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A lightweight software stack and synergetic meta-orchestration framework for the next generation compute continuum

W3C WoT Meetup 28: An Open-source Software Stack for IoT Virtualization and Convergence with Edge Computing Technologies

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NETMODE Lab

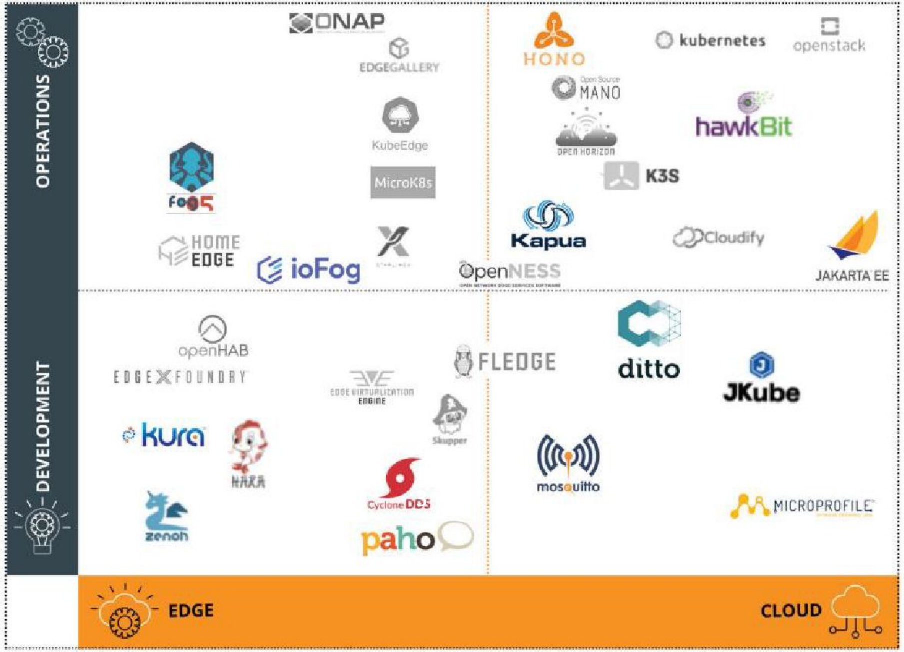
- Group: NETwork Management & Optimal DEsign Laboratory (NETMODE)
- School of Electrical and Computer Engineering
- NETMODE Personnel:
  - 5 Professors,
  - 9 Postdoc/Senior researchers,
  - 2 lab teaching personnel,
  - 20+ PhD candidates
- Main Research Areas:
  - 5G/6G communications/computing systems Edge, Fog and Cloud Computing
  - Optimal resource allocation and orchestration
  - Data modelling and analytics, semantics, interoperability
  - Dynamic systems modeling and optimal decision making
  - Hardware/Software Codesign
  - DSP systems implementation

Actively involved in various EU and national projects.

https://www.netmode.ntua.gr/

Main Challenges for the Computing Continuum

- need for **convergence of IoT technologies** based on novel architectural approaches, able to guarantee continuous and seamless openness and interoperability of the existing and emerging solutions.
- need for the provision of an **integrated meta-orchestration environment for hyper-distributed applications**, where a **synergy** between cloud and edge computing orchestration platforms takes place



Eclipse Foundation, From DevOps to EdgeOps: A Vision for Edge Computing, White paper, 2021

NEPHELE Vision

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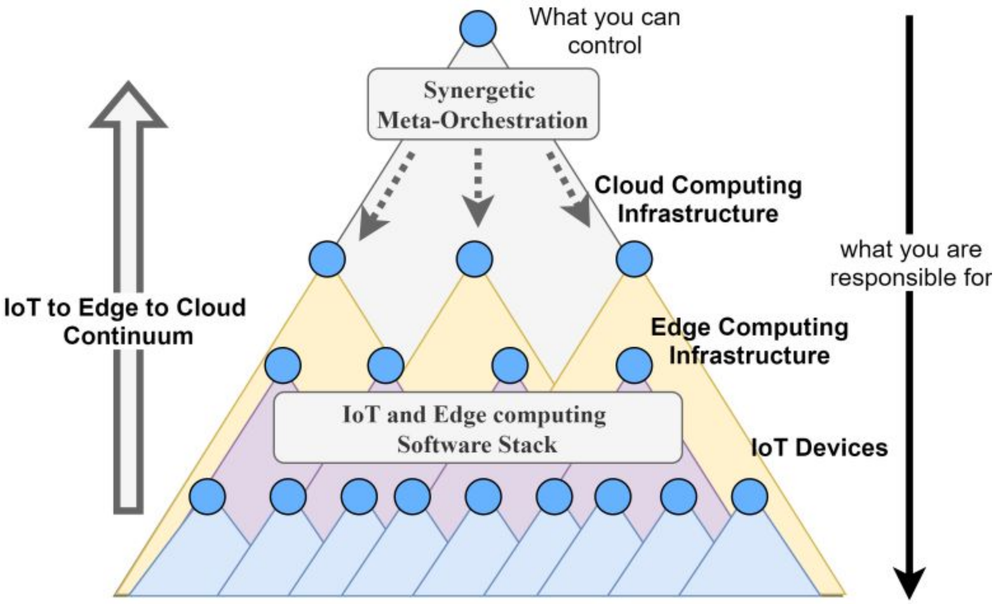
Project goals

