Performance Monitoring in Optical Networks

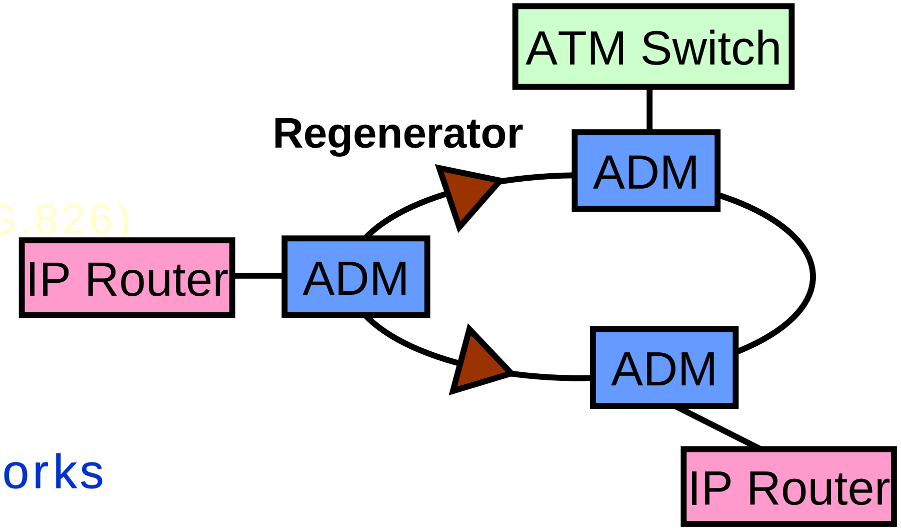
Lian-Kuan Chen
陳亮光

Lightwave Communications Laboratory,
Department of Information Engineering, The Chinese University of Hong Kong,
Hong Kong SAR.

Outline

- Optical performance monitoring (OPM): Why is it needed?
- Optical signal-to-noise ratio (OSNR) monitoring techniques
- System design aspects + future perspectives

OPM: A New Paradigm of Performance Monitoring



- Today's SDH/SONET Networks
  - BER at O/E/O locations
  - BIP checks of header & payload (G.826)

- Future all-optical transparent networks
  - O/E/O eliminated
  - Different modulation formats, bit rates, and protocols

    e.g. SDH/SONET, Gigabit Ethernet, ATM, IP over WDM

- Characterization of channel parameters without knowing

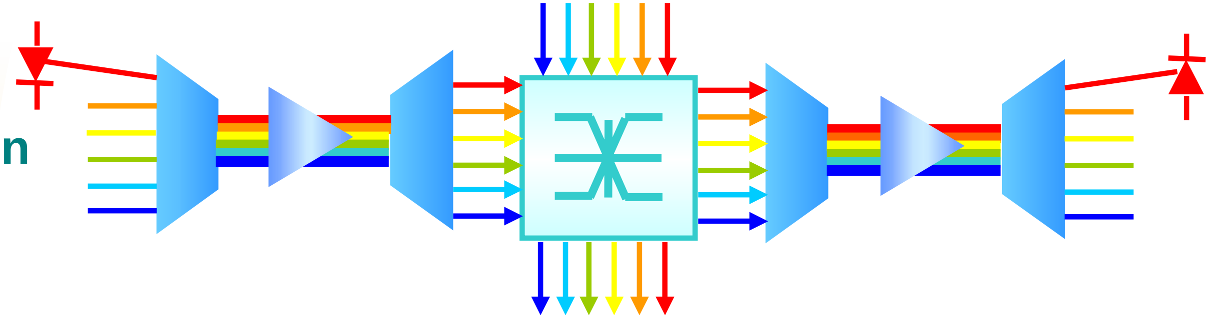
  ★origin ★transport history ★data format ★data content

  and

  ★at arbitrary network points

Drivers for more advanced OPM

- ***Technological drivers:***



Longer transmission distance

Higher bit rate

More intelligence

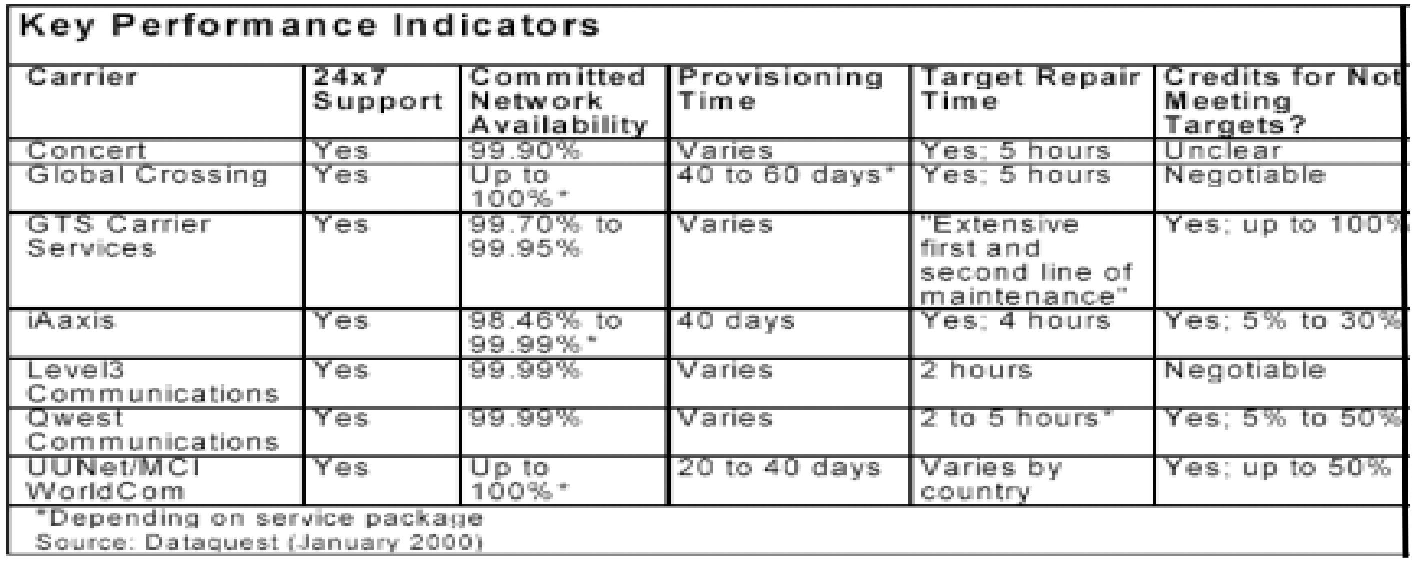
More stringent QoS requirements

Increased λ number

- ***Business drivers:***
  - Lower Operation & Maintenance costs
  - Enable SLA and service differentiation

Examples of Service Level Agreement

- QoS measured in terms of:
  - Committed network availability
  - Provisioning time
  - Target repair time and procedures
  - Penalties
  - Interface description …



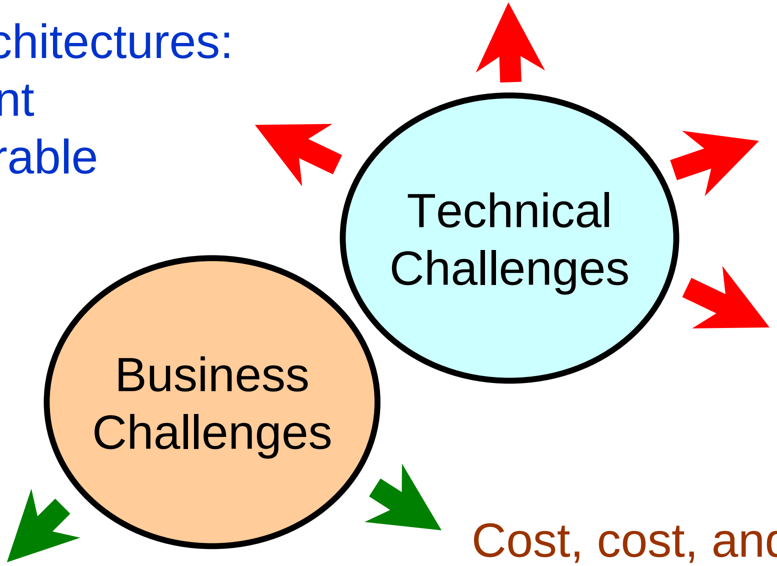
Key Performance Indicators

Carrier	24x7 Support	Committed Network Availability	Provisioning Time	Target Repair Time	Credits for Not Meeting Targets?
Concert	Yes	99.90%	Varies	Yes; 5 hours	Unclear
Global Crossing	Yes	Up to 100%*	40 to 60 days*	Yes; 5 hours	Negotiable
GTS Carrier Services	Yes	99.70% to 99.95%	Varies	"Extensive first and second line of maintenance"	Yes; up to 100%
iAaxis	Yes	98.46% to 99.99%*	40 days	Yes; 4 hours	Yes; 5% to 30%
Level3 Communications	Yes	99.99%	Varies	2 hours	Negotiable
Qwest Communications	Yes	99.99%	Varies	2 to 5 hours*	Yes; 5% to 50%
UUNet/MCI WorldCom	Yes	Up to 100%*	20 to 40 days	Varies by country	Yes; up to 50%

