Evolution of Optical Solutions to Support Fixed and Mobile Broadband Access Networks: A Research Perspective

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Outline

- The vision
- From convergence to confluence
- Confluent transmission technologies
- Autonomous networks
- Summary

The vision

Fixed networks based on flexible and scalable high-capacity transmission technologies that form mesh edge networks

- Ultra high availability
- Ultra low latency
- High energy-efficiency
- AI-native orchestration across mobile, fixed, and compute domains
- Autonomous network (zero touch)

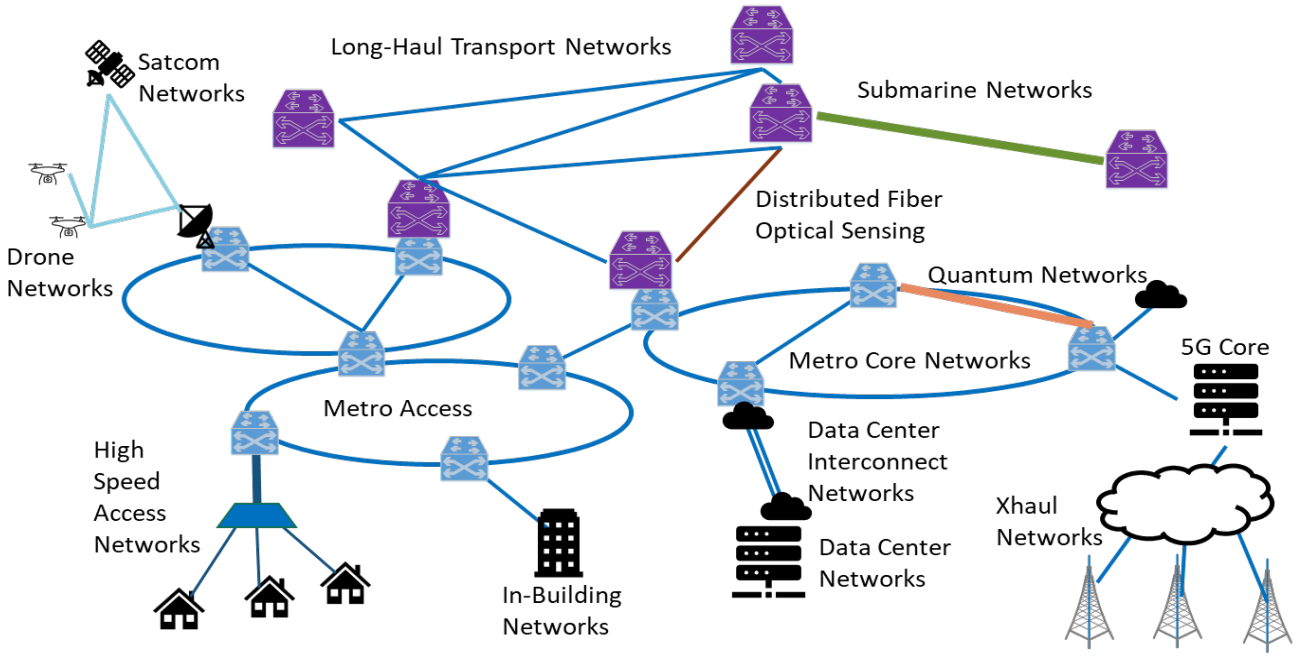
Flexible coexistence of:

- Analog and digital communication signals
- Sensing and communication signals

Mesh networking at the edge enabled by a seamless “confluence” of:

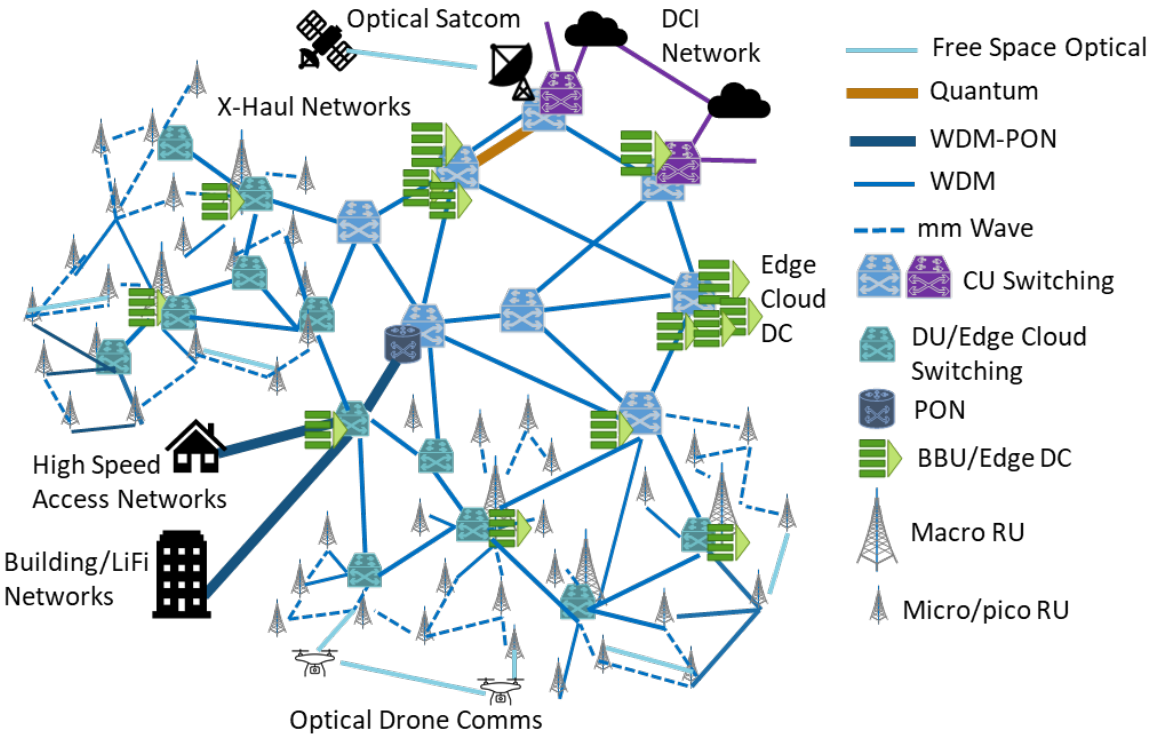
- Radio fixed wireless (RFW) – mmWave / (sub-) THz
- Free space optical (FSO)
- Flex-WDM transport using optical-spectrum-as-a-service (OSaaS)
- Integrated sensing and communication (ISAC) – fibre sensing

Example of different types of optical networks today



Vision: IEEE Future Network Roadmap
Access-edge with a unified mesh

- From broadband access to **AI backbone**
- **On-demand mesh** all the way to the edge
- **Multiple technologies** together: mmWave/THz + Fiber + FSO
- Low latency through path diversity to edge compute
- End-to-end **energy**, **latency** & **capacity**-optimized