- System of systems hierarchical approach
- IoT convergence
- Edge - Cloud convergence

Scope

Development of a software stack to achieve interoperability across the continuum


What you can control
Synergetic Meta-Orchestration
Cloud Computing Infrastructure
what you are responsible for
IoT to Edge to Cloud Continuum
Edge Computing Infrastructure
IoT and Edge computing Software Stack
IoT Devices

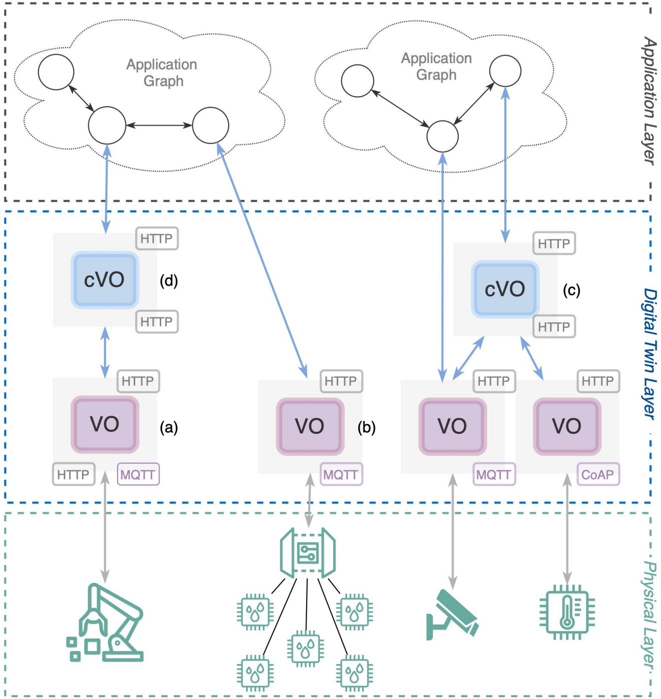
NEPHELE contributions to IoT Convergence

- **Wot-py-2** is the updated repository of the old python implementation of W3C WoT. Updated libraries and extensions of the software.

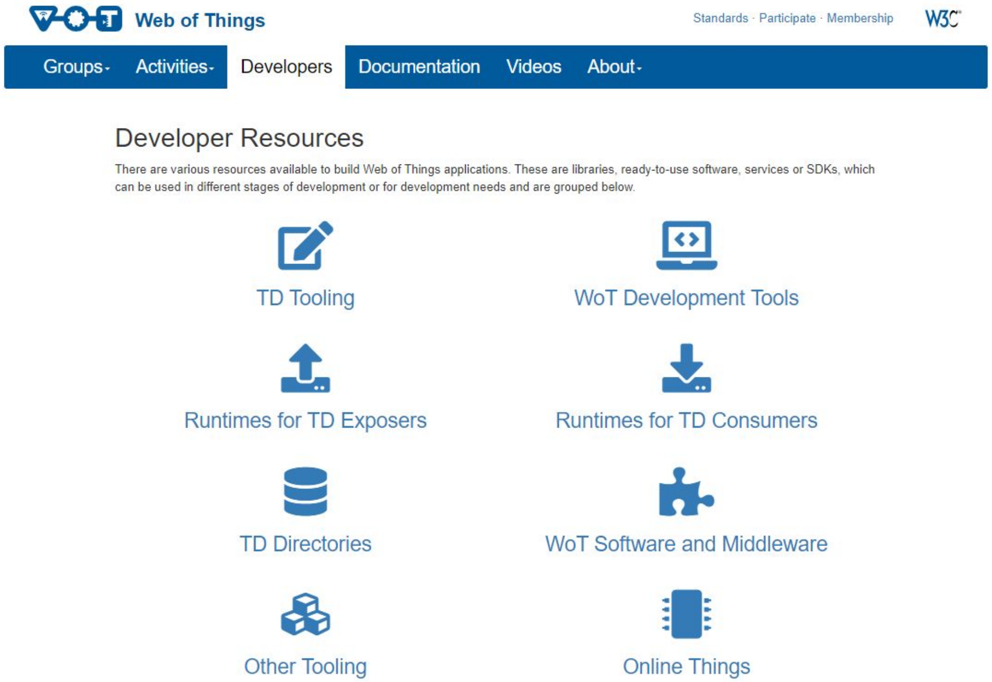
- **VO-WoT** is a Software Stack that acts as a wrapper binding the Wot-py-2 software with additional functionalities to enable the orchestration of IoT application graphs Two implementations W3C-WoT and OMA LwM2M.

