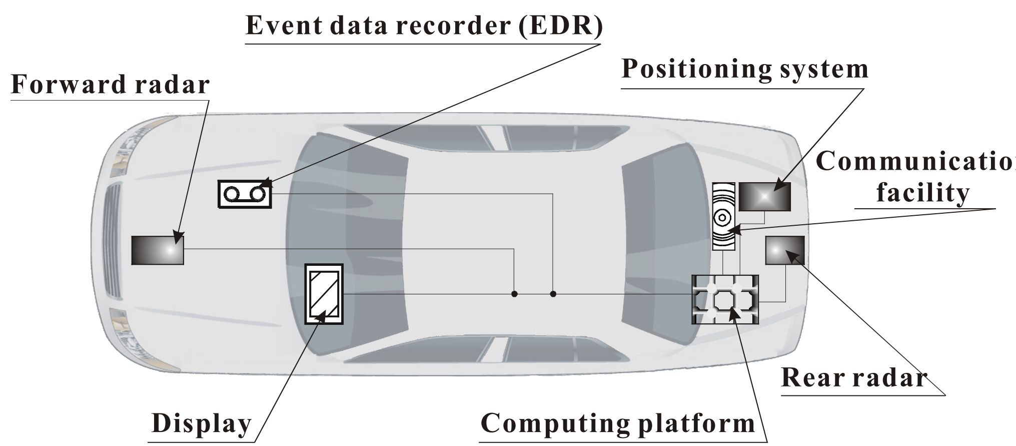
- Mobility
  - Affects network topology and partitioning.
- Urban scenario (i.e. Obstacles)
  - Affects connectivity and ultimately the user experiece
- Extended Open platform to access CAN
  - Would help boot-strap the ecosystem
  - May be essential in Electric Vehicles
- New Network Architecture
  - The IP based Network architecture is not fit for the Mobile Environment
  - A new Information Centric Network architecture may be the solution
- Application Development
  - Applications need to be designed for disruption and disconnection
  - The Industry should try to boot-strap an ecosystem
    - Shall we Look at Smartphone
    - Can we leverage their model

Convergence to a Standard: Government, Industry, Academia

- Federal Communications Commission created DSRC
  - … allocation of spectrum for DSRC based ITS applications to increase traveler safety, reduce fuel consumption and pollution, and continue to advance the nations economy.
    - FCC Report and Order, October 22, 1999, FCC 99-305
    - Amendment with licensing rules in December 2003
- DSRC Standards
  - ASTM E17.51, IEEE 802.11p
  - http://grouper.ieee.org/groups/scc32/dsrc/
- USDOT/CAMP have created Cooperative Intersection Collision Avoidance (CICAS) Consortium
  - http://www.its.dot.gov/cicas/cicas_workshop.htm
- Automotive companies created Vehicle Safety Communications Consortium (VSCC)
- Academia and Industry have sponsored several Special Issues, Workshops on the subject:
  - VANET, V2VCom, Autonet, MoveNet, etc

The Standard: DSRC / IEEE 802.11p

- Car-Car communications at 5.9Ghz
- Derived from 802.11a
- three types of channels: Vehicle-Vehicle ***service***, a Vehicle-Gateway ***service*** and a ***control broadcast*** channel .
- Ad hoc mode; and infrastructure mode
- 802.11p: IEEE Task Group for Car-Car communications



USDOT VII: Vehicle Infrastructure Integration Initiative

- http://www.itsa.org/vii.html
  - The VII Initiative is a cooperative effort between Federal and state departments of transportation (DOTs) and vehicle manufacturers to evaluate the technical, economic, and social/political feasibility of deploying a communications system to be used primarily for improving the safety and efficiency of the nation's road transportation system.

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Mobility and Penetration ratio.

- AD Hoc networks
  - Historically designed for specific applications or user groups. The network is deployed on demand in a specific condition within a specific group. The network scale is a generally not a main issue, the network is almost always connected.
- Vehicular Networks
  - The network includes several thousand of nodes, potentially every car. Is not given that all the cars are connected or equipped and is important to understand the physical channel, and the physical scenario roles. Penetration and deployment to be carefully designed.
  - Scale could become an issue if a flat model is assumed.

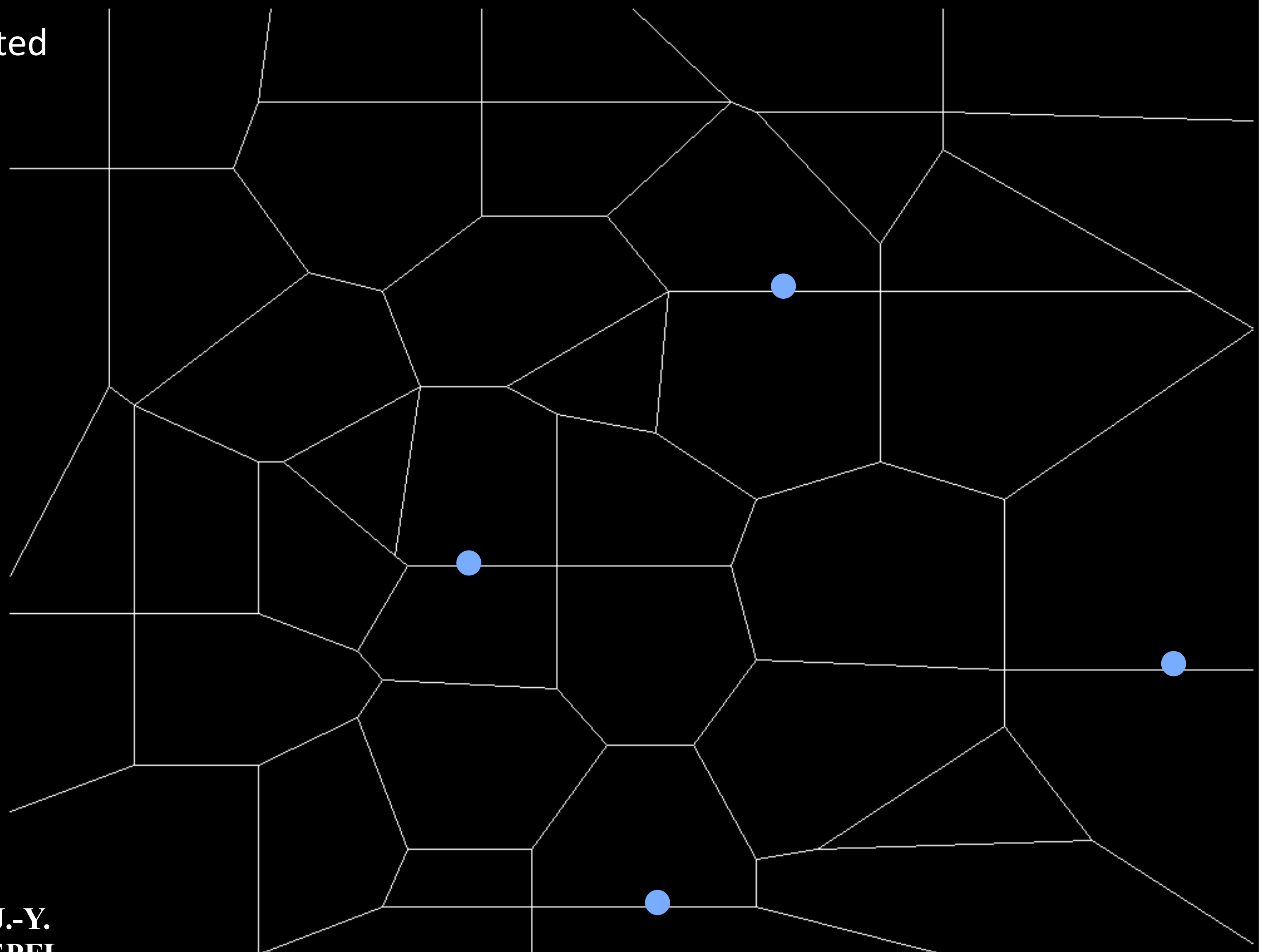
General Considerations

- New technologies and shifts in communication paradigms are posing a number of challenges to the current Internet architecture.
- The Wireless Challenges:
  - Mobility
  - Intermittent connectivity (i.e. Propagation)
  - Long Delays (DTN)
  - Path Discovery and Routing
  - . . .

Challenge #1 Mobility

City section mobility model (Camp 02)

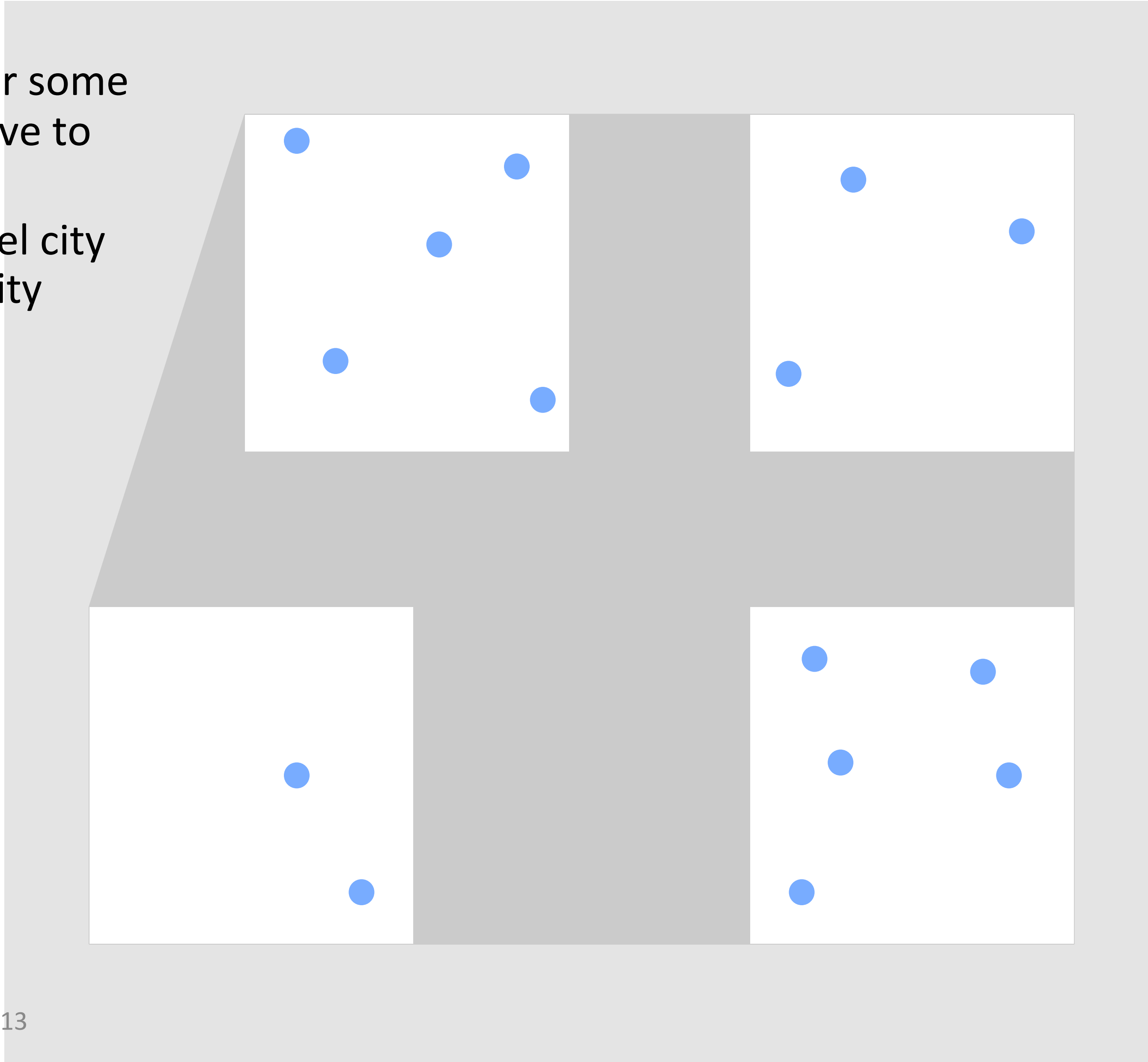
- RWP on general connected domain



courtesy of J.-Y. LeBoudec, EPFL

RWP with locality (Blazevic 04)

- Stay in one subdomain for some time then move to another
- Can also model city section mobility with locality



courtesy of J.-Y. LeBoudec, EPFL

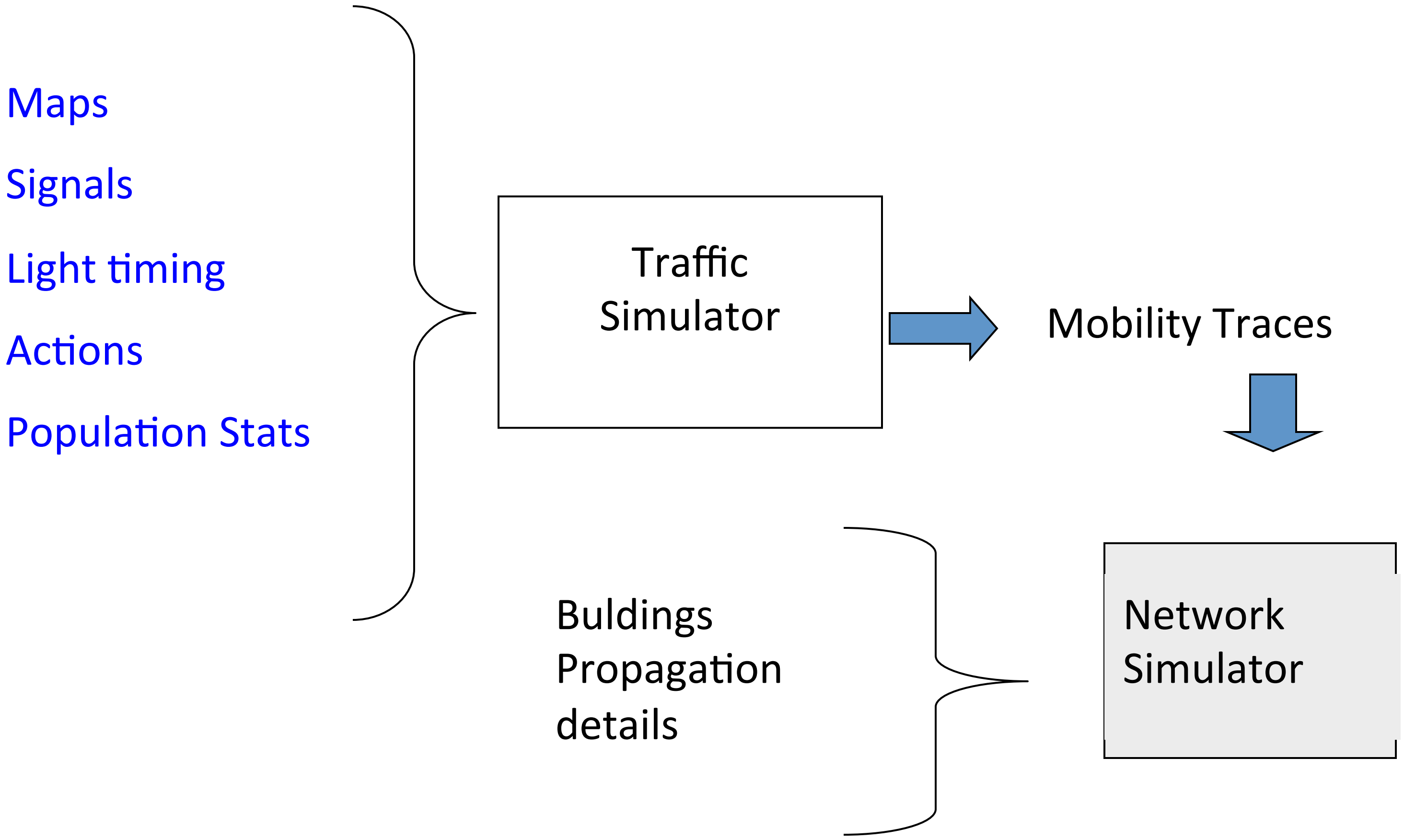
Example: Portland, Oregon (cont'd)

- Some statistcs:
  - Cars: 16,000/350
  - Area: downtown Portland (5kmx7km)
  - Granularity 1sec
  - Microscopic traffic simulation
  - Data: US Bureau of Census
  - Maps: Tiger/ Portland transportation Authority

Trace Driven Mobility

- Syntetic: Fine grain vehicular traces are generated by using a microscopic traffic simulator (I.e. CORSIM, TRANSITSIM, etc)
  - Issues:
    - Map details (Tiger Database, signals, buildings, etc)
    - Activities (why the cars move?)
    - Amount of data (15 minutes= about 4GB)
- Actual: Traces are collected from actual vehicle, and a model is inferred.
  - Issues:
    - Type of mobility
    - Generalization of the model

VANET detailed simulations

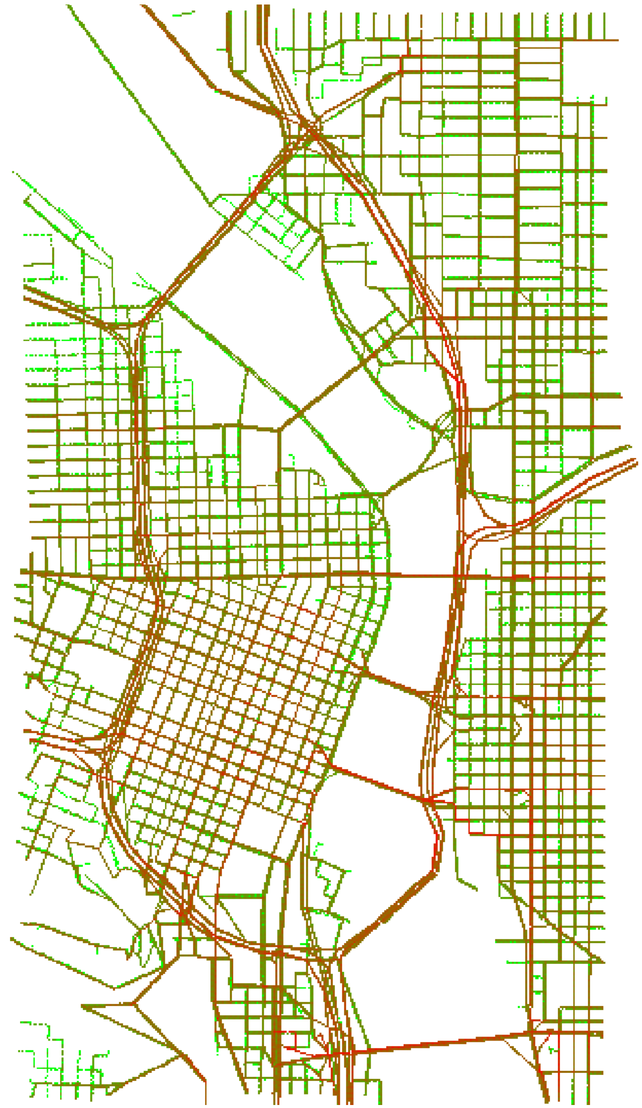


Mobility

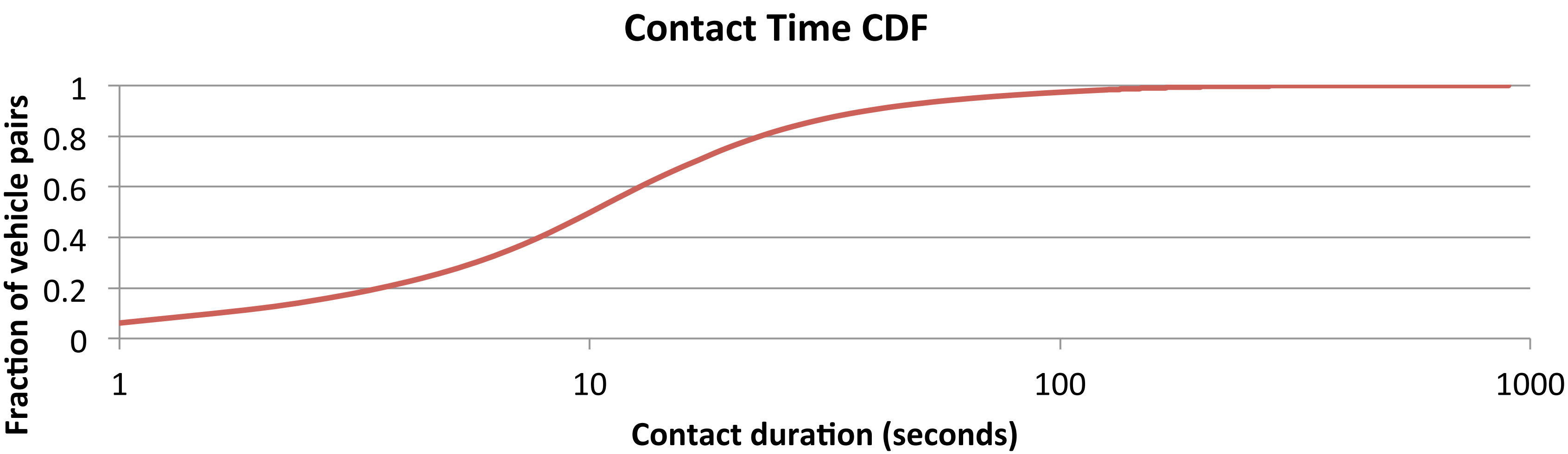
- Portland Oregon
- 5x7 KM
- Transims/NS2
- High Definition DOD Trace.
- 16,000 Cars

Vanets: Mobility

- Portland Traces:
  - Non-public mobility trace provided by Los Alamos National Laboratories
  - Generated Using TRANSIMS, based on mobility surveys
  - 15 minutes trace of a 3x7 Km area of the city of Portland (OR) representing a week-day from 8.00 to 8.15 am
  - The area contains urban and freeway traffic as well.
  - Contains 16.528 unique vehicles



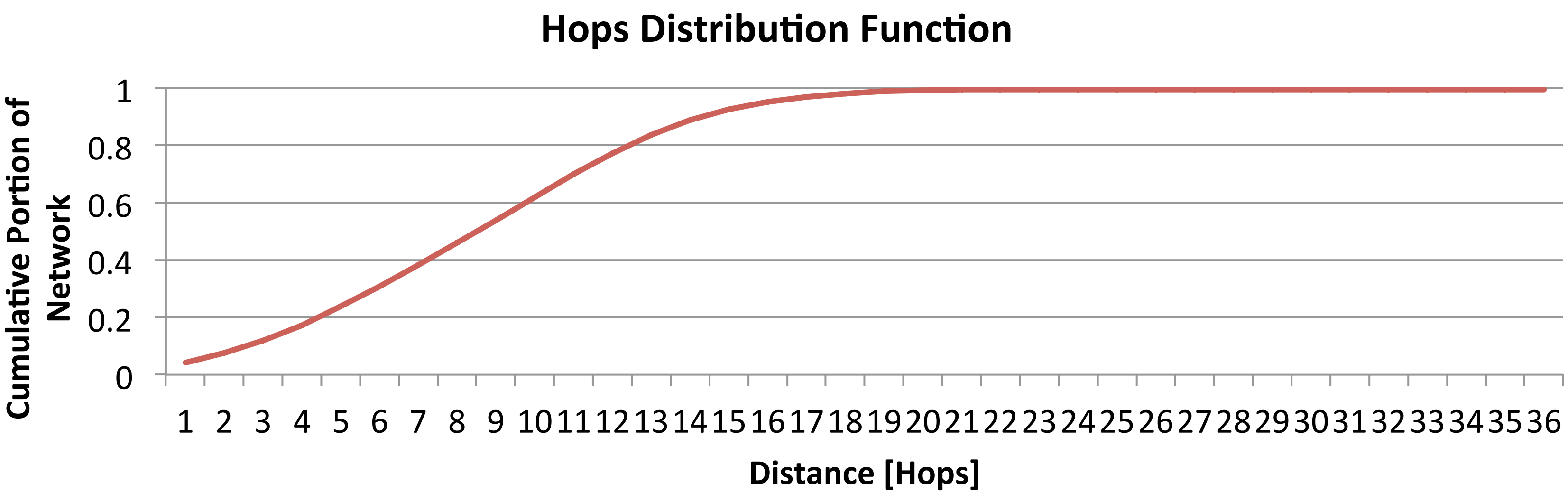
Mobility: Contact Time



- The median contact time is 10 seconds
- The average contact time is 14s
  The variance is 20.7

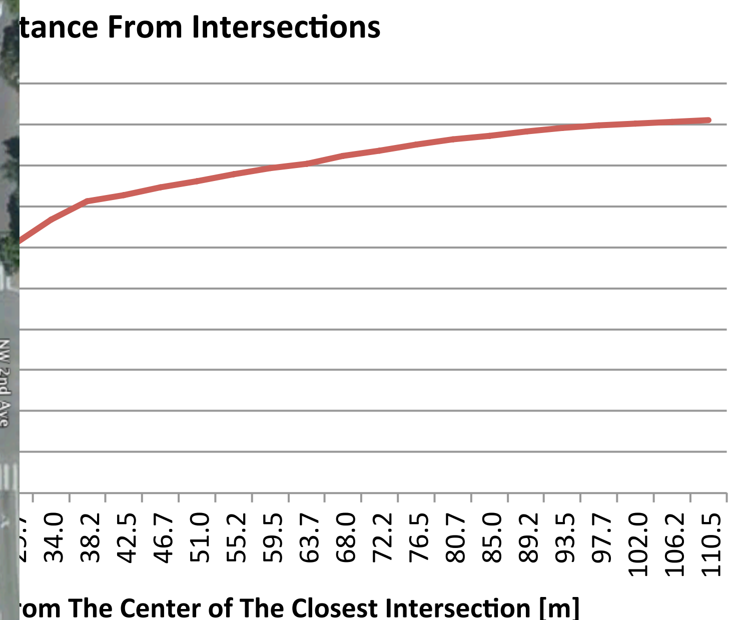
Network Topology

- Assuming: Penetration=1 (every car on the road is instrumented)
- Connectivity Index (CI): Average portion on network reachable from any node
- CI = 0.96; The network is almost fully connected



- The median hop distance is 9 hops
- There are paths 30 hops long.

