

# Photonics for AI Infrastructure

ITU and IEEE Photonics Society Workshop

Sunday 5<sup>th</sup> July, 13:00-16:30 ET, Montreal, Canada

## SENSING IN FIBER OPTIC NETWORKS: FROM COMMUNICATION INFRASTRUCTURE TO DISTRIBUTED INTELLIGENCE

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July 5, 2026

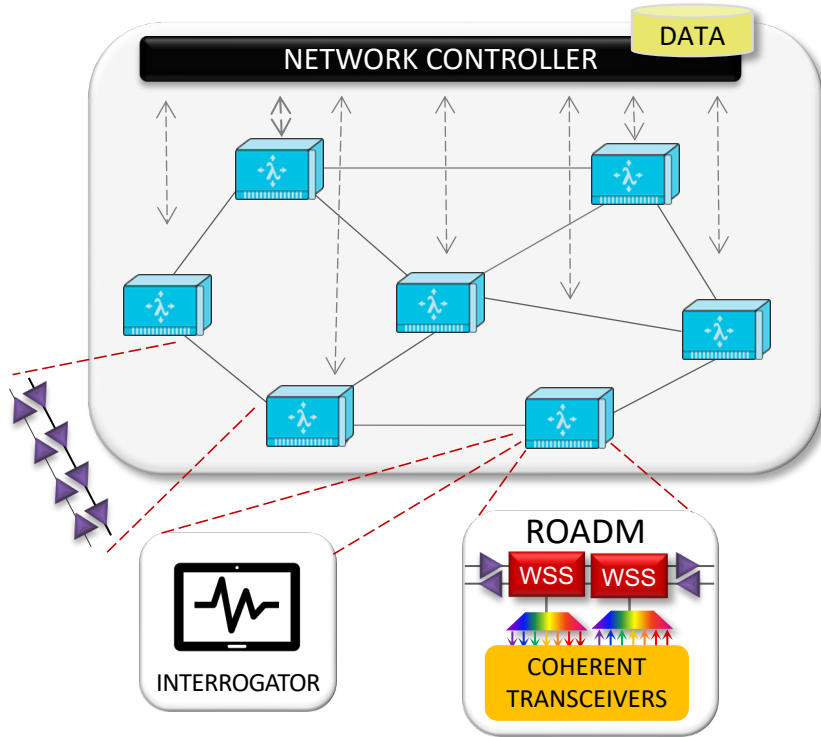
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# Outline

- Motivation and context
- Sensing in optical networks
- Interrogators or digital coherent receivers as sensors?
- AI-enabled fiber sensing
- Research challenges
- Key takeaways

# Why use optical fibers as sensors?



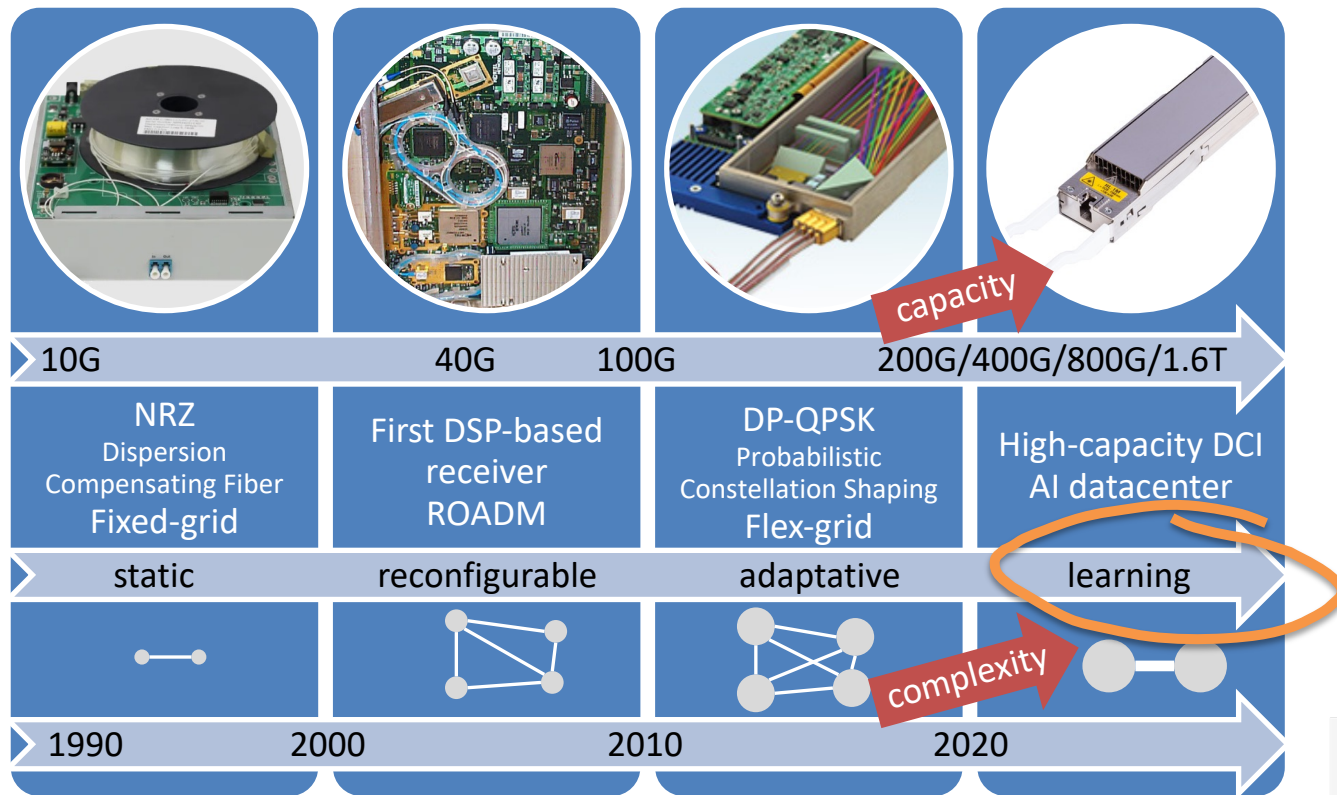
- Existing fiber infrastructure is ubiquitous
- Long reach
- Continuous monitoring over large areas
- Dual-use infrastructure:

*Telecom network overlaid  
with sensing functions*

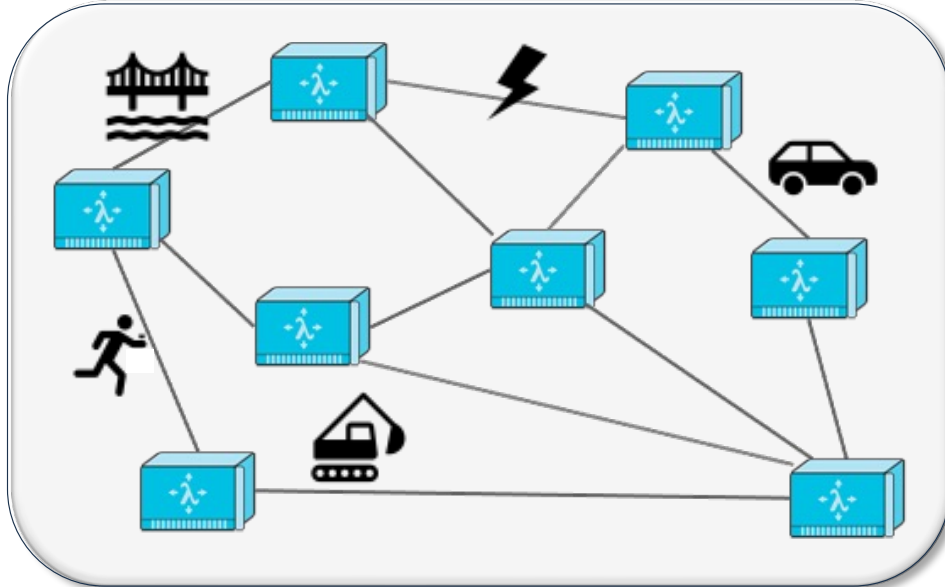
ROADM: Reconfigurable Optical Add-Drop Multiplexer  
WSS: Wavelength Selective Switch

A single fiber can provide thousands of sensing points

# Evolution of optical networks



# From communication networks to sensing networks



- Fault localization
- Infrastructure monitoring
- Traffic and mobility monitoring
- Environmental sensing
- Security applications

Communication → monitoring → sensing → situational awareness

# Fiber sensing technologies

| Technology        | Principle of operation                                                                                 | Quantity measured                                                                           | Typical applications                                                  |
|-------------------|--------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|-----------------------------------------------------------------------|
| OTDR              | Rayleigh backscatter intensity                                                                         | Fiber loss, faults                                                                          | Fault localization, link diagnostics                                  |
| DVS (OTDR-based)  | Changes in Rayleigh backscatter intensity                                                              | Vibrations                                                                                  | Intrusion detection, traffic/structural monitoring                    |
| $\Phi$ -OTDR/DAS  | Coherent detection of phase changes in Rayleigh backscatter                                            | Acoustic waves, dynamic strain                                                              | Pipeline, railway, perimeter monitoring                               |
| DTS               | Raman (or Brillouin) backscatter analysis                                                              | Temperature                                                                                 | Fire detection, power cable, pipeline                                 |
| Transceiver-based | Analysis of observable parameters: carrier phase, SOP, received signal quality, equalizer coefficients | Fiber and environmental perturbations: strain, vibration, temperature, polarization changes | Network health monitoring, event detection, infrastructure monitoring |

DVS: Distributed Vibration Sensing  
 DAS: Distributed Acoustic Sensing  
 DTS: Distributed Temperature Sensing  
 SOP: State of Polarization

