Empowered by Innovation NEC

Measurement-based Evaluation of Cooperative Awareness for V2V and V2I Communication

Mate Boban, Pedro M. d'Orey

NEC Laboratories Europe

{mate.boban, pedro.dorey}@neclab.eu

IEEE VNC, Dec 3rd, 2014.

Outline

- Motivation
- EU FP7 DRIVE C2X Experimental Platform
- Test Sites
- Metrics
- Results
- Conclusions

Motivation

- Cooperative Awareness: building block for safety & traffic efficiency applications
  - Vehicles periodically broadcast 1-hop CAMs (BSMs) with position, speed, heading,…
  - Purpose: creating precise picture of neighborhood dynamics

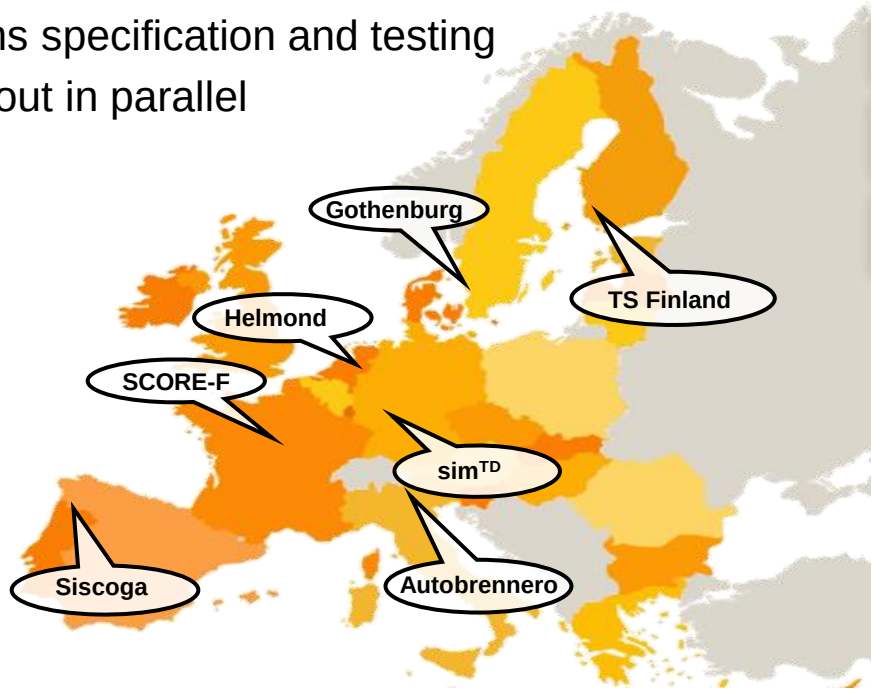
- Improved awareness → higher channel load and interference
- Previous work
  - Simulation based evaluation of cooperative awareness
  - Often, studies assume that cooperative awareness works
- **Goal**: evaluate the **performance of cooperative awareness** in V2X networks using measurements

EU FP7 DRIVE C2X

- European FP7 Integrated Project:
  - Duration: 2011-2014
  - Budget: 18.9 M€
- 34 partners, 13 support partners (OEMs, suppliers, road operators, etc.)

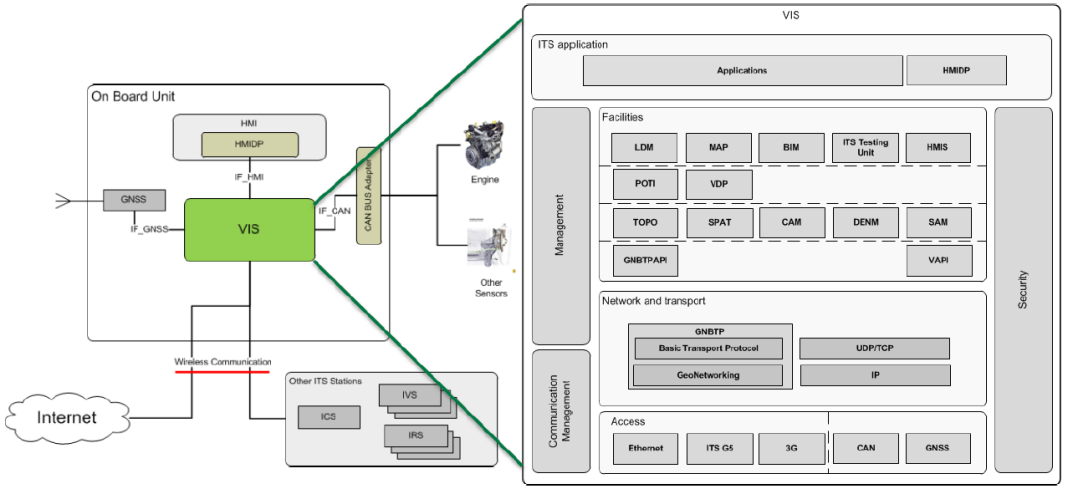
- Main Objectives:
  - Assessment of cooperative systems through Field Operational Tests (FOTs)
  - Harmonize Europe-wide cooperative systems specification and testing
  - Coordinate European national tests carried out in parallel

