Chair of Connected Mobility
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Developing and Validating a Generic Environment for Real-Time Networking Experiments

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Motivation 1

Provide a structured approach that enables computer network assessment with experiments which are:

- Accurate and realistic
- Scalable and highly configurable
- Reproducible and repeatable

Various approaches already exist, e.g., utilizing:

- Simulation – highly repeatable and configurable; may be unrealistic omitting real deployment artifacts
- Hardware – more realistic; varying levels of repeatability and possibly uses proprietary solutions

<u>Can we combine benefits of simulation and hardware approaches?</u>

Introducing **EnGINE** [1,2] experimental environment:

- Accurate, reproducible, and scalable experiments
- Based on commercial off the shelf (COTS) hardware and open-source software
- Configuration flexibility via Ansible playbooks
- A stepping stone towards a generalized solution

Initially limited scope with focus on highly demanding Intra Vehicular Networks (IVNs):

- Strict requirements on delay and bandwidth
- Enable new functionalities in vehicles such as autonomous driving, or over-the-air upgrades
- Current systems support required delays, but lack sufficient bandwidth → Emerging use of Ethernet
- Ethernet, by design, does not provide required determinism → Time-Sensitive Networking (TSN)

TSN and IVN requirements enhance development and validation of EnGINE.

→ Ensure that a generalized version will be able to support any computer networking experiments

Hardware Deployment 2

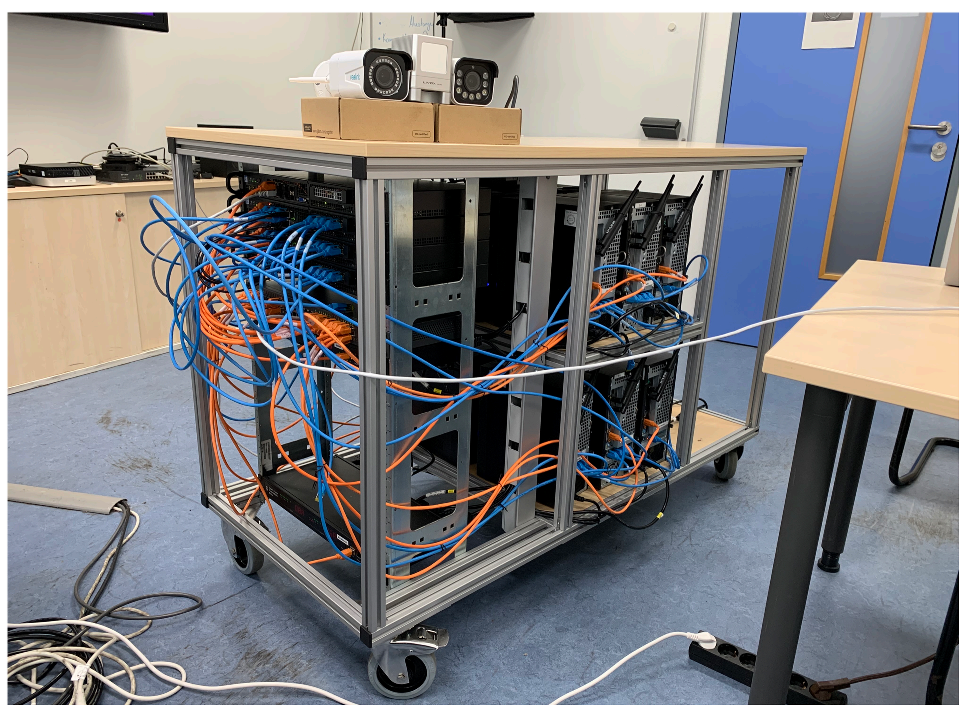
15 highly interconnected nodes acting as ZGWs/VCCs

COTS hardware and NICs with TSN support:

- Intel i210 – 1Gbit/s; IEEE 802.1 AS, Qav, Qbv
- Intel i225 – 2.5Gbit/s; IEEE 802.1 AS, Qav, Qbv
- Intel i350 – 1Gbit/s; IEEE 802.1AS
- Intel x552 – 10Gbit/s; IEEE 802.1AS

Sensors:

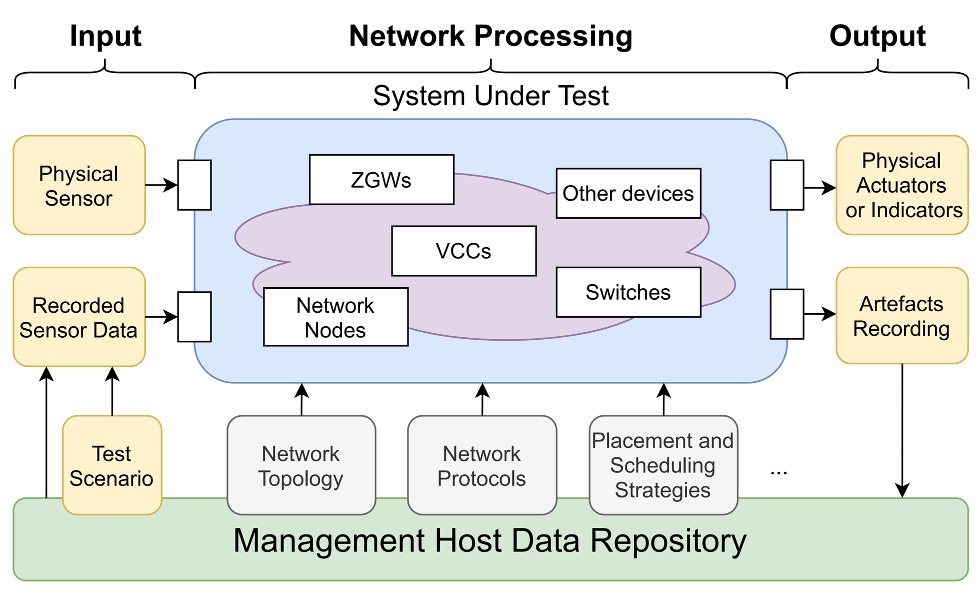
- LIDAR – Livoxtech Mid 40
- 2 Cameras – Reolink Full HD



Design Overview 3

Experiments defined based on three components

- Input – defines the experiment
- Network Processing – encompasses the tested system and hardware
- Output – recorded experiment results and artefacts



Experiment Orchestration 4

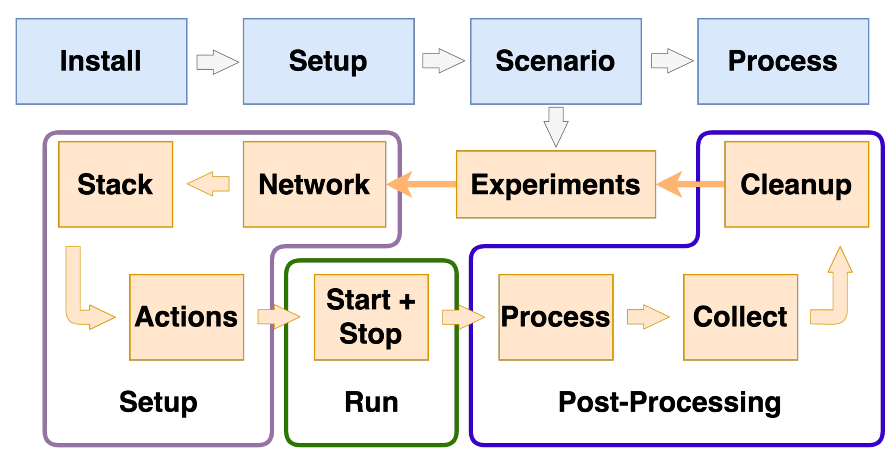
Orchestration accomplished using Ansible.

Experiments conducted in four phase campaigns being defined using five configuration files.

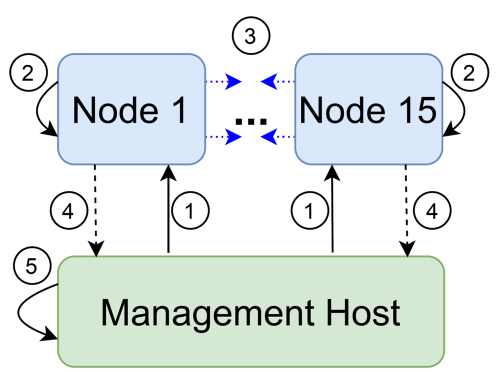
In Install and Setup phases prepare the environment.

Scenario phase conducts the individual campaign experiments in a loop.

Process prepares combined results of a campaign.



Node Management 5



1. Management host communicates with nodes
2. Nodes execute the tasks
3. Interact with other nodes
4. Store the collected artifacts
5. Process artifacts

Nodes managed using the POS framework [3] combined with Ansible and Bash scripts.

Individual tasks executed according to five campaign configuration files defining what Ansible playbooks need to be executed on the nodes.

During the actual execution of the experiment, tasks controlled locally on each node.