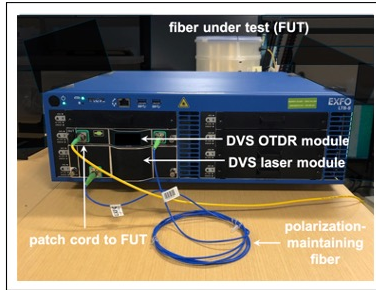
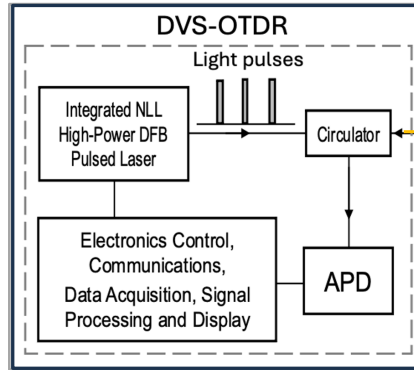
# Interrogator-based or transceiver-based sensing?

| Aspect                     | Interrogator-based sensing | Transceiver-based sensing     |
|----------------------------|----------------------------|-------------------------------|
| Hardware                   | Dedicated instrument       | Existing transceivers         |
| Additional deployment cost | High                       | Low                           |
| Spatial localization       | Excellent                  | Limited/indirect              |
| Spatial resolution         | Meter-scale                | Span/link scale               |
| Sensing signal             | Dedicated sensing signal   | Existing communication signal |
| Architectural integration  | Separate sensing system    | Integrated sensing            |

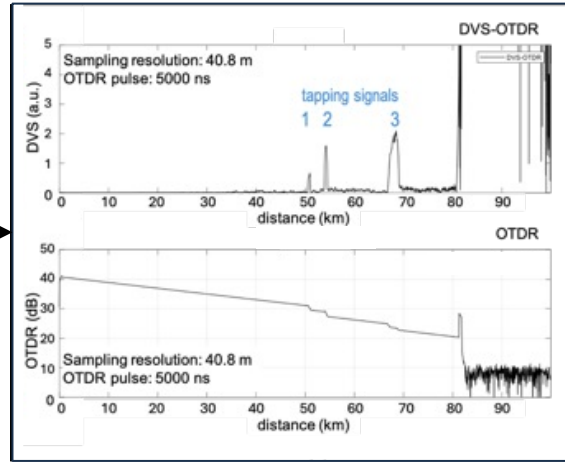
*Complementary role?*

Transceiver-based sensing (*network-wide operational awareness*)  
and Interrogator-based sensing (*high-resolution*)?

