Optical Network Automation and Programmability for 6G: State-of-the-Art, Vision, and Challenges

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Outline

Part 1

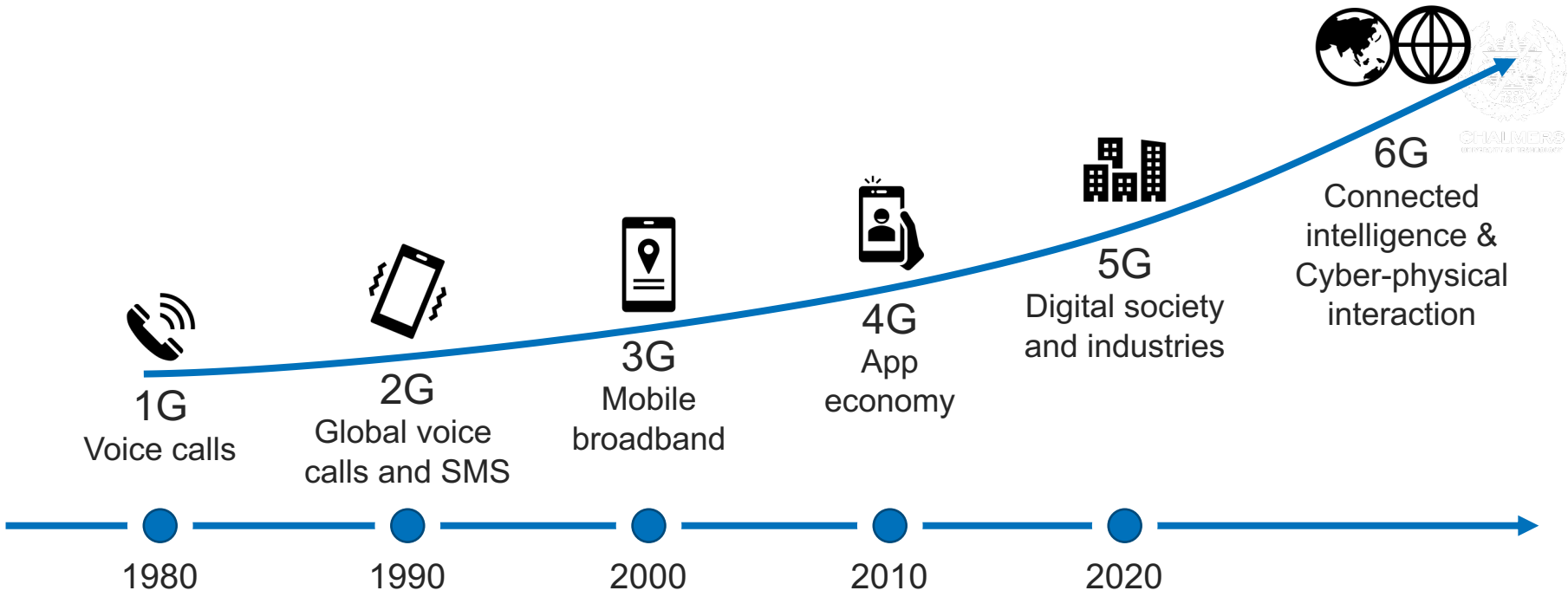
- Network generations
- 6G vision
- Use cases
- Representative architecture

Part 2

- Challenges
- State-of-the-art
  - Four representative works
- Concluding remarks

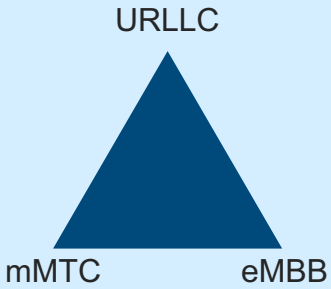
*The latest version of this slide set can be found here: https://research.chalmers.se/en/publication/537646

Network generations



*Wolfgang John, “The journey towards 6G: Going beyond connectivity services,” IEEE NetSoft, Madrid, Spain, June 2023.

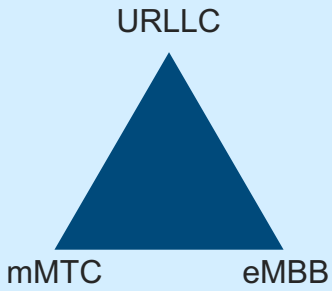
From 5G to 6G



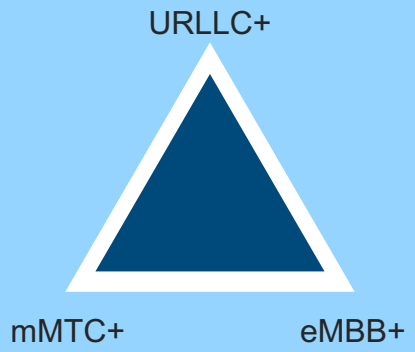
5G

*Wolfgang John, “The journey towards 6G: Going beyond connectivity services,” IEEE NetSoft, Madrid, Spain, June 2023.