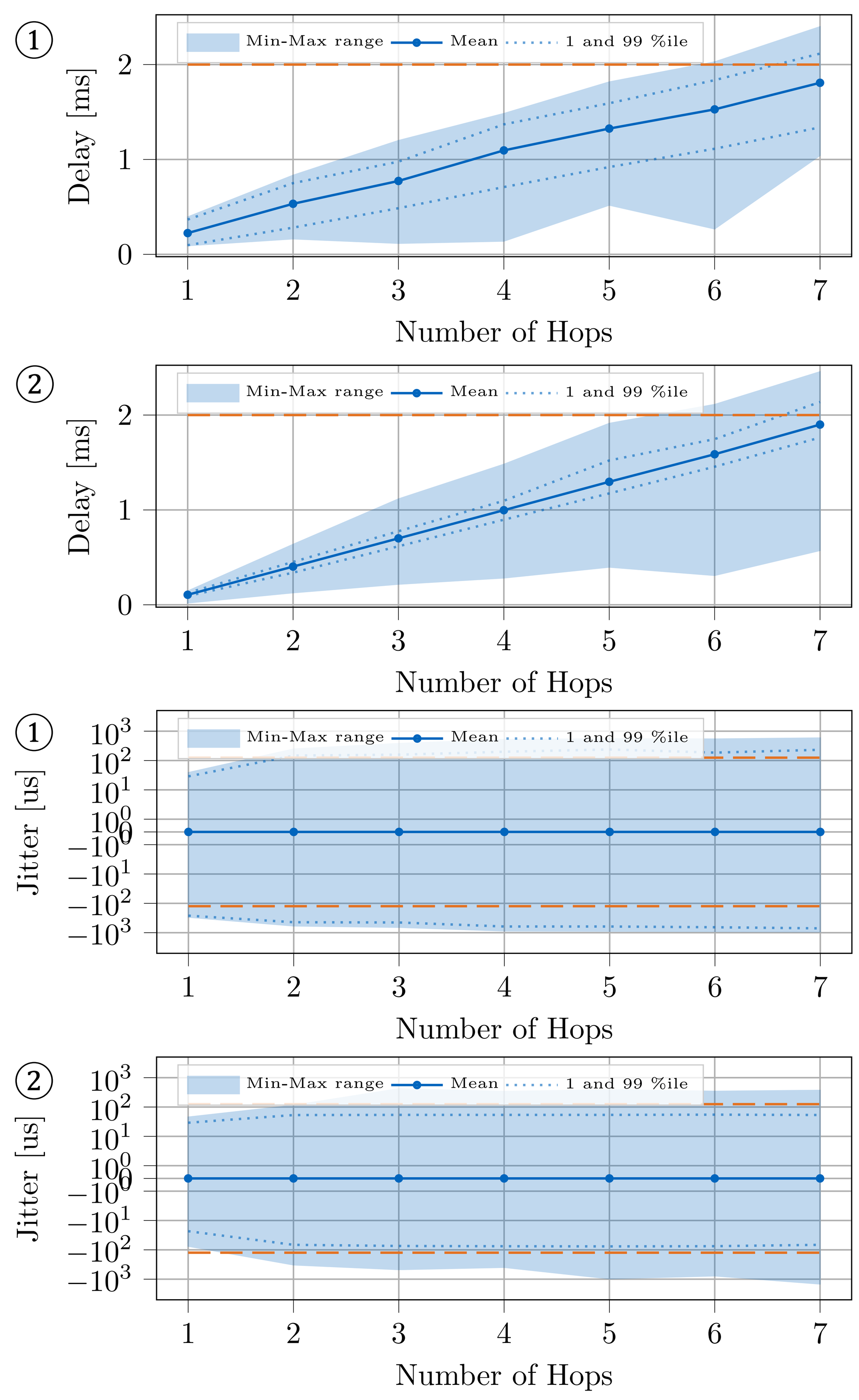
After all experiments are finished, the management host collects the results and evaluates them.

Framework Validation 6

Initial focus on IVN and TSN requirements

- Strict delay bound of 2ms across 7 hops
- Strict jitter bound of 100μs across 7 hops

Validation performed 1 without and 2 with TSN standard (IEEE 802.1 Qav) enforced on the nodes



Average delay within the required 2ms across all hop configurations with and without TSN

99 %ile jitter values also within the required 100μs if TSN employed in the network

Future Work 7

Generalize framework's capabilities beyond Layer 2 Ethernet and TSN:

- Include Layer 3 configurations
- Consider novel layer 3 protocols
- Consider various Transport Layer protocols
- Include application-level solutions
- Include more complex traffic generation capabilities

Enhance experiment types to embrace specialized hardware and software

- Include proprietary solutions
- Include other specialized NICs

Consider simulation capabilities to enhance the hardware solution – Digital Twin

Improve result evaluation capabilities

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[1] Rezabek, F., Bosk, M., Paul, T., Holzinger, K., Gallenmüller, S., Gonzalez, A., ... & Ott, J. (2021, October). EnGINE: Developing a Flexible Research Infrastructure for Reliable and Scalable Intra-Vehicular TSN Networks. In 2021 17th International Conference on Network and Service Management (CNSM) (pp. 530-536). IEEE.
[2] Rezabek, F., Bosk, M., Paul, T., Holzinger, K., Gallenmüller, S., Gonzalez, A., ... & Ott, J. (2022). EnGINE: Flexible Research Infrastructure for Reliable and Scalable Time Sensitive Networks. In Journal of Network and Systems Management (JNSM) Special Issue on High Precision, Predictable, Low-Latency Networking.
[3] Gallenmüller, S., Scholz, D., Stubbe, H., & Carle, G. (2021, December). The pos framework: a methodology and toolchain for reproducible network experiments. In *Proceedings of the 17th International Conference on emerging Networking EXperiments and Technologies* (pp. 259-266).