- DRIVE C2X designed and evaluated a set of V2V and V2I applications:
  - In-vehicle signage
  - Road works warning
  - Approaching emergency vehicle
  - …
- Website: www.drive-c2x.eu/



DRIVE C2X Experimental Platform

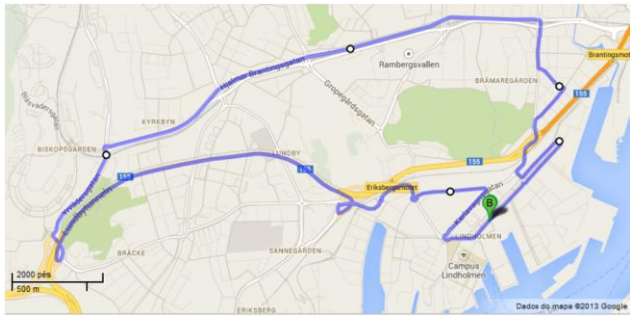
- GPS receivers for vehicle position data acquisition
- ITS-G5 compliant radios:
  - 5.9 GHz frequency band
  - Tx. power: 21 dBm
  - Vehicles
    - Omni-directional antennas on the roof of personal vehicles (1.44–1.66 m)
    - Vehicles had different setup (e.g. antenna position/type/gain)
  - RSUs
    - Higher antenna gains than vehicles (14 dBi)
    - Mounted at 9-11 meter gantries/posts
- Pre-production, ETSI standard compliant geo-networking stack
  - ETSI standard-compliant CAMs
  - Frequency: 10 Hz, Size: 100 Bytes
- Logging of all Tx/Rx CAMs for post-processing



Test Sites

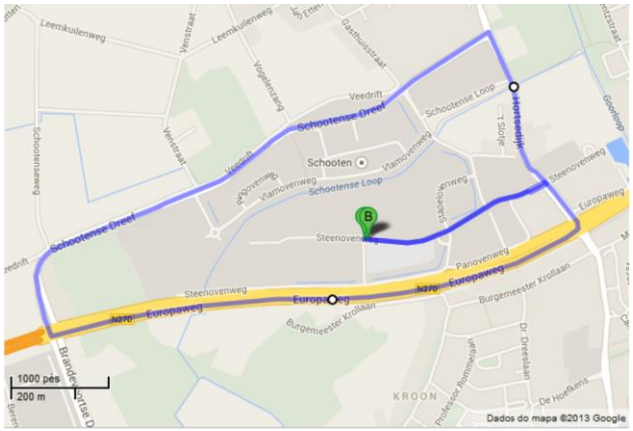
Gothenburg, Sweden

- Route: 11 km
- June 2013
- Suburban & urban highway
- Vehicles: 6



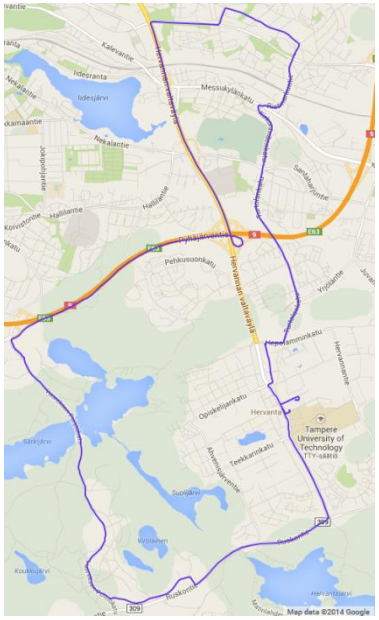
Helmond, the Netherlands

- Route: 6 km
- September 2012
- Suburban & highway
- Vehicles: 7

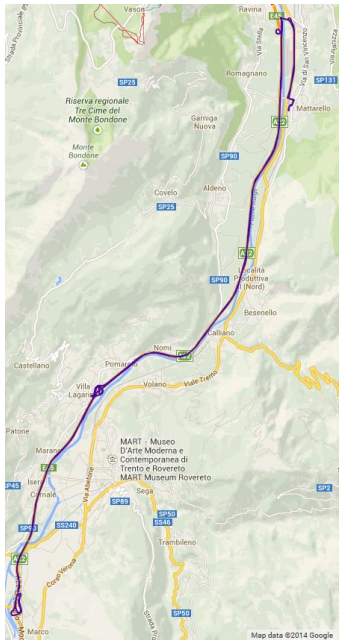


Test Sites

- Tampere, Finland
  - Route: 22 km
  - April, May 2013
  - Suburban, urban, highway
  - Vehicles: 3



