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Low Penetration Rate Cooperative V2X Traffic Surveillance System

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Main local partners: VTT, HSL HRT, Liikennevirasto, here, Trafi, Heureka, Finnish Meteorological Institute

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Outline

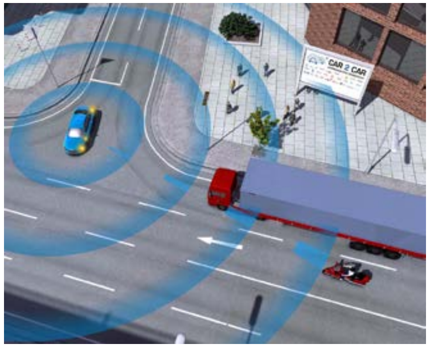
COLOMBO

- COLOMBO proposes to develop advanced traffic light control based on local and distributed floating car data (D-FCD)
  - obtained directly from vehicles

- D-FCD is provided by COLOMBO's traffic surveillance systems
  - Assumes low penetration of cooperative V2X systems
  - Fully distributed approaches

- Classify vehicles in three classes as function of traffic sensing capabilities:
  - Class A – vehicles not participating to traffic surveillance
  - Class B – vehicles equipped with sensors but not C2X
  - Class C – vehicles equipped with C2X technologies

- Develop Traffic monitoring system from data gathering, fusion and dissemination of traffic data obtained from class B and C vehicles, assisted by infrastructure nodes



source: Car 2 Car Communication Consortium web site

Low Penetration Traffic Surveillance

- Low Penetration Rate Cooperative V2X Traffic Surveillance
  - Low C2X Penetration - < 3% C2X technology
  - Multiple types of GPS devices
    - C2X, smartphones
  - Rely on WiFi-Direct on smartphones
    - Drivers or pedestrian on sidewalk
  - Rely on Bluetooth devices on vehicular sensors

- Objective:
  - Traffic Volumes / Traffic Dynamics (speed) in given zones

- Approaches followed in COLOMBO WP1
  - **Clustering** –
    - Vehicles cluster and let a cluster-head estimate the cluster dynamics
  - **Data Fusion from heterogeneous traffic data** –
    - C2X data is fused with Smartphones and sensor data
  - **C2X Message Propagation** –
    - Vehicles send messages and estimate the density & speed from its propagation rate

