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Network automation: challenges, enablers, and benefits

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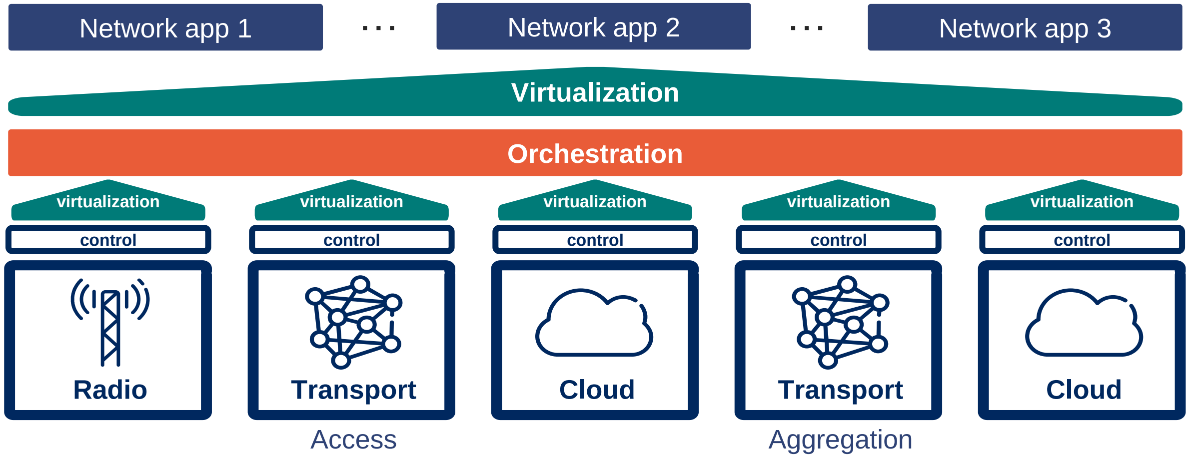
Telco infrastructure evolution

- Different generation of network infrastructure rollouts:
  - from **one** design/deployment per service
  - to **multipurpose** infrastructure orchestrating diverse resources with different requirements (e.g., latency, capacity, availability)
- Telcos are undergoing a **digital transformation** in both how they use their underlying technologies and their interaction with customers



Digital transformation: benefits

Operate networks with *optimized resources*

Better *costumer experience*

Ability to adapt to market changes and lead in *innovation*

Expanding service portfolios addressing new *vertical markets*

Increased return on investment (*RoI*)

Digital transformation: critical aspects

Shift from discrete network elements to an independently managed, ***virtualised communications*** and ***cloud*** *infrastructure*

Data: deployment of ***telemetry frameworks*** for new approach to the collection, analysis/visualization, distribution, and security of data collected from multiple sources

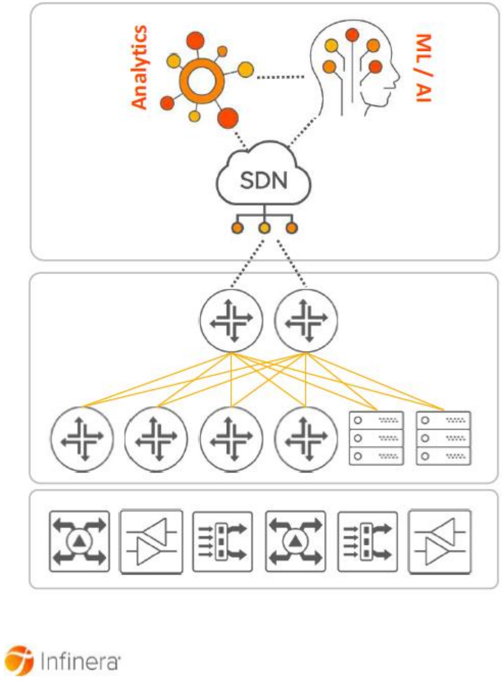
Security: digital services have higher security requirements, need to support full technology stack, the data, the service creation process, and the physical environment

Architecture: **open platforms** and **standardized APIs** to support both internal own-brand and external third-party services

Business models: critical to develop new flexibility in what to sell and how create value for both themselves and their partners

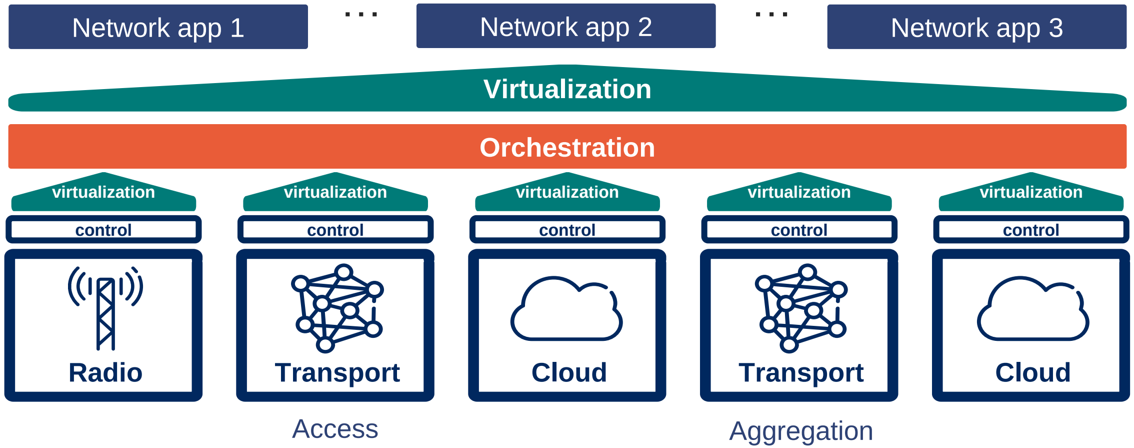
AI as a tool

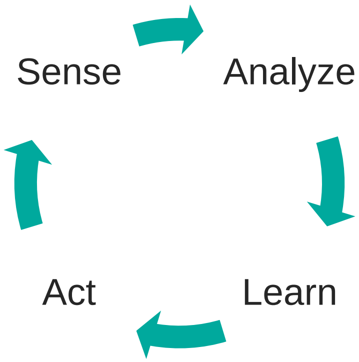
- Artificial Intelligence / Machine Learning as one of the main tools for network optimization
- Auto-configure
  - service provisioning based on
  - real-time physical layer data
  - full automation of physical layer
- Self-heal
  - failure prediction and preventive maintenance
  - root cause analysis and automatic repair
  - predict traffic and self-optimize
- Automate network re-configuration
  - suggest network augmentation
  - avoid congested areas
  - optimized power and cooling



Harald Bock, “A path towards a Smart Zero-Touch Transport Network,” OFC, 2021.

Self driving network concept





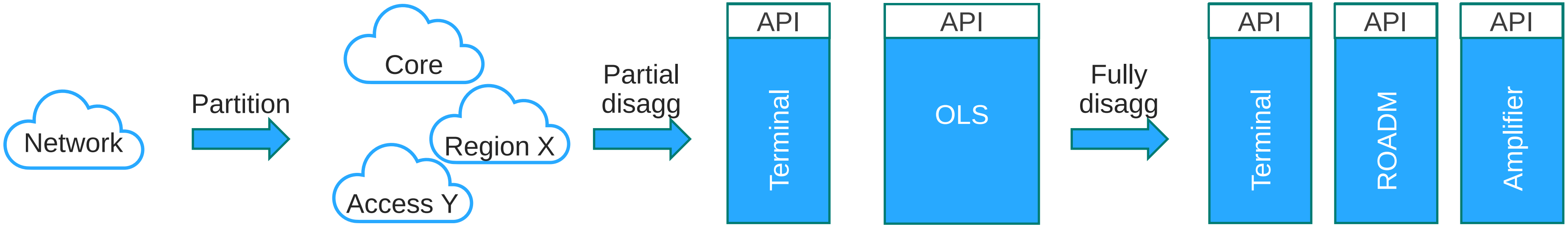
- Cognitive loop:
  - Monitoring generates knowledge (Sense)
  - Analytics and AI process the knowledge (Analyze + Learn)
  - AI/ML-based decision processes acts on the knowledge (Act)
- Performance are optimized and infrastructure learns how to operate also in the presence of previously unseen conditions

Outline

- Open platforms and APIs
- Monitoring frameworks
- ML-based orchestration
  - Provisioning
  - Scheduling
  - Security
- Open challenges
- Conclusions

Open and disaggregated networks

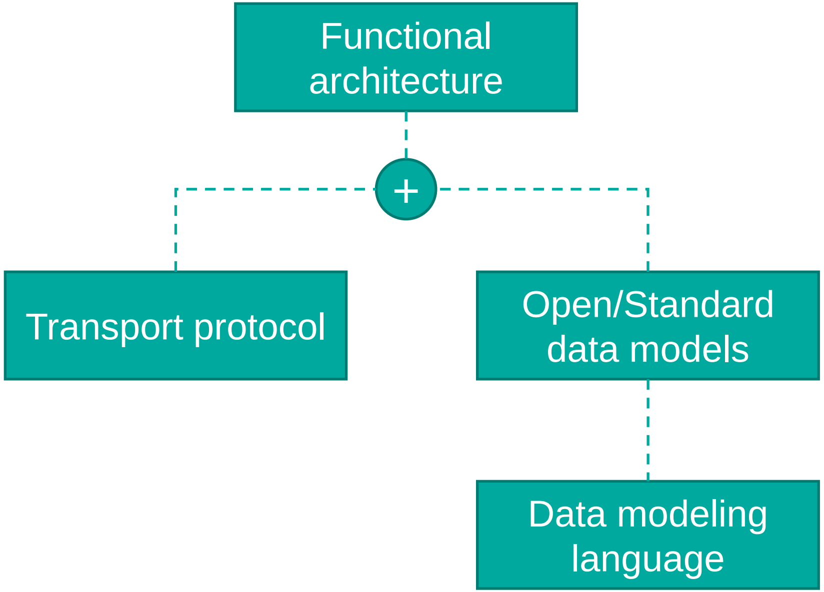
- Main benefits:
  - Break vendor lock-in
  - Optimize performance and costs
  - Independently evolve different network segments/devices
  - Facilitate integration of new devices/systems
  - Foster competition



S. Neidlinger, "Real-life achievements and gaps in autonomous optical networks," OFC, 2021.

(Data) Model-driven development

- Approach to design distributed systems
- Extensive use of data models and the modeling tool
- Data model enables automatic code generation, processing, and validation
- Data models and transport protocols can be evolved independently
- Business logic is also decoupled from the models



R. Casellas et al., “Advances in SDN control for Beyond 100G disaggregated optical networks,” ECOC, 2021.

What is a data model?

- Data model
  - Structures and defines data
  - “Representation of a system in terms of objects, entities, roles, relationships, cardinalities, constraints”
- Benefits
  - Unambiguous specification
  - Self-documentation
- How to use
  - Text file, versioned and integrated into a toolchain

```
module cttc-tv {
  namespace "http://www.cttc.es/ctv";
  prefix ctv;
  organization "CTTC";
  contact "ramon.casellas@cttc.es";
  description "TV Yang model";
  revision "2018-01-30" {
    reference “0.1”;
  }
  typedef volume-type {
    type int32 {
      range "0..100";
    }
  }

  container info {
    config false;
    leaf vendor {
      type string;
    }
    leaf serial {
      type string;
    }
  }
```

```
...
container parameters {
    config true;
    leaf input {
        type enumeration {
            enum hdmi1;
            enum hdmi2;
        }
    }
    leaf volume {
        type volume-type;
    }
    leaf channel {
        type uint32 {
            range "1..512";
        }
    }
  }
```

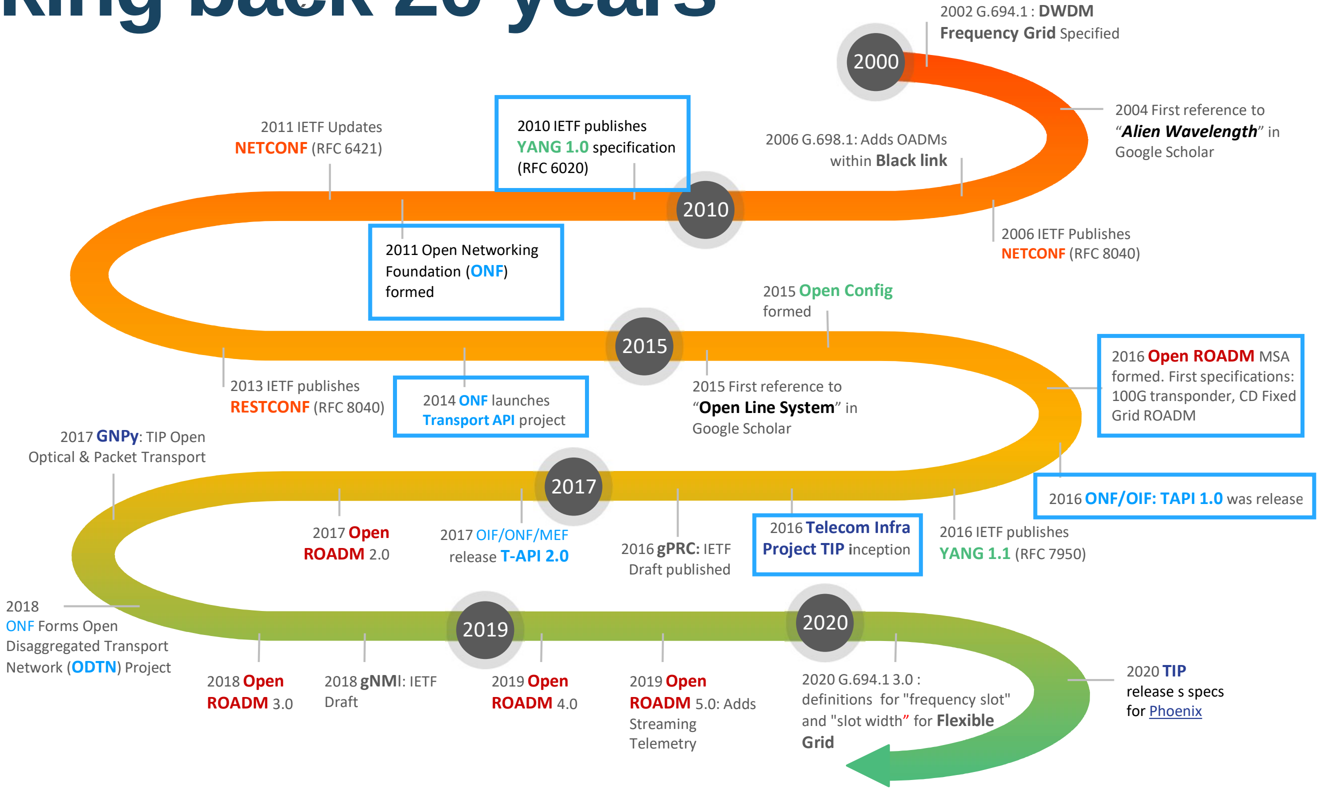
```
...
rpc reboot {
    input {
      leaf delay {
        type uint16;
      }
    }
    output {
      leaf status {
        type empty;
      }
    }
  }


  notification sleep {
    leaf delay {
      type uint16;
    }
  }

}
```

R. Casellas et al., “Advances in SDN control for Beyond 100G disaggregated optical networks,” ECOC, 2021.

Looking back 20 years



Infinera

Harald Bock, "A path towards a Smart Zero-Touch Transport Network," OFC, 2021.