From 5G to 6G



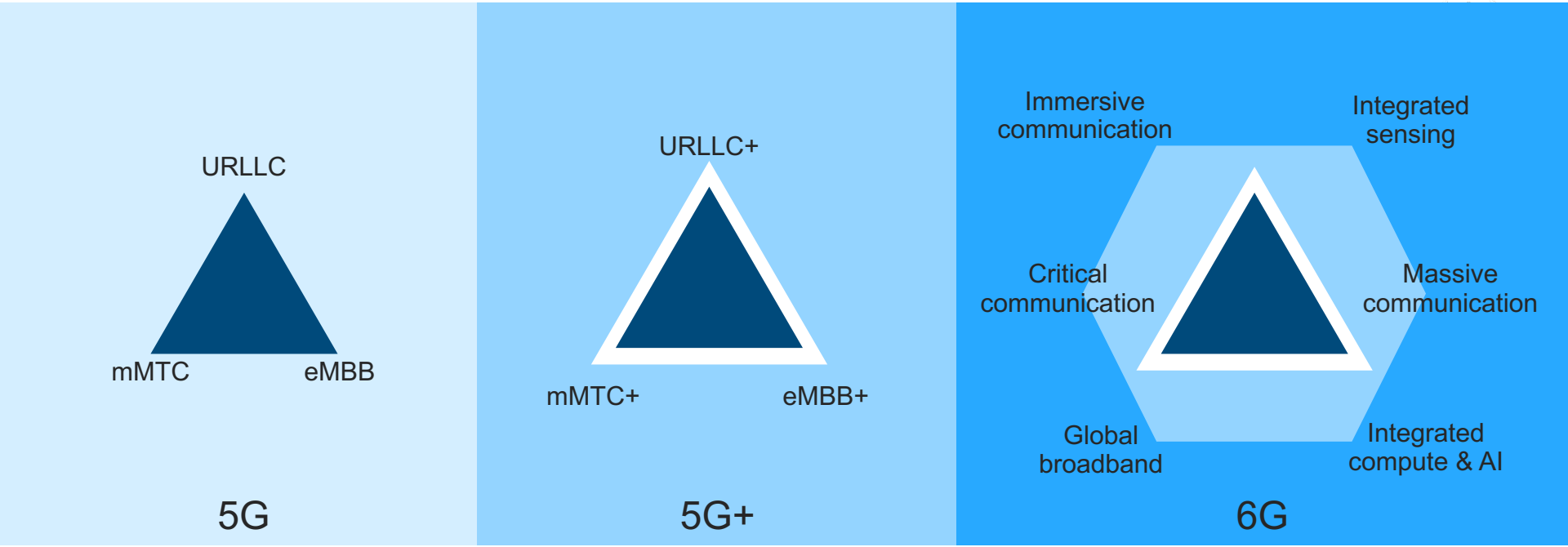
5G



5G+

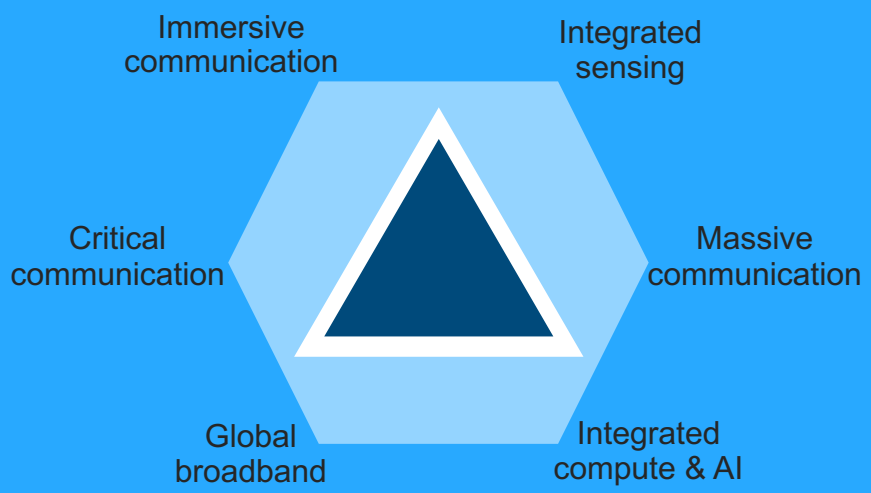
*Wolfgang John, “The journey towards 6G: Going beyond connectivity services,” IEEE NetSoft, Madrid, Spain, June 2023.

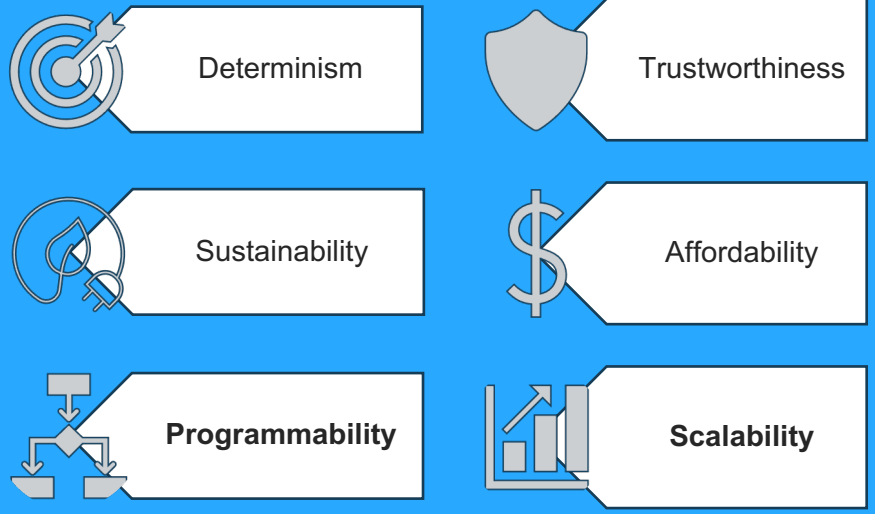
From 5G to 6G



*Wolfgang John, “The journey towards 6G: Going beyond connectivity services,” IEEE NetSoft, Madrid, Spain, June 2023.

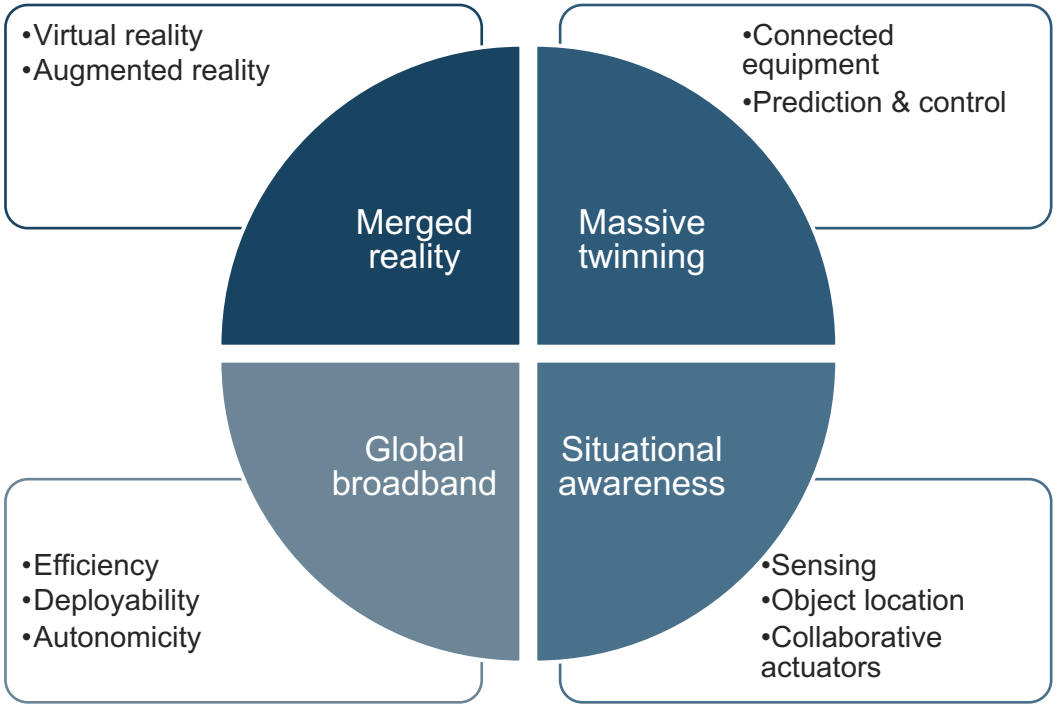
6G vision





*Wolfgang John, “The journey towards 6G: Going beyond connectivity services,” IEEE NetSoft, Madrid, Spain, June 2023.
** European Vision for the 6G Network Ecosystem

Use cases



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Representative architecture

End-to-end apps & optimization

Multi-Domain Telemetry & Optimization

Client Apps

...

