SCALING AUTOMOTIVE ETHERNET
Reconfigurability, Performance and the Future of Software-defined Vehicles

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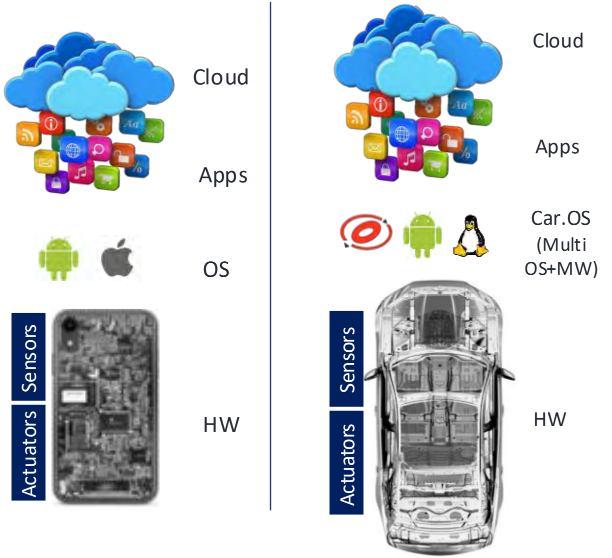
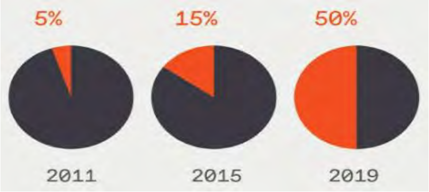
IEEE SA Ethernet & IP Technology Day 2024

AUTOMOTIVE SOFTWARE EVOLUTION

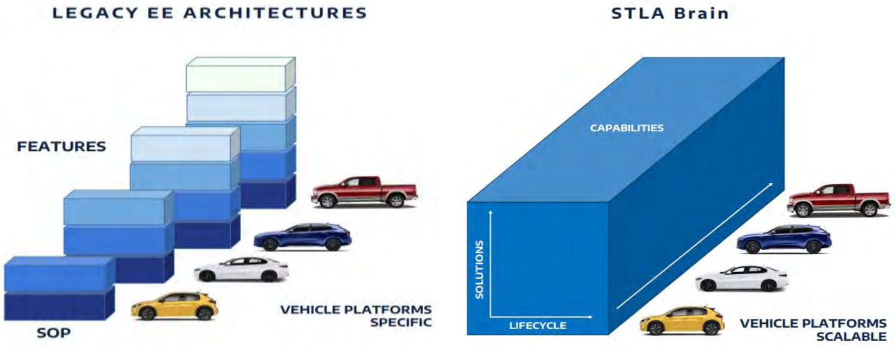


% of Electronics system/car cost

% of vehicles recalled due to electronic defects



(R. N. Charette, "How software is eating the car", IEEE Spectrum, 2021)



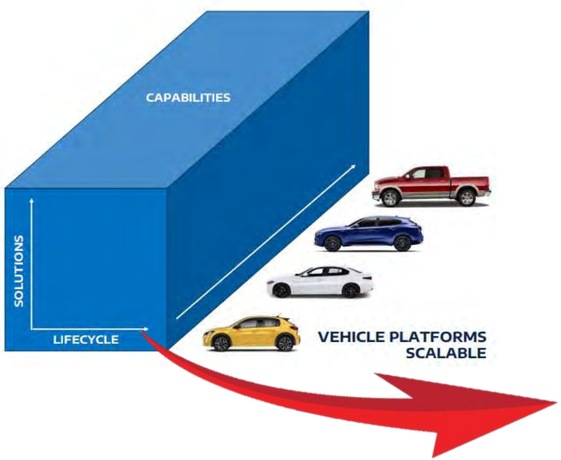
(Stellantis Software days, 2021)

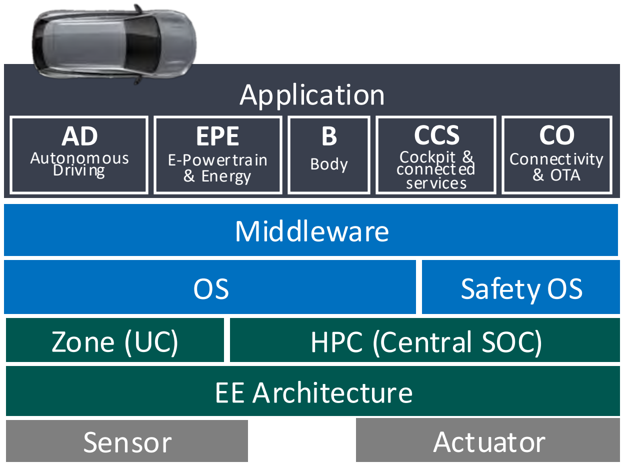
Hardware-defined
Off the lot = Depreciation

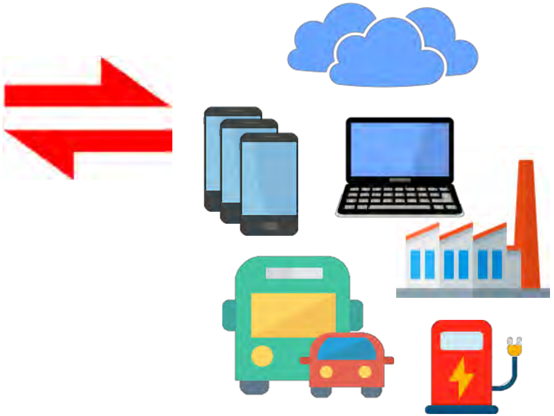
→

Software-defined
Update = Appreciation

STLA Brain

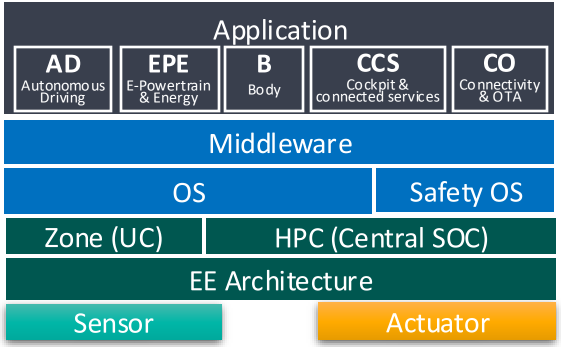


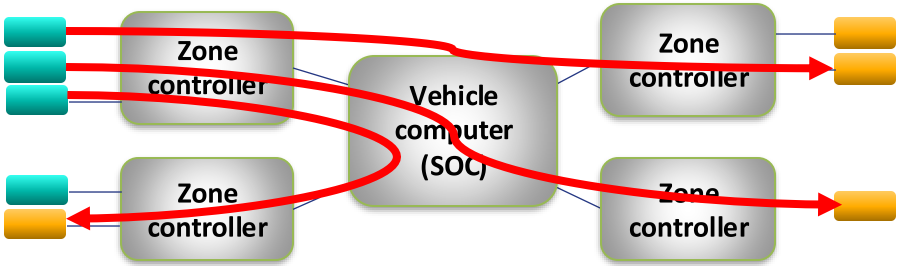




Reconfigurability:

