MAP-I Seminar
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# A Practical Approach on Vehicular Networks

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instituto de telecomunicações

creating and sharing knowledge for telecommunications

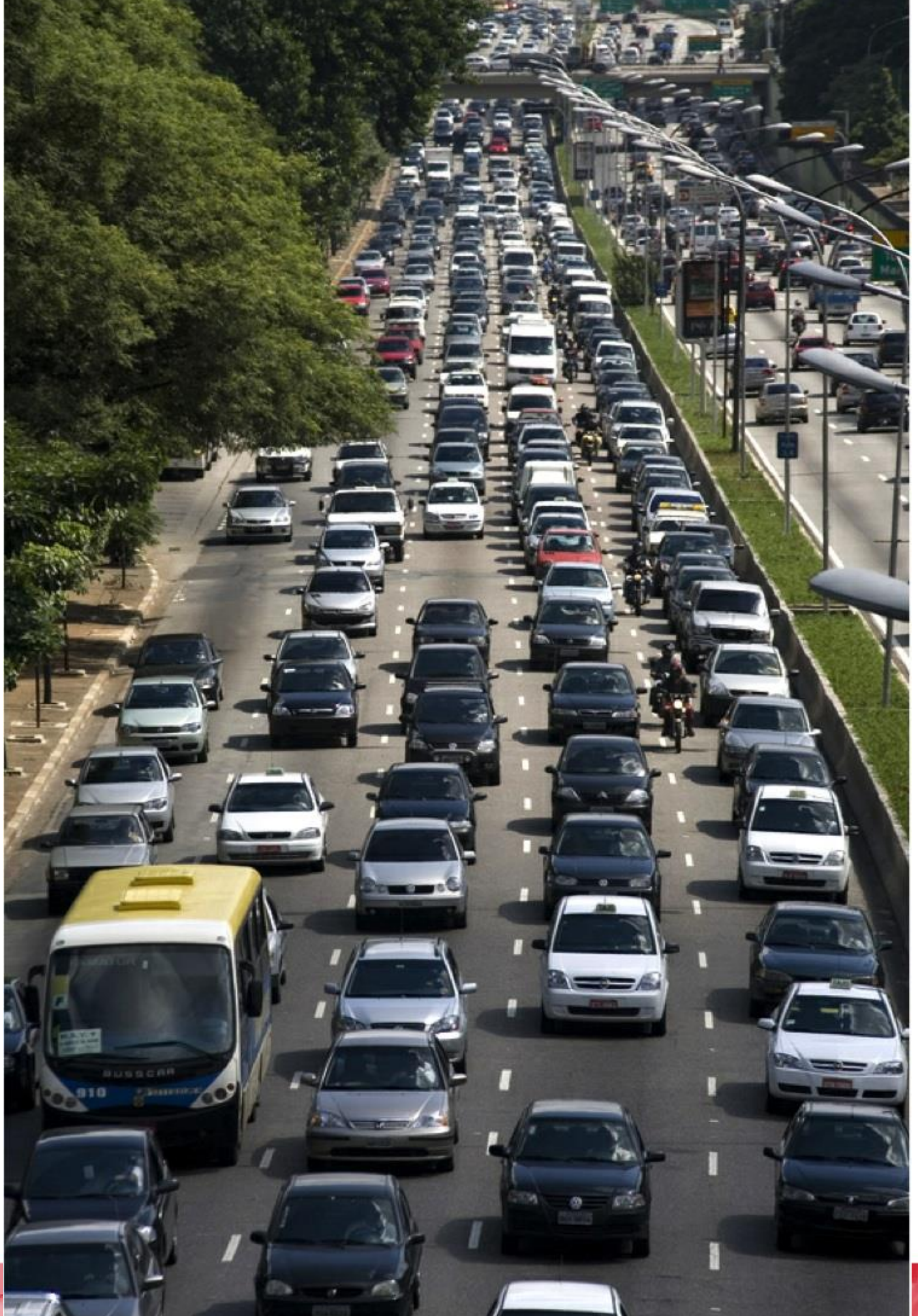
# Connecting Vehicles

Why communication in the roads?

**mobile data**
(telcos are seeking WiFi offloading solutions to cope with 1800% growth in traffic until 2016)

**continuous connectivity**
(connectivity anywhere, everytime)

**connected cars**
(all Internet-based services in the cars)



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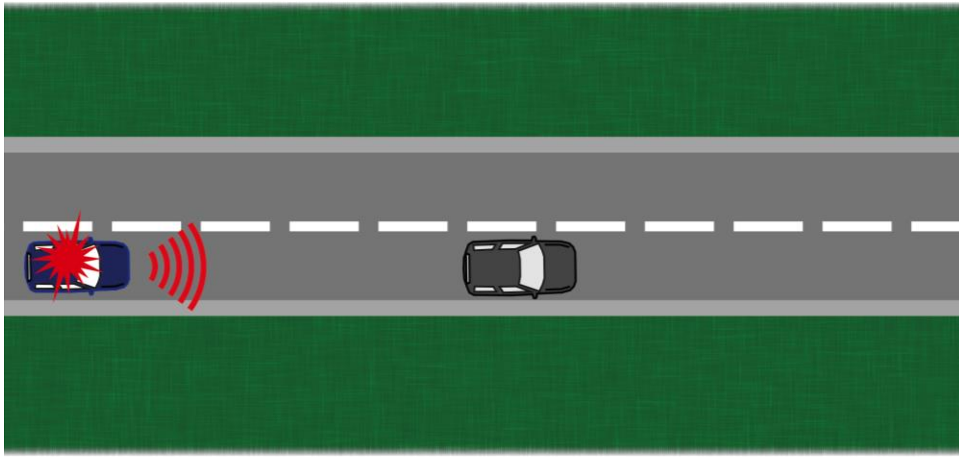
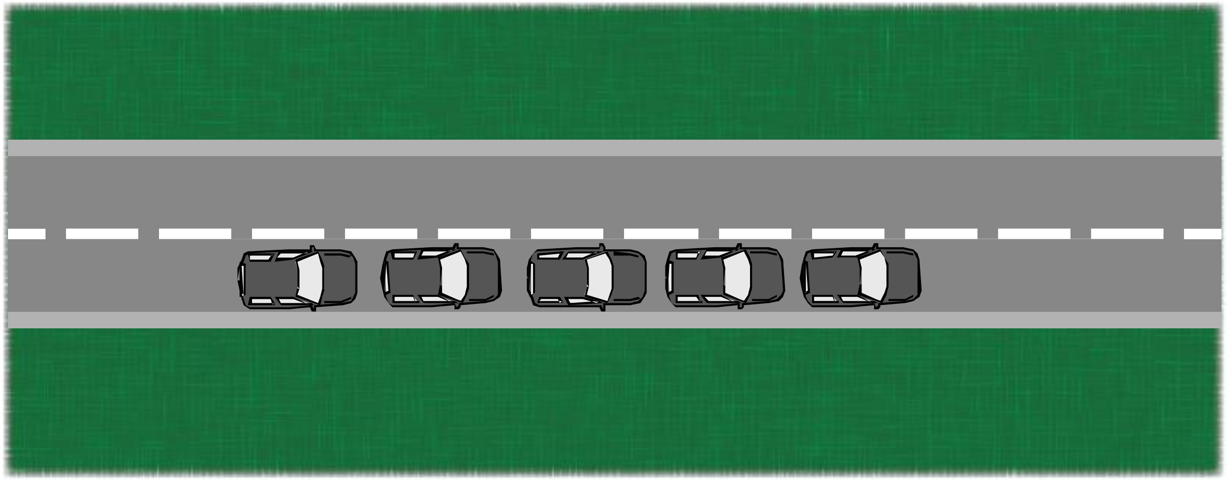
# Safety Applications

