Low Penetration Rate Cooperative V2X Traffic Surveillance System
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Outline

- 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
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
Virtual Sensor Approach for Cooperative Traffic Surveillance

- 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 –
  - **Precision**: how close is data from reality?
  - **Freshness**: how often is data provided?
Traffic state estimate through traffic fundamental diagrams

- Traffic flows follow three basic fundamental diagrams:
  - 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:
  - **Carry**: dissemination = vehicular speed
  - **Relay**: dissemination immediate = Multi-hop percolation exists
    - Laws of Physics: at least 1 vehicle every transmit range
    - Density of vehicle may be estimated!
  - **Hybrid**: carry takes lead over relay
Traffic state estimate through local neighborhood information

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

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!