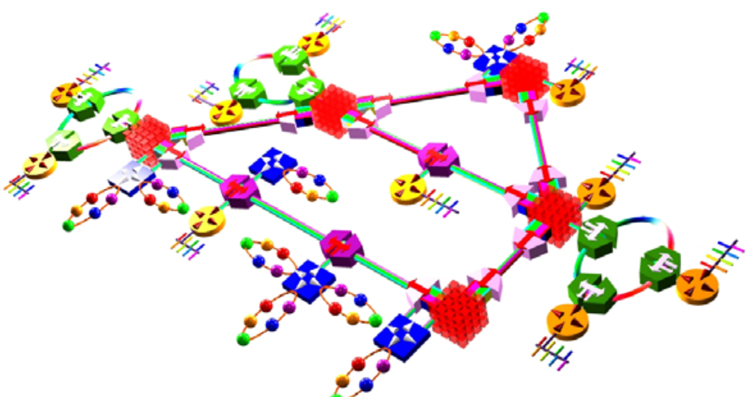
Optical Performance Monitoring Applications in Transparent Networks

Dan Kilper
Advanced Photonics Research
Lucent Technologies
dkilper@lucent.com

C. R. Giles, W. Weingartner, A. Azarov, P. Vorreau, and J. Leuthold

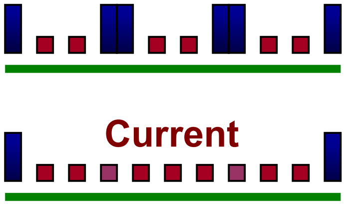


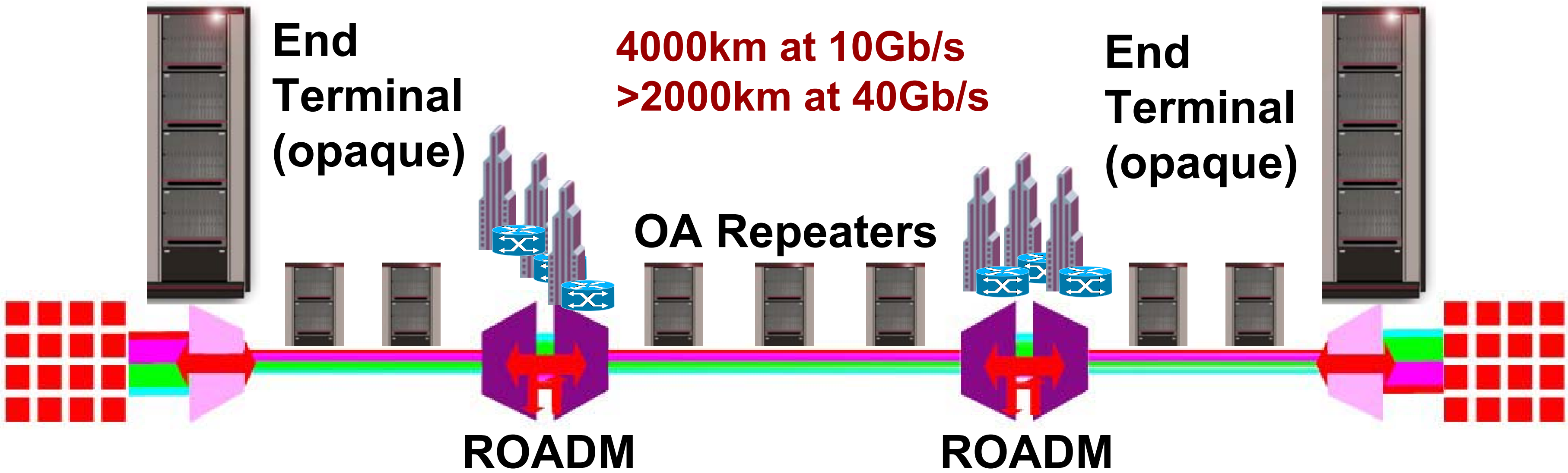
WOCC
April 22, 2005
Newark, NJ

Lucent Technologies
Bell Labs Innovations

Ultra-long Transport Systems

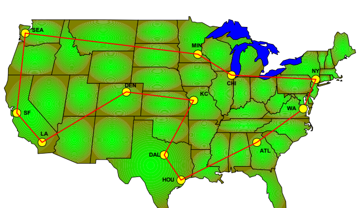
Point-to-Point Transparency



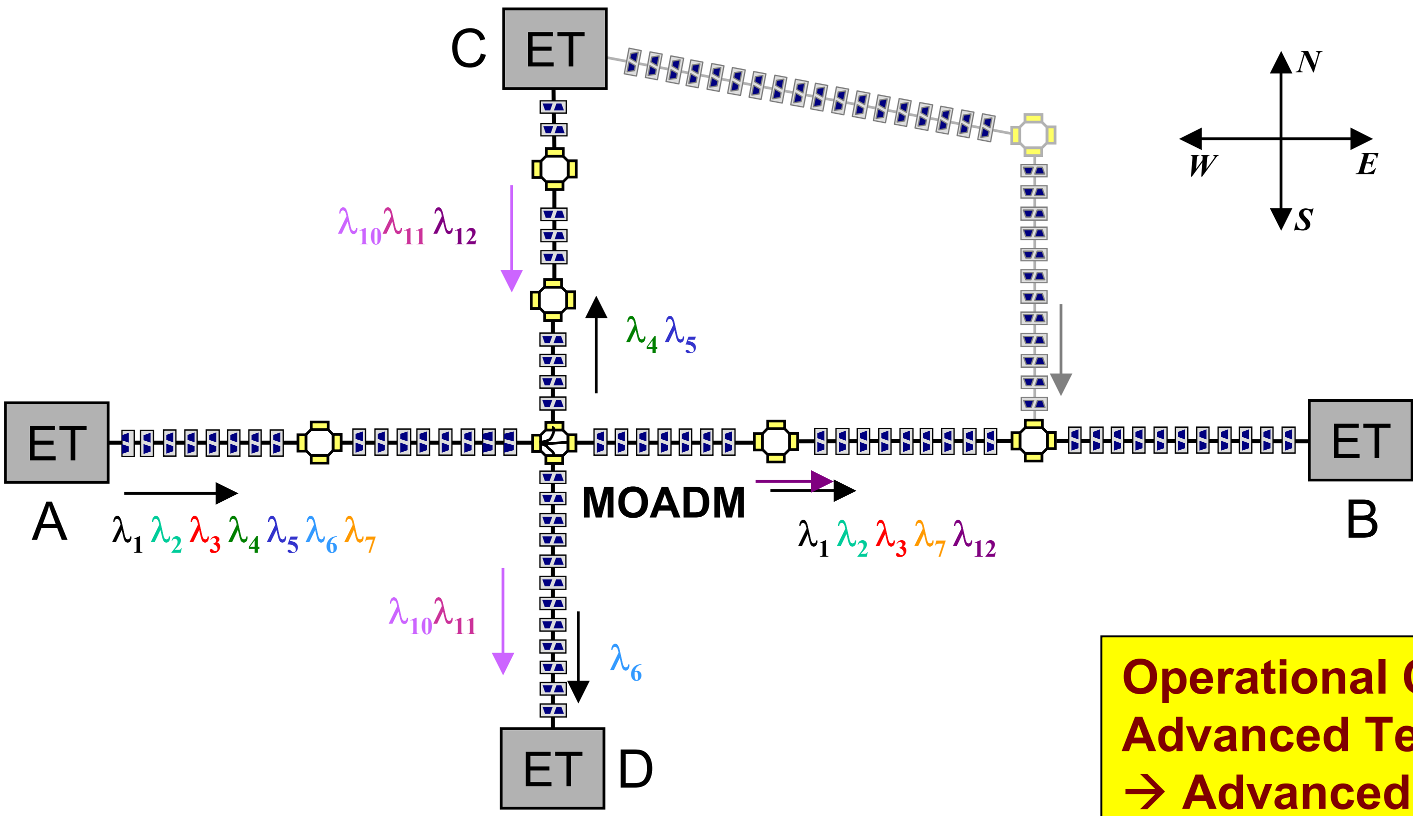


Advanced Technologies:
Raman Amplification
Dispersion Managed Solitons
Dynamic Gain Equalization
DPSK, Advanced Modulation Formats

Mitigation of:
Noise
Dispersion
Gain variation
Nonlinearity



ULH+ROADM/OXC MESH NETWORK



Operational Complexity + Advanced Technology → Advanced Monitoring

Transparent Reconfiguration

- Intersecting lines must discover one another and exchange topology information.
- Auto-provisioning must operate across the mesh network.
- Faults are correlated across multiple systems.

- Greater flexibility requires better stability & control

Lucent Technologies
Bell Labs Innovations

Optical Network Performance Monitoring

• First Generation: Total power monitoring. Amplifier gain adjustment, signal presence, link status verification.

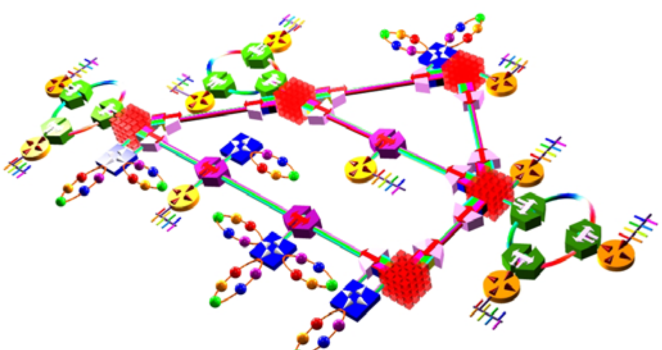
• Second Generation: WDM channel presence / power and wavelength. Auto-provisioning and gain flattening.

