Fog Computing for Cooperative and Autonomous Driving

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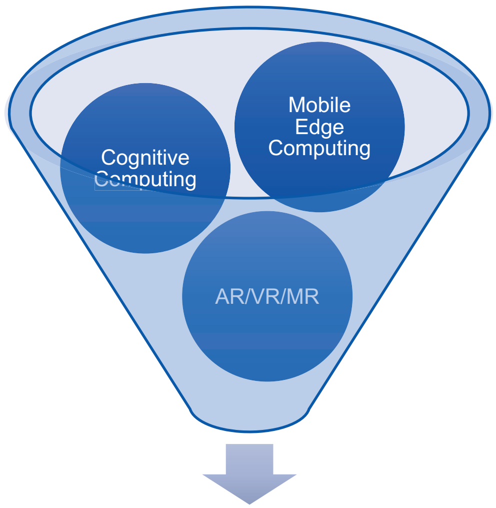
Mobile Cloud Computing (MC^2) Group

- 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



Cognitive assistance systems for smart mobility, manufacturing & healthcare

- **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.

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- **Application scenarios**

- **Task allocation and capacity planning**

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- Task allocation and capacity planning

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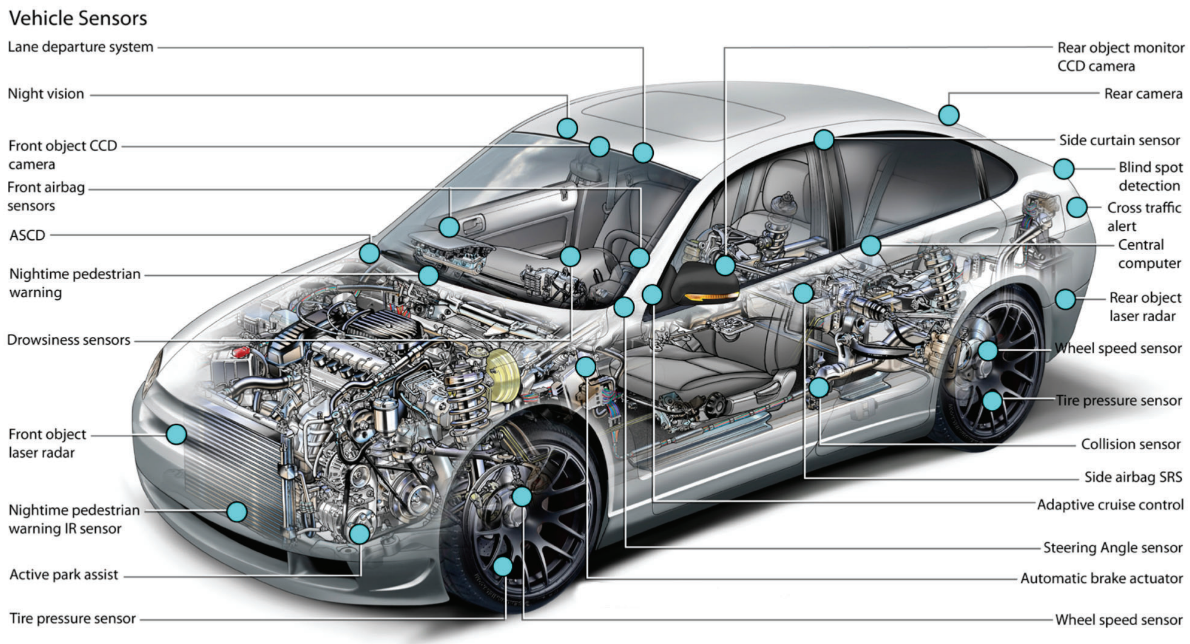
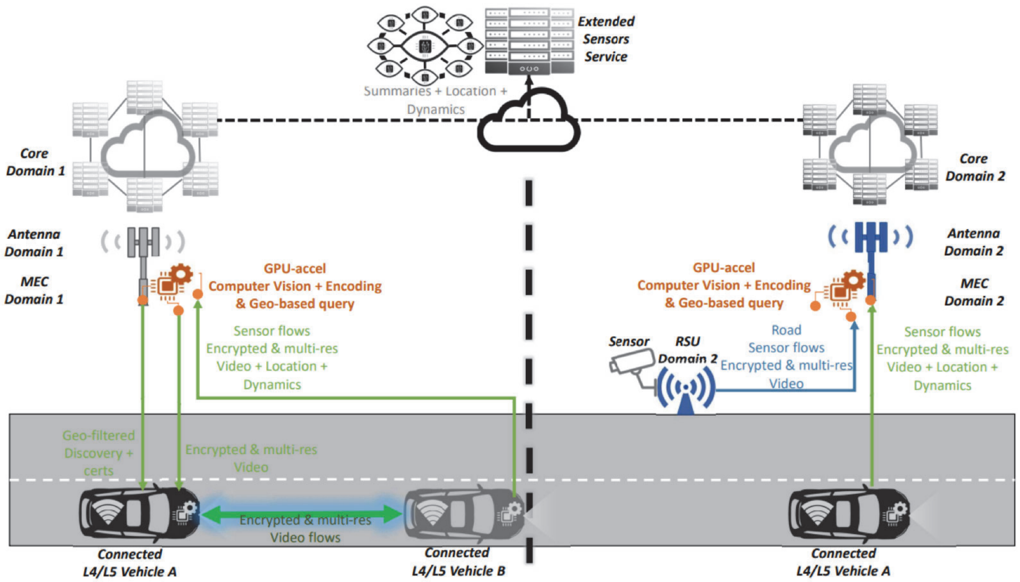


Vehicles currently on the road have 60-100 sensors onboard. This number is projected to increase to 200+.

