Intelligent Devices & Networking of Transport Networks: Evolution and Practice

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IEEE 802

ION-2030: Opening the Era of Intelligent Transport Networks

International Optical Network for 2030 and beyond

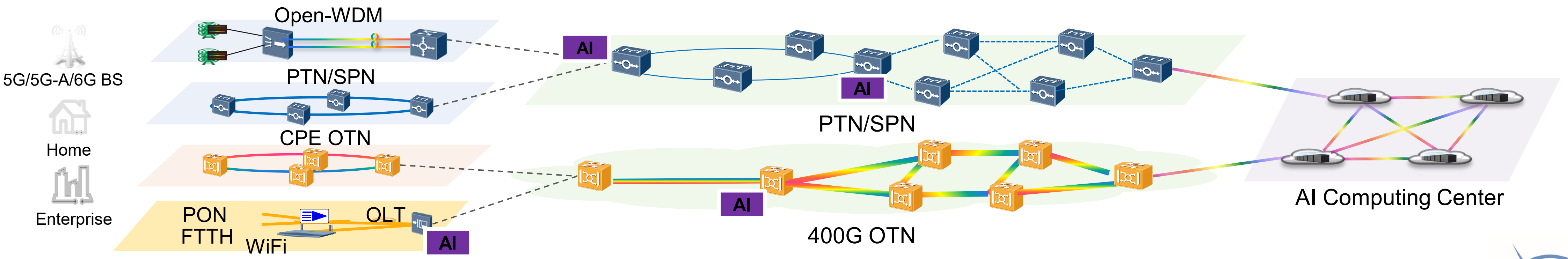
6G

AI

Data Center

Broadband Access

Deep convergence of AI with transport networks will reshape networking, evolving Internet of Everything into Intelligence of Everything.

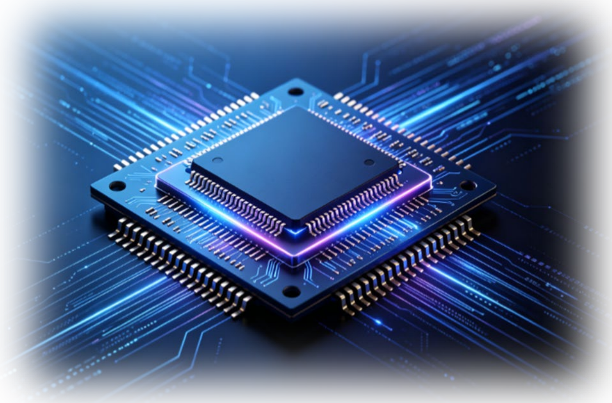


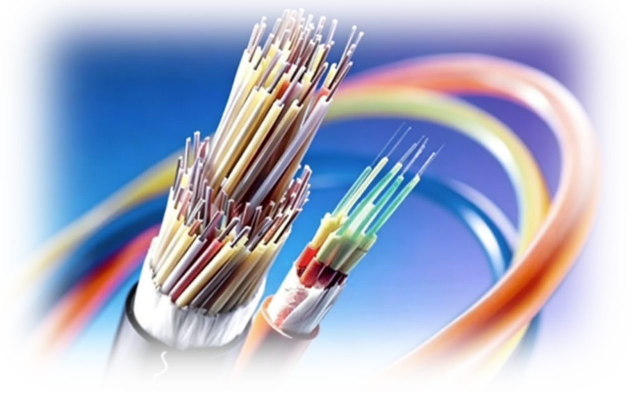
AI for Network

Optical networks have rich resources for AI-driven evolution.
Intelligent sensing is where AI gets its data foundation.

Intelligence Extends to the Infrastructure Layer

Real-time data from components, modules, and fiber infrastructure enables end-to-end transport network intelligence across data collection, intelligent analysis, and coordinated scheduling





AI for Network goes beyond the networking level, down to components, modules, and fiber links. This will form the foundation of an intelligent transport network.

Contents

Intelligent Optical Modules : from connection to sensing

As the primary module for sensing and monitoring optical path states via the data collection capability, optical modules become the natural entry point for AI applications.