But…Where are the Cars?



vehicles is within 25
an intersection

A. Rowstron and G. Pau —Characteristics of a Vehicular Network,
UCLA Computer Science Department Technical Report N. TR#090017, Summer, 2009.

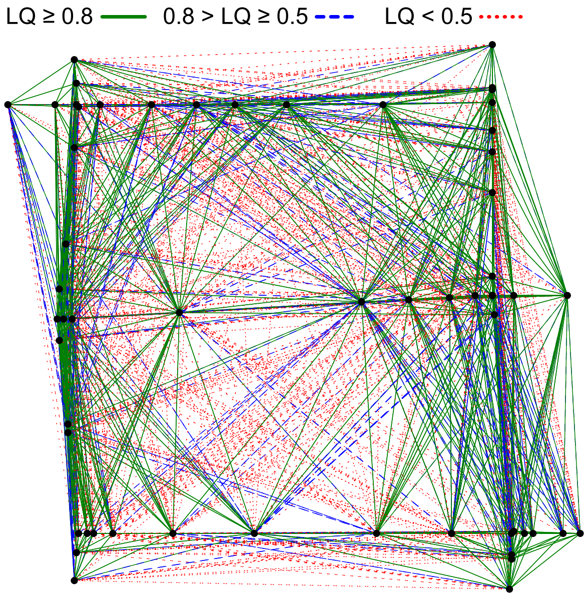
Challenge #2: Physical Envionment

State of the Art

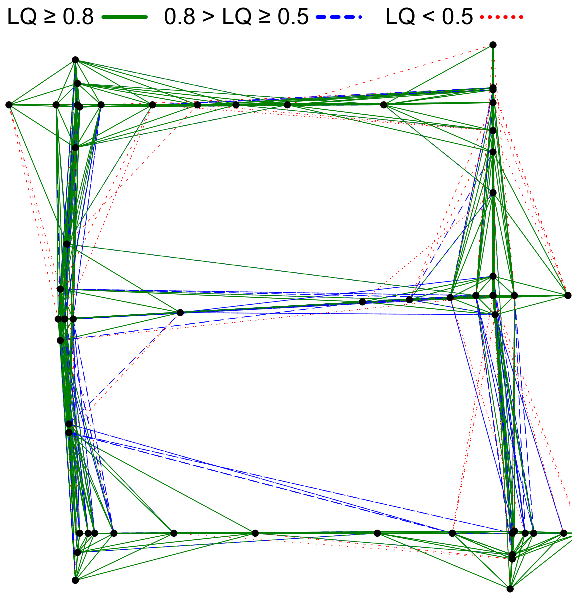
- Simulation is key to assess large scale performance; however very detailed propagation models are rare.
  - NS2 → Two Ray + Shadowing in some cases
  - Qualnet → Two Ray, Ricean model and Shadwoing, also has a number of Terrain models that take in consideration the Z factor.
- Missing:
  - Urban Propagation model (i.e. buildings exist)
    - Released by UCLA the corner model not perfect but good enough.

Why Propagation Matters

Topology



Two Ray



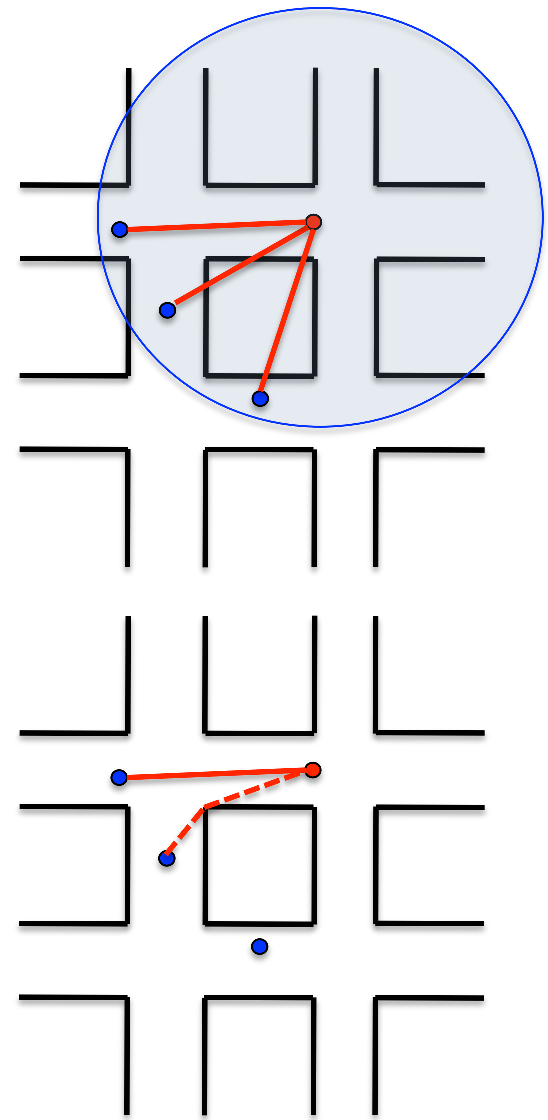
Corner

CORNER: A Step Towards Realistic Simulations for VANET – In proceedings of ACM VANET, co-located with Mobicom 2010.

E. Giordano, R. Frank, G. Pau, M. Gerla

Propagation in Urban Scenarios

- VANET studies were performed mainly using “flat” propagation schemes (Two Ray)
- In reality propagation is affected by obstacles (buildings)

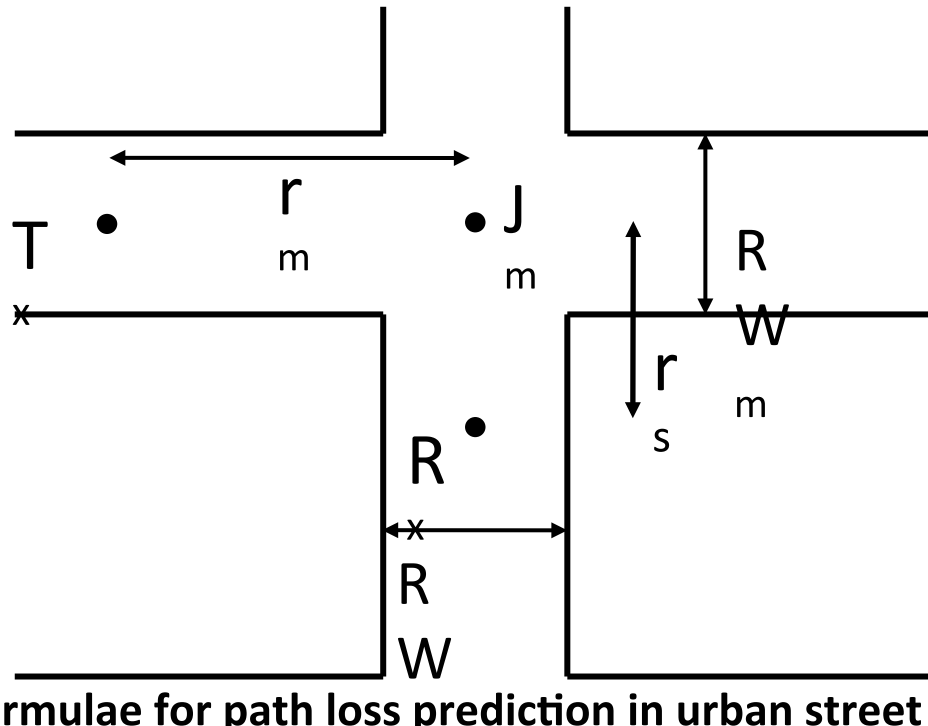


Motivation

- Flat propagation schemes lead to unrealistic results
- Ray Tracing techniques are too expensive:
  - Computation time
  - 3D Description of the environment
- Must find a trade-off between cost and realism
  - Urban propagation Path Loss formulae

Path Loss Formulae

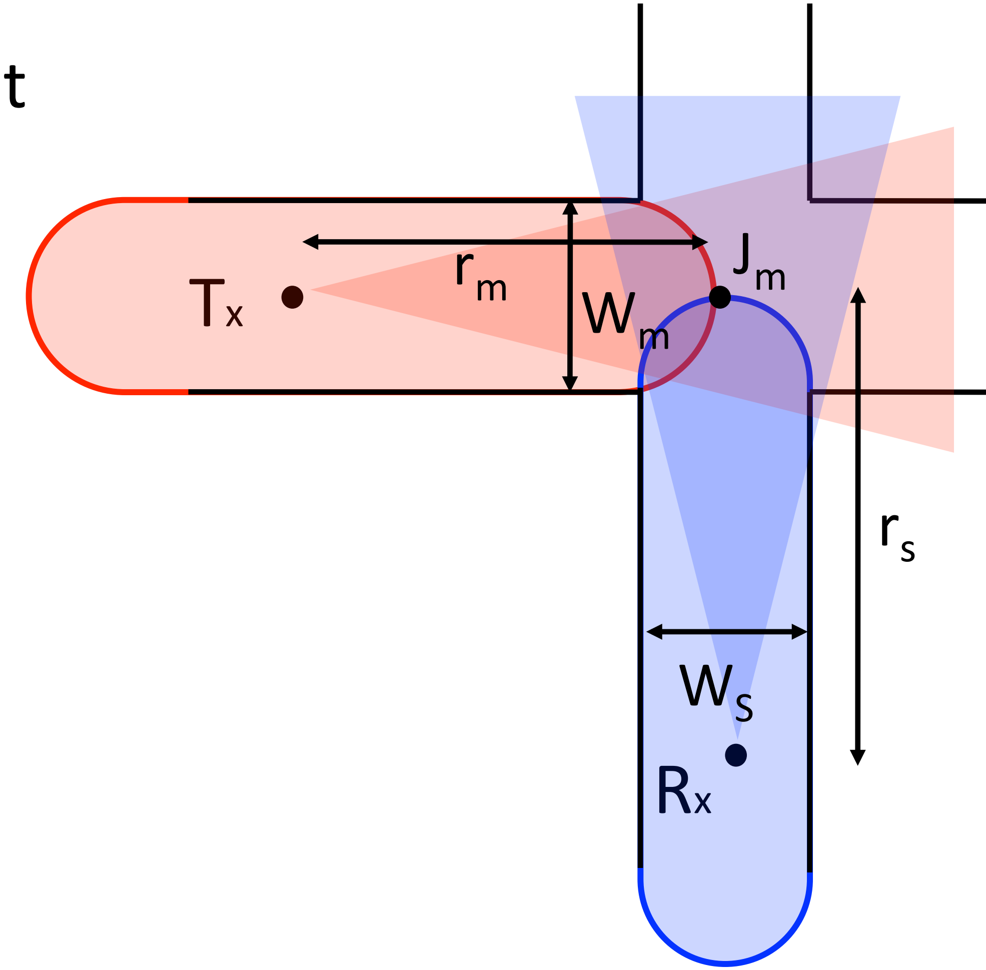
$$PL = 10\log\left[\left(\frac{\lambda}{4\pi}\right)^2 \frac{\lambda}{4 r_m r_s^{\,2}} + \left(\frac{\lambda}{4\pi\left(r_m + r_s\right)}\right)^2 10^{\frac{L_W N_{\min}}{10}}\right]$$



Analytical formulae for path loss prediction in urban street grid microcellular environments,
Q Sun, SY Tan, KC Teh - IEEE Transactions on Vehicular Technology, 2005 - ieeexplore.ieee.org

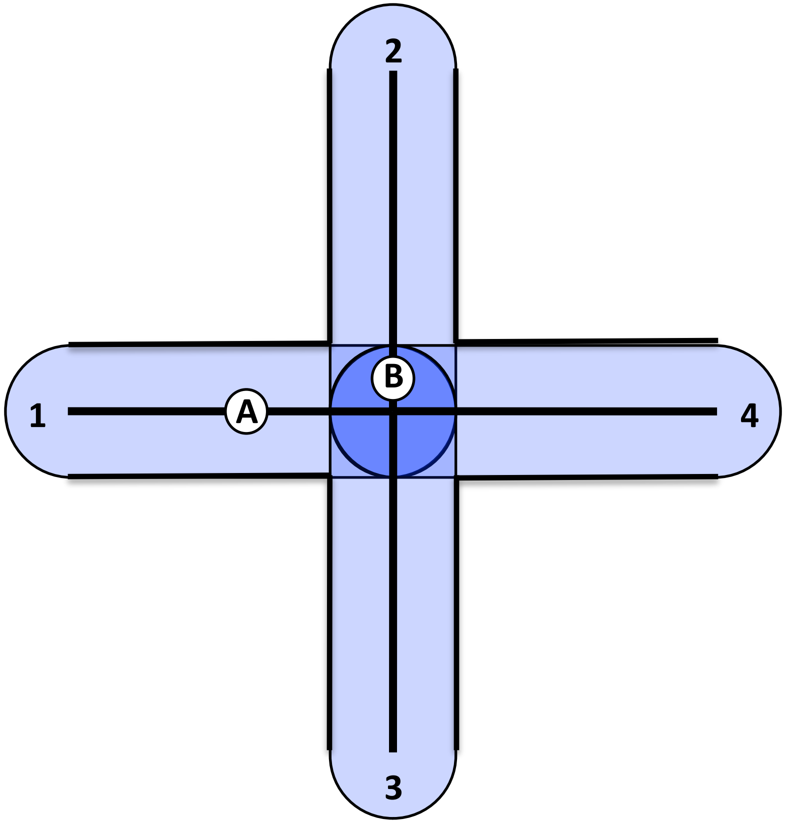
CORNER at a glance

- Relate the position of nodes to the environment
  - Specialized Reverse Geocoding
- Assess the propagation situation
  - LOS
  - NLOS1
  - NLOS2
- Compute formula parameters
- Apply the formula and compute the Path Loss



CORNER: Reverse Geocoding

- Regular Reverse Geocoding does not apply
- Need to assess the signal path.



- Define a proximity area
- Assign each vehicle a set of possible road segment
- Find the pair of segments that involves the least number of intersections (corners)

CORNER: Reverse Geocoding

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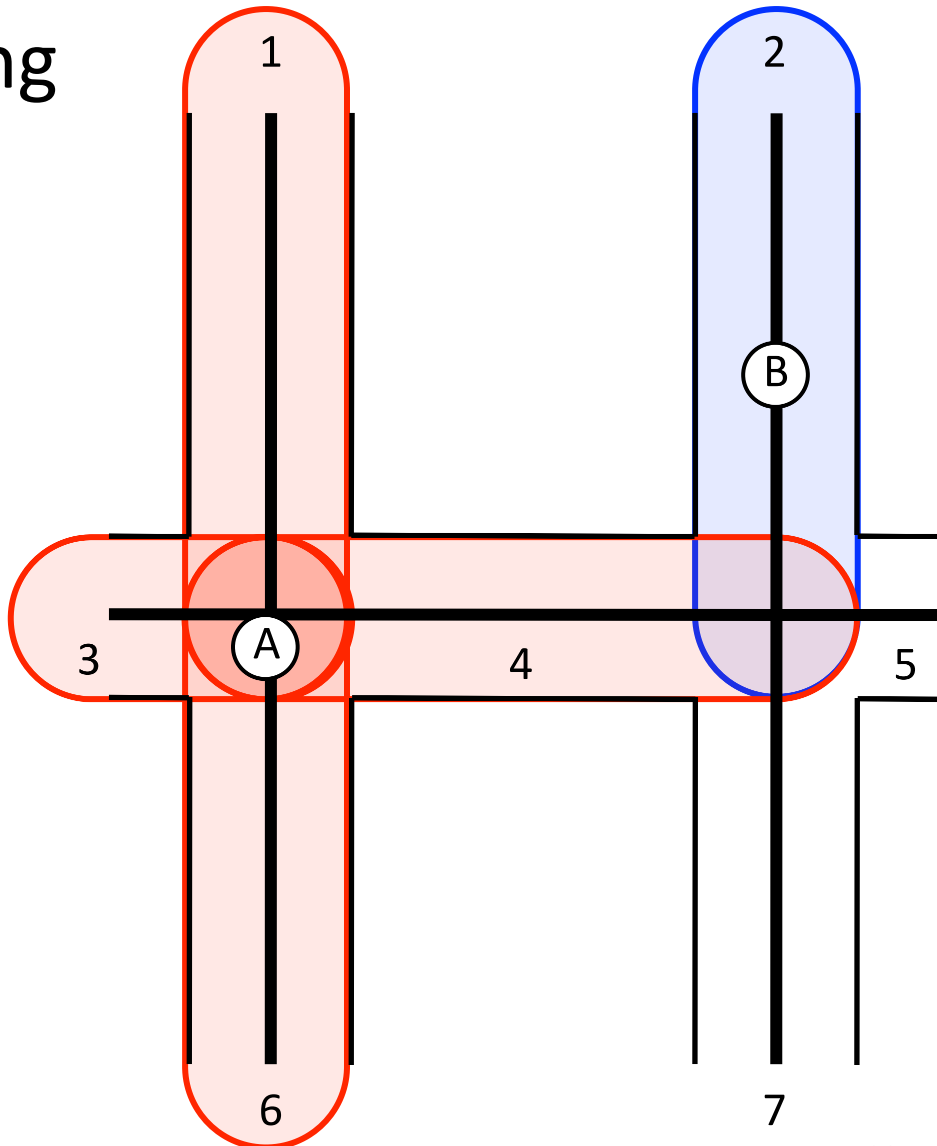
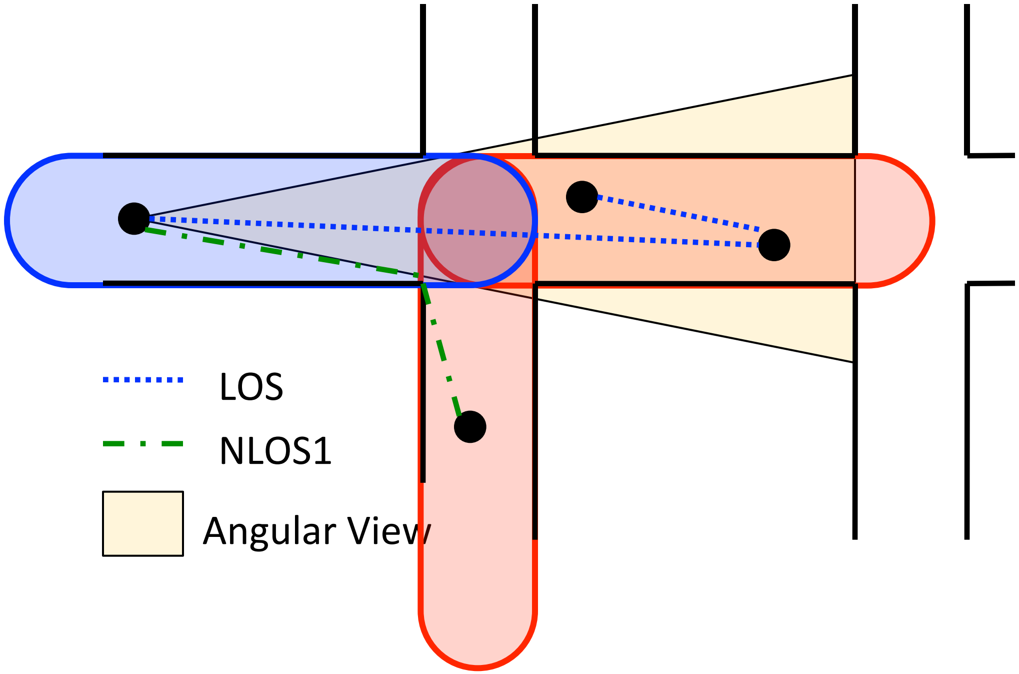


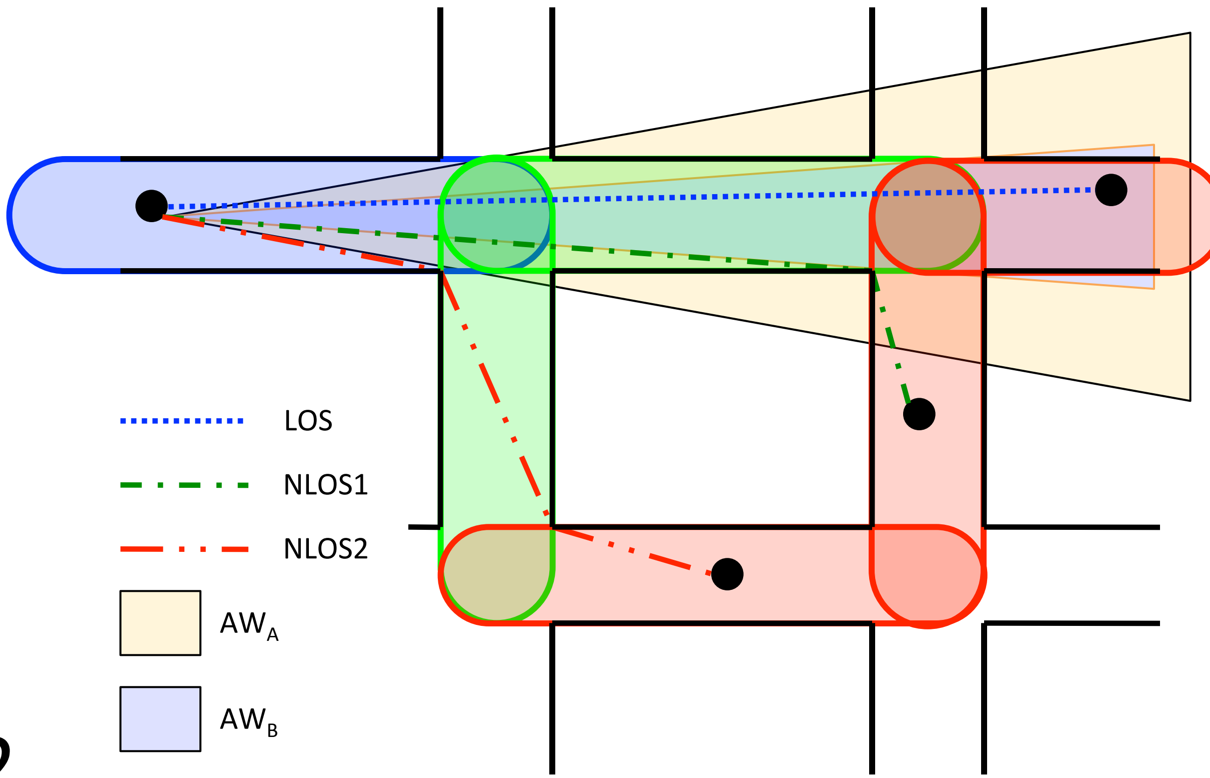
CORNER: Situation Assessment

- Same road segment: LOS
- Adjacent road segment: either LOS or NLOS1

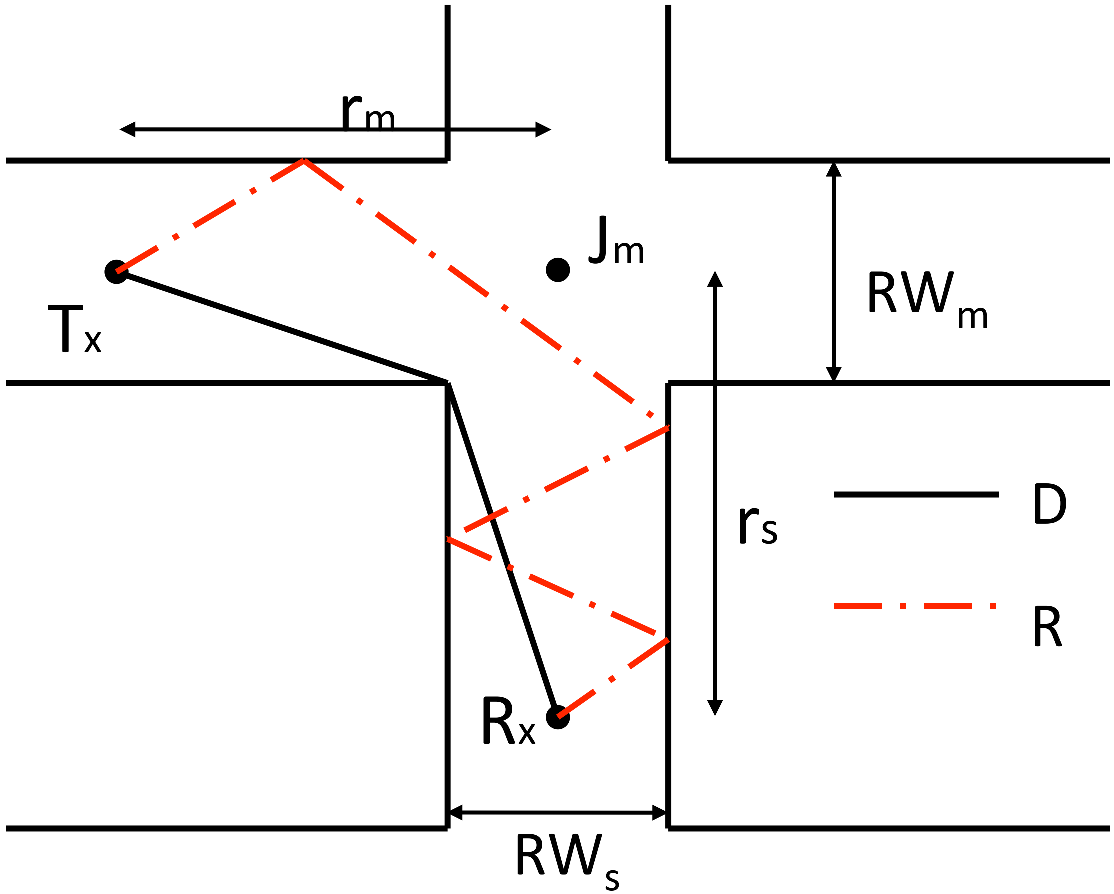


CORNER: Situation Assessment

- Same road segment: LOS
- Adjacent road segment: either LOS or NLOS1
- Connected road segment:LOS, NLOS1 or NLOS2



