Fog Computing for Cooperative and Autonomous Driving

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Mobile Cloud Computing (MC²) Group

• Founded in 2016
• 1 Associate Professor, 3 Postdocs, 9 Doctoral Students, 10+ Research Assistants
• 1 EU, 2 Academy of Finland, 3 Business Finland funded projects (ongoing)
• Website: mobilecloud.aalto.fi
• DataFog: A data-driven platform for capacity and resource management in vehicular fog computing (2019 – 2022)
  *This project is funded by Academy of Finland (grant number: 317432).

• 5G-Mobix: 5G for cooperative & connected automated mobility on x-border corridors (2018 – 2022)
  *This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 825496. More information can be found from [www.5g-mobix.com](http://www.5g-mobix.com).
• Application scenarios

• Task allocation and capacity planning
• Application scenarios

• Task allocation and capacity planning
Vehicles currently on the road have 60-100 sensors onboard. This number is projected to increase to 200+.

Source: Automotive Sensors and Electronics 2017
Extended Sensors

- Extending the perception obtained by the onboard sensors, with sensor data received from surrounding vehicles or road side units (RSUs)

Where to process the data?
  • Move computation close to where the data is generated

Where to gather and process the data collected from multiple sources?
Application Scenarios

- **Stationary edge/fog nodes**
  - Luminaires (Ensto)
  - Camouflage Radome Unit for connected devices (Nokia, Pernua)
  - Connector boxes for pole external devices (Nokia)
  - Composite pole (Etel Composites)
  - Utility box (device space) (Nokia, Etel Composites)
  - Energy harvesting & cooling network under ground
  - Drone docking station (Rumble Tools) or Weather sensor (Vaisala)
  - 5G radio (Nokia)
  - 180° / 360° panorama camera (Teleste)
  - Air quality sensor (Vaisala)
  - Pole display (Teleste)
  - Electric Vehicle charger (Ensto)

Smart light pole at Nokia Campus, Espoo. (Source: www.luxturr5g.com)

- **Mobile edge/fog nodes**

In-bus data processing (Source: digi.com)

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Source: infosys.com
Vehicular Fog Computing (VFC)

- Complement cellular fog nodes (stationary) with vehicular fog nodes (mobile)
- Deploy vehicular fog nodes (VFNs) on commercial fleets like buses, taxis and drones
  - One-hop communications

Temporal Variation in Vehicular Traffic

Availability of Services

Over 90% of client vehicles could receive services from nearby VFNs for more than 85% of the traveling time.

- Luxembourg SUMO Traffic scenario (LuST)
- Simulate the scenarios of video crowdsourcing using VeinsLTE
- One-hop DSRC and LTE
Vision-based Vehicular Applications

- Pedestrian, bike and vehicle detection
- Obstacle detection
- Traffic sign recognition
- Construction site detection
- Temporary lane closure detection
- Parking slot detection
- ...

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Crowdsourced Mapping

To facilitate autonomous driving anywhere in the world, we first need to map everywhere in the world. But not just any maps will do. Instead of overemphasizing global accuracy, Mobileye's crowdsourced, continuously updated map of the world digitizes precisely what AVs need—nothing more, nothing less. We're making maps for the autonomous future.

<table>
<thead>
<tr>
<th>Common Industry Approach – HD Maps</th>
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<tbody>
<tr>
<td>Scalable by-design</td>
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<tr>
<td>Reliance on dedicated mapping fleets with expensive sensors (lidar, camera, INS)</td>
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<tr>
<td>Manual/semi-automatic mapping process</td>
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<td>Infrequently updated – changes are not reflected in real time</td>
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<tr>
<td>Overly specified geometric accuracy in global coordinates</td>
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<tr>
<td>Relying on raw data on road semantics that have no specifics or insight on human driving patterns</td>
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<table>
<thead>
<tr>
<th>Mobileye's Approach – AV Maps</th>
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<tr>
<td>Scalable-by-design</td>
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<tr>
<td>Millions of Mobileye-equipped ADAS vehicles sending data to the cloud in small data packets (10kb/km)</td>
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<tr>
<td>Fully automated map generation at the push of a button</td>
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<td>Maps can be updated in near-real time because of sophisticated change-detection algorithms on millions of mapping agents</td>
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<tr>
<td>Superior local accuracy: where it matters</td>
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<tr>
<td>Using the &quot;wisdom of the crowd&quot; to create rich semantic layer of driving culture and traffic rules</td>
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Source: https://www.mobileye.com/
Automatic map update using dashcam video