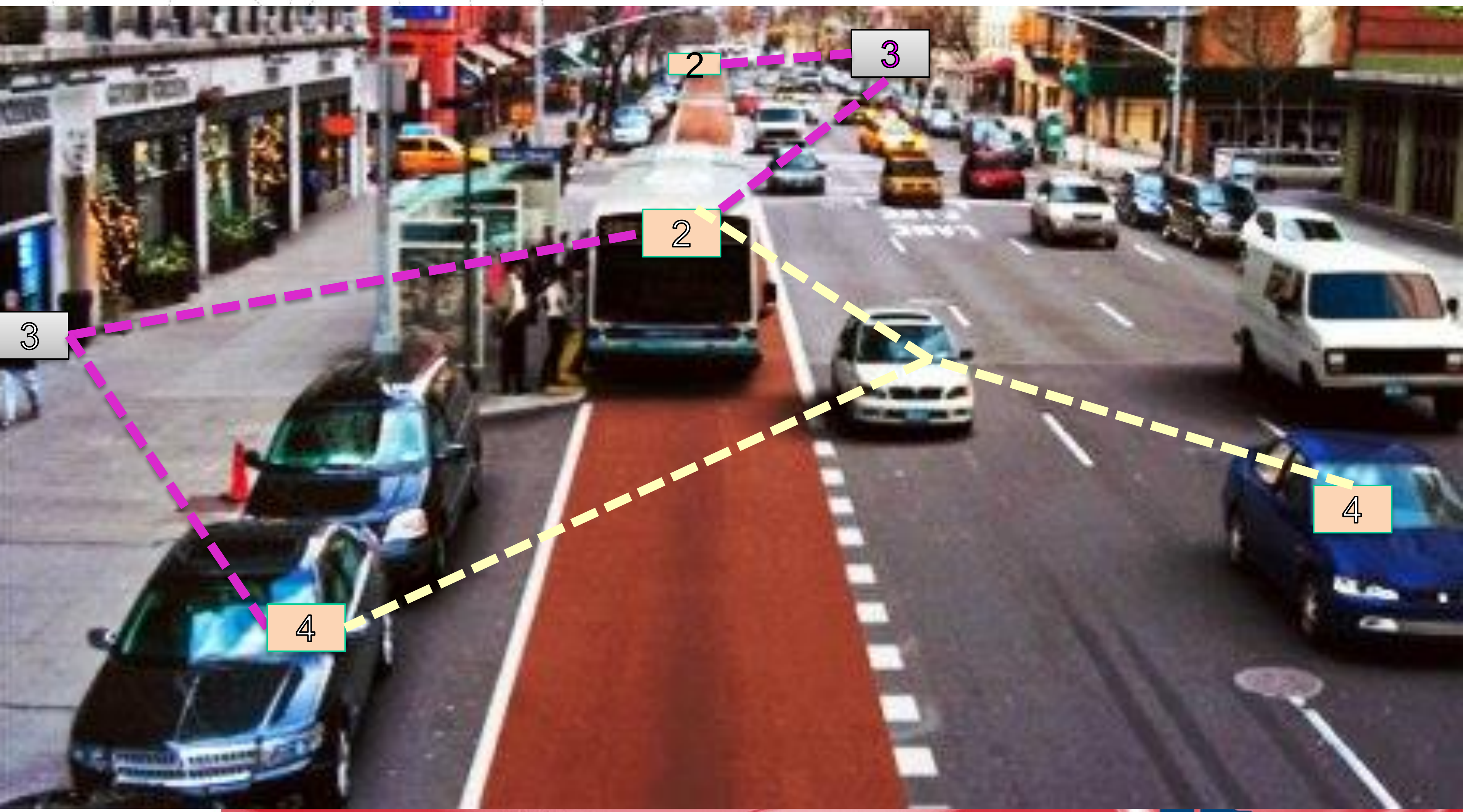


# Traffic and Fleet Management Applications

# M2M Applications

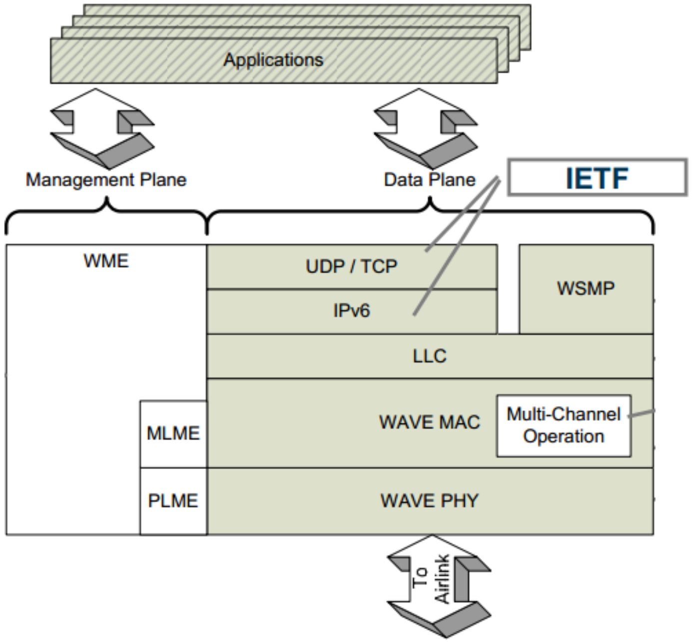
# Entertainment Applications

# How do Vehicular Networks Work?



# Vehicular Technology: DSRC - IEEE 802.11p and WAVE

- Improves transmission range
- Reduces the amount of necessary overhead when joining a BSS in 802.11
- IEEE 802.11p/1609.4 specify MAC sub-layer functionalities
  - Channel routing, coordination of access to the channels, channel switching, time synchronization




| Número do canal | 172 | 174 | 176 | 178 | 180 | 182 | 184 |
|---|---|---|---|---|---|---|---|
| | SCH | SCH | SCH | CCH | SCH | SCH | SCH |
| Frequência (GHz) | 5.86 | 5.87 | 5.88 | 5.89 | 5.9 | 5.91 | 5.92 |

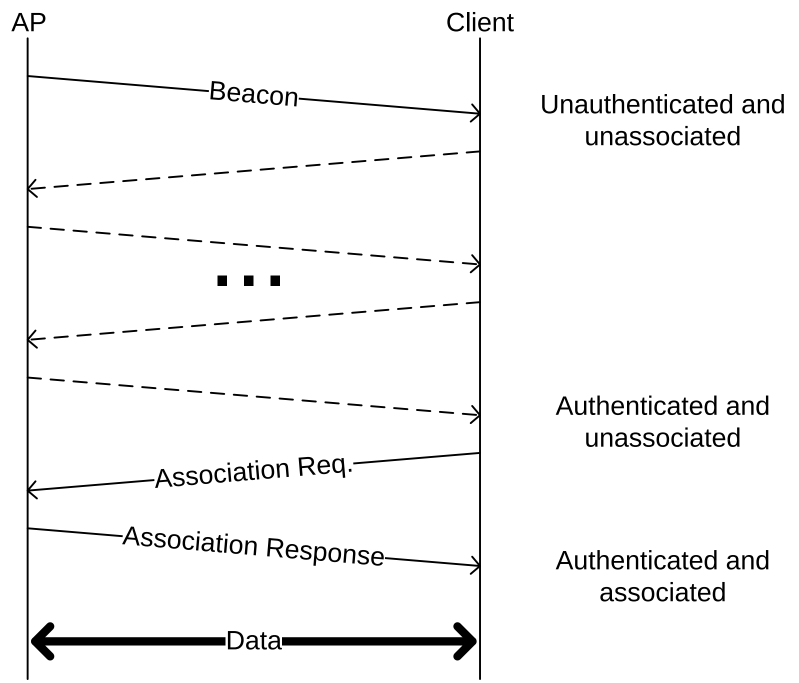
# Wi-Fi: Joining

3 Phases

Too many messages

Too much time

The car could be out of the range before the process was complete



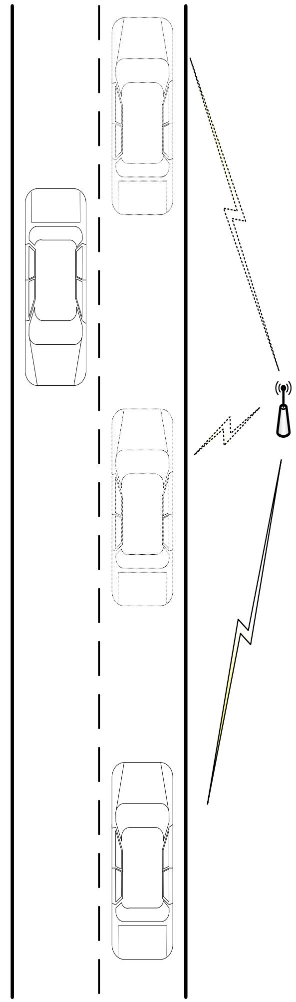
# WAVE Approach: MAC level

When a car is moving, the time it is covered by a BSS may be very short

No time for negotiation, handshakes or complex processes

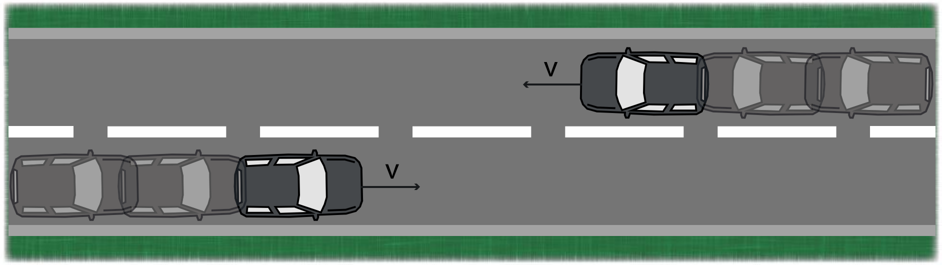
WAVE BSS

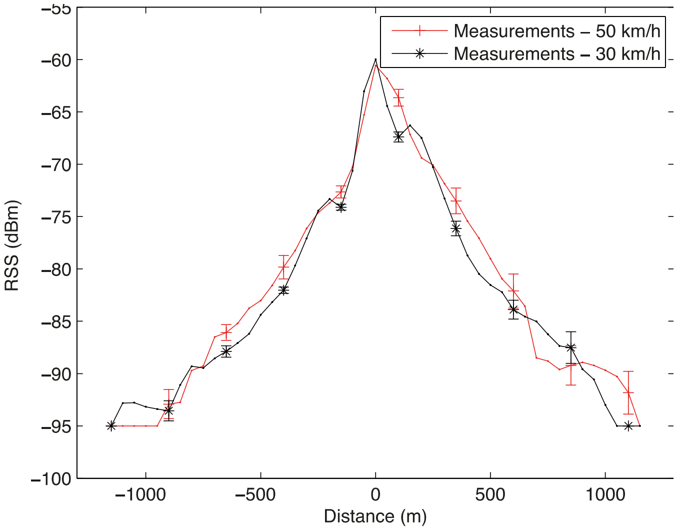
- WBSS is formed just by sending a demand beacon
- The demand beacon has information about the services provided by the WBSS and all the necessary data to join the BSS
- One beacon is enough for a station to join a WBSS