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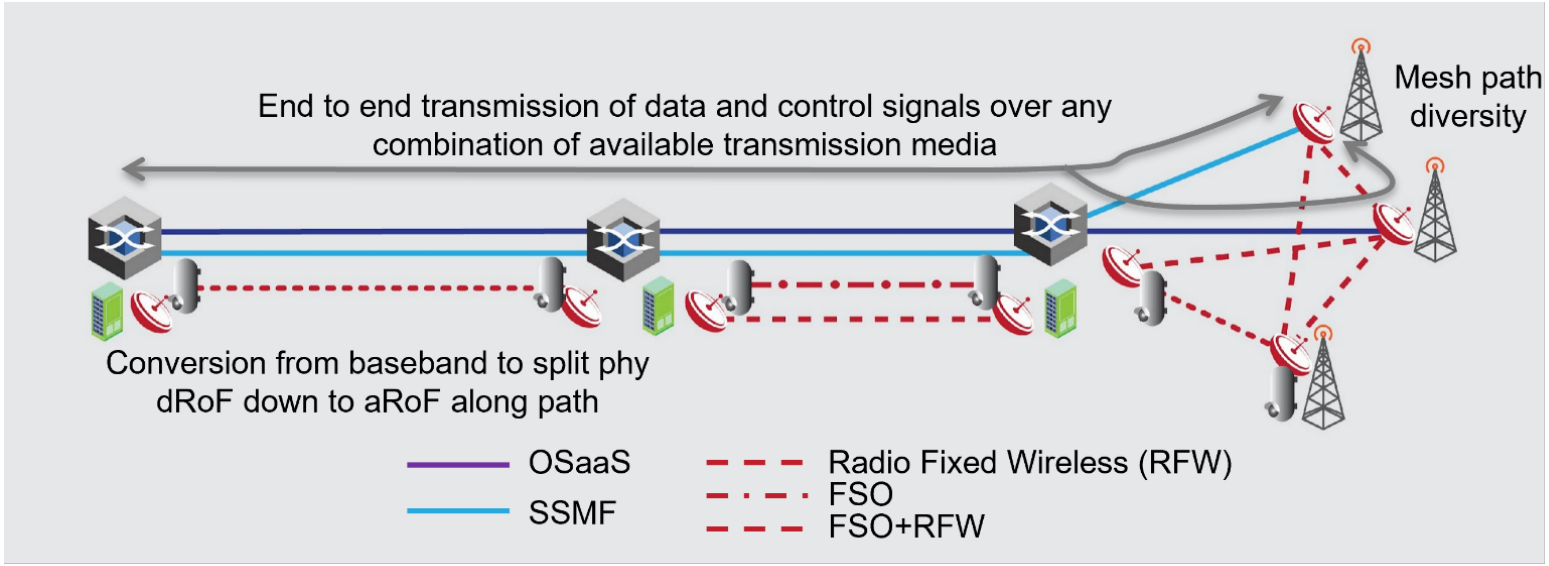
From convergence to confluence

Confluent transmission refers to a system that natively supports multiple transmission media and their signals as opposed to just a convergence of the enabling technologies.