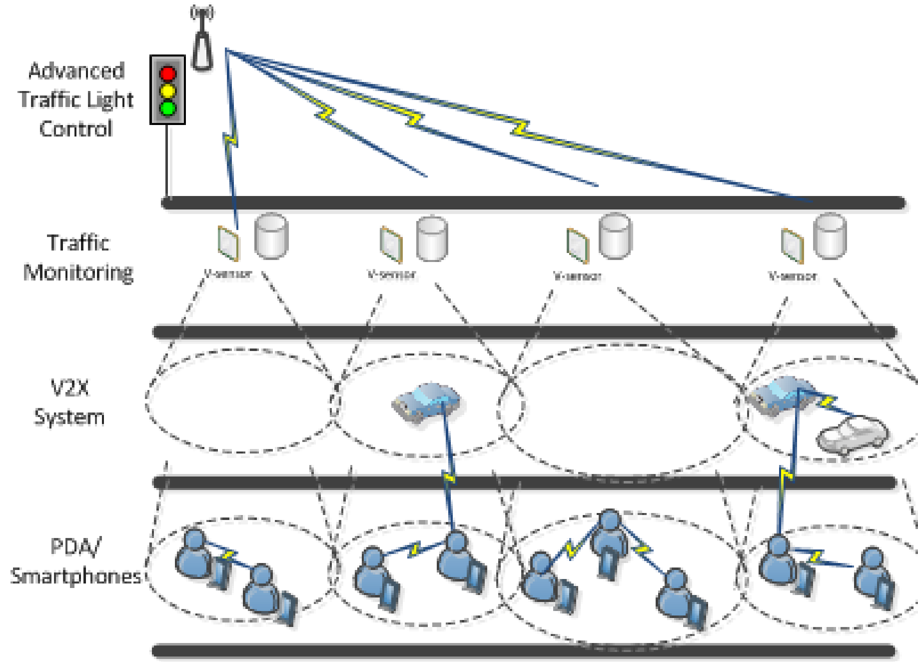
source: Volvo for C2CCC

source: Car 2 Car Communication Consortium

Virtual Sensor Approach for Cooperative Traffic Surveillance

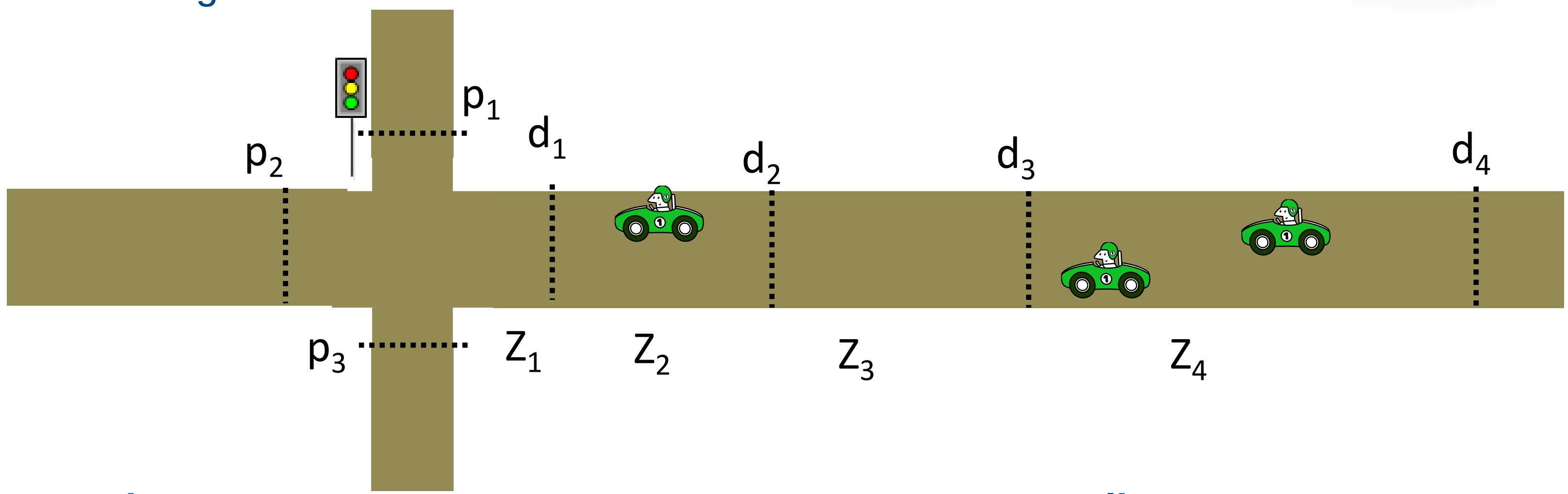
COLOMBO

- Virtual Sensors represent a zone where the traffic light needs traffic volumes
  - Virtual Sensors only have a 'virtual' existence from an artificial zone defining their coverage
- V2X vehicles (class C) in each zone will exchange traffic data to consolidate traffic volumes
- Consolidated volumes are transmitted to the RSU (direct, multi-hop)
  - Dissemination is transparent to RSU
- Low V2X penetration is compensated by Smartphones held by drivers and pedestrians in same zones