- Trento, Italy
  - Route: 60 km
  - July-Oct 2013
  - Highway
  - Vehicles: 4
  - **RSUs: 5**



- Varying conditions (e.g., time of day, veh. densities), but fixed controllable parameters (e.g., Tx power, CAM rate)

Metrics

1. **Packet Delivery Ratio (PDR)**
   - Ratio of correctly received packets

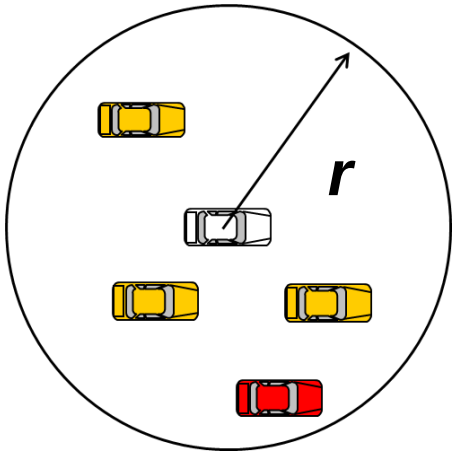
$$PDR_i = \frac{PR_i}{PT_i}$$

   - Shows link quality and effective range

2. **Neighborhood Awareness Ratio (NAR)**
   - Ratio of vehicles within radius *r* from which a message was received in time interval *t*

$$NAR_{i,r,t} = \frac{ND_{i,r,t}}{NT_{i,r,t}}$$

   - Shows effectiveness of CAMs



e.g., NAR = 3/4

vehicle *i* , range *r*, time interval *t* (1 s)

3. **Ratio of Neighbors Above Range (RNAR)**
   - Ratio of detected vehicles that are above *r*

$$RNAR_{i,r,t} = \frac{NA_{i,r,t}}{N_{i,t}}$$

   - Sheds light on potentially “unwanted” communication

Metrics

1. **Packet Delivery Ratio (PDR)**
   - Ratio of correctly received packets

$$PDR_i = \frac{PR_i}{PT_i}$$

   - Shows link quality and effective range

2. **Neighborhood Awareness Ratio (NAR)**
   - Ratio of vehicles within radius *r* from which a message was received in time interval *t*

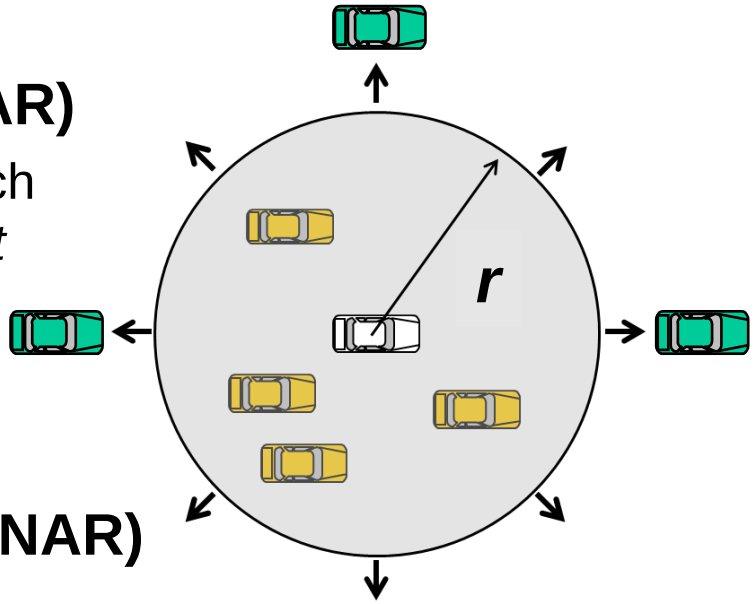
$$NAR_{i,r,t} = \frac{ND_{i,r,t}}{NT_{i,r,t}}$$