T-API

- Sponsored by ONF
- Technology-agnostic interfaces
- Topology, connectivity, path computation, virtual function
  - UML models, YANG schemas
  - TAPI OpenAPI

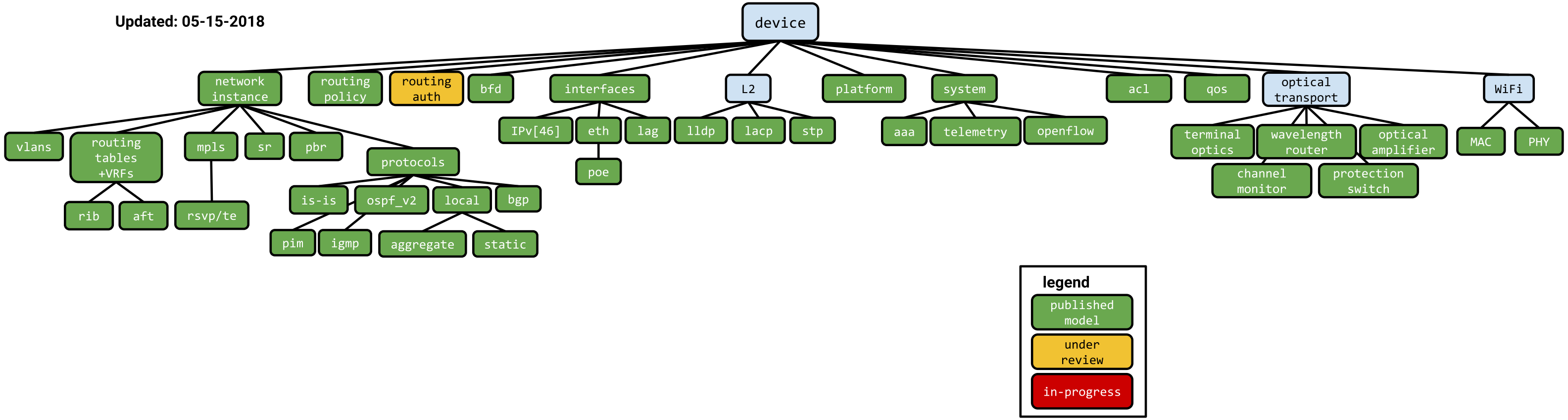
```
grouping path-service-end-point {
    container service-interface-point {
        uses tapi-common:service-interface-point-ref;
    }
    leaf layer-protocol-name {
        type tapi-common:layer-protocol-name;
    }
    leaf layer-protocol-qualifier {
        type tapi-common:layer-protocol-qualifier;
    }
    container capacity {
        uses tapi-common:capacity;
    }
    leaf role {
        type tapi-common:port-role;
    }
    leaf direction {
        type tapi-common:port-direction;
    }
    uses tapi-common:local-class;
}
```

```
rpc compute-p-2-p-path {
    input {
        leaf uuid {
            type tapi-common:uuid;
        }
        list name {
            key 'value-name';
            uses tapi-common:name-and-value;
        }
        container routing-constraint {
            uses routing-constraint;
        }
        container topology-constraint {
            uses topology-constraint;
        }
        container objective-function {
            uses path-objective-function;
        }
        list end-point {
            key 'local-id';
            min-elements 2;
            max-elements 2;
            uses path-service-end-point;
        }
    }
    output {
        container service {
            uses path-computation-service;
        }
    }
}
```

https://github.com/OpenNetworkingFoundation/TAPI

OpenConfig

- Vendor-neutral, model-driven network management designed by users
- Common data models
- Streaming telemetry
  - Efficient, incremental updates
  - Publish-subscribe paradigm

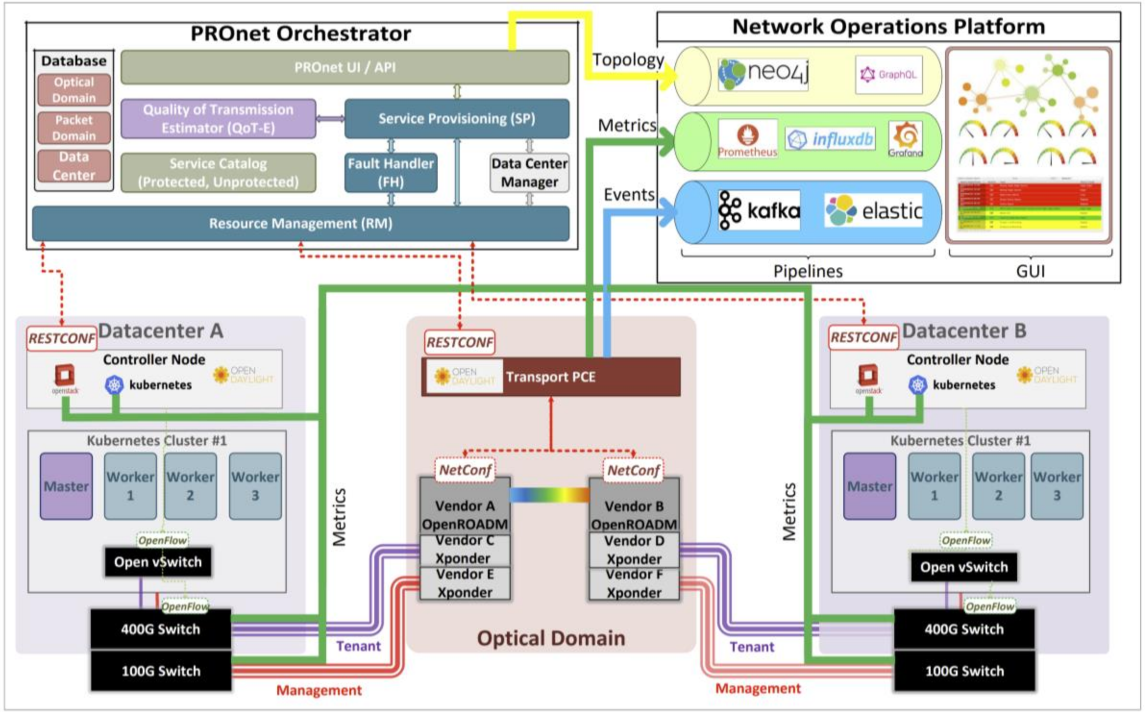


OpenROADM

- Defines interoperability specifications for Reconfigurable Optical Add/Drop Multiplexers (ROADM), including also transponders and pluggable optics
- Specifications consists of YANG models
- Common multi-wave interface between ROADMS
- Common single-wave interface between transponders or pluggable optics

Enabling multi-vendor optical networks

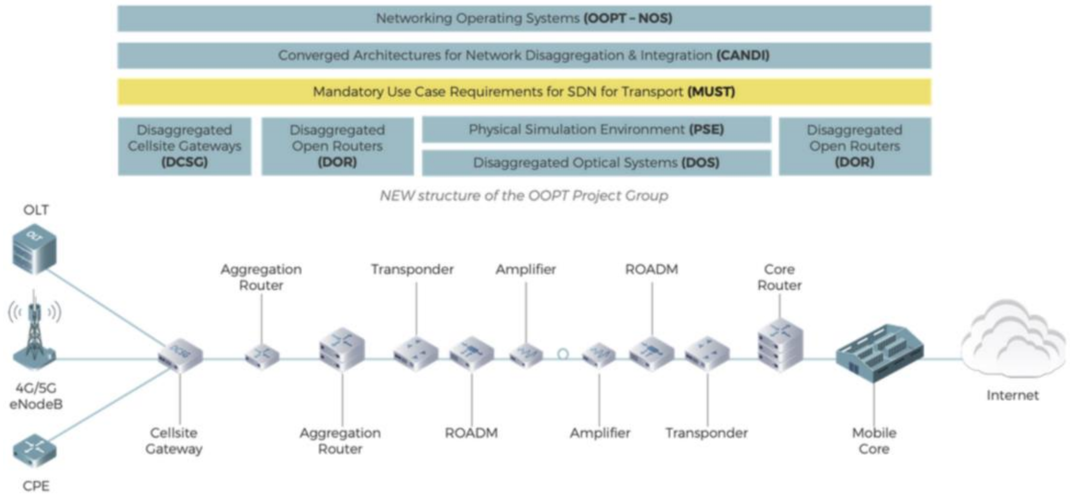
- Implements key functionalities of a network operations platform (NOP)
- Leverages open-source software and APIs
- Inter-operates OpenROADM-ready devices from different vendors under the same transport controller
- Integrates topology, metrics and events into a single NOP



N. Ellsworth et al., "A Non-Proprietary Network Operations Platform for OpenROADM Environment," OFC, 2021.

TIP OOPT

- Telecom Infra Project
  - Build open and disaggregated transport networks
  - Open Optical & Packet Transport (OOPT) group



TIP OOPT MUST Optical Whitepaper Target Architecture: Disaggregated Open Optical Networks.

Demonstration of partially disaggregated optical networks

- Demonstrates service provisioning
- Online physical impairment validation
- Validates the models
- Exposes the gaps that still exist

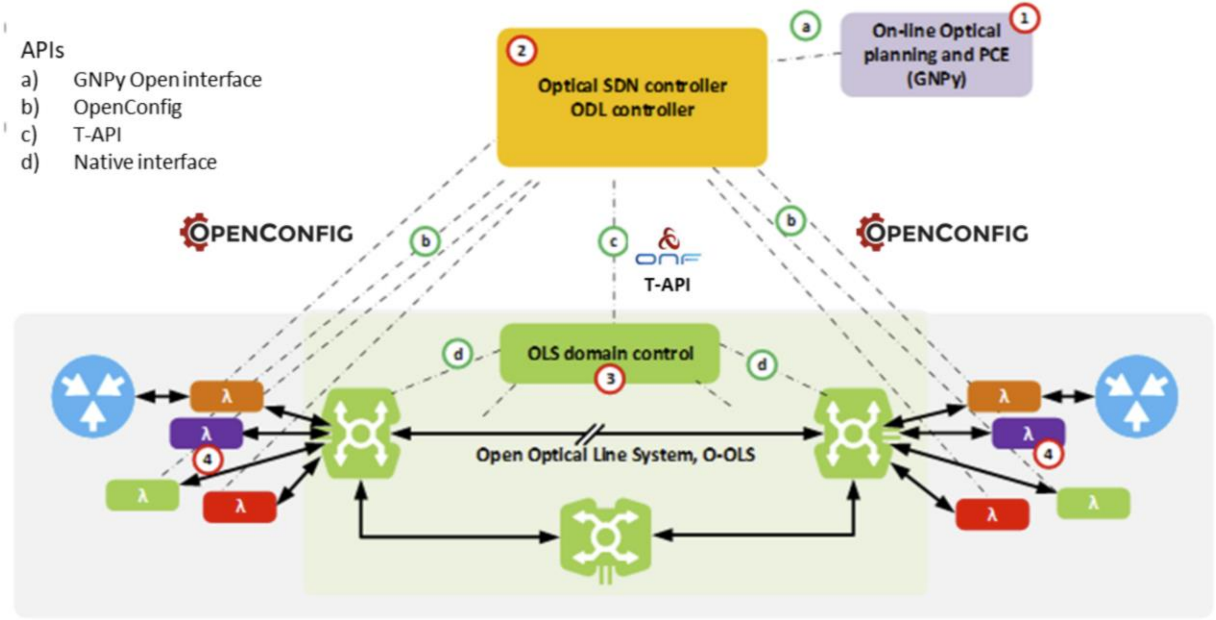
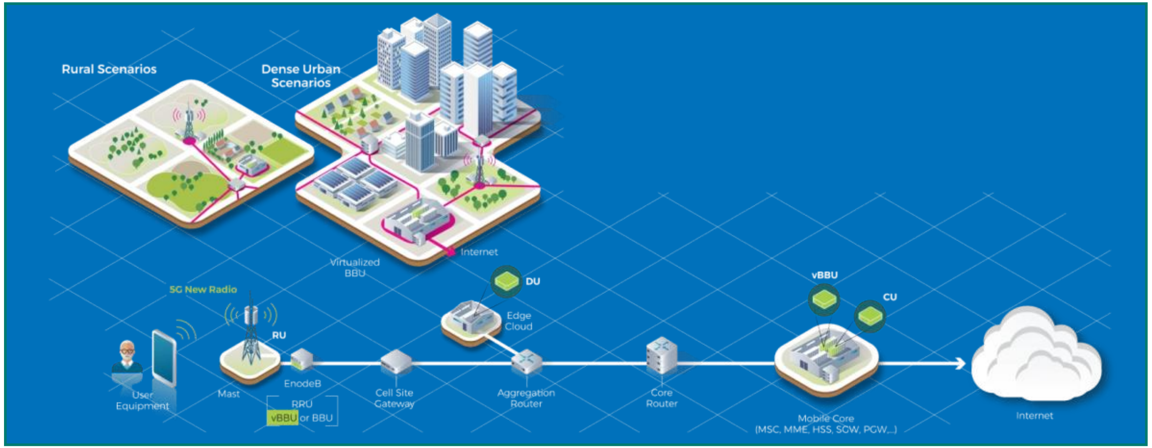


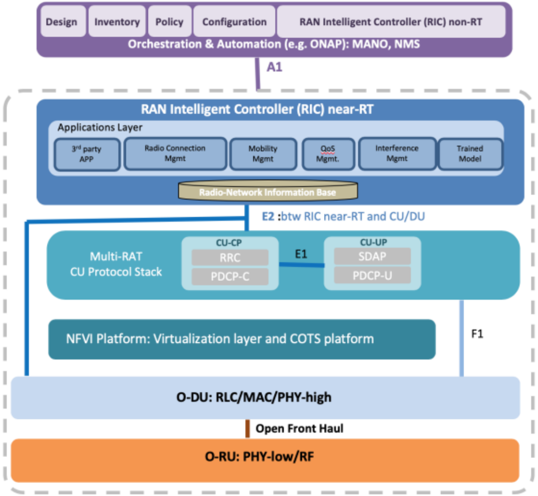
Fig. 1. Partially disaggregated open optical architecture.