TODAY

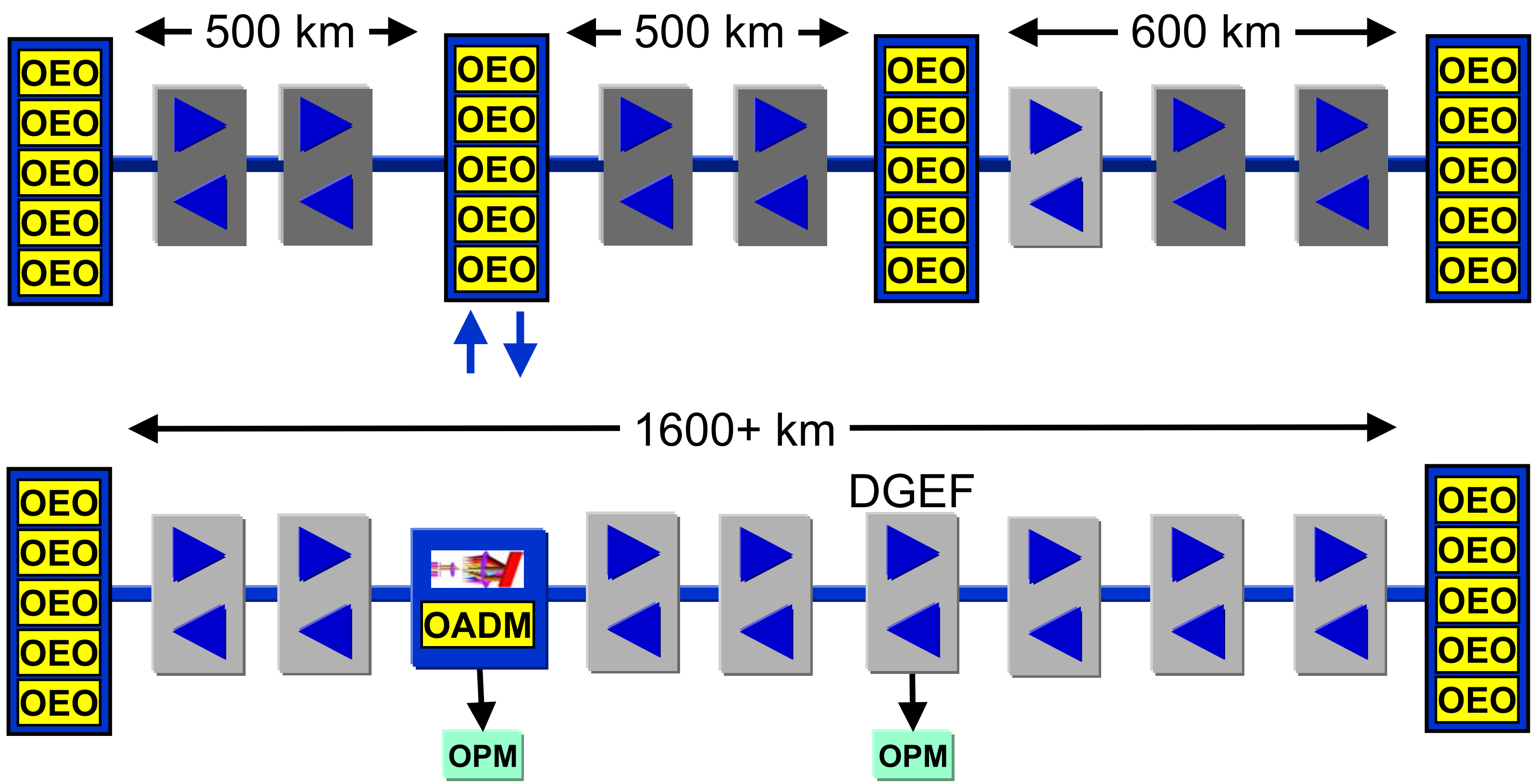
• Third Generation: Channel optical SNR / Q-factor, active dispersion compensation. Fault isolation, dispersion compensation.

• Fourth Generation: Transparent network management. Channel performance verification after link concatenation.

• Fifth Generation: In-situ link parameter extraction from detailed channel signatures. Preplanning / preprovisioning assessment. Resource database creation.

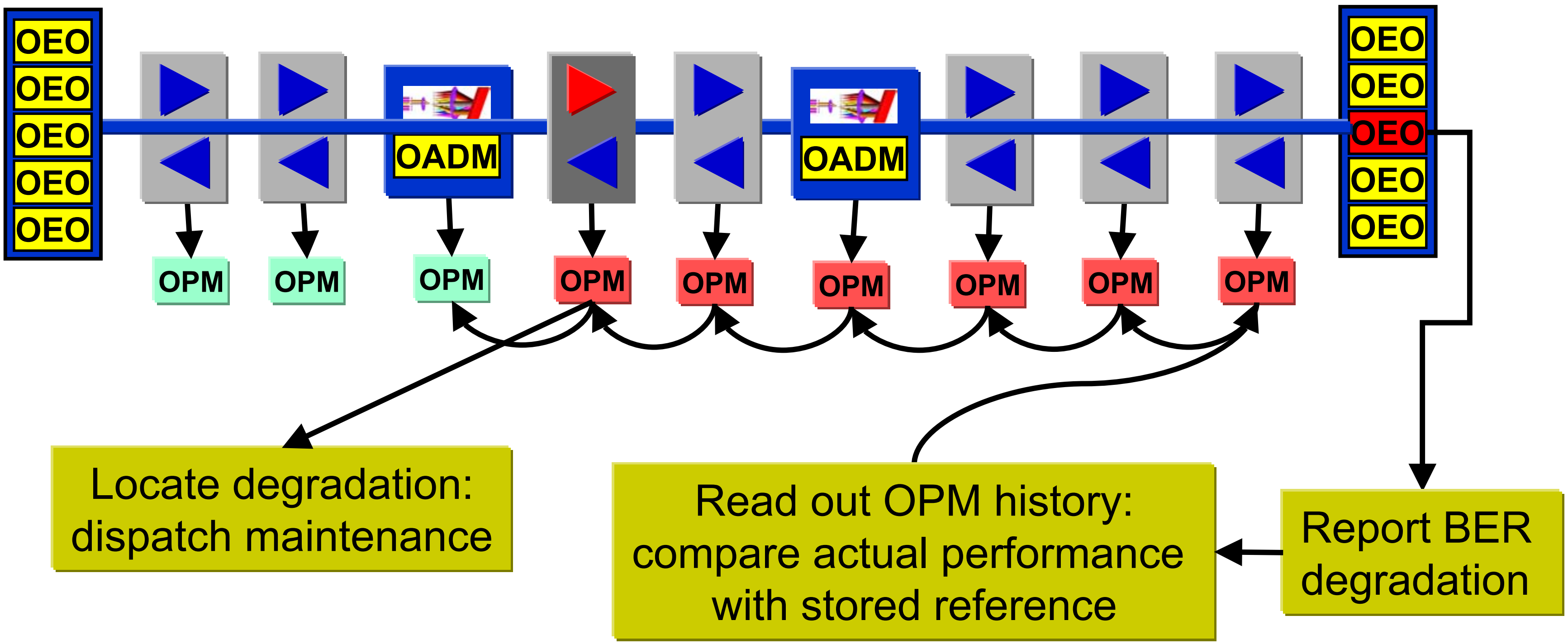


Eliminating Regenerators



- **Must also consider fault management requirements**
- **Cost of OADM/ULH technology (DGEF)/OPM < OEO**

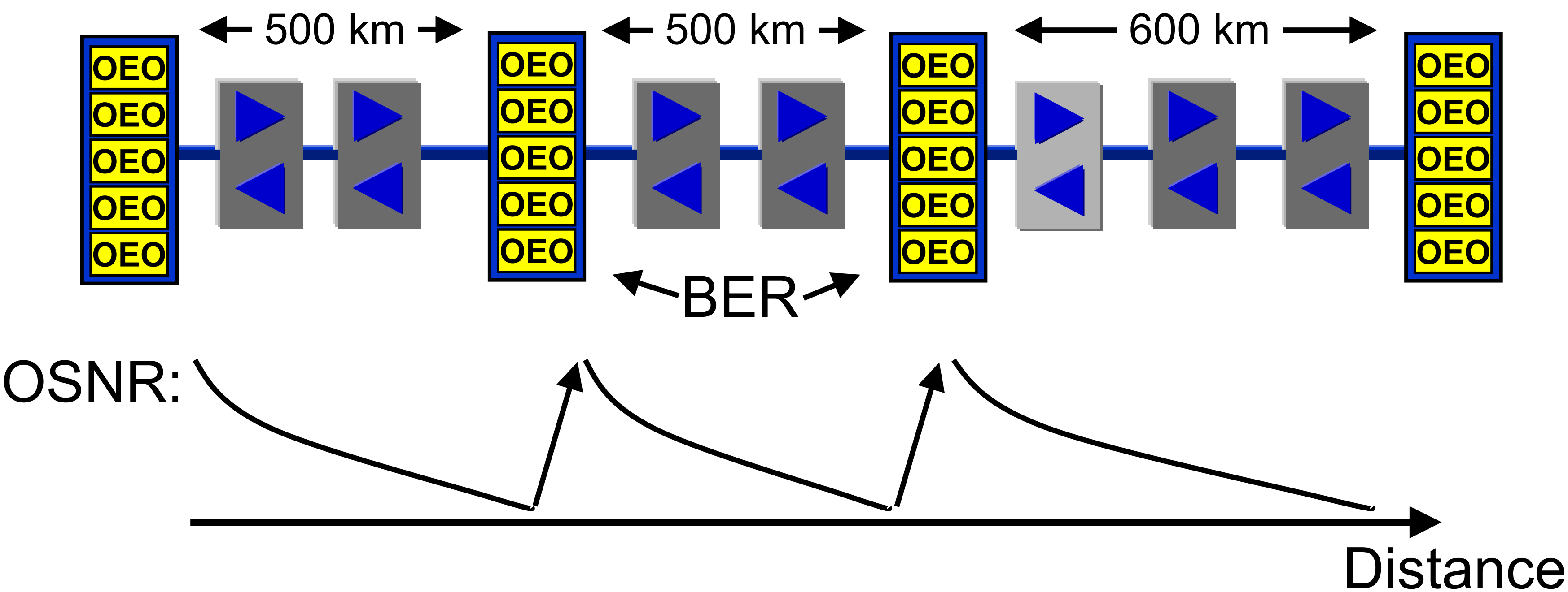
3G: DWDM Fault Management



- **Advanced technologies/network complexities**
  - **Component alarms may be insufficient**
- **Need OPM that correlates with end terminal BER**
  - **OPM registers change when end terminal BER alarm triggers**
- **OPM granularity to suit carrier opex goals**