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)**



Gorka Velez, Angel Martin, Giancarlo Pastor, and Edward Mutafungwa. 5G Beyond 3GPP Release 15 for Connected Automated Mobility in Cross-border context. Sensors 2019, 20, 6622. doi: 10.3390/s20226622

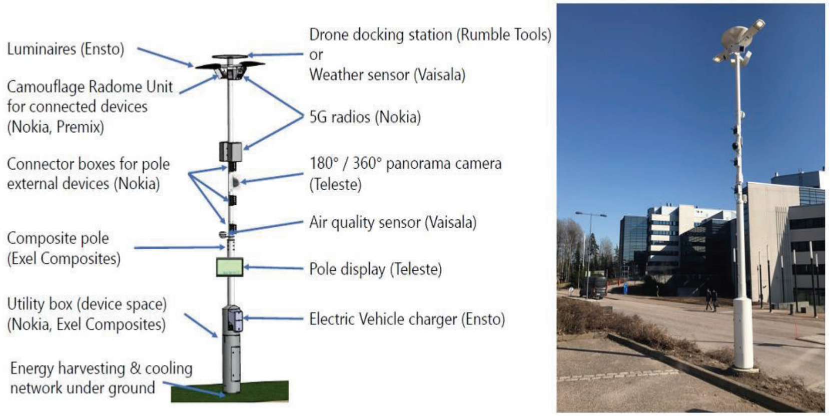
Where to process the data?

- *Move computation close to where the data is generated*

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

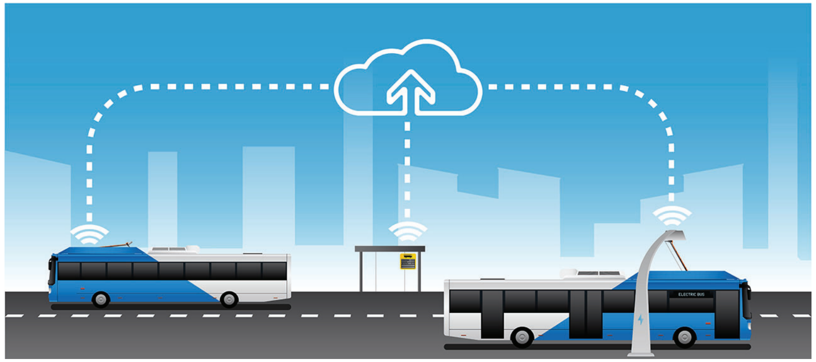
Application Scenarios

- **Stationary edge/fog nodes**



Smart light pole at Nokia Campus, Espoo.
(Source: www.luxturrim5g.com)