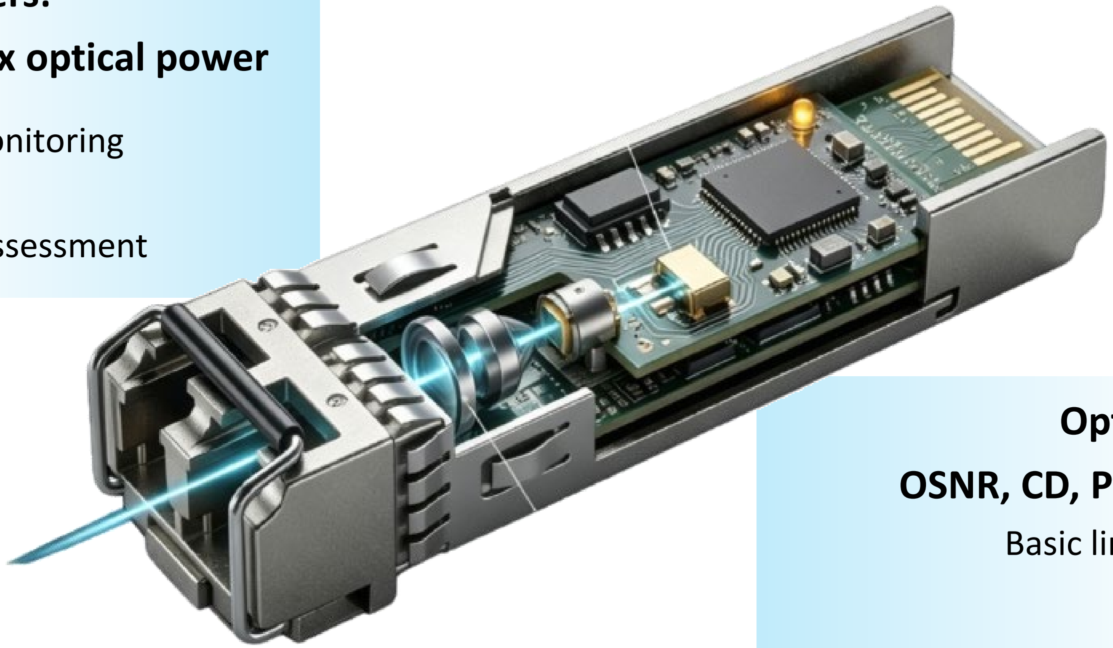
Basic parameters:

temperature, voltage, Tx/Rx optical power

Operational status monitoring

AI

Basis for degradation assessment



Optical parameters:

OSNR, CD, PMD, polarization state, etc

Basic link physical information

AI

Basis for intelligent diagnostics, performance optimization

Optical modules evolve from network connection points to sensing units.

AI can analyze and diagnose optical link status.

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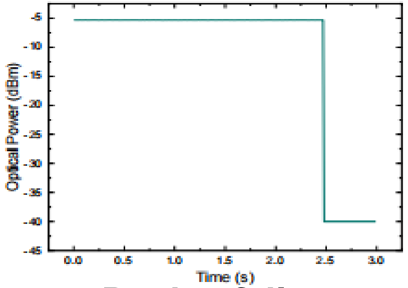
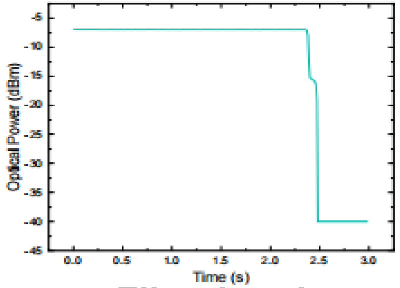
Practice: AI Fault Classification in Metro Network

Enabling fast diagnostics for optical path faults at the metro edge, enhancing the reliability of single-homed CPE connections.

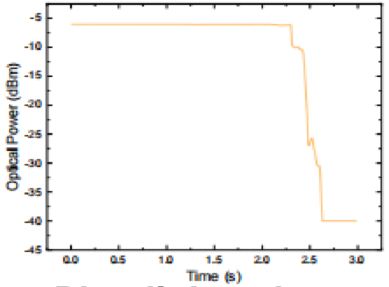
Five Typical Fault Types



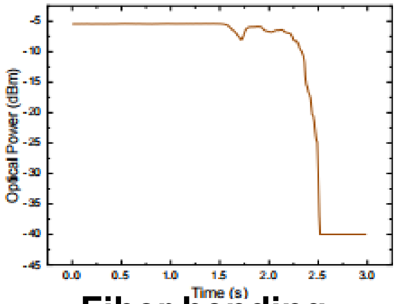
Device failure



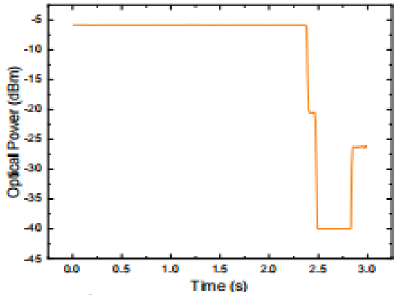
Fiber break



Pigtail detachment



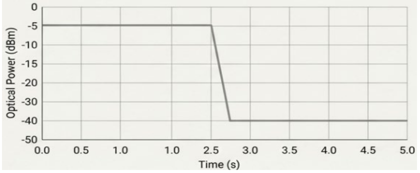
Fiber bending



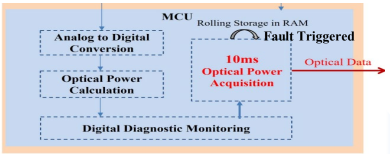
Connector loosen

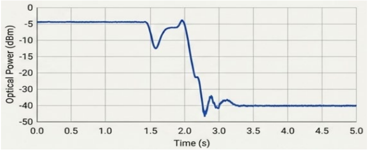
Two Key Enhancements

① Sampling enhancement

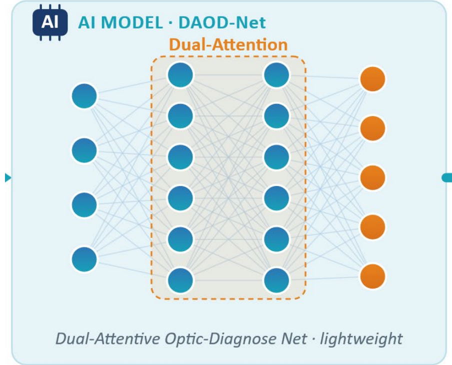


Similar patterns across different faults at second-level sampling





Software-triggered capturing optical power transients at 10ms resolution



OUTPUT · 5 FAULT CLASSES

- Device failure
- **Fiber break**
- Pigtail detachment
- Fiber bending
- Connector loosen