(c)VO Definitions

- A **Virtual Object (VO)** is the virtual counterpart of a physical device on the Internet of Things domain. It provides a set of abstractions for managing any type of IoT device through a virtualized instance while augmenting the supported functionalities through the VOStack.
- A **Composite Virtual Object (cVO)** is a software entity that is able to manage the information coming from one or multiple VOs (aggregation point) and provide advanced functionalities.



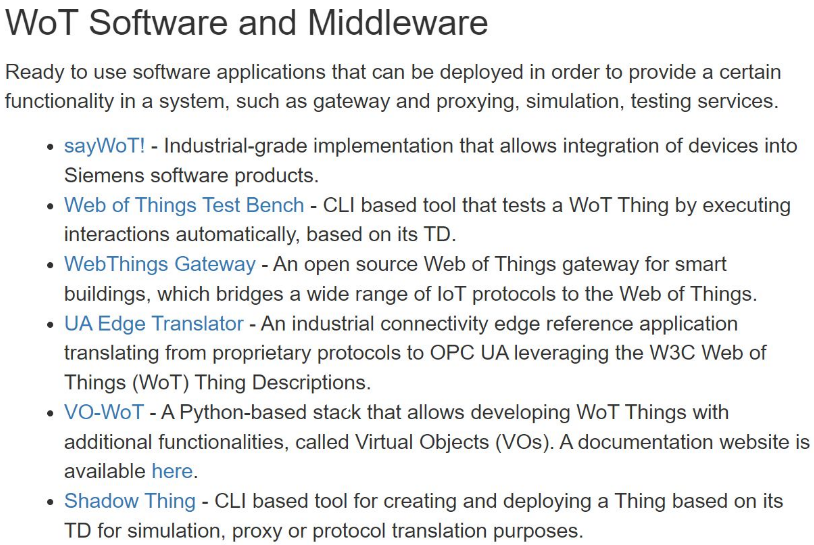
VOStack implementation in W3C WoT Developer Resources



Developer Resources

There are various resources available to build Web of Things applications. These are libraries, ready-to-use software, services or SDKs, which can be used in different stages of development or for development needs and are grouped below.

- TD Tooling
- WoT Development Tools
- Runtimes for TD Exposers
- Runtimes for TD Consumers
- TD Directories
- WoT Software and Middleware
- Other Tooling
- Online Things



WoT Software and Middleware

Ready to use software applications that can be deployed in order to provide a certain functionality in a system, such as gateway and proxying, simulation, testing services.

- sayWoT! - Industrial-grade implementation that allows integration of devices into Siemens software products.
- Web of Things Test Bench - CLI based tool that tests a WoT Thing by executing interactions automatically, based on its TD.
- WebThings Gateway - An open source Web of Things gateway for smart buildings, which bridges a wide range of IoT protocols to the Web of Things.
- UA Edge Translator - An industrial connectivity edge reference application translating from proprietary protocols to OPC UA leveraging the W3C Web of Things (WoT) Thing Descriptions.
- VO-WoT - A Python-based stack that allows developing WoT Things with additional functionalities, called Virtual Objects (VOs). A documentation website is available here.
- Shadow Thing - CLI based tool for creating and deploying a Thing based on its TD for simulation, proxy or protocol translation purposes.

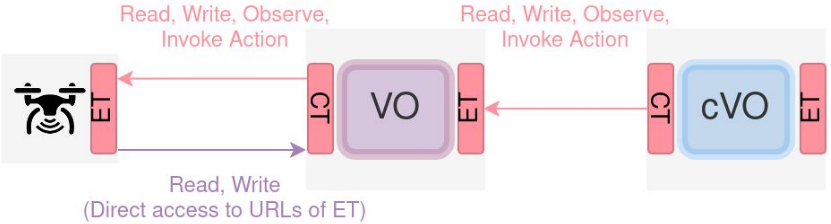
Deployment Types

The VO is deployed on Edge Servers and consumes things

Type A

Device with computing capabilities

e.g., Drone, Pi



Read, Write, Observe, Invoke Action

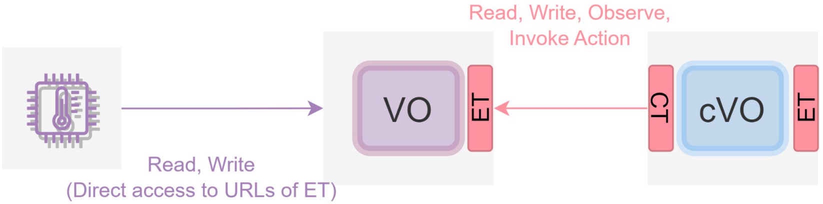
Read, Write, Observe, Invoke Action

Read, Write (Direct access to URLs of ET)