AI/ML Network Optimization

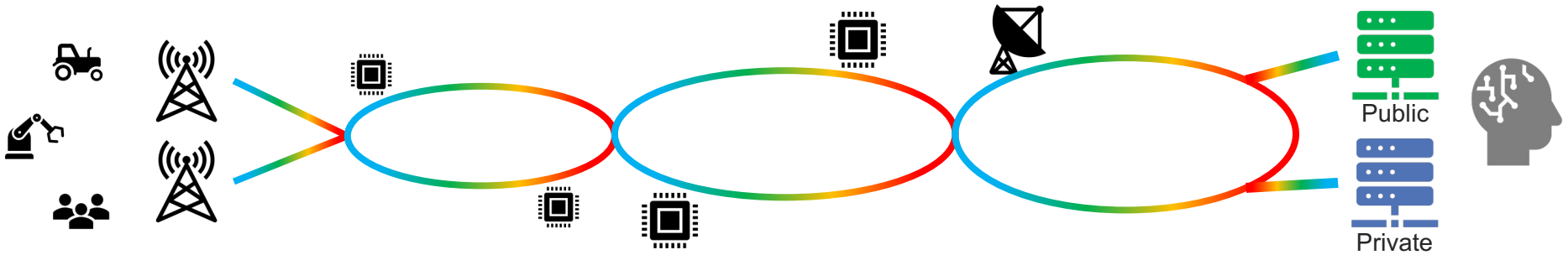
Control & orchestration

Wireless Domain Controller(s)

IP/Packet Domain Controller(s)

Optical Domain Controller(s)

Cloud Domain Controller(s)

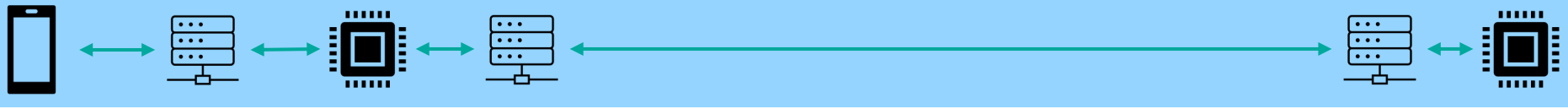


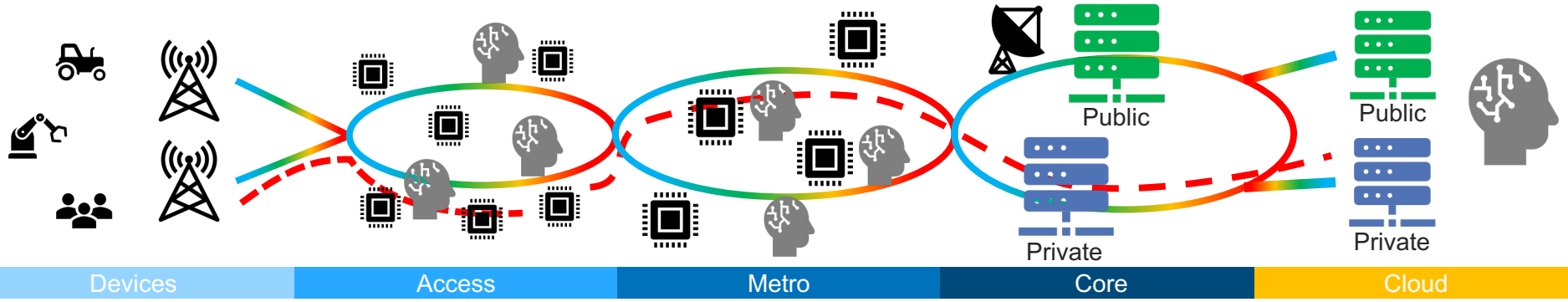
Devices | Access | Metro | Core | Cloud

App connectivity

Traditional – Each domain switches at the packet layer to reach a centralized processing pool