>95% accuracy · hours → seconds

② Lightweight AI algorithm

Fault diagnose time from hours **to seconds**

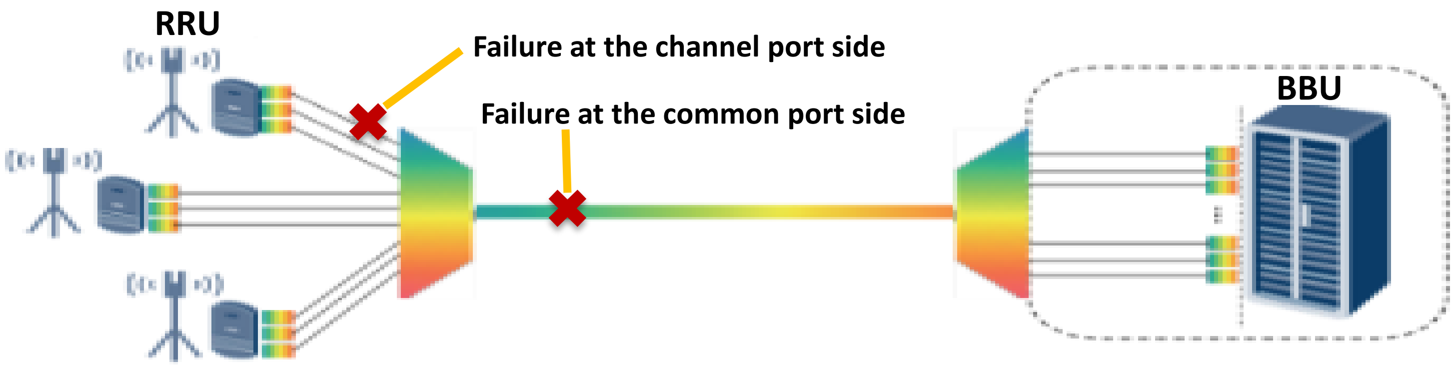
Precise recognition accuracy of **>95%**

AI-Embedded Optical Modules With Millisecond-Granularity Power Analysis for Autonomous Metro Transport Network and Field Trial, JLT 43(22), 2025

Practice : AI Fault Classification in Passive WDM Fronthaul

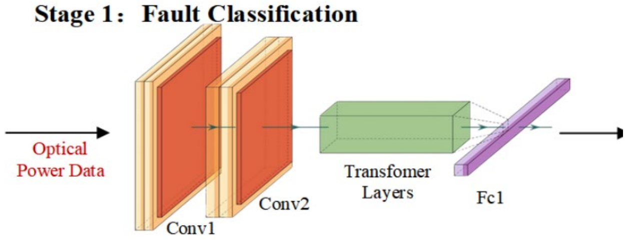
Faults on the common fiber, branches, and multiplexer/demultiplexer all show similar symptoms of optical power attenuation. Traditional O&M cannot accurately distinguish the fault layer.

Point-to-multipoint architecture:
Hard to pinpoint fault layer



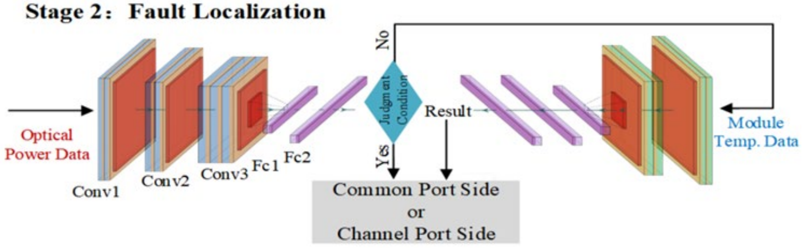
AI Multi-modal data fusion for Root-Cause Discrimination

Stage1：
Fault Classification



Stage2：
Fault Localization

Multi-modal fusion (temperature, optical power, etc.) as CNN input



92.4% accuracy in branch-vs-common fault discrimination, a 28.8% improvement over the RNN baseline.

First Demonstration of Autonomous Fault Diagnosis with AI-Embedded Optical Modules in Passive WDM Systems for Front-Haul Network, OFC 2026, M3A.3

