SLO-Aware Task Offloading within Collaborative Vehicle Platoons

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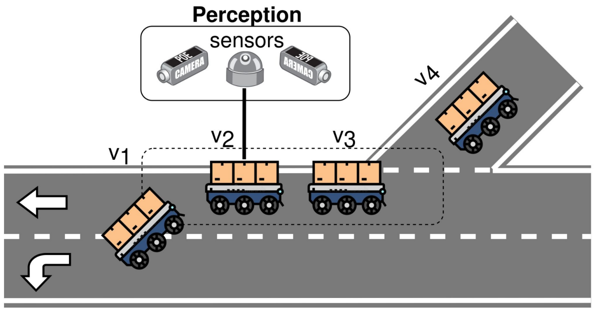
Problem Statement

Autonomous Vehicles (AVs) use services for perception and path planning, which pose **runtime requirements**

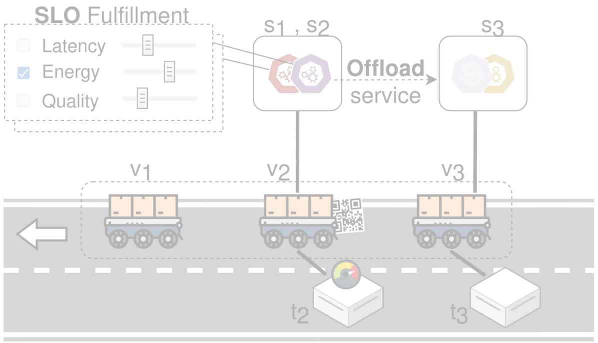
AV-enabling services have high computational demand, e.g., video or Lidar processing, but, AVs have **limited resources** available for scalability during runtime

Service offloading as an alternative; vehicle platoons can allocate services at **suitable** host and share results

When SLOs are violated, e.g., latency or quality, a service can be offloaded to a less utilized platoon member



Perception services executed in collaborative platoons



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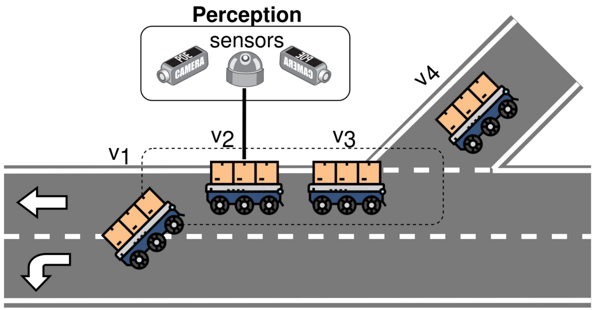

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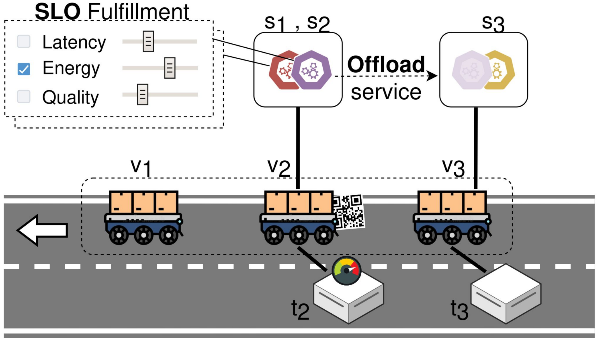

Offloading services to less utilized platoon members

Existing Shortcomings

Dynamic platoon disruptions

Vehicles can join or leave a platoon at any point, making it hard to train and apply an inference model in once consecutive session

⟶ Transfer decision models and tasks as devices join

Global impact of service offloading

Offloading a service to another device has implications on the resource availability of the remaining services on both sides