Lucent Technologies
Bell Labs Innovations

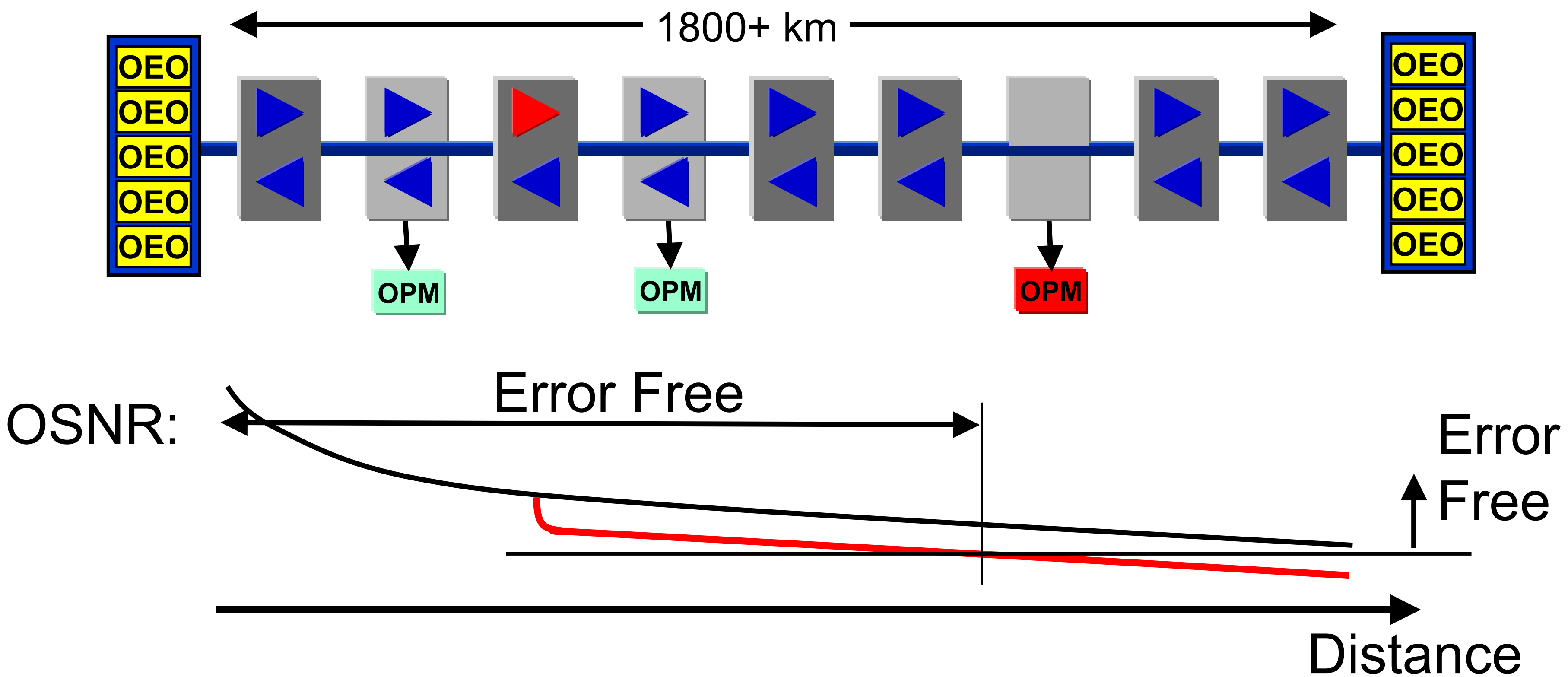
Electronic Fault Management



- **BER monitoring is sufficient**
  - **No errors in: No errors out**
  - **Noise does not propagate past regenerators**
- **Isolate faults to ~600 km**

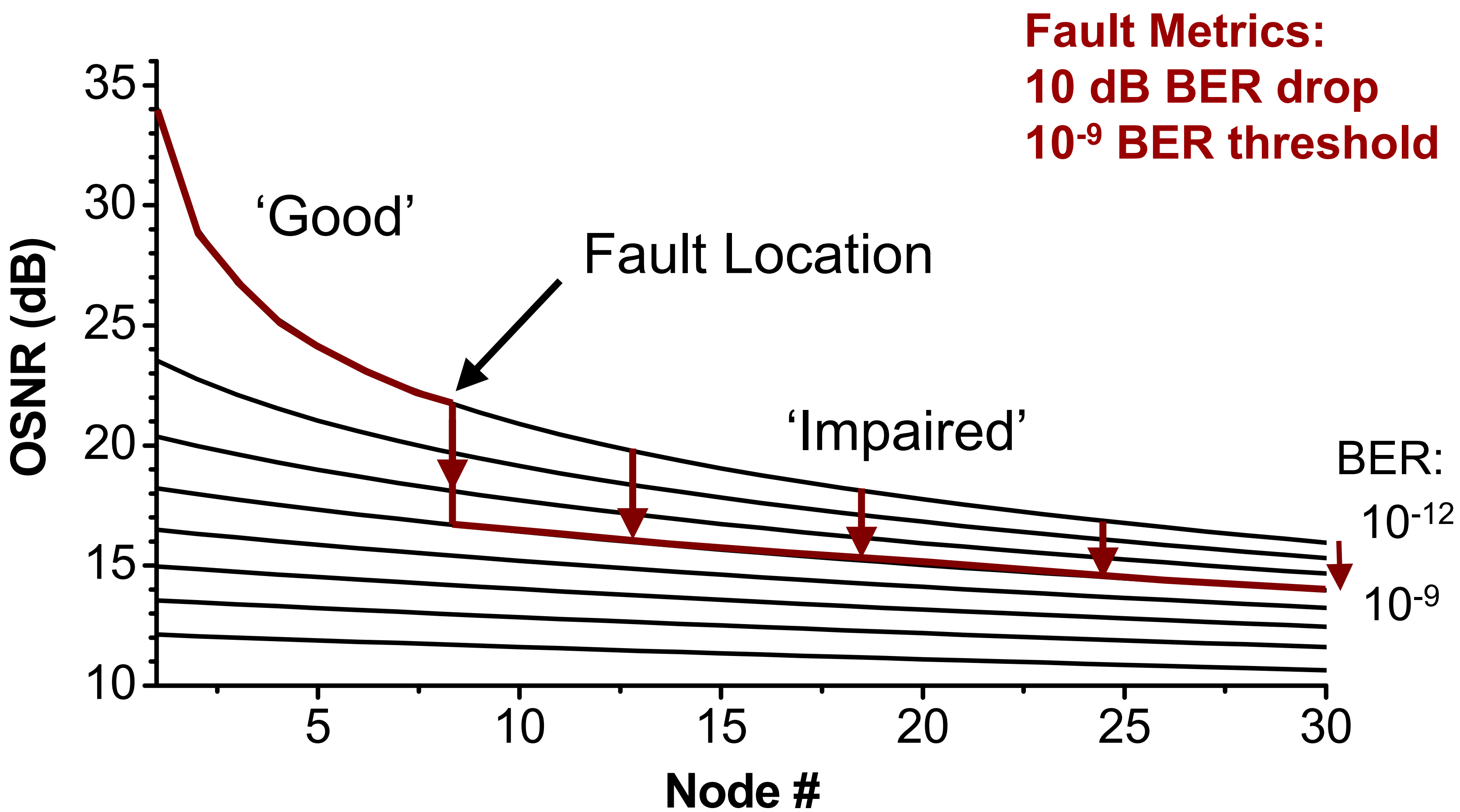
Lucent Technologies
Bell Labs Innovations

Ultra-Long Haul Transmission



- **Replace OEOs with OA repeaters: lose fault isolation**
- **BER at OA repeaters has limited benefit**
- **Noise propagates through repeaters**

Fault Isolation



- **Need sensitivity to wide variety of impairments.**
- **BER 10^{-9} gives ~ 4 orders of magnitude advanced warning in FEC-based links.**

Lucent Technologies
Bell Labs Innovations

OPM Fault Management Technologies

- **BER Measurement**
  - Sensitive to end terminal impairments
  - Problem: BER in network better than end term.