# Interrogator-based sensing: DVS-OTDR

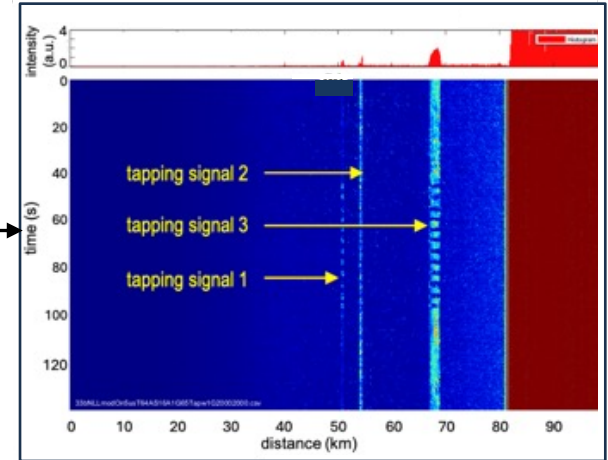


Data acquisition



Signal processing

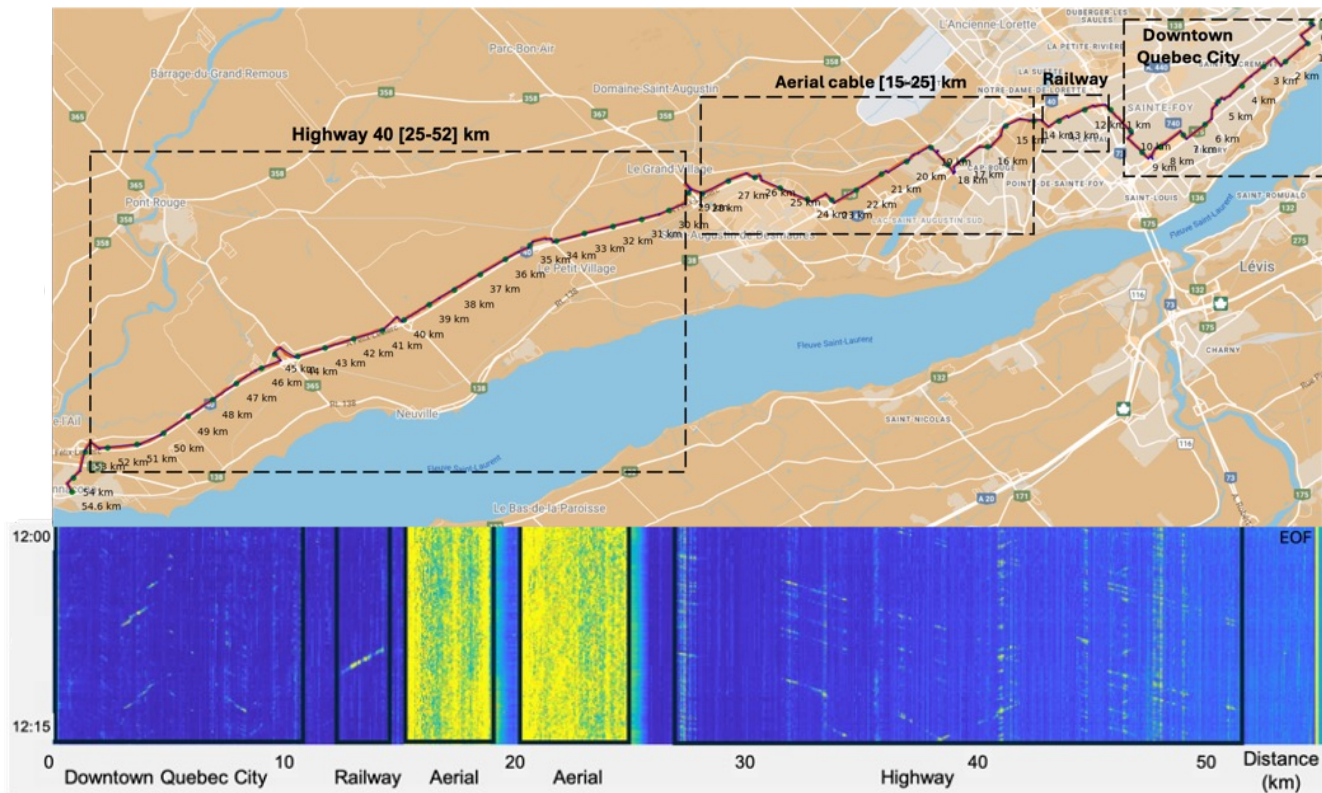
Vibration signal histogram



Waterfall

M. Leclerc, C. Tremblay, H. Chen et al., "High-sensitivity, long-reach localization and mapping of fiber optic networks using cost-efficient distributed vibration sensing, » SPIE Photonics West 2026, paper 13905-4.

# DVS-OTDR system for mapping fiber optic networks



## Events detectable:

- Fiber disturbances
- Road traffic near cable routes
- Construction activities
- Environmental fluctuations

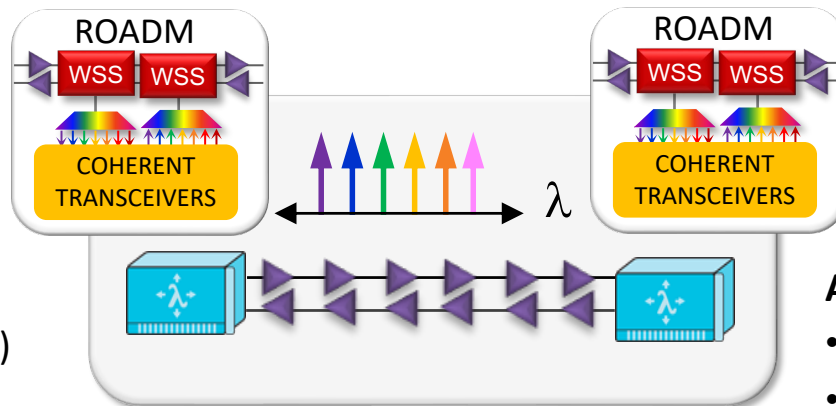
# Transceiver-based sensing

## Monitoring parameters

- Optical power levels
- Received power
- Signal-to-noise ratio (SNR)
- Bit error rate (BER)
- Q-factor
- Chromatic dispersion (CD)
- Polarization mode dispersion (PMD)
- etc.