Edge-based – Each domain switches at the packet layer





Representative architecture

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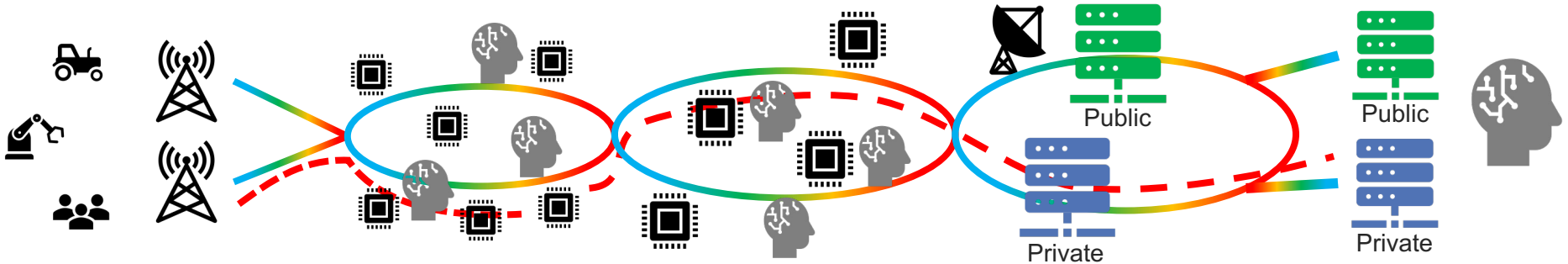
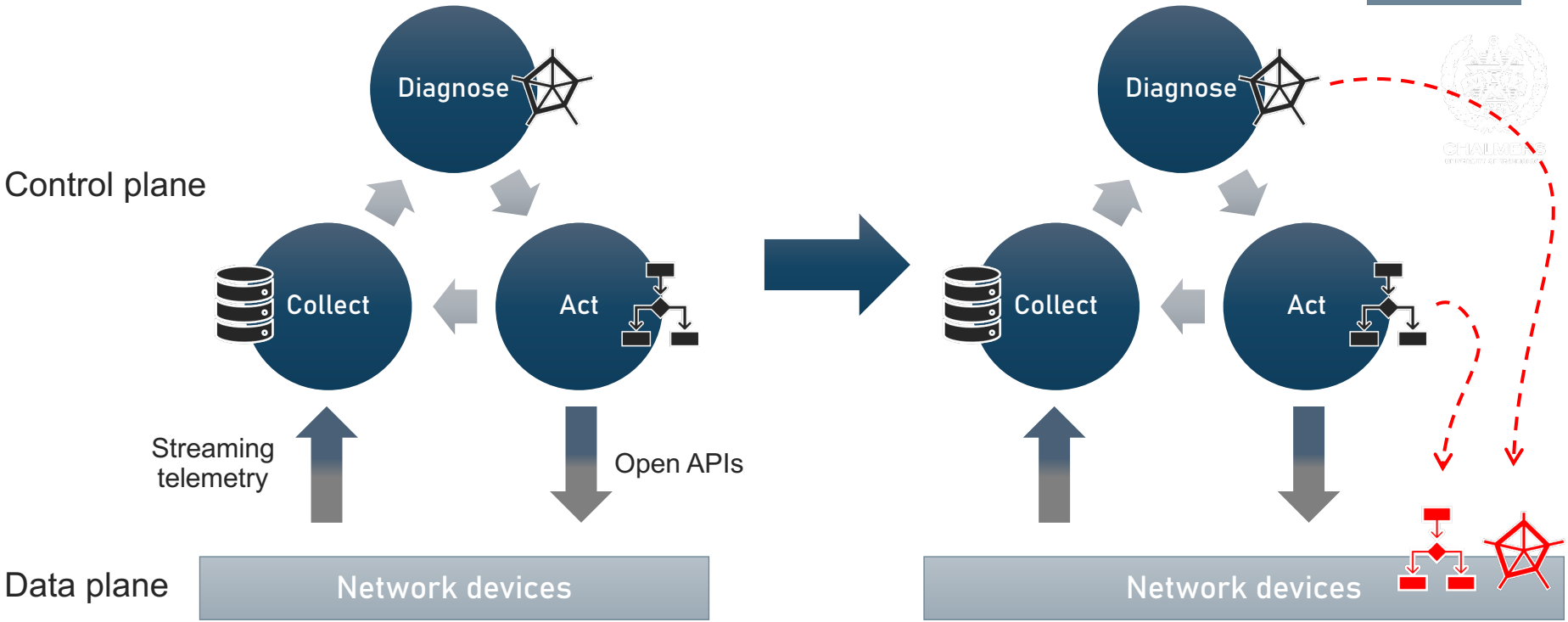


Network automation & programmability



*Achim Autenrieth, “Carrier Grade AI/ML for Network Automation”, invited talk, OFC 2022, 9 March 2022

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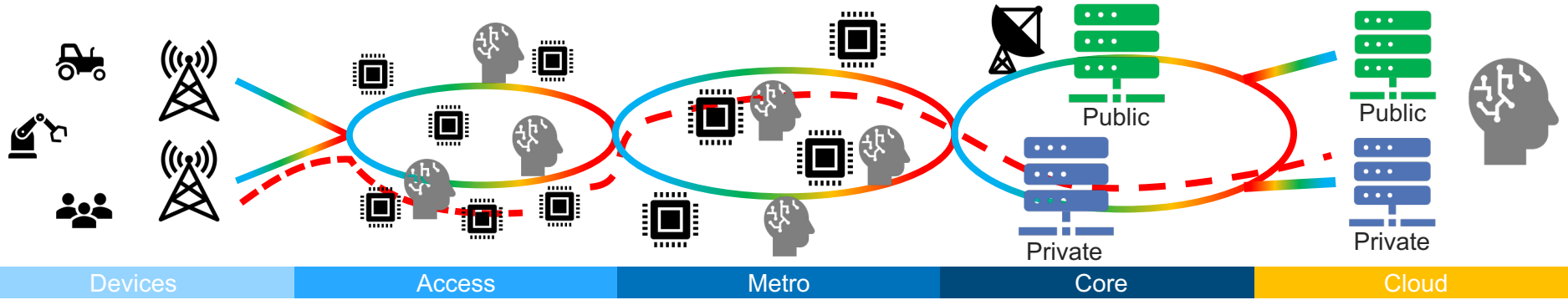
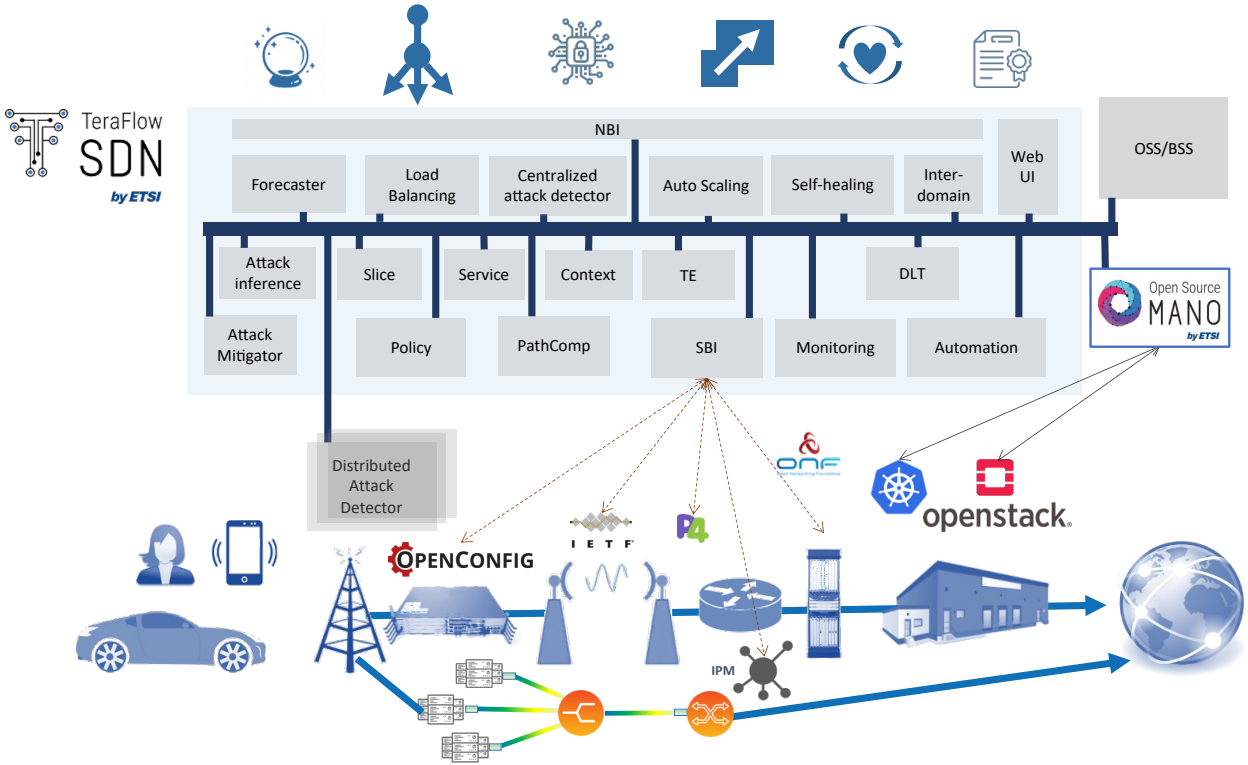
Automatic provisioning and operation