*Depending on service package
Source: Dataquest (January 2000)

Ref: Roland Bach, "Need for Optical Monitoring OPM for QoS", ACTERNA Deutschland
Also see "Service level agreement and provisioning in optical networks," Com. Mag. Jan 2004

Challenges of OPM



Complex system effects:
- CD, PMD, PDL, PDG, XPM, SPM,…
- Power + λ fluctuations
- Different format, bit rate

All-optical architectures:
- Transparent
- Reconfigurable

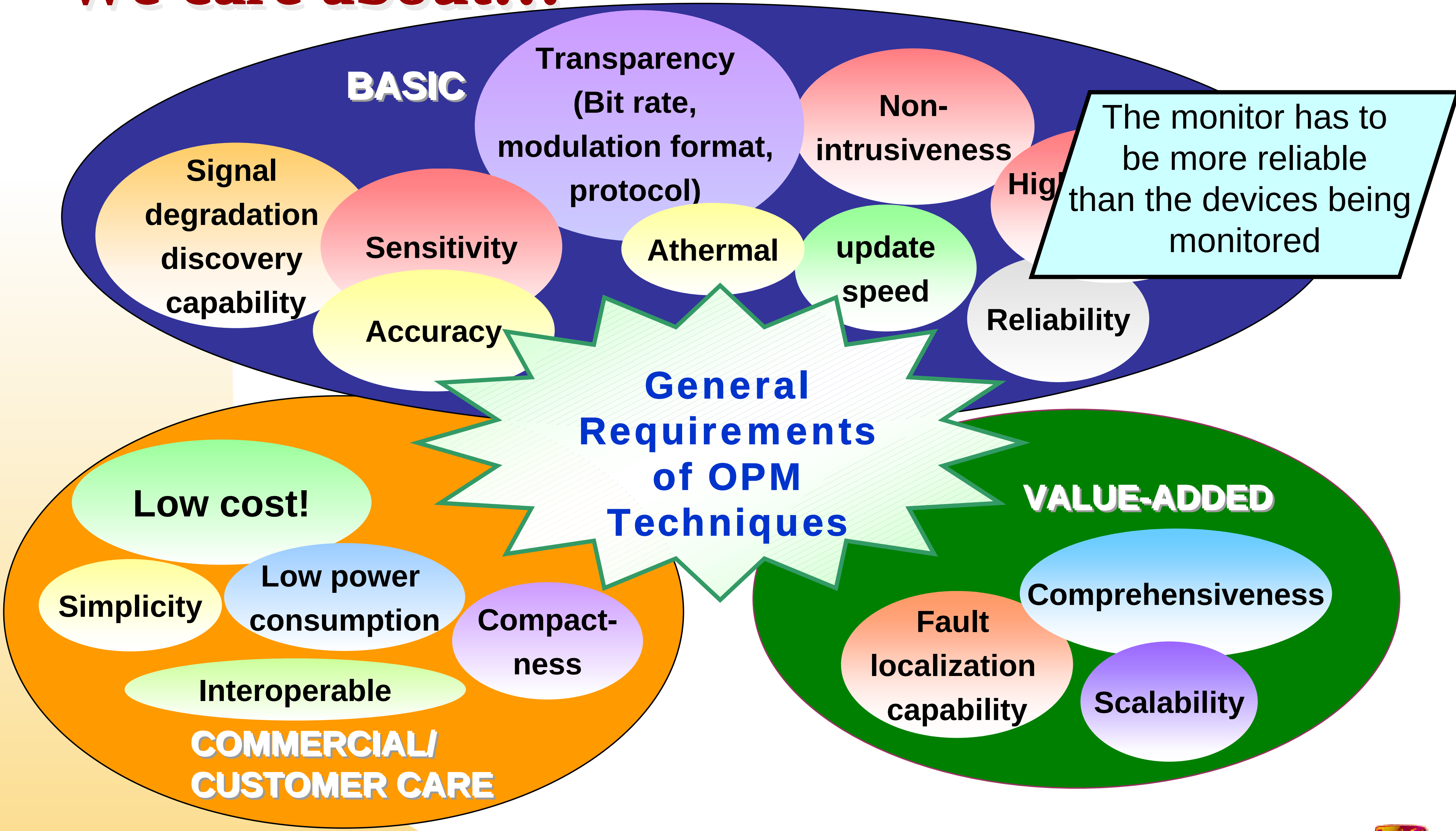
- Temperature, stress, dirt, aging
- damage, maintenance, repair

Inter-layer considerations:
- OPM metrics dissemination to upper layers
- OPM metrics correlation

Cost, cost, and cost!
- Optical vs. Electronics solutions

Standards + Interoperability:
- Standard-based vs. proprietary-based
- Vendors
- Inter-domain (ULH, metro, access)

We care about…



General Requirements of OPM Techniques

BASIC

Transparency (Bit rate, modulation format, protocol)

Non-intrusiveness

Hig

Signal degradation discovery capability

Sensitivity

Athermal

update speed

Accuracy

Reliability

The monitor has to be more reliable than the devices being monitored

COMMERCIAL/ CUSTOMER CARE

Low cost!