- **Noise loaded BER measurement**
  - Sensitivity close to BER

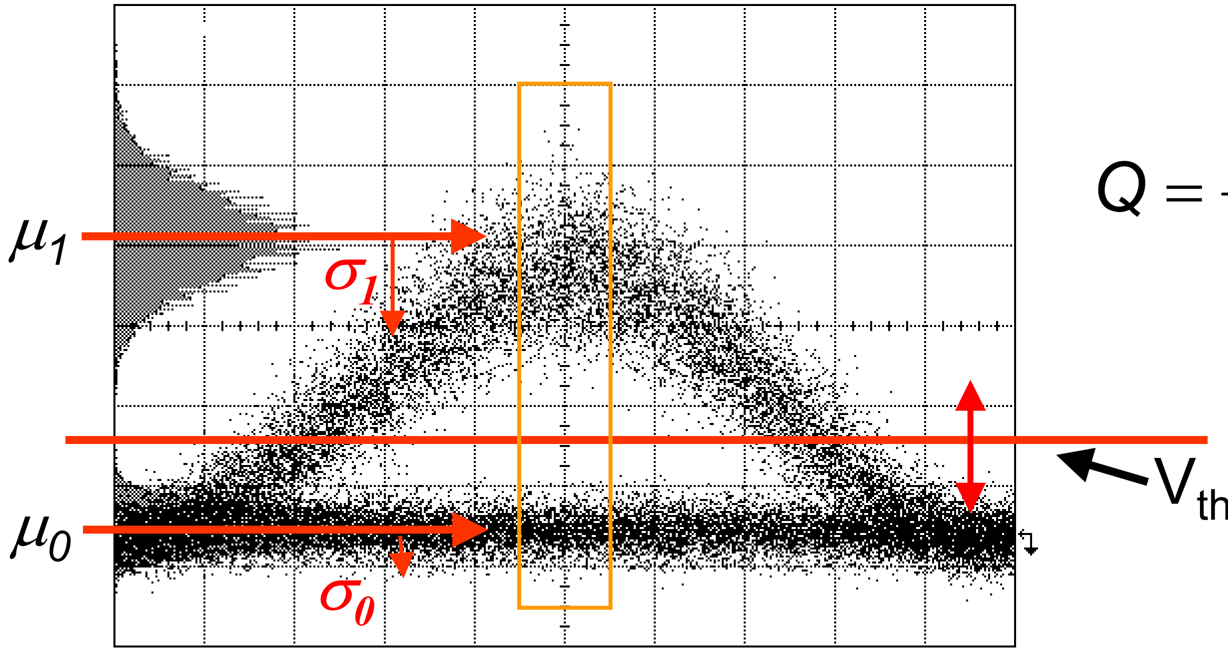
Q Factor

- **Other methods: OSNR, half-clock, pol. ext., histograms, tones, autocorrelation, …**
  - Must show advantage over Q/BER approach
    - Cost/sensitivity/impairment coverage
  - Target systems that cannot use Q-factor

Q Factor

- **Signal to Noise Ratio Measurement**

10G RZ Eye Diagram



$$Q = \frac{|\mu_1 - \mu_0|}{\sigma_1 + \sigma_0} \rightarrow \frac{Signal}{Noise}$$

$$BER(V_{th}) = \frac{1}{4}\left[erfc\left(\frac{|\mu_1 - V_{th}|}{\sigma_1 \sqrt{2}} \right) + erfc\left(\frac{|\mu_0 - V_{th}|}{\sigma_0 \sqrt{2}} \right) \right]$$

Lucent Technologies
Bell Labs Innovations

Q Factor Monitoring Techniques

(A) Variable threshold, dual decision – eye mapping

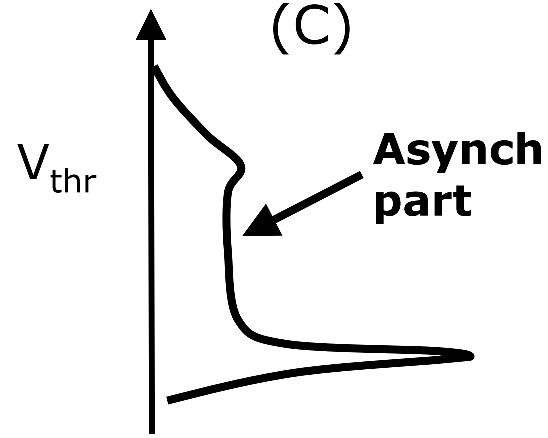
(B) Variable threshold, use FEC/integrate data

(C) Asynchronous histogram methods

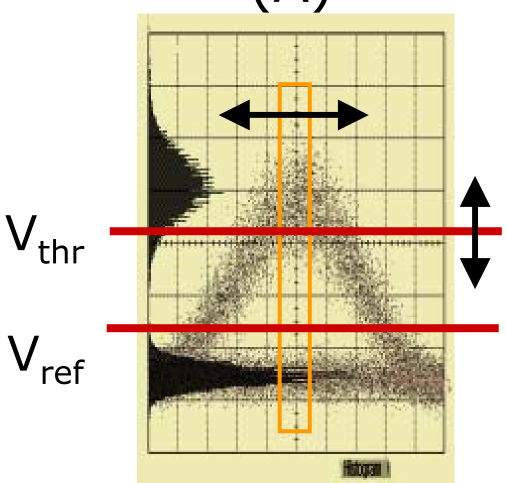
- **Sensitivity questions**

(D) Sampling techniques

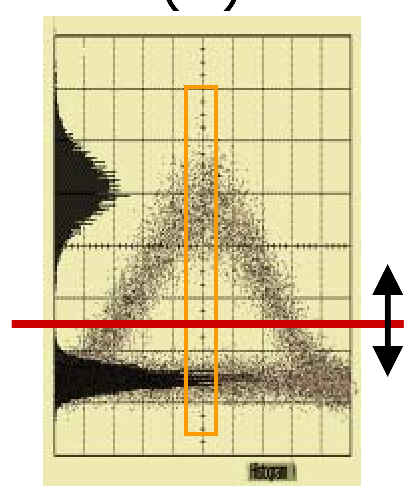
(C)



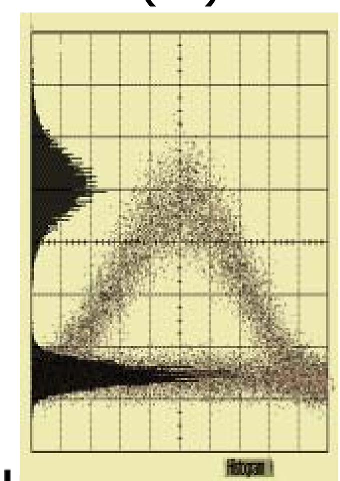
(A)



(B)

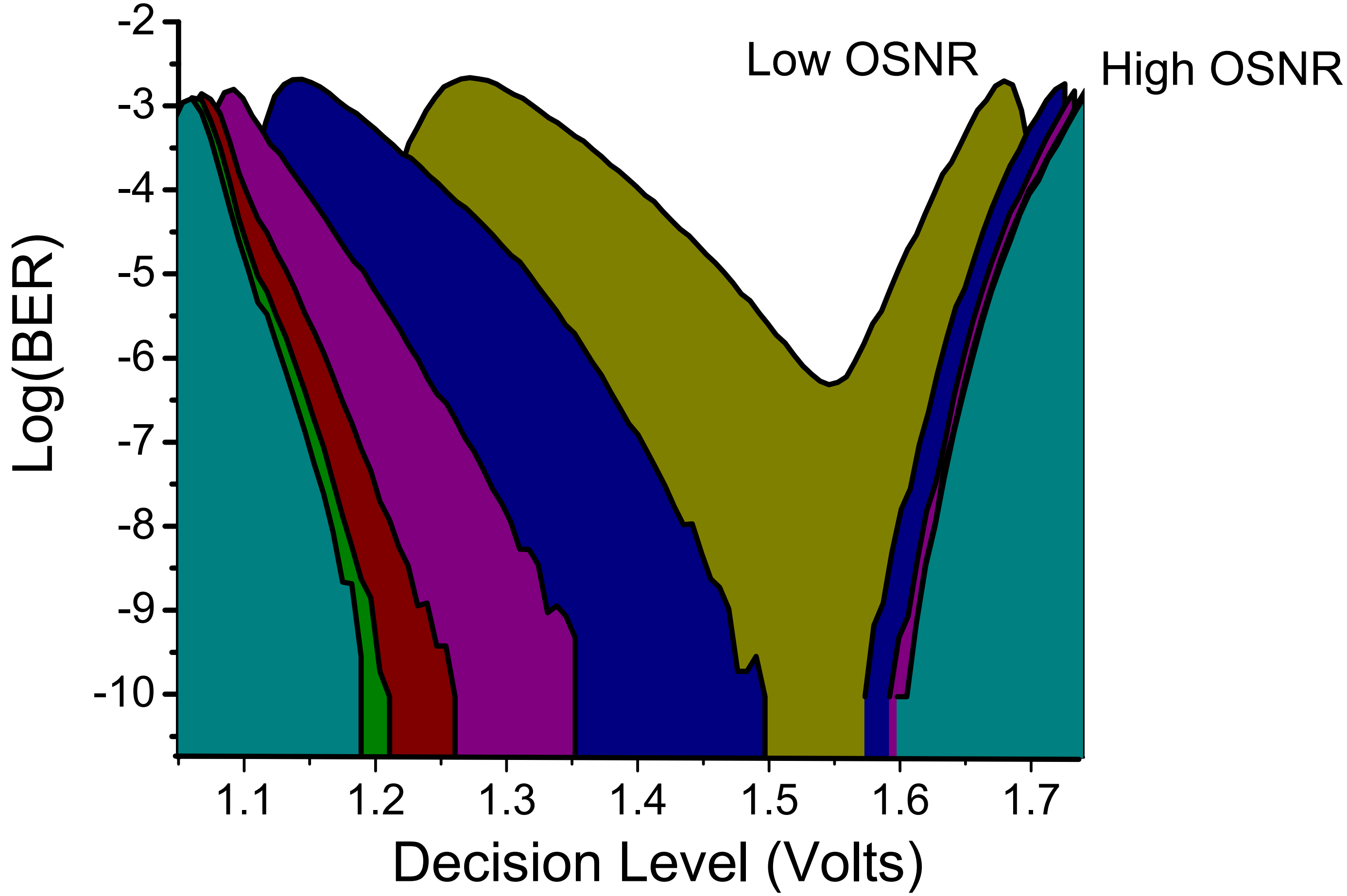


(D)