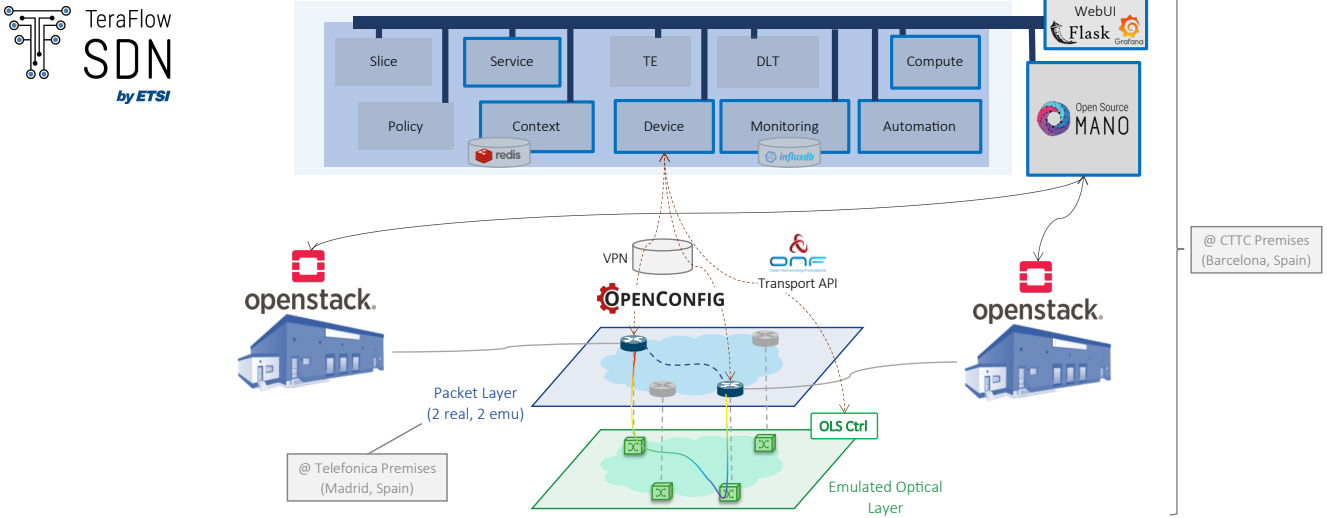
- **Key aspects:**
  - Automatic provisioning
  - Monitoring and response
  - Distributed telemetry & control



Scalable SDN Controller

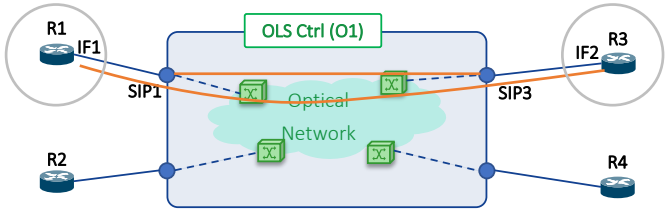


Automatic provisioning



*LI. Gifre, et al., "Demonstration of Zero-touch Device and L3-VPN Service Management using the TeraFlow Cloud-native SDN Controller, OFC, 2022

Automatic provisioning



OLS Ctrl configuration set used to populate TAPI data model templates:

Key	Value
/service[svc-uuid]	input_sip: SIP1, output_sip: SIP3, layer_protocol_name: PHOTONIC_MEDIA, direction, capacity_unit, capacity_value, …

Packet router R1 configuration set used to populate OpenConfig data model templates:

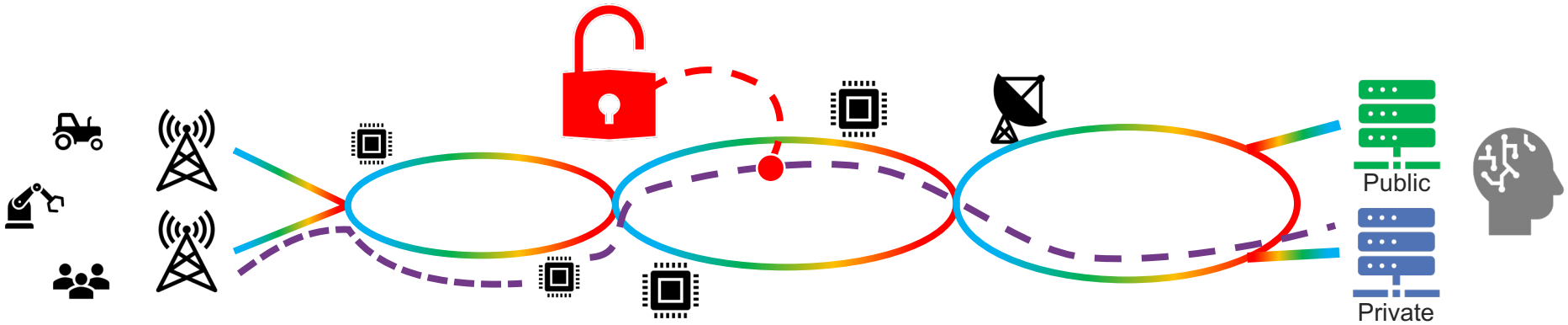
Key	Value
/interface[13/2/1]	mtu: 1512
/interface[13/2/1]/subinterface[400]	vlan_id: 400, address_ip: 3.3.2.1, address_prefix: 24
/net_inst[svc-uuid]	type: L3VRF, route_distinguisher: 65000:100
/net_inst[svc-uuid]/interface[13/2/1.400]	interface: 13/2/1, subinterface: 400
/net_inst[svc-uuid]/proto[DIRECT_CONN]	-
/net_inst[svc-uuid]/proto[STATIC]	-
/net_inst[svc-uuid]/proto[BGP]	as: 65000
/net_inst[svc-uuid]/table_conn[DIRECT_CONN][BGP][IPV4]	-
/net_inst[svc-uuid]/table_conn[STATIC][BGP][IPV4]	-
/routing_policy/bgp[rt_import]	-
/routing_policy/bgp[rt_import][route-target:65000:333]	-
/routing_policy/definition[import]/statement[3]	ext_community: rt_import, match: ANY, policy: ACCEPT_ROUTE
/net_inst[pkt-svc-uuid]/inter_instance_policies[import]	-
[last 4 repeated for export policies]	