Type B

Device with no computing capabilities

e.g., Sensor



Read, Write, Observe, Invoke Action

Read, Write (Direct access to URLs of ET)

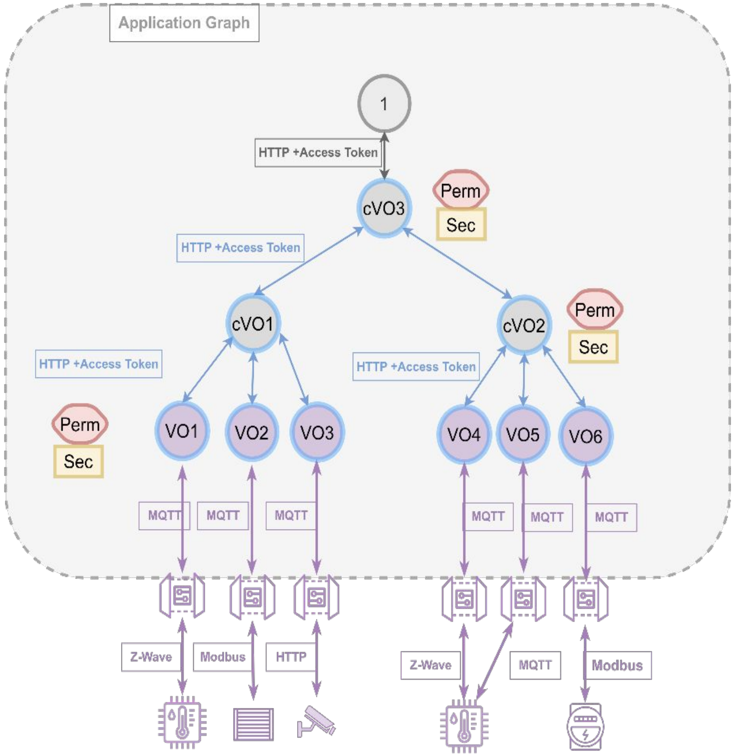
NEPHELE Smart Building Use Case

Application Graph Nodes

VO	Virtual Object
cVO	Composite Virtual Object
○	App Component
●	Service Component