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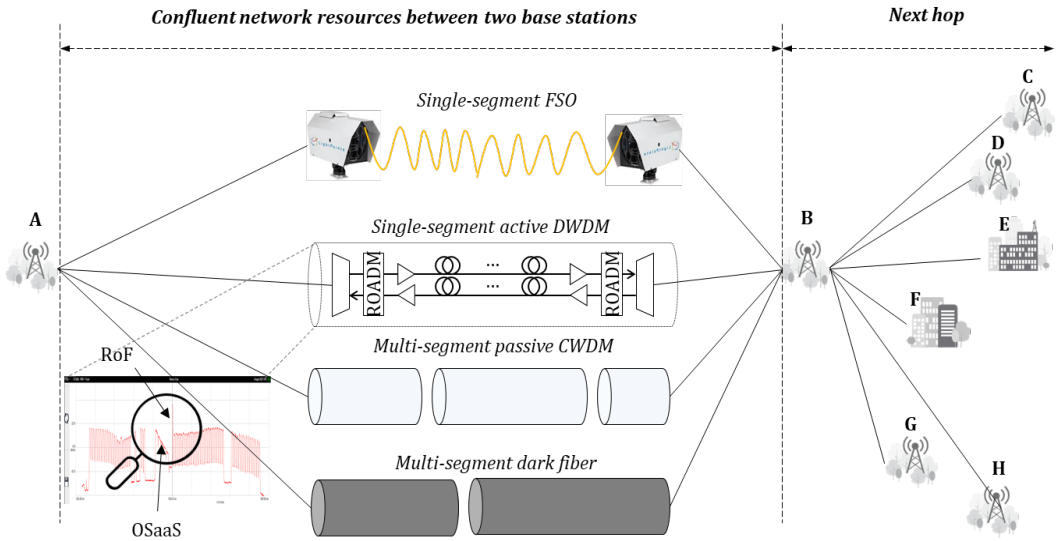
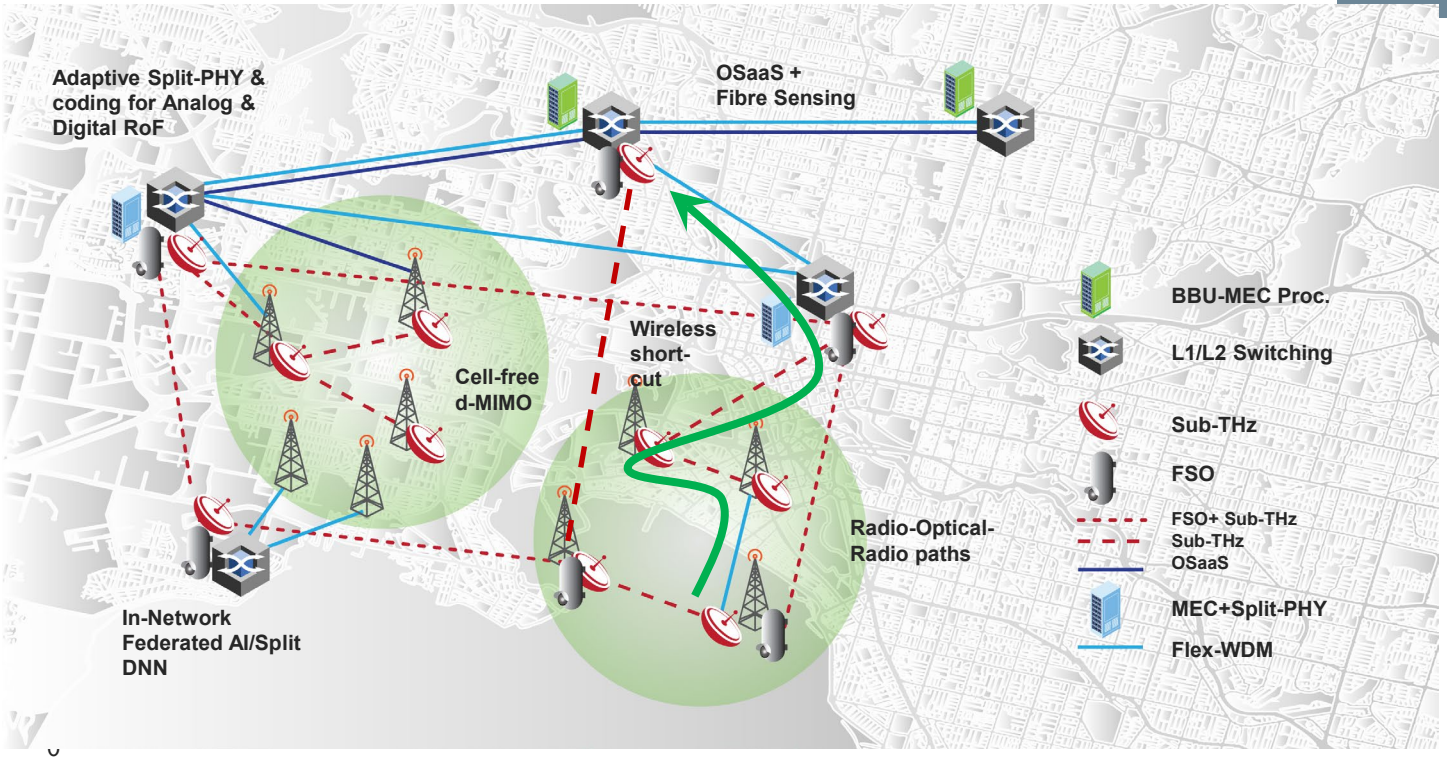
Confluent transmission technologies

- Plasmonic sub-THz link fixed wireless
  - 190-350 GHz (Y. Horst, et. al. OFC 2021)
  - 1 Tb/s @ 1 km
- FSO fixed wireless
  - 1 Tb/s @ 1 km
- Hybrid THz/FSO
  - Compensating atmospheric effects
- Fibre Spectrum Services (OSaaS)
  - Analog, digital, sensing
  - (K. Kaeval, et. al. JOCN 2022)