FEC Error Count Eye Mapping

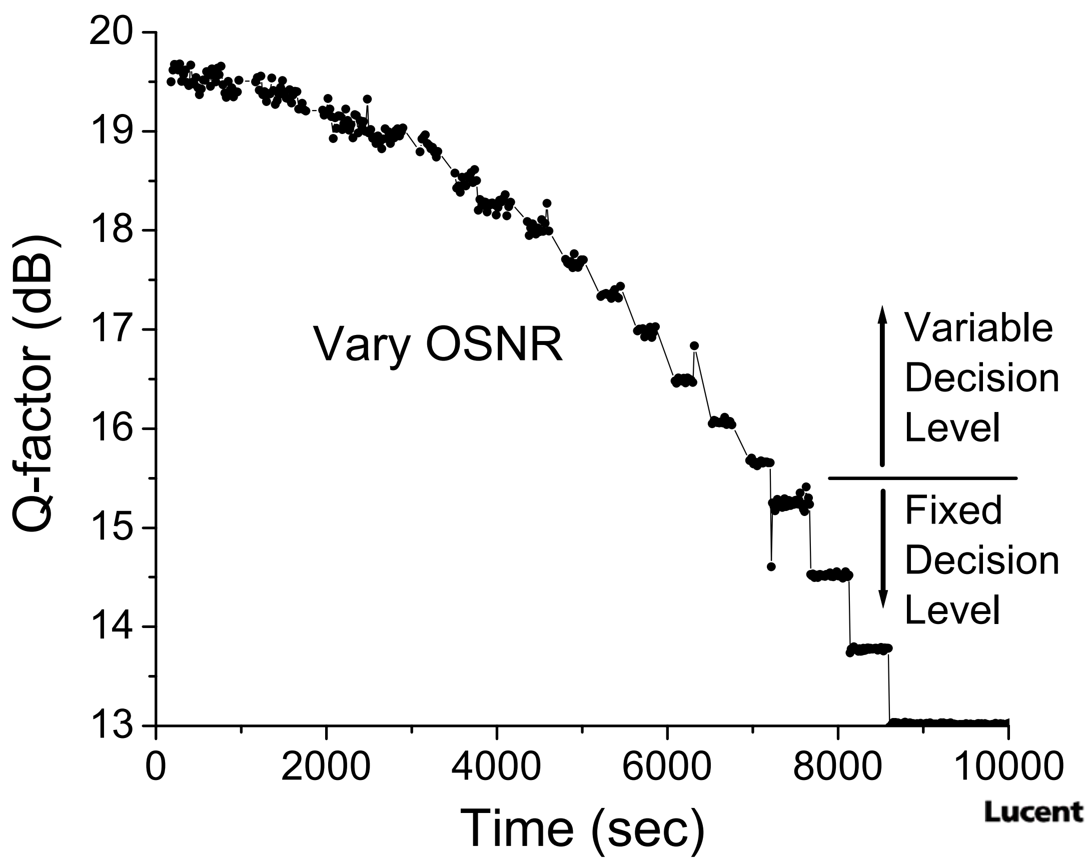
- **Vary voltage threshold across center of eye**
- **Use commercial 10 Gb/s receiver**



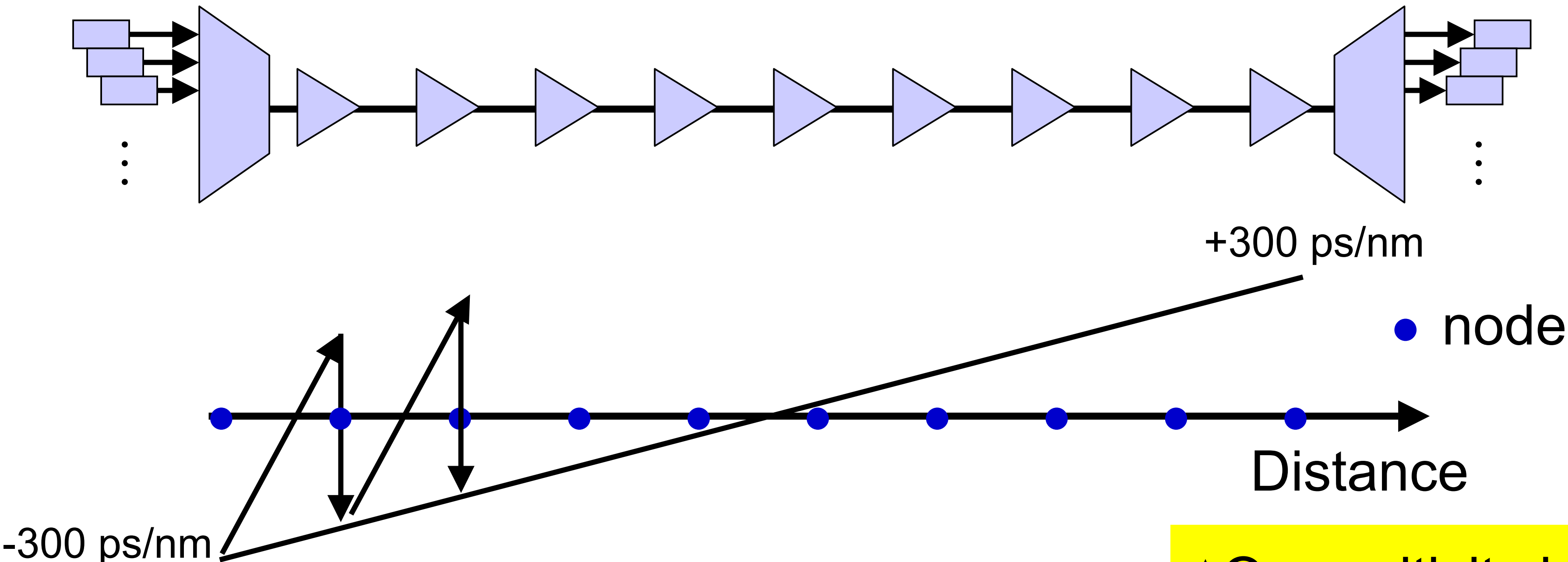
Lucent Technologies
Bell Labs Innovations

Q-factor vs. time

- **Determined measurement noise contributions under different conditions**
- **Error due to counting statistics, threshold voltage accuracy, power fluctuations**



Dispersion map issues



- **Q factor varies with dispersion map**
- **10Gb/s: up to 1000 ps/nm**
  - **OK for trend monitoring**
- **40 Gb/s: eye closed until end terminal**
  - **Would need per-channel DCM/tunable DCM**
  - **Also obstacle to 40G optical networks**

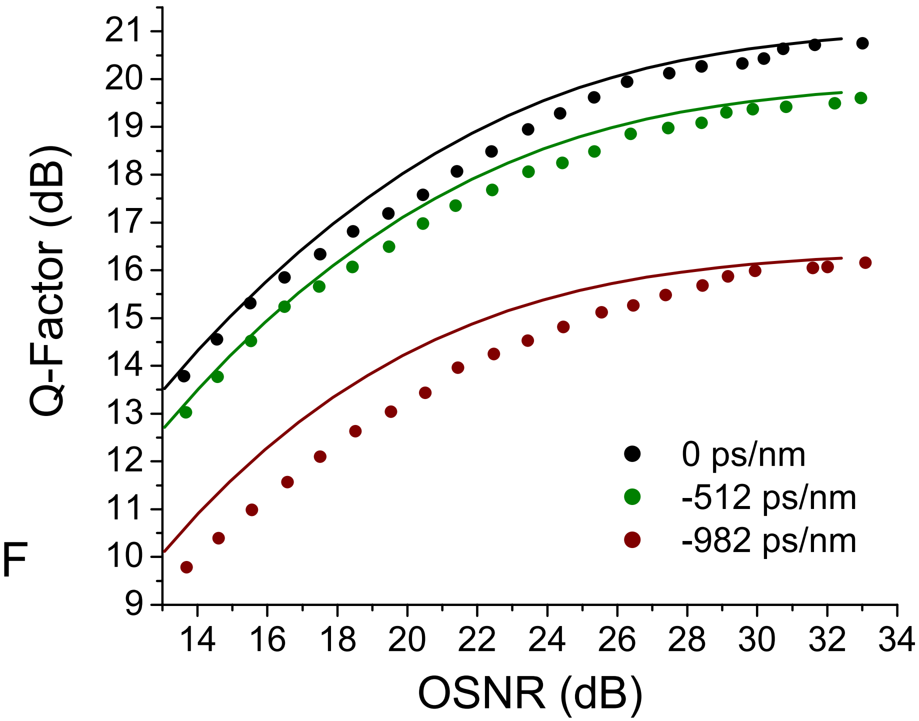
ΔQ sensitivity is weakly dependent on magnitude of Q factor

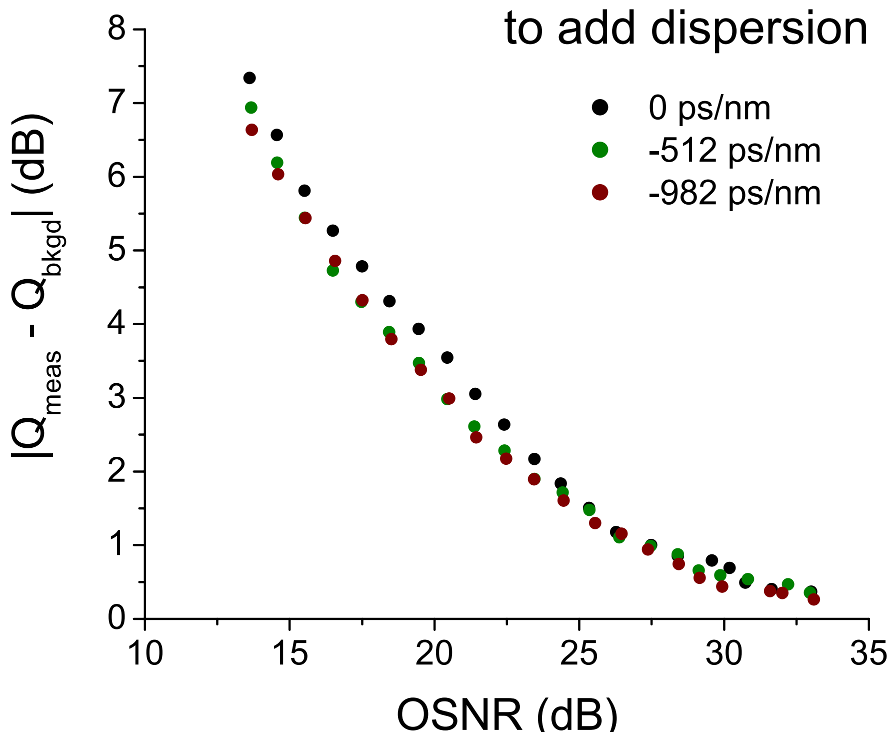
Lucent Technologies
Bell Labs Innovations