   - Shows effectiveness of CAMs

3. **Ratio of Neighbors Above Range (RNAR)**
   - Ratio of detected vehicles that are above *r*

$$RNAR_{i,r,t} = \frac{NA_{i,r,t}}{N_{i,t}}$$

   - Sheds light on potentially “unwanted” communication

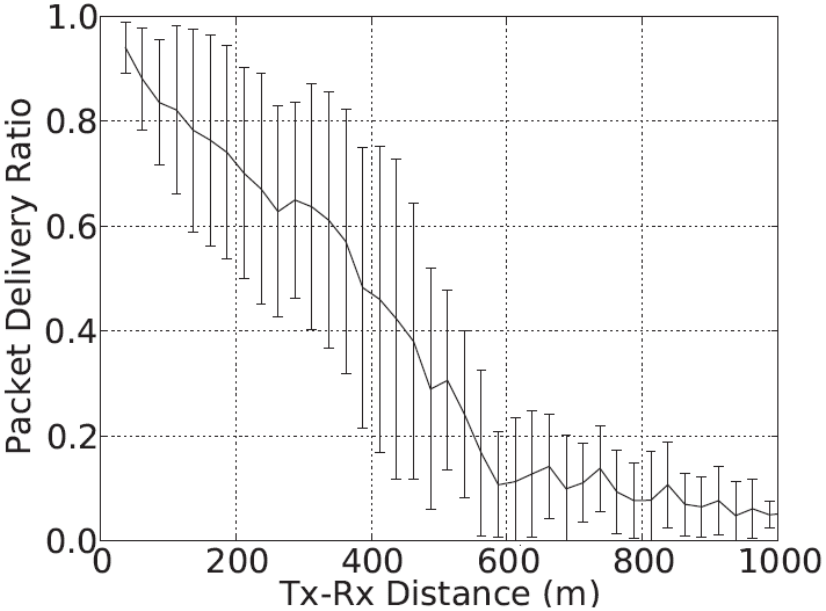


e.g., RNAR = 3/7

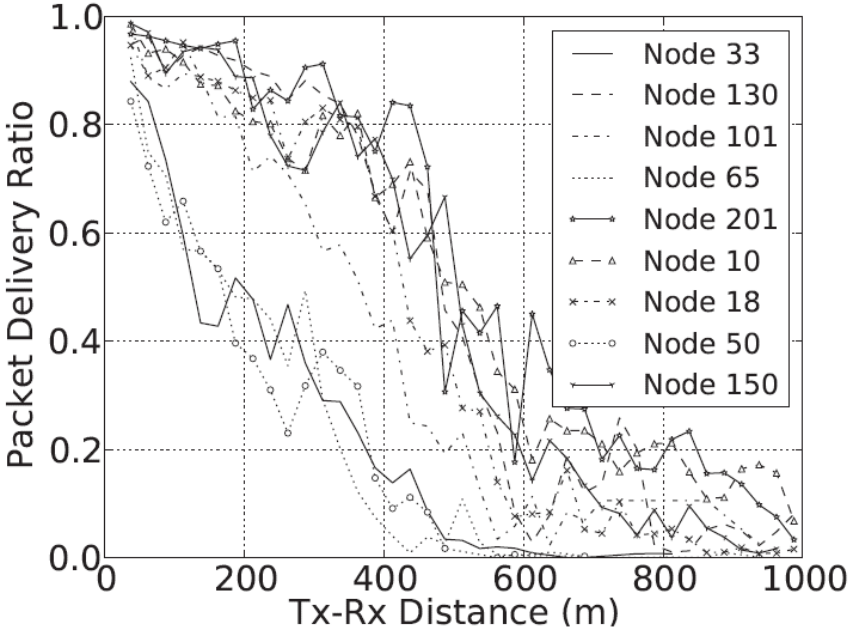
vehicle *i* , range *r*, time interval *t* (1 s)

Packet Delivery Ratio (PDR): V2V Results

- High PDR (90%+) up to 100m, below 20% above 600m
- Per-vehicle variation due to
  - Traffic conditions (shadowing due to other vehicles)
  - Different routes → Different propagation characteristics
  - Installation (e.g., antenna type/position, cable loss)