E. Le Rouzic et al., "Operationalizing partially disaggregated optical networks: An open standards-driven multi-vendor demonstration," OFC, 2021.

TIP OpenRAN and O-RAN

- TIP OpenRAN: Build 2G, 3G, 4G and 5G RAN solutions based on general-purpose vendor-neutral hardware, open interfaces and software
- O-RAN: Open, intelligent, virtualized and fully interoperable RAN



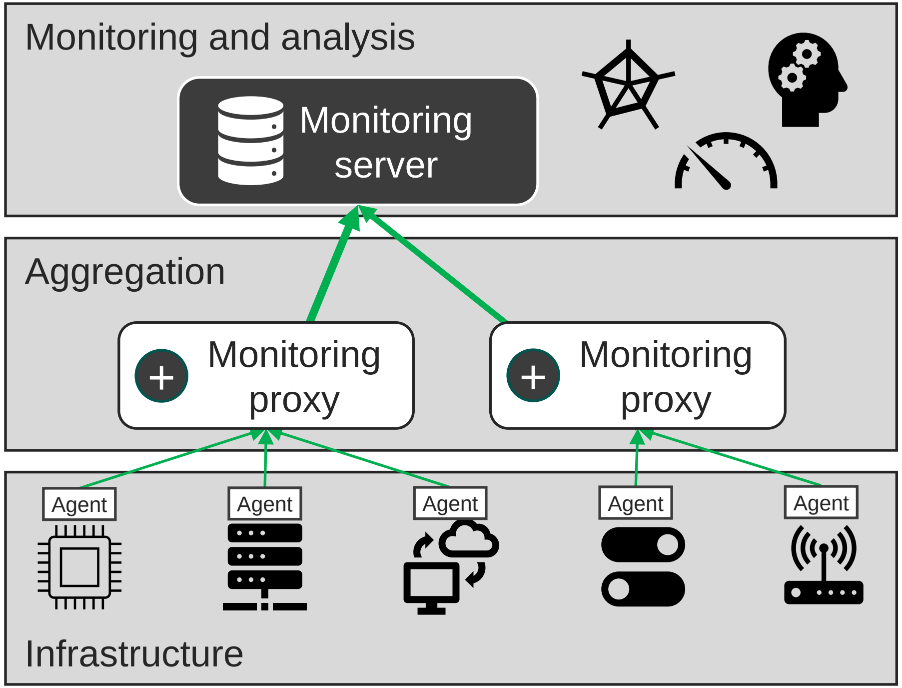


Outline

- Open platforms and APIs
- $\boxed{\text{Monitoring frameworks}}$
- ML-based orchestration
  - Scheduling
  - Provisioning
  - Security
- Open challenges
- Conclusions

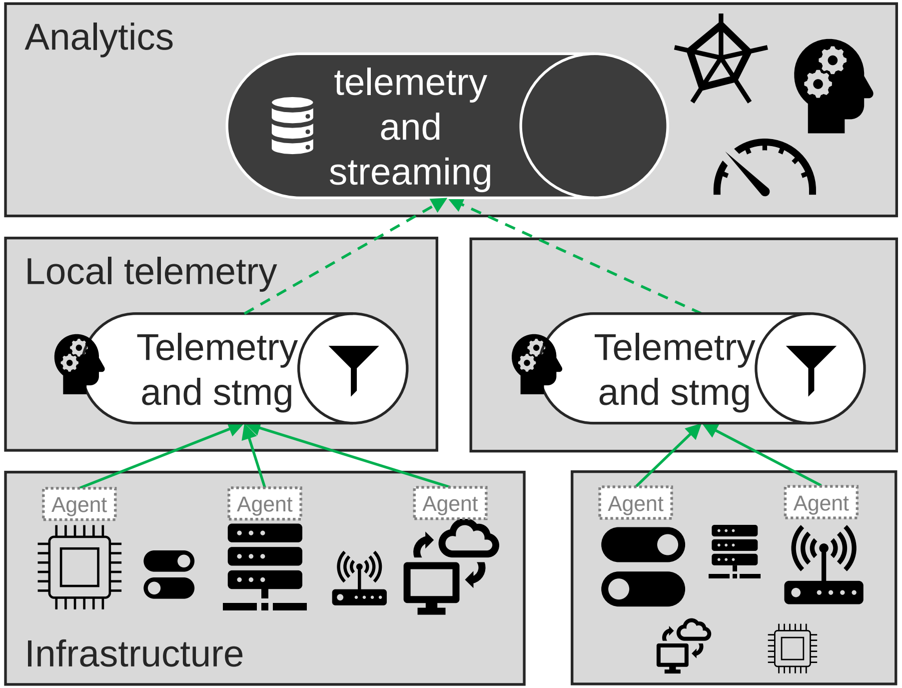
Traditional monitoring

- Centralized metric collector and analyzer
- Proxies operate based on receive-store-forward-flush
  - Serves only as data aggregation
  - Data is not available in real time
  - No intelligence
  - No data filtering
- Agents extract data from devices
- Incident analysis is performed after the fact
  - Batch processing
  - Monitoring metrics are kept for long time (at least few months)



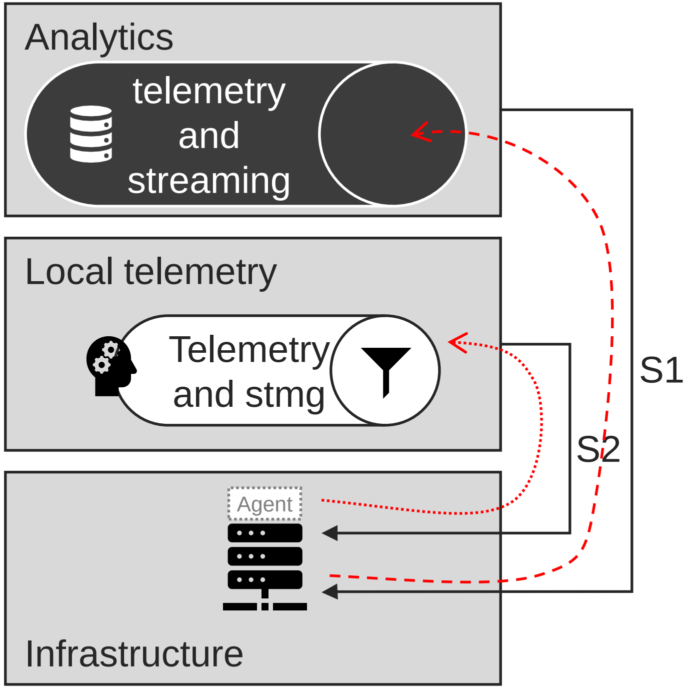
Towards telemetry

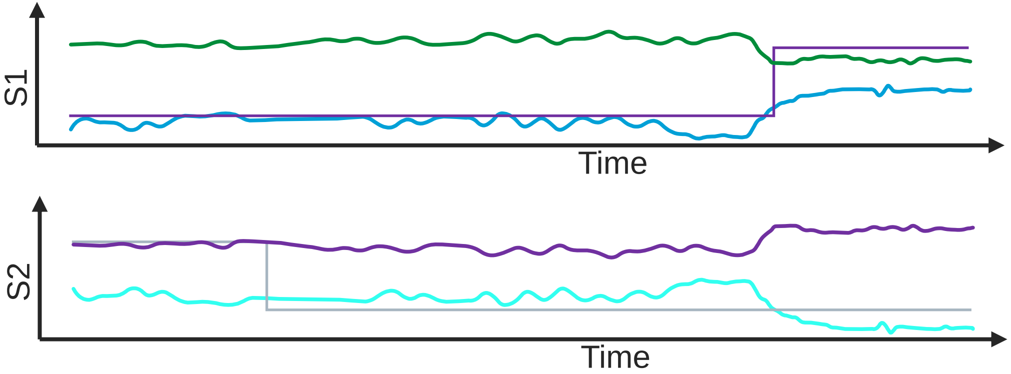
- Distributed monitoring
- Centralized analytics has global view of the system
- Local telemetry
  - Local real-time analytics
  - (Dynamic) data filtering towards the central telemetry*
- Agents only needed when devices don't have compatible monitoring interfaces
- Real-time monitoring and analytics
  - Metrics are kept for limited period of time
  - Summarized metrics may be kept for longer

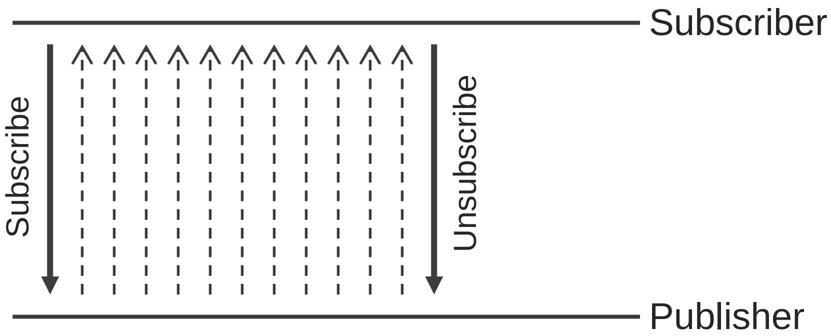


*X. Wang, et al., "Online feature selection for rapid, low-overhead learning in networked systems," CNSM, 2020.

Example architecture







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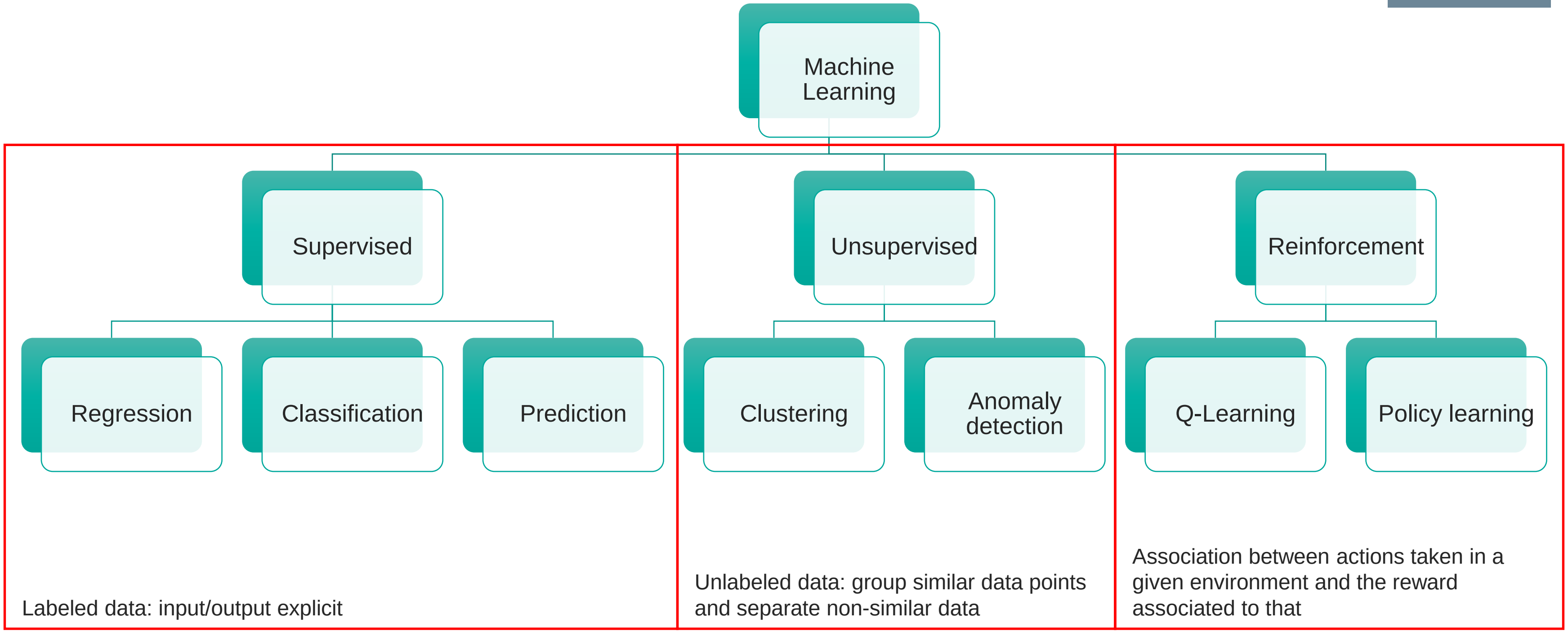
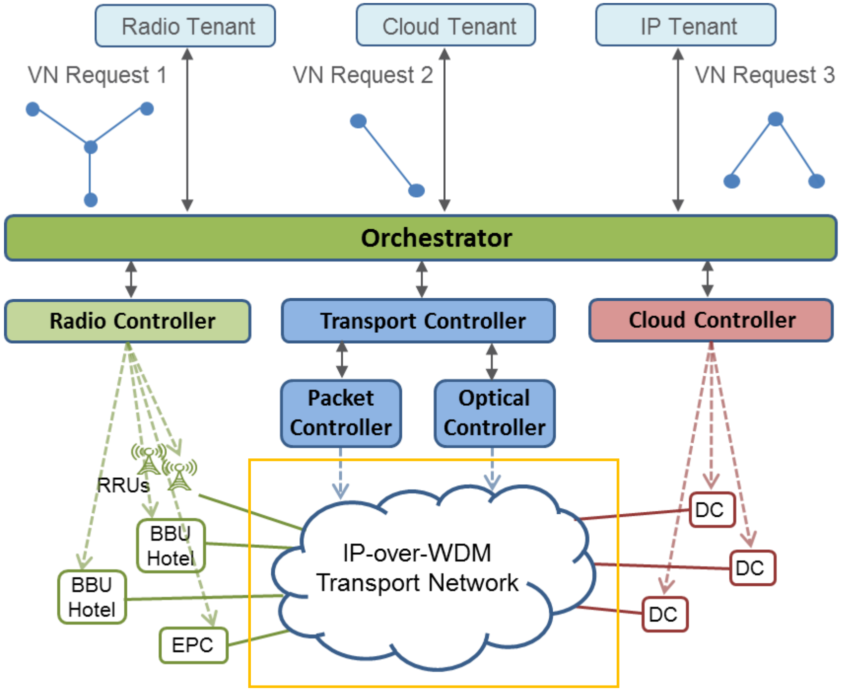
Machine learning methods