- **Mobile edge/fog nodes**



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

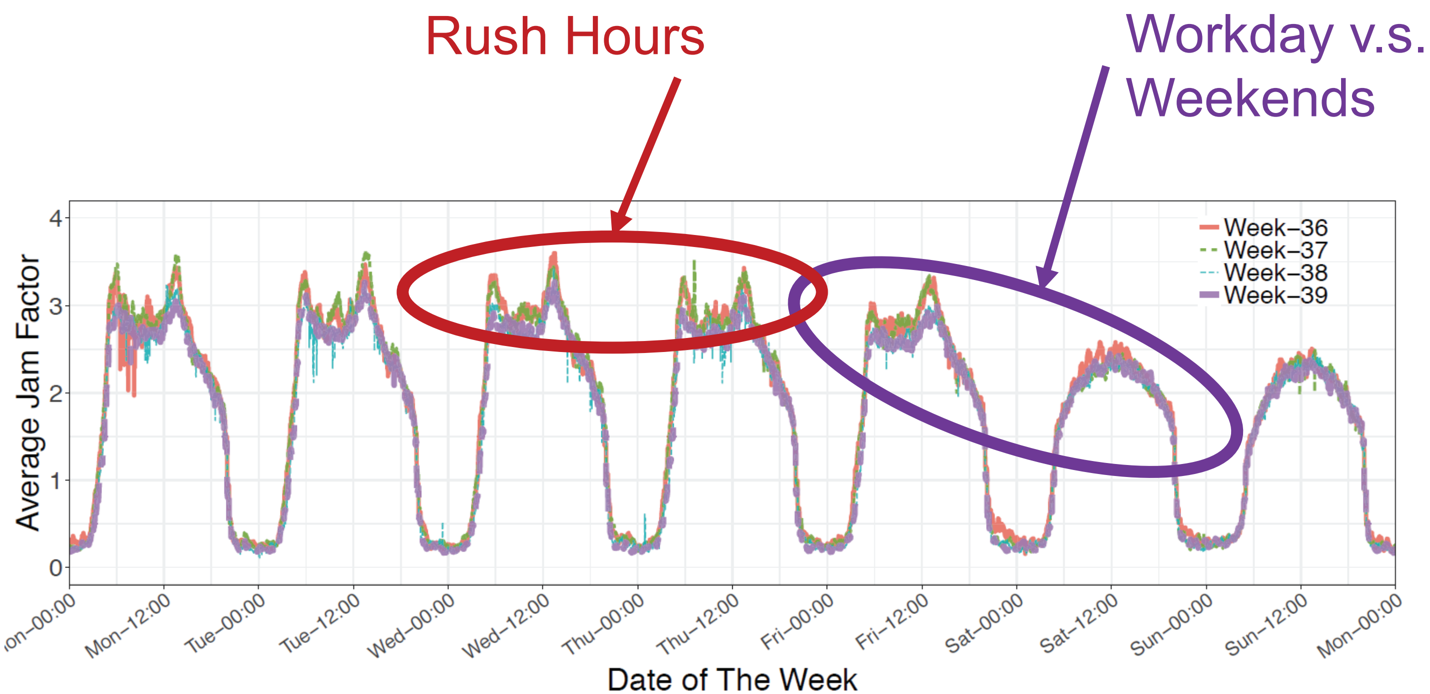
Source: infosys.com

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

Y. Xiao and C. Zhu, "Vehicular fog computing: Vision and challenges," in *Proceedings of 2017 IEEE International Conference on Pervasive Computing and Communications Workshops (PerCom Workshops)*, March 2017, pp. 6-9, doi: 10.1109/PERCOMW.2017.7917508.

Temporal Variation in Vehicular Traffic



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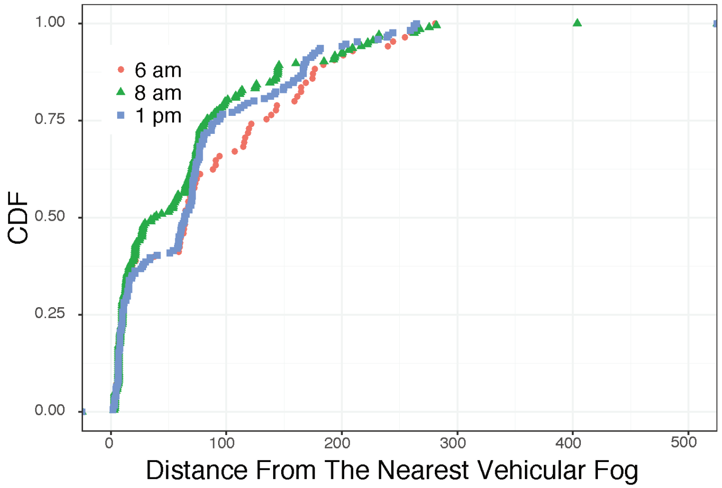
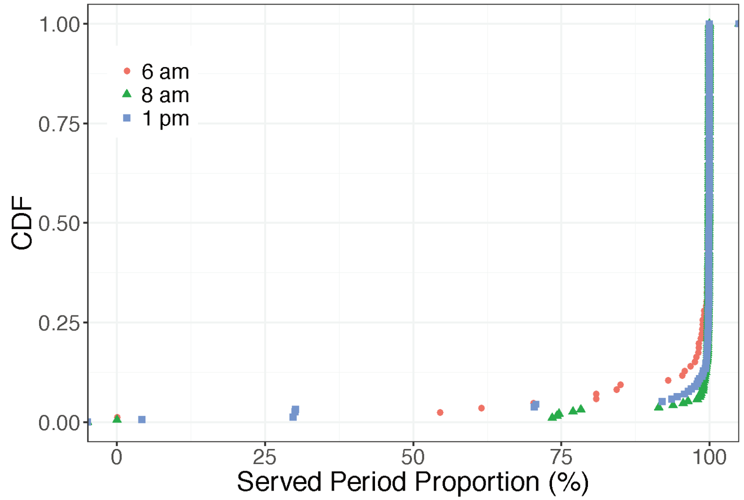
C. Zhu, G. Pastor, Y. Xiao and A. Ylä-jääski, "Vehicular Fog Computing for Video Crowdsourcing: Applications, Feasibility, and Challenges," in IEEE Communications Magazine, vol. 56, no. 10, pp. 58-63, OCTOBER 2018, doi: 10.1109/MCOM.2018.1800116.