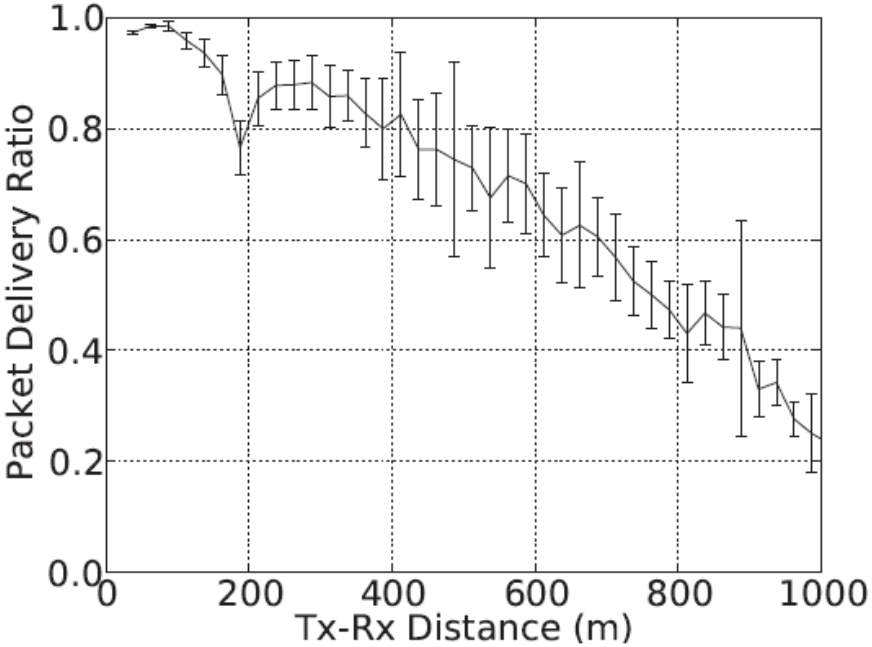
Overall V2V results
Highway, Helmond



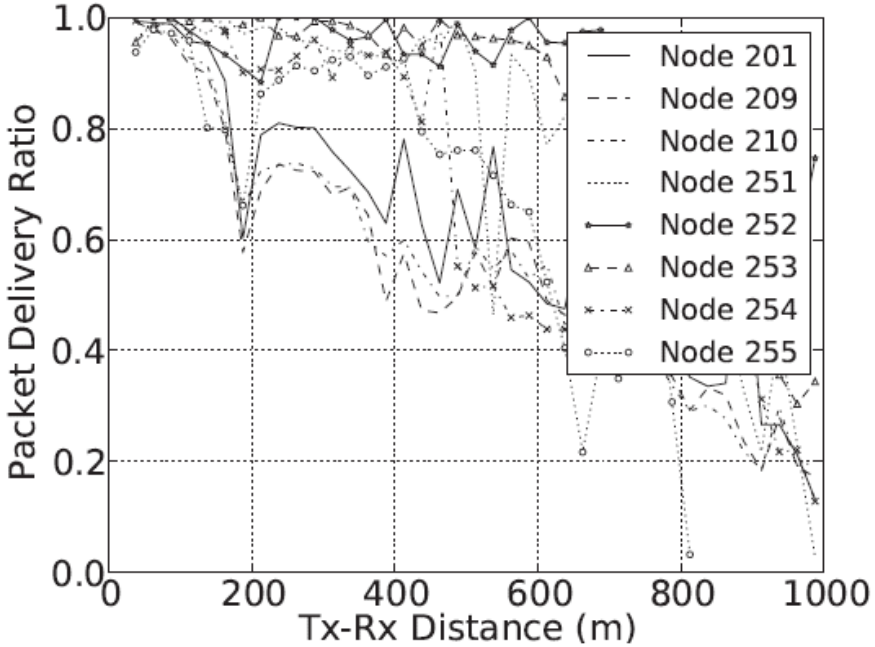
Per-vehicle V2V results
Highway, Helmond

Packet Delivery Ratio (PDR): V2I Results

- Higher PDR than V2V due to
  - Higher EIRP
  - Tall-mounted RSU antennas (more LOS communication)
- Strong effect of ground reflection @~200m