Simplicity

Low power consumption

Compact-ness

Interoperable

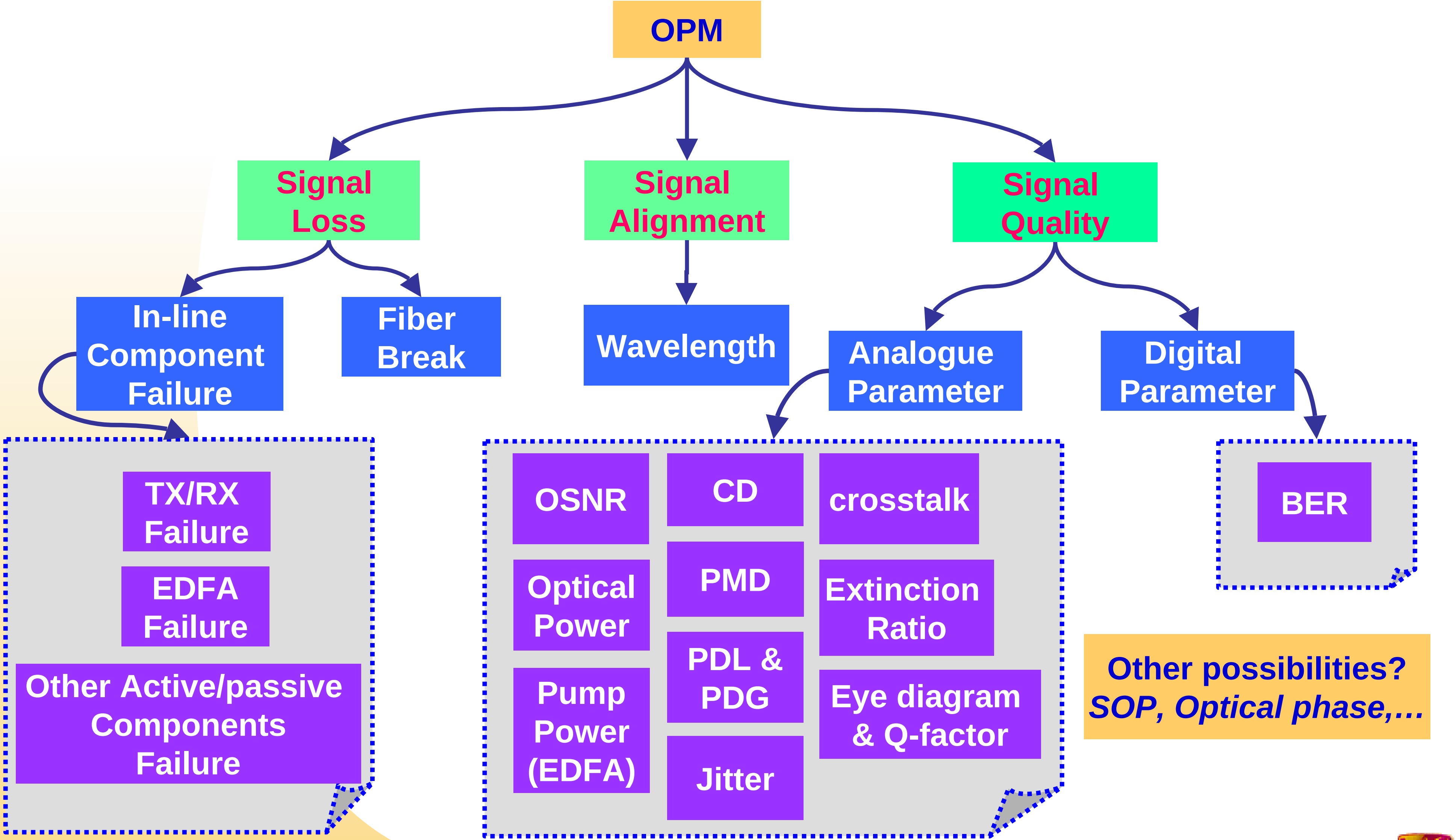
VALUE-ADDED

Comprehensiveness

Fault localization capability

Scalability

The broad spectrum of OPM



OPM

Signal Loss

- In-line Component Failure
  - TX/RX Failure
  - EDFA Failure
  - Other Active/passive Components Failure
- Fiber Break

Signal Alignment

- Wavelength

Signal Quality

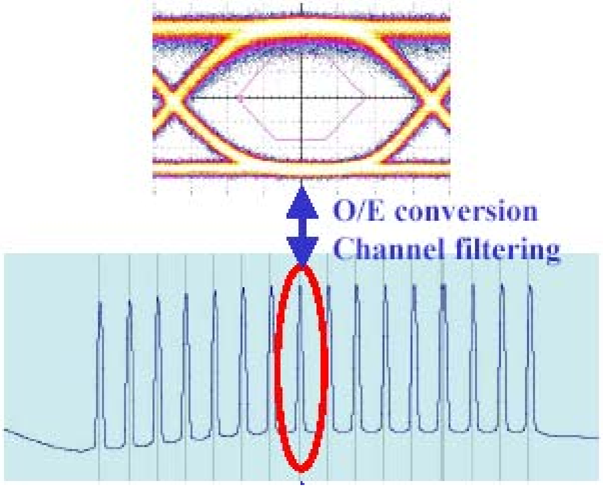
- Analogue Parameter
  - OSNR
  - Optical Power
  - Pump Power (EDFA)
  - CD
  - PMD
  - PDL & PDG
  - Jitter
  - crosstalk
  - Extinction Ratio
  - Eye diagram & Q-factor
- Digital Parameter
  - BER

Other possibilities?
SOP, Optical phase,…

Monitoring in time/frequency domain

- Time-domain
  - Eye diagram
  - BER
  - Histogram (synchronous and asynchronous)
  - Time-varying changes: PMD, jitter, power, …

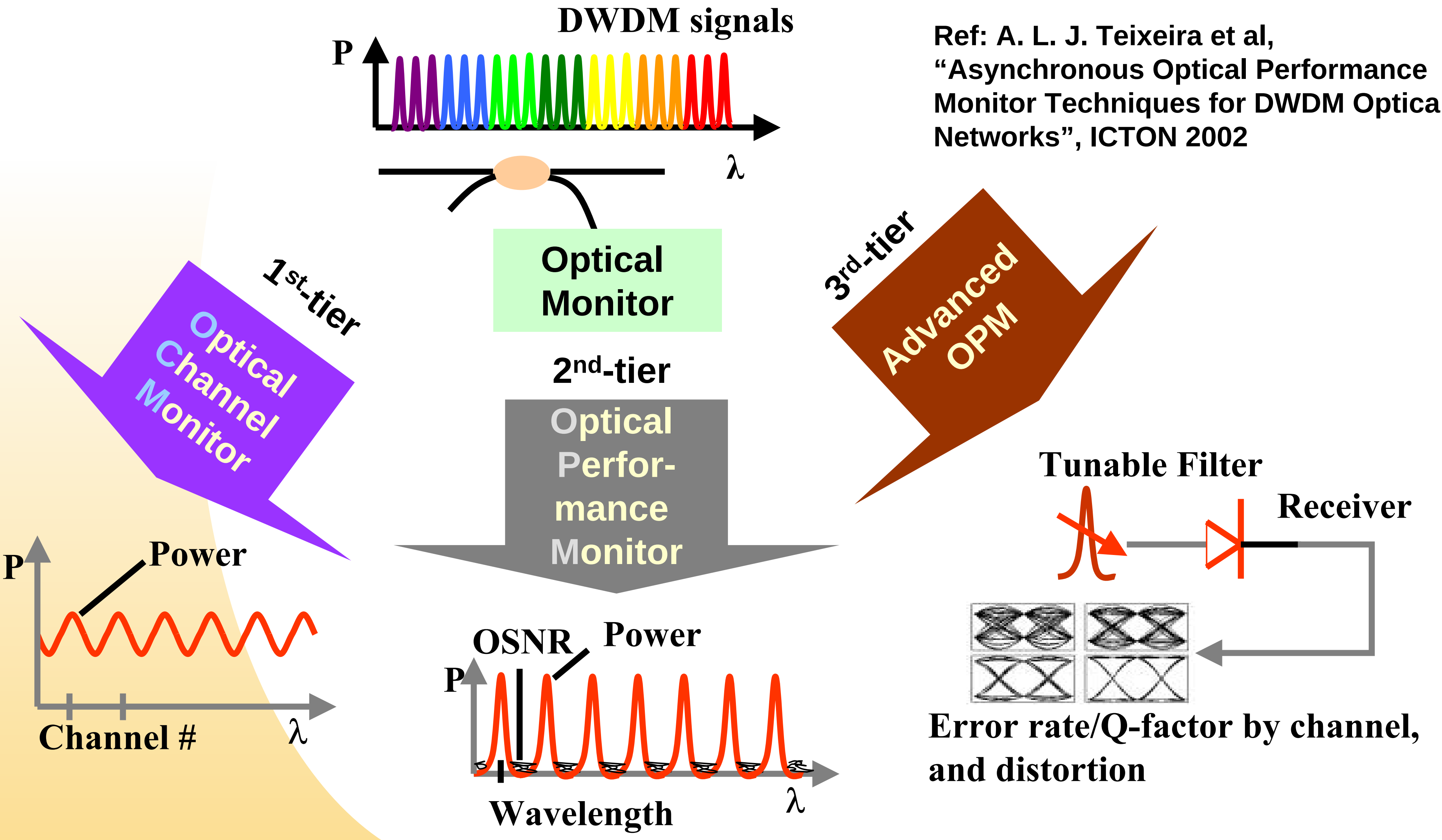
- Frequency-domain
  - Out-of-band
    - ASE noise (less accurate)
  - In-band
    - Power
    - Wavelength
    - ASE noise (more accurate)
    - Spectral width/data-rate
    - Clock tones power for CD/PMD compensation



Ref: Need for Optical Monitoring OPM for QoS, Roland Bach ACTERNA Deutschland, OFC2003

Three Tiers of OPM

Ref: A. L. J. Teixeira et al, "Asynchronous Optical Performance Monitor Techniques for DWDM Optical Networks", ICTON 2002