On demand wireless-wireline mesh



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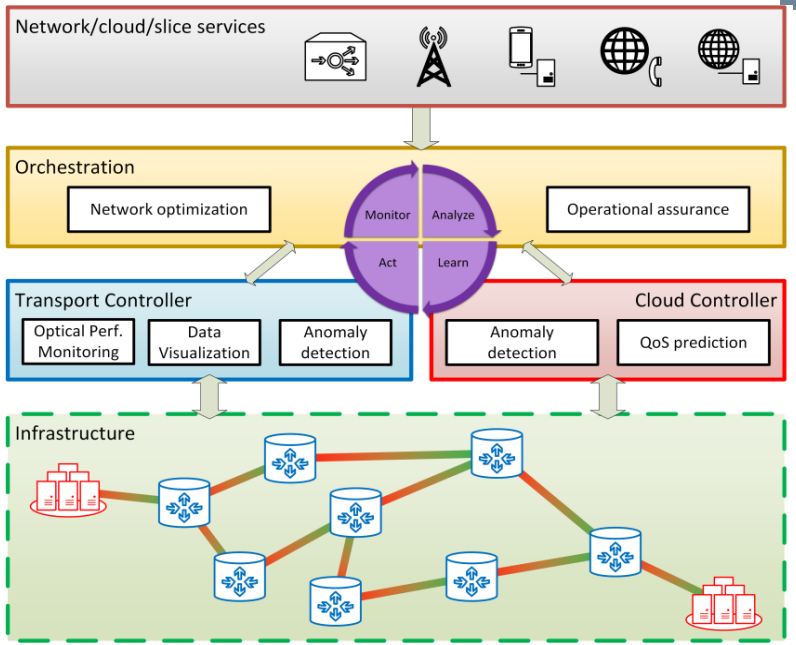
Automation in optical networks

- ML/AI-based policies can *self-adapt*, *explore* and *learn* how to operate also in the presence of previously unseen conditions
- Objective: efficient *resource management* (while enforcing QoS requirements), *proactive reconfigurations* (e.g., fault tolerance, defragmentation), fast *setup/tear down*, enabling *new/better services*