Traffic Surveillance for Traffic Light Control

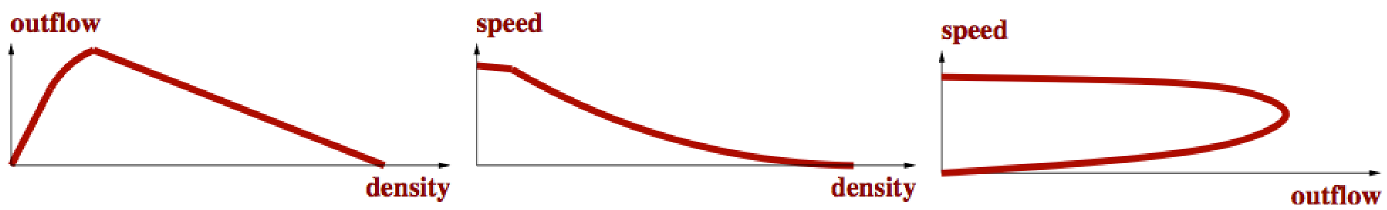
- The COLOMBO Traffic Light Control (TLC) requires dynamic and fresh traffic states
  - Arriving flows
  - Leaving flows



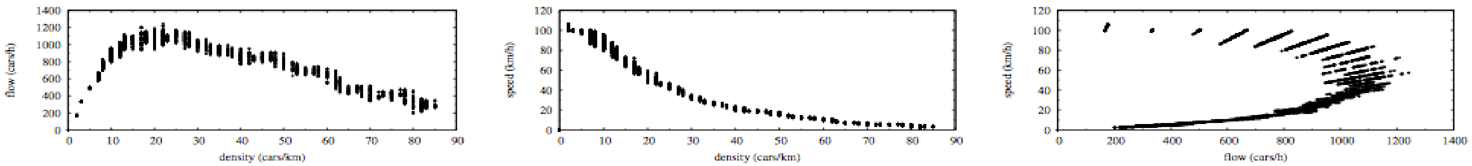
- **Measuring Zones** –
  - Z_x – measured zones [p_x-1 – p_x], [d_x-1 ; d_x]
  - d_x – measuring distances before TLC
  - p_x – measuring distances after TLC
- **Traffic Dynamics** –
  - Average speed in Z_x
  - Average Density of cars in Z_x
- **Data Quality** –
  - <u>Precision</u>: how close is data from reality?
  - <u>Freshness</u>: how often is data provided?

Traffic state estimate through traffic fundamental diagrams

- Traffic flows follow three basic fundamental diagrams:



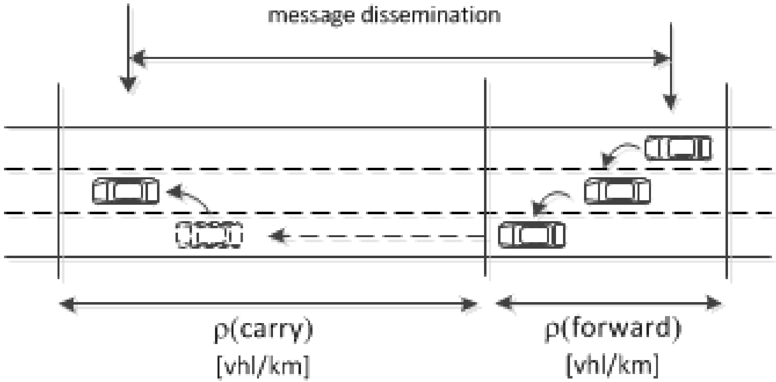
SUMO



- Traditionally used to validate models and traffic
  - Can be used to extract one component out of 1-2 two others
- Given a known street capacity (# lanes)
  - **Speed** can be extracted from **traffic density**
  - **Flow** (out) can be extracted from **traffic density**
- One challenge:
  - **traffic density**…

Traffic state estimate through data dissemination

- Related objective:
  - Given vehicular density
  - What is the multi-hop C2X dissemination delay?