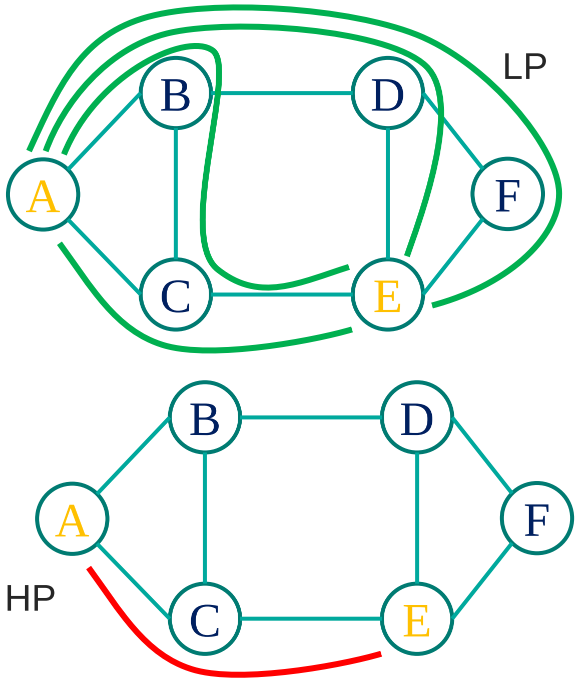
Routing of connectivity services with QoS

- Problem: provisioning CSs with different QoS constraints (i.e., priorities) and different revenue values
  - ✓ should be able to provision as many CSs as possible (to maximize revenue)
  - ✓ guarantee the required QoS constraints
- Intuition: beneficial to *proactively reject* a number of LP (low revenue) CSs to make room for HP (high revenue) ones – especially in with scares resources
- Tools: Machine Learning (ML) showed high potentials in bringing good performance benefits in the management of network infrastructures



Use case

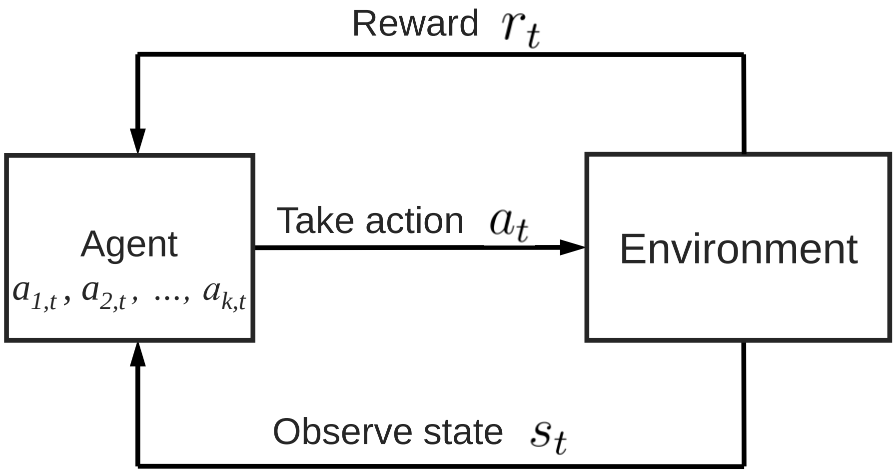
- Infrastructure providers (InPs) provisions connectivity services (CS) over optical transport infrastructure
- Normal latency CS:
  - ✓ Low Priority (LP)
  - ✓ Can be provisioned using any of the *k*-shortest-paths
  - ✓ Low revenue
- Latency-constrained CS:
  - ✓ High Priority (HP)
  - ✓ Required the provisioning over the shortest path
  - ✓ Generate 10 times more revenue than LP CS
- Objective: assign CS path that satisfy constraints (with rejection also as a viable option) s.t. revenue maximized



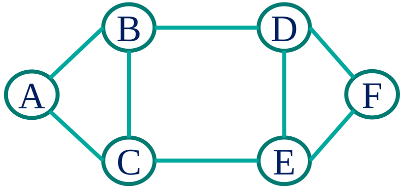
C. Natalino, et al., "Machine-Learning-Based Routing of QoS-Constrained Connectivity Services in Optical Transport Networks," OSA Networks, 2018.

Reinforcement learning

Stochastic policy network
implementing a routing policy



e.g., WDM network

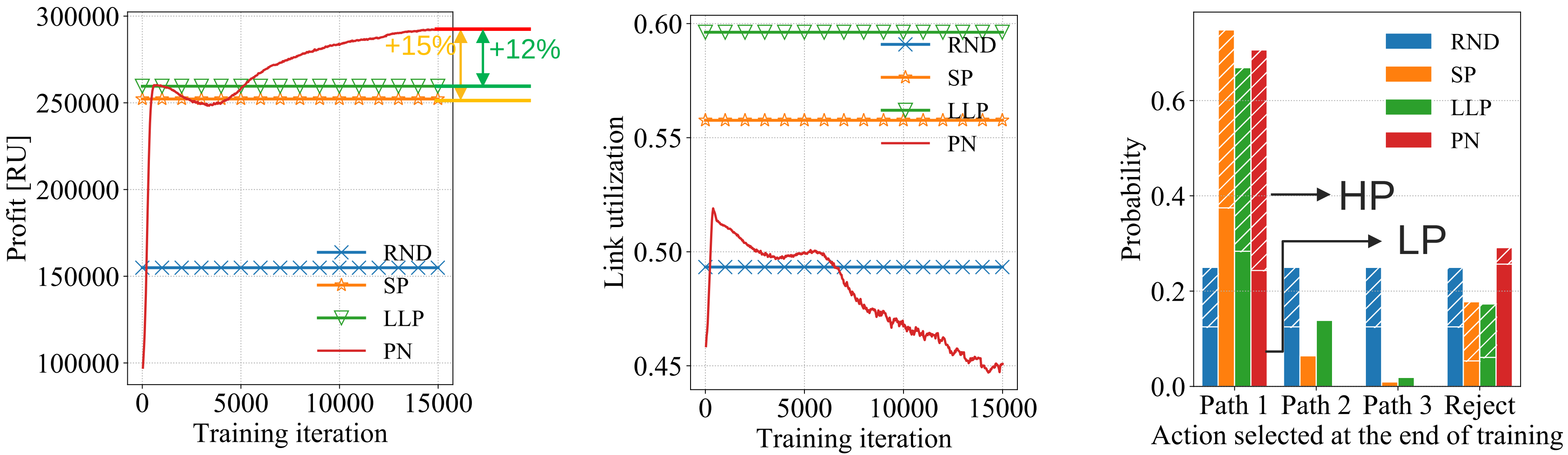


Goal: maximize the cumulative reward $\sum_t r_t$

Results

RND: Random
SP: Shortest Path
LLP: Least Loaded Path
PN: Policy Network

- Learning over 15000 training iterations with 25000 CS requests per iteration
- **High load** conditions

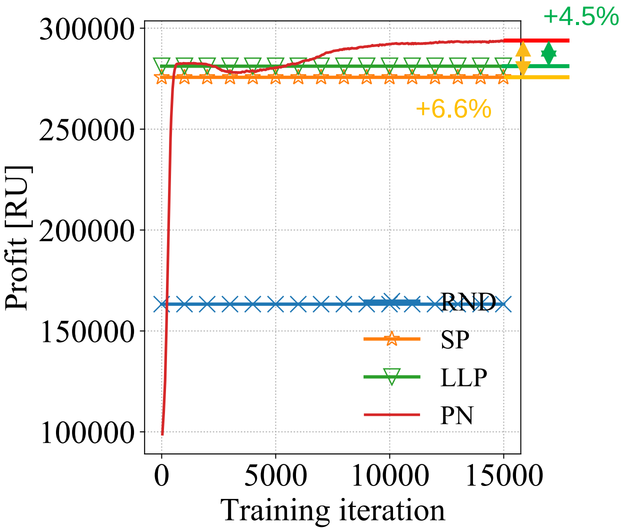


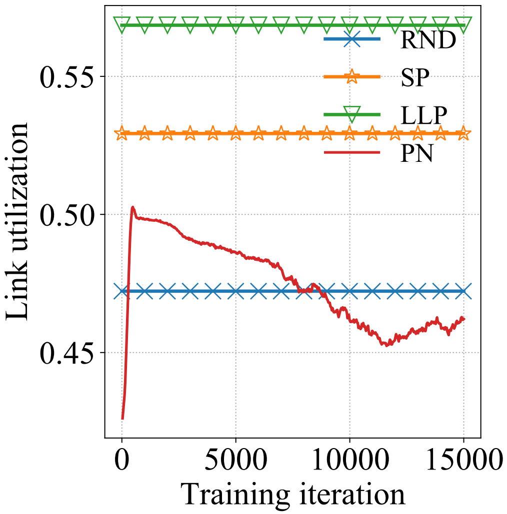
C. Natalino, et al., "Machine-Learning-Based Routing of QoS-Constrained Connectivity Services in Optical Transport Networks," OSA Networks, 2018.

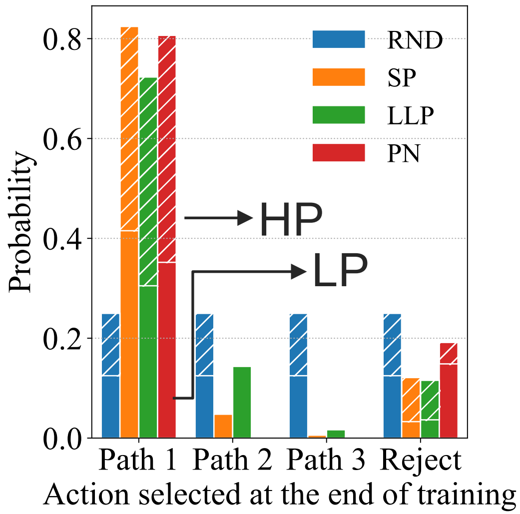
Results

RND: Random
SP: Shortest Path
LLP: Least Loaded Path
PN: Policy Network

- Learning over 15000 training iterations with 25000 CS requests per iteration
- **Lower load conditions**



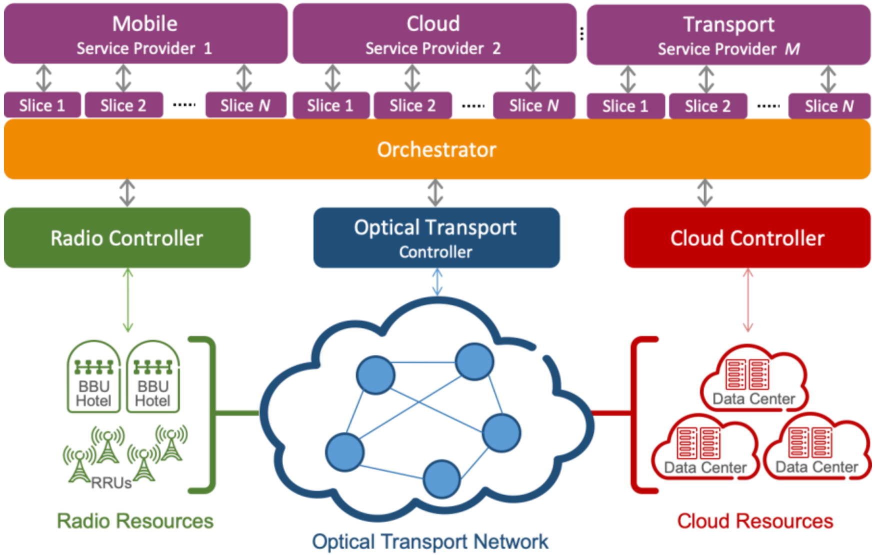




C. Natalino, et al., "Machine-Learning-Based Routing of QoS-Constrained Connectivity Services in Optical Transport Networks," OSA Networks, 2018.

