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

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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 $\rightarrow$ 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

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

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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

**Highway**

**Urban**

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?

![Graph showing Neighborhood Awareness Ratio vs Tx-Rx Distance for V2V and V2I in Highway, Trento.](image-url)
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

\[\text{~ 20\% detected vehicles above 200 m range}\]

\[\text{~ 90\% detected vehicles above 200 m range}\]

V2V, Trento

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

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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

Thank you for your attention!

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