# How does it behave in reality?

# A Framework for VANET Experimentation
# Real-world Measurements



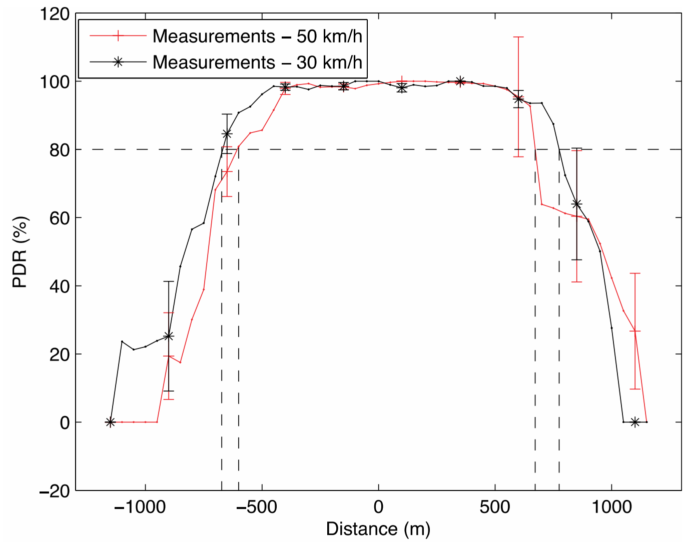




LoS

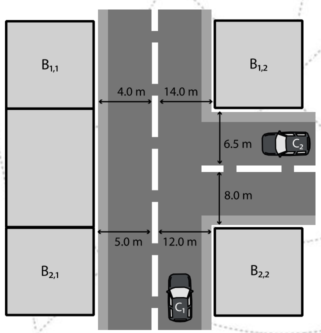
30 Km/h and 50 Km/h

20 dBm

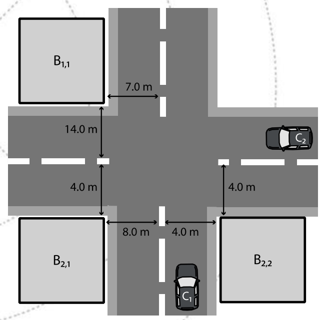
Up to 950m



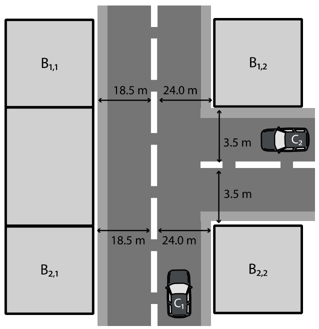
# A Framework for VANET Experimentation
# Real-world Measurements



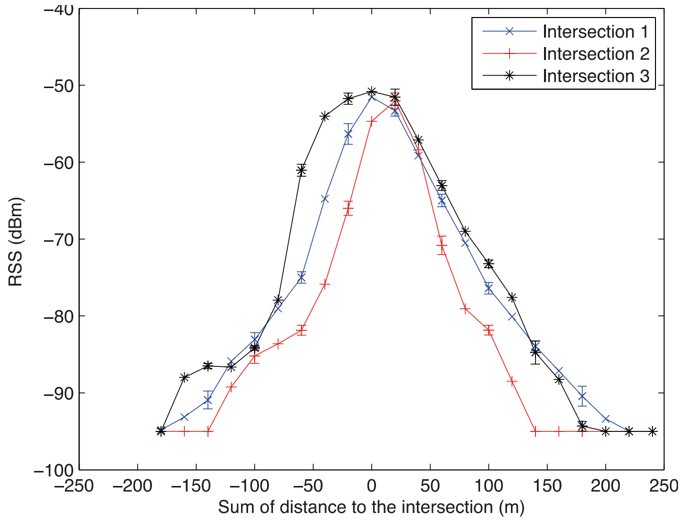

Intersection 1

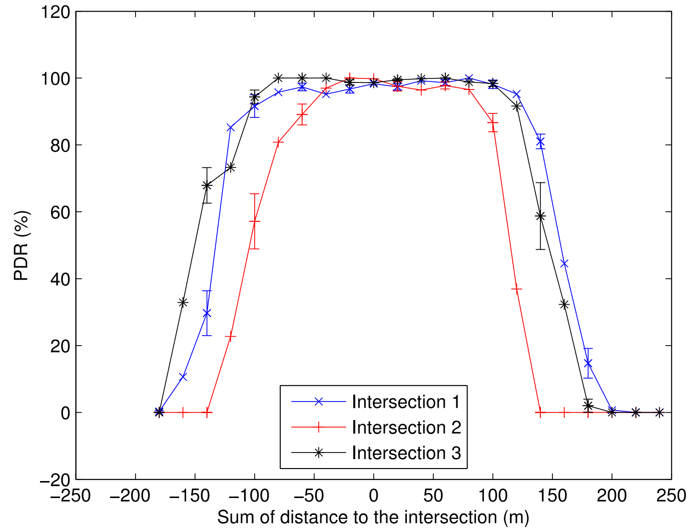



Intersection 2




Intersection 3

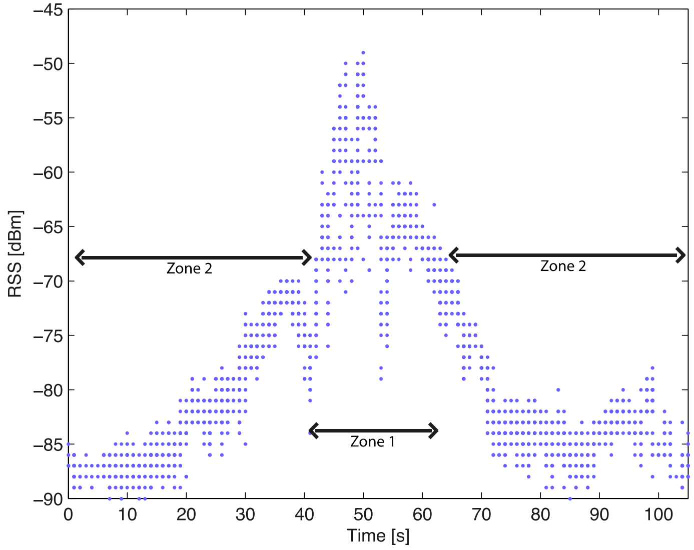



- NLoS
- 30 Km/h
- I1 and I3 – Buildings to reflect the signal
- I2 – No building to act as a reflector
- Vehicles can communicate as far as 75 m away from the intersection

# Simulation Vs. Experimentation Observations

- Two zones with distinct received signal strength variation patterns
- Gaussian distribution
- Zero mean (μ)

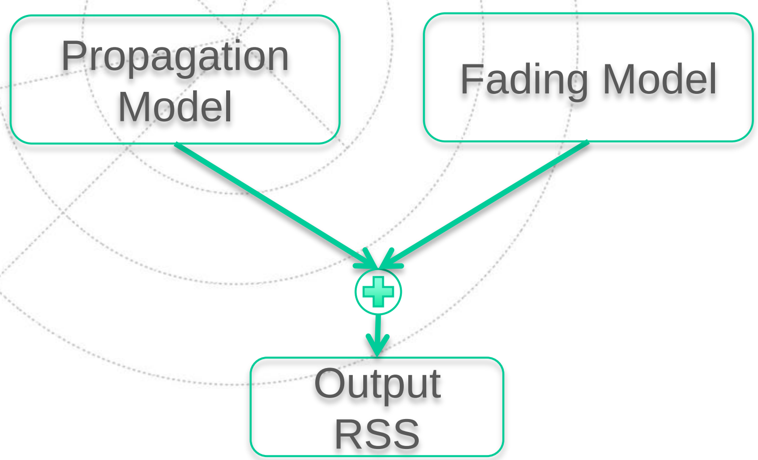



$$g(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

| Relative Speed (Km/h) | $\sigma_{zone1}$ | $\sigma_{zone2}$ |
|---|---|---|
| 30 | 2.76 | 1.62 |
| 60 | 2.89 | 1.72 |
| 100 | 2.81 | 1.66 |

| TX Power (dBm) | $\sigma_{zone1}$ | $\sigma_{zone2}$ |
|---|---|---|
| 23 | 2.76 | 1.62 |
| 18 | 2.06 | 1.30 |

# Simulation Vs. Experimentation
# The Model and Simulator




ns-3 NETWORK SIMULATOR

| Parameter | Value |
|---|---|
| TxPowerLevels | 1 |
| TxPowerStart | 12.51 dBm |
| TxPowerEnd | 12.51 dBm |
| TxGain | 2 dBi |
| RxGain | 2 dBi |
| EnergyDetectionThreshold | -95 dBm |

Propagation Model: Two-ray ground

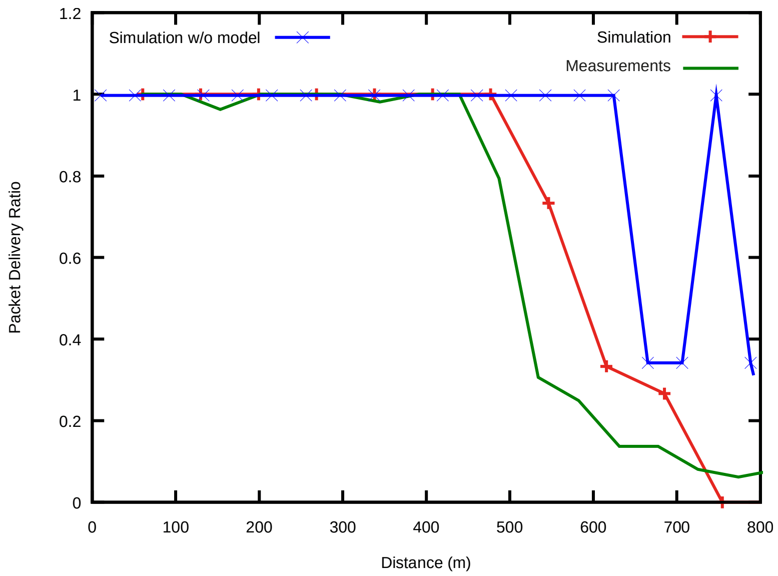
The output of the propagation model is combined with the output of the fading model, yielding the final received signal strength