ML-based slice scheduling

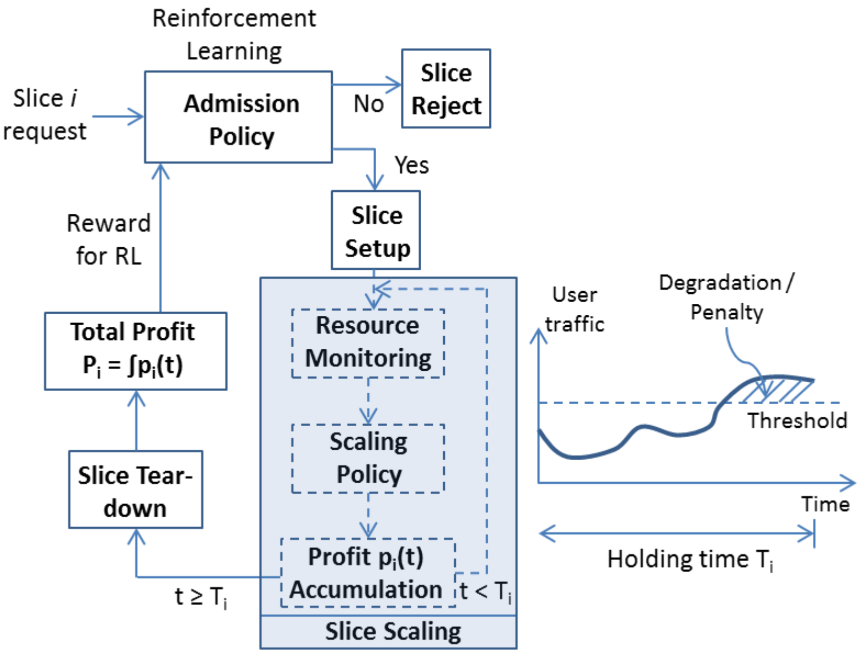
- Slicing: SDN and NFV allow InP to share resources among different tenants
- During provisioning/operation beneficial to adapt resources assigned to a slice to match time varying requirements: **dynamic slicing**
- Slice acceptance ratio can be greatly improved at the cost of small service degradation*
- Crucial to have intelligent policy that accepts only slices not likely to create performance degradation
  - understand when/where resource bottlenecks might appear in the infrastructure
  - deciding which slice to accept in order to maximize the profit of an InP



M. R. Raza, et.al.,, "Dynamic Slicing Approach for Multi-tenant 5G Transport Networks", in IEEE/OSA JOCN, Vol. 10, No. 1, 2019

Use case

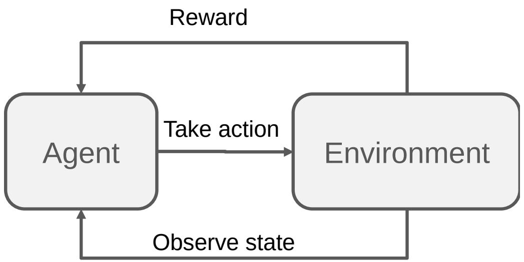
- Scenario:
  - tenant(s) requests slices with different requirements and priorities
  - different priorities mean different revenue and penalty levels
- Objective:
  - admission policy used by InP to accepts/rejects incoming slice request with aim to maximize Profit = revenue – penalty
- Intuition:
  - beneficial to proactively reject some low priority (low revenue) services to make space for future high priority (high revenue) ones



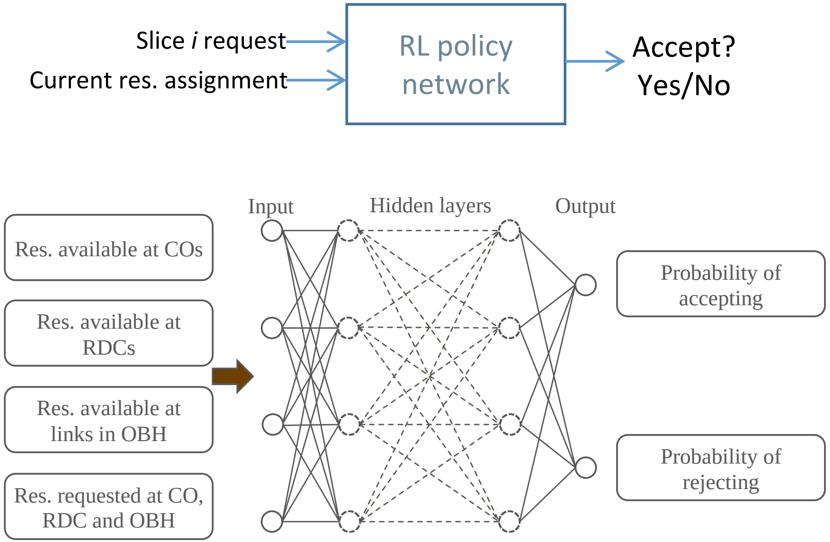
M. R. Raza, et al., "Reinforcement Learning for Slicing in a 5G Flexible RAN," JLT, 2019.

Slice admission using RL

- Understand how admission decisions impact the reward that is modelled as the loss of revenue



- Use *policy networks* to learn an admission policy that maximizes the reward over time

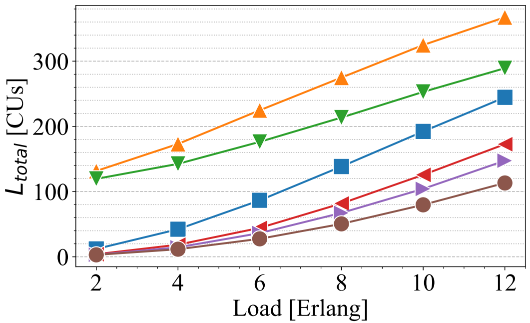


M. R. Raza, et al., "Reinforcement Learning for Slicing in a 5G Flexible RAN," JLT, 2019.

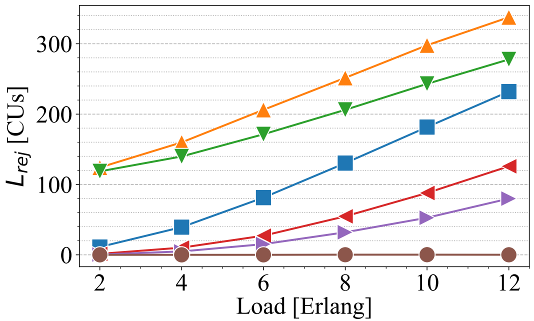
Performance evaluation

- Scaling policy = high priority first (HPF), with 50% HP-50% LP services
- L_total= L_rej+ L_deg (sum of the rejection loss and degradation loss), penalty ratio = 1.5
- NN with 4 hidden layer and 40 neurons
- Test results after 2500 training iterations
- RL shows 23% improvement vs. OS-50, 60% vs. RR-50, and 53% vs. Fit

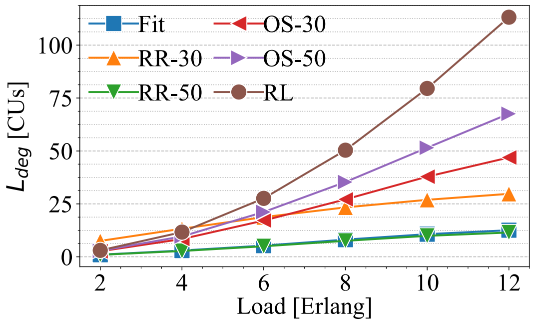
RR: Resource reservation
OS: Oversubscription



(a) Total loss L_{total}



(b) Loss from rejected services L_{rej}

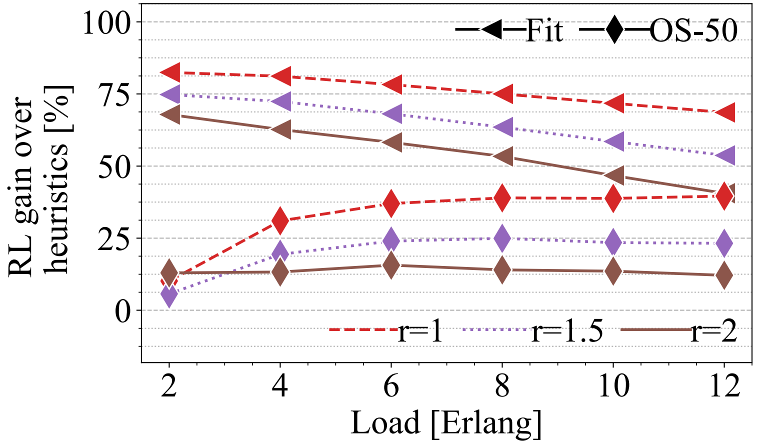


(c) Loss from degraded services L_{deg}

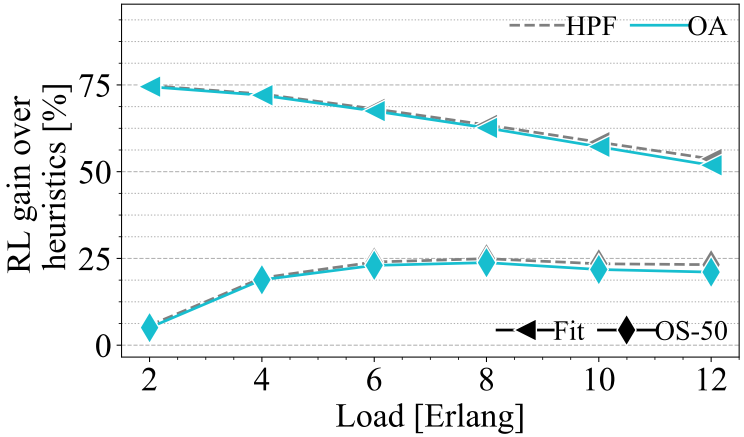
M. R. Raza, et al., "Reinforcement Learning for Slicing in a 5G Flexible RAN," JLT, 2019.

Varying penalty ratio and scaling policy

- Different penalty ratios (r) values
- Scaling penalty = r * rejection penalty
- Scaling policy = High priority first (HPF)



- Different scaling policies
- High priority first (HPF) and Order of Arrival (OA)
- Penalty ratio = 1.5



M. R. Raza, et al., "Reinforcement Learning for Slicing in a 5G Flexible RAN," JLT, 2019.

ML and anomaly/attack management

Anomaly/attack management
- Detect/identify anomalies/attacks, based on monitoring data
- Performed over different networking layers

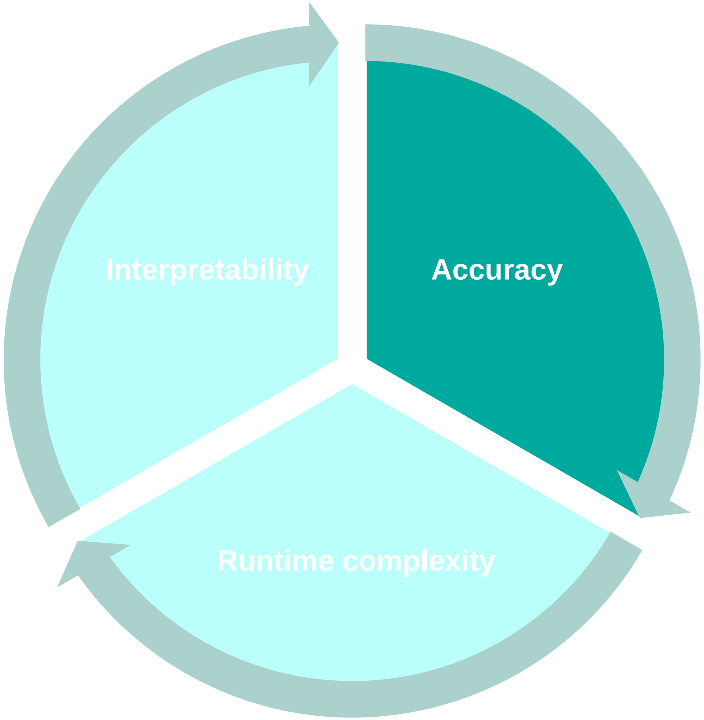
Anomalies
- Service degradation (bit rate, latency)
- Equipment degradation and malfunctioning
- Misconfiguration

Attacks*
- Service disruption attacks
- Disabling critical components
- Harmful signal insertion
- External polarization scrambling

Critical
- Accuracy
- Low false negative rate
  - No anomaly/attack remains undetected
- Low false positive rate
  - No unnecessary overhead spent on countermeasures

*M. Furdek, et al., “Machine learning for optical network security monitoring: A practical perspective,” IEEE/OSA JLT, April 2020.

ML for physical layer security



Aim:

Detect as many attacks as possible (reduce false negatives) with minimal likelihood of false alarms (caused by false positives)

Supervised learning

- A representative data set is collected, labeled and used to train the algorithm
- Complete information regarding what should be learned is available
- Fine-granular diagnostic info can be reported to the network management system
  - Presence of anomaly/attack, its type, intensity, or location

But:

- Anomalies/threats evolve and new ones emerge
- A representative data set is not always available
- Data labelling can be infeasible or too costly
- Complete information regarding what should be learned (e.g., normal/abnormal conditions) is not always available

Semi-supervised and unsupervised learning techniques can help!

M. Furdek, et al., "Machine learning for optical network security monitoring: A practical perspective," IEEE/OSA JLT, April 2020.