OSNR/Dispersion

- **Measure Q-Factor up to –982 ps/nm accum. dispersion**
- **OSNR sensitivity only weakly dependent on dispersion**

Use DCMs & SSMF to add dispersion



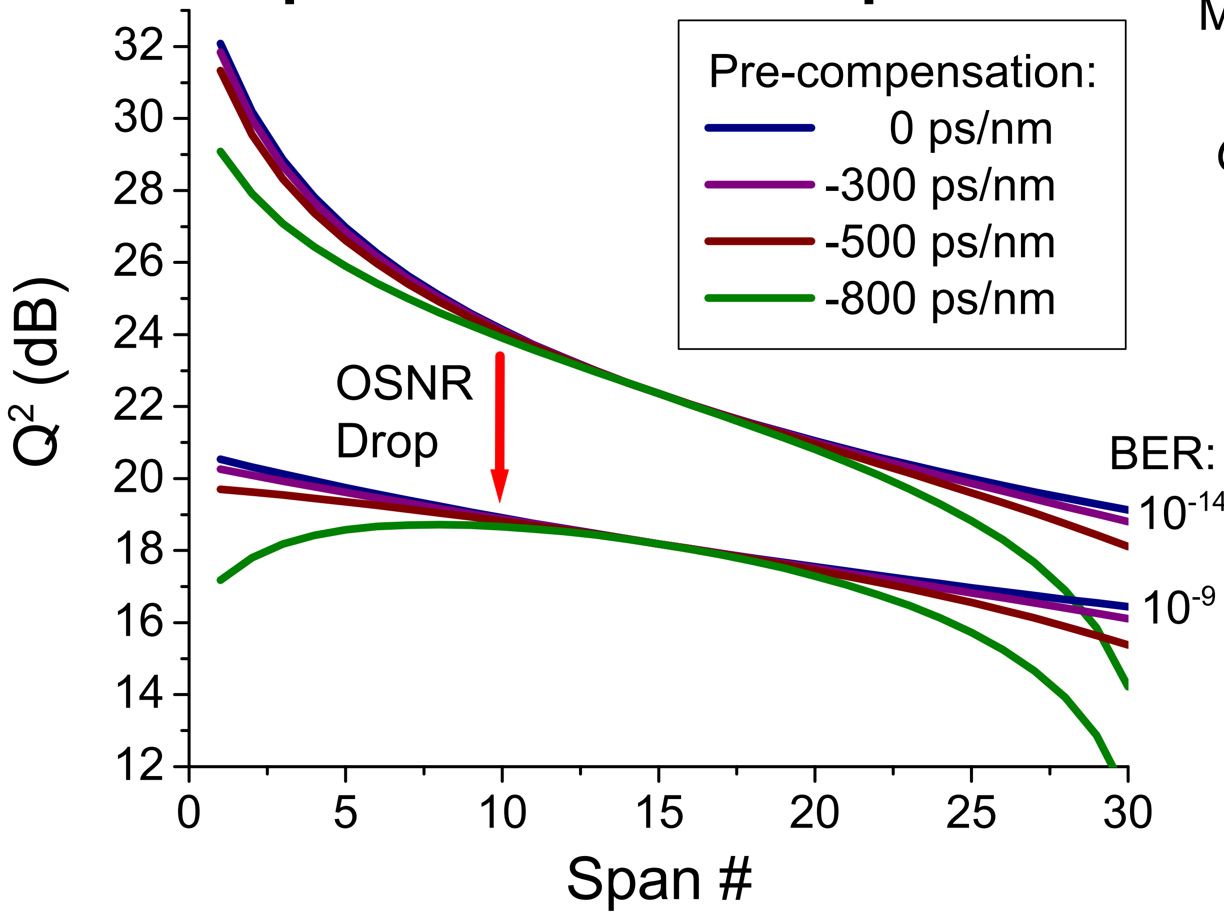


Dispersion managed solitons: pulses retain shape throughout transmission!

- Always within receiver Q-factor range

Sensitivity varies with monitor location

- **OSNR, non-linear impairments accumulate with distance**
- **Dispersion follows map**



Calculate "optical" Q on line:
Monitor independent:

$$Q = \frac{I_1 D_P - I_0}{\sqrt{\sigma^2_{Beat}(D_P) + \sigma^2_{ASE}} + \sqrt{\sigma^2_{ASE}}}$$

Dispersion Penalty

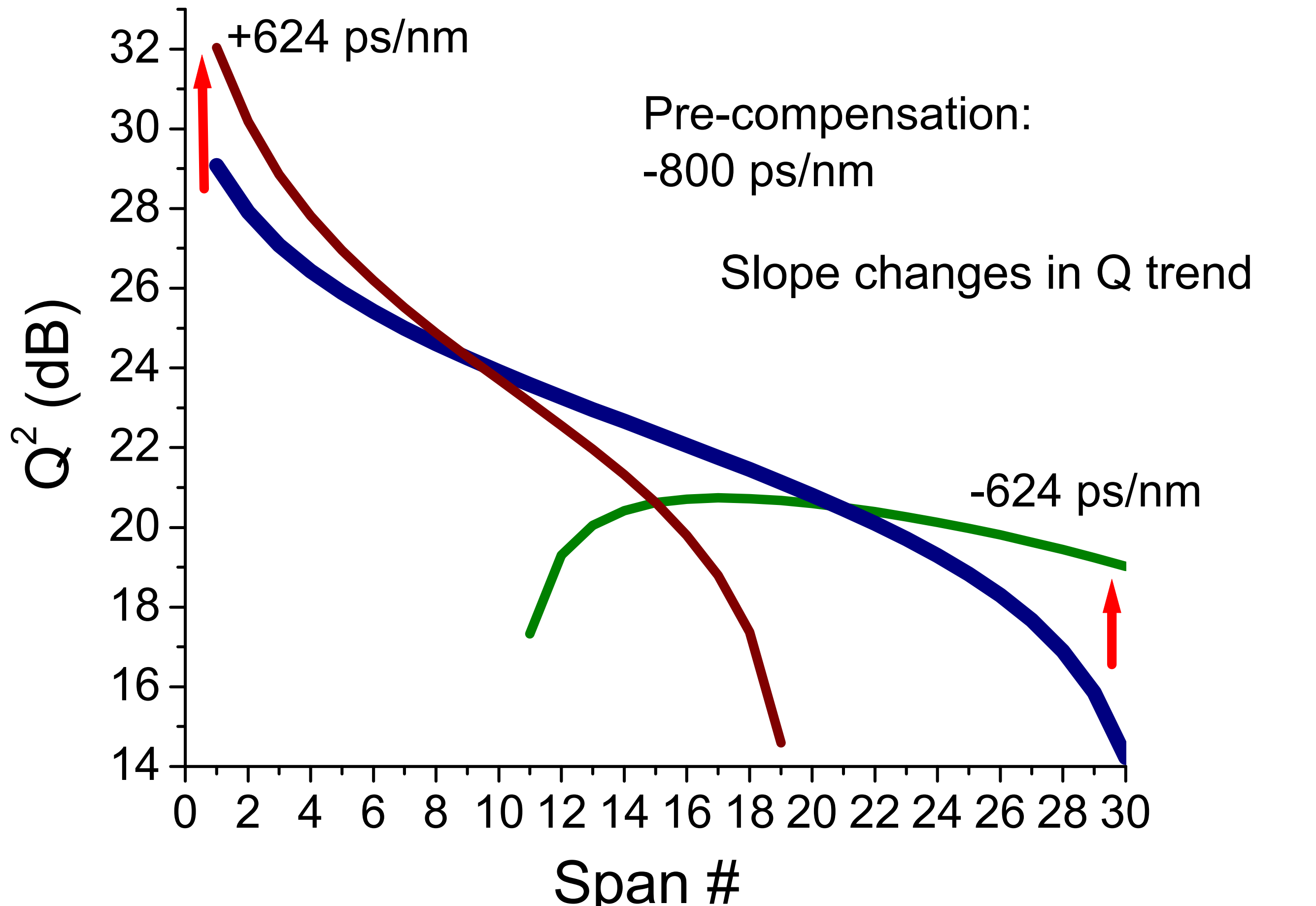
$$D_P = \sqrt{1 - (D_A f)^2}$$

D_A=Accum. Dispersion
f = scaling factor
(4 dB @ 800 ps/nm)

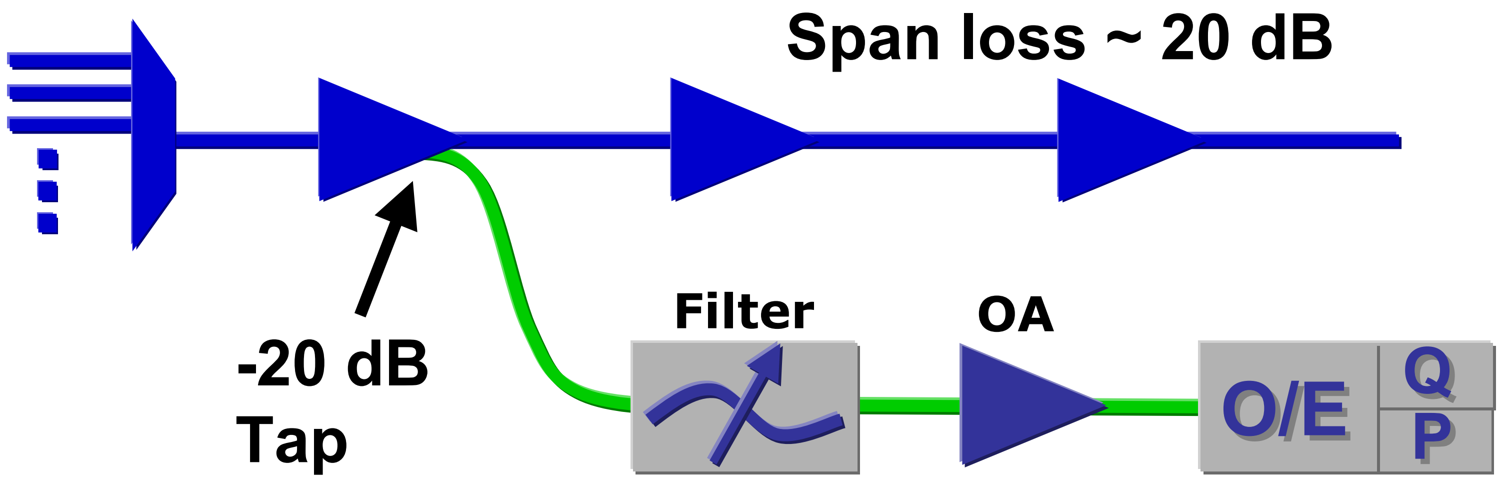
Dispersion faults

- **Strongly dependent on map**
- **Look for discontinuities along path**
- **Use +/- bands to identify dispersion problems**