⟶ Estimate how offloading affects both sides

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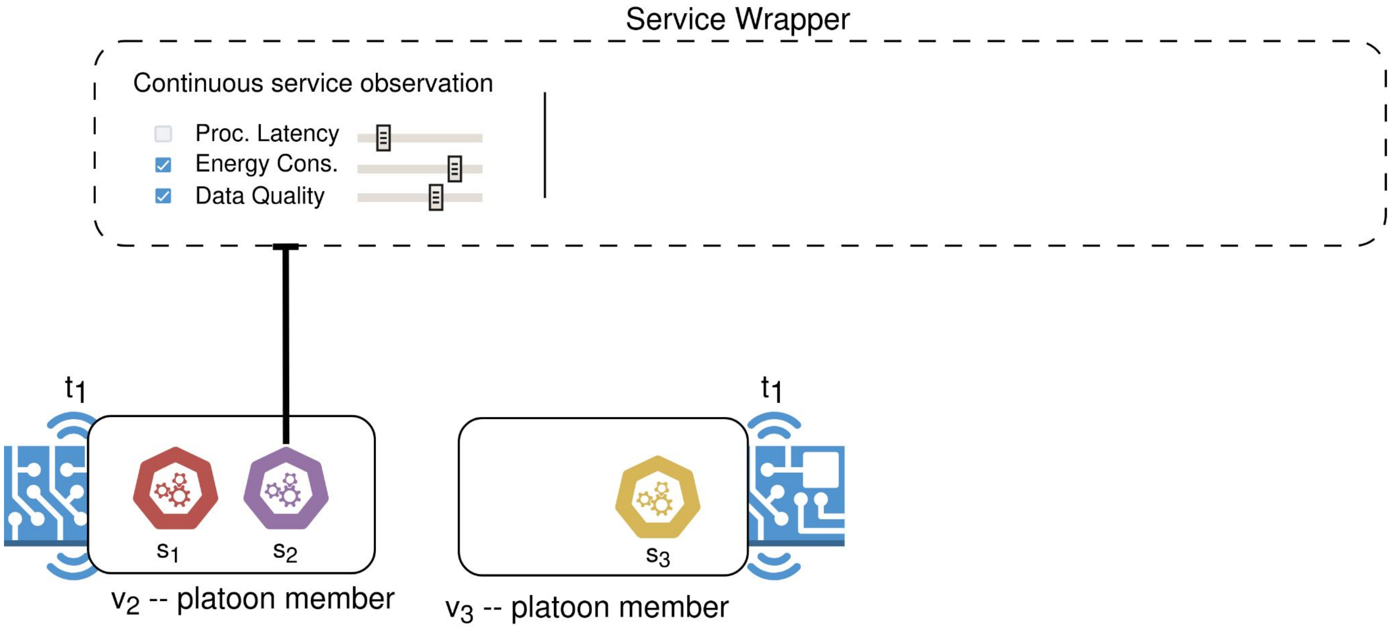
Methodology – Overview