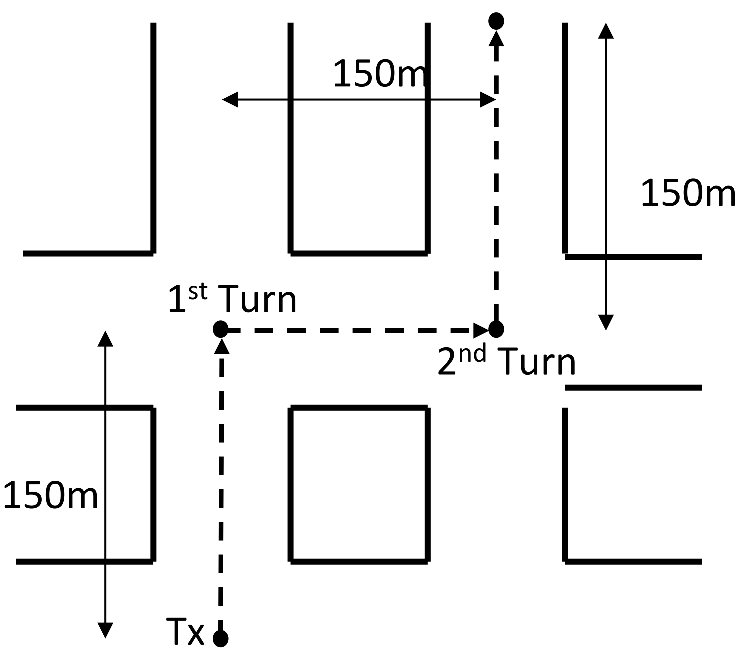
Formula Application

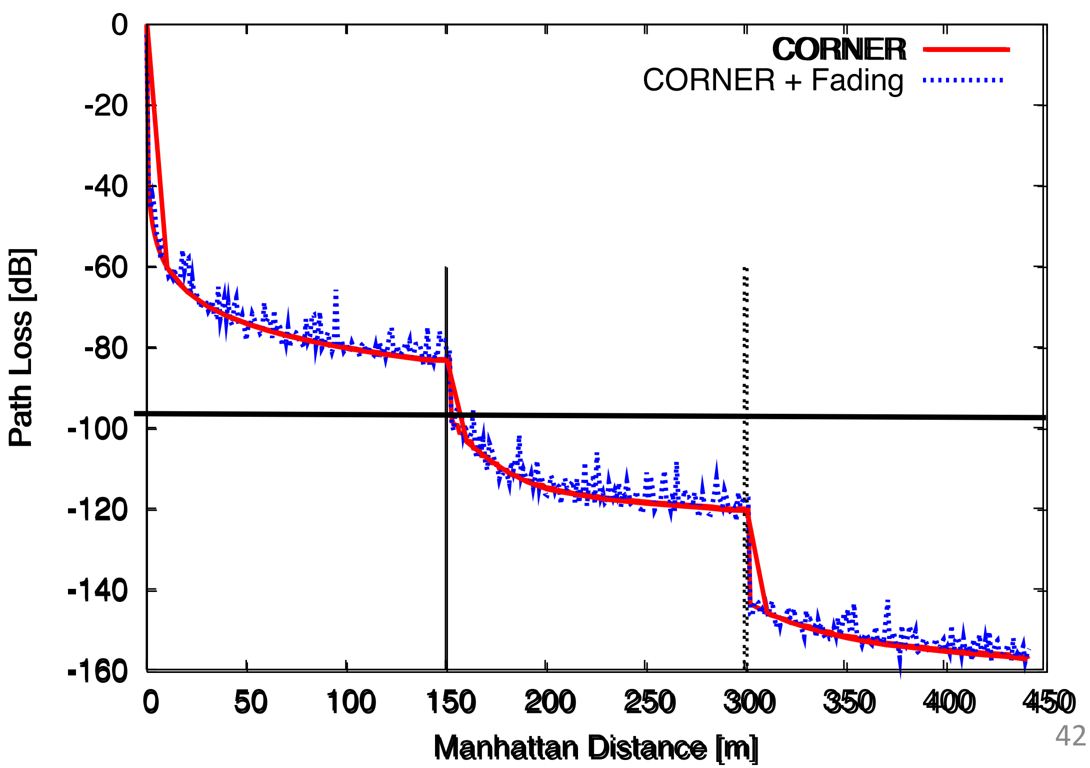


- Once propagation situation is assessed
- Formula parameters can be computed
- Apply the formula and obtain Path Loss

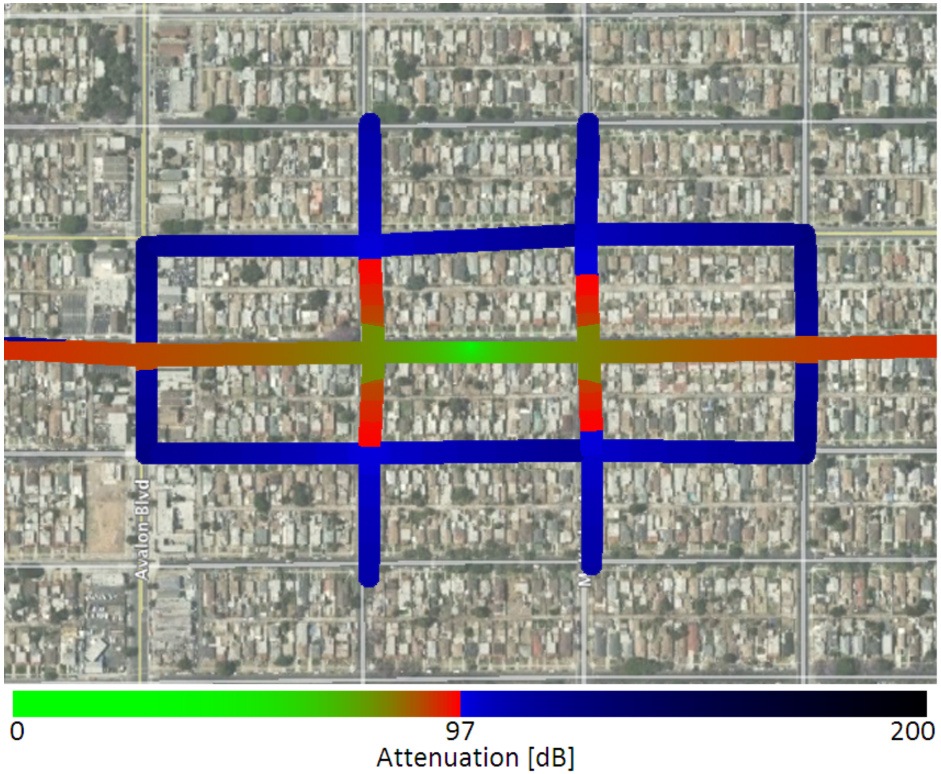
Propagation Example

- Fixed Tx
- Mobile Rx
  - Moves first from LOS to NLOS1 then to NLOS2

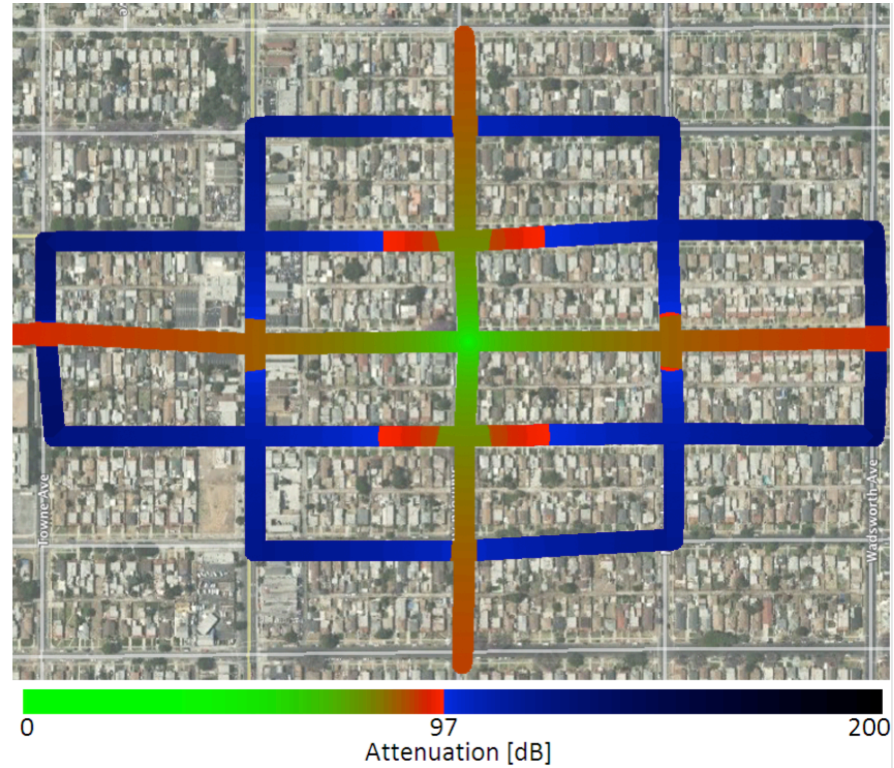




Intersections provide wider coverage



Source placed in the middle of the block



Source placed at the intersection

Observation #1: Vehicles at intersections can cover a much wider area

CORNER: Validation

- Instrumented 2 cars with:
  - A laptop
  - A IEEE802.11b/g wireless card
  - GPS receiver
- Each car broadcasts its position
  - Using raw sockets, directly at layer 2
  - 10 times per second
- 3 experiment sets
  - Fixed to mobile
  - Mobile to mobile
  - Fixed to fixed

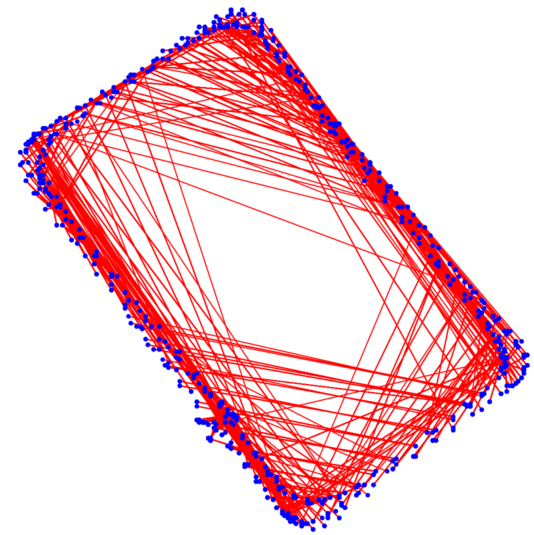
Fixed to Mobile

- Two nodes
  - One Fixed
  - One revolving around the block
- Comparison with simulation

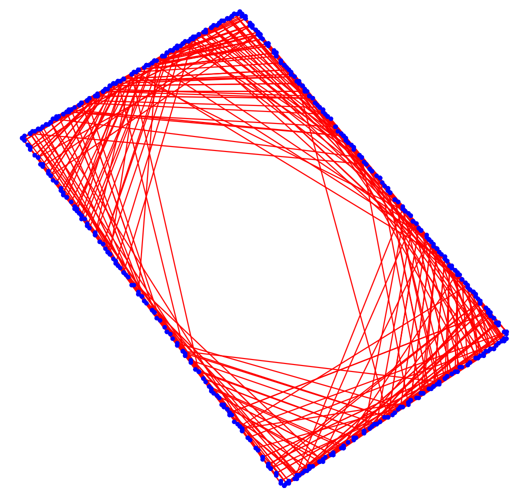
- The fixed node is periodically broadcasting
- The mobile node saves the location where it receives the packet

Mobile to Mobile

- Two cars revolving around the block in opposite direction
- Each one broadcasts its own position
- A link is plotted from the point the packet was sent to the point the packet was received



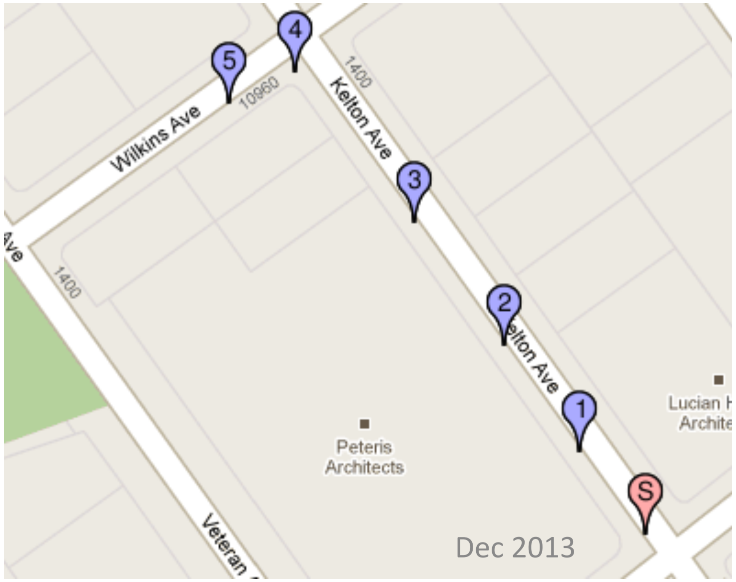
Field Experiment

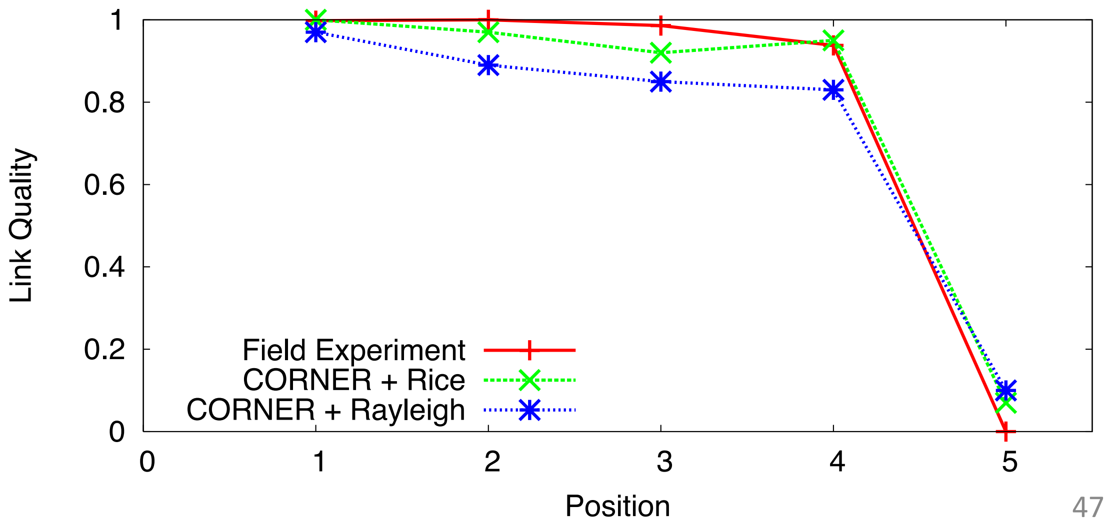


Simulation - CORNER

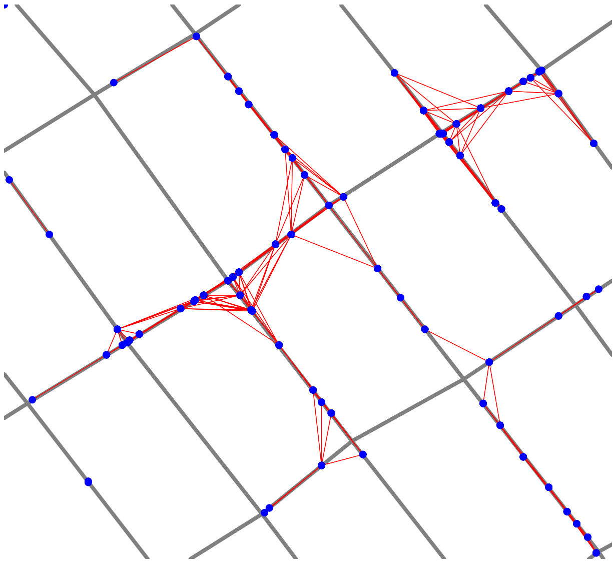
Fixed to Fixed

- Fixed sender
- Fixed receiver in different positions
- Compute the link quality as:
  - # Packets Received / # Packets Sent

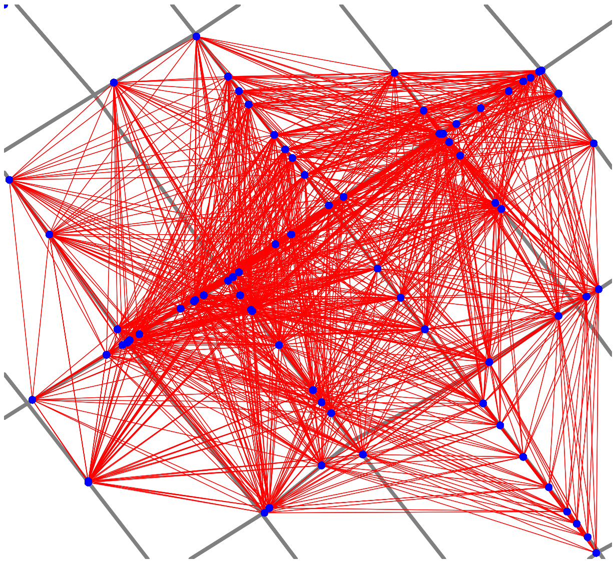




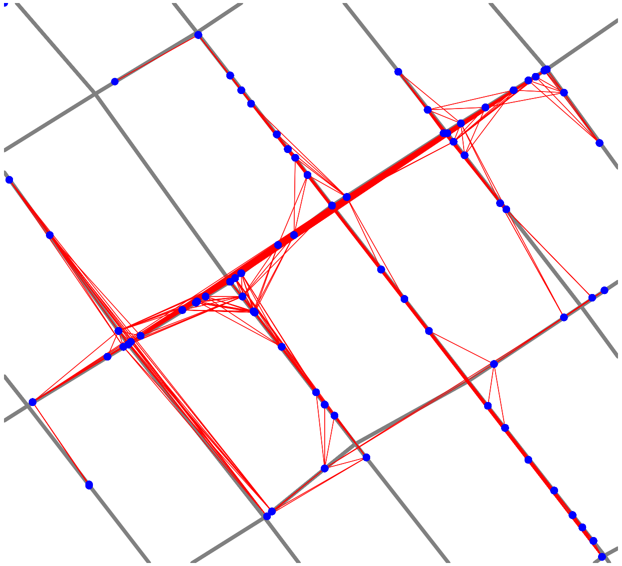
CORNER: Impact (1)



Range 80m



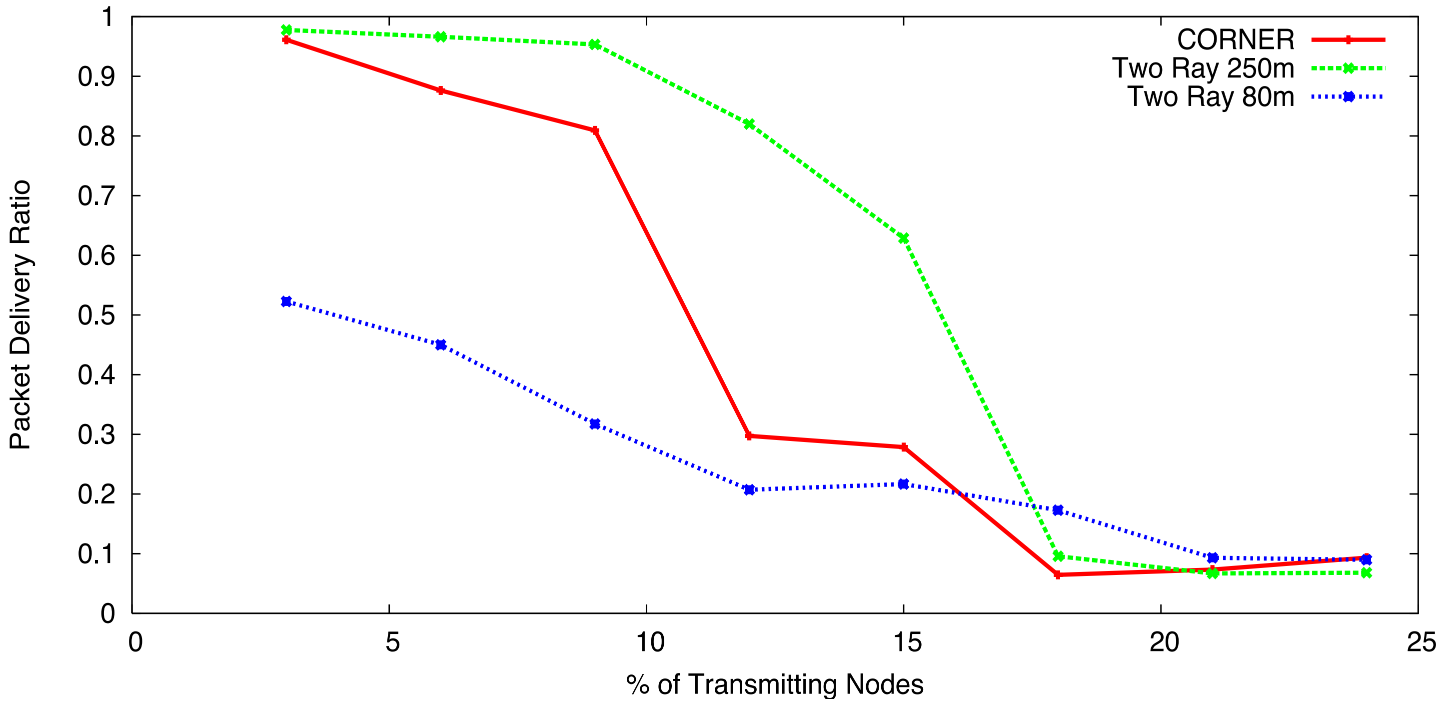
Range 250m



CORNER

	Range 80m	Range 250m	CORNER
Node Degree Average	7.6	47.2	19.9
Link Duration: Average	11.6	24.52	16.2
Connectivity Index:	0.69	0.99	0.99
Average Number of Hops:	4.2	1.5	2.3

CORNER: Impact (2)



- 80m range too pessimistic
- 250m range too optimistic
- There might be a range that approximates better, but depends on the map.

Remarks

- CORNER
  - A good trade off between realism and computational cost
  - Could be implemented for any network simulator
  - Independent of the mobility simulator
- http://nrl.cs.ucla.edu/~egiordano/vergiliusJoomla/
  - Source code of QualNet implementation
  - Binaries for the generation of Path Loss Matrix

VERGILIUS: a Scenario Generator for VANET

E. Giordano, E. De Sena, G. Pau, M. Gerla

giordano@cs.ucla.edu

http://cvet.cs.ucla.edu/vergilius.html

Introduction

- For VANET simulation is essential:
  - Large scale test beds are impossible
- Crucial that simulations reflect reality
  - Mobility
    - Real traces: realistic but too specific
    - Synthetic traces: not as realistic but tunable
  - Propagation
    - A propagation model that reflects reality is needed

Introduction (2)

- VERGILIUS implements:
  - A tunable scenario generator:
    - Provides realism when needed
    - Easily tunable traffic characteristics
  - A realistic Propagation Model: CORNER
    - Takes into account the presence of buildings
    - Light weight computation, can be run on the fly.
  - An extensive trace analyzer
    - Extract characteristics of the mobility

Sample Workflow

TIGER-CENSUS

Geographic Database:
provides the road topology

VERGILIUS

Scenario Generator:
Provides control over the kind of traffic to generate (uniform, aggregated etc.)