- **Scalability:** Able to adapt the global software for different car platform. (complexity management)
- **Modularity:** Able to independently create, modify, swap or remove software modules via OTA updates or HW swapping without affecting the overall system integrity. (vehicle personalization)
- **Reusability:** Able to reuse software components and repurpose ECUs and integrate them into new vehicle projects.

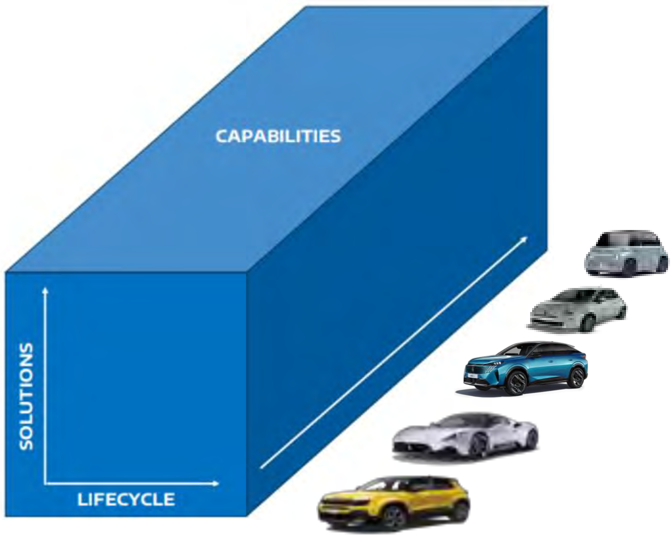




Performance:

- **Latency:** Minimize the network delay between request and response.
- **Throughput:** Maximize the amount of data exchanged within a given time frame.
- **CPU load:** Efficiently manage and offload CPU usage to prevent bottlenecks and ensure a better user experience.

Reconfigurability

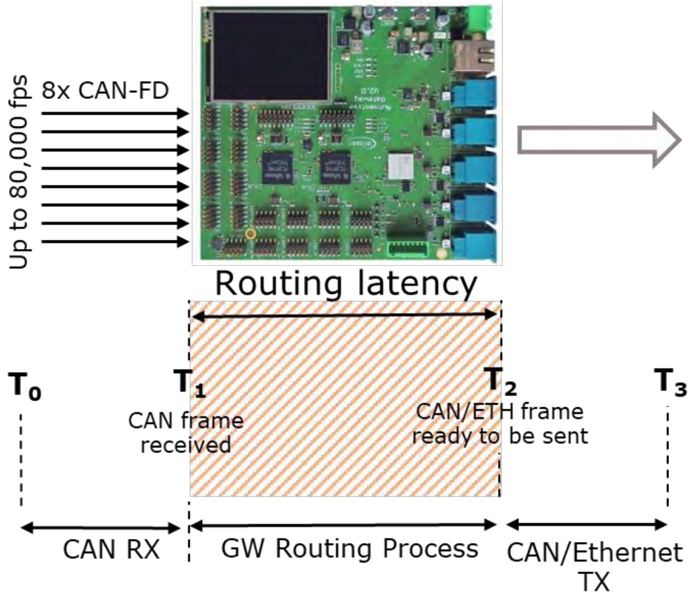


Performance

Why routing performance maters?

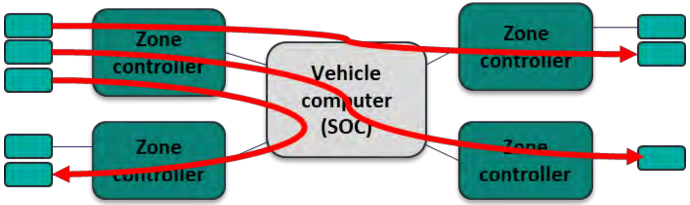
Routing latency requirements: < 1ms

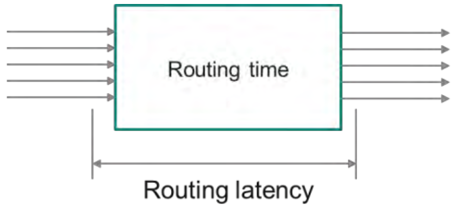
→what is the minimum routing performance required for the worst-case traffic estimation?

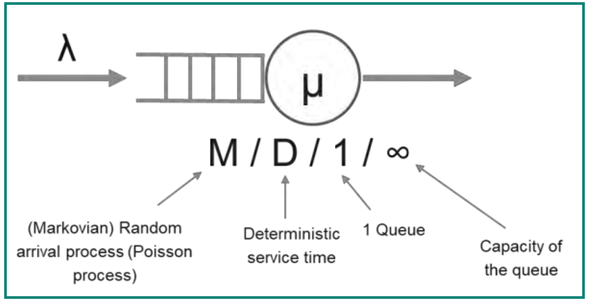


Model Assumptions:

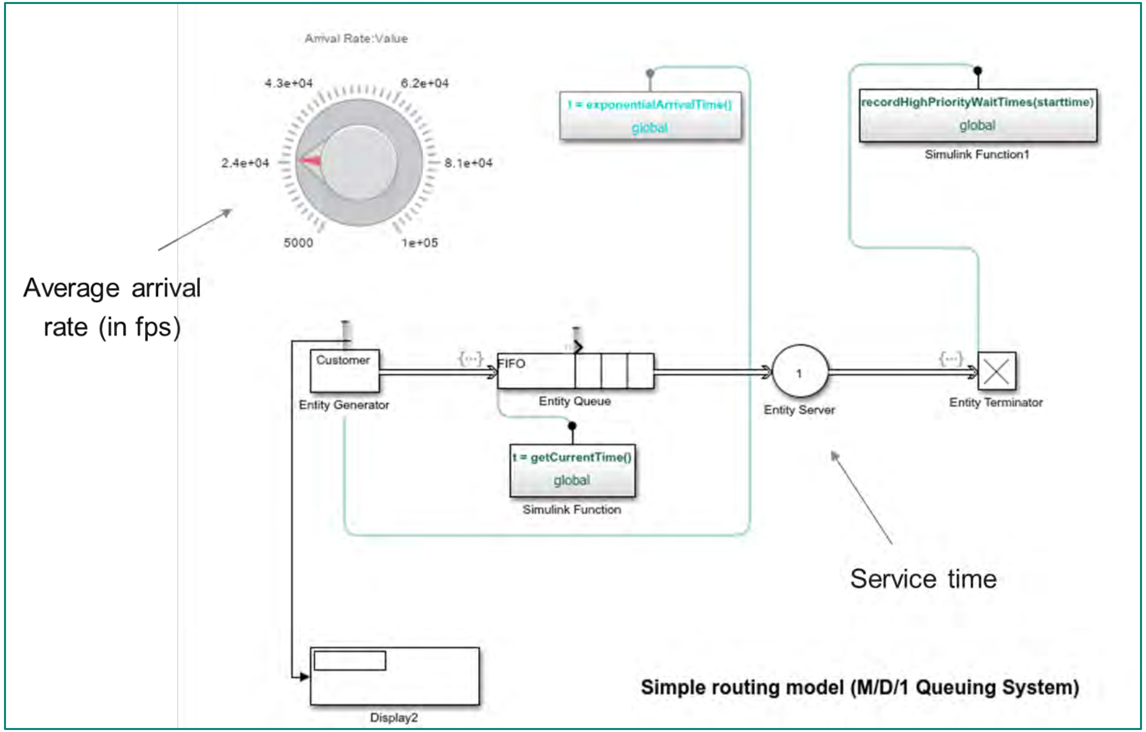
- Mixed traffic: 5000 frames per second (FPS) per CAN interfaces
- 3 scenarios:
  - Limited CAN connectivity: 8x CAN I/Fs -> 40K fps
  - Medium CAN connectivity: 12x CAN I/Fs -> 60K fps
  - Important CAN connectivity: 16x CAN I/Fs -> 80K fps
- Random arrival time for the incoming traffic
- Service/Routing time: deterministic
  - CPU based: 16.5µs (CAN2ETH@500MHz on Aurix TC4D CPU)
  - HW based: 5µs (CAN2ETH on Aurix TC4D Routing accelerator)







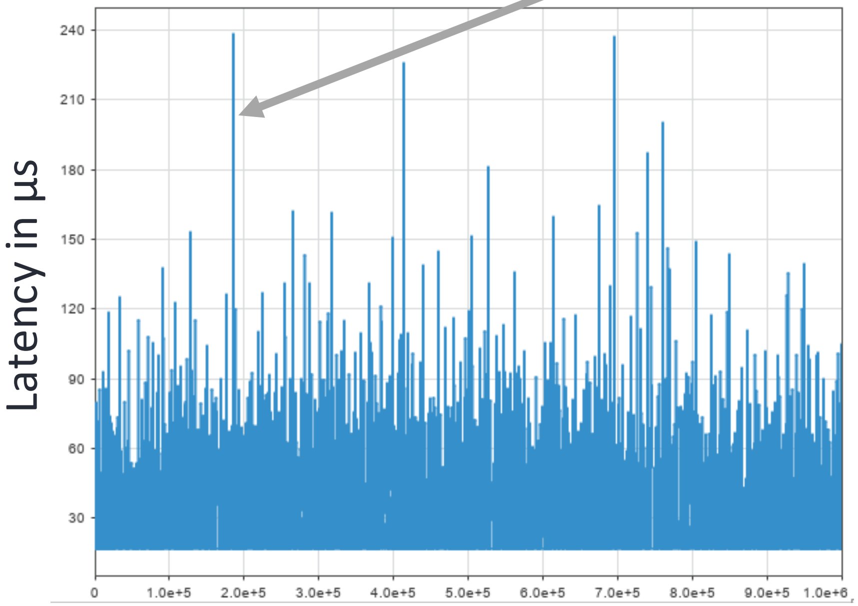
Kendall's notation



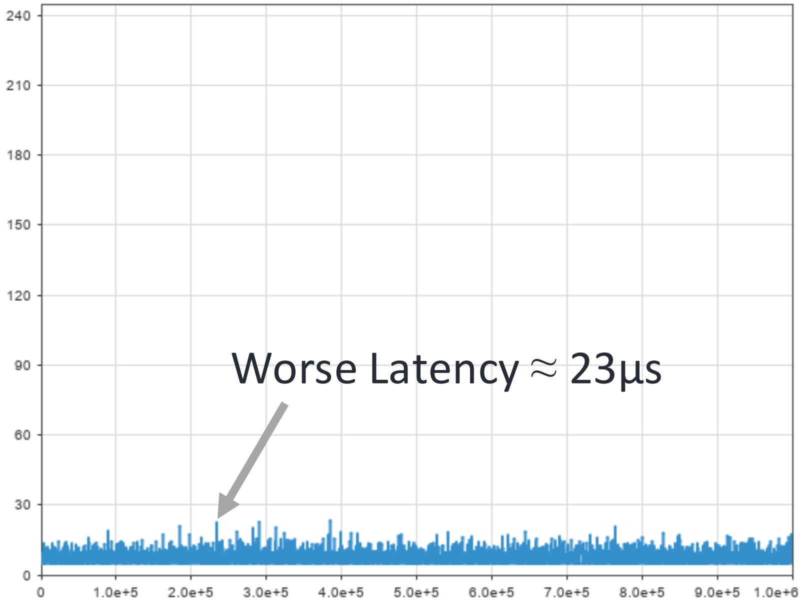
Matlab modeling

Limited throughput (40K fps)