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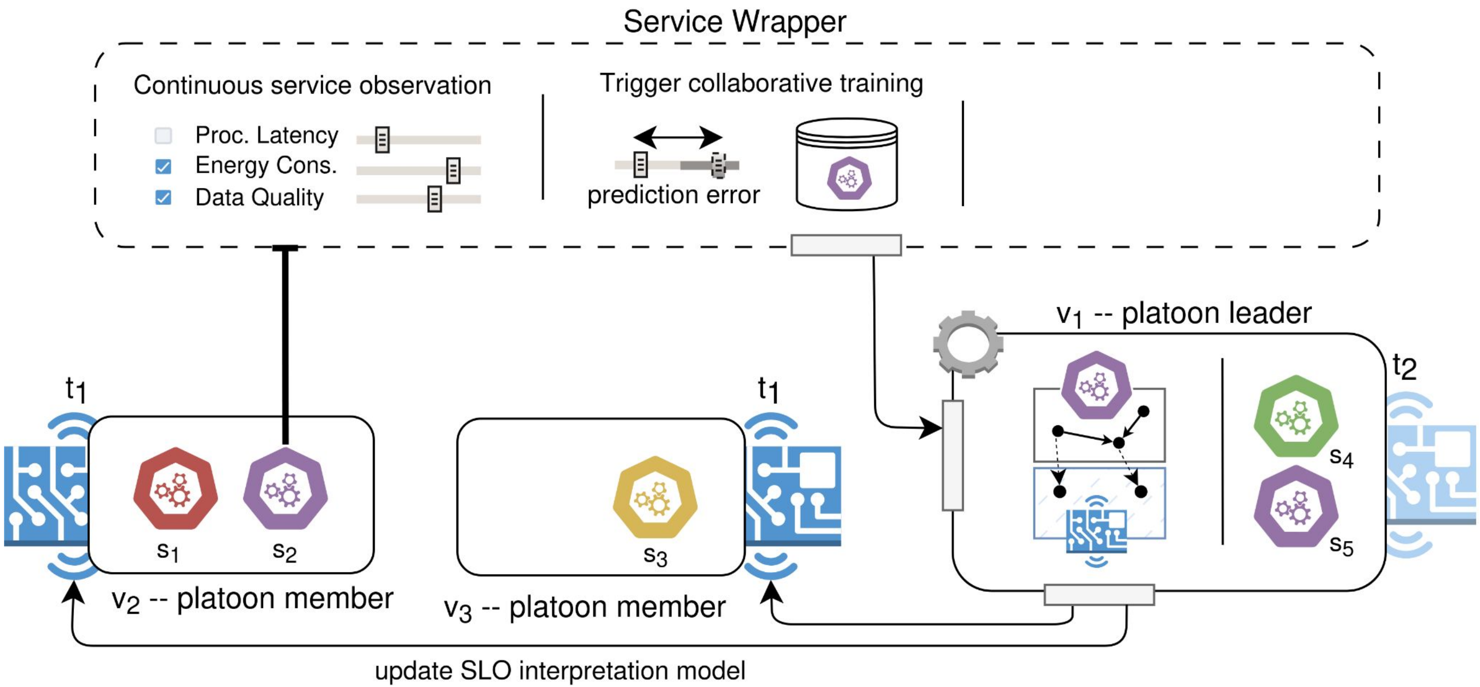

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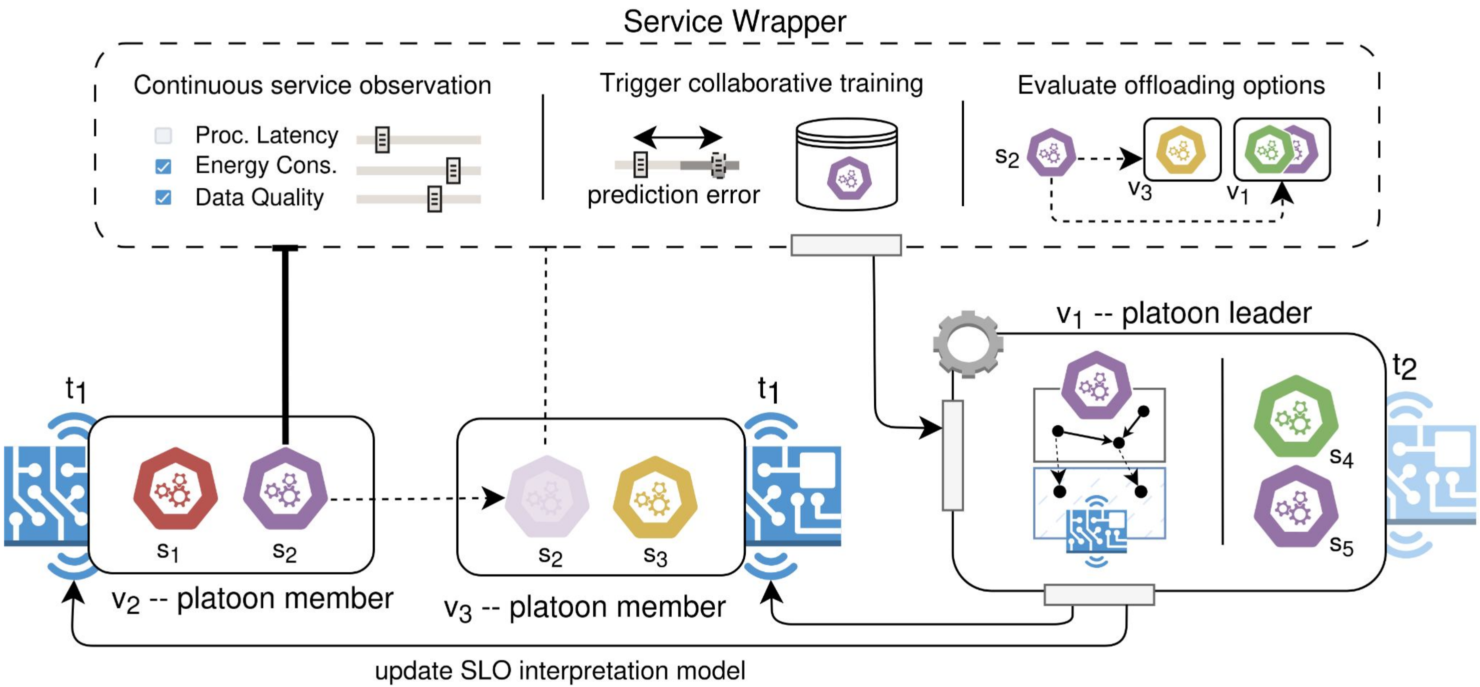
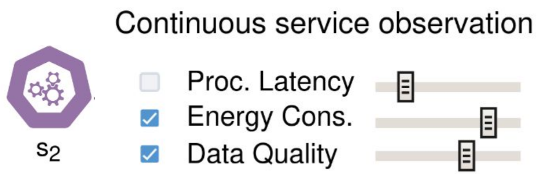
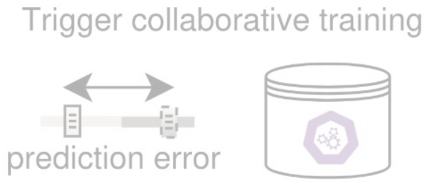