• A pipeline for **initiating** and **updating** 3D maps with dashcam videos, with a focus on automatic change detection based on comparison of metadata (e.g., the types and locations of traffic signs)
Initial Map Creation

A.1 Structure-from-Motion (SfM) point clouds

A.2.1 semantic segmentation

A.3 3D point cloud segmentation-> metadata

The camera poses are shown in red color.
Map Update

Data collected from Jakasaari, Helsinki (Feb 2019 vs. Dec 2019)
Latency

**Hardware:** Intel(R) i7-11700F processor clocked at 2.50GHz and an NVIDIA RTX 3070 8GB GPU.

**Latency:**

- Pixel-wise 3D localization (step B.1.1): 100ms per image
- Object detection (step B.1.2): 60ms per image
- Camera pose estimation based on SfM (B.1.3): 50ms per image

Overall: 5 fps if all the steps are run in sequence
5G testbed in Otaniemi

https://www.youtube.com/watch?v=Zv1smGBr7Xk
• Application scenarios

• Task allocation and capacity planning


Latency and Quality Balanced Task Allocation
Problem Formulation

- The objective is to minimize the service latency while keeping the service quality as high as possible
- **Constraints**
  - Service Latency Tolerance
  - Capacity/Resource Limitation
How to measure quality?

• Video resolution

• Quality of Information (QoI), application-specific
  • Take object recognition as example, we calculate the QoI as the number of pixels covering the targeted objects in each image.
Trade-offs

- Resolution vs. transmission latency
- Transmission distance vs. transmission latency
- Sampling rate vs. resource consumption
- Server workload vs. processing delay

...
FlexSensing

- Determine the rate of data collection for each sensing vehicle in the targeted area and assign processing tasks to VFNs based on the estimated QoI and the workload of VFNs.

- Apply a deep Q-network (DQN) to learn the optimized task allocation strategies for increasing the QoI of collected data while reducing the processing latency.

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State of a data collector: geo-info, configuration of dashcam
State of VFN: geo-info, #customer vehicles
Capacity Planning

Input:

- Expected quality of service
- Estimated demand and supply (vehicle traffic, application profiles)
- Cost estimation (installation costs, operating costs)

Output:

- Where to deploy fog nodes? How much capacity for each node?

A Helsinki city map that covers 869 road segments and 9421 bus traces.
TABLE III: Comparison of fog node distribution on weekdays using $DS$, $CP$-$CO$, and $CP$-$AB$, where $#$ represents the cluster ID.

<table>
<thead>
<tr>
<th>CFN</th>
<th>VFN</th>
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<tbody>
<tr>
<td>Downtown</td>
<td></td>
</tr>
<tr>
<td>$DS$</td>
<td>#4</td>
</tr>
<tr>
<td>$CP$-$CO$</td>
<td>#13</td>
</tr>
<tr>
<td>$CP$-$AB$</td>
<td>#14</td>
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<tr>
<td></td>
<td>#18</td>
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<td></td>
<td>#24</td>
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<td></td>
<td>#35</td>
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<tr>
<td>Suburb</td>
<td></td>
</tr>
<tr>
<td>$DS$</td>
<td>#2</td>
</tr>
<tr>
<td>$CP$-$CO$</td>
<td>#8</td>
</tr>
<tr>
<td>$CP$-$AB$</td>
<td>#20</td>
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<td>#28</td>
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<td>#34</td>
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<td>#42</td>
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</tbody>
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$DS$: fog nodes on both cellular base stations and buses, and installing VFNs on a minimum number of buses that can cover the selected bus journeys.

$CP$-$CO$: fog nodes only on cellular base stations

$CP$-$AB$: fog nodes on cellular base stations and all the buses in the study area

When the unit installation cost becomes lower, or when the operational time becomes longer, $DS$ will have higher potential for cost-saving compared to $CP$-$CO$. 
VFogSim


Source code can be downloaded from https://mobilecloud.aalto.fi/?page_id=1441
- Can be used for evaluating task allocation and capacity planning solutions
- Support the mobility of fog nodes
- Output: QoS, techno-economic performance
- Configurable inter-service prioritization and pricing strategies
Summary

- Edge/Fog Computing is a key enabling technique for cooperative & autonomous driving
- Challenges mainly come from the mobility of vehicles including the ones carrying fog computing nodes
- Task allocation/resource management algorithms must be lightweight
- Capacity planning needs to take into account uncertainty in both vehicle traffic and application profiles
Questions?