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)
  L. Codeca, R. Frank, and T. Engel, "Luxembourg SUMO Traffic (LuST) Scenario: 24 Hours of Mobility for Vehicular Networking Research," Proc. IEEE VNC, 2015, pp. 1–8.
- 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
- …

Crowdsourced Mapping

Source: https://www.mobileye.com/

Automatic map update using dashcam video

Aziza Zhanabatyrova, Clayton Leite, and Yu Xiao, "Automatic Map Update using Dashcam Videos", arXiv, Sep 2021 (revised in Jan 2022), https://arxiv.org/abs/2109.12131

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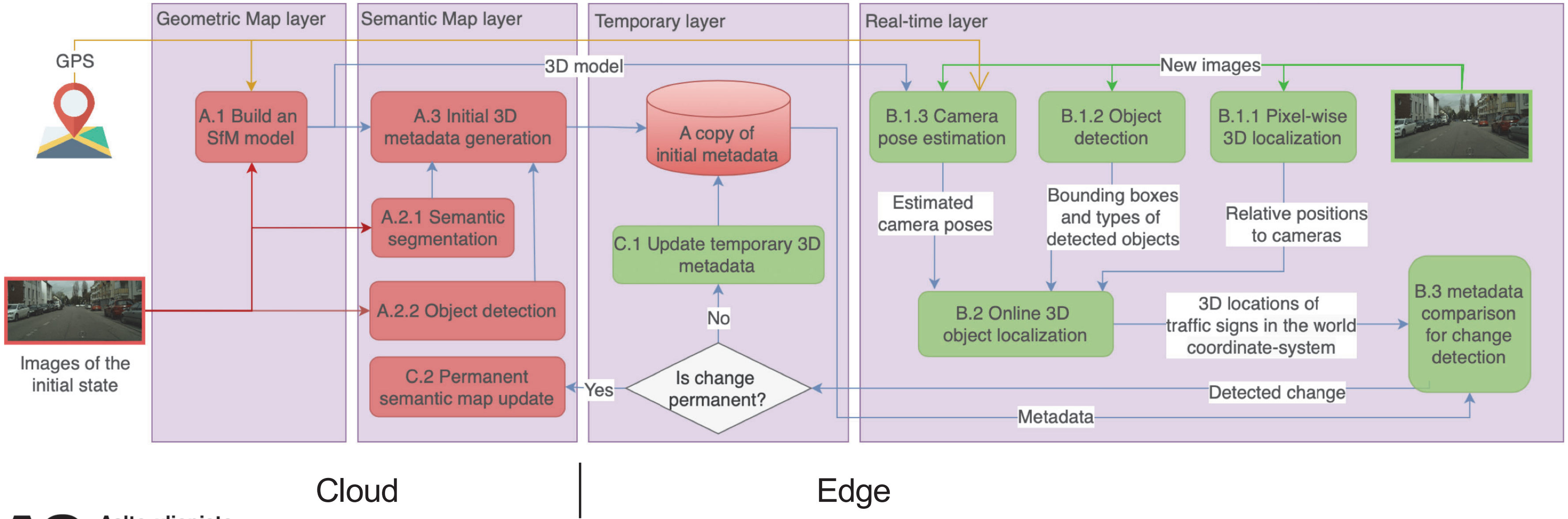
- A pipeline for initiating and updating 3D maps with dashcam videos, with a focus on automatic change detection based on comparison of metadata (e.g., the types and locations of traffic signs)



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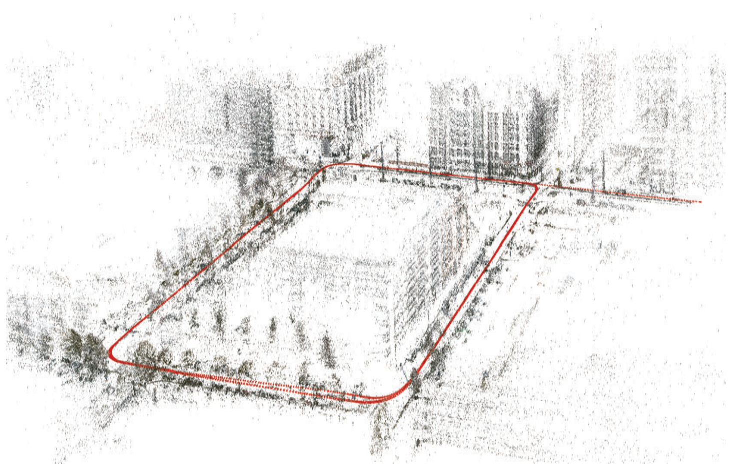
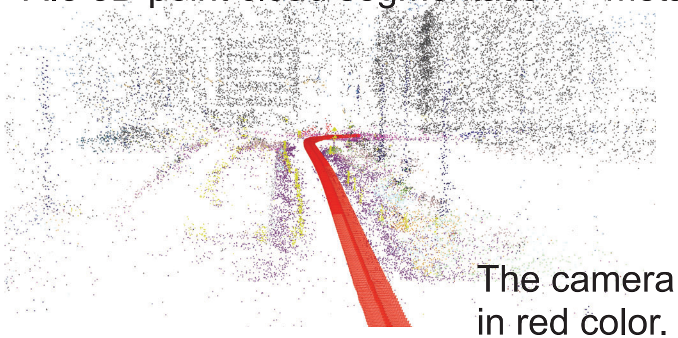
Initial Map Creation

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.