CORSIM

Mobility Simulator:
provides detailed road traffic traces

VERGILIUS

Trace Analyzer:
Provides:

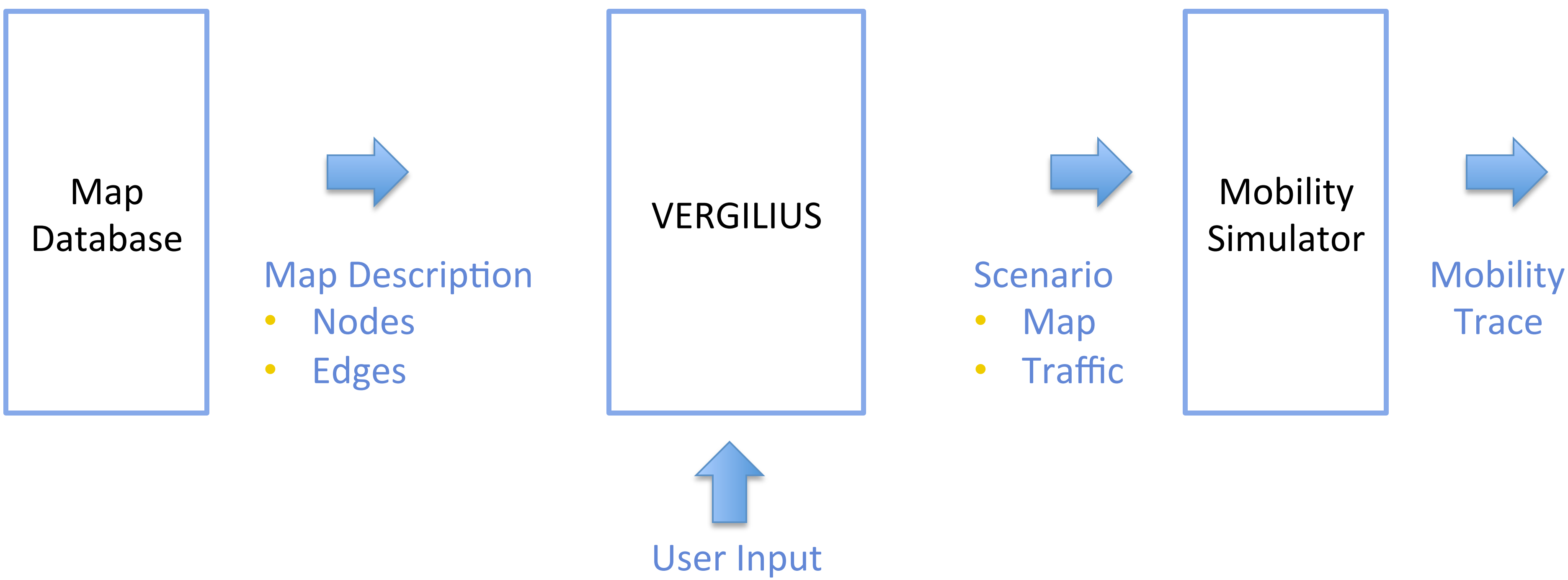
- Propagation matrix considering buildings.
- Connectivity and Interference metrics based on topology

QualNet

SCALABLE NETWORK TECHNOLOGIES

Network Simulator:
provides network metrics

Scenario Generator



- Traffic Scenario:
  - Input Flows & Turn Probabilites
  - Route Descriptions

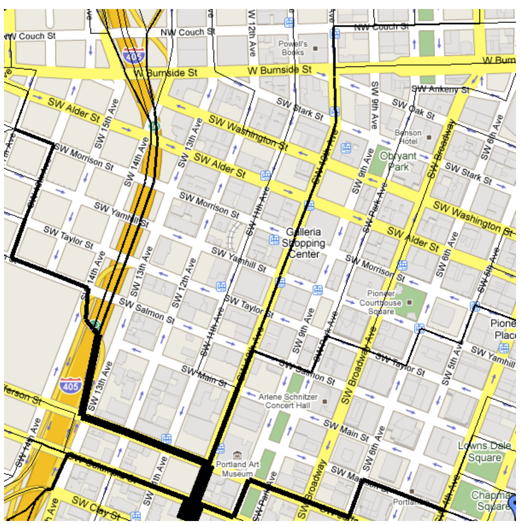
Equivalent

Routes Generation

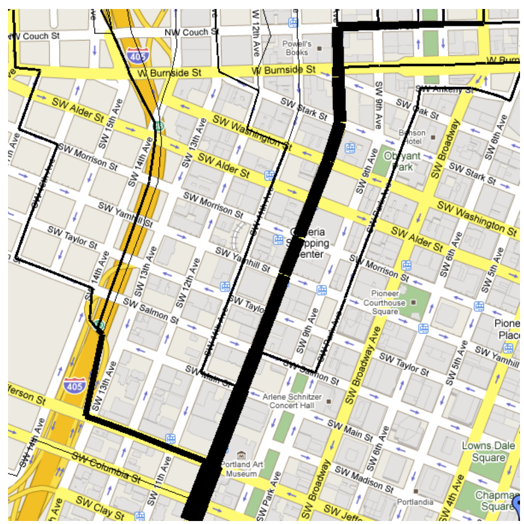
- All routes go from an entry point to an exit point
- The number of routes originating from one entry point can be set
  - Deterministically
  - Randomly
    - Uniform Distribution
    - Poisson Distribution
    - Based on the importance of the road
- The destination for each route can be set:
  - Deterministically
  - Randomly
- The Route will take the Dijkstra shortest path based on:
  - Distance
  - Time to Traverse

Choice of Route Destination

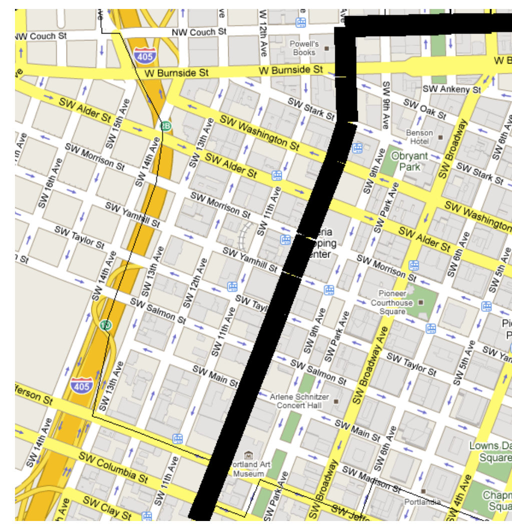
- Random tunable distribution
- Trip Aggregation Factor (TAF)
- Using TAF we can change the nature of the traffic.



TAF = 0



TAF = 5



TAF = 100

Effect of the Trip Aggregation Factor

SCENARIO TOPOLOGY_BASED
ENTRY_FLOW_MODE UNIFORM
TB_INPUT_FLOW CONSTANT 360
SCENARIO_DIJKSTRA_WEIGHT TIME

SCENARIO RANDOM
SCENARIO_DIJKSTRA_WEIGHT TIME
TAF = 4
AVERAGE_ARRIVALS 4200
ENTRY_FLOW_MODE WEIGHTED
WEIGHTED_FLOWS_EXPONENT 1

Trace Analyzer (1)

	Scenario A	Scenario B
Average Number of Nodes:	91.78	92.61
Node Degree: Average / Variance	13.16 / 121.37	24.42 / 234.72
Link Duration: Average / Variance	3.95 / 39.98	11.15 / 256.19
Connectivity Index:	0.96	0.96
Average Number of Disconnected Nodes:	0.61	0.42
Average Number of Hops:	2.91	2.25
Average Hidden Nodes:	874.22	1828.25

- **Average Number of Nodes:** Number of nodes present in the area averaged over time.
- **Node Degree:** Number of neighbors of each node, averaged over each node and over time
- **Link Duration:** Duration of the connection between a pair of nodes averaged over all pairs and over time

Trace Analyzer (2)

	Scenario A	Scenario B
Average Number of Nodes:	91.78	92.61
Node Degree: Average / Variance	13.16 / 121.37	24.42 / 234.72
Link Duration: Average / Variance	3.95 / 39.98	11.15 / 256.19
Connectivity Index:	0.96	0.96
Average Number of Disconnected Nodes:	0.61	0.42
Average Number of Hops:	2.91	2.25
Average Hidden Nodes:	874.22	1828.25

- **Connectivity Index (CI):** defined as the average portion of the network that is reachable from each vehicle in the mobility trace, regardless of the path length. CI provides a better insight onto the partitioning of the network.

Trace Analyzer (3)

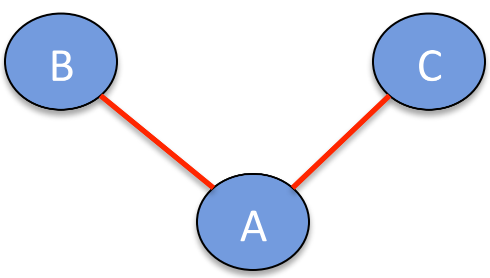
	Scenario A	Scenario B
Average Number of Nodes:	91.78	92.61
Node Degree: Average / Variance	13.16 / 121.37	24.42 / 234.72
Link Duration: Average / Variance	3.95 / 39.98	11.15 / 256.19
Connectivity Index:	0.96	0.96
Average Number of Disconnected Nodes:	0.61	0.42
Average Number of Hops:	2.91	2.25
Average Hidden Nodes:	874.22	1828.25

- **Average Number of Disconnected Nodes (AD):** the average number of nodes that are disconnected from the network, i.e. that have no neighbors. It provides information on how often there are vehicles that are separated from the rest of the network.
- **Average Number of Hops (AH):** the average number of hops needed to reach all nodes in the network.

Trace Analyzer (4)

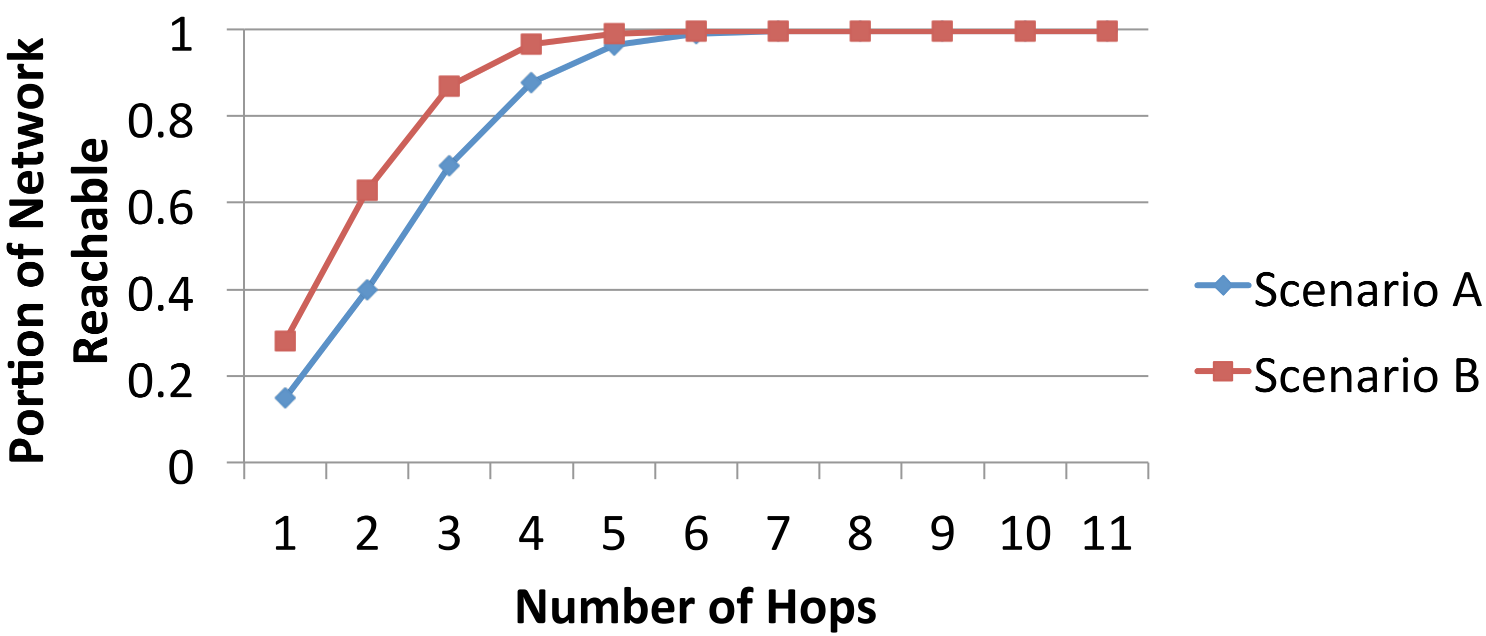
	Scenario A	Scenario B
Average Number of Nodes:	91.78	92.61
Node Degree: Average / Variance	13.16 / 121.37	24.42 / 234.72
Link Duration: Average / Variance	3.95 / 39.98	11.15 / 256.19
Connectivity Index:	0.96	0.96
Average Number of Disconnected Nodes:	0.61	0.42
Average Number of Hops:	2.91	2.25
Average Hidden Nodes:	874.22	1828.25

- **Average Hidden Nodes:** the average number of nodes that have two neighbors that are not each other neighbors.



Trace Analyzer (5)

- **Hops Distribution Function (HDF):** the average portion of network that is reachable given a maximum number of hops. Provide information about the stretch of a network, i.e. what is the average distance in hops needed to traverse the network.



Challenges and Opportunities in Urban Vehicular Systems

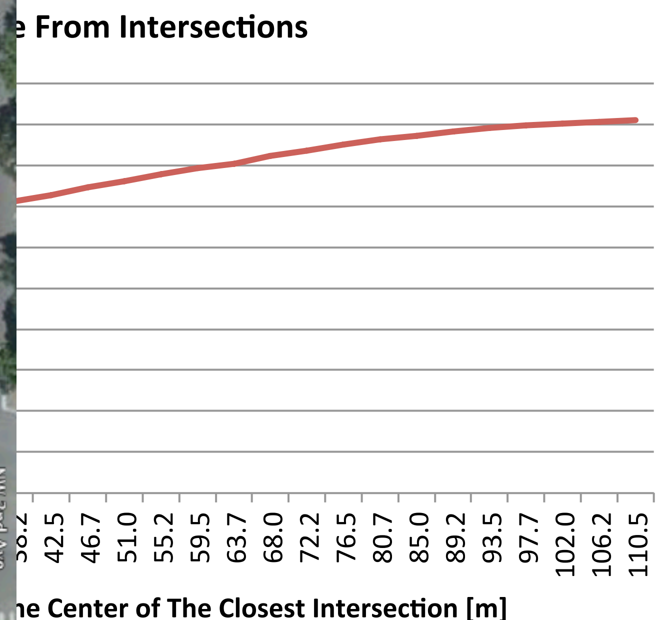
An Analysis from a Realistic Trace

(Eugenio Giordano, Giovanni Pau, Antony Rowstron)

Description of The Trace

- 15 minutes 1 second granularity
- Portland downtown @ 8am –8.15am
    - 16000 different vehicles
    - Avg of 3500 vehicles in the trace
    - Synthetic trace developed by the Los Alamos National Lab for national security.
    - Based on Activity surveys

Vehicles density



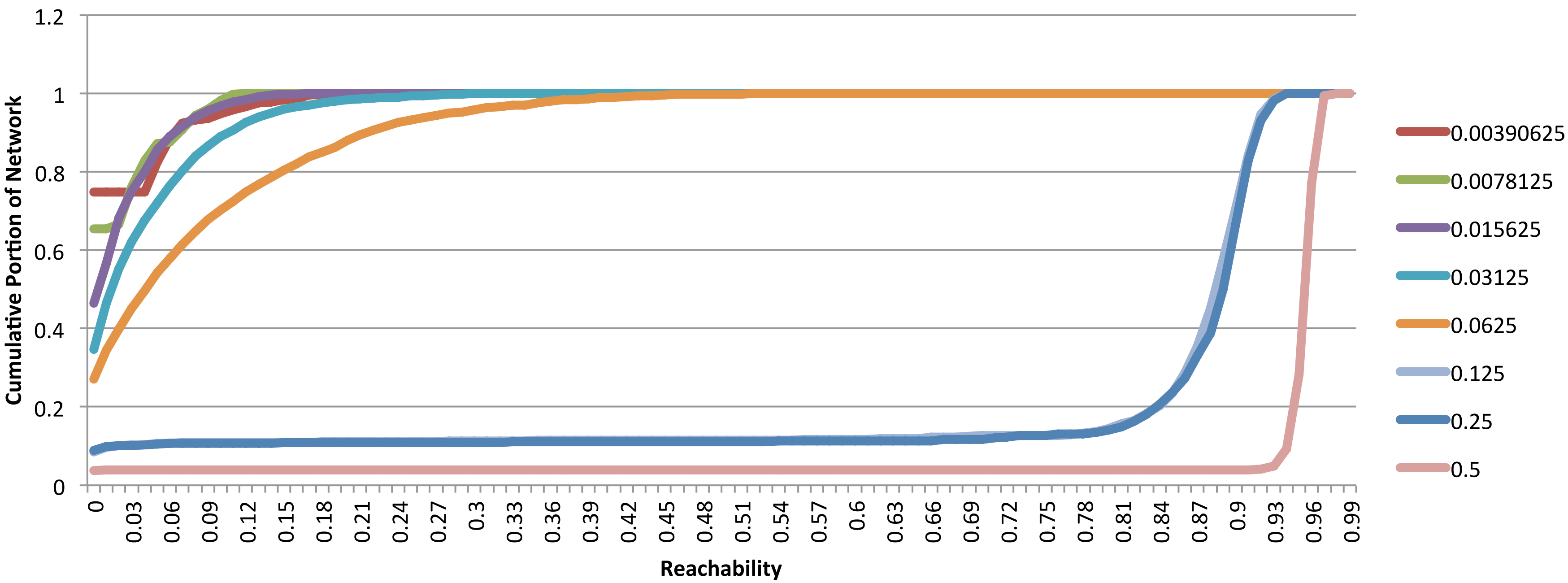
les is within 25
ersection

s higher at

Partitions Analysis

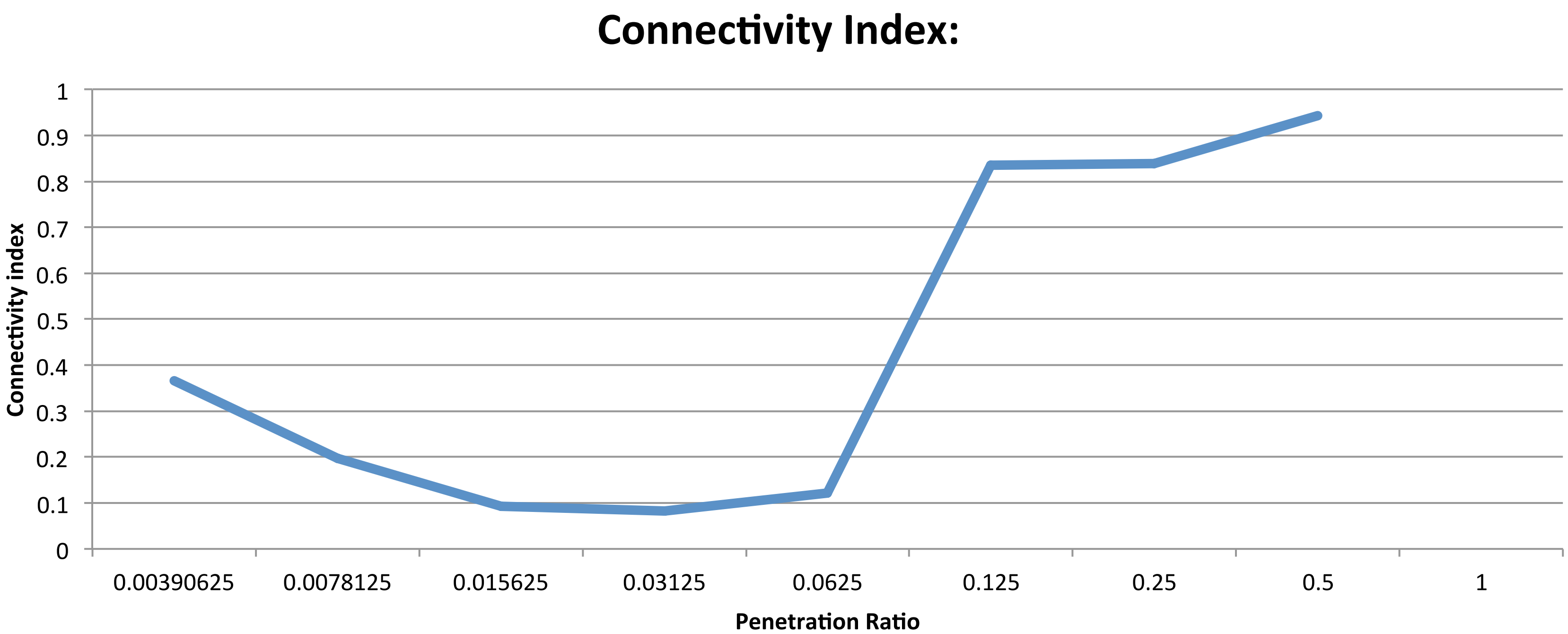
- Is the network really partitioned?
  - The median of the partition size is 1, this suggests that there are many small partitions and a few large partitions. I believe this needs some further investigation.
  - Connectivity Index (CI) Analysis
    - CI is the number of vehicles a vehicle can reach regardless of the number of hops
    - Compute the average CI per second then CDF or Average… Let's see the results

Reachability



- Reachability: portion of the network that a node can reach.
- How to read the cumulative: For reachability X the portion of network that can reach at most the portion X of the network
- Two different results:
  - For low penetration ratios the network is partitioned. E.G. for 0.0625 we have that all network has at most 0.51 reachability (meaning no node can reach more than 51% of the network)
  - For higher penetration ratios the network is not partitioned. A small portion of nodes is isolated, and the rest of the network is almost fully connected.

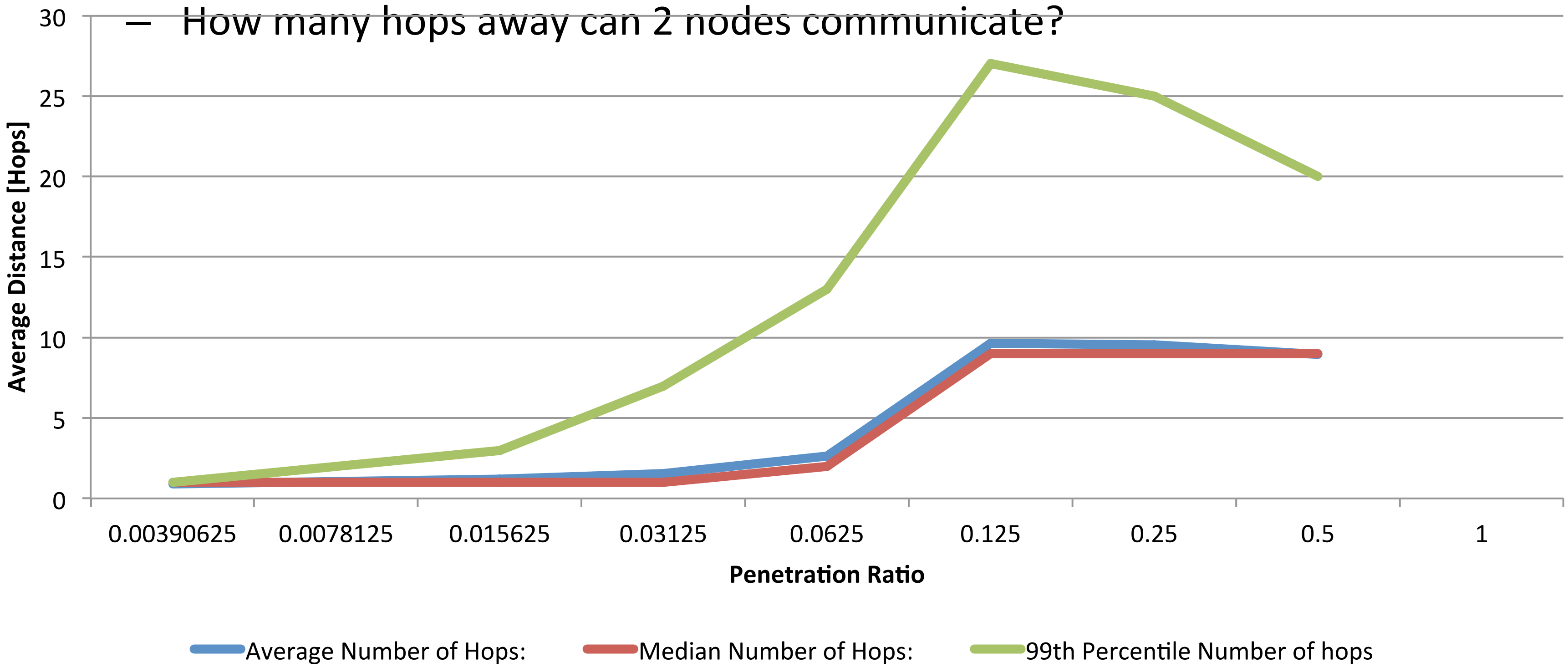
Connectivity Index (CI)



- CI is the average of the reachability.
  - Reflects the result of previous graph
  - At Penetration R 0.125 the network connects

Hop Distance Analysis

- How far are the nodes in terms of hops?
  - As the Penetration R increases each node can reach more portion of the network, the stretch increases
  - When the network connects (0.125) we have a 10 hops distance (on average!!!)
- Is a flat multihop network feasible?
  - How many hops away can 2 nodes communicate?