Worse Latency ≈ 239µs



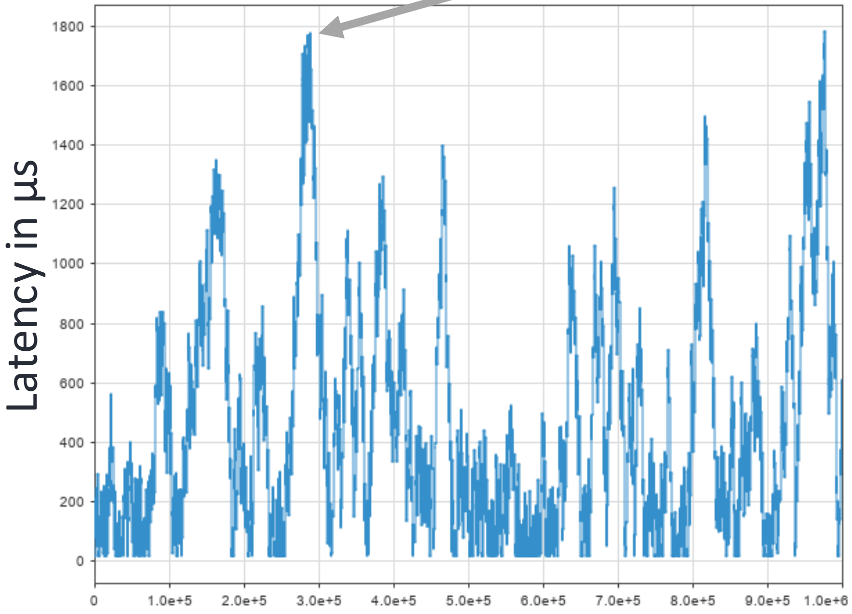
Service/Routing time: 16.5µs



Service/Routing time: 5µs

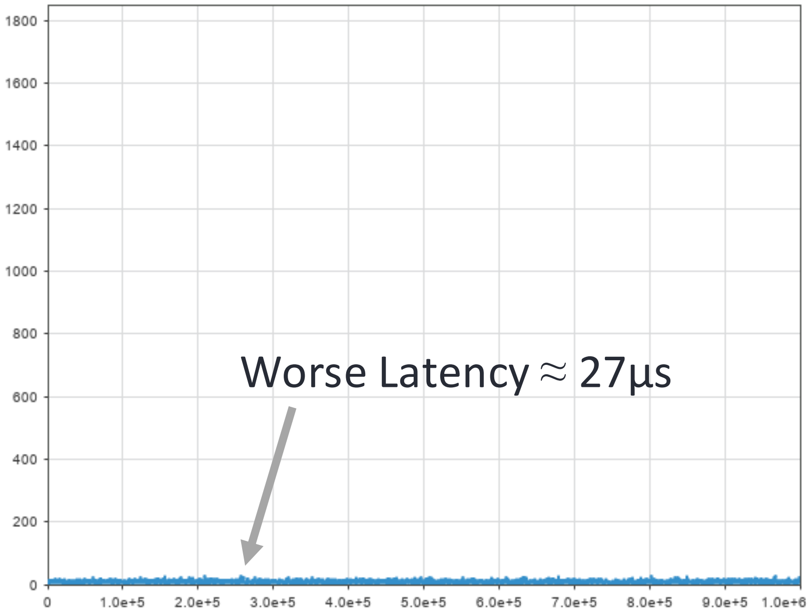
Medium throughput (60k fps)

Worse Latency ≈ 1.8ms



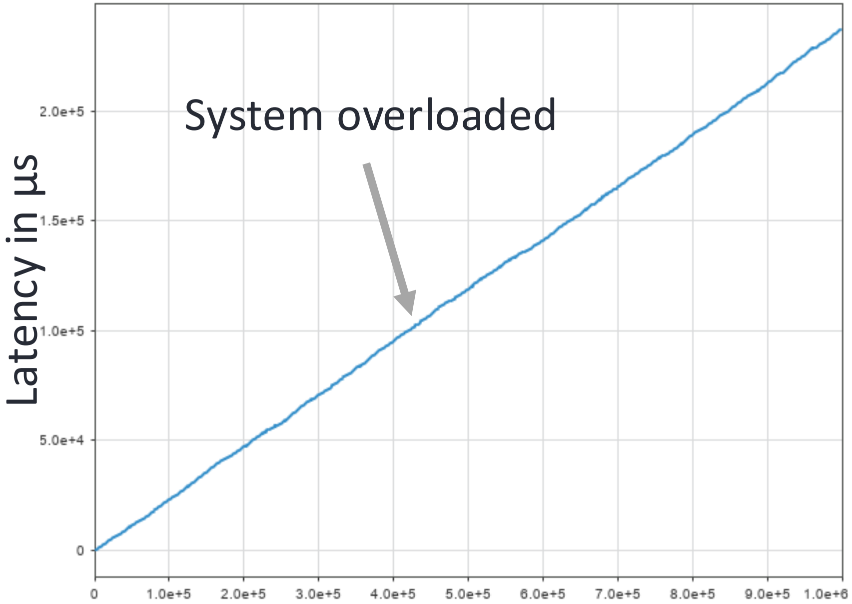
Service/Routing time: 16.5µs

Worse Latency ≈ 27µs



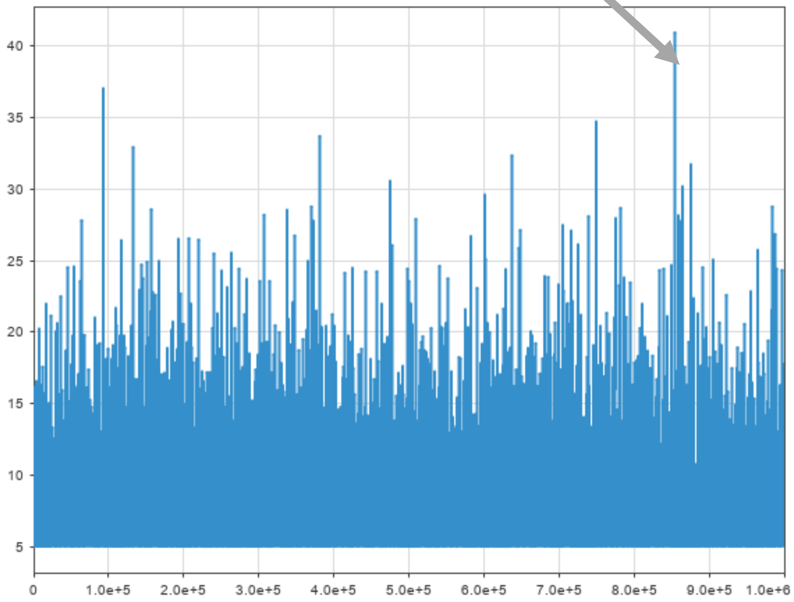
Service/Routing time: 5µs

High throughput (80k fps)