Methodology – Phases

Service Observation
(**1**) Track metrics of processing services in a local buffer;
(**2**) use metrics to evaluate local SLO-F(ulfillment);
(**3**) compare actual SLO-F with historical prediction using a Bayesian Network (BN) ⟶ SLO-I(nterpretation) model;
(**4**) get retrain factor from prediction error and buffer size



Collaborative Training
(**1**) When retraining threshold is met, send buffer to a mutable platoon leader; (**2**) leader computes an updated SLO-I model for the source device type; (**3**) leader distributes update model to all vehicles with device matching type; (**4**) substitute BN during service runtime



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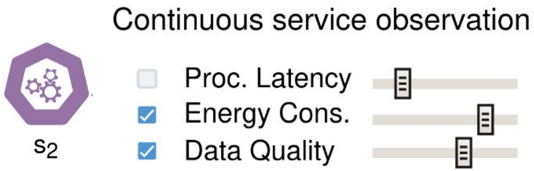

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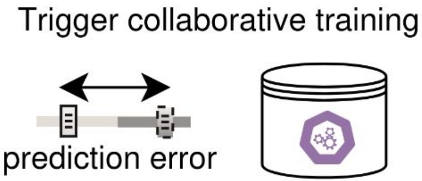
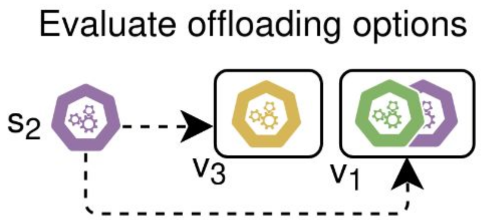


Methodology – Phases (cont.)