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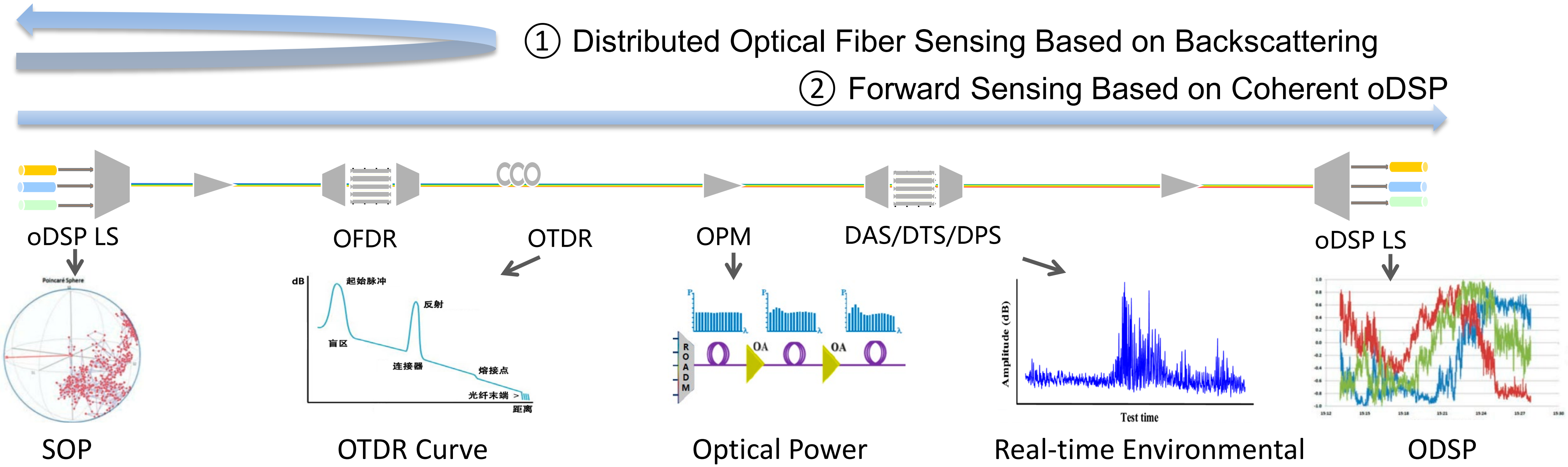
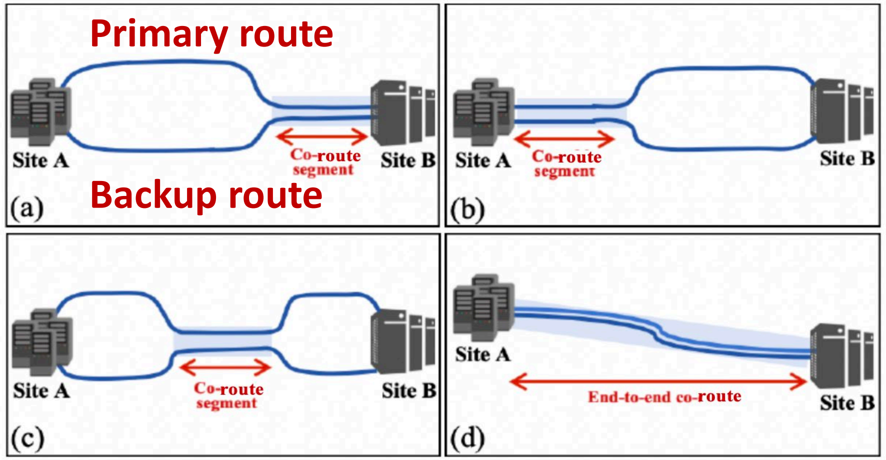
AI-Driven Intelligent Sensing for Optical Fiber

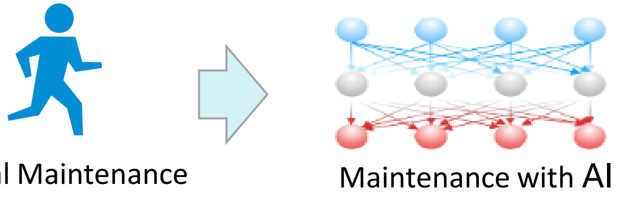


Optical fiber sensing data are characterized by high diversity, massive volume, and complex features.
By integrating AI, we can achieve co-route detection, fiber risk early warning, and link fault localization.

Intelligent Identification of Co-route Optical Fibers



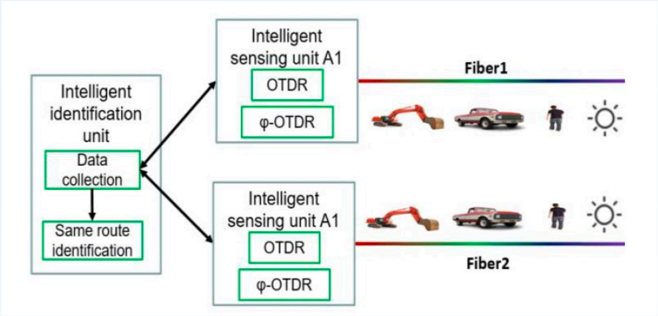
- The passive nature of optical fiber combined with the inaccuracy of manual O&M, leads to inaccurate resource information and frequent co-route faults in optical networks.
- When **primary** and **backup** routes are in the same cable, a single incident can take down both, leading to a complete service interruption, severely degrading user experience and resulting in significant economic losses.



Real network data collection and labeling are required to support the training of the AI model for co-route identification.