# Simulation Vs. Experimentation Validation

## Figure of merit:

$$C_{a,b} = \left(1 - \frac{|d_{a80\%} - d_{b80\%}|}{d_{a80\%}}\right) \times 100$$

Based on the distance at which a PDR of 80% is achieved in simulation and in the measurements




One vehicle travelling away from the other at 30 Km/h

Transmission Power: 12 dBm

Concordance with model: 91.3%

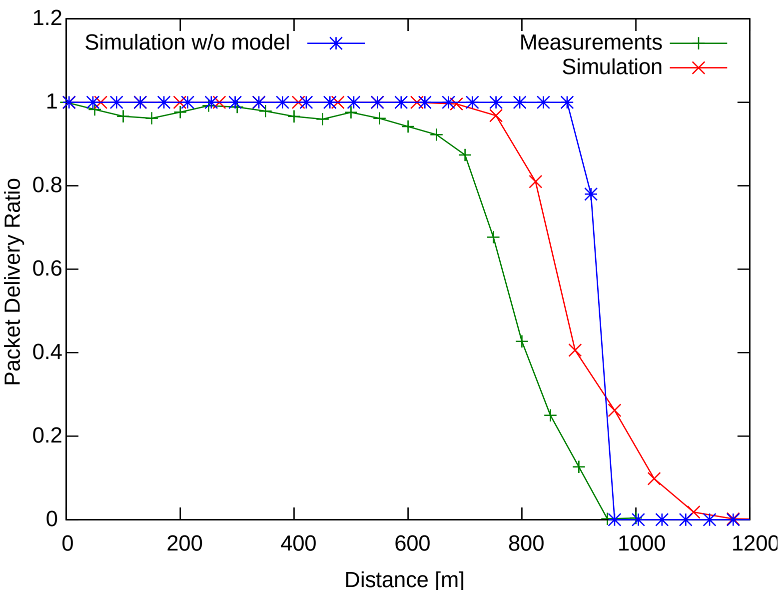
Concordance without model: 69.4%

# Simulation Vs. Experimentation Results

## Figure of merit:

$$C_{a,b} = \left(1 - \frac{|d_{a80\%} - d_{b80\%}|}{d_{a80\%}}\right) \times 100$$

Based on the distance at which a PDR of 80% is achieved in simulation and in the measurements




One vehicle travelling away from the other at 50 Km/h

Transmission Power: 23 dBm

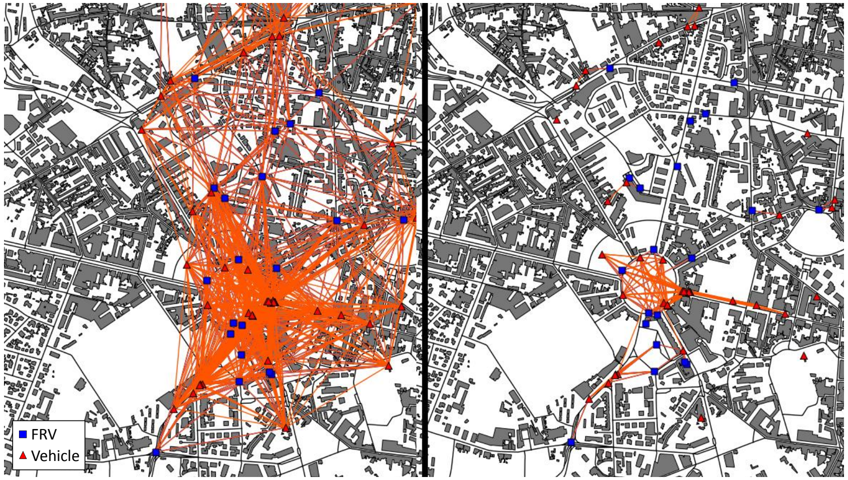
Concordance with model: 84.9%

Concordance without model: 71.8%

# How many cars in a city?

# 3-D Infrastructure Provisioning and Connectivity Analysis

- Infrastructure is important to:
  - Ensure full-connectivity of the network
  - Alleviate congestion in very dense scenarios
- Mobile infrastructure can improve the connectivity and ease the deployment process
- Considering buildings in VANET infrastructure planning is crucial

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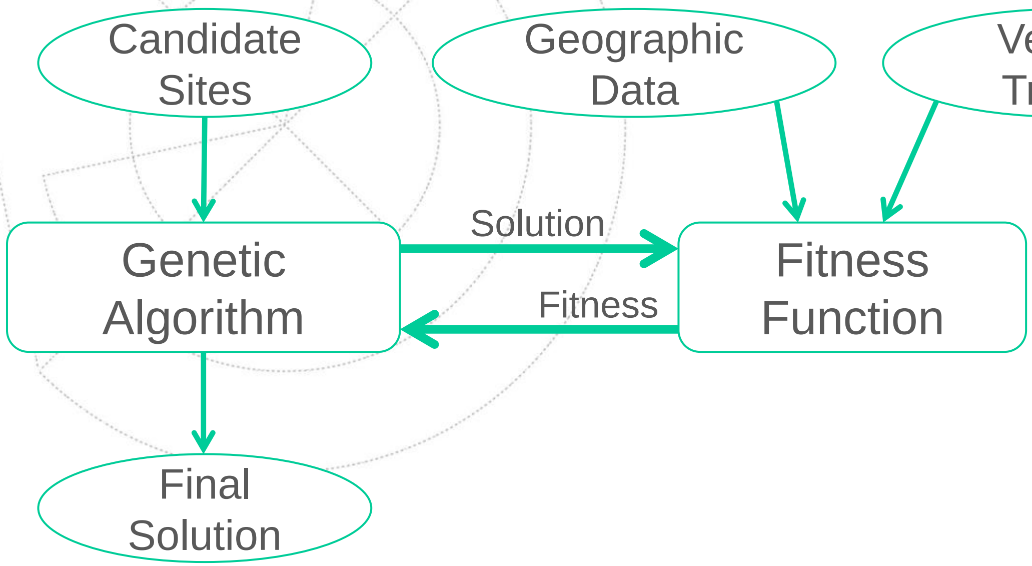
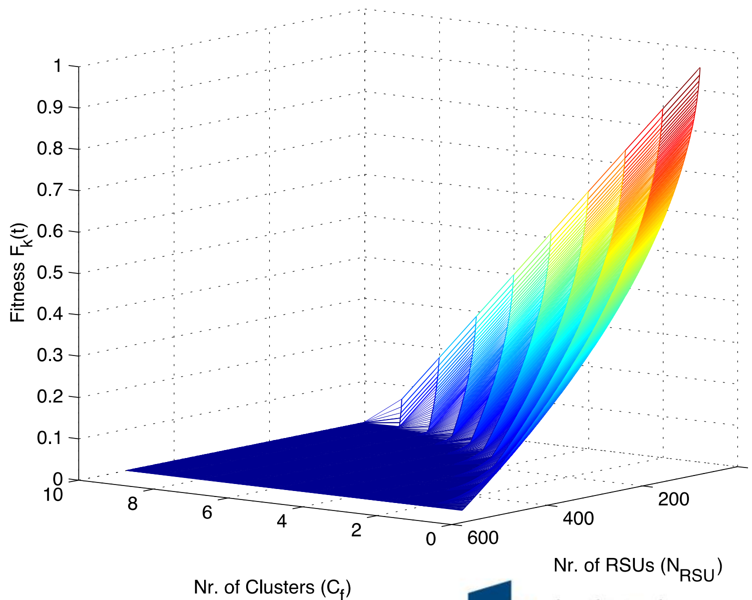
# 3-D Infrastructure Provisioning and Connectivity Analysis: Method

- Genetic Algorithm
- Fixed-route vehicle selection mechanism
- Topology and topography of the area
- Real-world mobility traces from a fleet of Taxis and public buses in the city of Porto
- List of suitable sites for RSU deployment

# 3-D Infrastructure Provisioning and Connectivity Analysis: Genetic Algorithm




$$F_k(t) = \frac{C_i - C_f + I_i - I_f}{C_i - 1 + I_i} - \sqrt{\frac{R}{S}}$$

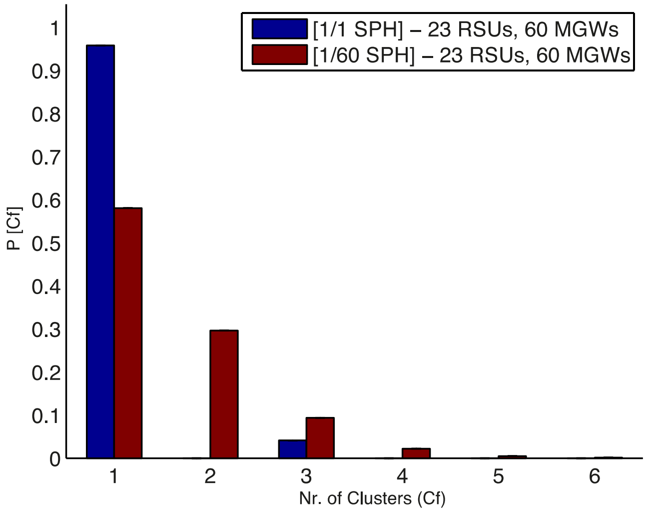



- Candidate sites are encoded as a bit string
- Genetic Algorithm and fitness function are independent