## Capabilities:

- Phase tracking
- Polarization tracking
- Frequency offset estimation

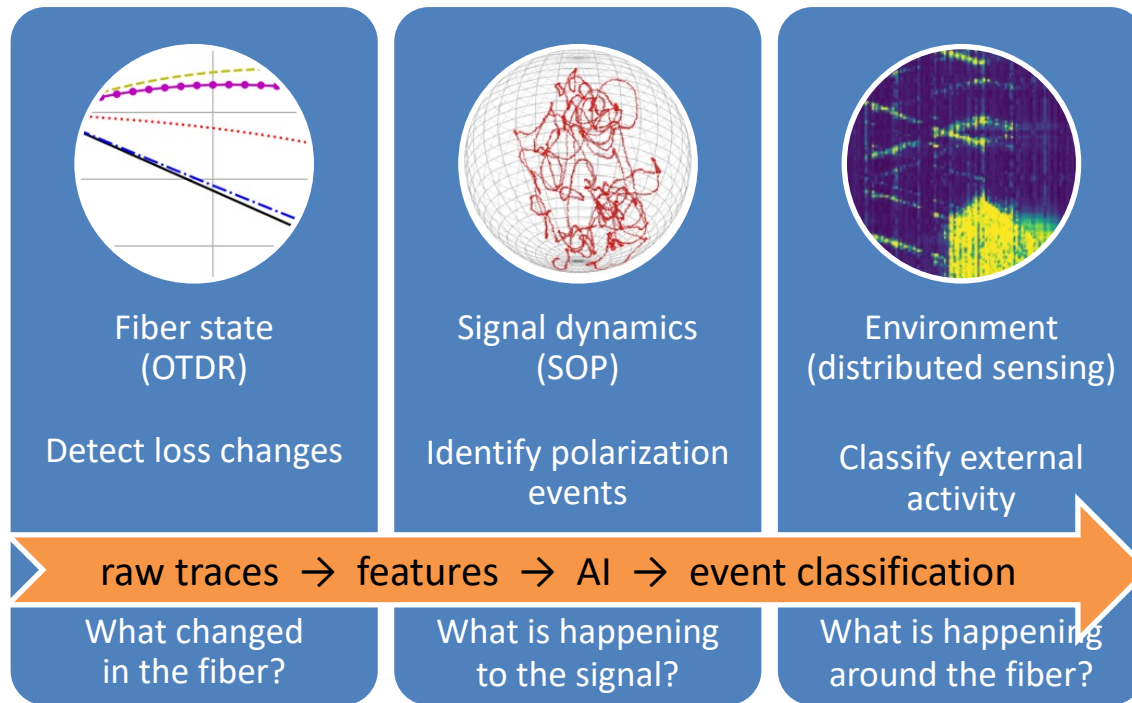


## Advantages

- No dedicated interrogator
- Reuse deployed equipment
- Existing communication channel
- Real-time DSP measurements
- Network-wide visibility