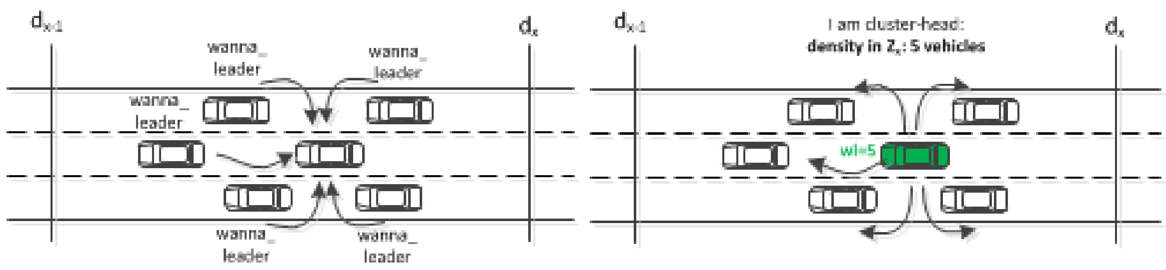
- In COLOMBO: reverting the question
  - Given the **C2X dissemination delay**, what is the **average density** ?
- Tradeoff:
  - <u>Carry</u>: dissemination = vehicular speed
  - <u>Relay</u>: dissemination immediate = Multi-hop percolation exists
    - Laws of Physics: at least 1 vehicle every transmit range
    - Density of vehicle may be estimated !
  - <u>Hybrid</u>: carry takes lead over relay

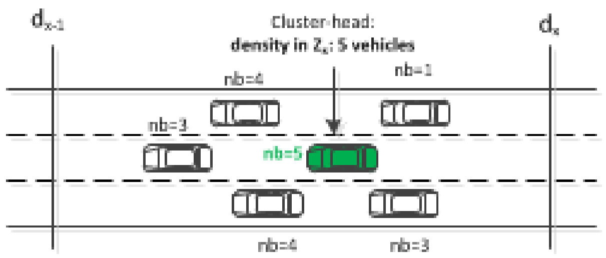
Traffic state estimate through local neighborhood information

COLOMBO

- Reactive Approach – **Distributed Auction**
  - Each node request (broadcast) to be come a cluster leader
  - The node with the maximum request announces it becomes leader
  - Any node receiving this message joint its group

- Proactive Approach: **Node Mapping Protocol (NMP)**
  - periodically send beacons with information from neighbors (id, position, speed, direction, and **number of known nodes**)
  - The node with larger neighbor set becomes leader





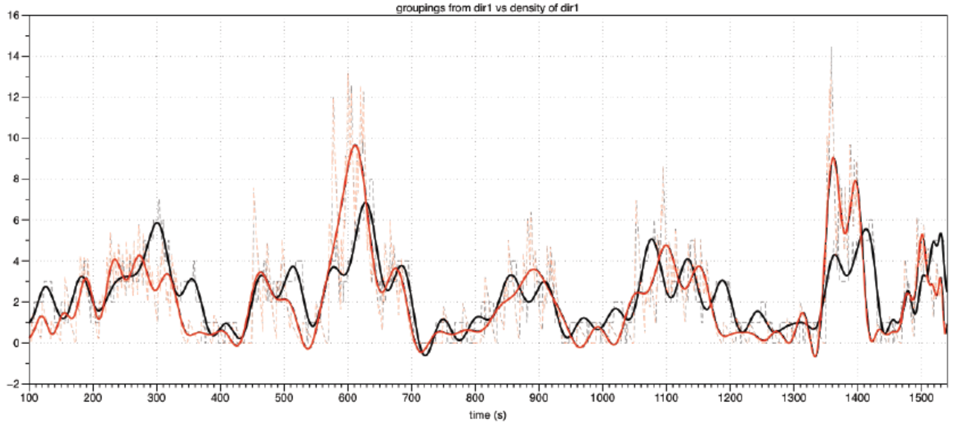
- **Cluster Leader**:
  - Gathers the number of neighbors contained in the measured area
  - Fuse and consolidate from missed data
  - Transmit it to the traffic light