Service Offloading

(**1**) Calculate evidence to load off according to prediction error and absolute SLO violation; (**2**) if offloading threshold is met, estimate for each platoon member how offloading a service there would impact SLO-F at source and target device; (**3**) choose best option and orchestrate service relocation



- ❑ Estimated SLO-F dependent on resource availability
- ❑ Agency to offload lies with the processing service itself
- ❑ Frequency of wrapper execution decides reactivity

Experimental Environment

→ Build a physical vehicle platoon from Edge devices; use multiple instances of NVidia Jetson equipped with GPUs

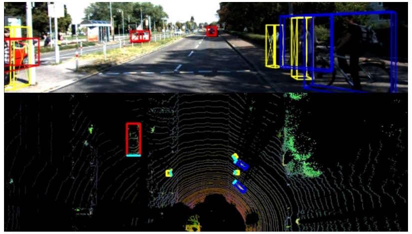
Full Device Name	ID	Price[8]	CPU	RAM	GPU	CUDA
Jetson Orin NX (3)	*NX*	450 €	ARM Cortex 8C	8 GB	Volta 1k	11.4
Jetson Orin AGX	*AGX*	800 €	ARM Cortex 12C	64 GB	Volta 2k	12.2

→ Provide three perception services for AVs; process streaming data (video / point cloud) according to SLOs

ID	Service Description	CUDA	Parameters	SLOs
CV	Object Detection with Yolov8 [26]	Yes	*pixel*, *fps*	**time**, **energy**, **rate**
LI	Lidar Point Cloud Processing [6]	Yes	*mode*, *fps*	**time**, **energy**
QR	Detect QR Code w/ OpenCV [21]	No	*pixel*, *fps*	**time**, **energy**

CV

LI



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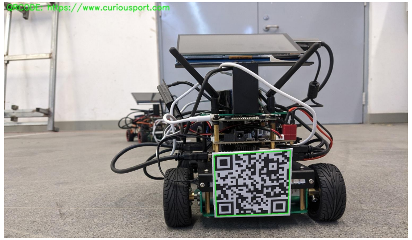


[1] https://github.com/borissedlak/intelligentVehicle/

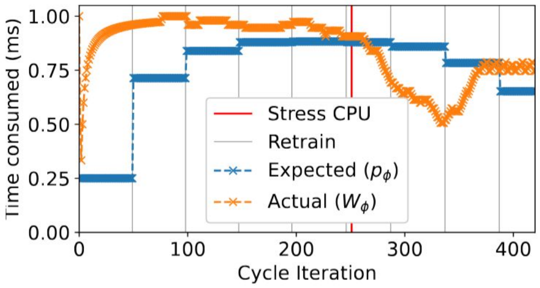
Evaluation: SLO-dependent Retraining

→ Evaluate if SLO-dependent retraining (i.e., evidence to retrain > t) improves SLO-F after SLO violations

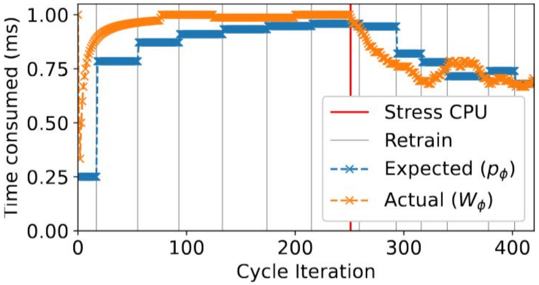
Setup: Execute *LI* service on Jetson *Orin*; start without prior understanding, i.e., blank SLO-I model; let the agent retrain its SLO-I model until it has a good prediction accuracy; after 125s, disturb its predictions by introducing 40% CPU stress

Result: Using SLO-dependent retraining, the agent reported improved prediction accuracy both before and after stress

Implication: Useful for accelerating model updates during phases with dynamic behavior; short cycles improve accuracy