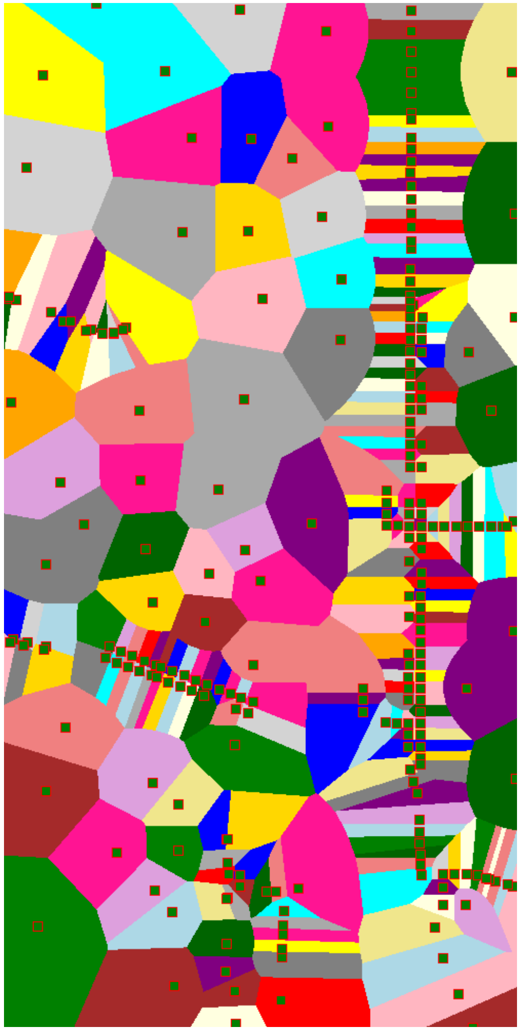


Solutions

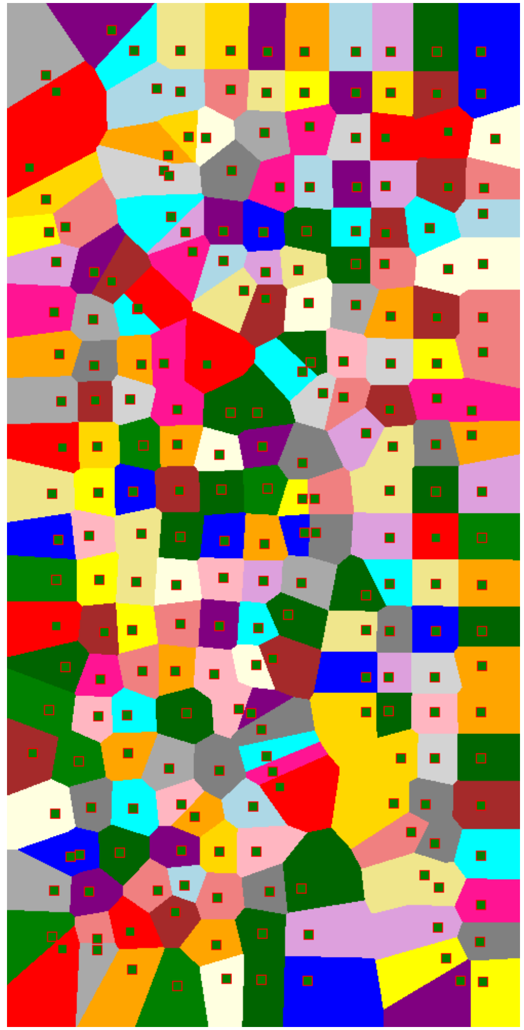
- The Network is partitioned and too big:
  – Solution:
    - Disruption/Delay tolerant
      - +No Management
      - +Comes at no cost
      - - Delay (probably not for human interaction)
    - Infrastructure Aided
      - - Cost
      - -Management
      - +Shorter paths, more coverage -> low delay

3 AP placement methods:

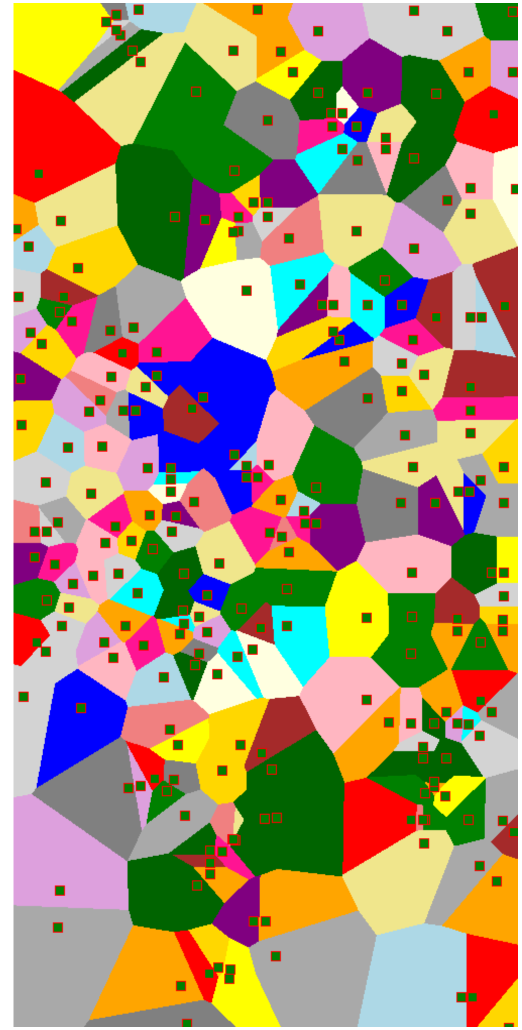
- AP are ALWAYS placed at intersections
- IMPORTANCE: based on the density of the
- GRID: Intersections closest to the ideal grid
- Random: Intersections chosen Randomly
- AP ARE NEVER on FREEWAYS.



IMPORTANCE

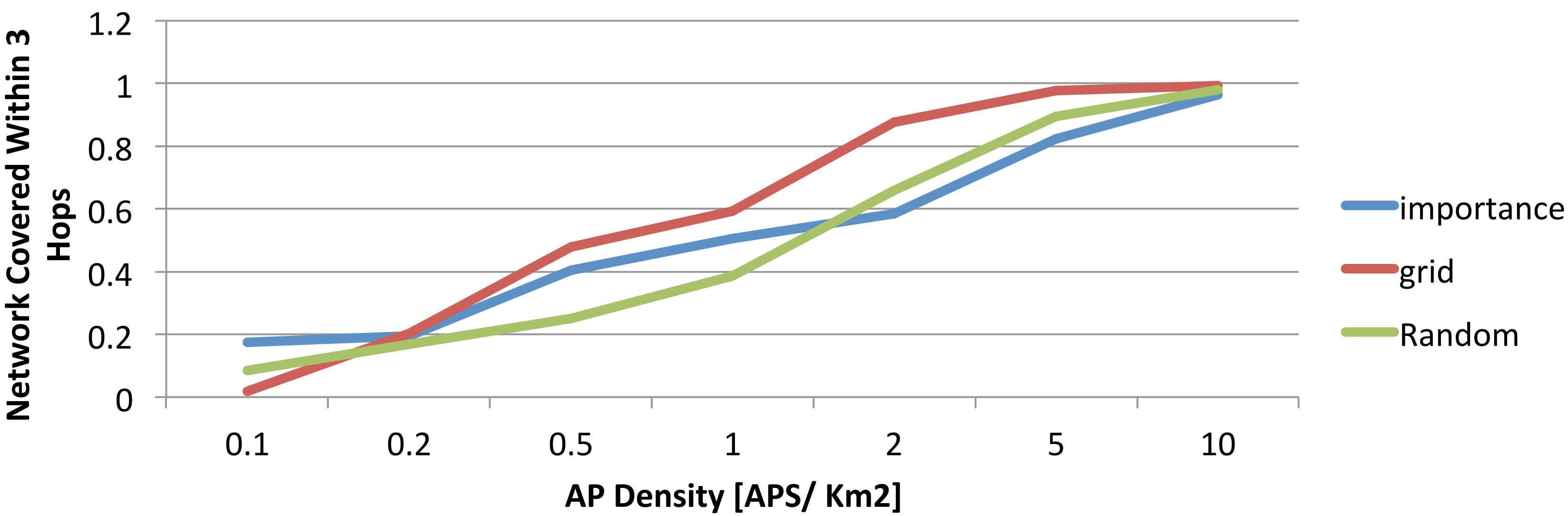


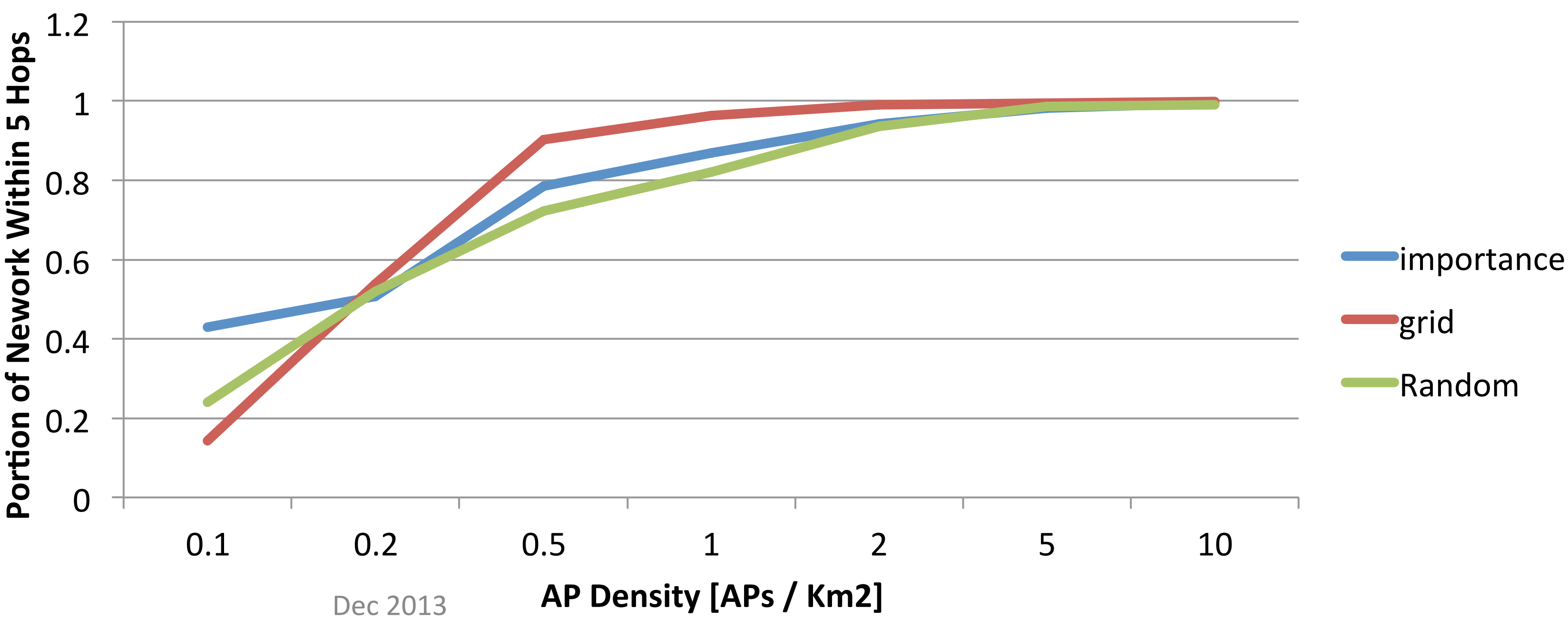
GRID



RANDOM

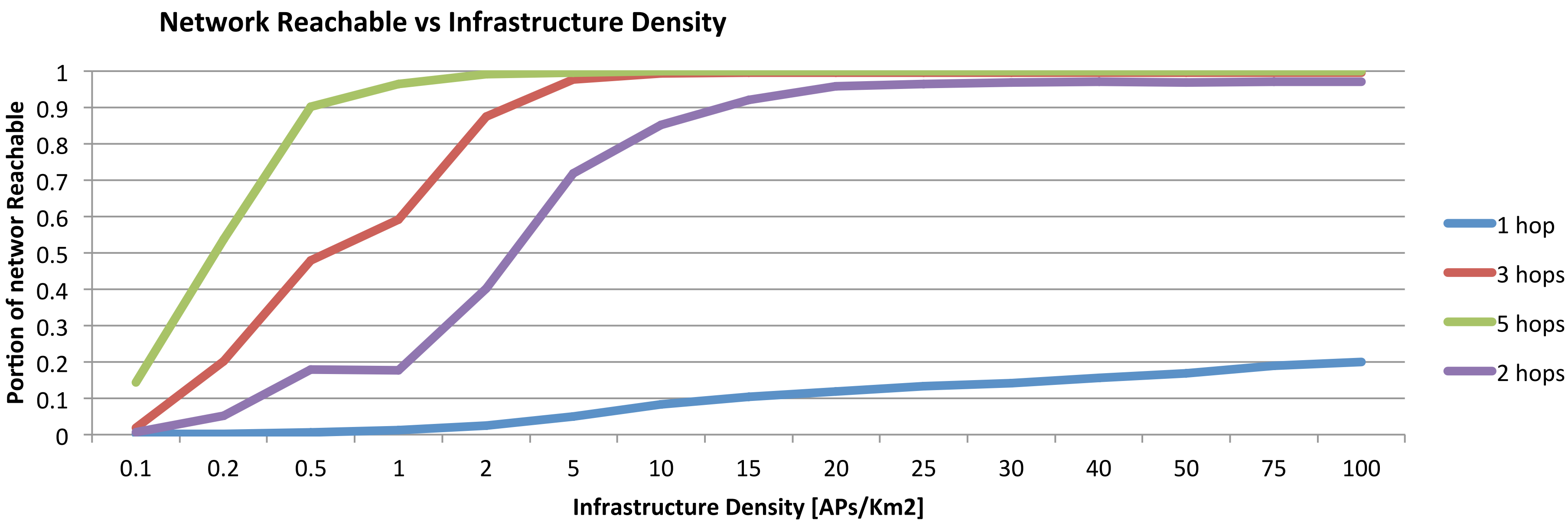
Methods Comparison (Penetr R = 1)





Infrastructure Hops distance vs AP density

AP placement: GRID

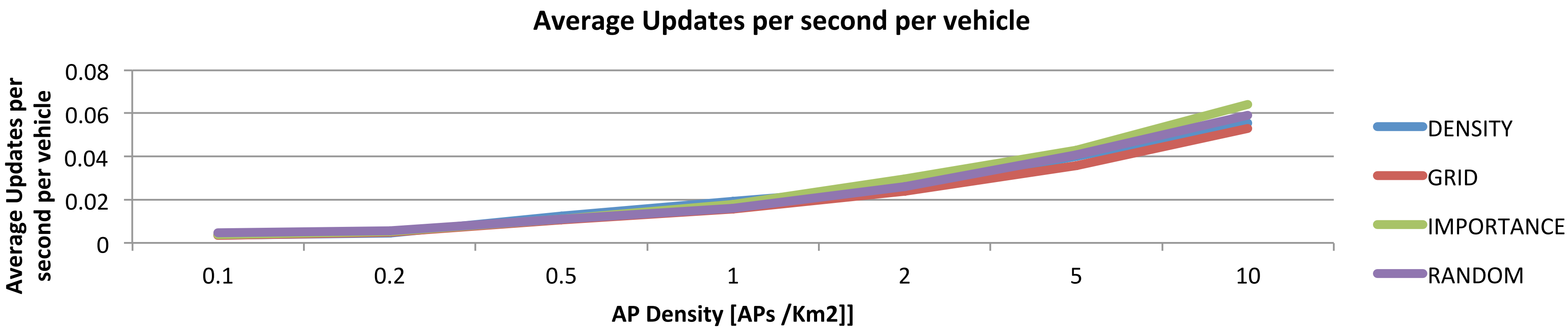


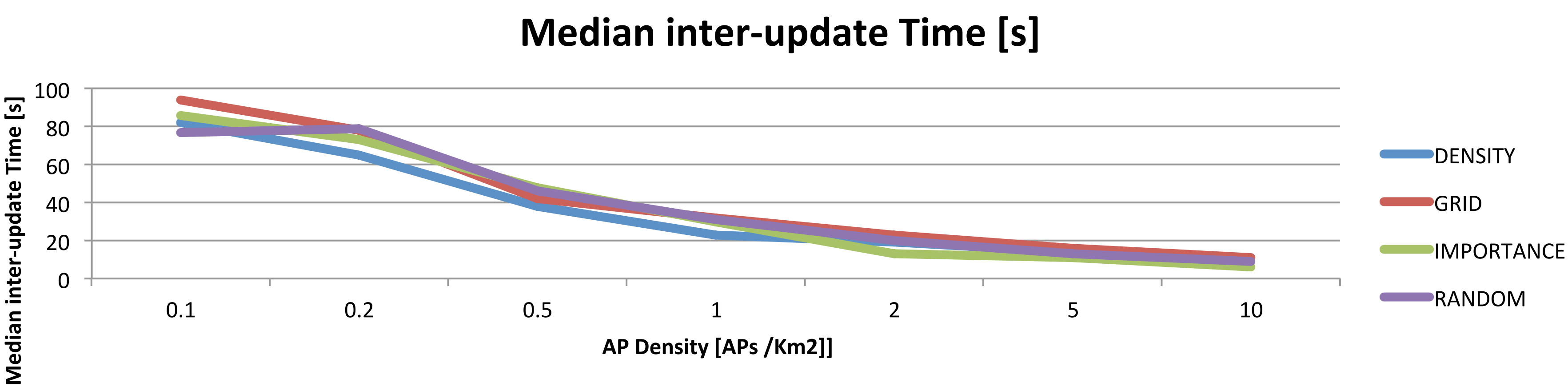
- Full connectivity at 1 hop (V2I only) is not feasible
- With 10 APs/Km^2 the whole network is within 3 hops of the infrastructure

Infrastructure aided (cons)

- It needs management!!
  - DHT or GHT
  - Evaluate the overhead cost in terms of Number of updates needed

Infrastructure aided: cost





- Updates increase
- Association time decreases

Challenge #3 Application Design

Issues

- Mobility and Propagation result in disconnections and large delays, applications need to be a-synchronous to cope with such events.

- Few Examples in following slides.

Used Tools

TIGER-CENSUS

VERGILIUS

CORSIM

VERGILIUS

QualNet

SCALABLE NETWORK TECHNOLOGIES

Geographic Database:
provides the road topology

Scenario Generator:
Provides control over the kind of traffic to generate (uniform, aggregated etc.)

Mobility Simulator:
provides detailed road traffic traces

Trace Analyzer:
Provides:

- Propagation matrix considering buildings.
- Connectivity and Interference metrics based on topology

Network Simulator:
provides network metrics

CarTorrent : Opportunistic Ad Hoc networking to download large multimedia files

Alok Nandan, Shirshanka Das

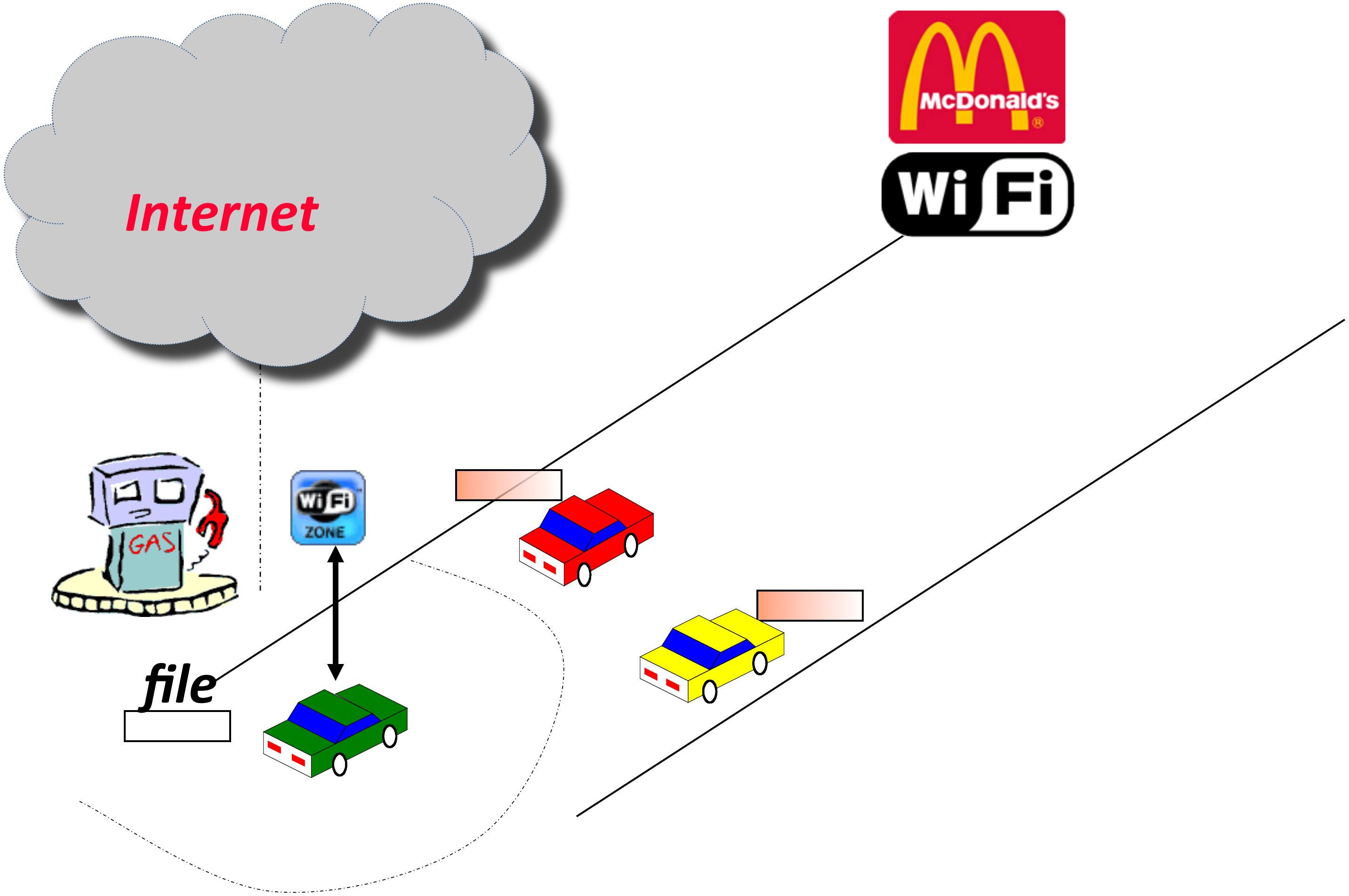
Giovanni Pau, Mario Gerla

WONS 2005

You are driving to Vegas
You hear of this new show on the radio
Video preview on the web (10MB)

♪ ♪♪
♪
♪

One option: Highway Infostation download



Incentive for opportunistic "ad hoc networking"

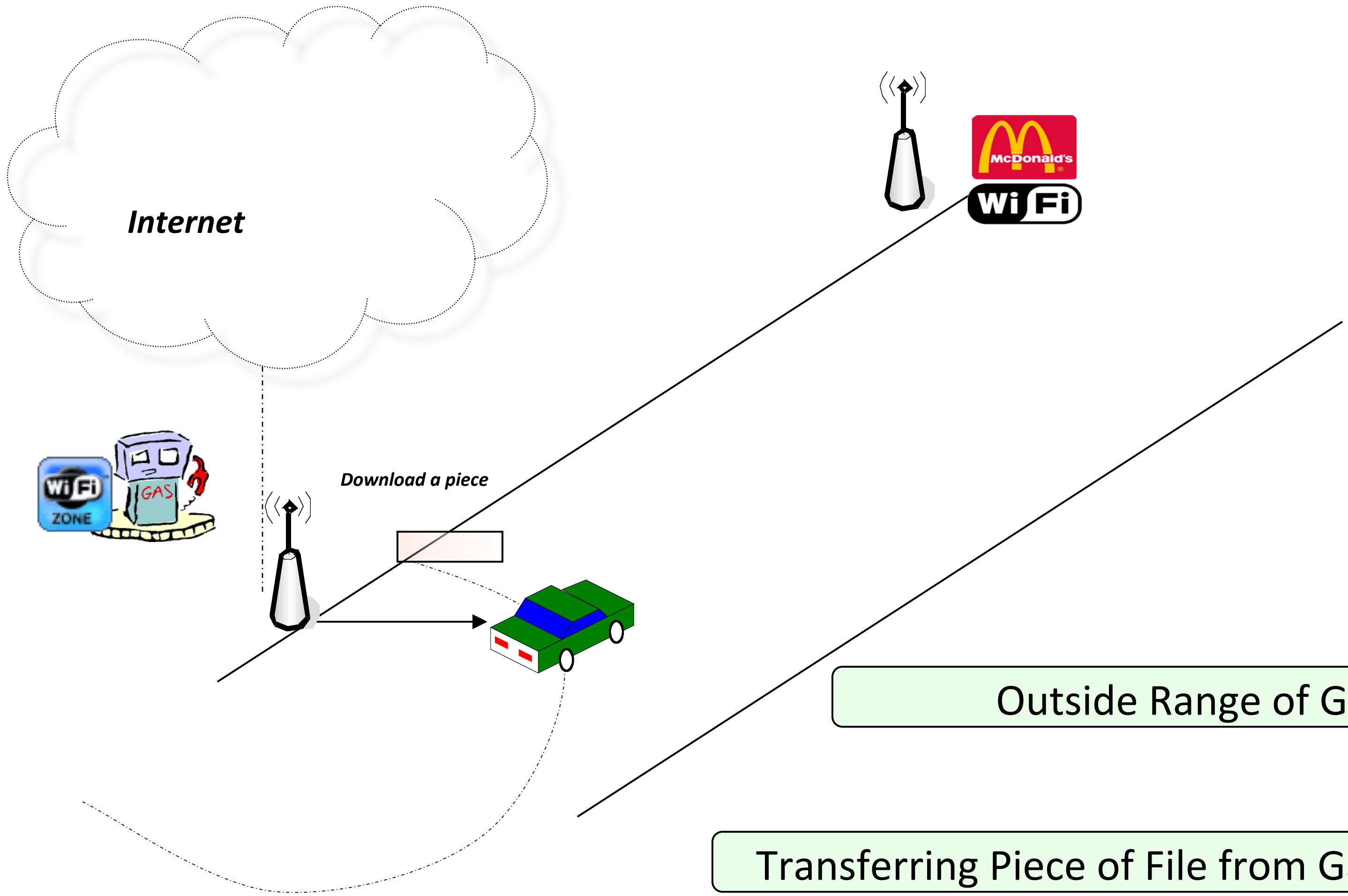
♪
Problems:

Stopping at gas station for full download is a nuisance
Downloading from GPRS/3G too slow and quite expensive

Observation: many other drivers are interested in download sharing (like in the Internet)

Solution: Co-operative P2P Downloading via Car-Torrent

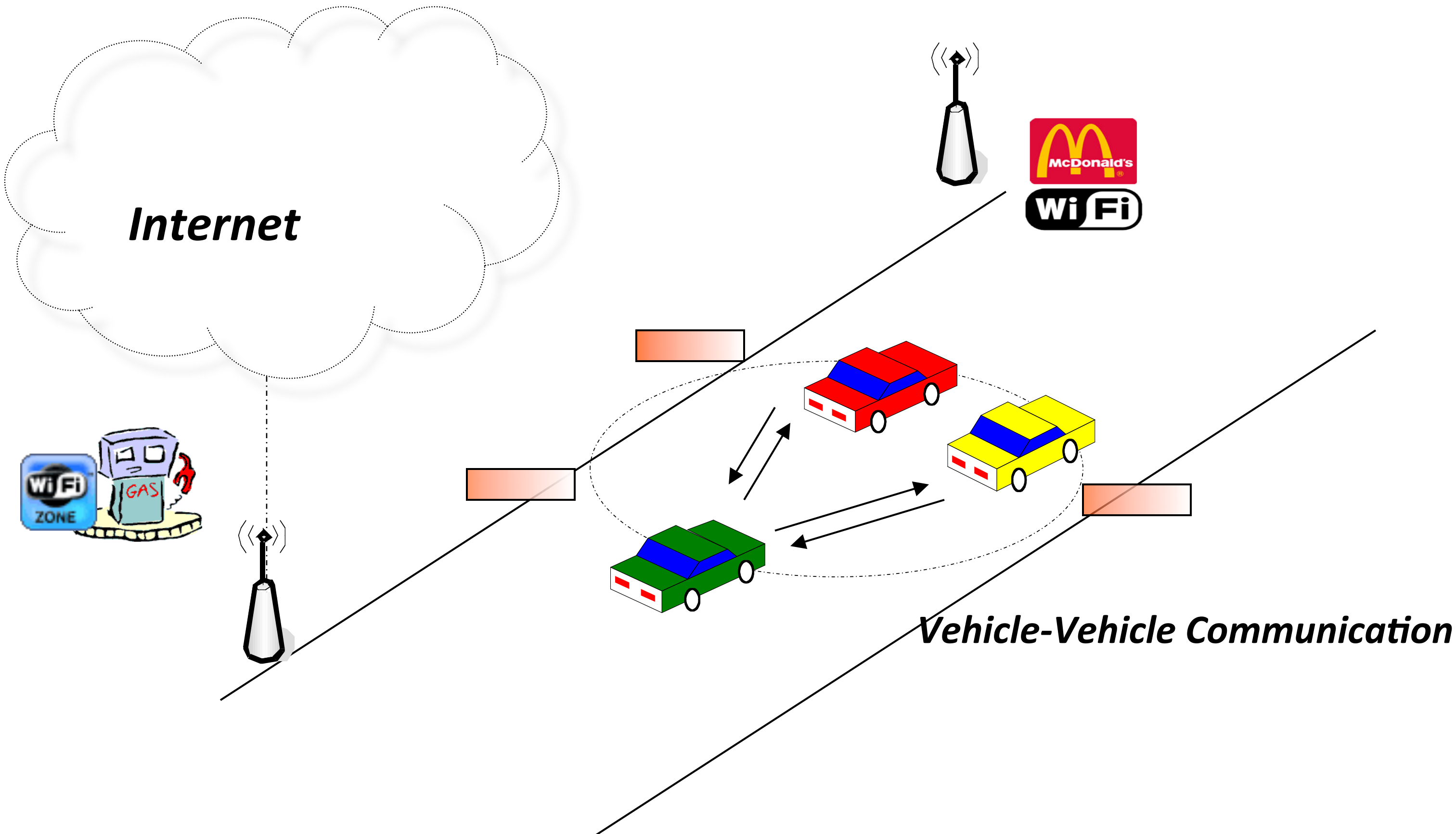
CarTorrent: Basic Idea



Outside Range of Gateway

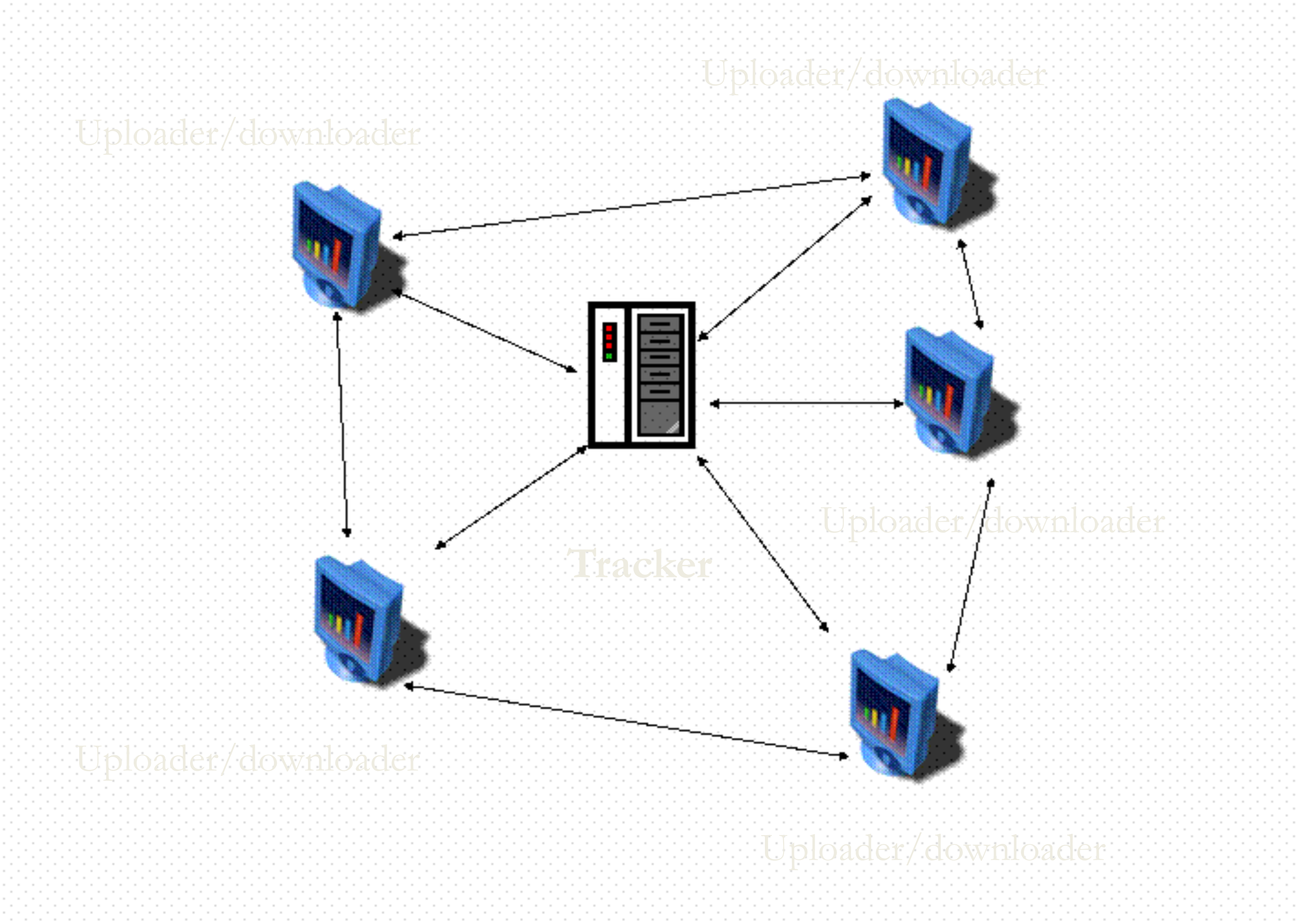
Transferring Piece of File from Gateway

Co-operative Download: Car Torrent

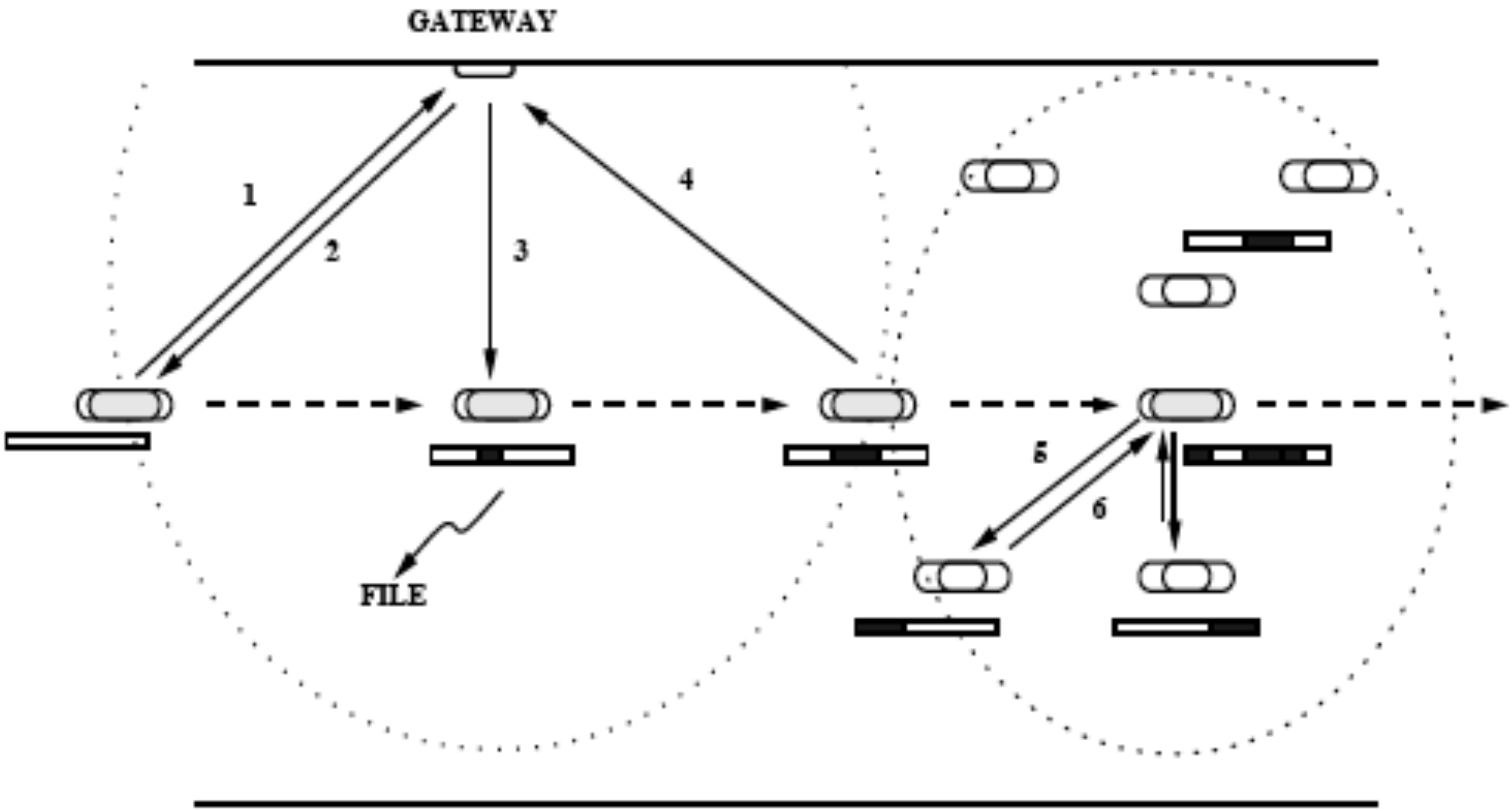


Exchanging Pieces of File Later

BitTorrent: Internet P2P file downloading



CarTorrent: Gossip protocol

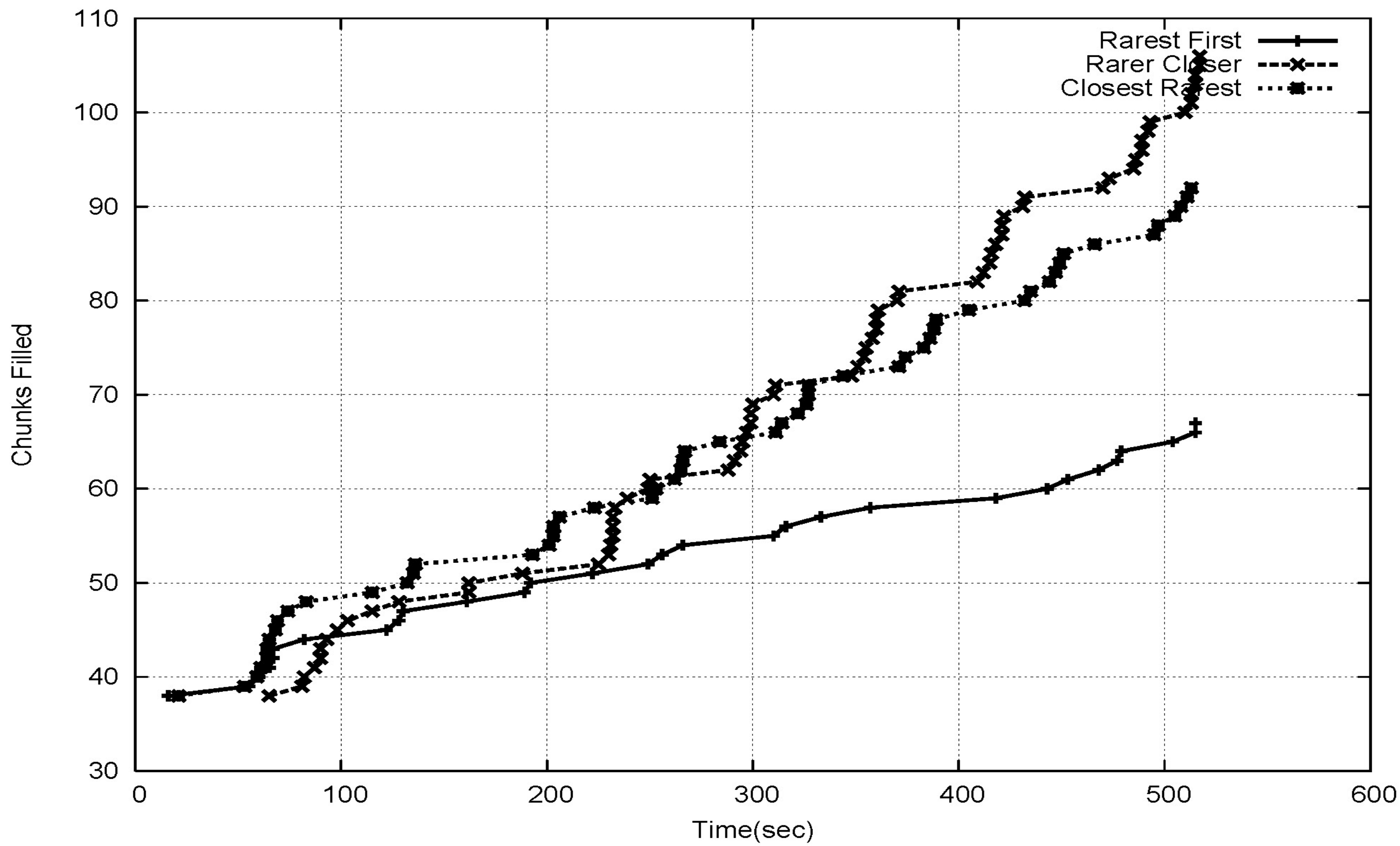


A *Gossip message* containing Torrent ID, Chunk list and Timestamp is "propagated" by each peer

Problem: how to *select the peer* for downloading

♪

Selection Strategy Critical

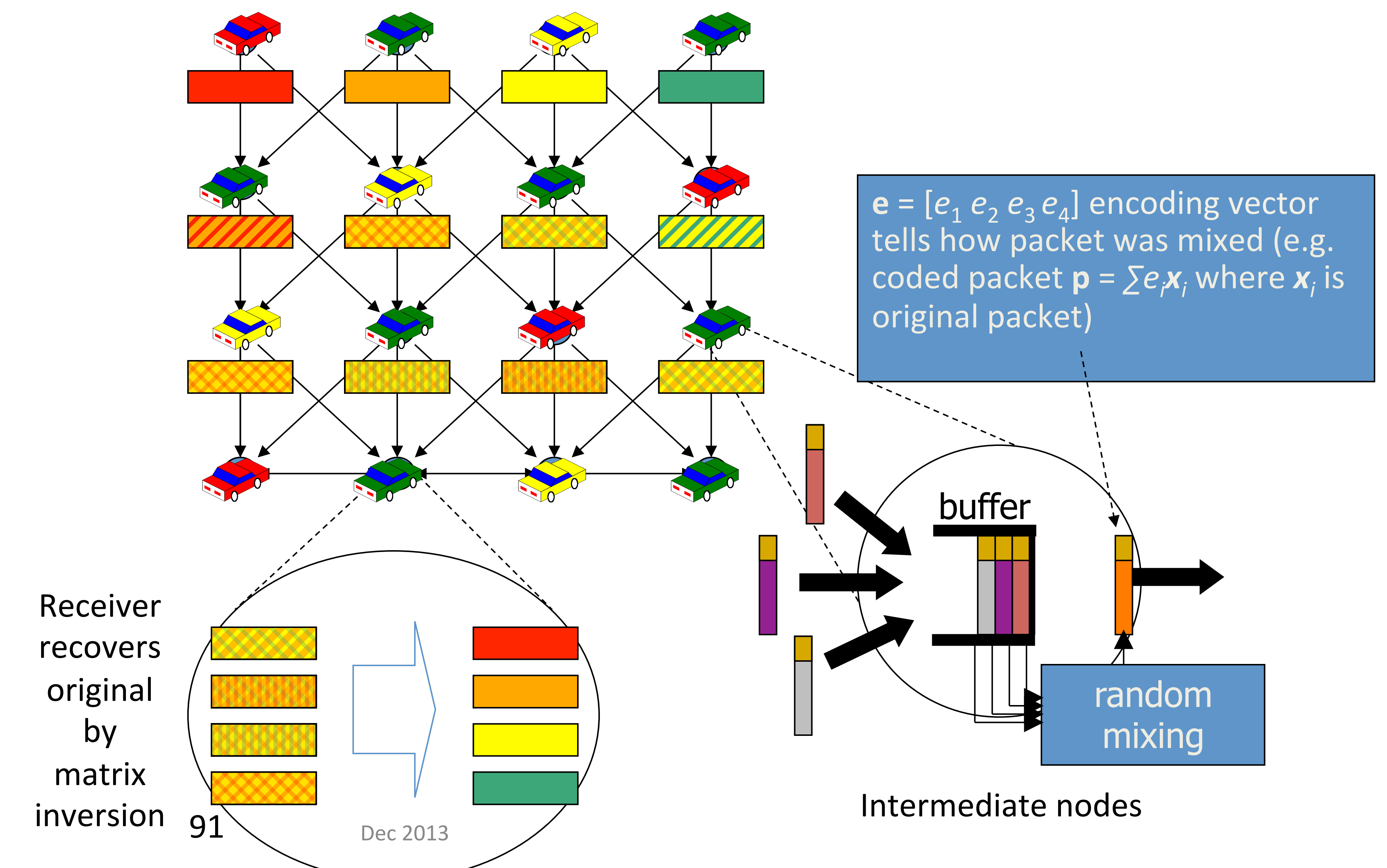


CarTorrent with Network Coding

- Limitations of Car Torrent
  - **Piece selection critical**
  - **Frequent failures due to loss, path breaks**
- New Approach –network coding
  - **"Mix and encode" the packet contents at intermediate nodes**
  - **Random mixing (with arbitrary weights) will do the job!**