Optical Monitor

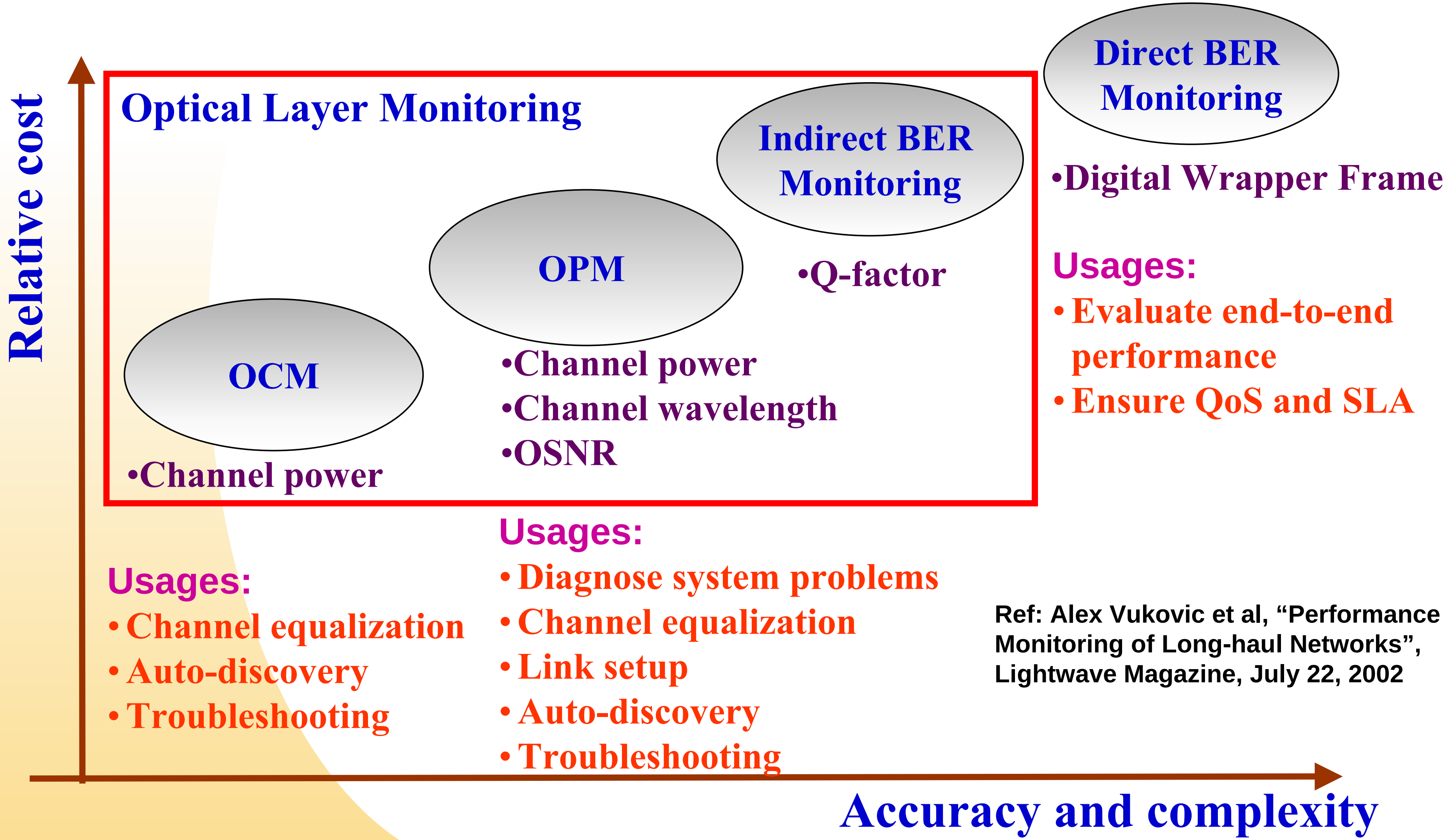
1st-tier
Optical Channel Monitor

2nd-tier
Optical Perfor-mance Monitor

3rd-tier
Advanced OPM

Error rate/Q-factor by channel, and distortion

Compromise between cost and accuracy



OCM
- Channel power

Usages:
- Channel equalization
- Auto-discovery
- Troubleshooting

OPM
- Channel power
- Channel wavelength
- OSNR

Usages:
- Diagnose system problems
- Channel equalization
- Link setup
- Auto-discovery
- Troubleshooting

Indirect BER Monitoring
- Q-factor

Direct BER Monitoring
- Digital Wrapper Frame

Usages:
- Evaluate end-to-end performance
- Ensure QoS and SLA

Ref: Alex Vukovic et al, “Performance Monitoring of Long-haul Networks”, Lightwave Magazine, July 22, 2002

Making a judicious choice

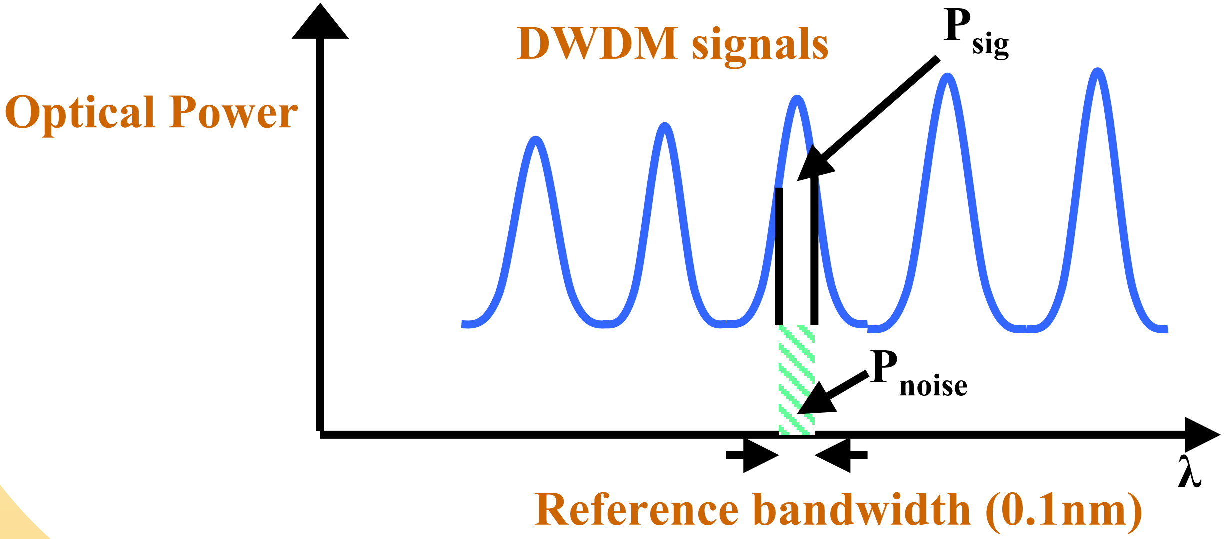
- **Considerations:**
  - Right choice of monitoring/mitigation techniques
    - Optical monitoring techniques for WDM networks
    - Will *electronics mitigation* techniques on channel-by-channel basis drive OPM unnecessary?
  - Suitable amount of monitoring
    - Effectiveness
    - Computation power (accuracy)
    - Budget
  - Placement of monitoring points
    - Within one network (all nodes or some strategic points)
    - Inter-domain (ULH, metro, access, …)
  - Update Frequency

Outline

- Optical performance monitoring (OPM): Why is it needed?
- Optical signal-to-noise ratio (OSNR) monitoring techniques
- System design aspects + future perspectives

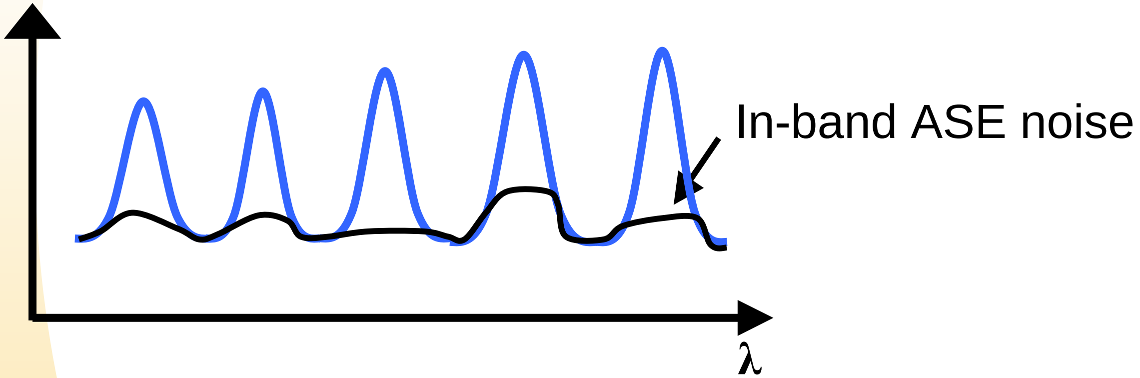
OSNR monitoring techniques

- OSNR(dB) = 10log(P_{sig}/P_{ASE})
- Uses of OSNR in
  - Link setup, control, and optimization
  - In-service characterization of optical signal quality
  - Correlation with end terminal BER
- Making OSNR measurements