*LI. Gifre, et al., “Demonstration of Zero-touch Device and L3-VPN Service Management using the TeraFlow Cloud-native SDN Controller, OFC, 2022

Monitoring and response

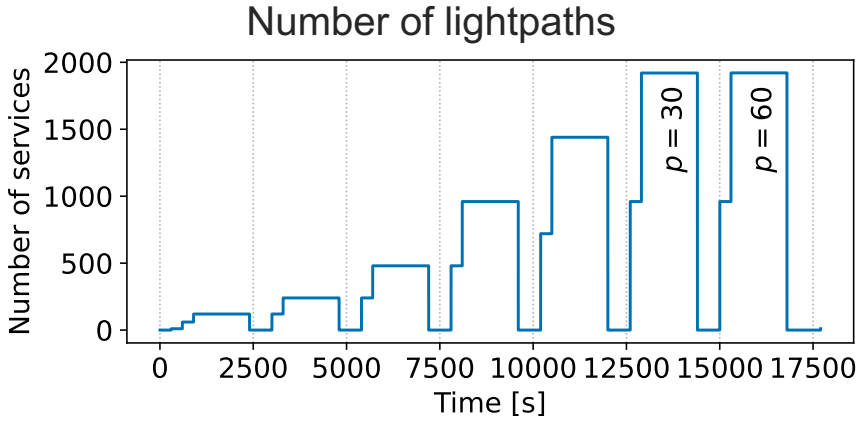
The network must respond to failures and threats

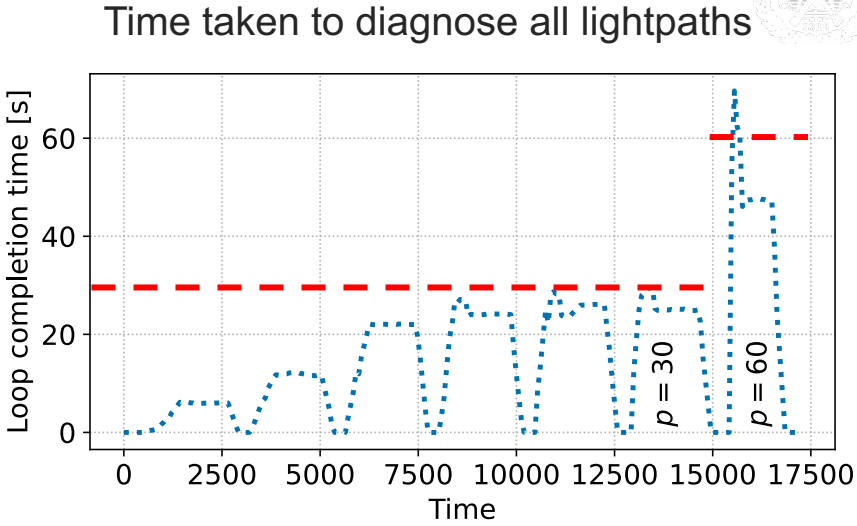
- Physical layer attacks
- Misconfiguration
- Failures



Monitoring and response

Representative results



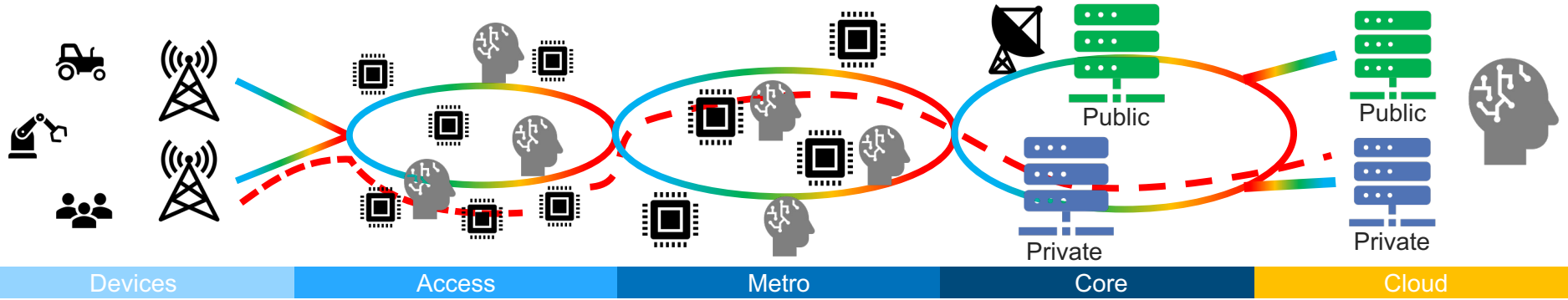


p ➔ Target loop time

* C. Natalino et al., "Flexible and scalable ML-based diagnosis module for optical networks: a security use case [Invited]," JOCN, 2023.

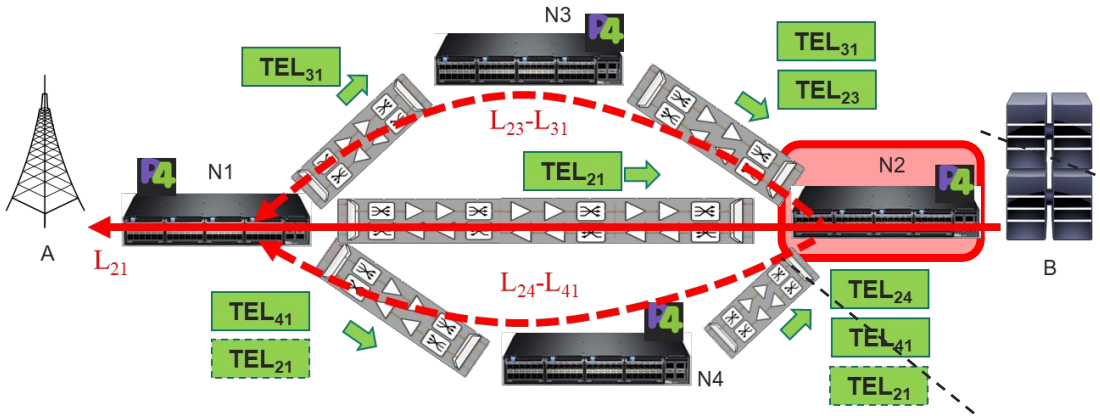
Distributed telemetry & control

- **The network needs fast response to soft failures**
  - Decision can be made locally
  - Outer loop (e.g., ML-based) can decide thresholds