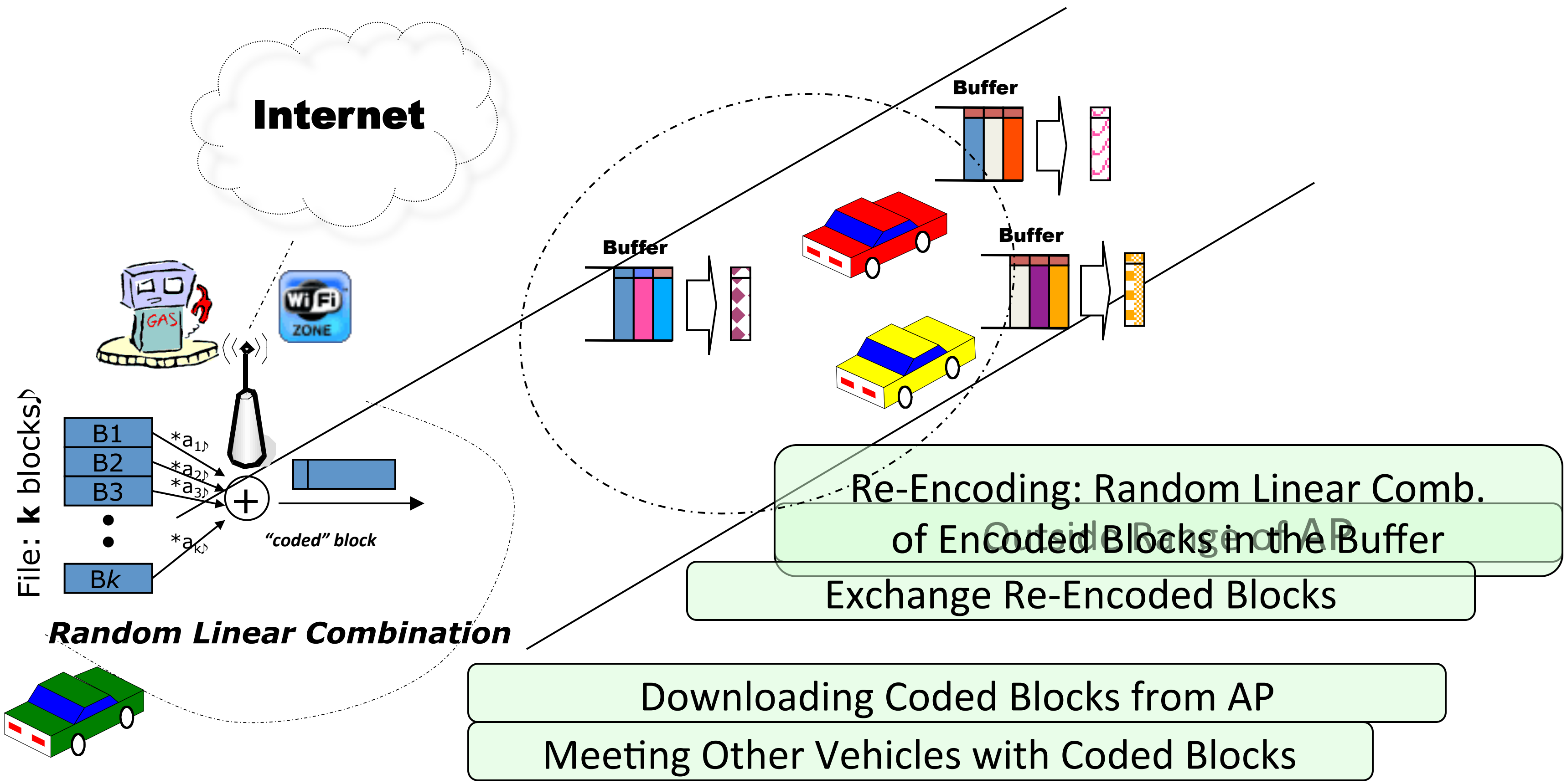
♪

Network Coding



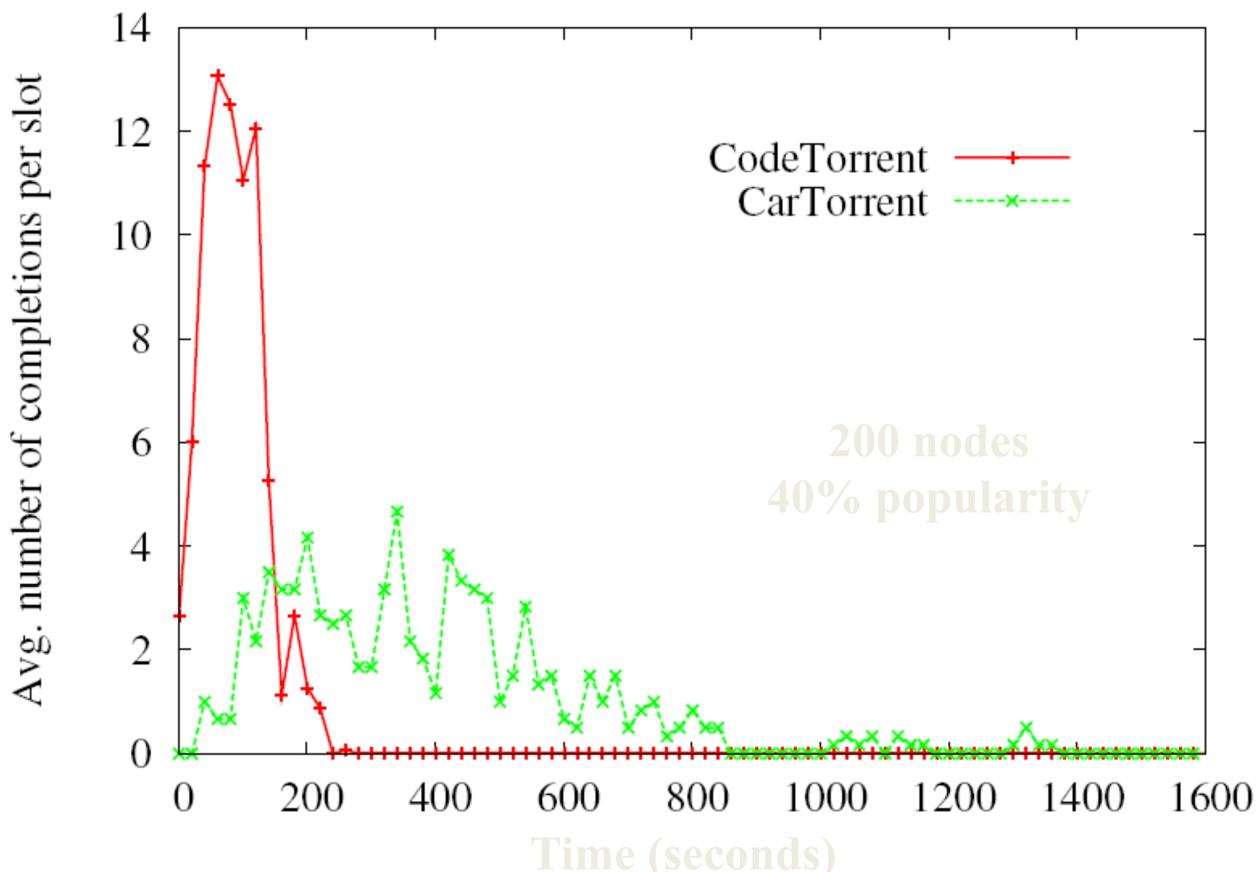
CodeTorrent: Basic Idea

- **Single-hop pulling (instead of *CarTorrent* multihop)**



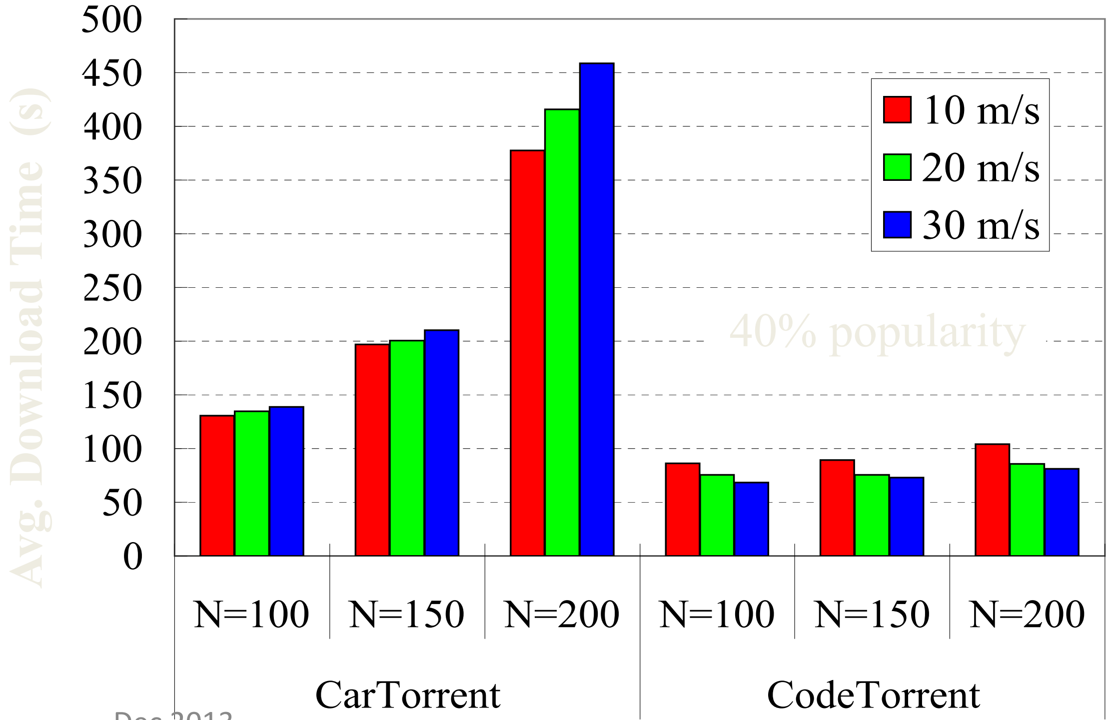
Simulation Results

- Avg. number of completion distribution



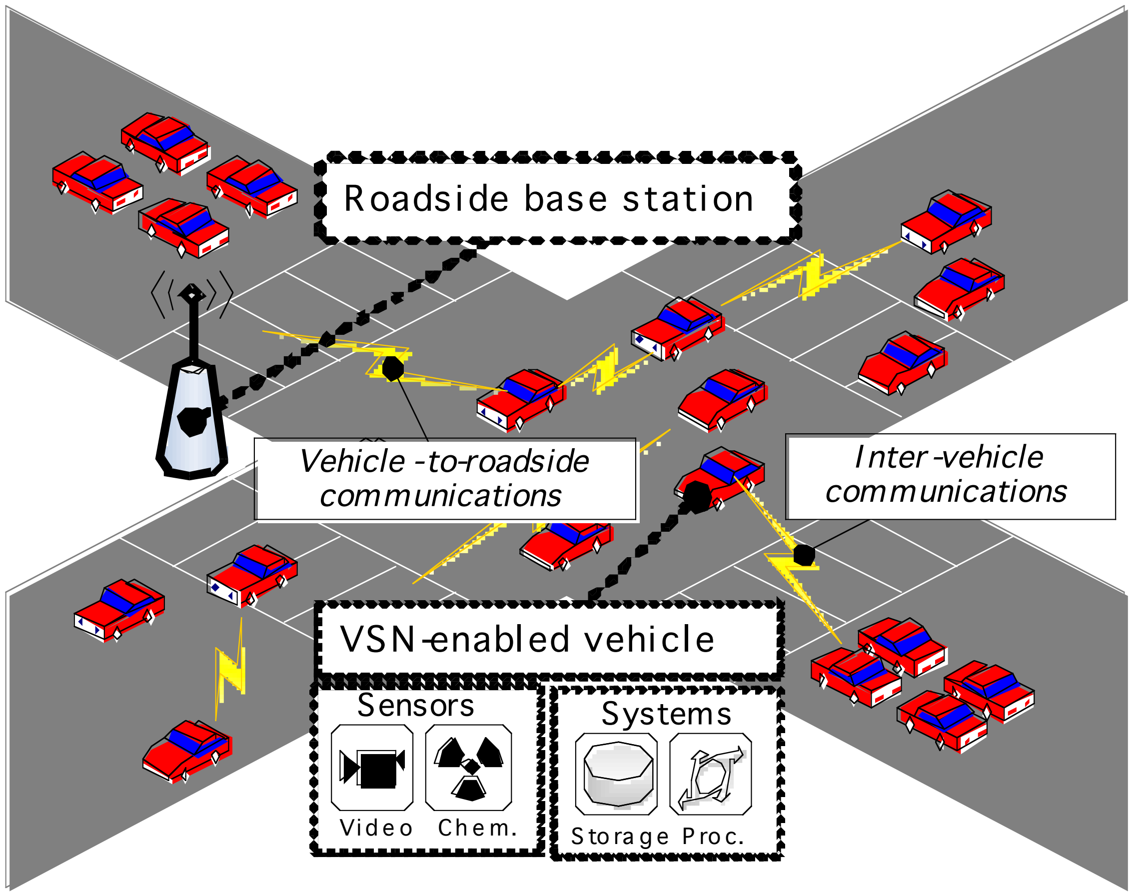
Simulation Results

- Impact of mobility
  - Speed helps disseminate from AP's and C2C
  - Speed hurts multihop routing (*CarT*)
  - Car density+multihop promotes congestion (*CarT*)



Vehicular Sensor Networks

Vehicular Sensor Network (VSN)

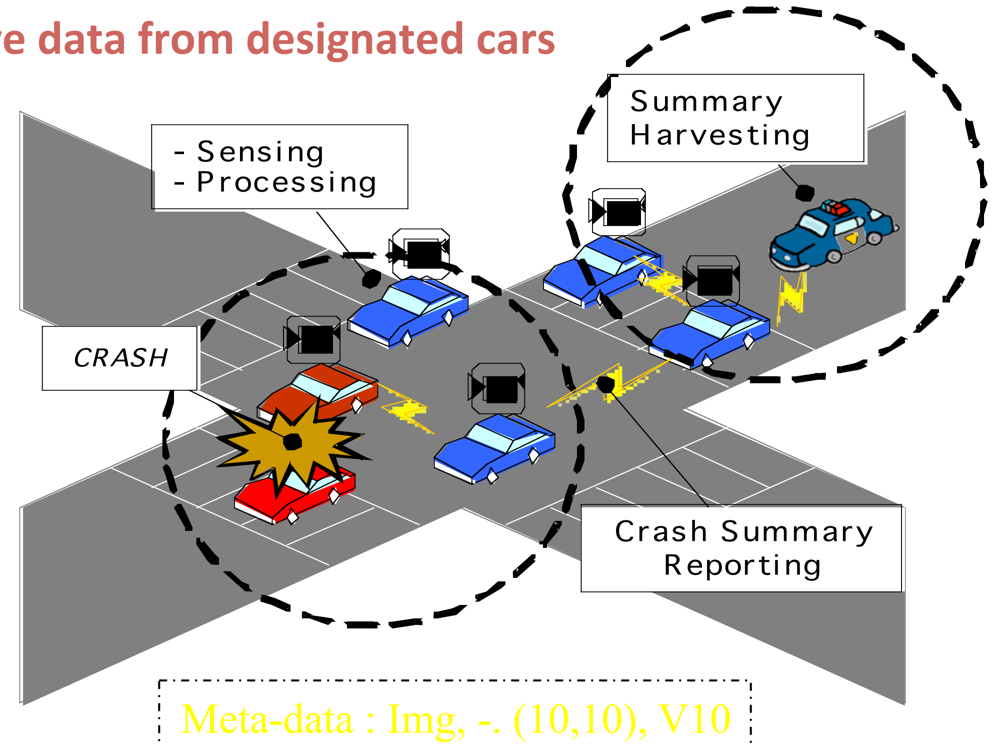


Vehicular Sensor Applications

- Environment
  - Traffic congestion monitoring
  - Urban pollution monitoring
- Civic and Homeland security
  - Forensic accident or crime site investigations
  - Terrorist alerts

Accident Scenario: storage and retrieval

- **Designated Cars:**
  - Continuously **collect** images on the street (store data locally)
  - Process the data and **detect** an event
  - **Classify the event as** Meta-data (Type, Option, Location, Vehicle ID)
  - **Post** it on distributed index
- **Police retrieve data from designated cars**

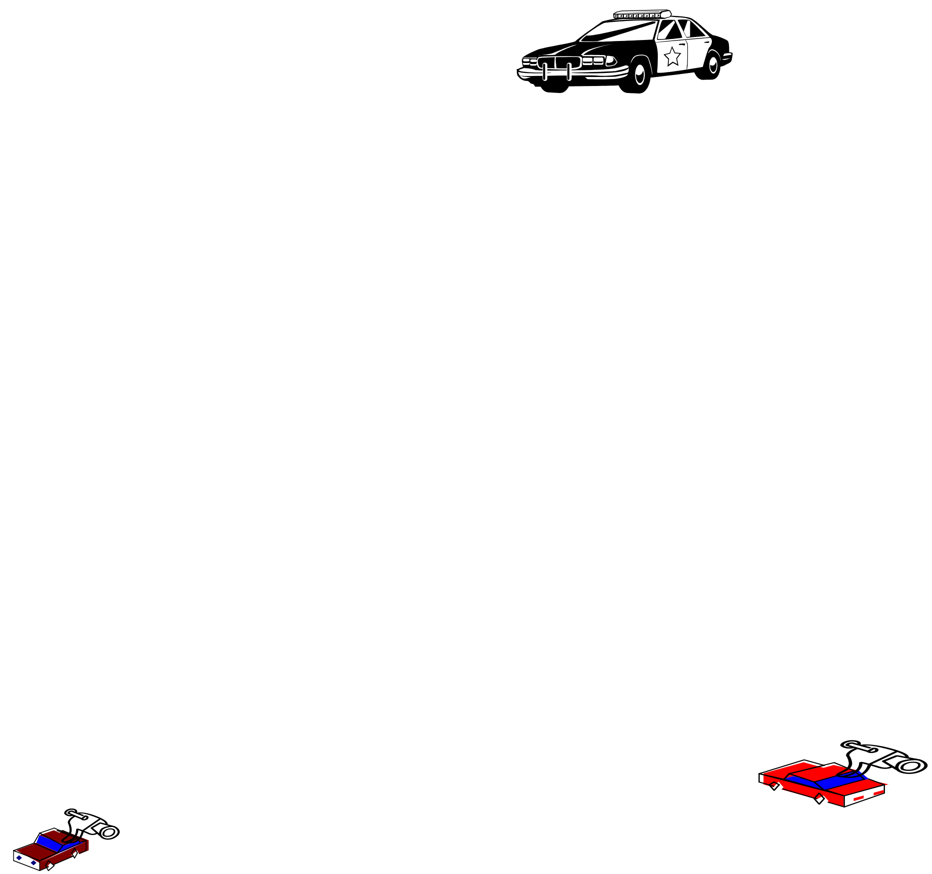


How to retrieve the data?

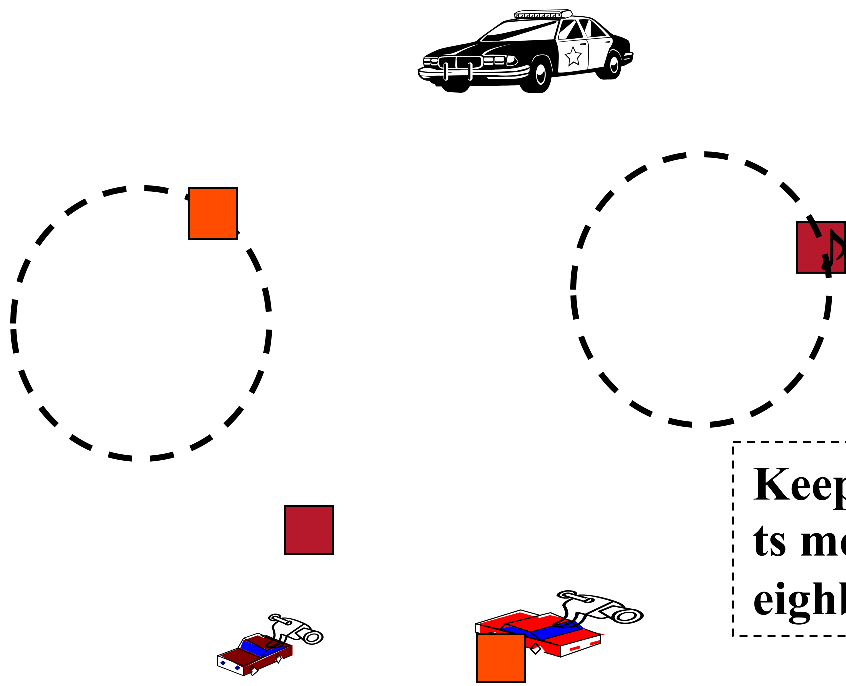
- “Epidemic diffusion” :
  - *Mobile nodes* periodically broadcast *meta-data* of events to their neighbors
  - A *mobile agent* (the police) queries nodes and harvests events
  - Data dropped when stale and/or geographically irrelevant

Epidemic Diffusion

- Idea: Mobility-Assist Meta-Data Diffusion



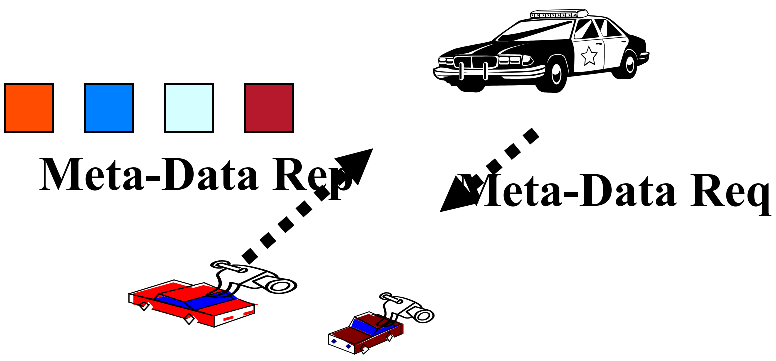
Epidemic Diffusion
- Idea: Mobility-Assist Meta-Data Diffusion



**Keep "relaying" i
ts meta-data to n
eighbors**

**1) "periodically" Relay (Broadcast)
its Event to Neighbors
2) Listen and store
other's relayed events
into one's storage**

Epidemic Diffusion
- Idea: Mobility-Assist Meta-Data Harvesting



1. **Agent (Police) harvests Meta-Data from its neighbors**
2. **Nodes return all the meta-data they have collected so far**

End Part 1

Routing Schemes

Routing scheme Issues

- Routing challenges for VANET
  - The network can frequently form partitions preventing end-to-end communication strategies.
  - Resource discovery and naming are problematic as the vehicles are in general unreliable and frequent arrivals and departures occur.

Routing scheme Issues

- Existing routing protocols designed for MANET are not suitable for VANET.
- The VANET uses position-based routing(PBR), because it outperforms topology-based routing in highly dynamic vehicular environments.

Routing scheme Issues

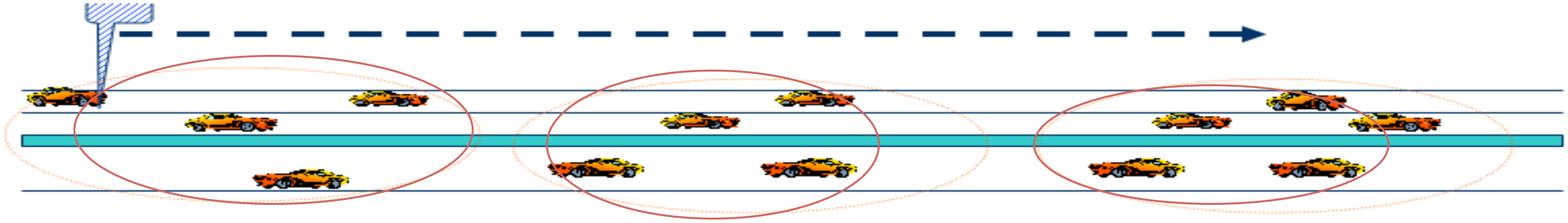
- PBR
  - PBR requires that each node determine its own position through the use of Global Positioning System(GPS).
  - PBR thus does not require the establishment or maintenance of routes but routing decisions at each node is based on the destination's position contained in the packet header.
  - With PBR, each node selects for each packet the next reachable forwarder that is geographically closest to the destination.

Routing scheme Issues

- Partitioned network(Cont.)
  - Mobility can also create temporary network partitions that interrupt end-to-end connectivity and cause packet loss.
  - In order to reduce the number of network partitions, oncoming traffic is included when determining next hops.

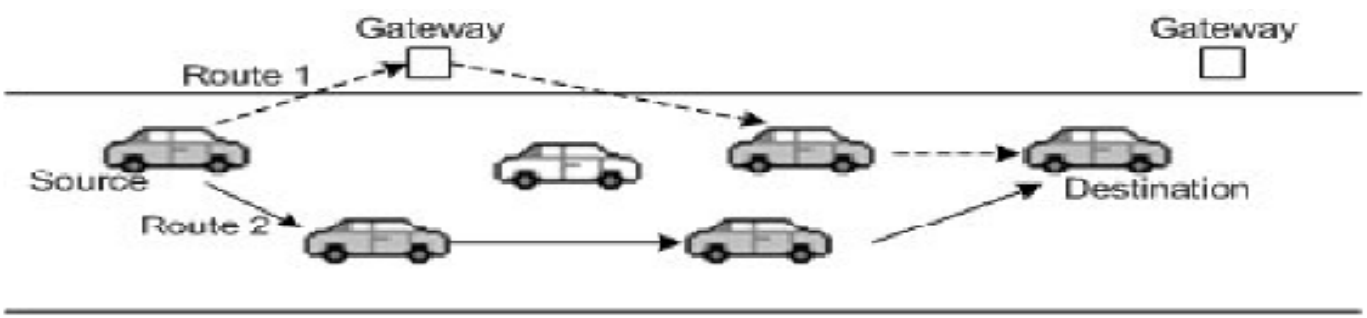
Routing scheme Issues

- Partitioned network(Cont.)
  - Forward mode
    - Message forwarding within a partition
  - Catch-up mode
    - Vehicle movement allows message propagation between partitions

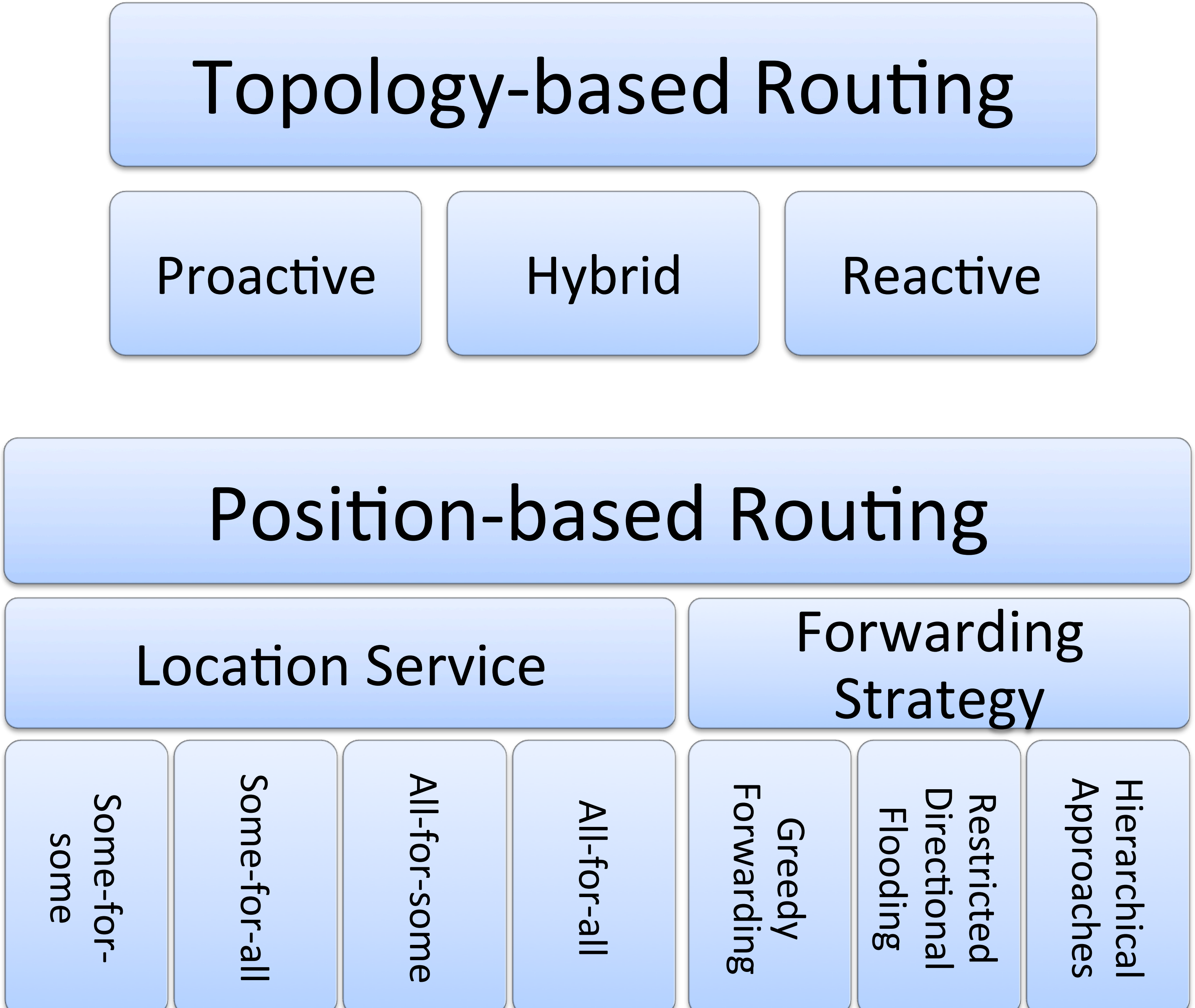


Routing scheme Issues

- Partitioned network
  - In order to bridge gaps in IVC networks and improve multi-hop routing performance, an alternative would be to forward data packets to its destination via roadside infrastructures.