Reported OSNR monitoring techniques

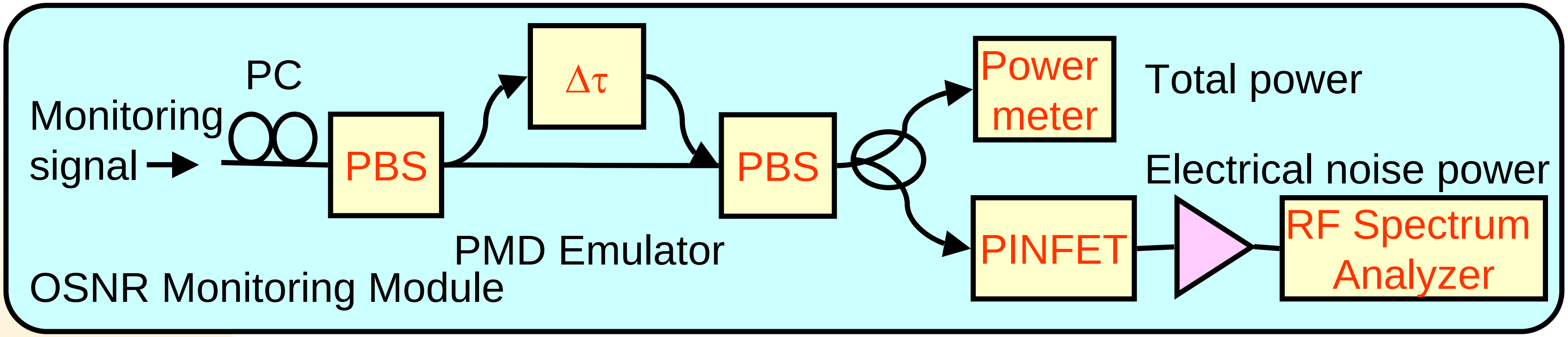
- Out-of-band: noise taken outside channel bandwidth
  - +: Measurable by traditional OSA
  - -: Different EDFA gains for channels, effect of optical filtering,…
    $\rightarrow$ out-of-band noise $\neq$ in-band noise

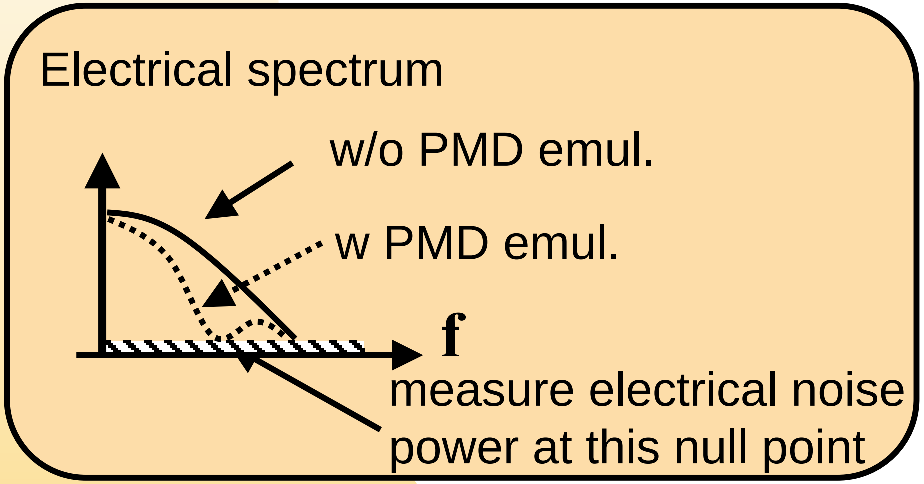


- In-band: noise taken within channel bandwidth
  - Electrical spectral analysis
  - Polarization-assisted optical power analysis
  - Subcarrier CNR correlation
  - Mach-Zehnder interferometric method

Electrical spectral analysis

- Orthogonal delayed-homodyne method





+: Bit-rate and modulation format independent
+: Insensitive to PMD

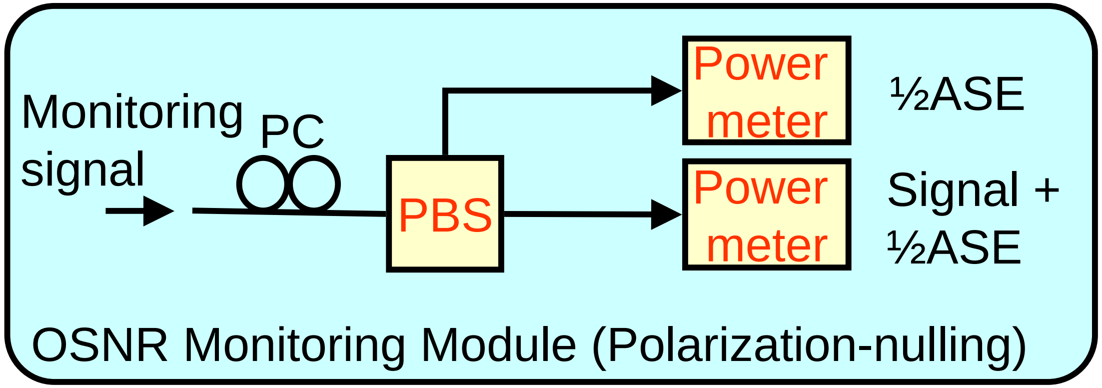
-: Complexity
-: High monitoring power required
-: High resolution power measurement required
-: Sensitive to chromatic dispersion

Ref: C. J. Youn et al, "OSNR Monitoring Technique Based on Orthogonal Delayed-Homodyne Method", OFC 2002 & IEEE PTL Vol. 14, Oct 2002.

Polarization-assisted power analysis

- Monitor by polarization-nulling or by degree-of-polarization (DOP)

Signal	**Noise**
Polarized	**Unpolarized**



Monitoring signal

PC

PBS

Power meter

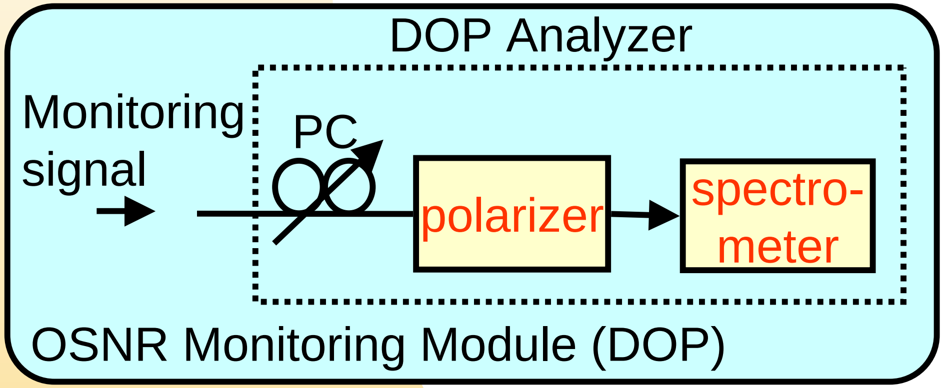
½ASE

Power meter

Signal + ½ASE

OSNR Monitoring Module (Polarization-nulling)

Ref: J. H. Lee et al, "OSNR Monitoring Technique using Polarization-Nulling Method", IEEE PTL, Vol. 13, Jan 2001.