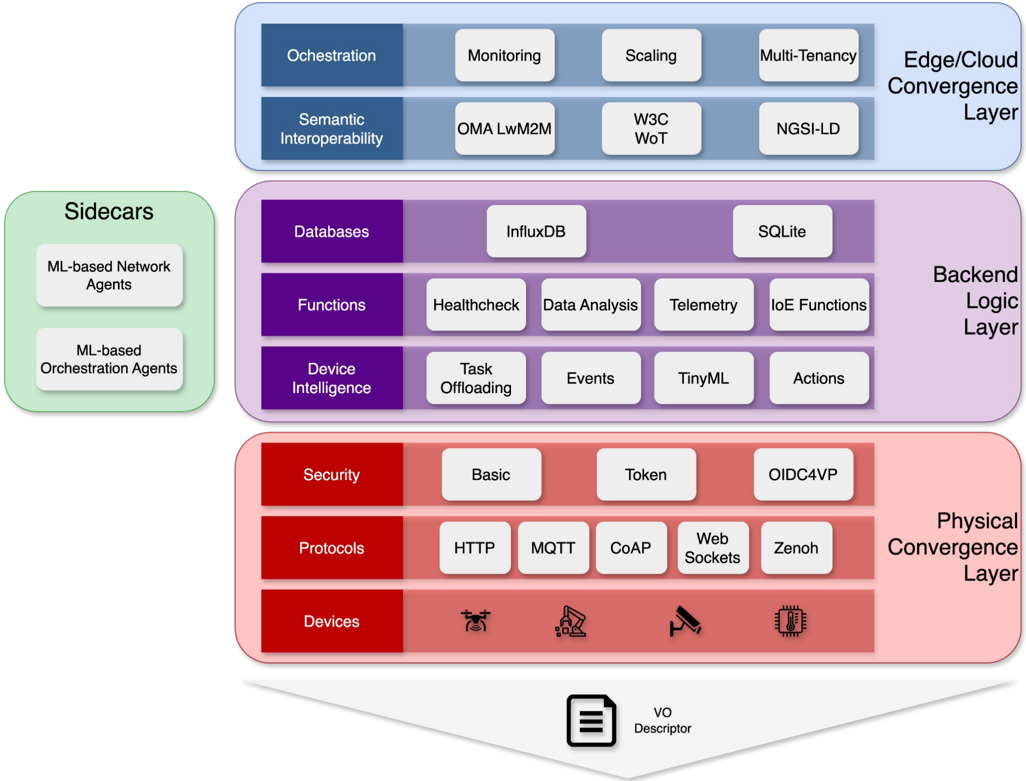
Application Graph Constraints

QoS	Quality of Service
Sec	Security
Perm	Permissions



1	Monitoring Application
cVO1	HVAC + Thermostat Room 1
cVO2	HVAC + Thermostat Room 2
cVO3	Smart Energy Balancer
VO1	Temperature/CO2/Humidity Room 2
VO2	HVAC Room 1
VO3	Camera - Occupancy monitoring
VO4	Temperature/CO2/Humidity/Pressence/Luminosity Room 2
VO5	TinyML and microCEP Engine - Presence Detection Room
VO6	Energy Consumption
	IoT Gateway
	Power Meter

VOStack Architecture



Edge/Cloud Convergence Layer

- Ochestration: Monitoring, Scaling, Multi-Tenancy
- Semantic Interoperability: OMA LwM2M, W3C WoT, NGSI-LD

Backend Logic Layer

- Databases: InfluxDB, SQLite
- Functions: Healthcheck, Data Analysis, Telemetry, IoE Functions
- Device Intelligence: Task Offloading, Events, TinyML, Actions

Physical Convergence Layer

- Security: Basic, Token, OIDC4VP
- Protocols: HTTP, MQTT, CoAP, Web Sockets, Zenoh
- Devices

Sidecars

- ML-based Network Agents
- ML-based Orchestration Agents

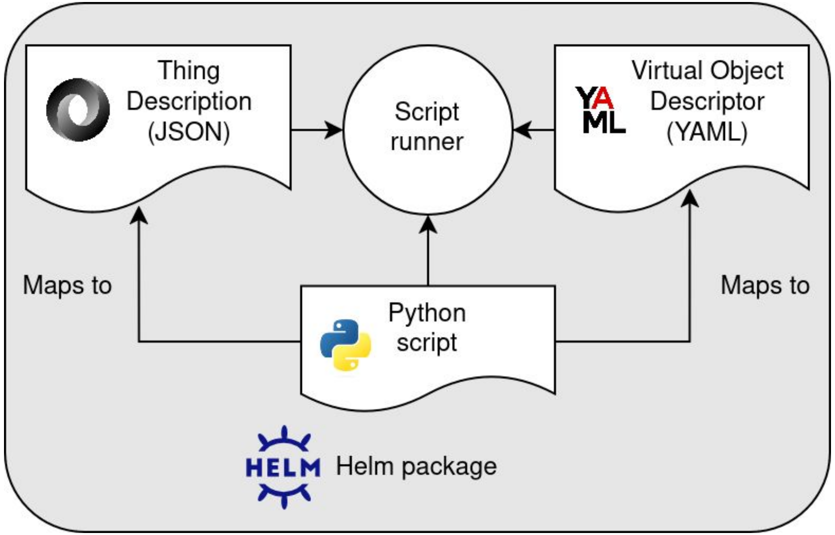
VO Descriptor

VO Automatic Deployment

- **Thing Description:** Web of Things W3C Thing Description JSON that contains Properties, Actions and Events

- **Virtual Object Descriptor:** YAML descriptor that contains configuration options for the VO

- **Python script:** application code that defines code execution and can be mapped to declarations made in the other two files



Python Package on PyPi

- **vo-wot**
- Executable that takes the 3 files as input

Wot-py-2 extensions

- Extension of Protocol Bindings
- Security Mechanisms
- Periodic Functions - Repeat Functions in irregular intervals
- InfluxDB

Supported Protocol Bindings

wot-py-2

- HTTP(S)
- CoAP
- WebSockets
- MQTT
- Zenoh
  - Pub-Sub protocol
  - Based on Zenoh Routers

Authentication mechanisms

- Basic username-password authentication
- Bearer token authentication

InfluxDB Integration

- Time-series Database
- Automatic saving of **Property** values on read/write operations
- Logging of **Action** invocations and **Event** emission
- InfluxDB sidecar (for VOs)

VOStack Functionalities and Sidecars

- Orchestration/Virtualization
- OpenID for Verifiable Credentials (Security Mechanism)
- RTSP server for video streams
- Network Optimization Sidecars (TSN/SDN)
- Proxy Mode for cVOs/VOs