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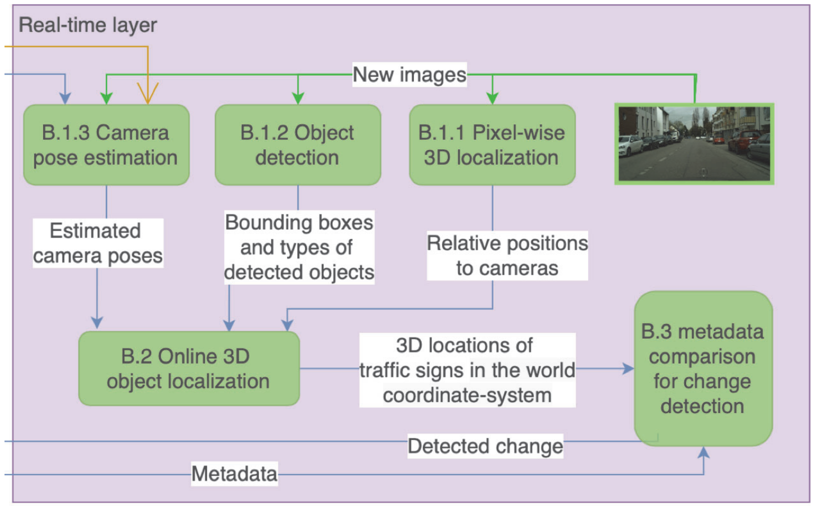
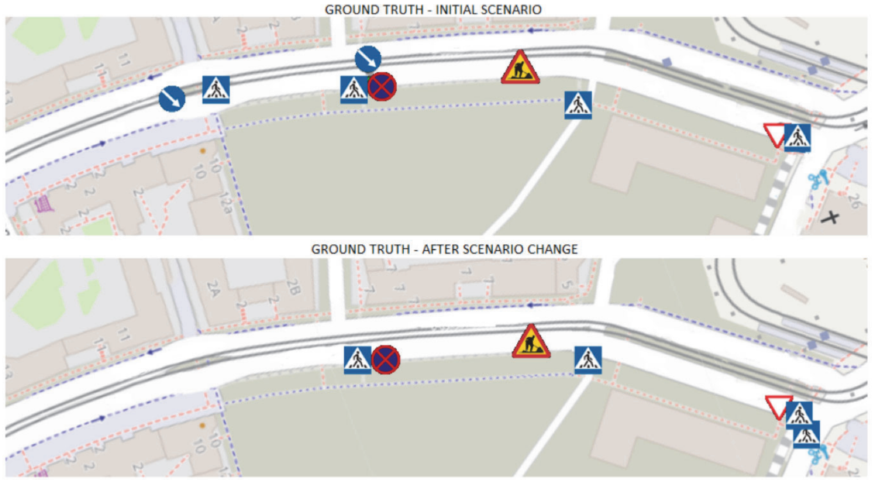
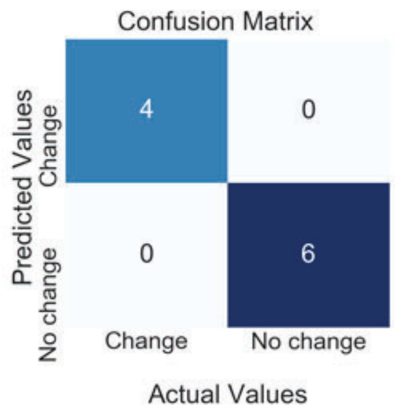
Map Update







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

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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**

C. Zhu, Y. -H. Chiang, Y. Xiao and Y. Ji, "**FlexSensing: A QoI and Latency Aware Task Allocation Scheme for Vehicle-based Visual Crowdsourcing via Deep Q-Network**," in *IEEE Internet of Things Journal*, doi: 10.1109/JIOT.2020.3040615. 2020.

C. Zhu, Y. -H. Chiang, A. Mehrabi, Y. Xiao, A. Ylä-Jääski and Y. Ji, "Chameleon: Latency and Resolution Aware Task Offloading for Visual-Based Assisted Driving," in *IEEE Transactions on Vehicular Technology*, vol. 68, no. 9, pp. 9038-9048, Sept. 2019, doi: 10.1109/TVT.2019.2924911.

C. Zhu *et al*., "Folo: Latency and Quality Optimized Task Allocation in Vehicular Fog Computing," in *IEEE Internet of Things Journal*, vol. 6, no. 3, pp. 4150-4161, June 2019, doi: 10.1109/JIOT.2018.2875520.