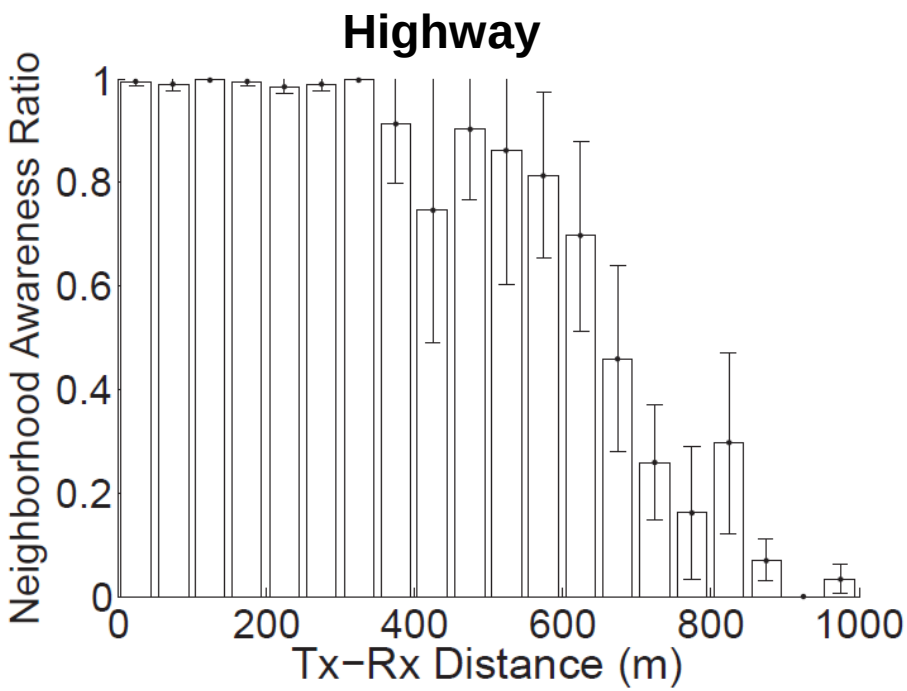
Overall V2I results
Highway, Trento



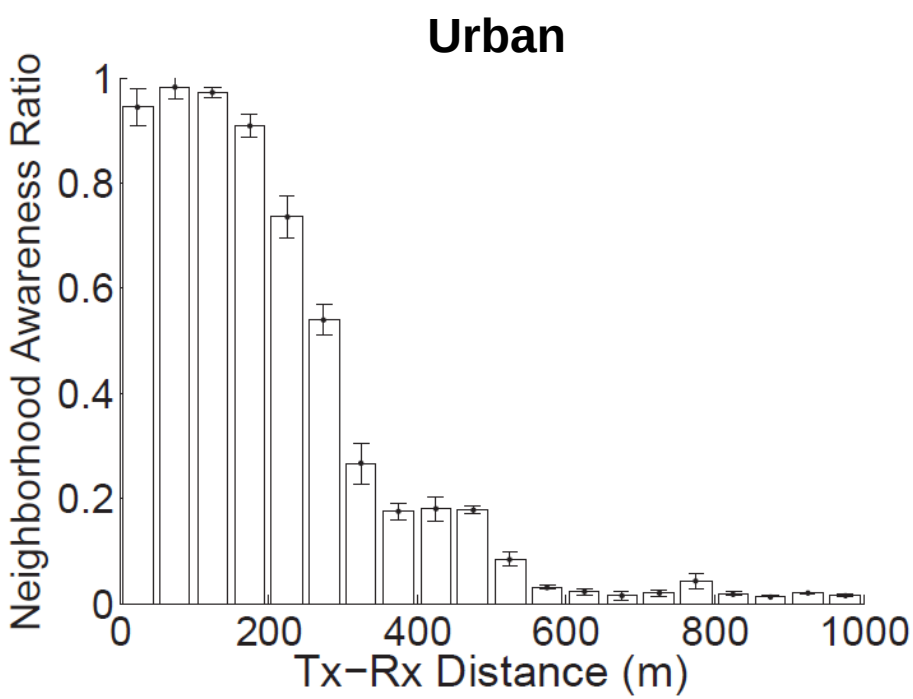
Per-vehicle V2I results
Highway, Trento

Neighborhood Awareness Ratio (NAR) Results: Highway vs Urban

- Neighborhood awareness strongly affected by link quality (PDR)
- 90% neighbors detected up to 350m (Highway) and 200m (Urban)
  - Important for applications: awareness requirements can be fulfilled at significantly differing distances, even within a test site/location