The transceiver becomes a distributed sensor endpoint

# AI-enabled fiber sensing... why AI?

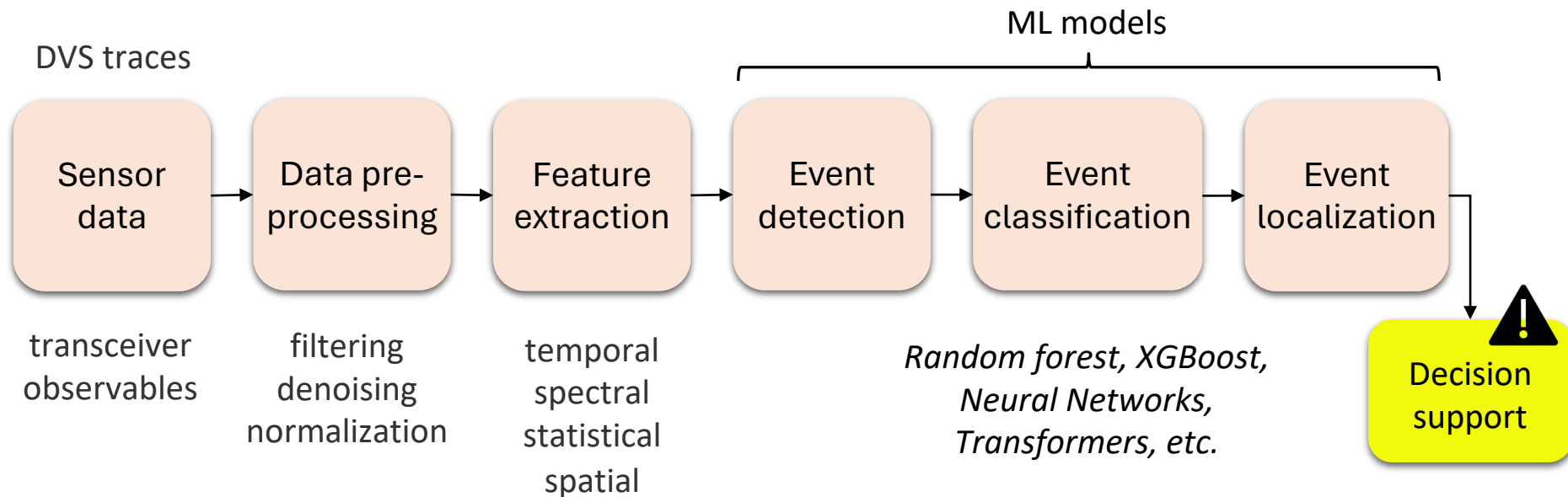


## Challenges:

- Massive data volumes
- Noisy measurements
- Complex event signatures

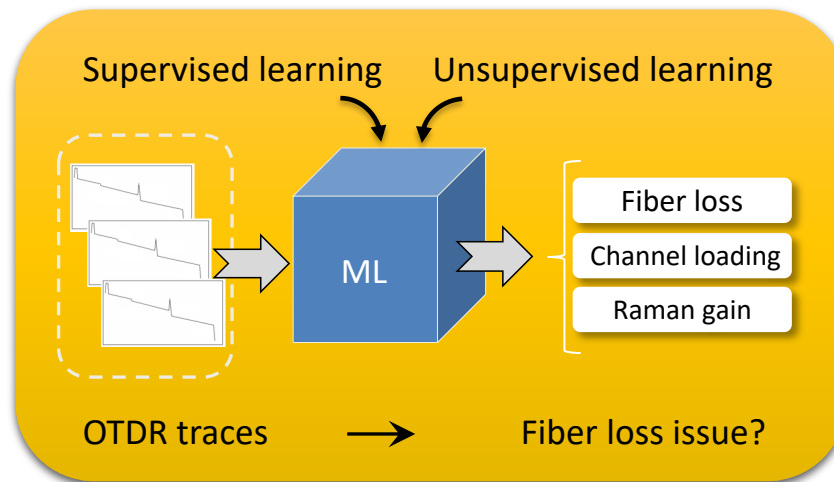
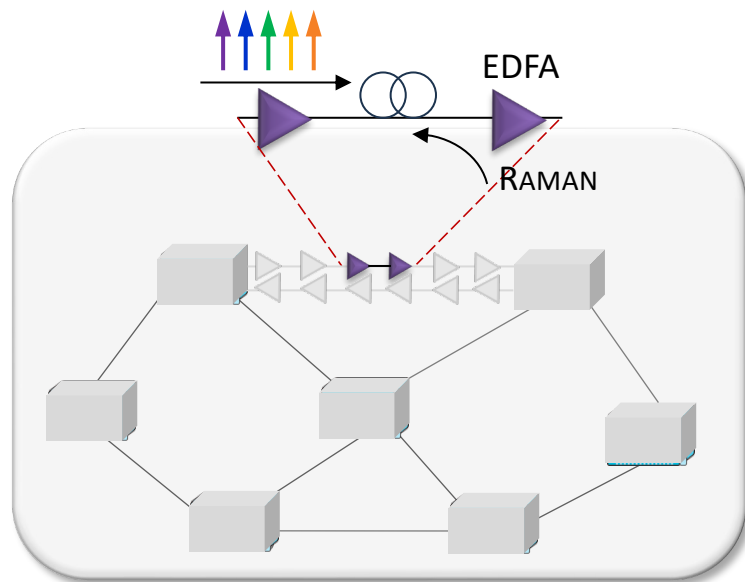
Classification transforms physical signals into actionable information

# Typical AI pipeline for fiber-based event detection



AI converts heterogeneous measurements  
into event detection and actionable insights

# AI-based classification of OTDR events



C. Tremblay, M. Tabatabaei, D. W. Boertjes, Y. Pei, and C. Desrosiers, "Supervised and unsupervised learning for classifying changes in optical time domain reflectometer traces," J. Opt. Commun. Netw. 17, D118-D124 (2025).

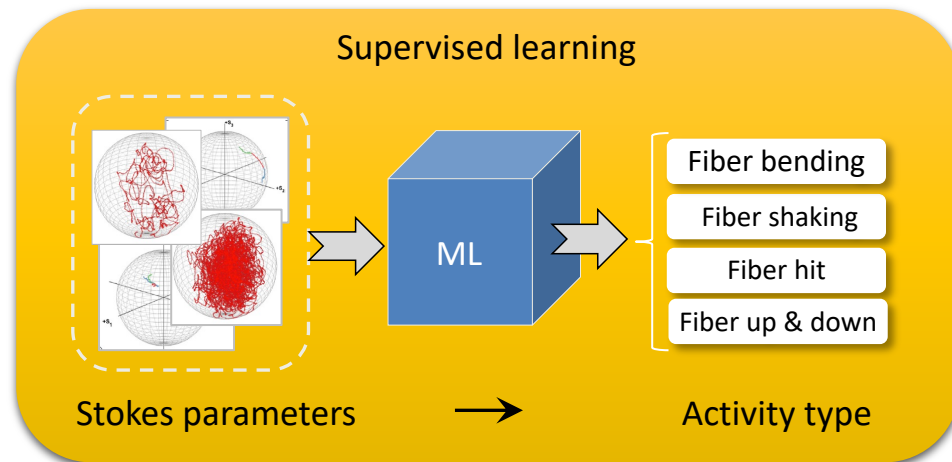
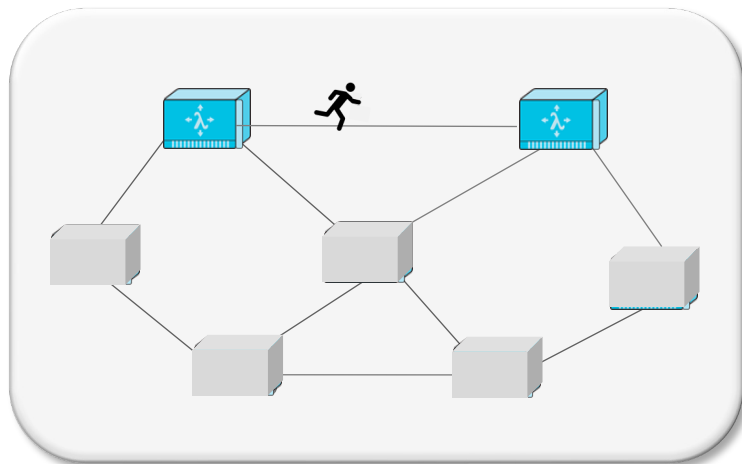
**ciena**