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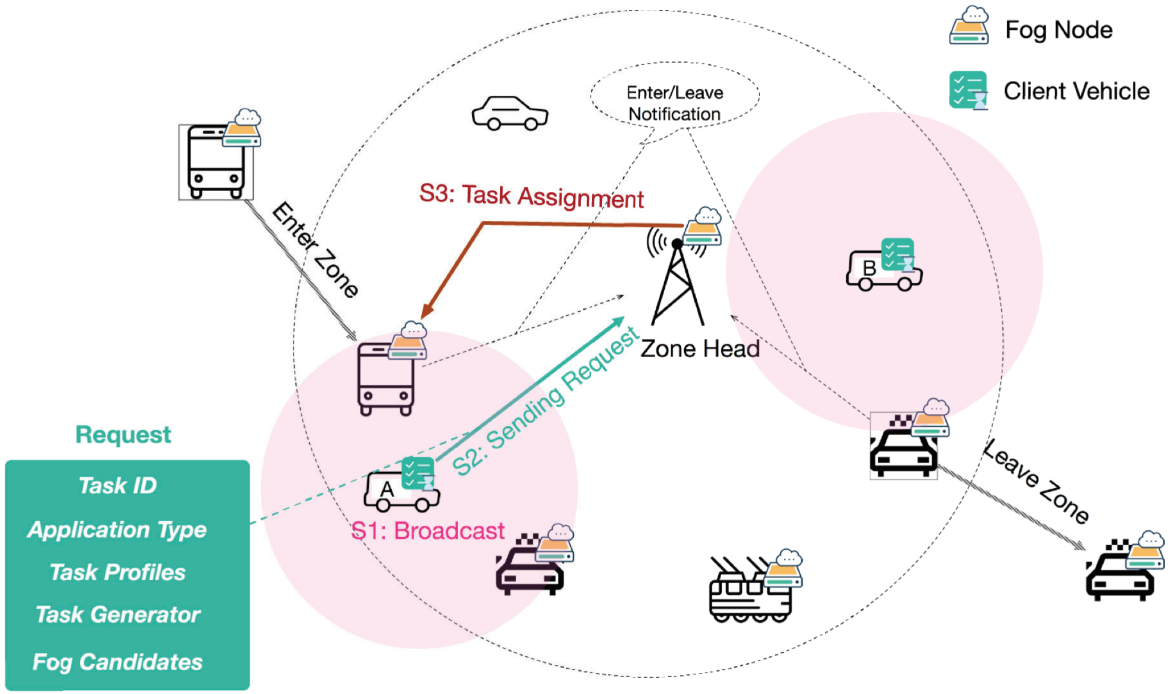
Latency and Quality Balanced Task Allocation



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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?

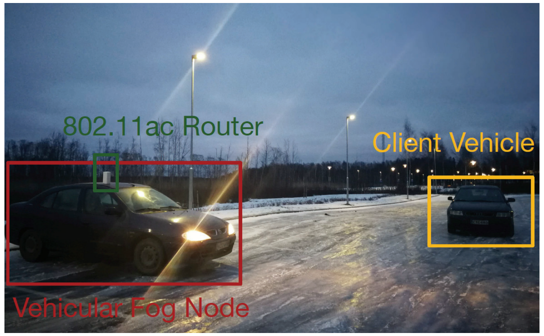
- **Video resolution**
- **Quality of Information (QoI), application-specific**
  - Take object recognition as example, we calculate the QoI as the number of pixels covering the targeted objects in each image.

