Performance Monitoring in Optical Networks

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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:**
- More intelligence
- Higher bit rate
- Increased $\lambda$ number
- Longer transmission distance
- More stringent QoS requirements

**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

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

*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 + $\lambda$ fluctuations
- Different format, bit rate

Technical Challenges
- Temperature, stress, dirt, aging
- Damage, maintenance, repair
- Inter-layer considerations:
  - OPM metrics dissemination to upper layers
  - OPM metrics correlation

All-optical architectures:
- Transparent
- Reconfigurable

Business Challenges

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

Cost, cost, and cost!
- Optical vs. Electronics solutions
We care about...

**BASIC**

- Signal degradation discovery capability
- Sensitivity
- Accuracy
- Transparency (Bit rate, modulation format, protocol)
- Non-intrusiveness
- Athermal
- Update speed
- Reliability

**VALUE-ADDED**

- Comprehensiveness
- Interoperable
- Fault localization capability
- Scalability

**COMMERCIAL/CUSTOMER CARE**

- Low cost!
- Simplicity
- Low power consumption
- Compactness

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

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The broad spectrum of OPM

- Signal Loss
  - In-line Component Failure
  - Fiber Break
- Signal Alignment
  - Wavelength
- Signal Quality
  - Analogue Parameter
  - Digital Parameter

Other possibilities: SOP, Optical phase, ...

Parameter Types:
- analogue
- Digital

Components:
- TX/RX Failure
- EDFA Failure
- Other Active/passive Components Failure
- OSNR
- Optical Power
- Pump Power (EDFA)
- CD
- PMD
- PDL & PDG
- Jitter
- crosstalk
- Extinction Ratio
- Eye diagram & Q-factor
- BER

Other Active/passive Components Failure
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

Compromise between cost and accuracy

Optical Layer Monitoring
- OCM
  - Channel power
- OPM
  - Channel power
  - Channel wavelength
  - OSNR
  - Q-factor

Indirect BER Monitoring
- Direct BER Monitoring
  - Digital Wrapper Frame
  - Evaluate end-to-end performance
  - Ensure QoS and SLA

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

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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_sиг/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

![Diagram of DWDM signals with optical power and reference bandwidth (0.1nm)]
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,...
  → out-of-band noise ≠ 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

In-band ASE noise
Electrical spectral analysis

- Orthogonal delayed-homodyne method

Polarization-assisted power analysis

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

<table>
<thead>
<tr>
<th>Signal</th>
<th>Noise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polarized</td>
<td>Unpolarized</td>
</tr>
</tbody>
</table>

![Diagram of OSNR Monitoring Module (Polarization-nulling)]

- Simple
- Relatively low monitoring power needed
- No electrical processing
- Large dynamic range
- Sensitive to PMD


Ref: M. Petersson et al, “Multi-channel OSNR Monitoring for WDM networks”, ECOC 2002
Polarization-assisted power analysis

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

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

(b) Proposed polarization-nulling with off-center narrowband filtering

- No total power under/over-estimation!
- Only small noise power over-estimation!

Half ASE noise measurement within narrower noise equivalent bandwidth

w/o PMD

w/ PMD

Polarization-assisted power analysis
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

![Diagram of optical monitoring system]

- Monitor carrier power


\[
OSNR = \sqrt{\frac{B_{ESA}}{\Delta \nu}} \cdot \frac{CNR}{m^2}
\]

- 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


<table>
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<tr>
<th>Signal</th>
<th>Noise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coherent</td>
<td>Non-coherent</td>
</tr>
</tbody>
</table>

+: 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/](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 SUBSYSTEM 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
Outline

- Optical performance monitoring (OPM): Why is it needed?
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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

- Fault localization:

*Ref: K.J. Pak et al., OFC’04 FF1

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

<table>
<thead>
<tr>
<th>Uses:</th>
<th>Examples:</th>
</tr>
</thead>
</table>
| **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


- High speed sampling techniques