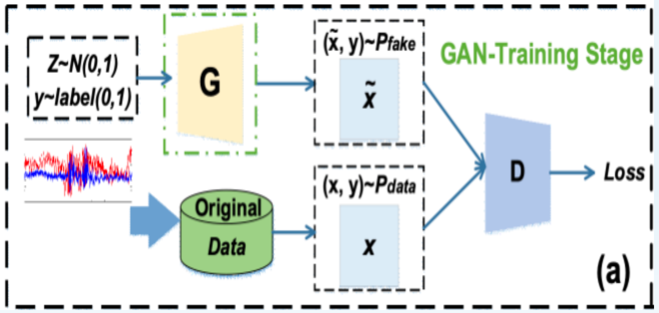
Practice: Realization of Co-route Intelligent Identification

Key Data Parameters



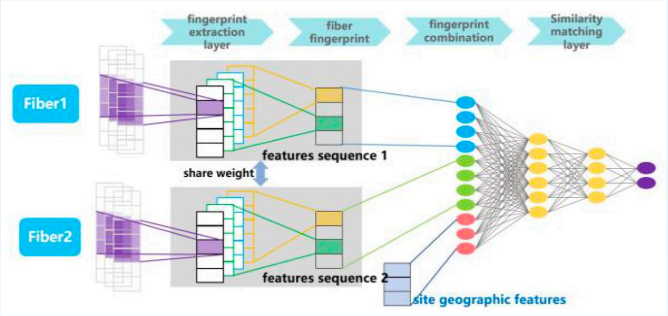
- Static **OTDR data**
- Dynamic **ϕ-OTDR data**

Automatic Data Generations



- Balanced the number of co-route and non-co-route samples using **GANs**
- Improved the recall rate of co-route identification from **95.9% to 99.8%**

AI Identification Models



- Designed a **self-attention Siamese neural network model**
- Achieved an **accuracy of 96%** in co-route identification

This co-route identification method has been deployed in networks., overcoming the data-model mismatch caused by complex cable deployments, and driving intelligent optical network O&M.

1) Research and Experiment on AI-based Co-cable and Co-trench Optical Fibre Detection, ECOC 2022, We4B.2
2) Highly-precise Fiber Co-route Segment Location with Multi-modal Vibration Analysis and Field Demonstration for Intelligent Optical Network, OFC 2025, M1C.7
3) Field Trial of Concurrent Co-cable and Co-trench Optical Fiber Online Identification Based on Ensemble Learning, OE 31(26), 2023

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Intelligent Traffic Analysis Enables Fine-Grained Service Identification

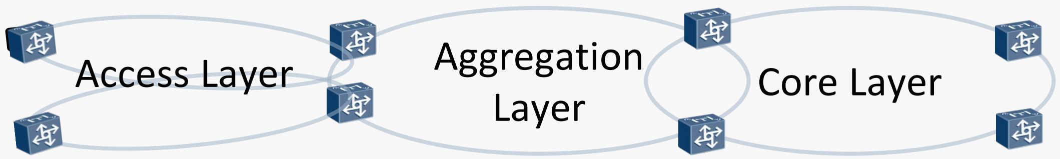
Traffic Collection

Use Case

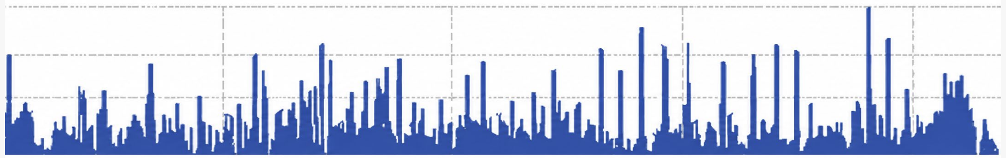
File Download

Video & Live

AI Agent Q&A



Fine-grained traffic

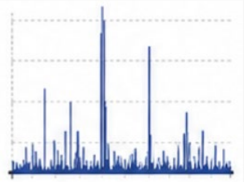


Traditional networks serve only as passive transport pipes, aggregating all service traffic

Traffic Analysis

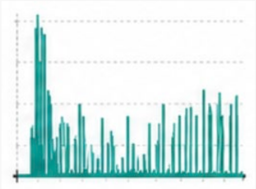
Features

File Download



- Large average packets
- Long duration

Video & Live



- on-and-off bursts
- Small/medium packets

AI Agent Q&A

- Intermittent bursts
- Streaming output

Intelligent Traffic Analysis

Class 1: Low-Latency	Class 2: High-Throughput	...	Class N: Long-Lived

Differentiated service delivery: high bandwidth / low latency / high reliability / high concurrency

Service-feature identification is the prerequisite for differentiated delivery

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Intelligent Awareness: Rising to the Encrypted-Traffic Challenge

Conventional Service Awareness

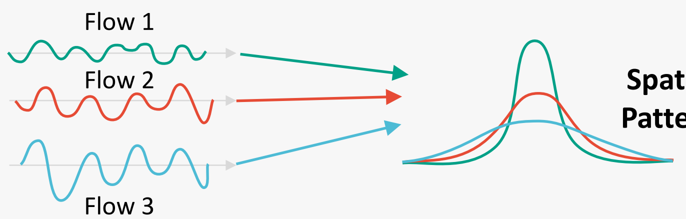
IP	Port	Protocol	Port	IP
Source Address	Source Endpoint	Transport Type	Destination Endpoint	Destination Address

Classify by IP headers

Classify by signature fields

These methods only see plaintext traffic, and fall short as encryption becomes the norm