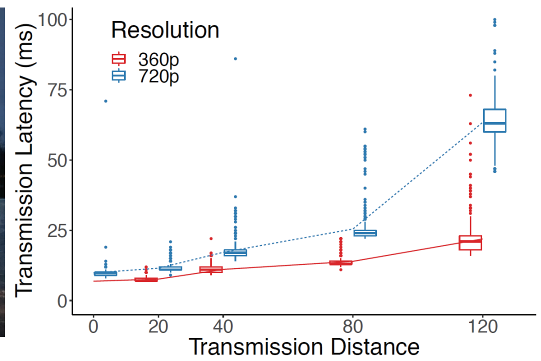
50 m

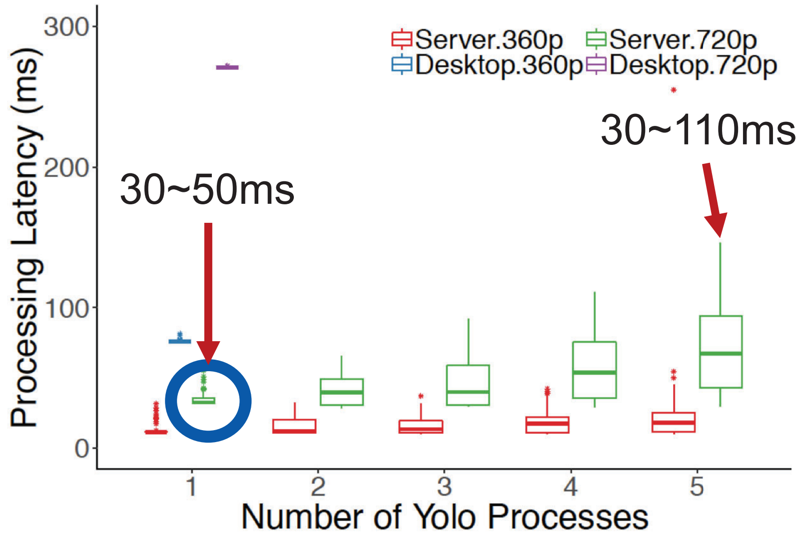
5 m

Trade-offs

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

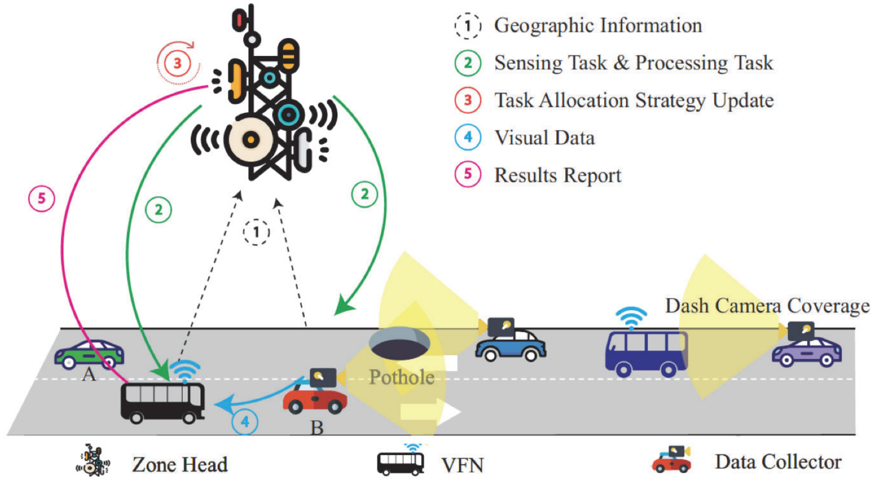


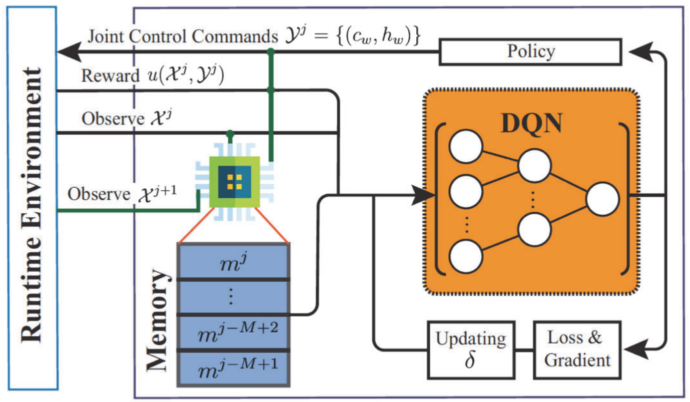




FlexSensing

- 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





Zone Head
(One Agent In A Service Zone)

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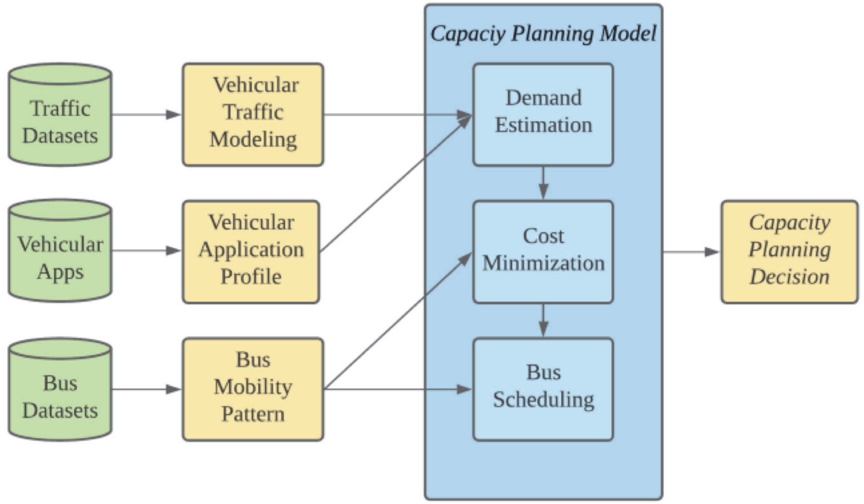
State of a data collector: geo-info, configuration of dashcam
State of VFN: geo-info, #customer vehicles

*W. Mao, O. U. Akgul, A. Mehrabi, B. Cho, Y. Xiao and A. Ylä-Jääski, "**Data-Driven Capacity Planning for Vehicular Fog Computing**," in IEEE Internet of Things Journal, doi: 10.1109/JIOT.2022.3143872.*

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?**

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A Helsinki city map that covers 869 road segments and 9421 bus traces.

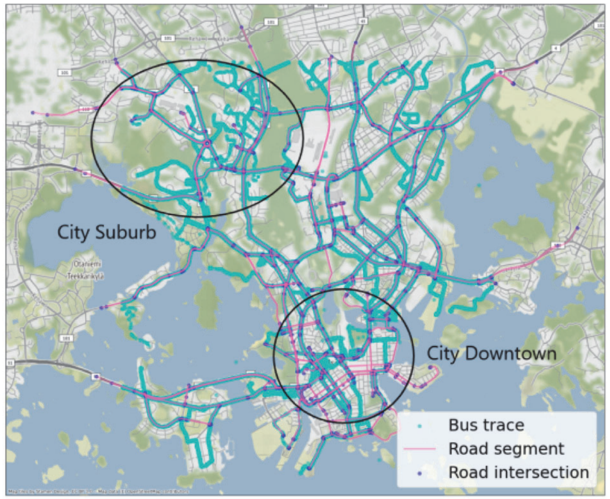

TABLE III: Comparison of fog node distribution on weekdays using *DS, CP-CO, and CP-AB*, where # represents the cluster ID.