Distributed telemetry & control

Proposed solution

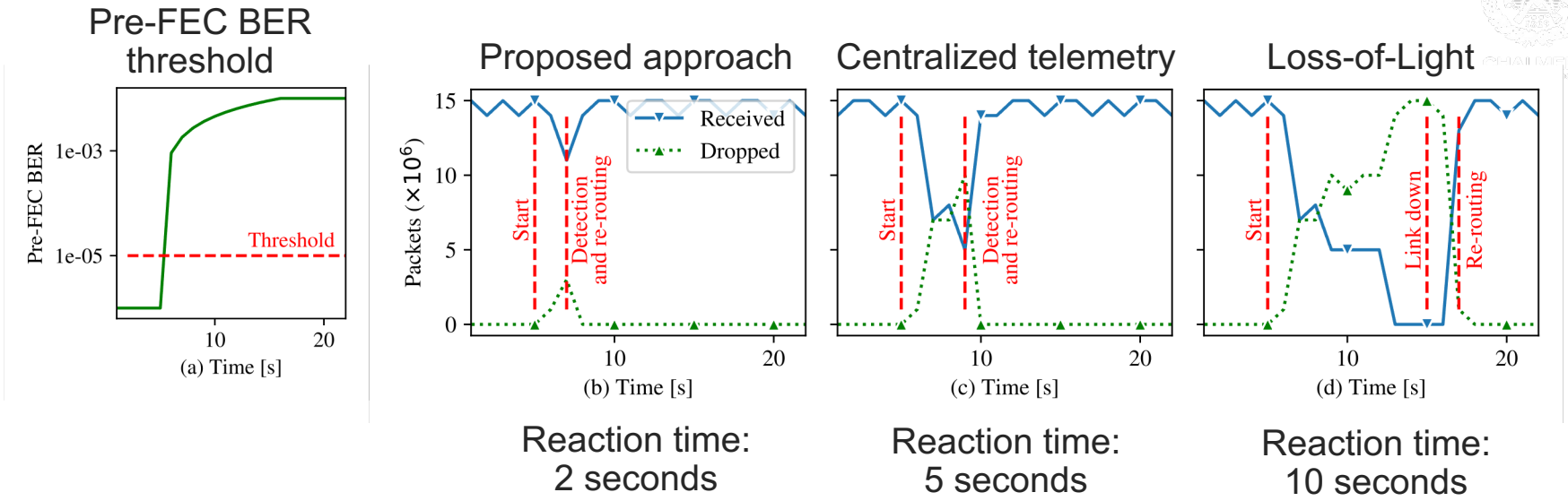


if $Q_{L_{21}} \geq T_{L_{21}}$ **then**
  $do\_nothing()$
else if $Q_{L_{23}} \geq T_{L_{23}} \wedge Q_{L_{31}} \geq T_{L_{31}} \wedge max(B_{L_{23}}, B_{L_{31}}) \geq max(B_{L_{24}}, B_{L_{41}})$ **then**
  $use\_route(L_{23}, L_{31})$
else if $Q_{L_{24}} \geq T_{L_{24}} \wedge Q_{L_{41}} \geq T_{L_{41}} \wedge max(B_{L_{24}}, B_{L_{41}}) > max(B_{L_{23}}, B_{L_{31}})$ **then**
  $use\_route(L_{24}, L_{41})$
end if

* F. Cugini, et al., "P4-based Telemetry Processing for Fast Soft Failure Recovery in Packet-Optical Networks," OFC, 2023, M1G.2.

Distributed telemetry & control

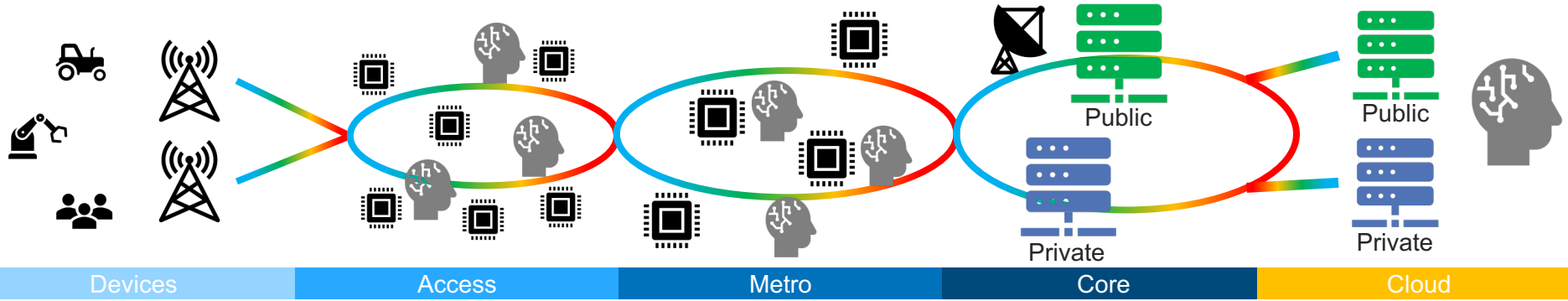
Performance assessment



* F. Cugini, et al., "P4-based Telemetry Processing for Fast Soft Failure Recovery in Packet-Optical Networks," OFC, 2023, M1G.2.