Intelligent Service Awareness



Reading services from a flow's spatio-temporal patterns

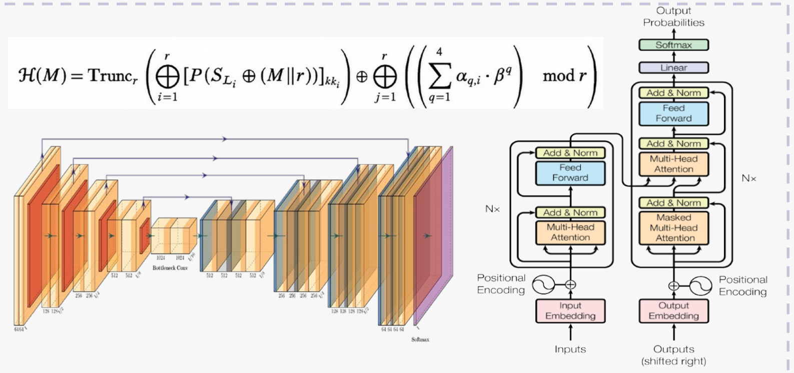
Timing statistics:
Packet size & spacing...

Transport behavior:
TCP, UDP...

... ...

Session behavior:
Connection duration...

$$\mathcal{H}(M) = \mathrm{Trunc}_r\left(\bigoplus_{i=1}^{r}[P(S_{L_i} \oplus (M\|r))]_{kk_i}\right) \oplus \bigoplus_{j=1}^{r}\left(\left(\sum_{q=1}^{4}\alpha_{q,i}\cdot\beta^q\right) \bmod r\right)$$



Fine-grained sensing reads encrypted and plaintext traffic alike

Intelligent awareness is the key to seeing inside that traffic—delivering tailored service guarantees and allocating resources on demand

Intelligent Traffic Awareness for Green, Smart Optical-Network Scheduling

Legacy Architecture: Static & Fixed

Static traffic configuration

✗ Can't follow real-time demand

✗ All elements stay powered on

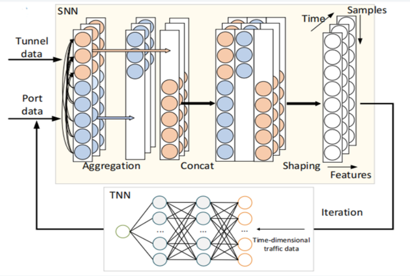
Now: AI Traffic Migration

✓ Predicts demand & schedules traffic in real time

✓ Concentrates traffic onto fewer elements

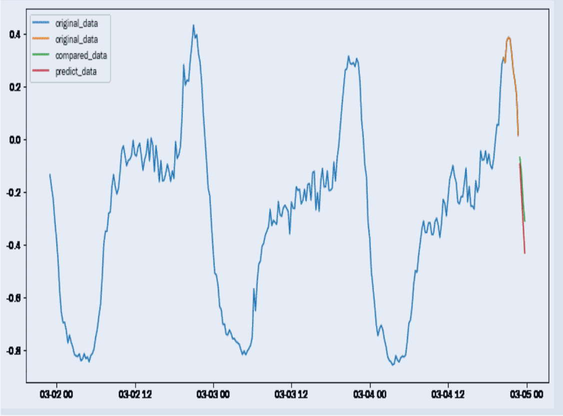
✓ Powers down idle elements to cut energy use

Intelligent Architecture: Dynamic & Adaptive



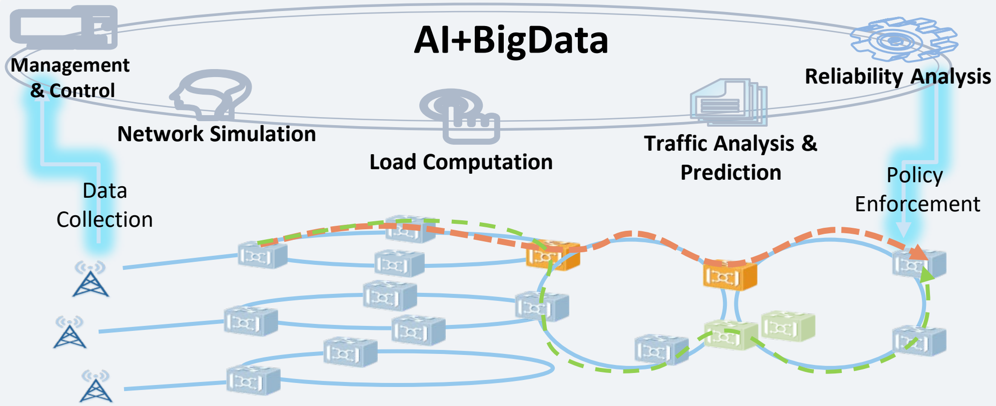
Time: traffic temporal features

Time: holiday / calendar info

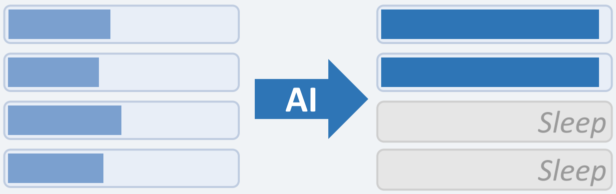


AI-Based Traffic Prediction

An **AI spatio-temporal graph neural network** learns traffic patterns across the whole network and predicts future bandwidth demand