DOP Analyzer

Monitoring signal

PC

polarizer

spectro-meter

OSNR Monitoring Module (DOP)

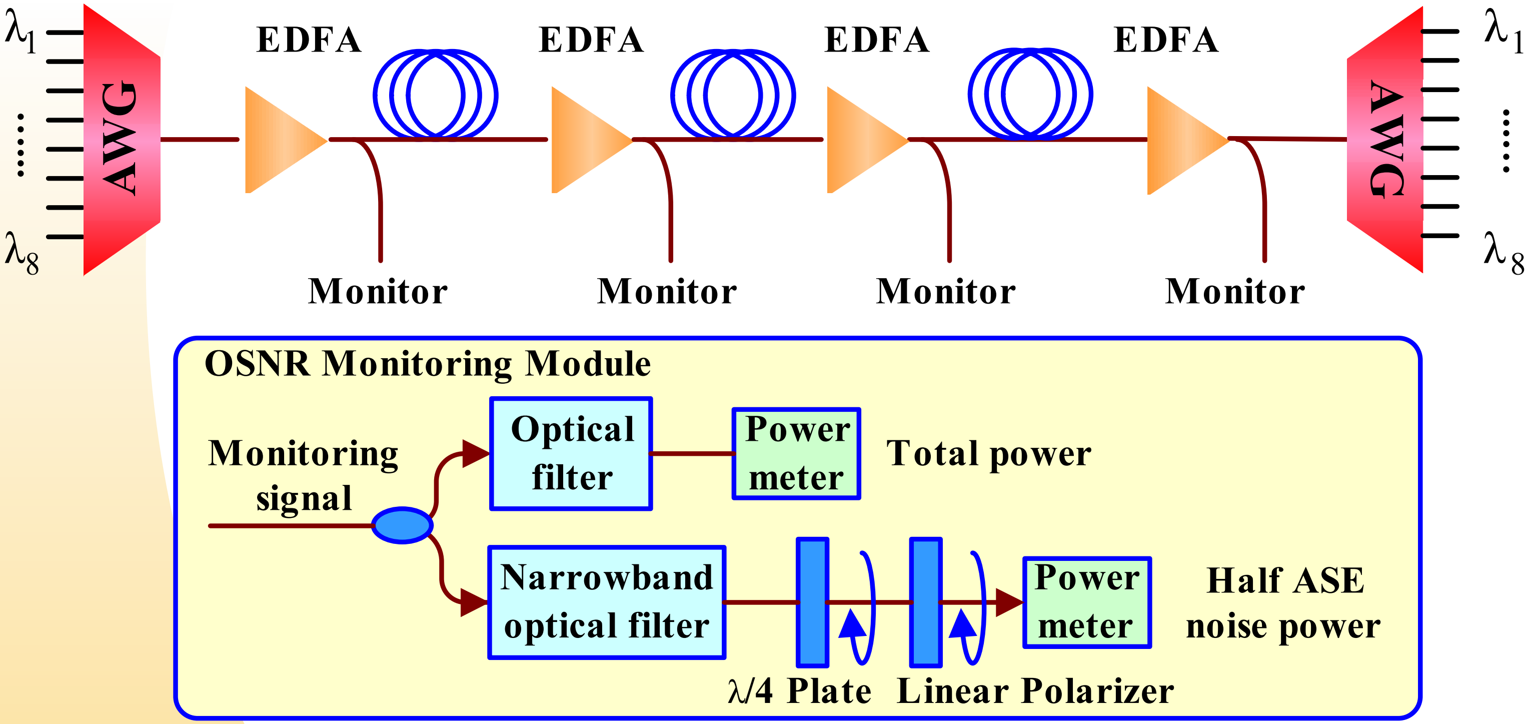
Ref: M. Petersson et al, "Multi-channel OSNR Monitoring for WDM networks", ECOC 2002

+: Simple
+: Relatively low monitoring power needed
+: No electrical processing
+: Large dynamic range

-: Sensitive to PMD

Polarization-assisted power analysis

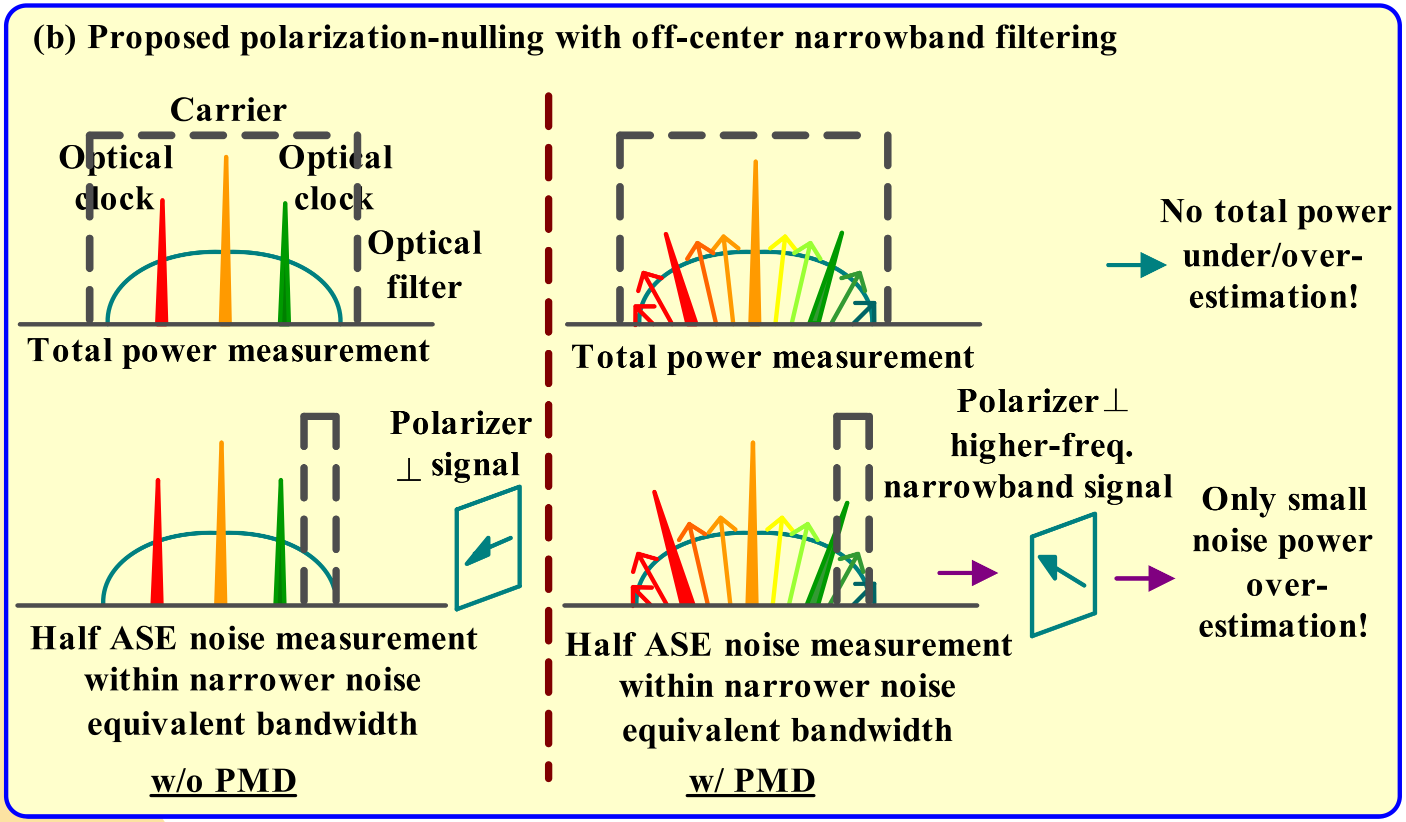
- Monitor by polarization-nulling with off-center narrowband filtering



Ref: M. H. Cheung et al, "A PMD-insensitive OSNR Monitoring Scheme Based on Polarization-Nulling with Off-center Narrowband filtering", Paper FF2, Proc. OFC'04.