Unsupervised vs. semi-supervised learning

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Requirements:
- **No prior knowledge of attacks**
- **Only attack presence can be reported**

Semi-supervised learning

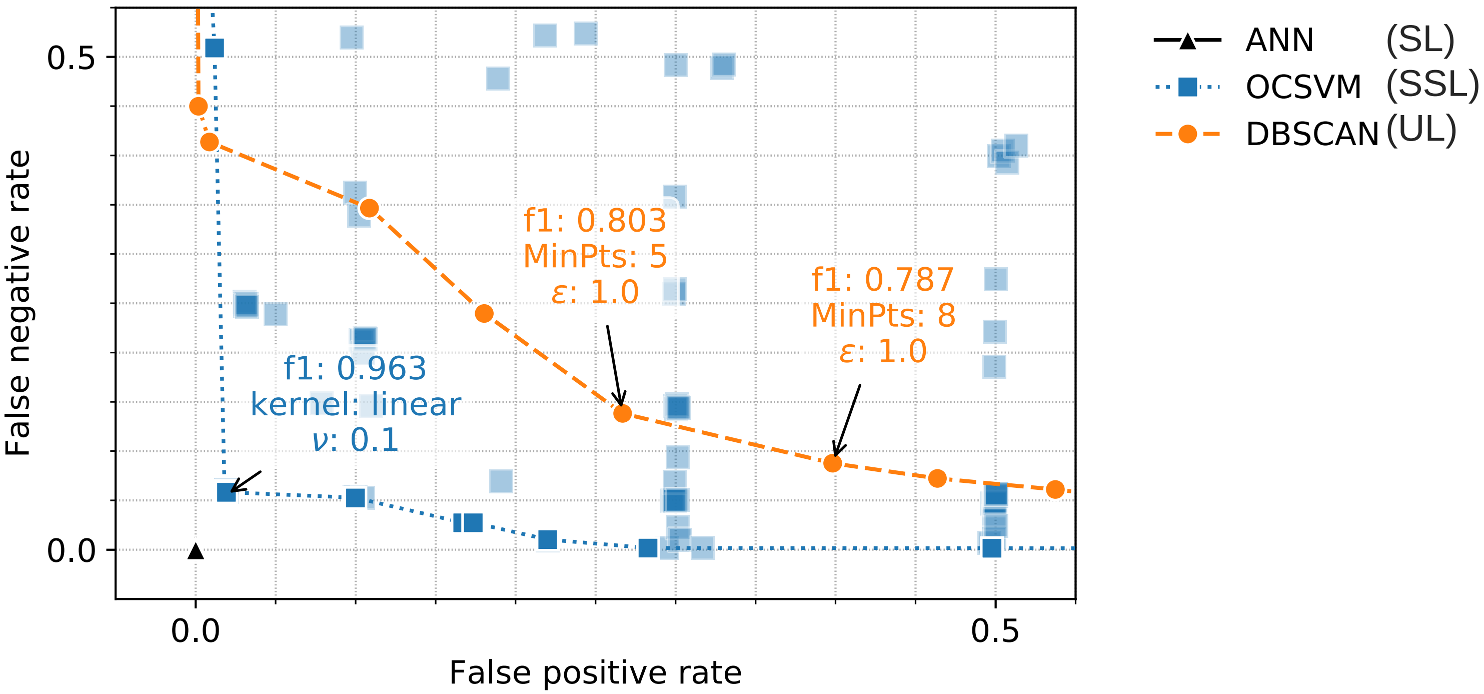
- **A small amount of data is labeled**
  - E.g. the normal operating conditions are known
- The algorithm is trained to detect outliers
- **One-class support vector machine (OCSVM)**
  - Infers the properties of normal cases and distinguishes them from abnormal ones

Unsupervised learning

- **No labeled data**
  - The dataset has no clear input/output nor strictly defined normal/abnormal conditions
- The algorithm learns to identify similarities among different inputs
- **Density-Based Spatial Clustering of Applications with Noise (DBSCAN)**
  - Monitoring samples are separated into clusters and outliers

M. Furdek, et al., “Machine learning for optical network security monitoring: A practical perspective,” IEEE/OSA JLT, April 2020.

Accuracy comparison



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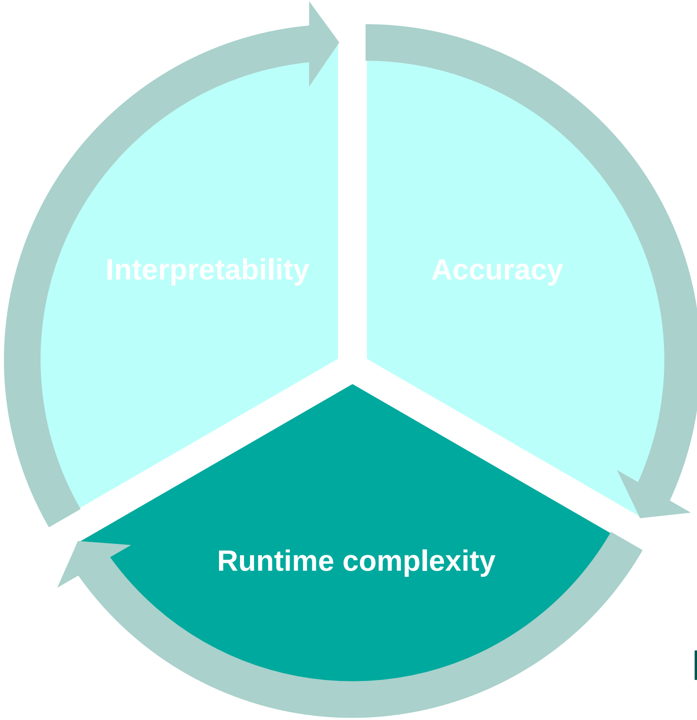
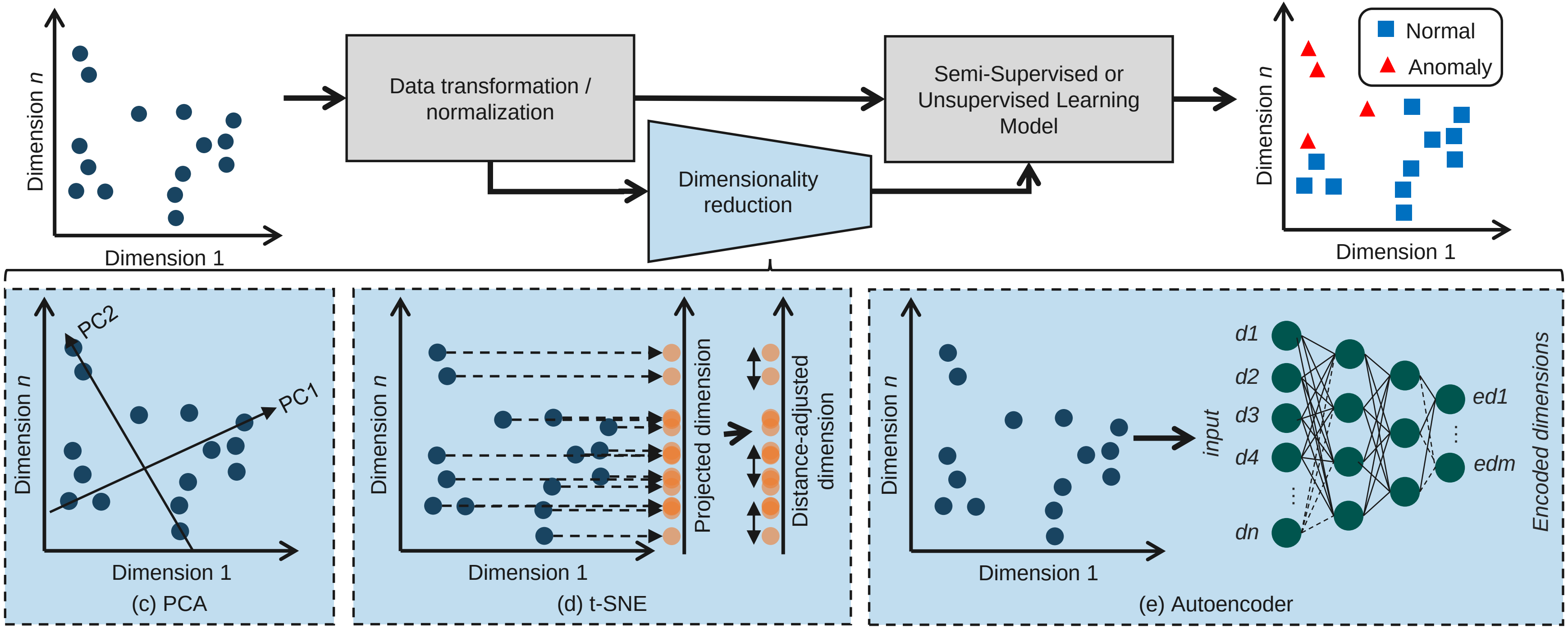
ML for physical layer security



Aim:

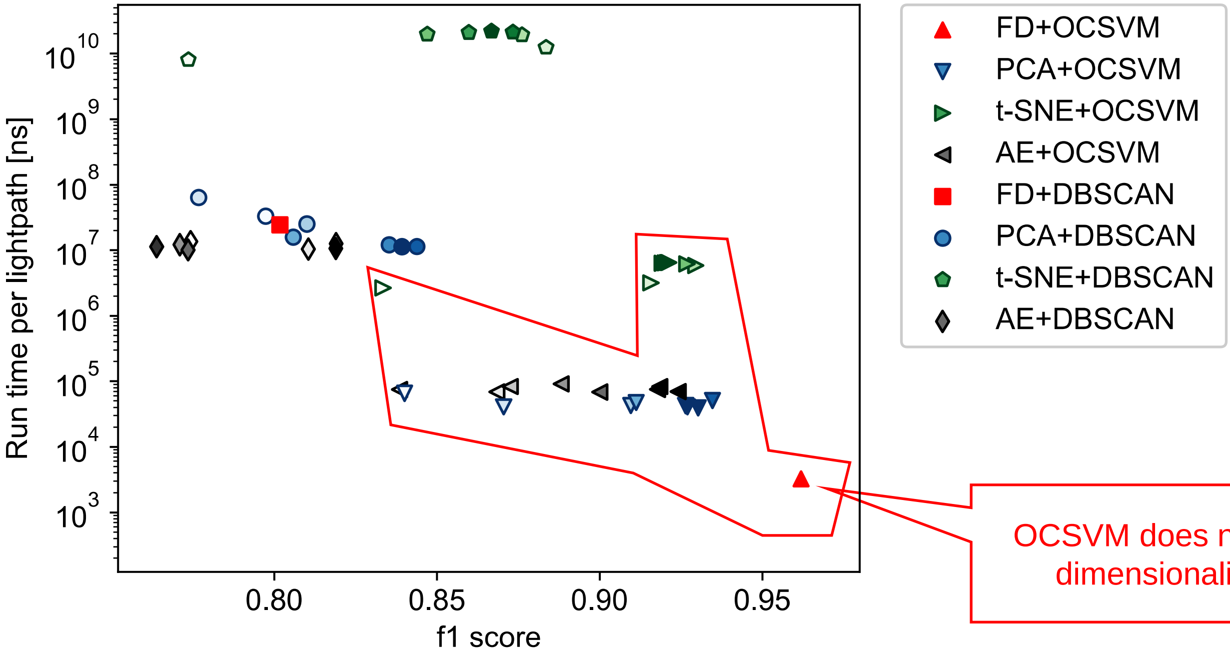
Reduce the processing load by using the most relevant dataset features

Dimensionality reduction



M. Furdek, et al., "Optical network security management: requirements, architecture, and efficient machine learning models for detection of evolving threats," JOCN, 2021.

Runtime improvement - all

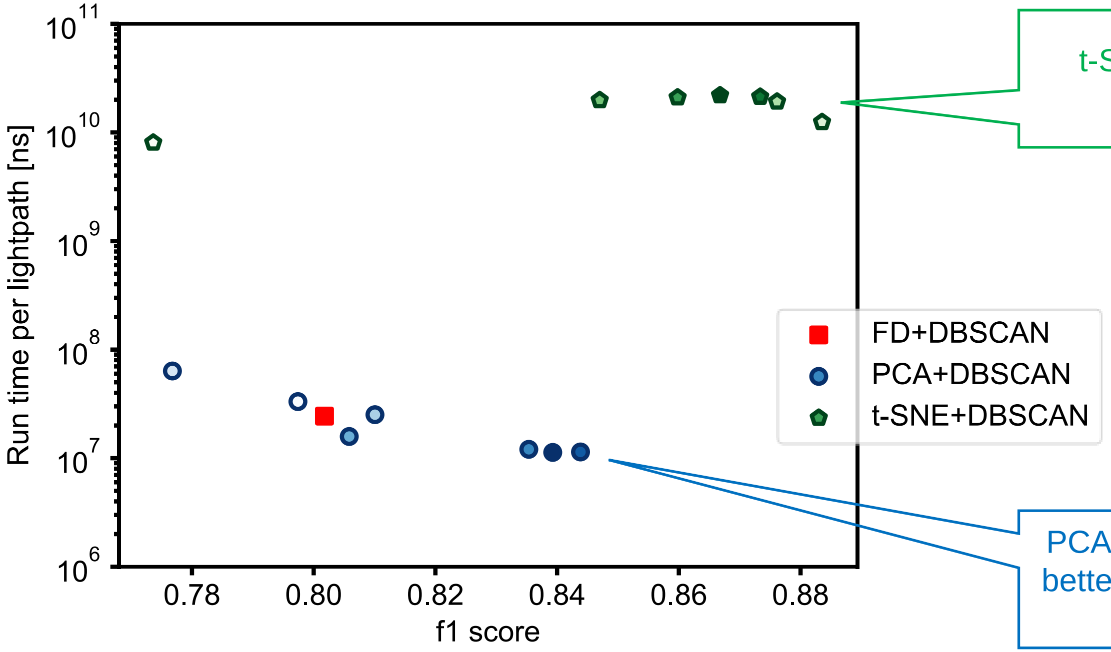


FD = full dataset

OCSVM does not benefit from dimensionality reduction

M. Furdek, et al., "Optical network security management: requirements, architecture, and efficient machine learning models for detection of evolving threats," JOCN, 2021.