+/- 624 ps/nm for
10^{-9} BER degradation



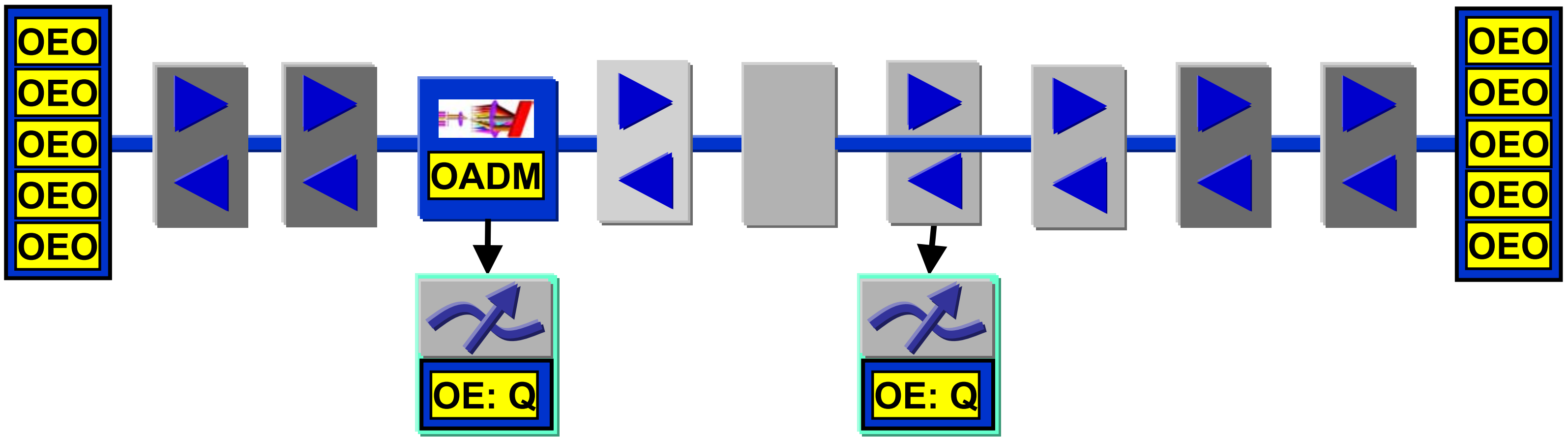
Performance Polling: Tunable Filter + OA



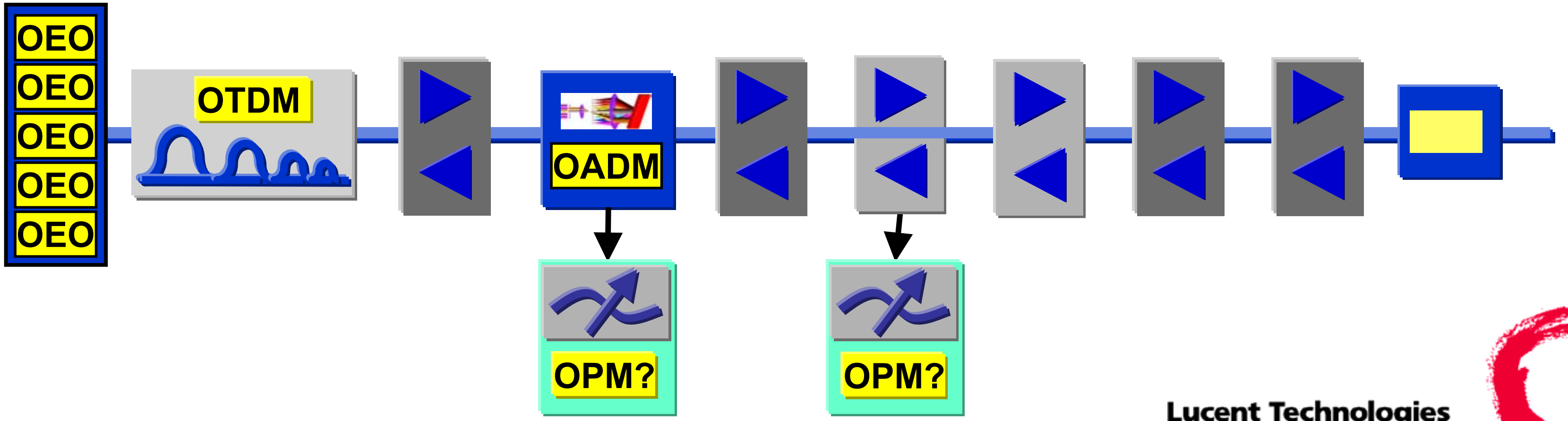
- Guarantee equal or better sensitivity than end terminal
- Replace entire OEO terminal with single OE, channel selector, and single channel OA
- *O/E provides BER, conventional PM, Q-factor, average power, channel presence, wavelength drift*

WDM vs. (O)TDM

WDM: Access signals with OE throughout system



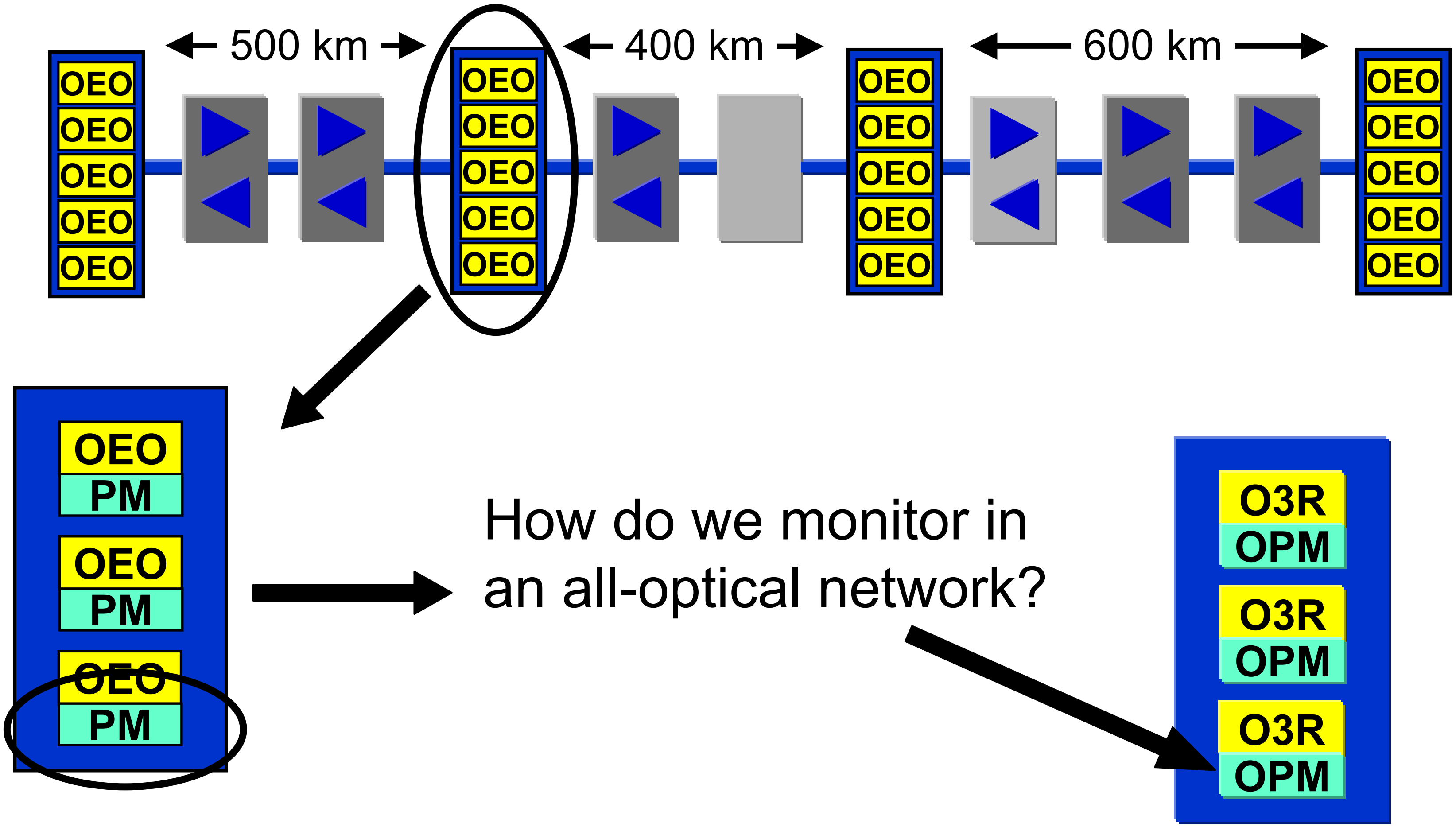
OTDM: OE not available/feasible within network