	CFN						VFN
Downtown	**#4**	**#13**	**#14**	**#18**	**#24**	**#35**	**region**
DS	16	20	21	14	21	22	146
CP-CO	17	20	22	15	21	25	0
CP-AB	16	20	21	14	21	22	543
Suburb	**#2**	**#8**	**#20**	**#28**	**#34**	**#42**	**region**
DS	9	20	10	14	13	9	45
CP-CO	9	22	11	14	13	9	0
CP-AB	9	20	10	14	13	9	603

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

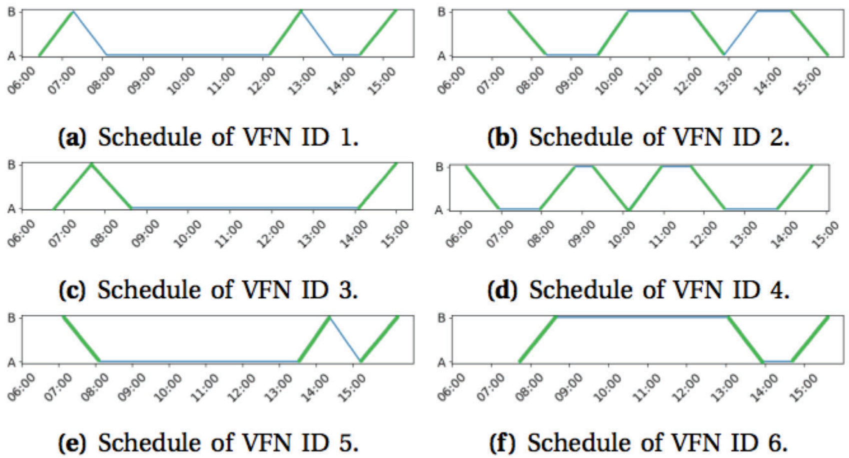

Fig. 9: Schedules of the 6 VFNs from bus line No. 322 in Helsinki, where A and B are the departure stops in two directions. The green lines represent the schedules of the 22 selected journeys, and the blue lines represent the turn-around time between the journeys.

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

*O. Akgul, W. Mao, Byungjin, C., and Y. Xiao, "**VFogSim: a data-driven platform for simulating vehicular fog computing environment**", TechRXiv, April 2022, https://doi.org/10.36227/techrxiv.17829398.v2*

Source code can be downloaded from https://mobilecloud.aalto.fi/?page_id=1441

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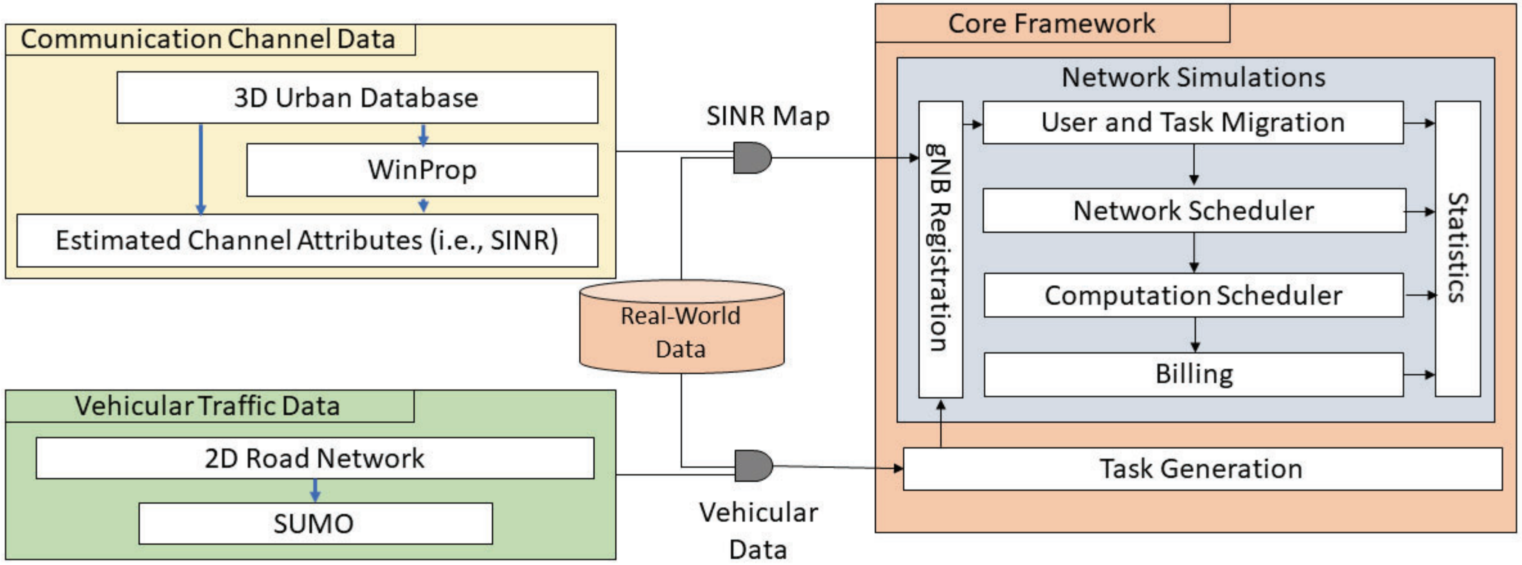

- **Can be used for evaluating task allocation and capacity planning solutions**
- **Support the mobility of fog nodes**
- **Output: QoS, techno-economic performance**
- **Configurable inter-service prioritization and pricing strategies**

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?