## AI for classifying changes in OTDR traces and detecting real fiber issues

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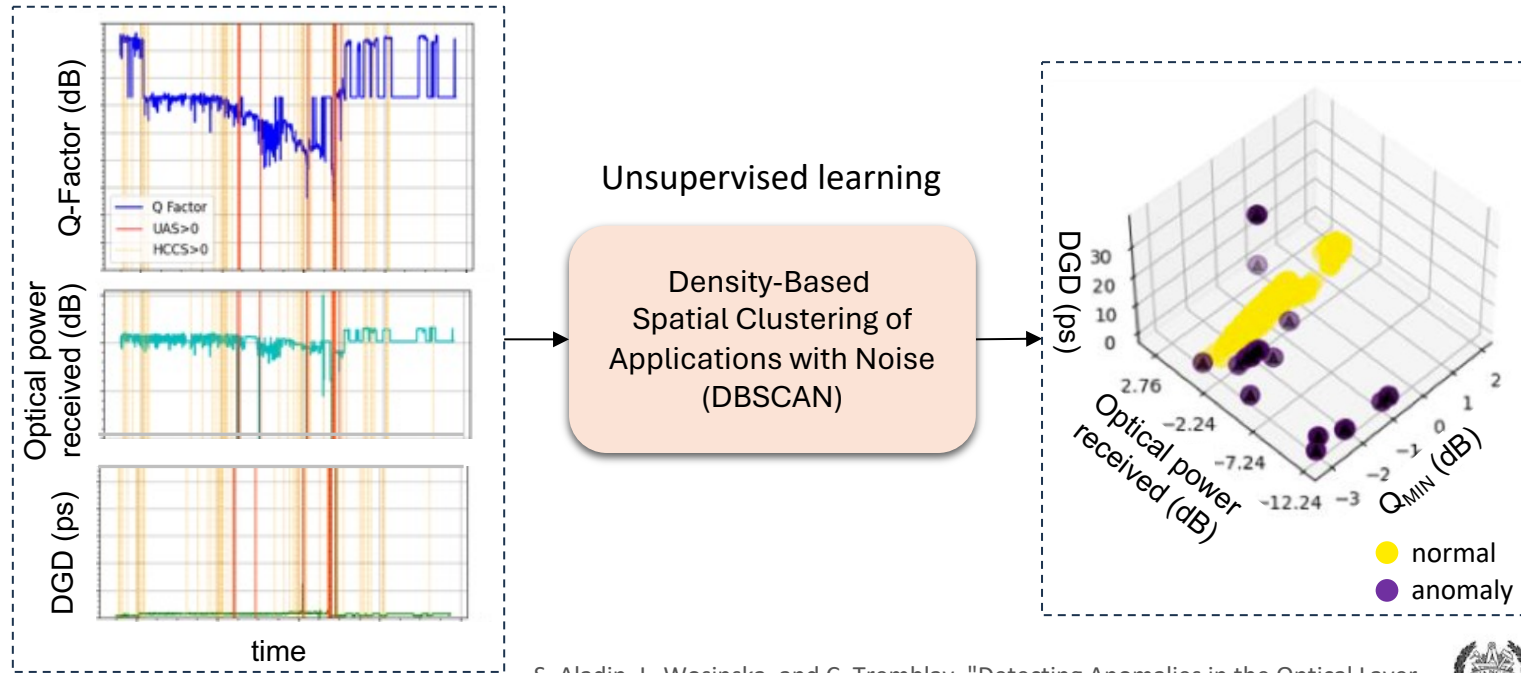
# AI-based classification of SOP event signatures



- Identify external activities around optical cables
- Distinguish polarization signatures

E. Dossev, P. Djukic, and C. Tremblay, "Decision Trees for Event Signature Classification on Fiber Optic Cables in Quaternion Coordinates," ECOC 2022, paper We4B.6.

# AI-enabled anomaly detection in optical networks



UAS: unavailable seconds  
HCCS: high correction count seconds  
DGD: differential group delay

S. Aladin, L. Wosinska, and C. Tremblay, "Detecting Anomalies in the Optical Layer Using Unsupervised Machine Learning," OFC 2024, paper Th31.4.