Routing through Roadside Infrastructures


Topology-based Routing
Proactive
Hybrid
Reactive
Position-based Routing
Location Service
Forwarding Strategy
Some-for-some
Some-for-all
All-for-some
All-for-all
Greedy Forwarding
Restricted Directional Flooding
Hierarchical Approaches

Topology-based Routing

- Proactive:
  - Classical routing strategies (distance vector, link state)
  - Maintain all the routing information in tables, for each node's pair
  - + Routing info updated, delay minimized (QoS)
  - - Significant bandwidth occupation, even for unused paths

Topology-based Routing

- Reactive:
  - A route is discovered only when it is needed (2 phases: discovering and sending)
  - + Efficiency (bandwidth, energy..),
  - - Delay for first packet, still intense network traffic in high mobility network

Topology-based Routing

- Hybrid
  - Combine local proactive routing and global reactive routing
  - + Efficiency and Quality of Service
  - - Limited amount of topological changes that can be tolerated (it still needs to maintain at least those network path that are currently in use)

Position-based Routing

- Uses additional information about the physical position of nodes
- Routing decision are based on these information
- Establishment or Manteinance of routes is not required
- Geographic Broadcasting is supported naturally

Forwarding Strategy

- Greedy Packet Forwarding
- Restricted Directional Flooding
- Hierarchical Routing

Greedy Packet Forwarding

" A node tries to forward the packet to one of its neighbors that is closer to the destination than itself "

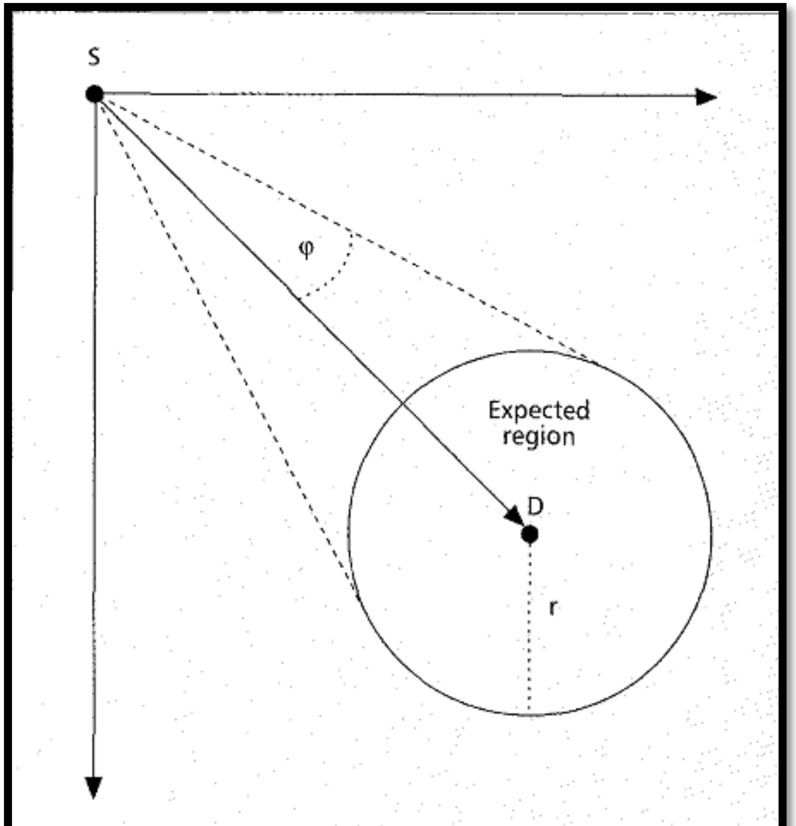
- Next-hop selection (most forward within r, nearest with forward progress, compass routing..)
- Recovery Strategy (face-2 and perimeter routing strategy, using planar graph)

Restricted Directional Flooding

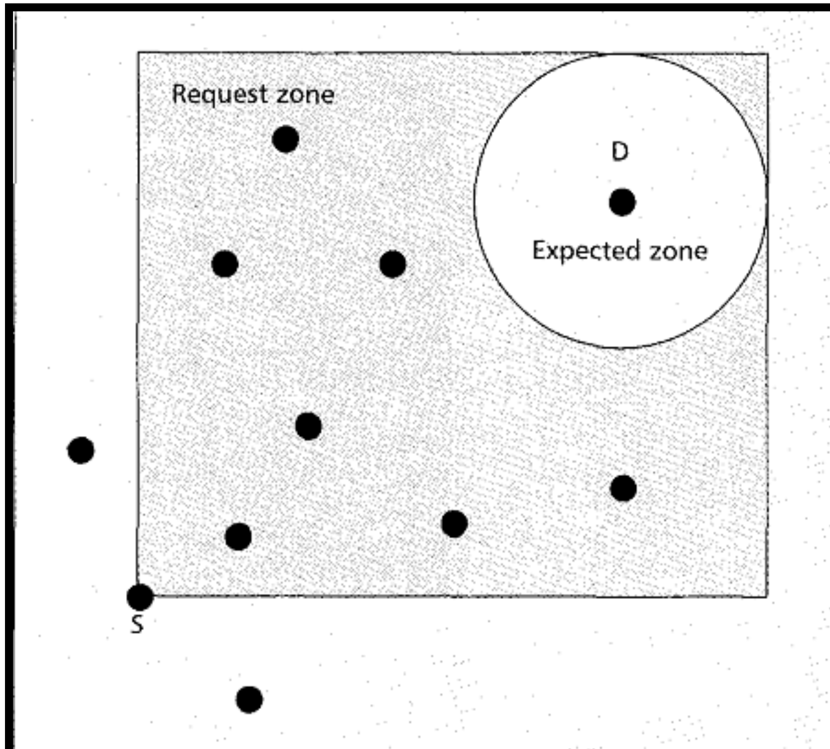
" The sender S of a packet with destination D will forward the packet to all one-hop neighbors that lie in the direction of D "

- Different definition of "lie in the direction of D"

Restricted Directional Flooding



■ Figure 9. *Example for the expected region in DREAM.*



■ Figure 10. *Example of request and expected zones in LAR.*

Hierarchical Routing

“ Routing is structured in two layer, one for long and one for short distance. Location aware routing is used for routing on long distances, while when a packet arrives close to the destination a proactive distance vector scheme is adopted ”

- The Location Aware Routing usually used is the greedy approach, and the repair mechanism used can be different

Forwarding Strategy

- Greedy Packet Forwarding
  - Benefit: efficient and very well suited for use in ad hoc networks with a highly dynamic topology
  - Drawback: the position of the destination needs to be known with an accuracy of one-hop transmission range
- Restricted Directional Flooding
  - Benefit: very robust against the failure of individual nodes and position inaccurancy
  - Drawback: communication complexity of O(n), doesn't scale to large network with high volume of data transmission
- Hierarchical Routing
  - Benefit: more tollerant than greedy towards position inaccuracy
  - Drawback: significantly more complex to implement

Qualitative Characteristic for judge a position based routing

- Loop-freedom
- Distribuited operation
  - Localized routing algorithm
  - Non-localized routing algorithm
    - Global routing algorithm
    - Zonal routing algorithm
- Path Strategy
  - Single path strategy
  - Flooding
  - Multi-path strategy
- Metrics
  - Hop count
  - Power metric
  - Cost metric
- Memorization
- Guaranteed message delivery
- Scalability
- Robustness (cope with position deviation, or communication model deviation)
- Flooding rate

Geographic Source Routing

- Created to deal with high mobility of nodes and the specific topological structure of a city
- Position based routing supported by a map of the city

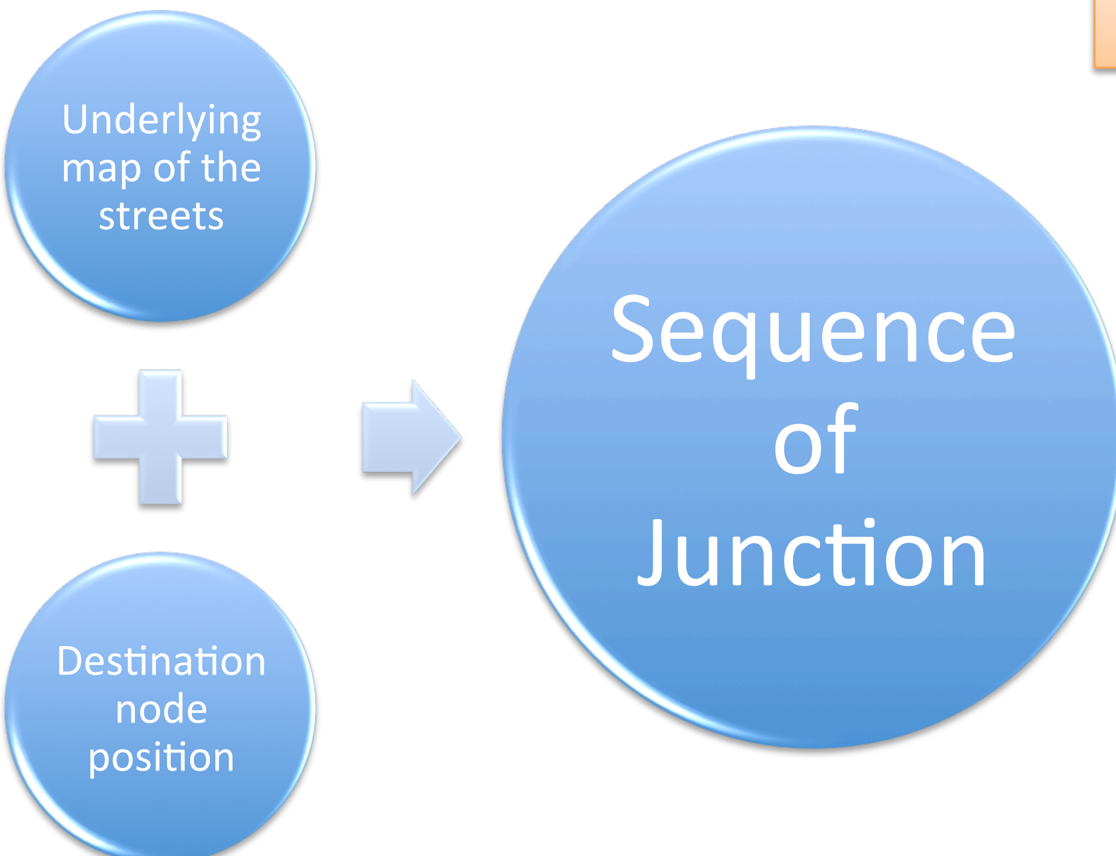
Geographic Source Routing

- Location Service: ‘ Reactive Location Service ‘
  - Derived from reactive non position based routing
  - The querying node floods the network with a position request for a specific node
  - When that node receive the query, it reply with his position
  - Several option implemented for avoiding intensive flooding

Geographic Source Routing

- Path Computing:

Greedy forwarding between junctions



Add the sequence in the packet header

VS

Compute on each node

Geographic Source Routing

- Good packet delivery ratio in dense network
- The location service overhead is growing with the network size, because more nodes flood the location packets
- As for reactive topology based routing, the first packet has a big delay
- No cope with connectivity lack (if there isn't connectivity on a path selected between two junction, the packet is dropped)
- If greedy fails instead, it's used his recovery strategy to cope with the problem

Questions?

Spatially Aware Routing

- Based on Geographic Source Routing, it makes use of spatial model to predict and avoid forwarding failures due to permanent topology holes (caused by spatial constraints)
- To prevent is better than cure:
  – geographic forw. is stateless, so every packet should initiate a recovery process
  – The recovery process is not high-performance for delay and hope count

Spatially Aware Routing

- Location Service: GRID
- Forwarding Strategy: Geographic Source Route with recovery strategy in case of connectivity lack along the path
  - Suspend the packet
  - Switch to greedy forwarding
  - Recompute the GSR

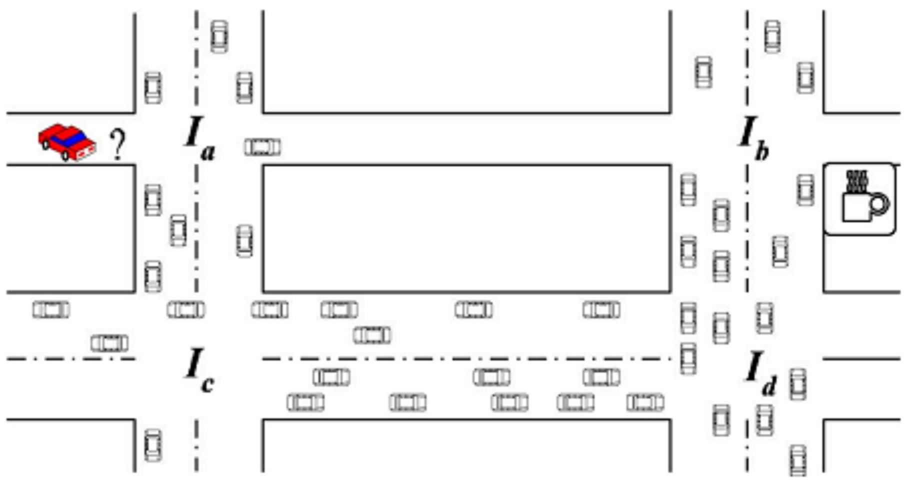
Spatially Aware Routing

- Good packet delivery ratio, better with a recovery strategy even simple like a small buffer
- The delay of SAR is low, because without any recovery method, if a packet cannot be forwarded it's immediately dropped. Introducing the suspend buffer, the delay grow a lot, but for dense network the grow became small
- The hop count of SAR is a lot smaller than SARB with low vehicle density, but it become similar enhancing the density
- The overhead introduced is depending on the number of junctions, so grow with the growing of the map

Vehicle-Assisted Data Delivery

- In delay-tolerant application, when a route doesn't exist, the last node can carry the packet until it reach the next forwarding node
- It's assumed known the map of the streets, as the traffic informations and statistics
- Location Service: similar to DREAM, with periodic beacon message

Vehicle-Assisted Data Delivery

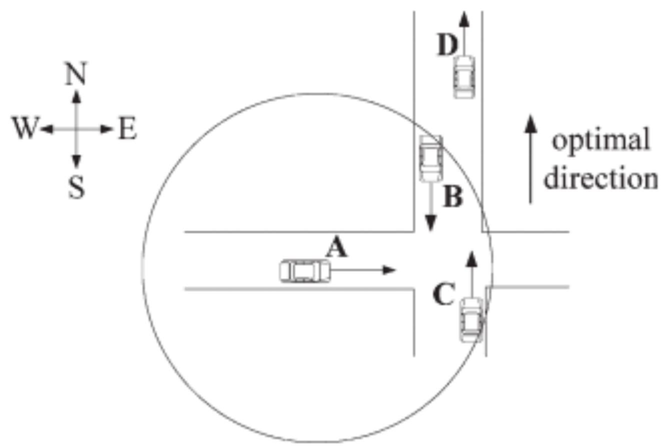


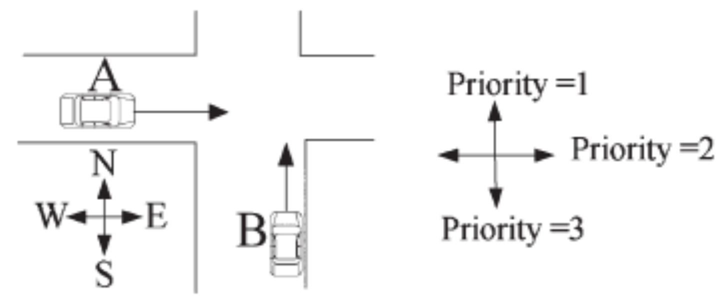
- Transmit through wireless channel as much as possible
- If the packet has to be carried through certain roads, the one with higher speed should be chosen
- Due to dynamisn of Vanet, dynamic path selection should continuosly be executed

VADD: Packet Forwarding Path

- Definition of Delay for every neighboring intersection
- Forwarding to the road with smaller delay
- If not possible, carry
- Use of three packet modes: Intersection, StraightWay and Destination

VADD: Intersection Mode





- Location First Probe: may result in routing loops
- Direction First Probe: free from routing loops, but can have long delay
- Hybrid Probe: L-VADD is used until a loop is detected, than D-VADD and then again L-VADD
- One Computation for Intersection: avoiding disagreement on preferred direction and redundant computation

VADD: Other Modes

- StraightWay Mode:
  - It’s used a greedy algorithm to reach the next intersection. If it’s not possible, the packet is carried
- Destination Mode:
  - When the packet is “near” to the destination, the exact destination location became the current destination, and greedy algorithm is used

Vehicle-Assisted Data Delivery

- Good packet delivery ratio, better in D-VADD and in H-VADD, that avoid loops
- The % of data dropped is almost zero avoiding loops
- The delay for H-VADD and D-VADD is similar with low vehicle density, but H-VADD is two time faster in dense network (like L-VADD)
- The overhead is basically due to the location service implementation

Anchor-based Street and Traffic Aware Routing

- Unique use of information on city bus routes to identify an anchor path with high connectivity for packet delivery
  - Similar to Geographic Source Routing, but the sequence of junction is calculated using traffic awareness and street weight depending also on width and number of bus line
    - Statistically Rated Map Vs Dynamically Rated Map
- New recovery strategy for packed routed to a local maximum
  - Local Recovery: path recalculation and road exclusion with an "out of service" information
- Location Service presence assumed

Anchor-based Street and Traffic Aware Routing

- Better delivery ratio than GSR without local recovery
- Bigger improvement than GSR introducing the local recovery
- Delay similar to GSR, and not amplified by the local recovery
- Can introduce big overhead for propagate dynamical information on traffic

A Digital Map/GPS Based Routing and Addressing Scheme for Wireless Ad-Hoc Networks

- It's a geographical information based routing, that exploit also a digital map database with topology and node distribution
- The routing algorithm it's hybrid: first a proactive protocol, then a reactive one
- Note: it's also proposed an addressing scheme

Digital Map/GPS Based Routing

- Proactive Protocol: Location Service
  - Periodically is sent from every node an information message with its position and velocity
  - Every node store the info about all his neighbours
- Reactive Protocol: Delivery
  - Delivery to a Node
  - Delivery to an Area

Digital Map/GPS Based Routing

- Delivery to a Node:
  - It's found the intersection closest to the source and the one closest to the destination
  - It's calculated the shortest path
  - The packet is forwarded along this path using a greedy method, intersection after intersection
  - Ack for each transmission
  - Upper limit on the number of hops to avoid loops

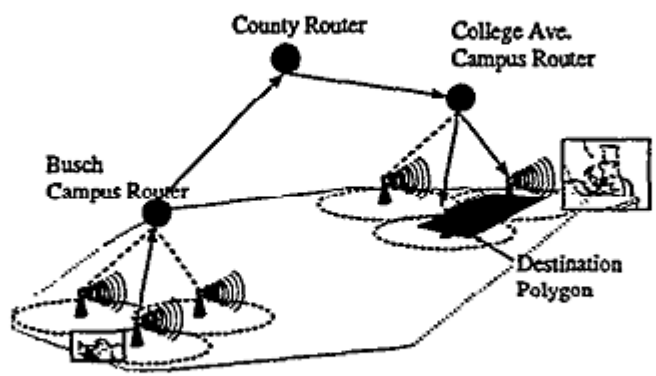
Digital Map/GPS Based Routing

- Delivery to an Area:
  - Similar to delivery to a node
  - When the last intersection is reached, the goal become the ideal center of the area
  - From there, the packet is broadcasted to all the nodes lying in the area

- Testing has to be done

GeoCast: Geographic Addressing and Routing

- Introduced for sending message to geographic destination, defined not only as single point but also as arbitrary polygon
- An address is expressed with two coordinate: latitude and longitude
- There is an hierarchical infrastructure behind, used for the forwarding



Geographic Random Forwarding

- Its goal is to minimize the power consumption of the nodes
- It's a receiver contention scheme, with a new collision avoidance scheme based on a second frequency managing a busy tone

Geographic Random Forwarding

- Sending Phase:
  - The node switch to the active state and monitors both frequencies for T seconds
  - If both are idle, a RTS message is broadcasted, containing the location of sender and destination
  - A CTS message from the potential relays is attended (Start, Continue waiting o Collision action)
  - ACK is expected (go back to sleep, retry or give up and notify)
    - Packet Duplication Problem: solved by intermediate nodes or the destination

Geographic Random Forwarding

- Receiving Phase:
  - Periodical wake up and listening
  - If the start of a message is detected, the node activate the busy tone
  - If a RTS is received, its determinated own priority as a relay, based on the relative location of itself, S and D
  - The priority is partitioned in class from A1 to An
  - For each class, starting from A1, all the active node aswer with a CTS and wait for an answer
  - If a packet start is heard, the designed relay will continue to receive, and all the others go back to sleep
  - If Continue is heard, all A1 nodes go sleeping, and the A2 nodes will contend for the CTS
  - If Collision is heard, it means that more than one node in the same area sent the CTS
    - Each of the colliding relay randomly choose if continue or drop, until only one last

Geographic Random Forwarding

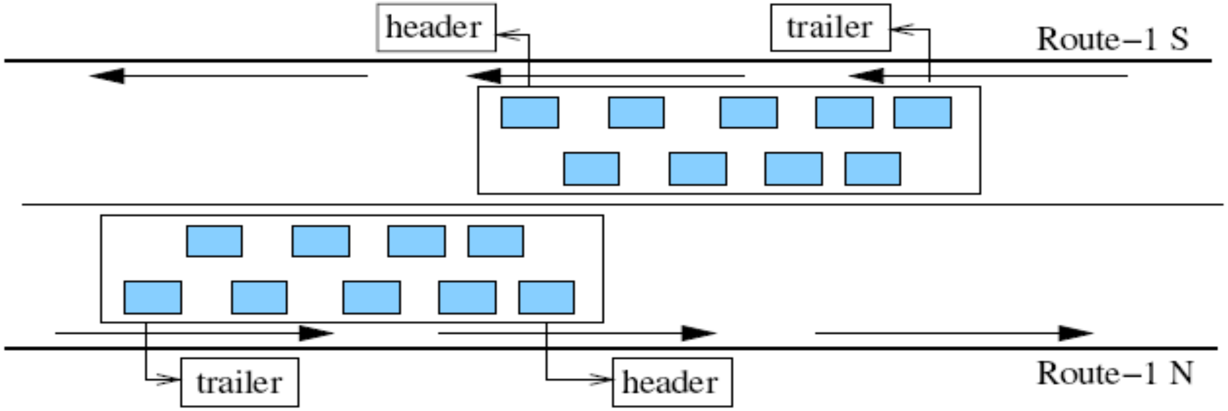
- For large duty cycle the energy consumption is dominated by the listening activity
- Decreasing that, the fact that the transmitter must spend energy to find a neighbor becomes dominant
- Better results are obtained in dense networks
- A Location Service is needed, even if here is not considered

Routing schemes From the Automotive

- DDP
  - Directional Propagation Protocol(DPP) utilize the directionality of data and vehicles for information propagation.
  - DDP is comprised of three components:
    - Custody Transfer Protocol(CTP)
    - Inter-Cluster Routing Protocol
    - Intra-Cluster Routing Protocol

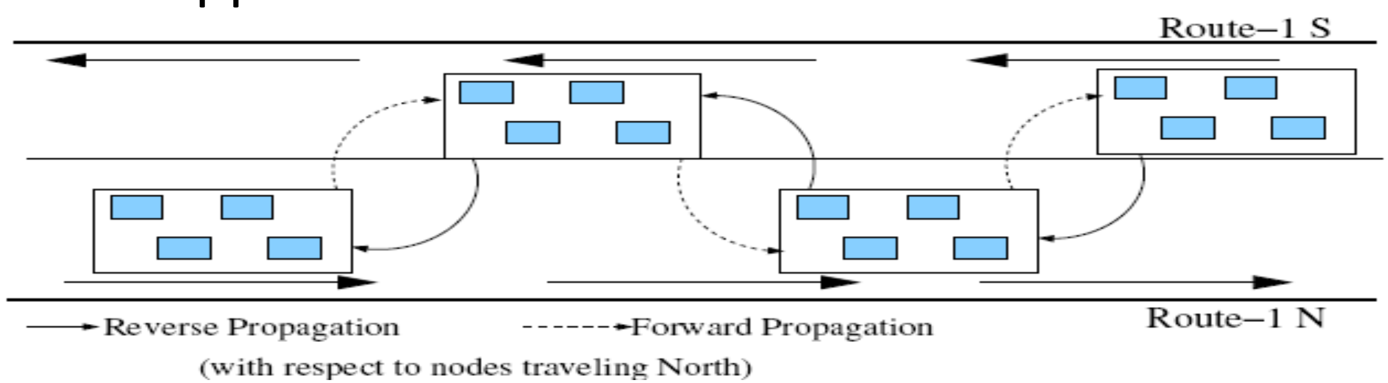
Routing schemes From the Automotive

- DDP(Cont.)
  - Each cluster has a header and a trailer, located at the front and rear of each cluster, entrusted with the task of communicating with other clusters.



Routing schemes From the Automotive

- DDP(Cont.)
  - Inter-Cluster Routing & Intra-Cluster Routing
    - Immediately routed to header or trailer depending upon the direction in which in which information needs to propagate.
    - Any duplicate messages received at any of the nodes are dropped.



Routing schemes From the Automotive

- DDP(Cont.)
  - Custody Transfer Protocol(CTP)
    - The custody is implicitly transferred to another cluster that is in front along the direction of propagation and is logically the next hop in terms of the message path.
    - The traffic in opposing direction acts as a bridge but is never given custody of the message.
    - The custody of the message may be accepted or denied by a cluster by virtue of it being unable to satisfy the requirements of the message.

Routing schemes From the Automotive

- MOPR
  - Movement Prediction based Routing(MOPR) algorithm predicts future positions of vehicles involved in each routing path based on their positions, speeds, and directions.
  - So MOPR is able to estimate links lifetime.
  - MOPR predicts if an intermediate routing node is likely to cause a rupture link during the transmission time or not.

Routing schemes From the Automotive

- MOPR(Cont.)
  - MOPR dynamically selects the most stable route among the routes provided by classical multi-path routing algorithms.
  - What is a stable route?
    - It is the one composed by(more) stable nodes.
  - What is a stable node?
    - It should have a direction and a speed similar to the ones of the destination node(and the source node).
    - Note that intermediate nodes can be moving or static.

Routing schemes From the Automotive

- MOPR(Cont.)