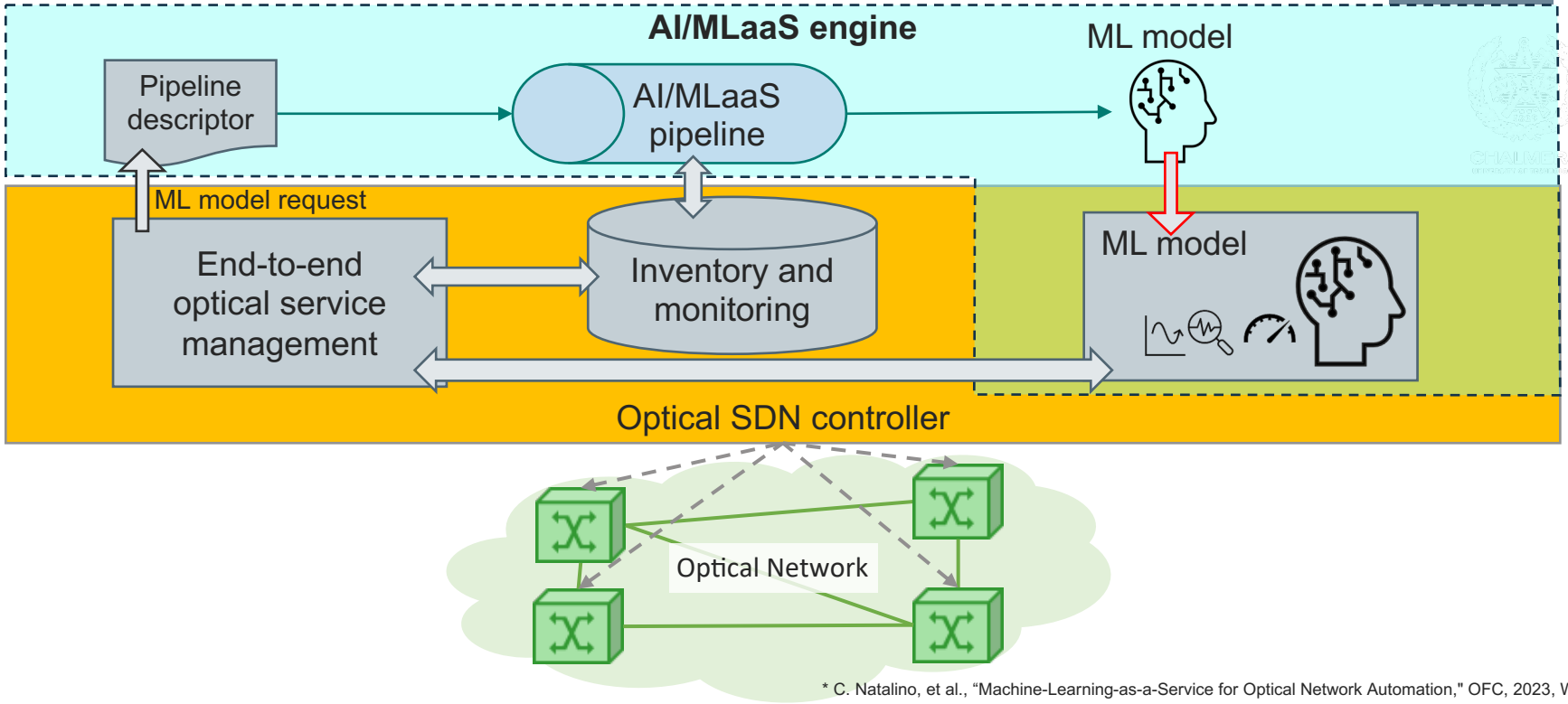
Ubiquitous AI/ML

- **Current way of building, deploying and maintaining AI/ML models is not scalable**
  - Numerous empirical decisions
  - Per-task model engineering
  - Model-specific workflows



Ubiquitous AI/ML

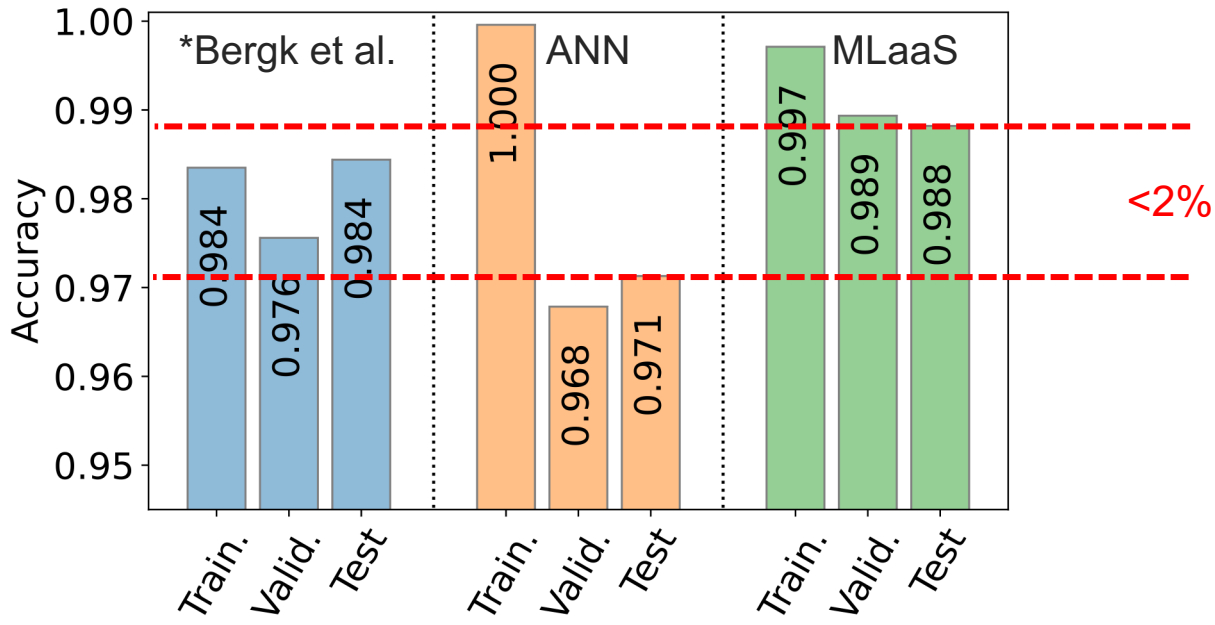
AI/ML-as-a-Service



* C. Natalino, et al., “Machine-Learning-as-a-Service for Optical Network Automation," OFC, 2023, W4G.3.

Ubiquitous AI/ML

Preliminary results



* G. Bergk et al., JOCN, 14, 43–55 (2022). DOI: 10.1364/JOCN.442733.
** C. Natalino et al., OFC, W4G.3, 2023.

Open questions

How can we make ***network services more accessible*** to the customers?

How can we fully realize ***self-driving multi-layer multi-domain networks***?

How can we ensure the ***security and privacy of the control plane*** when adding automation?

Can current ***open platforms and standards*** handle upcoming technologies?

How can we increase the ***added value*** of network services?

Final remarks

- Optical networks are the ultimate technology for network slicing
  - Important milestones have been achieved over the past few years
  - Complexities and specificities of the physical layer need attention
- The role of AI/ML needs to be better understood
  - Trustworthiness, explainability, accountability, etc.
- Open APIs need continuous updates
  - Follow latest device developments
  - Enable advanced use cases

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- Achim Autenrieth
- Wolfgang John
- Ali Balador

- Celtic-Next projects AI-NET-PROTECT and AI-NET-ANIARA
- TeraFlow H2020
- Chalmers' ICT Area of Advance

CELTIC-NEXT
Next Generation Telecommunications

AI-NET-PROTECT

AI-NET-ANIARA

TeraFlow

TeraFlow SDN by ETSI

ICT, digitalisation and AI
Aiming for a smarter, safer society.

VINNOVA
Sweden's Innovation Agency

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References and further reading

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- F. Cugini, et al., “P4-based Telemetry Processing for Fast Soft Failure Recovery in Packet-Optical Networks,” OFC, San Diego, CA, USA, 2023. DOI: 10.1364/OFC.2023.M1G.2.
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Thank you! ☺

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Thank you! ☺

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