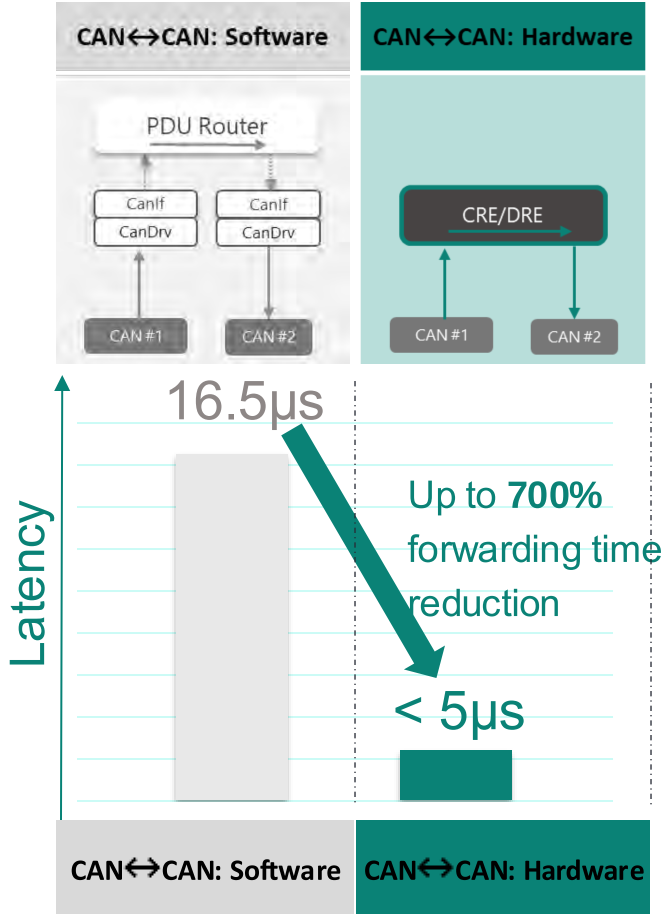
Service/Routing time: 16.5µs

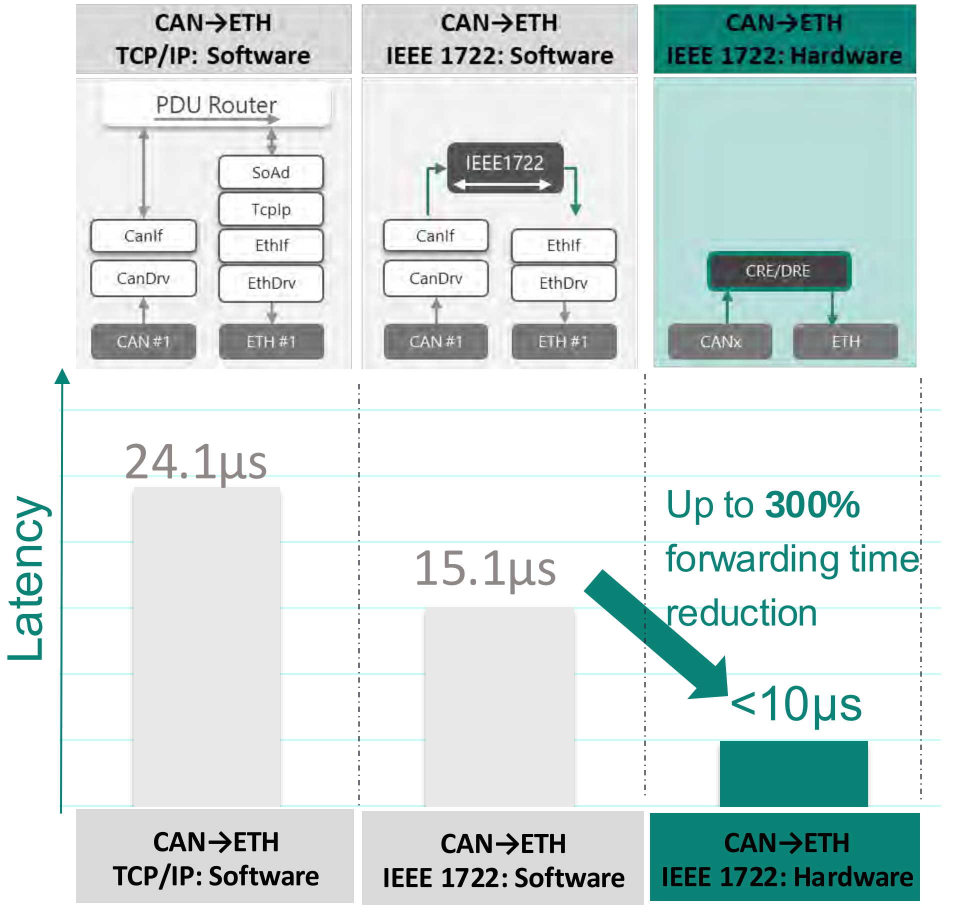
Worse Latency ≈ 41µs



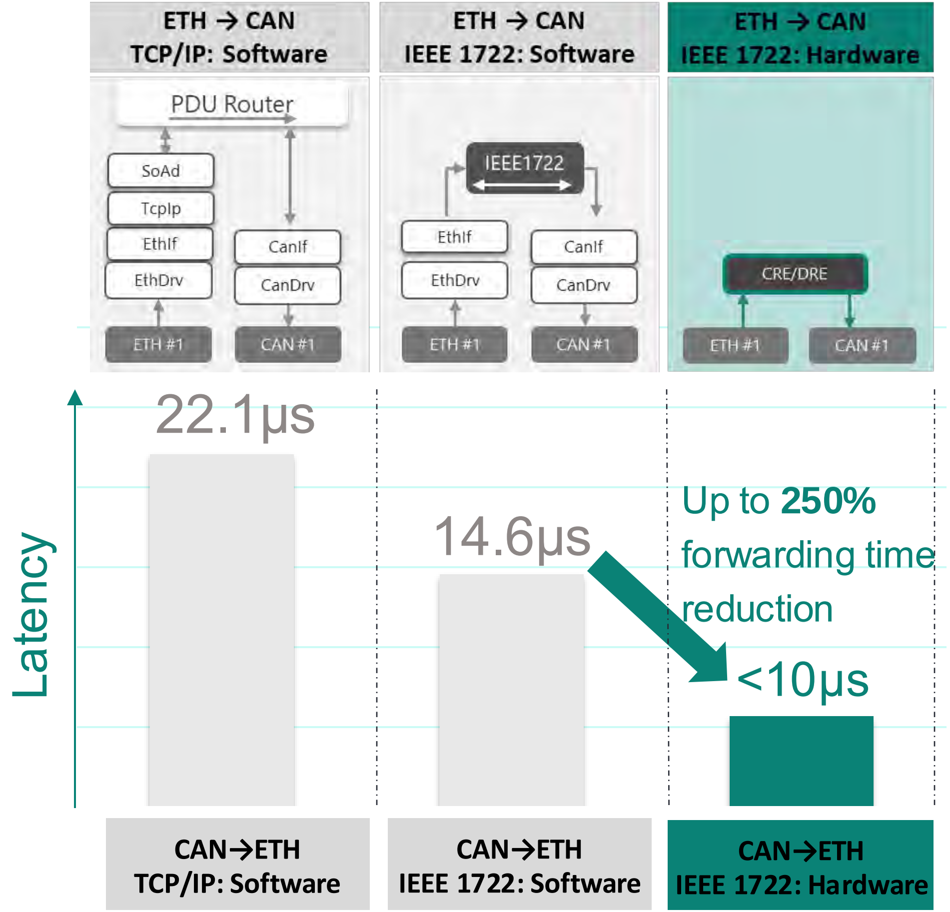
Service/Routing time: 5µs

AURIX MICROCONTROLLER TC4X: HW ACCELERATION OF CAN -> CAN & ETHERNET ROUTING





AURIX MICROCONTROLLER TC4X: HW ACCELERATION OF ETH -> CAN ROUTING



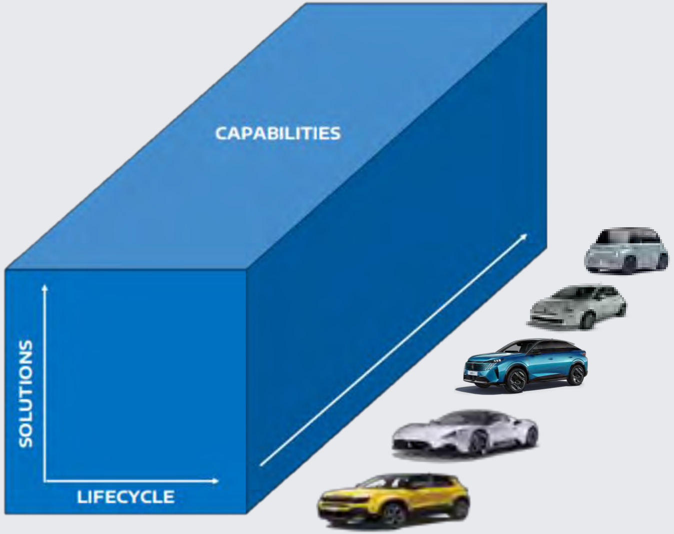
SUMMARY

1. **Minimum routing latency ≠ Average routing latency ≠ Worse case latency**
   - Routing 1 frame in 15µs ≠ Routing X frames in average in 15µs

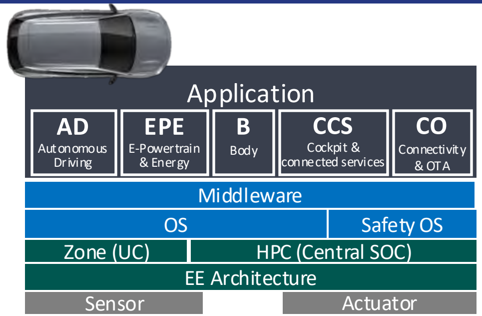
2. **Traffic matters:**
   - Routing speed on the MCU should be higher than the incoming throughput
   - Traffic from multiple interfaces -> random arrival time