AI Traffic Migration

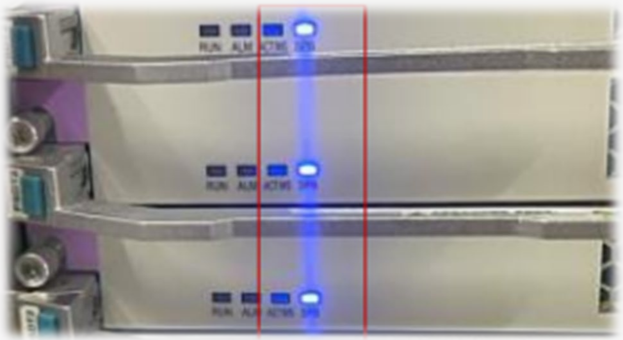


Idle Elements Sleep → Energy Saved

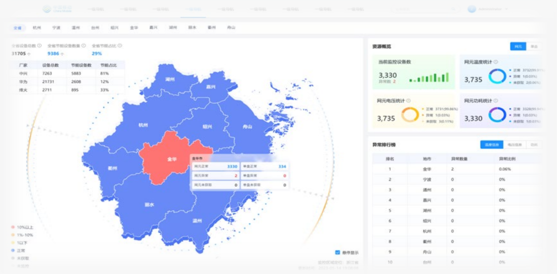
Closed loop: data collection, bandwidth prediction and Green policy enforcement

Practice: Intelligent Traffic Awareness — Network-Level Smart Scheduling

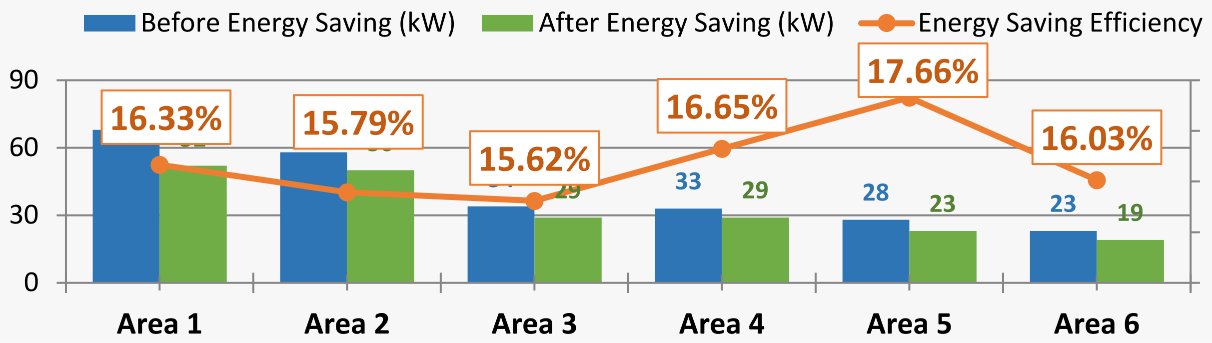
Card-Level Energy Saving



Real-Time Energy Visibility & Control



Provincial Metro: Annual Savings



AI-driven energy optimization is now live across all 31 of China Mobile's provincial networks, cutting power use by up to 18% — real-world proof that intelligent scheduling pays off at scale

1) AI-Driven Hitless Network-Level Energy Optimization with Reliability-Aware Bandwidth Reservation Algorithm and Field Trial, ECOC 2025, 755
2) Field Trial of Intelligent Network-level Energy Saving Strategy over Large-scale Database of Commercial Transport Networks, ECOC 2024, 110699
3) Intelligent Network-Level Energy Saving Strategy With STGNN-Driven Traffic Prediction and Path Optimization in Transport Networks and Field Trial, IEEE ACCESS 13, 2025

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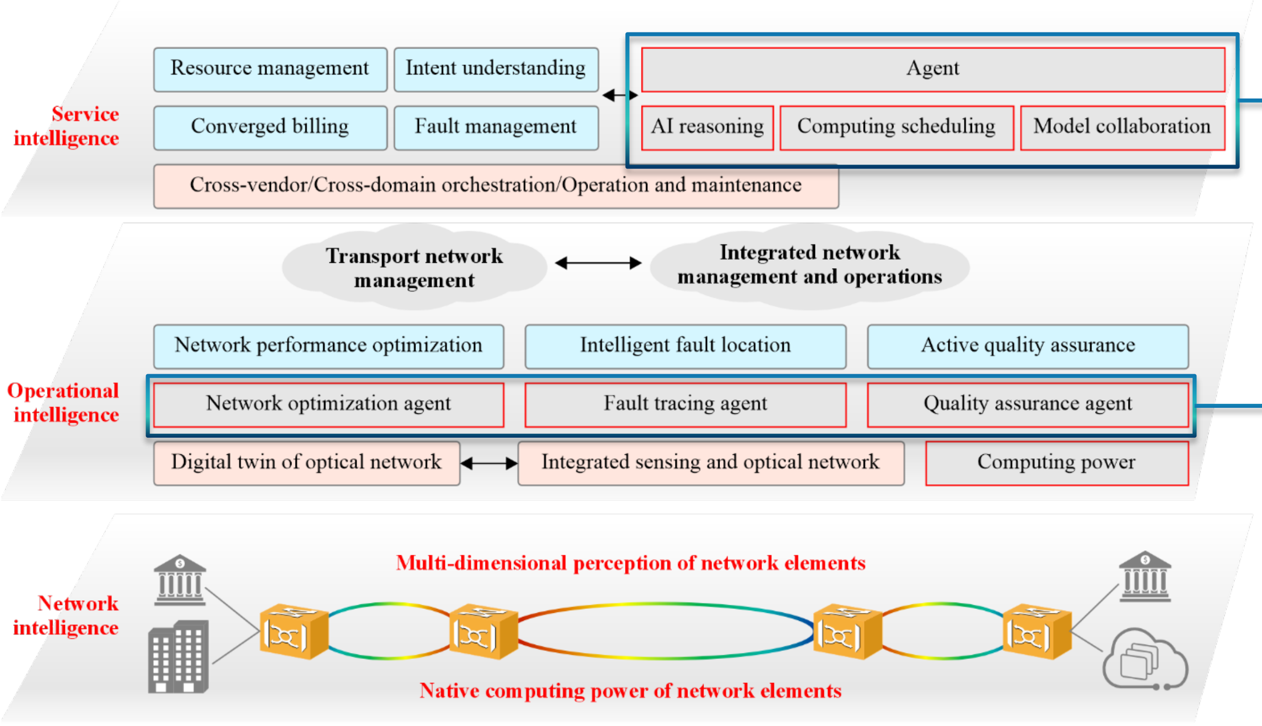
AI Agents: Powering Intelligent Optical Network Evolution