# 3-D Infrastructure Provisioning and Connectivity Analysis: Results

Mobile gateways are not capable of connecting the whole network alone

There is a threshold above which more MGWs do not bring further improvement

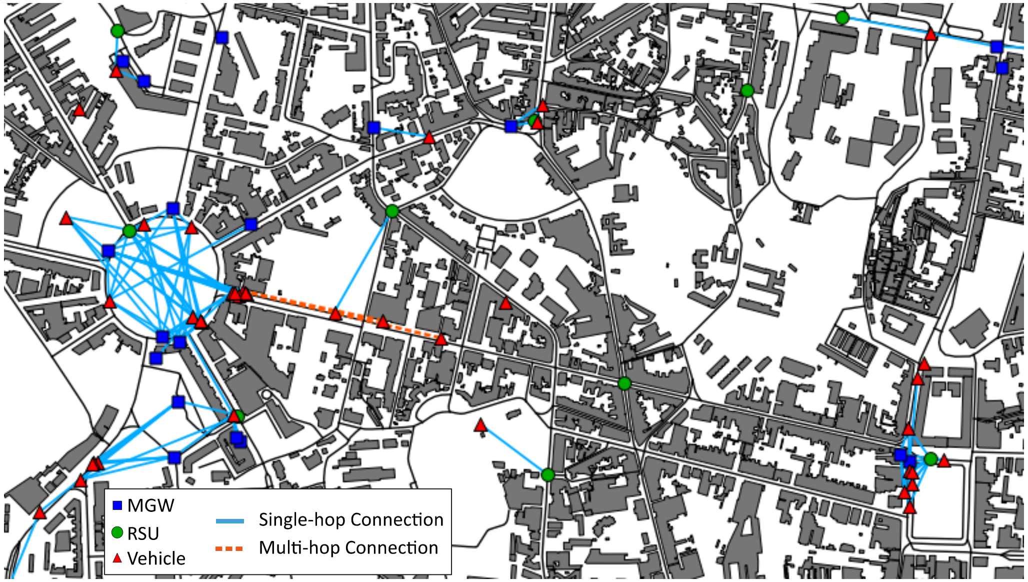



- RSUs can connect the network by themselves
- However, MGWs can reduce the number of RSUs when combined with them
- Reduction of 25% on the number of RSUs (8) at the expense of 60 MGWs

# 3-D Infrastructure Provisioning and Connectivity Analysis: Results

- With RSUs and MGWs, most of the communications are performed within a 1-hop and 2-hop distance

| Nr. of Hops | Conn. Time (%) |
|---|---|
| 1 | 90.24 |
| 2 | 9.45 |
| 3 | 0.28 |
| 4 | 0.03 |

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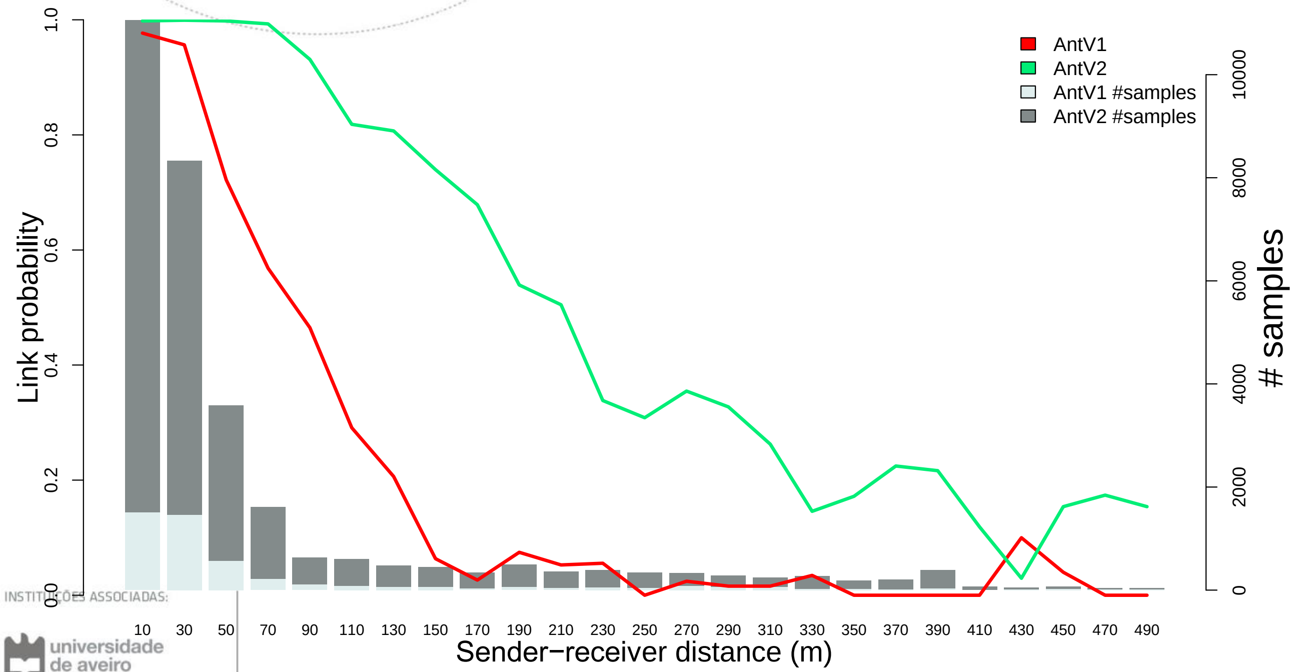
# 3-D Infrastructure Provisioning and Connectivity Analysis: Taking real connectivity results

- City environment; installation in taxis: real even more real
- Example:
  - Antenna height



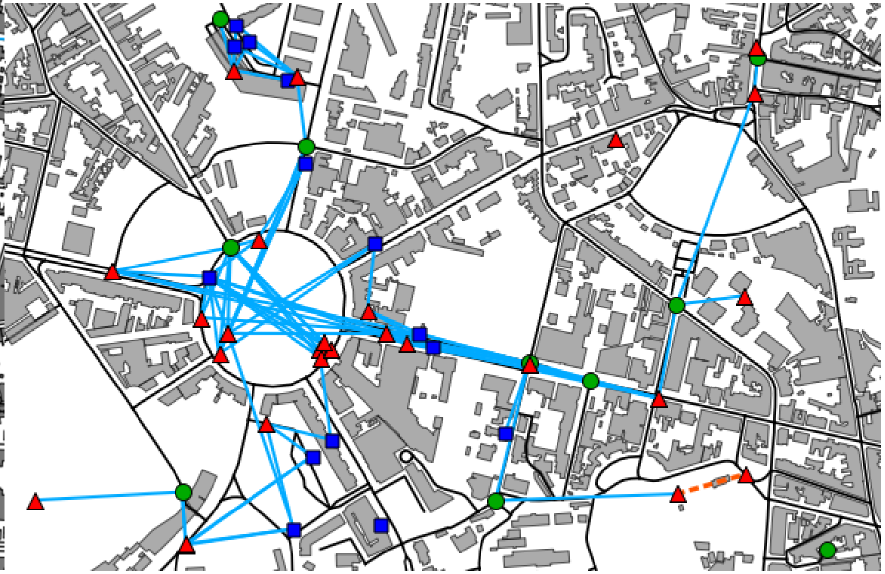

# 3-D Infrastructure Provisioning and Connectivity Analysis: Taking real connectivity results

| Nr. of Hops | Conn. Time (%) |
|---|---|
| 1 | 90.24 |
| 2 | 9.45 |
| 3 | 0.28 |
| 4 | 0.03 |

| Nr. of Hops | Conn. Time (%) |
|---|---|
| 1 | 94,70 |
| 2 | 5,17 |
| 3 | 0,11 |
| 4 | 0,02 |

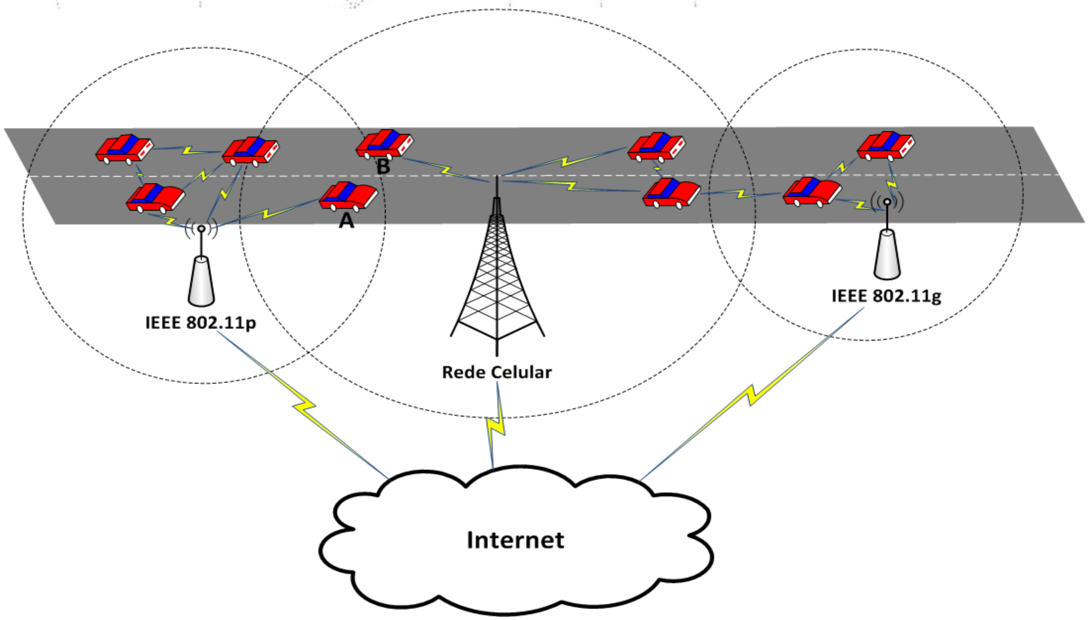
23 RSUs (100-600 radio range)