Runtime improvement - DBSCAN



t-SNE + DBSCAN achieves much better accuracy

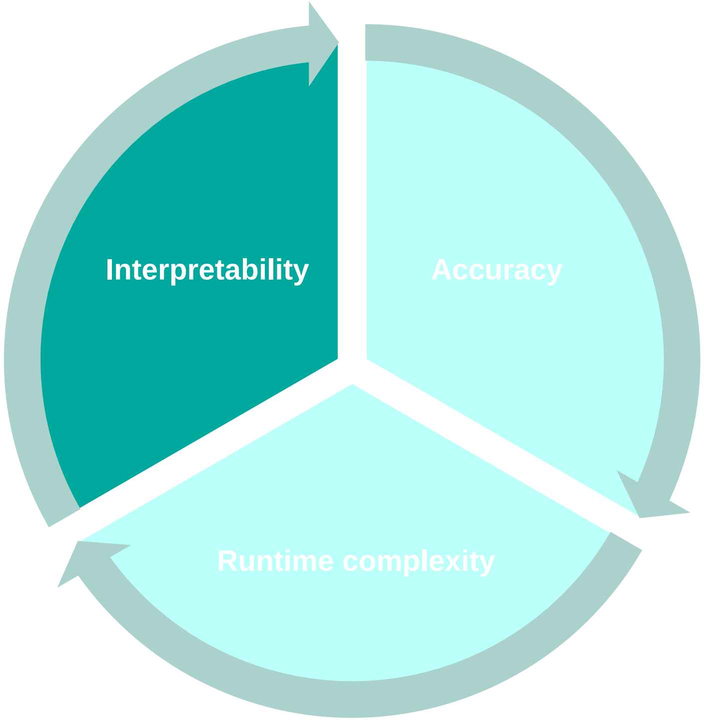
PCA + DBSCAN achieves much better accuracy, with reduction in run time

M. Furdek, et al., "Optical network security management: requirements, architecture, and efficient machine learning models for detection of evolving threats," JOCN, 2021.

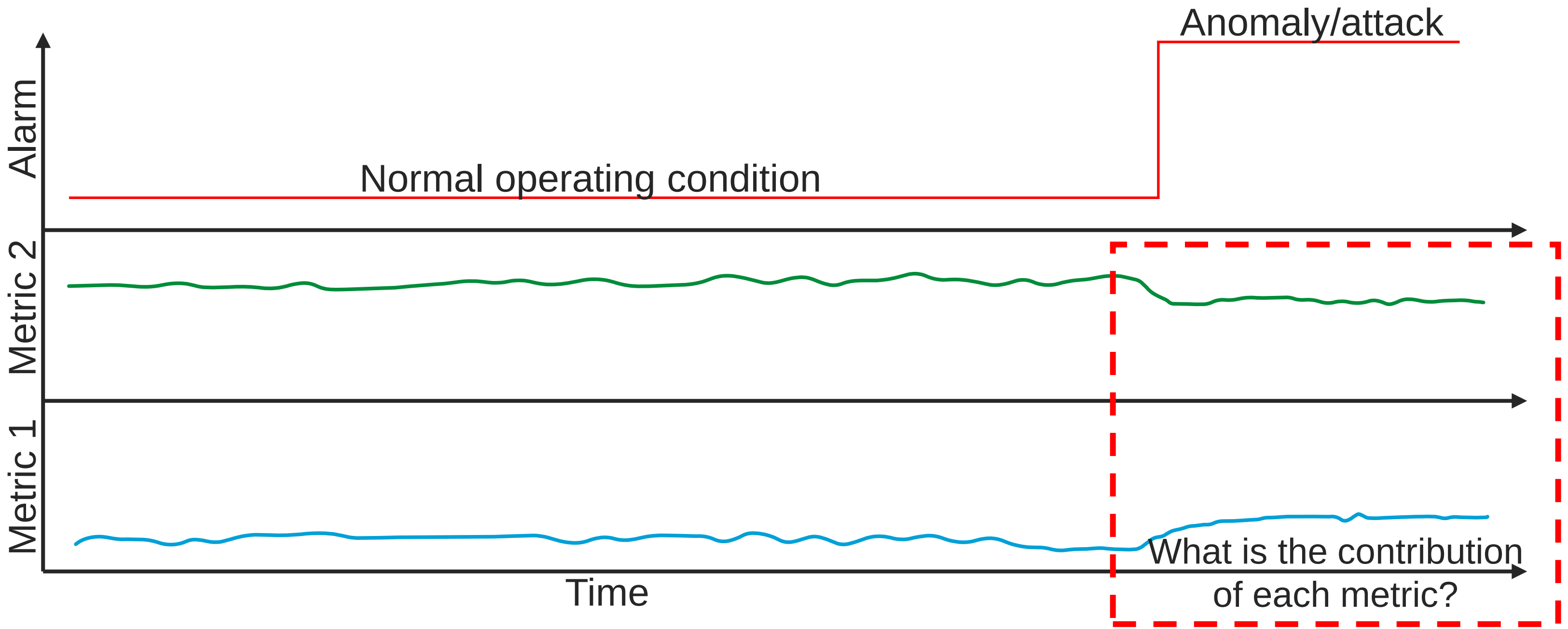
ML for physical layer security

Aim:

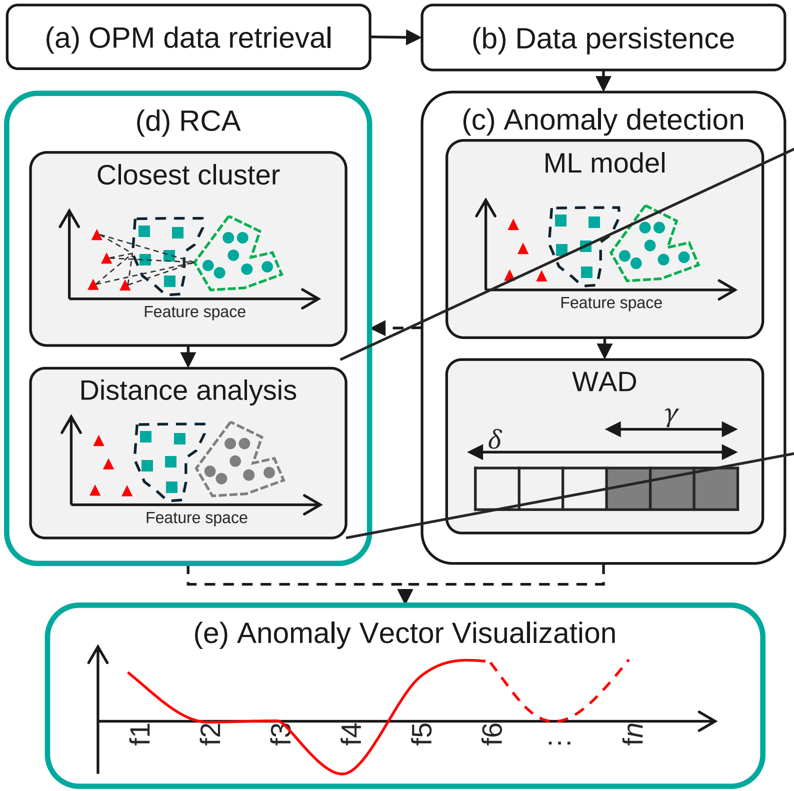
Expose the metrics (features) that motivated the algorithm to flag some condition as an *anomaly*

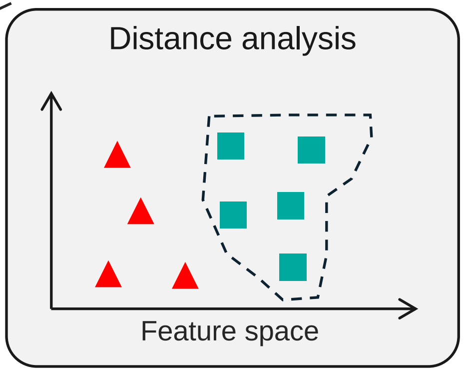


Why do we need interpretability



Root cause analysis framework





Metric i	μ Attack	μ Normal	AV_i
1	1.2	0.8	0.4
2	4.5	5.3	0.8
3	2.8	2.9	0.1

Examples of metrics: received signal power, bit rate, latency, jitter, queue length, etc.

C. Natalino, et al., "Root Cause Analysis for Autonomous Optical Networks: A Physical Layer Security Use Case," *ECOC*, 2020.

Other places where ML is used

- Traffic prediction
- Optical Routing and Spectrum Assignment
- Quality of Transmission (QoT) estimation
- Privacy-preserving models (federated learning)
- …

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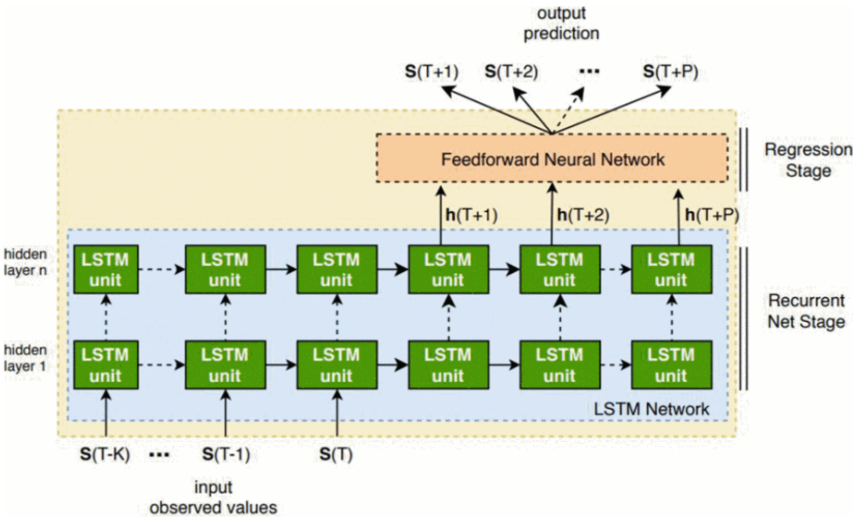

H. D. Trinh, et al., "Mobile Traffic Prediction from Raw Data Using LSTM Networks," PIMRC, 2018.

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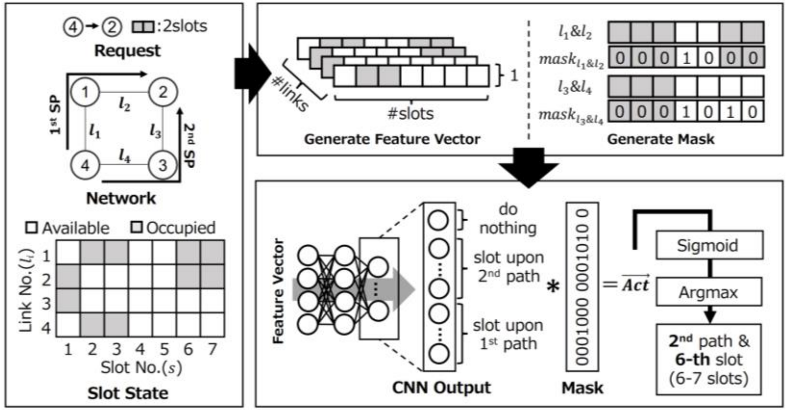

Fig. 1: Overview of Mask RSA inference with $K = 2$. Based on utilization of whole FSs and mask, Mask RSA decides path and FSs concurrently.

M. Shimoda, T. Tanaka, "Mask RSA: End-To-End Reinforcement Learning-based Routing and Spectrum Assignment in Elastic Optical Networks," ECOC, 2021.

Other places where ML is used

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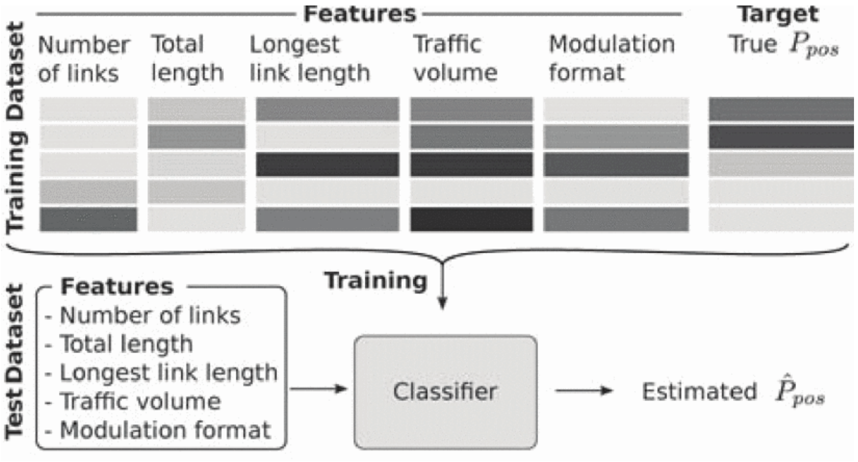

C. Rottondi, et al., "Machine-learning method for quality of transmission prediction of unestablished lightpaths," JOCN, 2018.