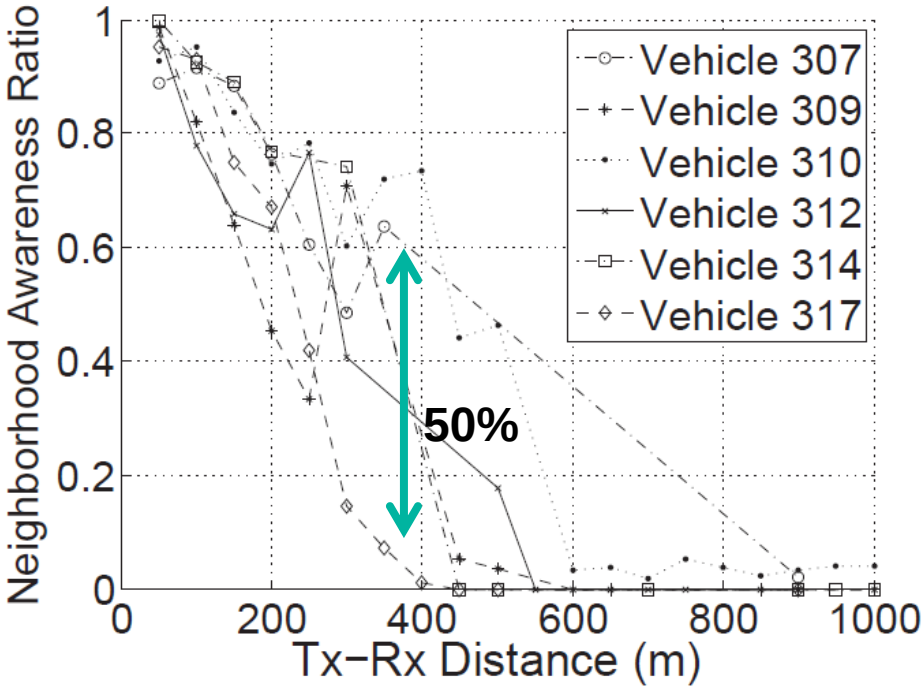
V2V results,Tampere



V2V results,Tampere

Neighborhood Awareness Ratio (NAR) Results: Per-vehicle Variation

- Neighborhood perception can vary 50% between nearby vehicles
  - Awareness is dominated by shadowing
  - Important for design of algorithms (e.g., congestion control)

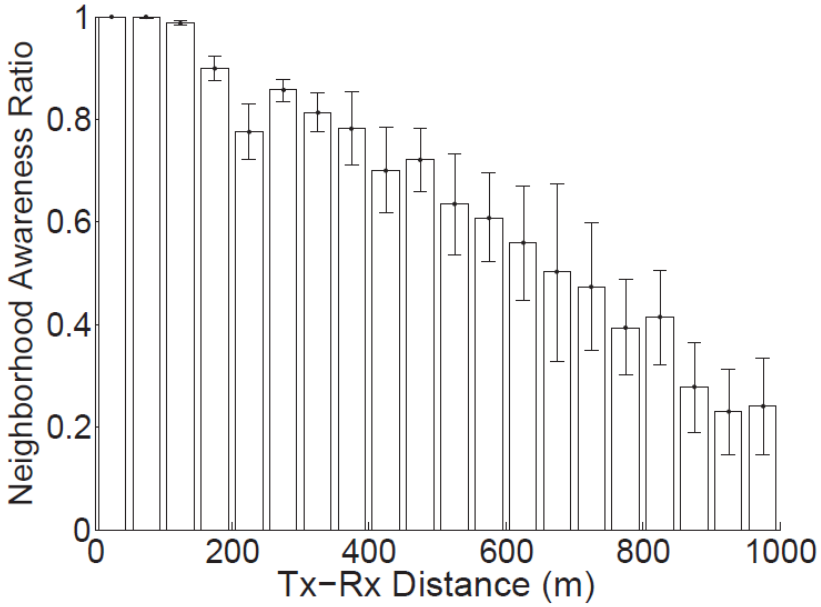


Per-vehicle V2V results
Highway, Gothenburg

Neighborhood Awareness Ratio (NAR) Results: V2V vs V2I

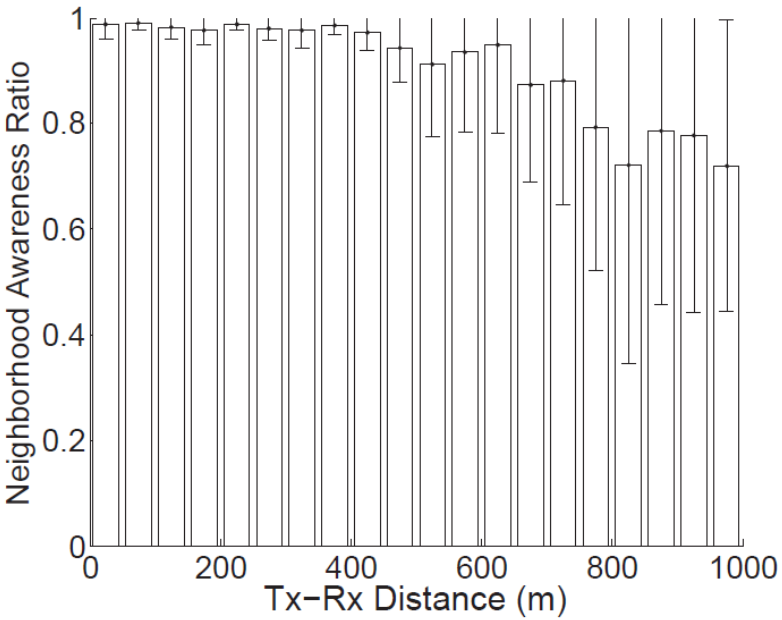
- V2I: 90%+ awareness @ 600+m
- Q: do we need to be aware of vehicles 1km+ away?