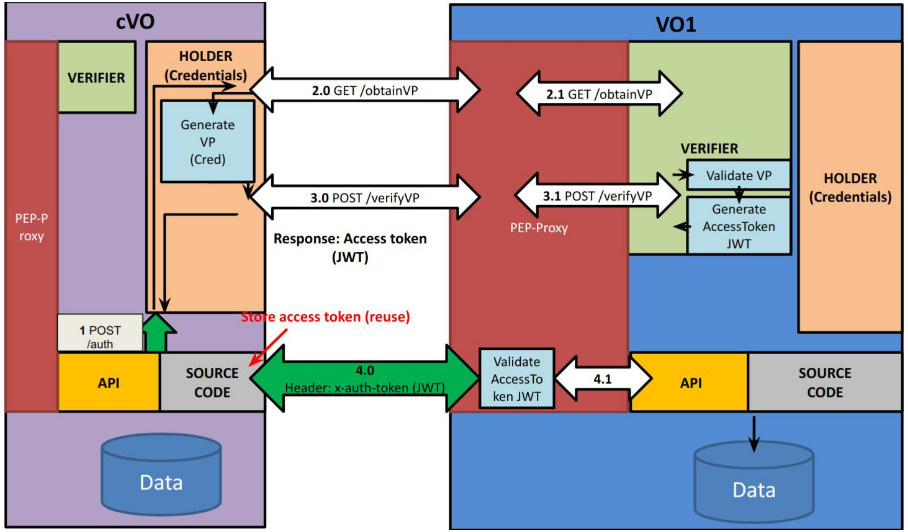
VO Orchestration

Kubernetes deployment:

- VO Docker image
- Helm package
- Overridable defaults with developer declared values
- Integration of the VO in a microservice-based architecture/graph

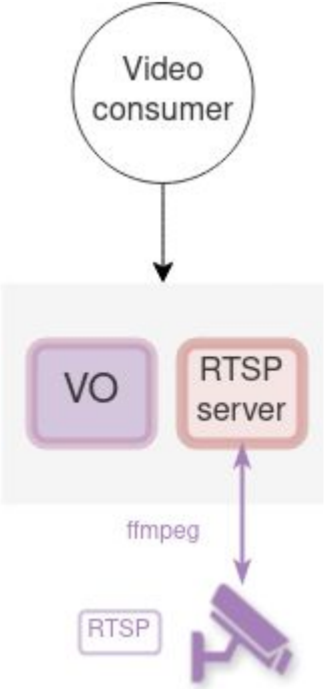
OpenID for Verifiable Credentials

- Centralized **Issuer** component issues credentials
- VO uses **Holder** sidecar to store credentials
- Access passes through **proxy** that validates credentials



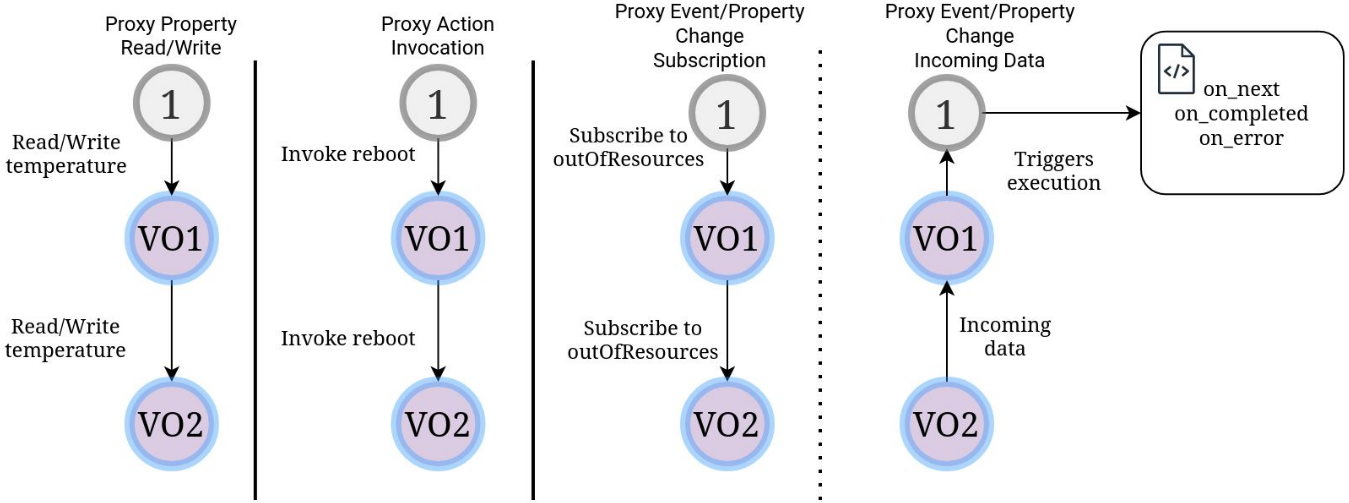
RTSP Video proxy

- RTSP server sidecar
- **ffmpeg** redirects video stream to sidecar
- Video property exposes video stream URL