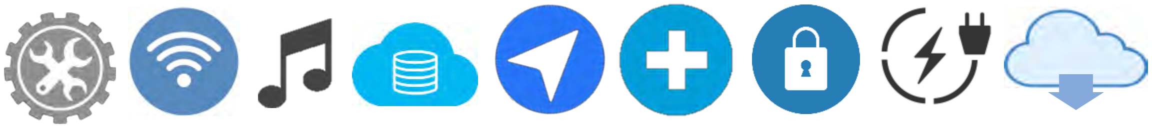
3. **To have a reduced jitter: Routing speed >> Incoming throughput**

Reconfigurability



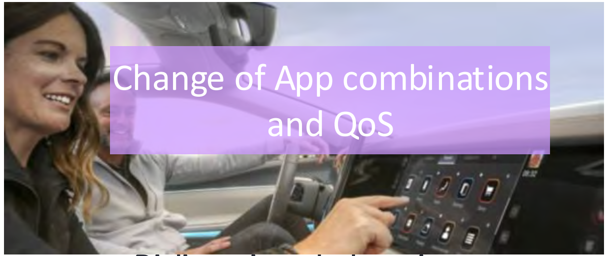
Performance





Key requirement	Description	EV	ADAS	Connected service	Customization
OTA updates	Add new feature Improve performance Fix issues	Battery management Modular powertrain	Scalable ADAS platform Sensor fusion	Regional adaptation Enhance connectivity and information	Multi-brand configuration Personalized settings Adaptive Interiors In-vehicle commerce
Remote configuration	Activate services Adapt configuration for vehicle models or regions				
Modular software	Add/remove/update/swap a software component without impacting the entire system				