V2V



Highway, Trento

V2I

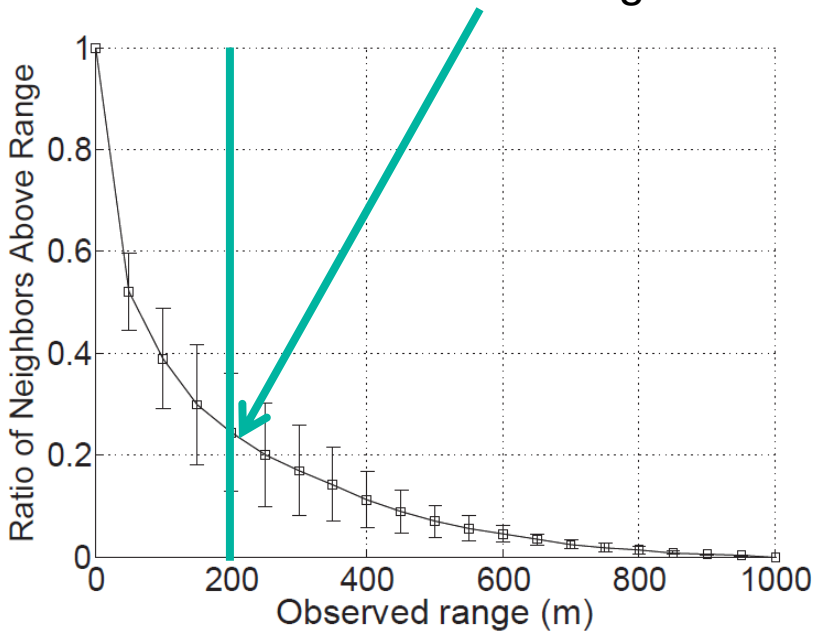


Highway, Trento

Ratio of Neighbors Above Range (RNAR) Results

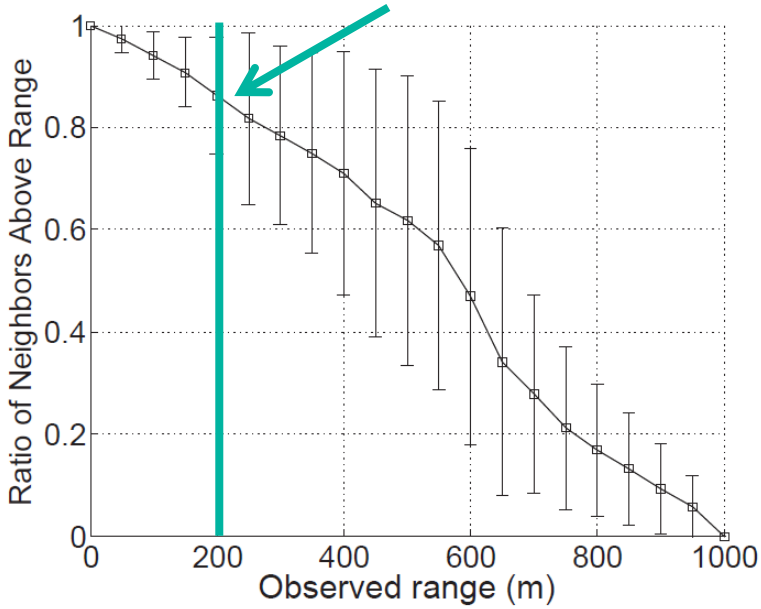
- Proportion of channel load due to distant neighbors can be high
  - In full-penetration VANETs, this can be a show-stopper
  - Interplay between benefit and unwanted transmissions (NAR vs RNAR)
- Problem is exacerbated in case of V2I

~ 20 % detected vehicles above 200 m range



V2V, Trento

~ 90 % detected vehicles above 200 m range



V2I, Trento

Summary

- We empirically analyzed performance of single-hop cooperative message exchange in
  - V2V and V2I communication
  - Highway, Suburban, Urban environments
  - In terms of
    - **NAR** → effectiveness of CAMs
    - **RNAR** → load caused by far-away neighbors
- Results
  - V2V communication contained within 500m, V2I goes up to 1km+
  - Neighborhood awareness through CAMs
    - Works well up to 100m
    - Dependent on environment
    - Vehicles have different awareness levels even in the same test site
  - Load from distant neighbors can be high, in particular for V2I

Conclusions

Need to find awareness/load balance based on

- Application requirements: required range, required awareness ratio
- Constraints: propagation environment, vehicular traffic density

Distance (m) above which Neighborhood Awareness Ratio (NAR) falls below 90%

Environment	Sweden	Netherlands	Finland	Italy
Highway V2V	100	250	400	200
Suburban V2V	100	150	350	N/A
Urban V2V	N/A	N/A	200	N/A
Highway V2I	N/A	N/A	N/A	650

Our metrics and results can be used as an **input** for:

- Design of cooperative awareness parameters (e.g., generation rate)
- Congestion control (e.g., power and rate control)
- Interference analysis of fully-deployed VANETs

Empowered by Innovation

NEC

Thank you for your attention!

{mate.boban, pedro.dorey}@neclab.eu