Other places where ML is used

- Traffic prediction
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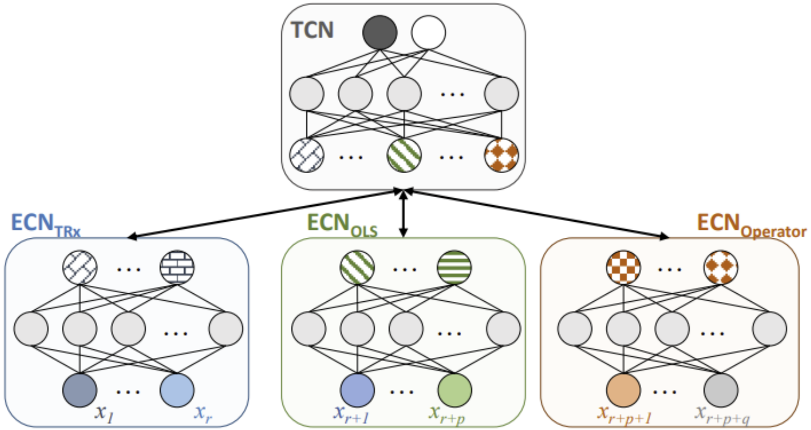

N. Hashemi, et al., “Vertical Federated Learning for Privacy-Preserving ML Model Development in Partially Disaggregated Networks,” ECOC, 2021.

Outline

- Open platforms and APIs
- Monitoring frameworks
- ML-based orchestration
  - Provisioning
  - Scheduling
  - Security
- $\boxed{\text{Open challenges}}$
- Conclusions

Some open challenges

Where to start and with which tasks? Decide use case of interest, and then the elements and functionalities that should be automated

Trust AI to act on the network autonomously? What's the level of human intervention? What skill will be required for network engineers?

Cost of retrieving data? Data availability, storage in the network elements for online access, cost of H/W and S/W are key elements

Confidentiality requirements. Which data to share among vendors and operators? How can this data sharing/data exchange be standardized?

How to perform E2E planning/operation of multi-domain networks in an automated context

Scalability with the number of services of the "knowledge loop"

Impact of network automation on other network KPIs (e.g., energy consumption)

Accountability and traceability of action taken

Network automation initiatives

- Network automation included in the **Horizon EU strategic plan** and in the 5G Infrastructure Association "**European Vision for the 6G Network Ecosystem**"
- *H2020 TeraFlow project* (https://www.teraflow-h2020.eu) is proposing cloud-native SDN controller able to cope with digital transformation challenges including techno economics
- *Celtic* launched *AI-NET* (Accelerating digital transformation in Europe by Intelligent NETwork automation - https://www.celticnext.eu/project-ai-net/) to strengthen industry position in secure cloud, data centre and artificial intelligence technologies

In summary

Virtualization, telemetry frameworks, AI, open architectures enable a paradigm shifts towards self driving networks

Potential benefits are evident:

- optimization of network resources
- better costumer experience
- flexible service portfolio and short time to market
- increase RoI

… but substantial work still needed:

- data availability
- standardized APIs
- security/privacy/accountability/traceability
- scalability

Success dictated not only by ability to overcome the technical challenges but also on how to best leverage the new businnes ecosystem that will be created

Acknowledgments

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People

- Andrea Di Giglio – Telecom Italia
- Marija Furdek – Chalmers
- Rehan Raza – KTH, now Ericsson
- Marco Schiano – Telecom Italia
- Peter Öhlen – Ericsson

Projects

- TeraFlow – H2020
- AI-NET Protect - CELTIC Plus
- AI-NET Aniara - CELTIC Plus
- Sendate Extend - CELTIC Plus
- Safeguarding Optical Communication Networks from Cyber-Security Attacks - VR
- Kista Backhaul (K5) – VINNOVA and Ericsson

TeraFlow

VINNOVA

AI-NET

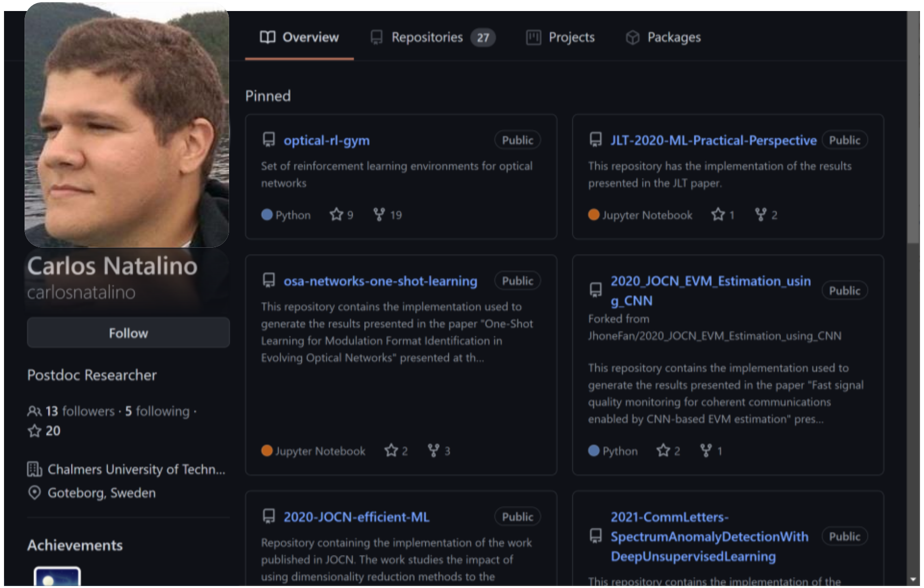
AI-NET-PROTECT

ANIARA

Gitub repository

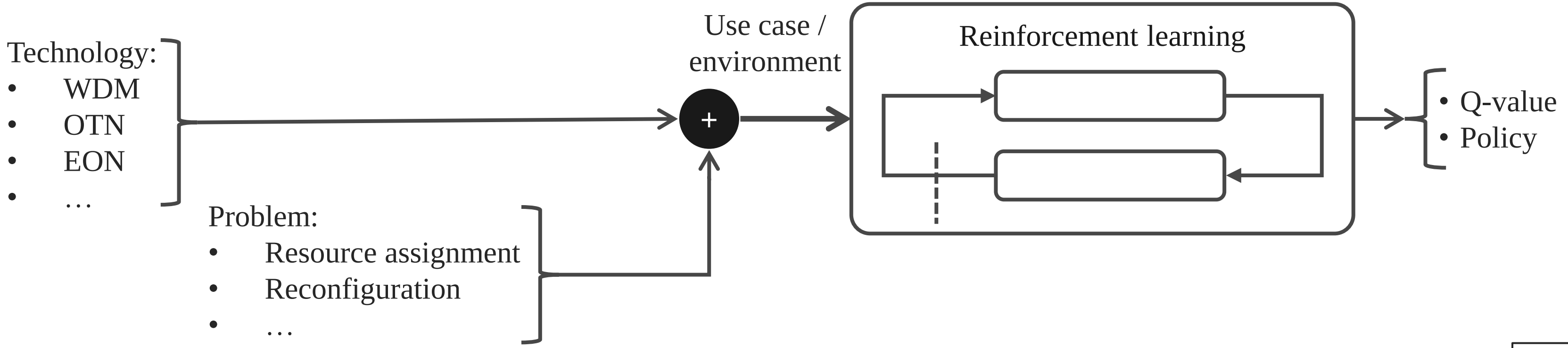
- Interested in reproducing some of the results presented so far?

- https://github.com/carlosnatalino



Optical RL-Gym

- Driven by the need of an open-source optical network environment
- Allows to implement different use cases for network performance optimization
- Built upon OpenAI Gym’s conventions/interface
  - Allows to use open-source RL agents
  - Easy and quick first steps towards RL research in optical networks



https://github.com/optical-rl-gym

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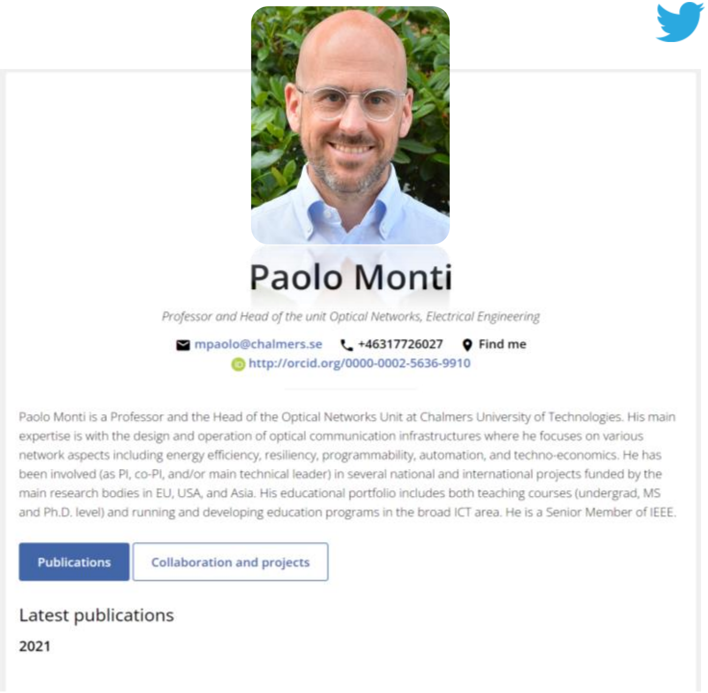
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Paolo Monti is a Professor and the Head of the Optical Networks Unit at Chalmers University of Technologies. His main expertise is with the design and operation of optical communication infrastructures where he focuses on various network aspects including energy efficiency, resiliency, programmability, automation, and techno-economics. He has been involved (as PI, co-PI, and/or main technical leader) in several national and international projects funded by the main research bodies in EU, USA, and Asia. His educational portfolio includes both teaching courses (undergrad, MS and Ph.D. level) and running and developing education programs in the broad ICT area. He is a Senior Member of IEEE.

Publications | Collaboration and projects

Latest publications

2021

https://www.chalmers.se/en/staff/Pages/Paolo-Monti.aspx

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Carlos Natalino is a postdoc with the Optical Networks Unit, focusing on the application of machine learning to telecommunication infrastructure problems. Among the main topics are the design and management of optical networks and cloud computing infrastructures, with special focus on resource and energy efficiency, security, reliability and survivability. He has been involved in several national and international projects funded by research bodies in EU and Brazil. He has also been involved in teaching computer programming courses in Brazil and Sweden. He is an IEEE member.

Teaching | Publications | Collaboration and projects

EEN060 and EEN065 - Applied object-oriented programming

- 2021 LP4 (EEN065): Course PM
- 2021 LP3 (EEN060): Course PM
- 2020 LP4 (EEN065): Course PM
- 2020 LP3 (EEN060): Course PM (requires login)

Page manager Published: Mon 14 Jun 2021.

https://www.chalmers.se/en/staff/Pages/Carlos-Natalino-Da-Silva.aspx

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Further readings

- C. Natalino, et al., "A Proactive Restoration Strategy for Optical Cloud Networks Based on Failure Predictions," *ICTON*, 2018.
- C. Natalino, et al., "Machine-Learning-Based Routing of QoS-Constrained Connectivity Services in Optical Transport Networks," OSA Networks, 2018.
- C. Natalino, et al., "Machine Learning Aided Orchestration in Multi-tenant Networks," SUM, 2018.
- H. D. Trinh, et al., "Mobile Traffic Prediction from Raw Data Using LSTM Networks," PIMRC, 2018.
- M. R. Raza, et al., "A Slice Admission Policy Based on Reinforcement Learning for a 5G Flexible RAN," ECOC, 2018.
- C. Rottondi, et al., "Machine-learning method for quality of transmission prediction of unestablished lightpaths," JOCN, 2018.
- X. Chen, et al., "DeepRMSA: A Deep Reinforcement Learning Framework for Routing, Modulation and Spectrum Assignment in Elastic Optical Networks," JLT, 2019.
- M. R. Raza, et al., "Reinforcement Learning for Slicing in a 5G Flexible RAN," JLT, 2019.
- M. Furdek, et al., "Machine Learning for Optical Network Security Monitoring: A Practical Perspective," in *JLT* 2020.
- C. Natalino, et al., "Root Cause Analysis for Autonomous Optical Networks: A Physical Layer Security Use Case," *ECOC*, 2020.
- X. Wang, et al., "Online feature selection for rapid, low-overhead learning in networked systems," CNSM, 2020.
- Marija Furdek, et al., "Optical network security management: requirements, architecture, and efficient machine learning models for detection of evolving threats," JOCN, 2021.
- C. Natalino, et al., "Spectrum Anomaly Detection for Optical Network Monitoring Using Deep Unsupervised Learning," in IEEE Commu. Letters, 2021.
- Harald Bock, “A path towards a Smart Zero-Touch Transport Network,” OFC, 2021.
- S. Neidlinger, “Real-life achievements and gaps in autonomous optical networks,” OFC, 2021.
- N. Ellsworth et al., "A Non-Proprietary Network Operations Platform for OpenROADM Environment," OFC, 2021.
- E. Le Rouzic et al., "Operationalizing partially disaggregated optical networks: An open standards-driven multi-vendor demonstration," OFC, 2021.
- N. Hashemi, et al., “Vertical Federated Learning for Privacy-Preserving ML Model Development in Partially Disaggregated Networks,” ECOC, 2021.
- R. Casellas et al., “Advances in SDN control for Beyond 100G disaggregated optical networks,” ECOC, 2021.
- M. Shimoda, T. Tanaka, “Mask RSA: End-To-End Reinforcement Learning-based Routing and Spectrum Assignment in Elastic Optical Networks,” ECOC, 2021.
- N. Hashemi, et al., “Vertical Federated Learning for Privacy-Preserving ML Model Development in Partially Disaggregated Networks,” ECOC, 2021.
- https://opennetworking.org/
- https://github.com/carlosnatalino/ and https://github.com/carlosnatalino/optical-rl-gym

12th International Conference on Network of the Future
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Coimbra, Portugal (Virtual Conference)

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Network automation: challenges, enablers, and benefits

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