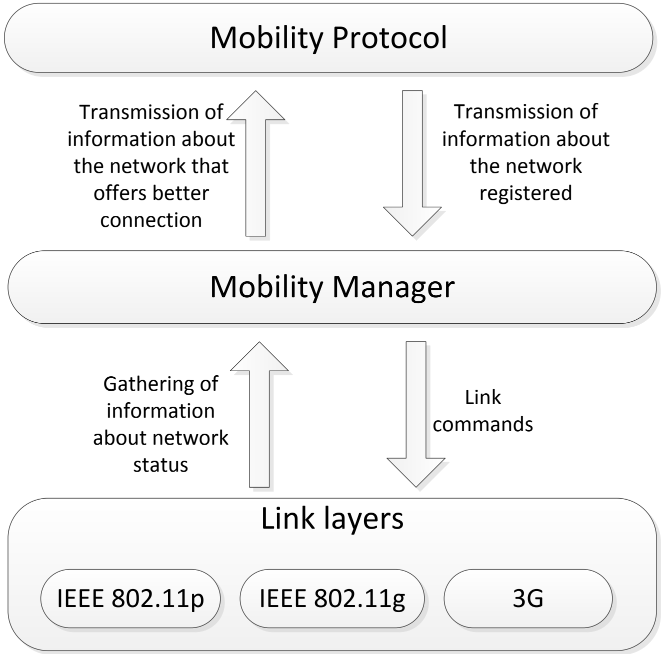

28 RSUs (real radio range)



# How to seamlessly interconnect to infrastructure and provide mobility?

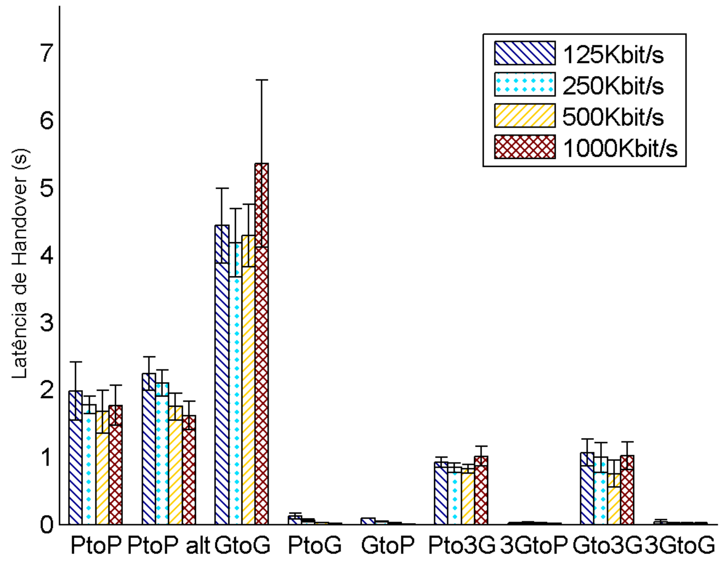
# Seamless Connection to Infrastructure



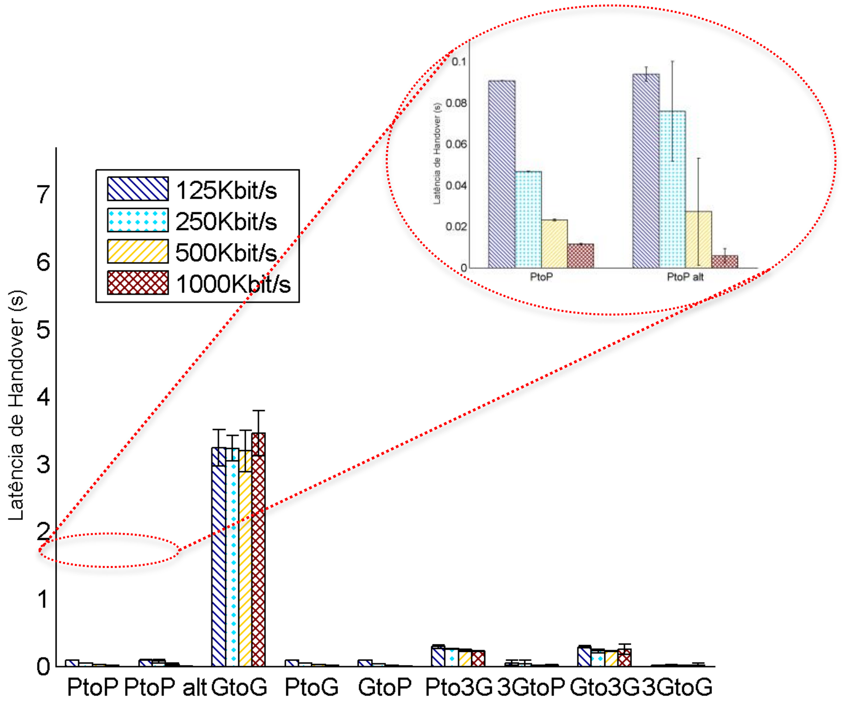



# Handover Latency: lab environment

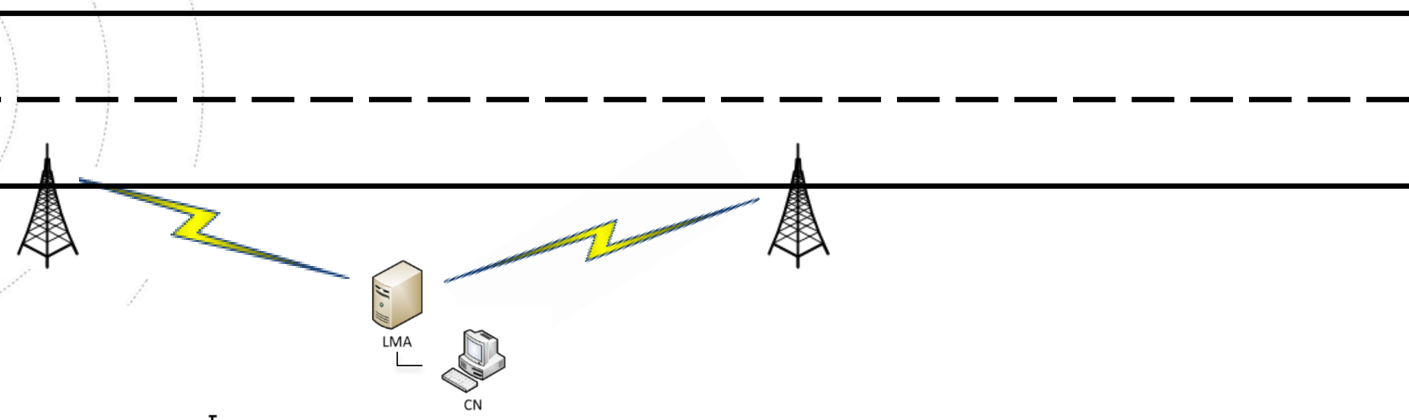
## MIPv6:

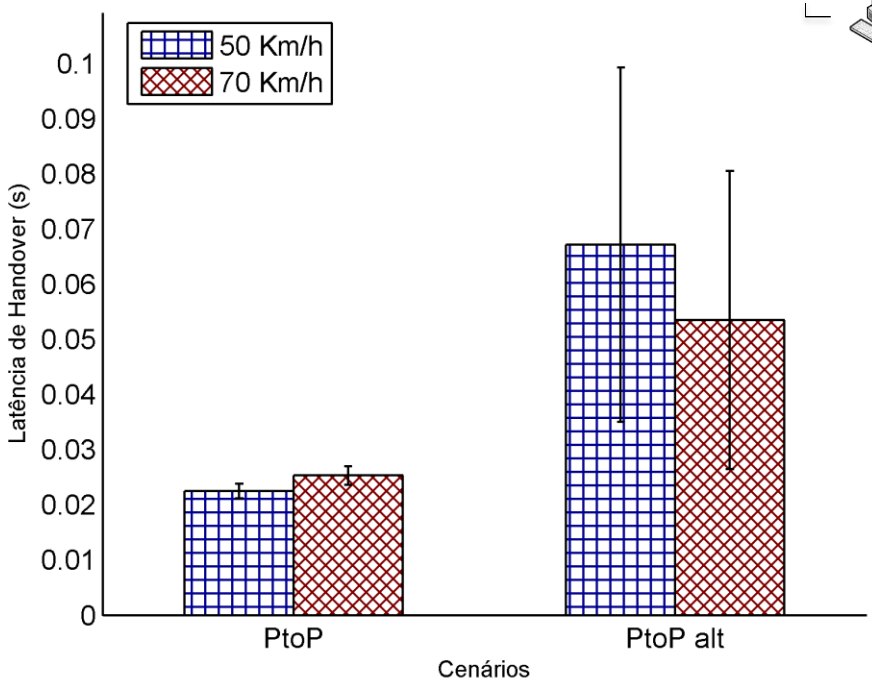



## PMIPv6:



# Handover Latency: real environment




No main differences when compared to lab environment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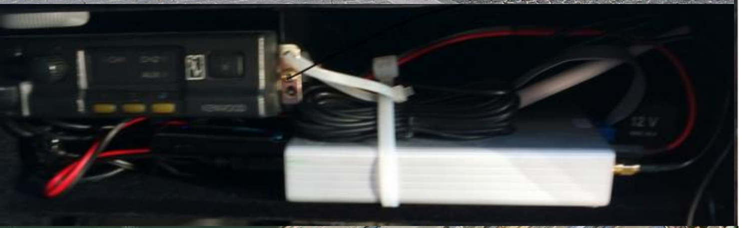
# Deployed Plaforms