Software on demand



Remote control

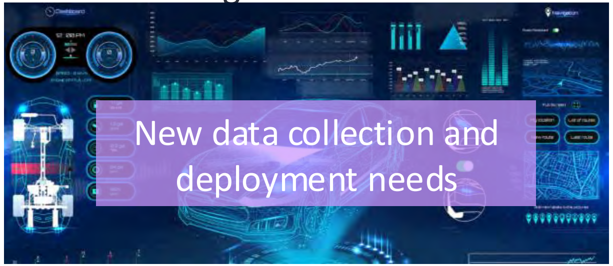
Automated/cooperative driving

Bidirectional charging

Shared mobility

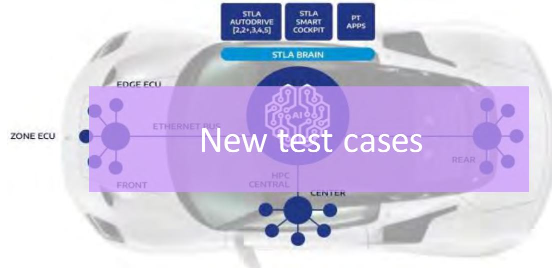
Multi brand management

Digital twin



Vehicle repair

Shadow mode

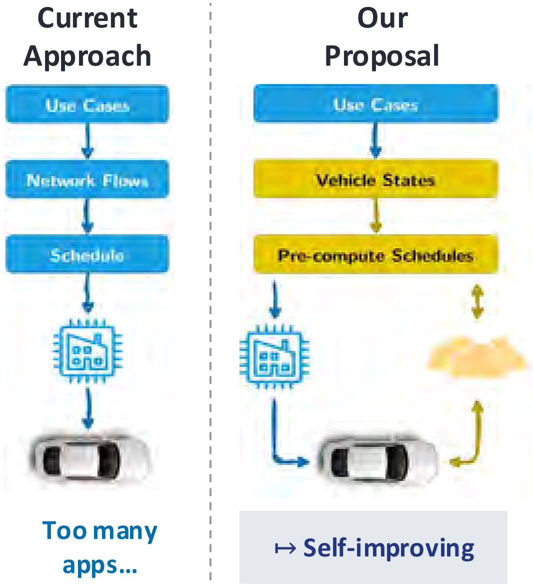


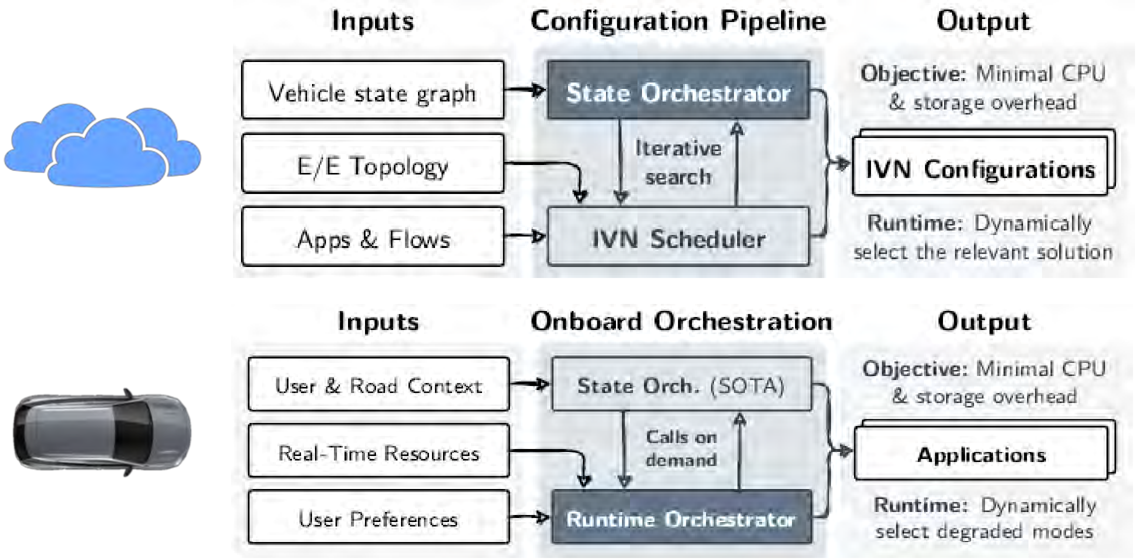
(Source: Ankita Saraf, Linkedin, June 2023)

Proposal

Dynamic reconfiguration system for all applications

Problem : Network configuration: Worst-case scenarios. Not actual usage.
Runtime : Reconfiguration for car brands and regions. Customization.
Reusability : Carryover features and hardware



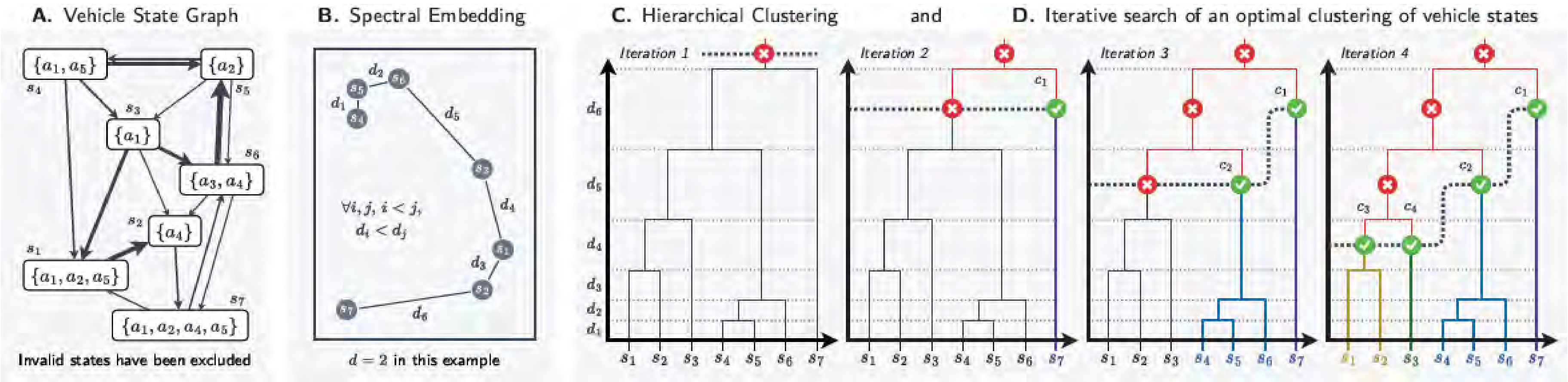


Offboard

Core concept – Observe service lifecycle patterns

Solution – Cluster vehicle states

Results – Feasible and performant



	Worst case	Unclustered	Clustered	Gains
Number of apps allocated	13% (mean)	100%	100%	0%
Number of produced configurations	1	150	39	74%
Sum of transition probabilities	0	3411.5	413.7	87.9%
Number of scheduler calls	1	150	57	62%