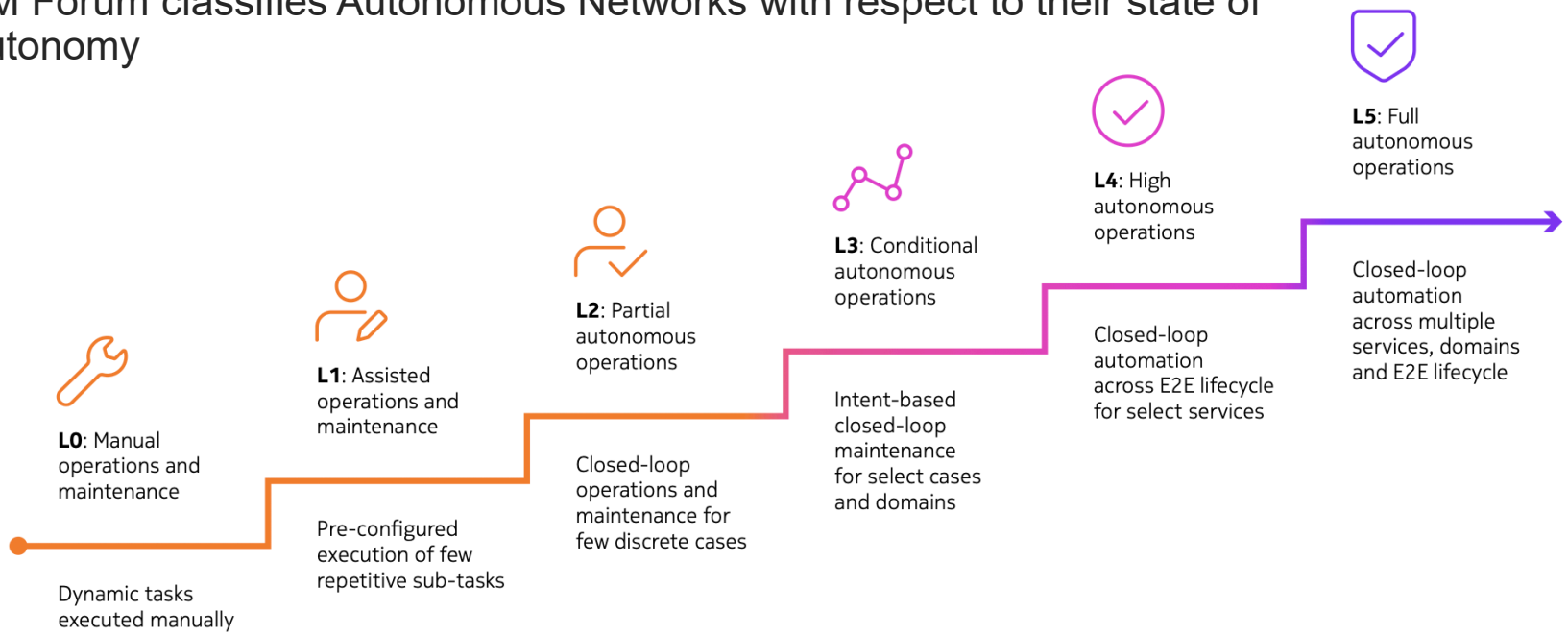


- **Zero-touch** provisioning and operation, resource orchestration and optimization, network robustness and reliability

Network autonomy

Full network autonomy: “zero touch”

TM Forum classifies Autonomous Networks with respect to their state of autonomy

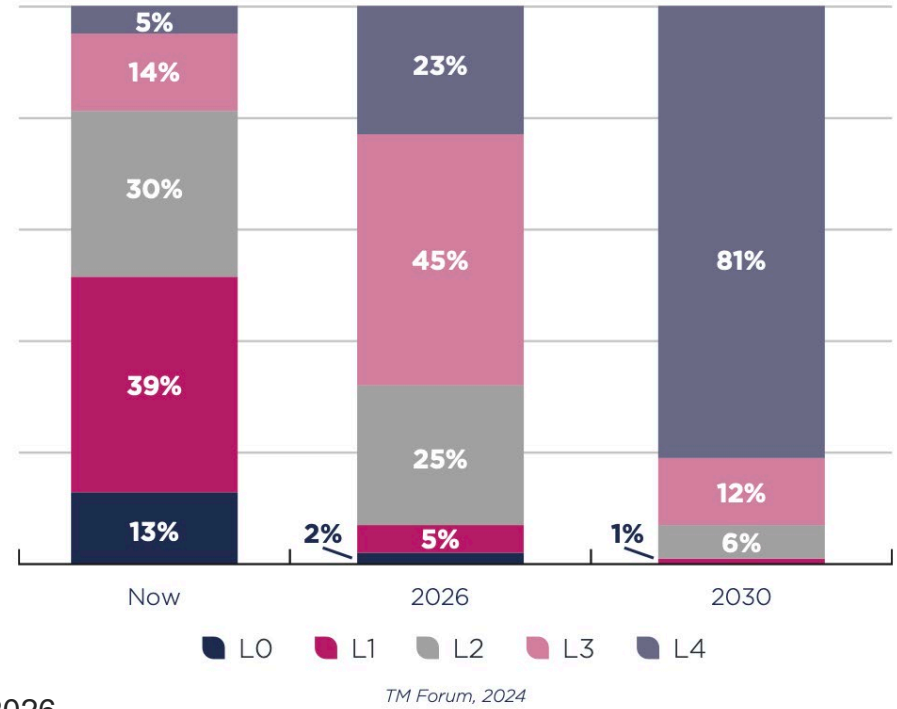


Nokia Bell Labs: Autonomous Networks: What is the current state and how to move forward?

The road to full autonomy

- Autonomous networks: current **global average** is between **level 2** and **level 3**
- Majority of CSPs **aspire** to reach at least **level 3** (conditional autonomy) by the end of **2028**
- Many CSPs aim to reach **level 4** by **2030**
- Reaching **level 5** (fully autonomous networks) might never happen in full extent
- M**oving to level 4** and approaching **level 5** will require **AI/ML** and other **advanced technologies**

TM Forum: Autonomous Network Operation – Benchmark report, 2024



TM Forum, 2024

Summary

- For decades radio and optical networks have been ‘converging’:
  Separate systems that can be interfaced together
- Confluence involves integration of data and control plane signals → seamless connectivity, joint optimization and orchestration of wireless and wireline links for best performance: latency, energy and capacity
- New FSO and THz links enable fixed wireless at Tb/s, i.e., approaching wireline capacities
- Coexistence of analogue, digital and sensing signals → greater optimization flexibility
- Better enable cell-free access (d-MIMO) networks
- Zero touch: full network autonomy

Thank you !

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