(a) Without SLO-dependent retraining

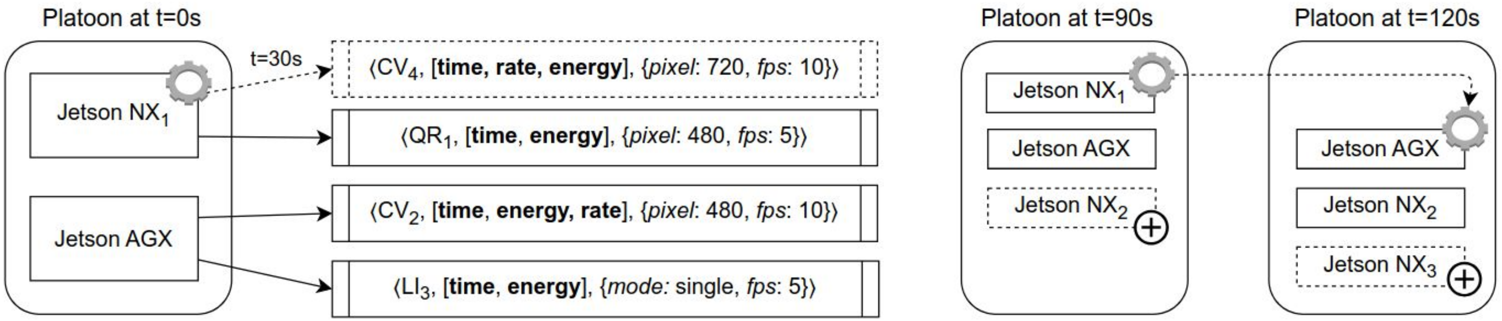


(b) With SLO-dependent retraining

Evaluation: Global SLO Fulfillment

→ Evaluate the global SLO-F of the methodology

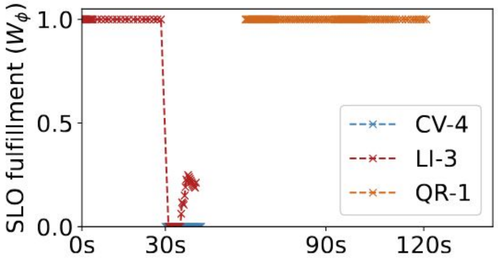
- ❑ **t=0**; start processing at two platoon members
- ❑ **t=30**; start a new service (i.e., *CV4*) at device NX1
- ❑ **t=90**; Add a new device (i.e., *NX2*) to the vehicle platoon
- ❑ **t=120**; Add one vehicle, and remove the existing leader



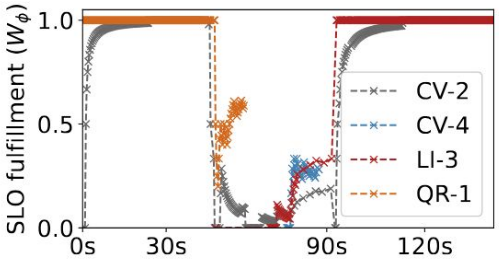
Evaluation: Global SLO Fulfillment (cont.)

Result: Initially, *NX1* and *AGX* had an SLO-F of 100%; at **30s**, *NX1* starts a new service, which crushes the SLOs for all its services; the devices shift services and improve SLO-F slightly; at **90s**, adding a new device to the platoon recovers SLO-F; at **120s** changing platoon leader had no negative impact

Implication: Services can be offloaded dynamically within the AV platoon to find the optimal assignment given available resources; also, we could show that the platoon leader is mutable and cannot become a single point of failure



(a) Orin NX_1



(b) Orin AGX

Conclusion

Perception services have high computational requirements, that **constrain** the deployment, i.e., where and how to execute

Forming platoons of AVs allows to **share resources** between vehicles by offloading services according to members’ capacity

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Services estimate the expected SLO-F according to **historical data**, retrain their SLO-I model, and decide to offload to another platoon member if this promises to improve global SLO-F

Methodology evaluated in a physical testbed; we could show that smaller platoons could shuffle services according to available resources so that a list of SLOs was fulfilled

Let’s **discuss**!

Please come forward with any **question** you have

@

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Evaluation: Platoon Scalability

⟶ Evaluate the scalability of increasing platoons

Setup: Start a platoon with a single vehicle that executes a CV service; every 25s (= 50 iterations) add a vehicle to the platoon and measure wrapper execution time

Result: Linear impact of platoon size on the wrapper execution time, exception for |P| = 0, which is obsolete

Implication: Given an evaluation interval of 500ms, the services might struggle to evaluate larger platoos with |P| > 3; can structure platoon into smaller subgroups or adjust evaluation interval