# How everything started…

CMU|Portugal Project DRIVE-IN through a real need…

We were crazy enough to promise to connect 500 vehicles (by far the largest vehicular testbed in the world)…

… it was not easy…

But we did it! ☺

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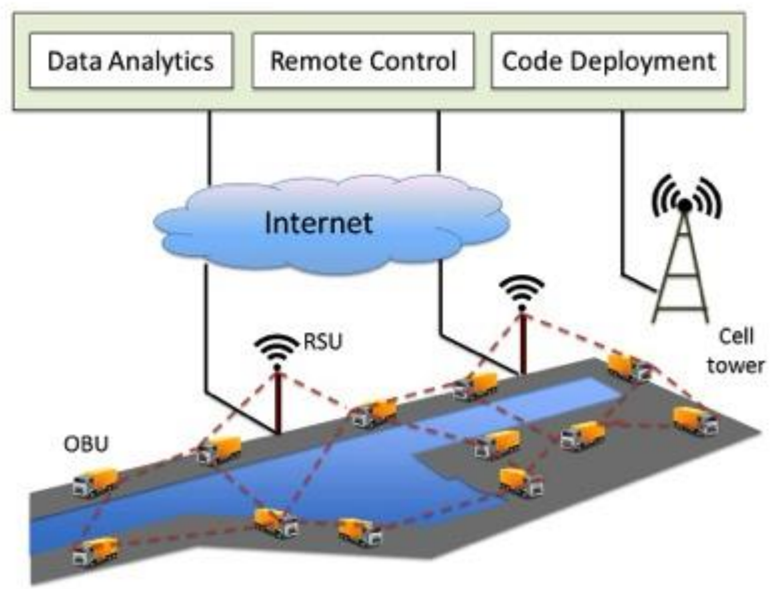
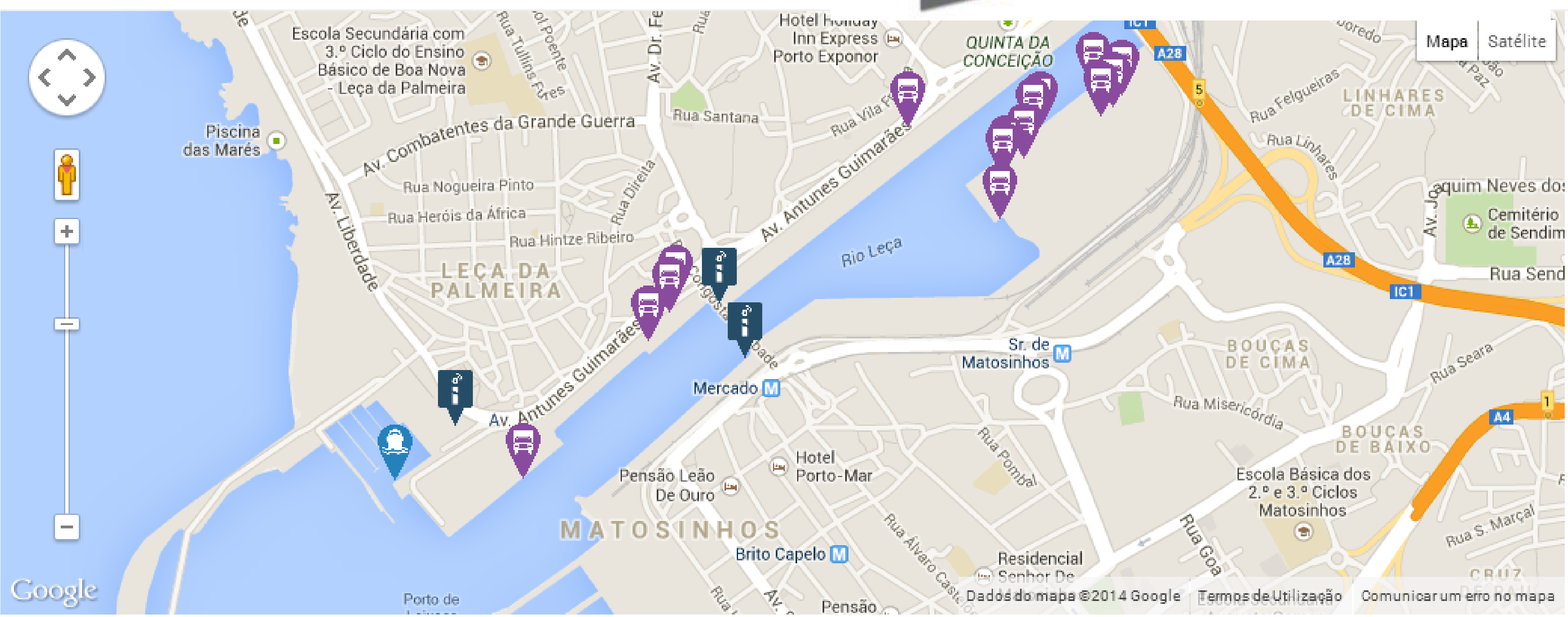
# Harbor Pilot
# The Network

- 25 trucks
- 2 tow boats, 2 patrol vessels
- 5 road side units
- 1 plug and play unit for vehicles




Total vehicles displayed (online in the last 2 minutes): 18

# Harbor Pilot Results

- 5 road side units
- Latency in the .11p network <= 10 msec
- Congestion latency <= 100 msec
- Handover time <= 100 msec
- Density of vehicles in rush hour: 25 trucks in the harbor
- Coverage >= 600m in LoS

A day in a vehicular network

http://youtu.be/0YwDMe8Kbgw

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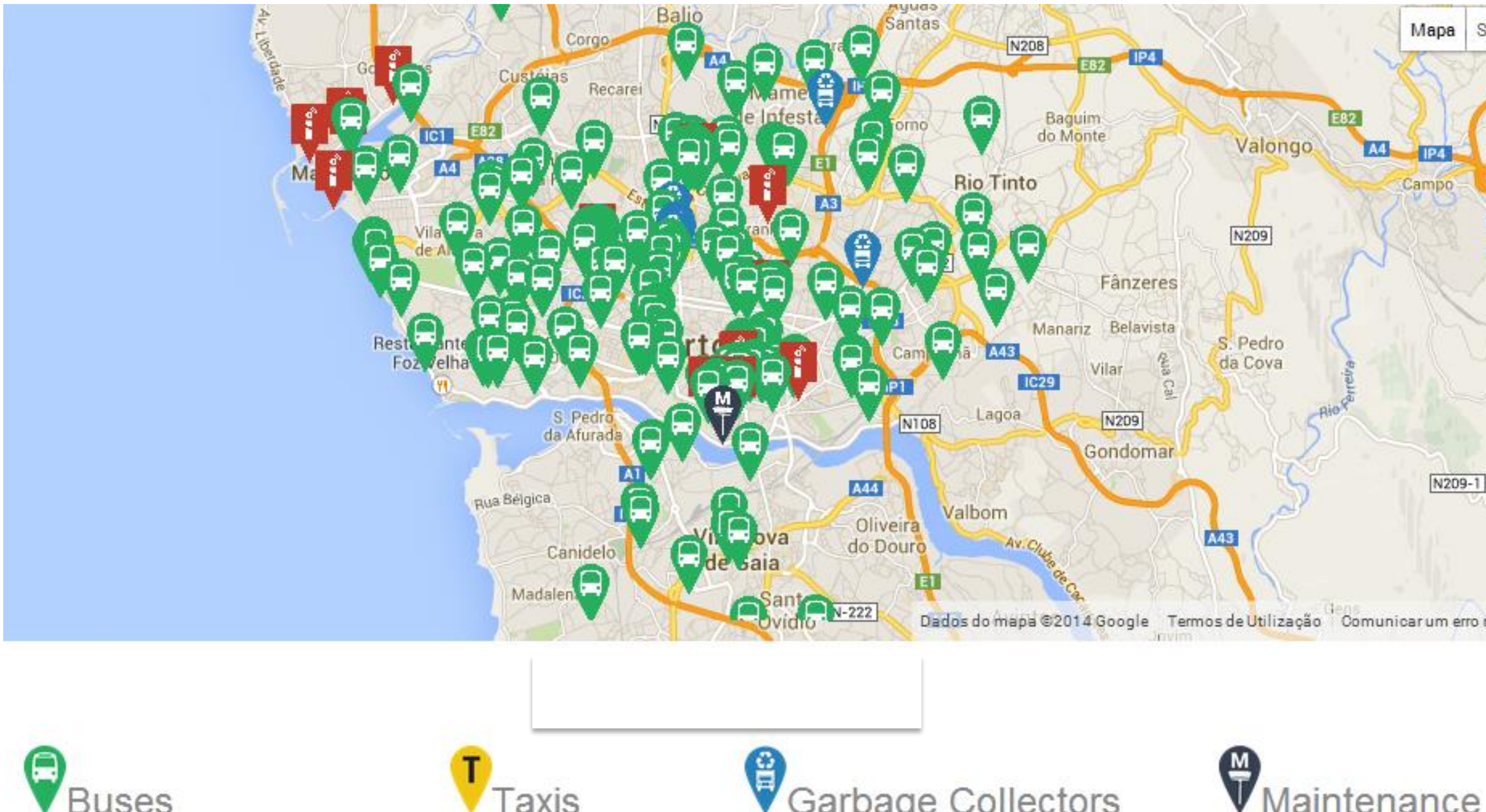
# City Pilot
# The Network