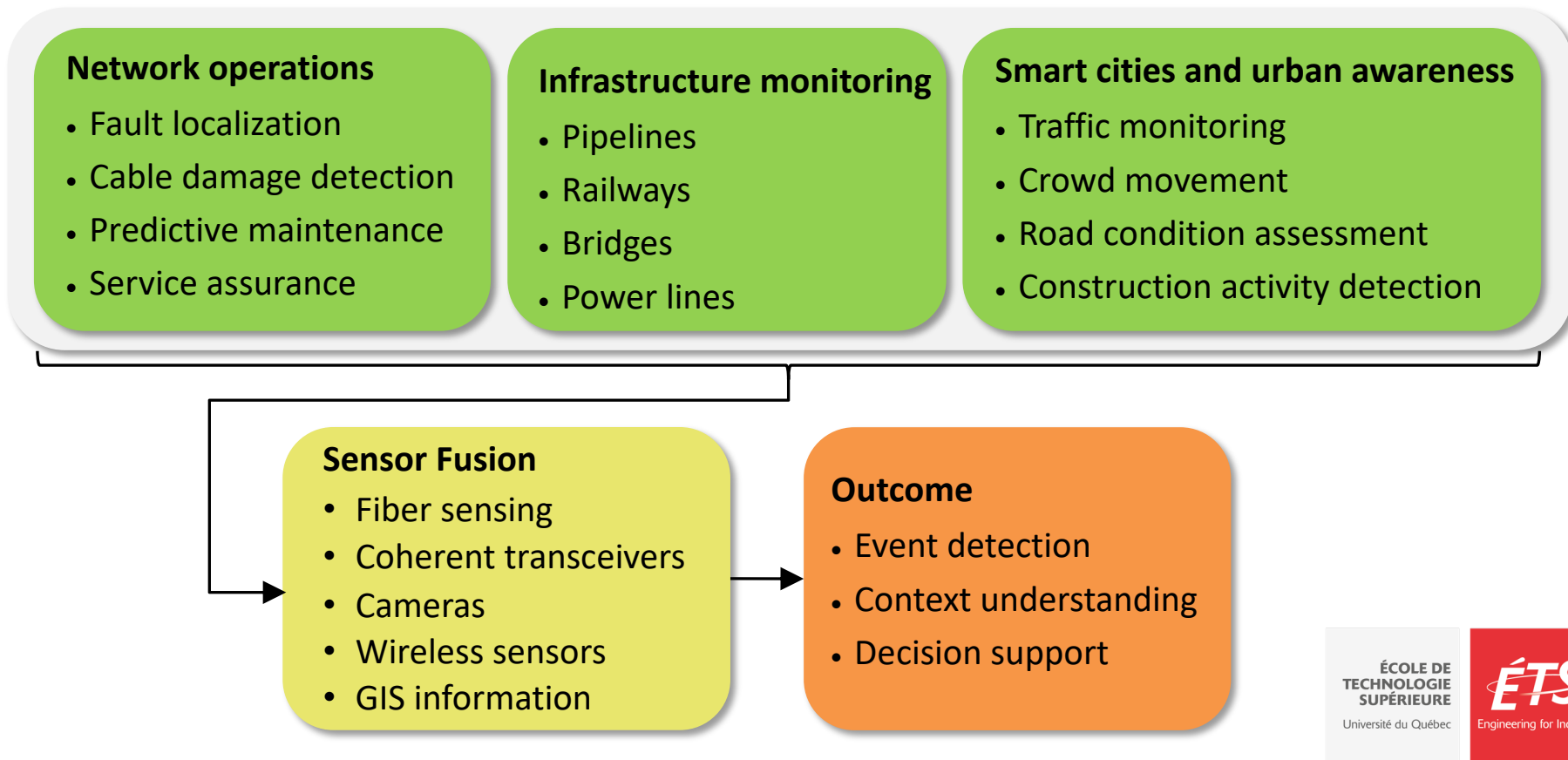
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## Extracting collective anomalies in historical telemetry preceding loss of signal

# Towards situational understanding



# Open challenges and future directions

## *Towards intelligent fiber infrastructures...*

### Open Challenges

- Scalability
- Label scarcity
- Real-time processing
- Multi-domain data fusion
- Privacy concerns

### Future directions

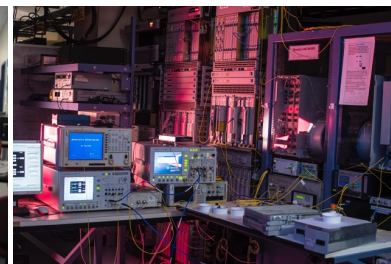
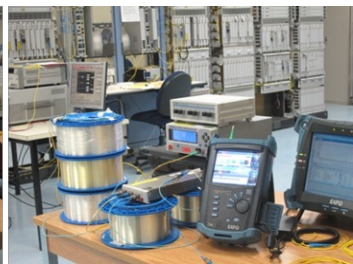
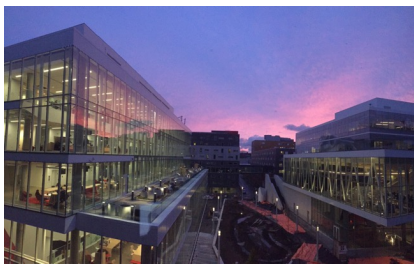
- Integrated communication and sensing
- AI-enabled sensing and network operations
- Multi-modal sensor fusion
- AI-enabled interpretation (situational understanding)
- Autonomous monitoring and predictive maintenance
- Digital twins for infrastructure monitoring

From measurements → events → context → understanding

# Key takeaways

- Optical fibers are powerful communication and sensing platforms.
- DAS/DVS provides fine-grained distributed vibration monitoring.
- Coherent transceivers enable low-cost opportunistic sensing.
- Combining both approaches unlocks large-scale situational awareness.
- AI is essential to transform raw measurements into actionable insights.
- Future networks will provide communication, monitoring, and situational understanding.

*"Next-generation optical networks may become one of the world's largest distributed sensing infrastructures."*



Thanks!

Current research activities at the Network Technology Lab:

*AI and machine learning for optical networks*

*advanced fiber sensing*

*hybrid classical-quantum communication systems*

Any questions?

*Interested in joining our team?*

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