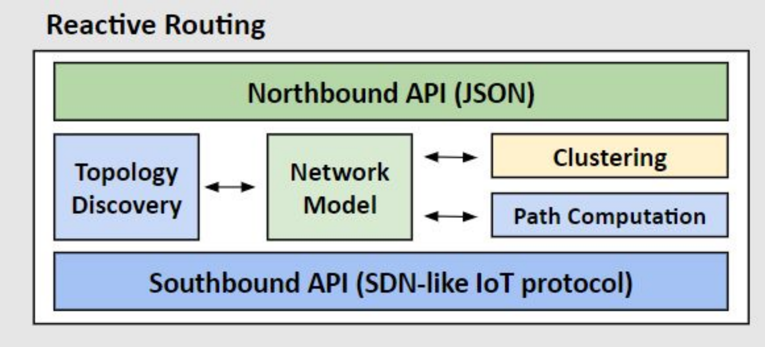
Proxy functions

- Can turn a cVO into a proxy to other VOs



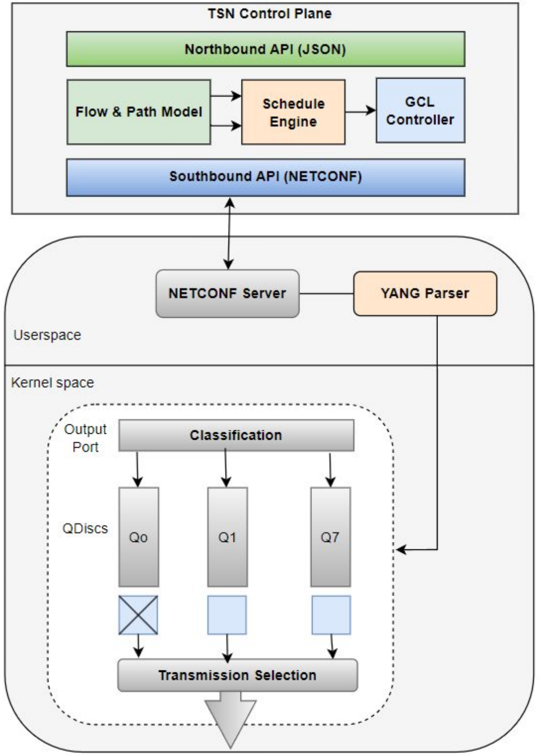
Software-defined networking (SDN)

- Writes SDN configuration to SDN controller
- **Northbound API**
  - Reception of application and resource requirements
- **Southbound API**
  - Exchange of control messages between the Reactive Routing control plane and the IoT nodes
  - Topology control
  - Routing control
  - Data delivery control



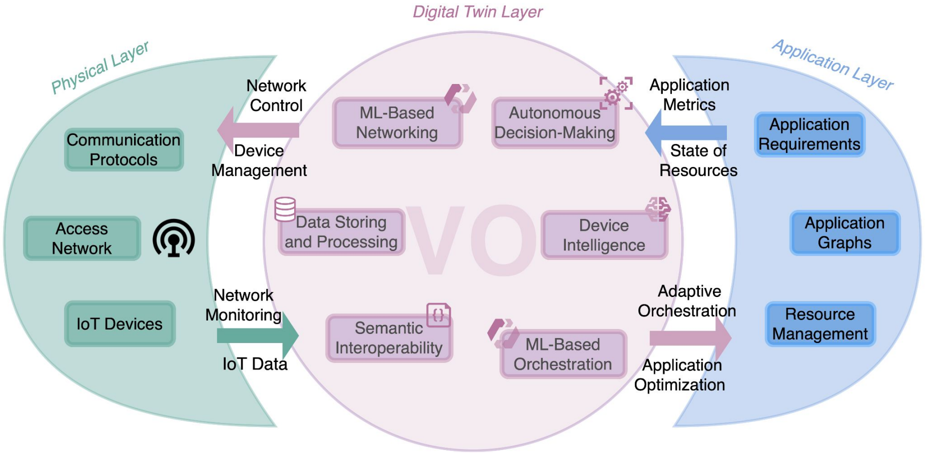
Time Sensitive Networking (TSN)

- Injection of **flow** and **path** Properties
- Triggering of **TSN Scheduler**
- Send schedule to **NETCONF server**