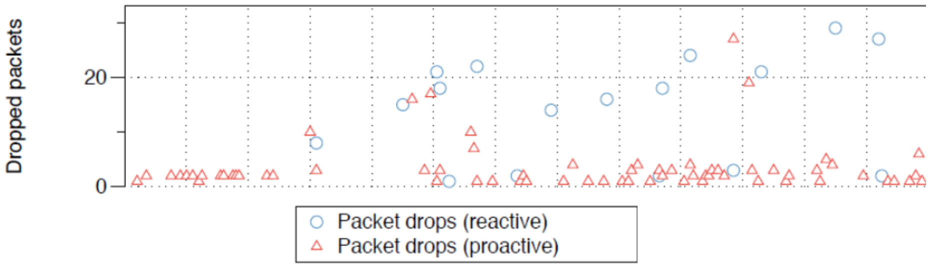
Traffic state estimate - evaluations

- 100% Car type C: Two-way linear scenario, 100% penetration

- Traffic Density:
  - Black: Oracle
  - Red: Proactive

- Observation:
  - ~98% precision in #detected vehicles in each direction



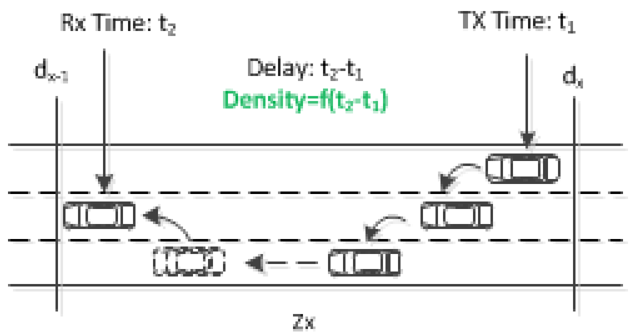


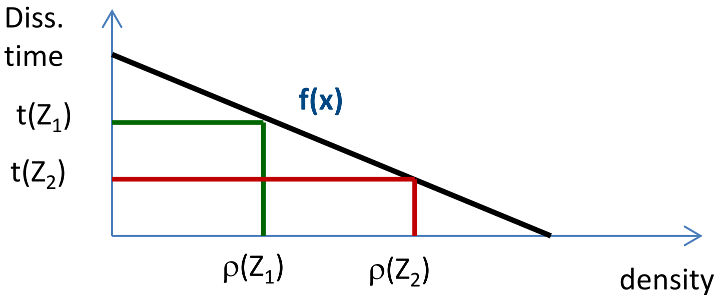
- Packet Losses:
  - Related to channel congestion
  - Hinders quality of fusion protocol
  - Proactive (red) creates less overall (and less critical) collisions than reactive (green)

P. Bellavista, L. Foschini, E. Zamagni, "**V2X Protocols for Low-Penetration-Rate and Cooperative Traffic Estimations**", to appear in the Proc. of IEEE VTC-Fall 2014, Sept. 2014, Vancouver, Canada.

Traffic state estimate through local neighborhood information

- **Reverse Dissemination**:
  - Car entering a zone: transmit a packet
  - Last car before leaving the zone: receives the packet





- **Mapping Function f(x)**:
  - Given dissemination time
    - Provides a respective density
  - Mapping function is critical to obtain:
    - Linear function in free-flow
    - Exponential in congested mode

Summary

- COLOMBO's cooperative & distributed traffic surveillance system has been presented
  - Tailored to traffic light control required data:
    - traffic density / traffic speed – per 'virtual' sensing zone (virtual induction loops)
      - Precise & fresh data (as close as possible to reality)

- Two approaches followed:
  - **Topology-based**: cluster-heads extracts neighborhood visibility (density)
  - **Dissemination-based**: relationship between dissemination time and density

- Some initial results have been presented
  - Data quality close to benchmark (simulated mobility with SUMO)

More information is available at

http://colombo-fp7.eu/

Thank you!