400 buses, 150 taxis, 20 municipality vehicles, 8 road side units



# City Pilot Results

Bandwidth > 10 Mb/sec

Latency in the .11p network <= 10 msec

Congestion latency <= 100 msec

Handover time <= 100 msec

Density of vehicles in rush hour (in the map, 1Km$^2$): >90 buses

Coverage >= 600m in LoS

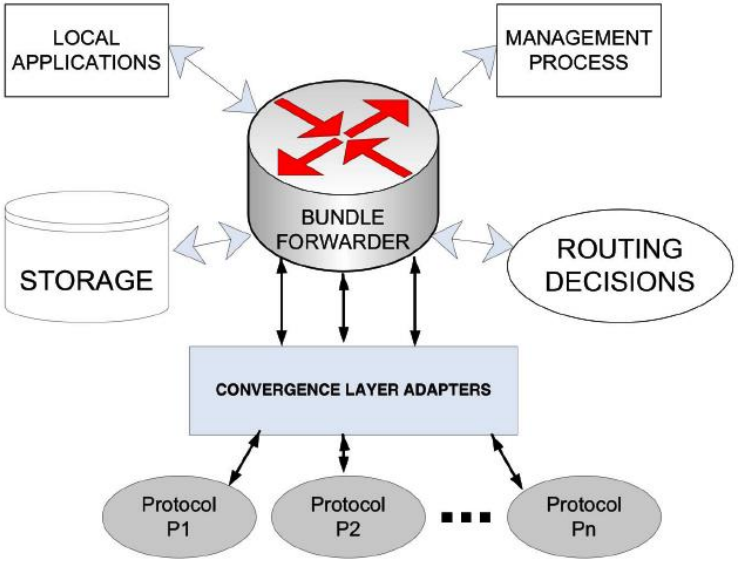
Up to 6 videos in the bus, simultaneously

Many internet access users

# Vehicular Network at Leixões Harbor


Mesh connected trucks use M2M connections over IEEE 802.11p links to upload big data for harbor management.

# DTN - Overview




**DTN**: Delay-/Disruption-Tolerant Networking

Permanent storage allows tolerance to delay and disruption.

PDU: Bundle. Contains all information for transaction (authentication, options, etc.).

Congestion: concern at storage level, as well as at link level.

Routing:

Considers that nodes may carry data in space

Decides when to forward.

# DTN Routing Protocols

Three routing protocols were used:

**Epidemic**: bundles flooded to neighbors at each contact.

**Static**: routes are pre-configured so that OBUs relay only directly to RSUs.

**PRoPHET:**

- Probabilistic Routing Protocol using History of Encounters and Transitivity (PRoPHET)
- Gradient-based, uses concept of delivery predictabilities between nodes, looks at past contacts.

# Tests - Harbor Trucks

## Setup:

Registering GPS location each second and sending to database:

**≈ 35 KB** files sent **each 10 minutes,** from each truck's OBU to server on the Internet.


Duration = 24h ; Bundle storage limit = 3 MB ; Bundle lifetime = 6h

# Results – Summary Table

| Metrics Routing Protocols | Bundles Delivered | Delay* | Number of Useless Replicas* | Number of Useless Transmissions* |
|---|---|---|---|---|
| **Epidemic** | 98.8 % | 341 ± 55 s | 4.4 ± 0.2 | 31.0 ± 2.1 |
| **Static** | 92.8 % | 926 ± 167 s | 2.8 ± 0.1 | 22.5 ± 1.0 |
| **PRoPHET** | 86.0 % | 1893 ± 409 s | 2.3 ± 0.2 | 6.7 ± 0.7 |

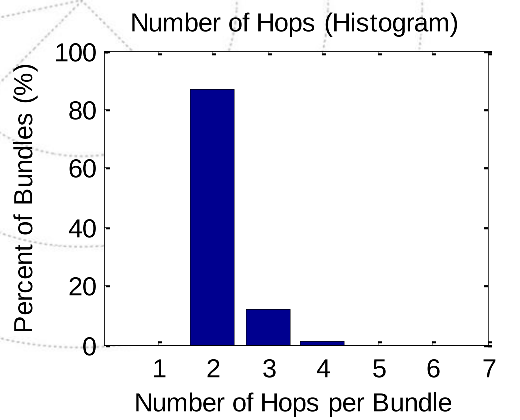
*Per bundle average for delivered bundles. 95% confidence intervals.

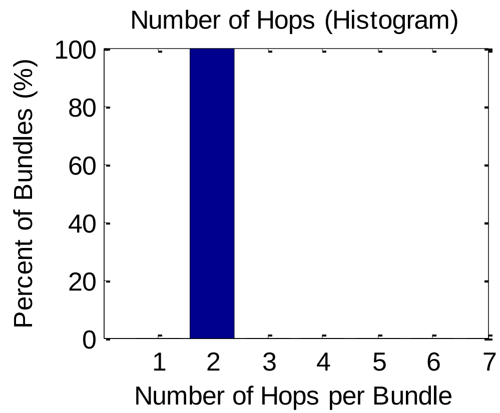
- **Trade-off:** Delay and Delivery Rates vs. Number of Transmissions and Replicas
- **PRoPHET:** Delay much higher than static routing: means nodes are not transmitting whenever they see an RSU.

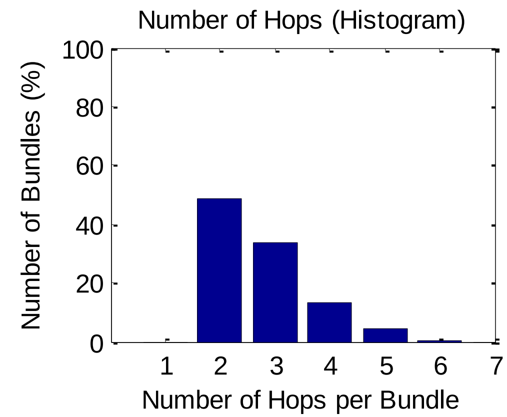
# Results – Analysis

**Epidemic** | **Static** | **PRoPHET**

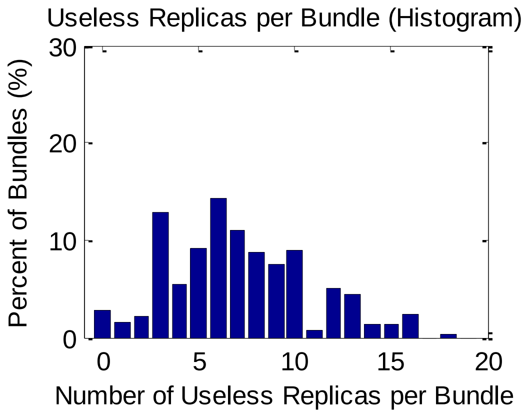
## Number of Hops

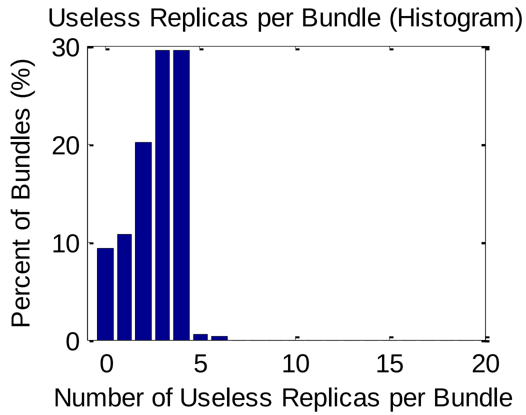


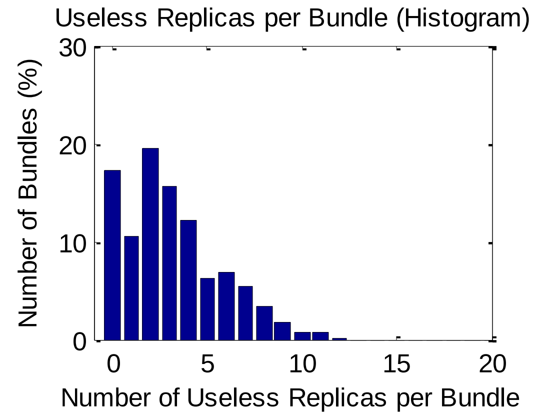




## Useless Replicas



# Results – Measured Observations

High levels of replication improve delay and delivery rates, as long as network is not saturated.

⇨ Need to find an equilibrium point.

Transmissions keep occurring even after bundles have already been delivered to the destination, wasting resources.

⇨ Need of a strategy to deliver acknowledgements to the concerned elements of the network.

# Final Thoughts

- Theory and reality can be very apart
- However, with reality knowledge we can develop new theory models that can match the real environment
- Real platforms are the key!
  - They are costly to deploy
  - They take much resources effort
  - But it is the only way to develop accurate network mechanisms!

# Thanks!

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Credits to: André Cardote, Carlos Ameixieira, Jorge Dias, Filipe Neves, Luís Coelho, Rui Meireles, Romeu Monteiro, Luís Guedes, Tiago Condeixa