Polarization-assisted power analysis

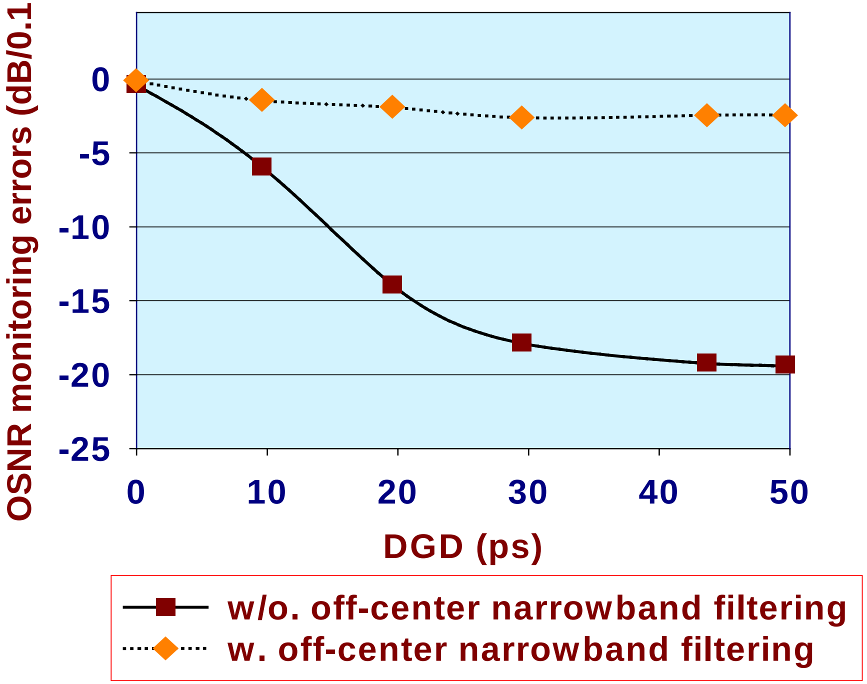
- Monitor by polarization-nulling with off-center narrowband filtering – Robustness to PMD enhanced



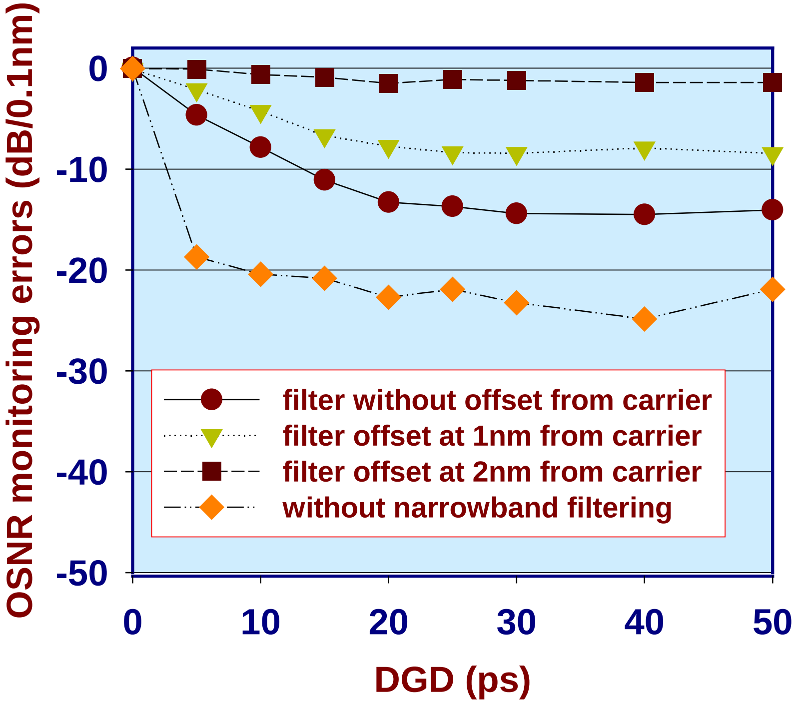
Polarization-assisted power analysis

- Monitor by polarization-nulling with off-center narrowband filtering – Robustness to PMD enhanced

OSNR monitoring errors for 25-ps 10-Gb/s RZ-OOK data

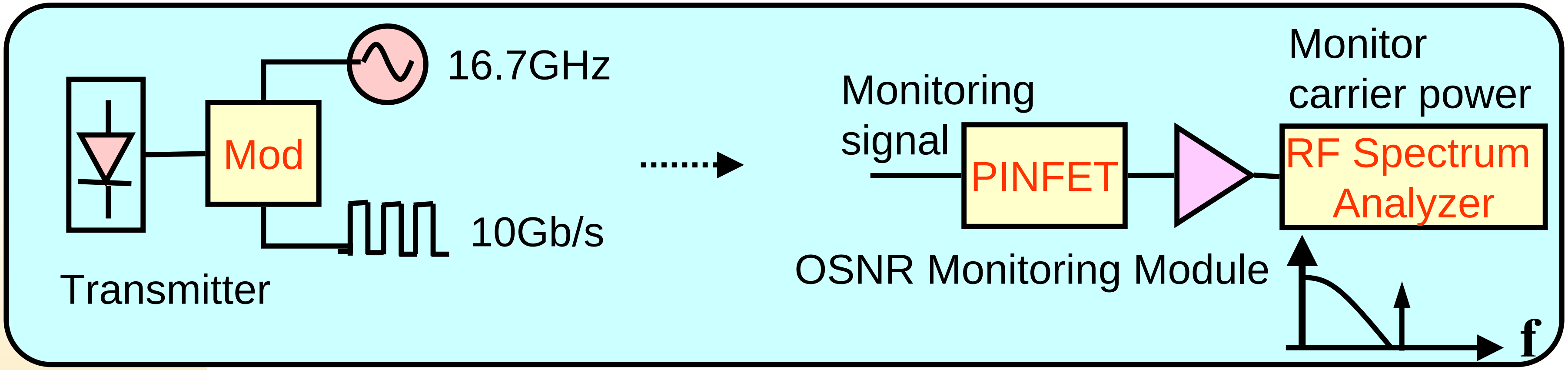


OSNR monitoring errors for 2.5-ps 40-Gb/s OTDM RZ-OOK data



Subcarrier CNR correlation

- Monitor OSNR by correlation with carrier-to-noise ratio of subcarrier



Ref: G. Rossi et al, "Optical Performance Monitoring in Reconfigurable WDM Optical Networks Using Subcarrier Multiplexing", IEEE JLT Vol. 18, Dec 2000

$$OSNR = \sqrt{\frac{B_{ESA}}{\Delta\nu}\frac{CNR}{m^2}}$$

CNR : carrier − to − noise ratio

B_{ESA} : resolution bandwidth of electrical spectrum analyzer

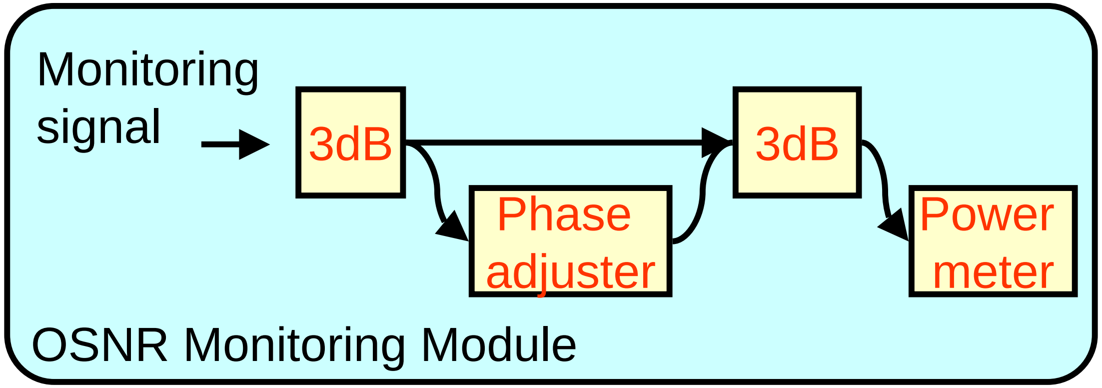
$\Delta\nu$: optical bandwidth

m : modulation depth of subcarrier

+: Simultaneous multiple channel monitoring
+: Simple

-: Extra bandwidth needed
-: Sensitive to PMD and CD

Mach-Zehnder interferometric method


Monitoring signal

3dB

Phase adjuster

3dB

Power meter

OSNR Monitoring Module

Ref: Z. Tao et al, “A Novel Method to monitor OSNR Using a Mach-Zehnder Interferometer”, CLEO/PR 2001. Peking University, China

Signal	**Noise**
Coherent	**Non-coherent**

+: Relatively insensitive to PMD
+: Potentially low-cost
+: Simple

-: Require accurate matching of coupling ratio

OSNR Monitoring Standards

- Industry standards can be found at http://global.ihs.com/
  - ***BS EN 61280-2-9*** **Revision: 02** Chg: Date: 00/00/02

    FIBRE OPTIC COMMUNICATION SUBSYSTEM TEST PROCEDURES - PART 2-9: DIGITAL SYSTEMS - OPTICAL SIGNAL-TO-NOISE RATIO MEASUREMENT FOR DENSE WAVELENGTH-DIVISION MULTIPLEXED SYSTEMS
  - ***IEC 61280-2-9*** **Revision: 02** Chg: Date: 10/00/02