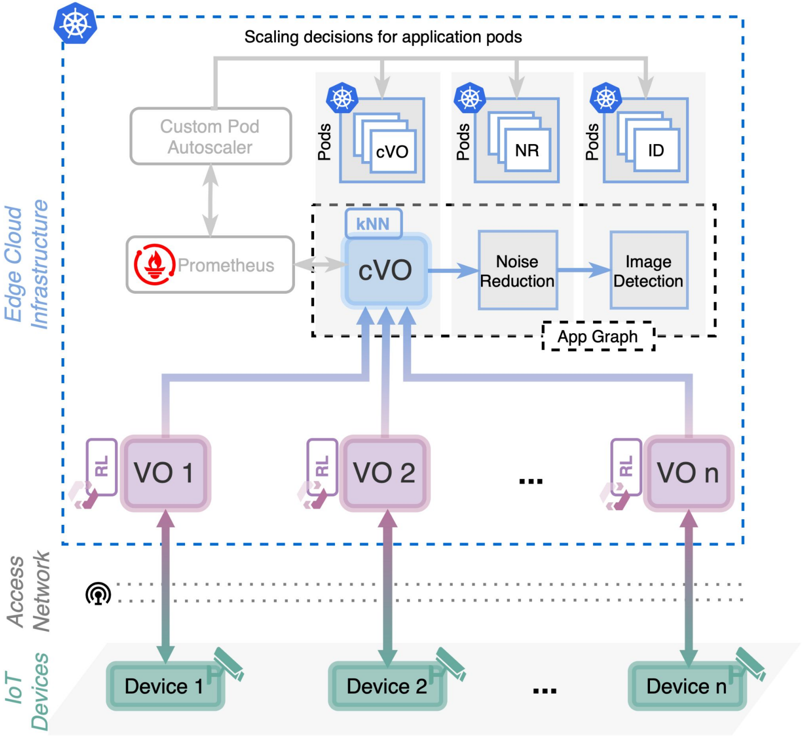
VO-based Digital Twin

- Modular Development of Digital Twins
- Control over the Physical Layer with Actions, Events to enable dynamical orchestration of IoT
- VO as the "controller" for the orchestration of application graphs



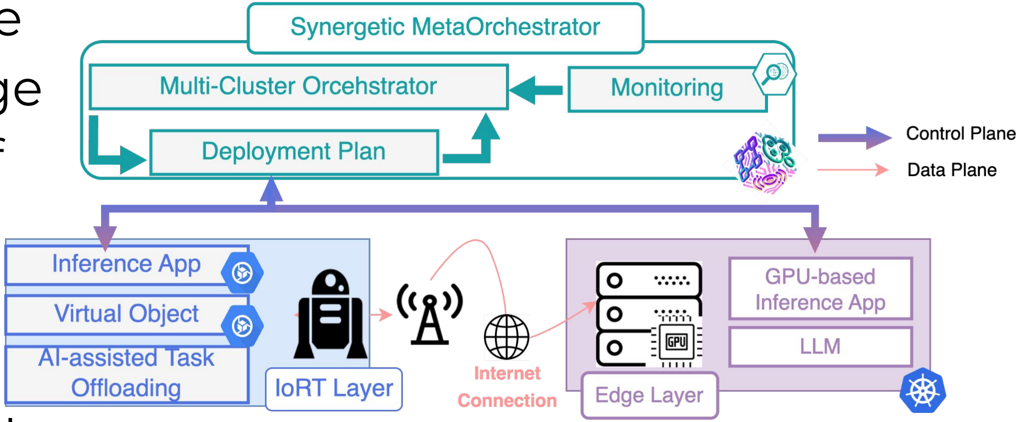
VOStack for Orchestration

- **VO** controls the rate of offloaded images coming from devices depending on an RL agent that considers the network part
- **cVO** controls the orchestration of the application graph depending on the incoming traffic



VOStack for Edge AI Offloading

- **VO** utilizes an AI-assisted mechanism to control the Task Offloading in an Edge AI scenario for Internet of Robotic Things
- The **VO** also emits an event towards the SMO to trigger the on-demand deployment of resources



Roadmap

- Follow the ongoing activities of W3C WoT - especially the updates of node.js implementation
- Support and development of new features in wot-py-2
- Release of VO-Stack as an Eclipse Open-Source Project or as part of Eclipse ThingWeb
- Continuous maintenance and contributions to VOStack to bridge the gap with orchestration and control of IoT

Eclipse Research Labs GitLab Repository

https://gitlab.eclipse.org/eclipse-research-labs/nephele-project/vo-wot

Documentation

https://netmode.gitlab.io/vo-wot/

Thank you for your attention!

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