Full research paper: P. Laclau, S. Bonnet, B. Ducourthial, X. Li and T. Lin, "Predictive Network Configuration with Hierarchical Spectral Clustering for Software Defined Vehicles," *IEEE 97th Vehicular Technology Conference (VTC2023-Spring)*, Florence, Italy, 2023, pp. 1-5

Onboard

AXIL – Automotive eXperience Integrity Level

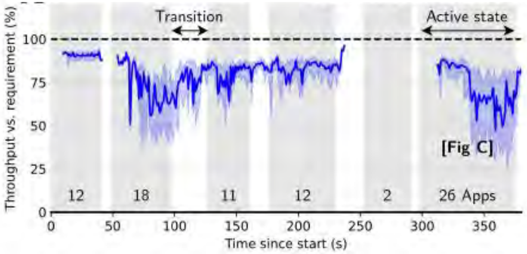
Controllability / Ease of Substitution	Exposure	Failure Severity (ASIL) / Quality of Experience (QoE) (AXIL)			
		Q1 - Frustrating	Q2 - Bothering	Q3 - Acceptable	Q4 - Pleasant
S1 - Easy	E1 - Low	QM	QM	QM	QM
	E2 - Medium	QM	QM	QM	QM
	E3 - High	QM	QM	QM	A
	E4 - Constant	QM	QM	A	B
S2 - Medium	E1 - Low	QM	QM	QM	QM
	E2 - Medium	QM	QM	QM	A
	E3 - High	QM	QM	A	B
	E4 - Constant	QM	A	B	C
S3 - Difficult	E1 - Low	QM	QM	QM	A
	E2 - Medium	QM	QM	A	B
	E3 - High	QM	A	B	C
	E4 - Constant	A	B	C	D

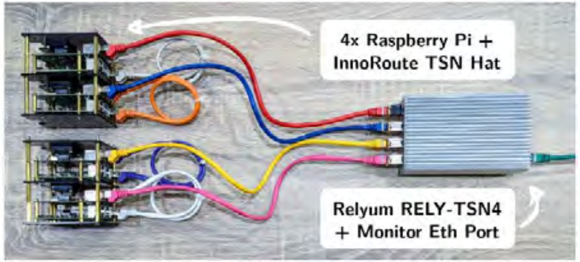
New metric to evaluate each feature's contribution to onboard UX.
Can be dynamically personalized.

Core concept – Apps with degraded modes
- ↦ Runtime modes have a UX priority (AXIL)
- ↦ What if too many apps are requested?

Solution – Fast onboard algorithm to:
- ↦ Activate the best UX applications
- ↦ Stay within onboard resources

Physical Test Bench – 4 ECUs dynamically allocating service requests





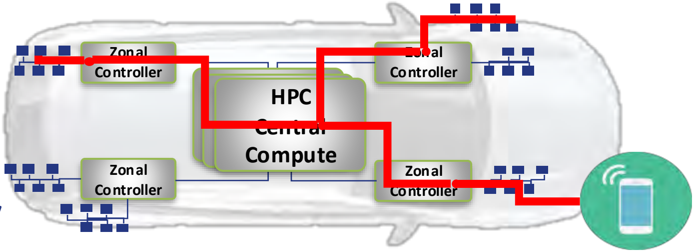
Full paper (core concept): P. Laclau, S. Bonnet, B. Ducourthial, X. Li and T. Lin, "Enhancing Automotive User Experience with Dynamic Service Orchestration for Software Defined Vehicles," to be published in IEEE Transactions on Intelligent Transportation Systems, 2024. **Full paper (validation):** P. Laclau, S. Bonnet, B. Ducourthial, T. Lin and X. Li, "Experimental Validation of User Experience-focused Dynamic Onboard Service Orchestration for Software Defined Vehicles," IEEE 27th International Conference on Intelligent Transportation Systems (ITSC), Edmonton, Canada, 2024

PERFORMANCE & RECONFIGURABILITY TRADE-OFF

Solution Type	Performance	Reconfigurability	Cost	Complexity	Use cases
Hardware-based	High	Low	High	High	Critical systems
Software-based	Moderate	High	Low	Low	Apps requiring frequent updates & configurations
Hybrid	**Balanced**	**Moderate**	**Medium**	**Medium**	**Features needing both performance & flexibility**

Hybrid solution requires an optimized design.
- Knowledge on both hardware/software
- Knowledge on end-to-end feature deployment

Automotive trends and automotive use cases
Performance needs in in-vehicle network
Reconfigurability needs
Tradeoff between performance and reconfigurability



Reactivity of remote features

Vehicle (re)configuration and software traceability (UN R156)

Network Configuration

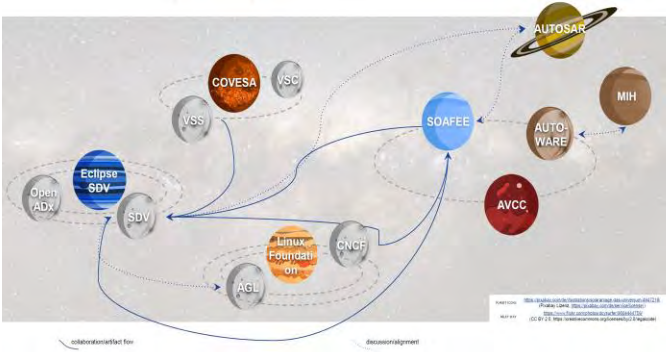
- Performance
- In-car marketplace
- Cybersecurity
- Safety

Ethernet is an important enabler !

Diagnosticability and Repairability

New testing concept to improve software maturity (digital twin, shadow mode)

Standardization and Reference Design



(Source: Eclipse SDV – Who are we?, D. Krippner, ETAS, EclipseCon2022)