ION-2030 Vision: Transitioning to Agent-based, AI-Native Optical Networks



ITU-T GSTR-ION-2030 Figure 4 – Illustration of AI-native optical network architecture

AI Agent in Service layer:

Domain-specific modelling enables fully lifecycle automation for optical networks

AI Agents in Control layer:

AI agents automatically handle tasks: Network optimization, fault tracing, quality assurance…

Intent-Driven Autonomy

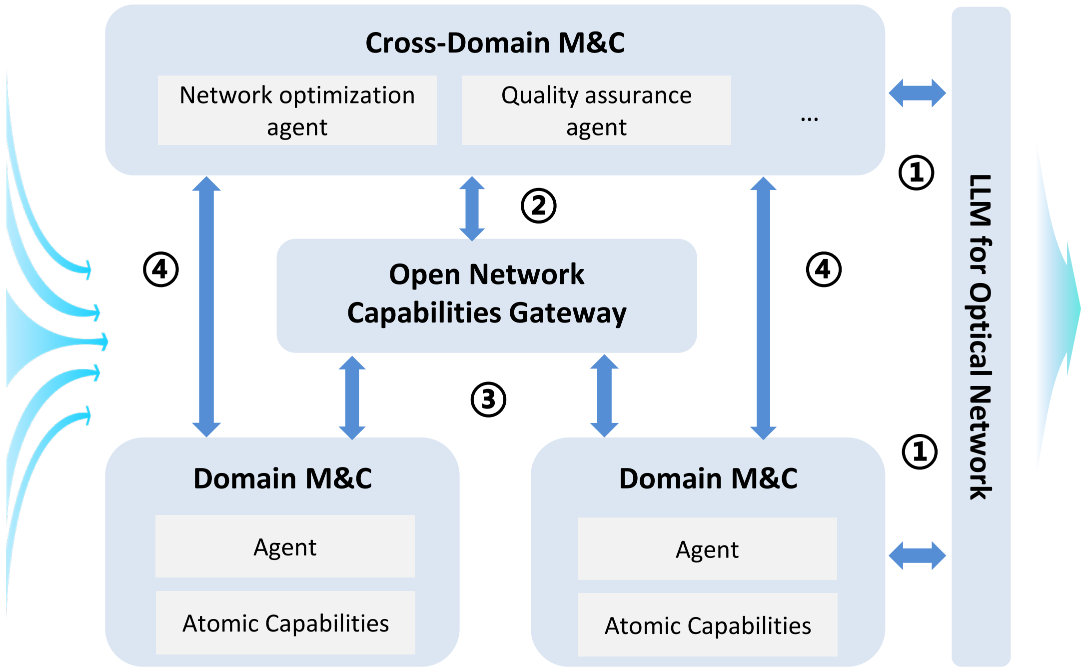
Intelligent Open Architecture for Optical Networks

Optical network AI Agents are mainly within single-domain management and control (M&C) systems.
For full-lifecycle intelligence, building an intelligent open architecture with AI Agents is essential.

four layers of openness for ON AI Agents

1. Open-Source LLM for Optical Networks
2. Open Network Capability Access Mechanism
3. Standardization of Network Capability Abstraction
4. Agent-to-Agent Protocol Extension for Optical Networks

Intelligent open ON architecture



Efficient multi-agent interoperability

Accelerate ON AI innovation and application

Rapid deployment of new AI capabilities

Open Framework for AI in Optical Networks (ON)

Intelligent Open ON Architecture

Open-Source ON LLM	Open Network Capability Access	ON Capability Abstraction	Multi-Agent Collaboration
Domain-specific corpus for model training	**Register**: Unified management	**Standardized description** of network capabilities	**Extended A2A protocol** for multi-round task processing
Open LLM weights for model sharing	**Update**: lifecycle management	**Standardized interfaces** for capability invoking	**Structured prompts** for precise semantic delivery
Unified benchmarks for model evaluation	**Search**: discovery and matching	**Unified security control** for capability access	
	Invoke: Secure authorization		

Future standardization for AI in optical networks

Thank you!

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