    FIBRE OPTIC COMMUNICATION SYBSYSTEM TEST PROCEDURES - PART 2-9: DIGITAL SYSTEMS - OPTICAL SIGNAL-TO-NOISE RATIO MEASUREMENT FOR DENSE WAVELENGTH-DIVISION MULTIPLEXED SYSTEMS
  - ***TIA/EIA-526-19*** **Revision: 00** Chg: Date: 06/00/00

    OFSTP-19 OPTICAL SIGNAL-TO-NOISE RATIO MEASUREMENT PROCEDURES FOR DENSE WAVELENGTH-DIVISION MULTIPLEXED SYSTEMS

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- Optical performance monitoring (OPM): Why is it needed?
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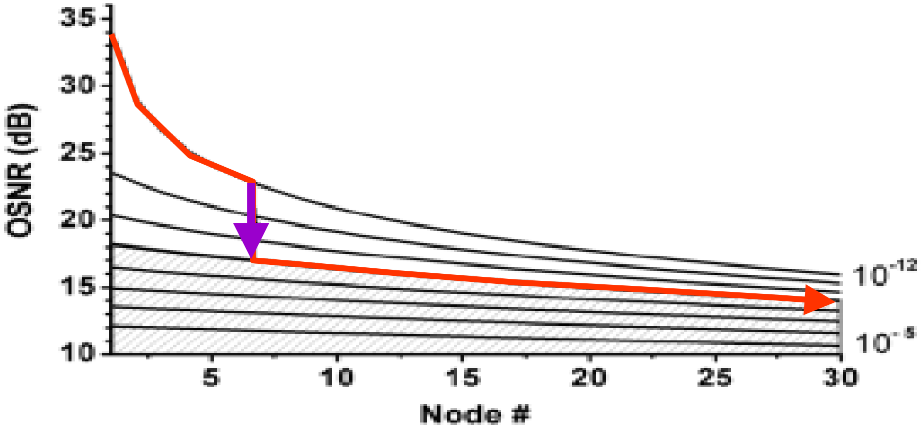
- System design aspects + future perspectives

Features of advanced OPM techniques

- Comprehensiveness:
  - making measurements on multiple parameters
    - Simultaneous PMD and GVD monitoring
    - Simultaneous PMD and OSNR monitoring
    - Simultaneous wavelength, power, and path monitoring*
  - Integrate various functions (X+OPM) into a single, simple module

***Ref: K.J. Pak et al., OFC'04 FF1**

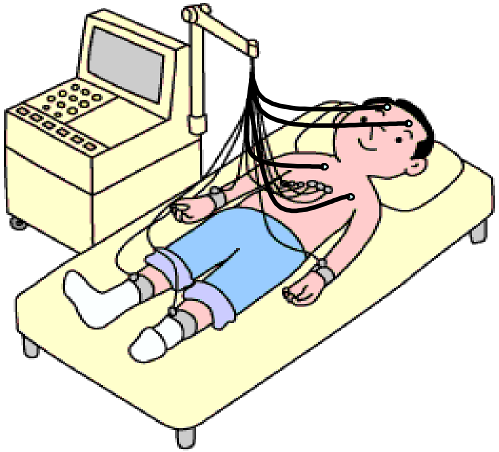
- Fault localization:



Ref: D. C. Kilper et al, "Monitoring optical network performance degradation due to amplifier noise", JLT, Vol. 21, May 2003

Centralized vs. Distributed OPM

- Distributed OPM
  - More information easily collected and processed
  - Cost and ways to integrate OPM with in-line components are of concern



- Centralized OPM
  - Collect information from other segments of optical transmission links
  - Process information at a strategic point
    - Example: OTDR
  - Fault localization capability is a desirable feature

Other related research

- Sensor Networks
- Computer Tomography

Summary

- OPM in next-generation high-speed transparent reconfigurable long-haul networks is a key enabler

- OPM comprises different tiers of monitoring to cater for different needs. Both optical surveillance schemes and OSNR monitoring are indispensable.

- The key challenges for OPM: developing a cost-effective OPM technique and integrating OPM into different system design.

Not Just a Bonus Element

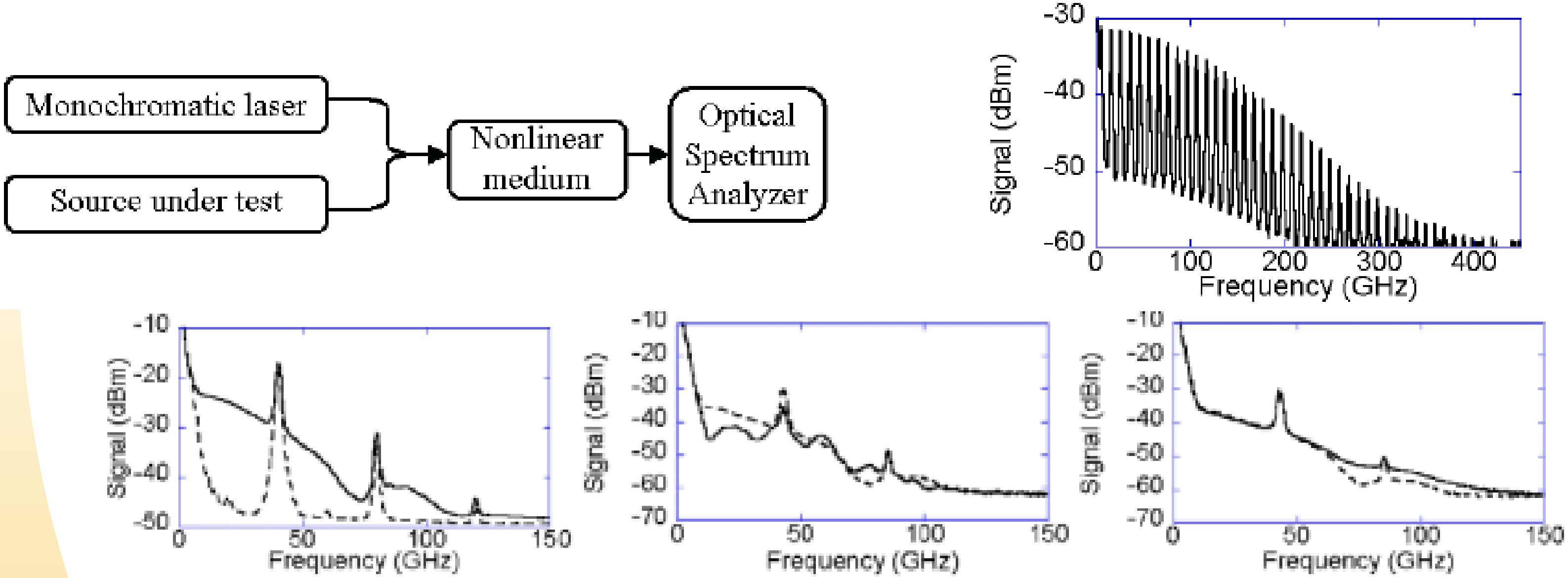
Uses:	Examples:
Signal quality characterization	■ Relating OSNR with BER ■ Early signal degradation alarm
Fault management	■ Fault detection, localization, and isolation ■ Resilience mechanism activation
Active compensation	■ Dynamic CD + PMD monitoring and compensation
Quality of service (QoS) provisioning	■ SLA fulfillment verification

OPM/Management & Control Plane Communications

- Dissemination of monitoring signal to the corresponding network management unit and related network elements (NE)
- How to design monitoring frequency and storage memory of NE? And also fault alarms, fault clearances and threshold setting?
- How to optimize the network planning to provide highly reliable channels for monitor and control signal dissemination and regular channels for data transmission?
- Further considerations in physical layer and higher layer protocol
  - Horizontal communication between nodes to isolate the problem - GMPLS LMP's "Link Verification" and "Fault Management"
  - Inter-vendor collaboration

Going 40Gb/s and beyond: How OPM advances?

- Optical diagnostics with high temporal resolution, high sensitivity, or phase sensitivity needed
  - High bandwidth optical RF spectrum measurement



Ref: C. Dorrer, "New techniques for high-speed optical characterization" Paper FF5, Proc. OFC'04.

  - High speed sampling techniques