Lucent Technologies
Bell Labs Innovations

QoS Monitoring in Transparent Networks

Quality of Service (QoS): per channel BER

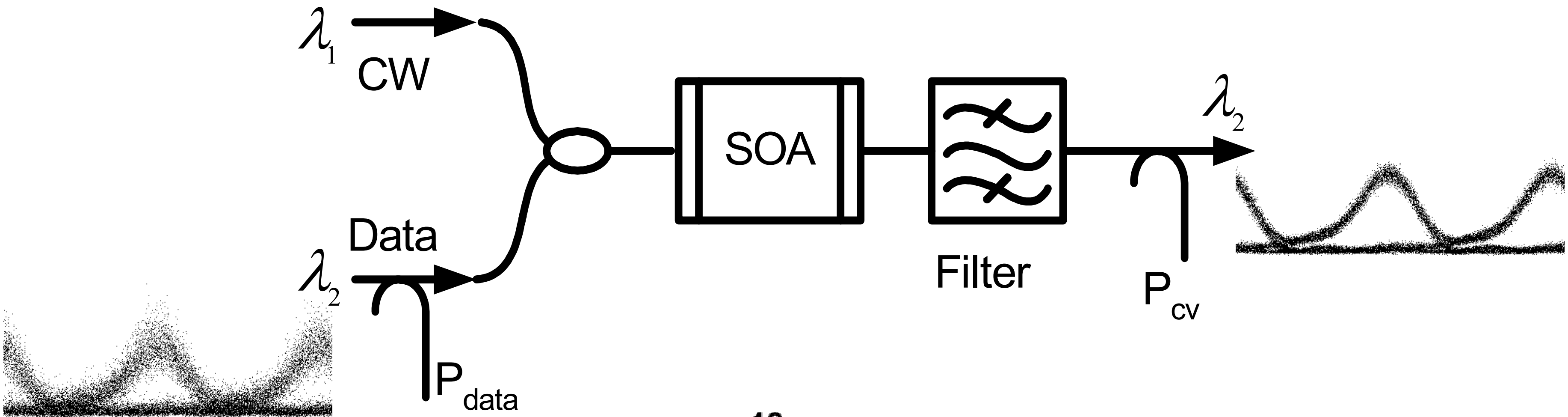


Lucent Technologies
Bell Labs Innovations

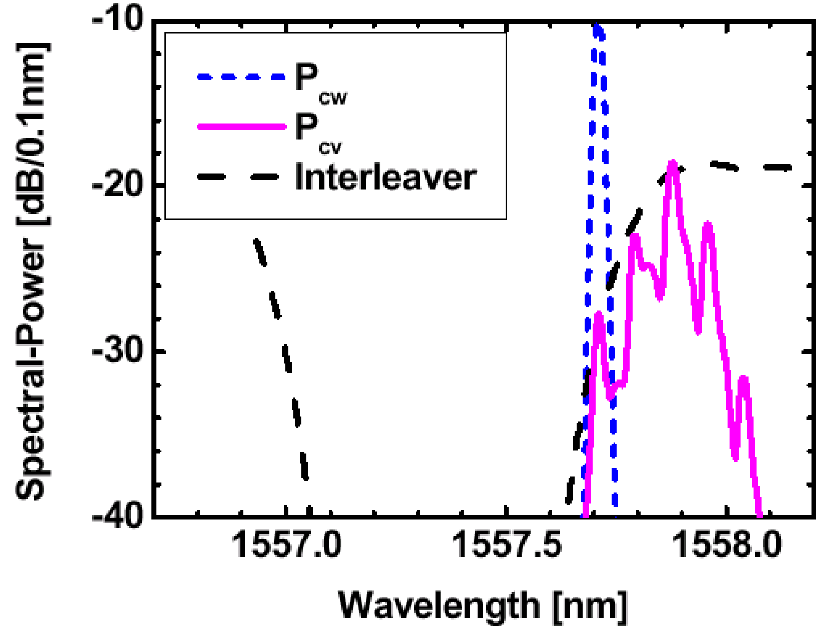
Regeneration Applications

- Unambiguous indication of signal quality
  - Correlation with common impairments
    - Do not need to isolate or measure impairments
    - No contingencies on relative impairment contributions
- Absolute measure of signal quality
  - Usually only coarse measure
    - Error free/not error free
    - Guarantee above threshold: 10^{-14} BER
- Satisfy operating requirements of system
  - System specific: input power, modulation format, etc.

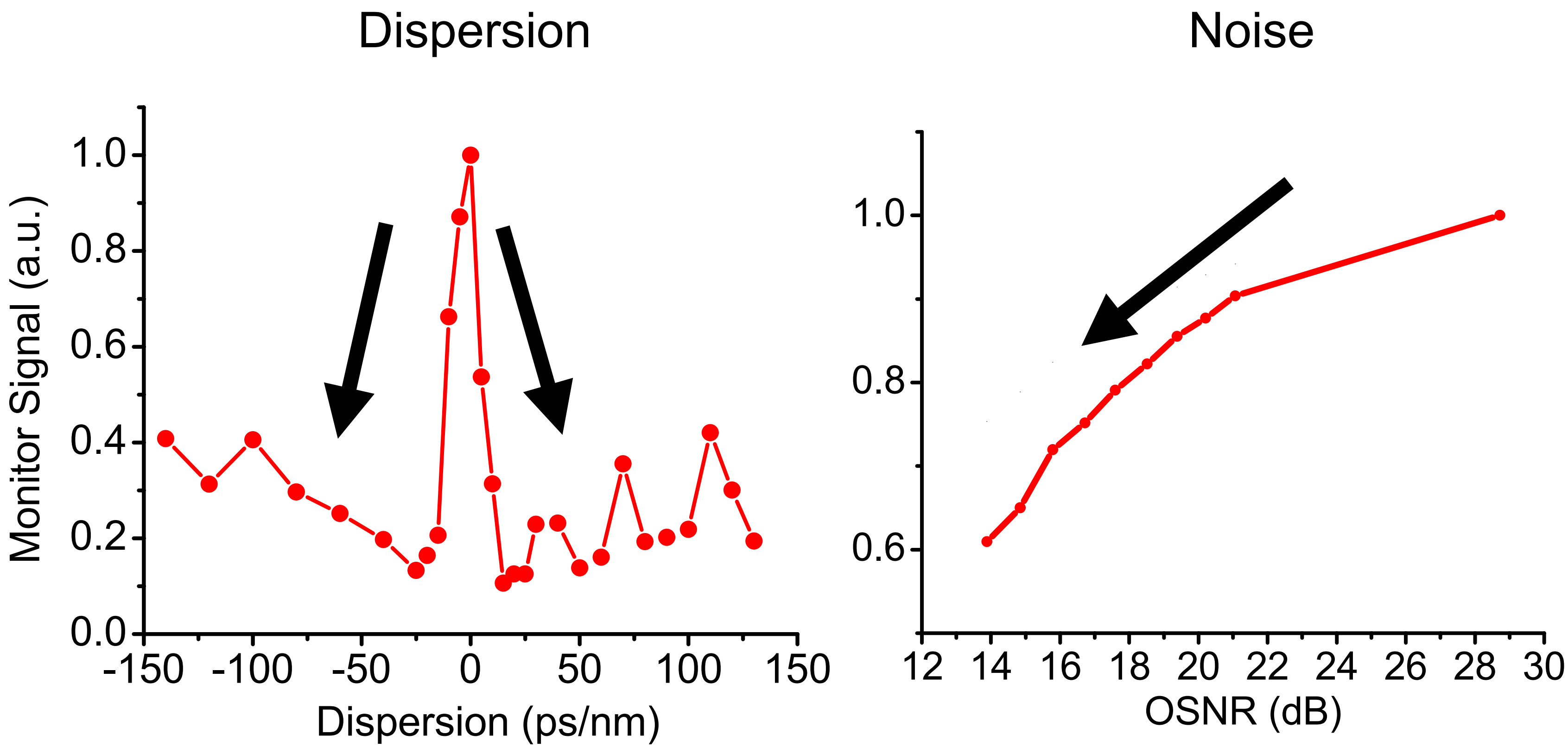
Optical Regeneration + Monitoring



For given input power: more or less power will arrive at the output depending on the input signal quality and the filter characteristics



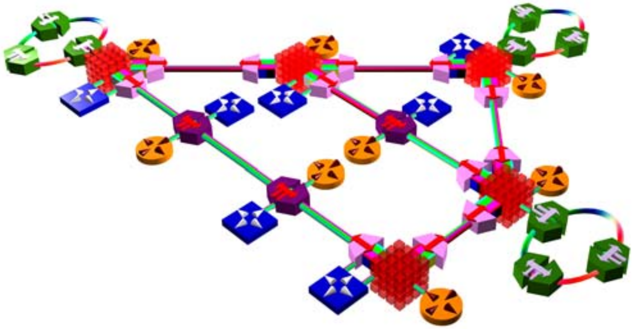
Unambiguous Quality Indicator: P_{out}/P_{in}



Unable to isolate noise or dispersion
But....

Monitoring signal decreases with decreasing signal quality

Lucent Technologies
Bell Labs Innovations



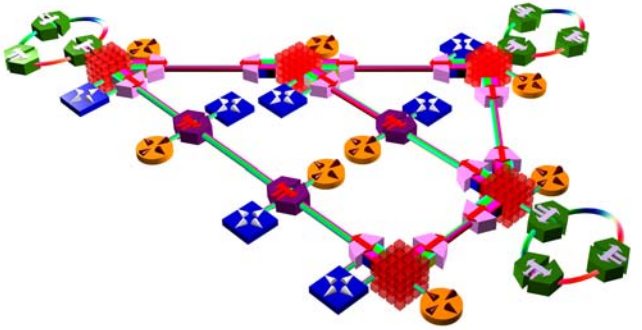
Summary

• Transparent optical networks generate a need for new system monitoring and management methods

• Focus on applications will drive technology development

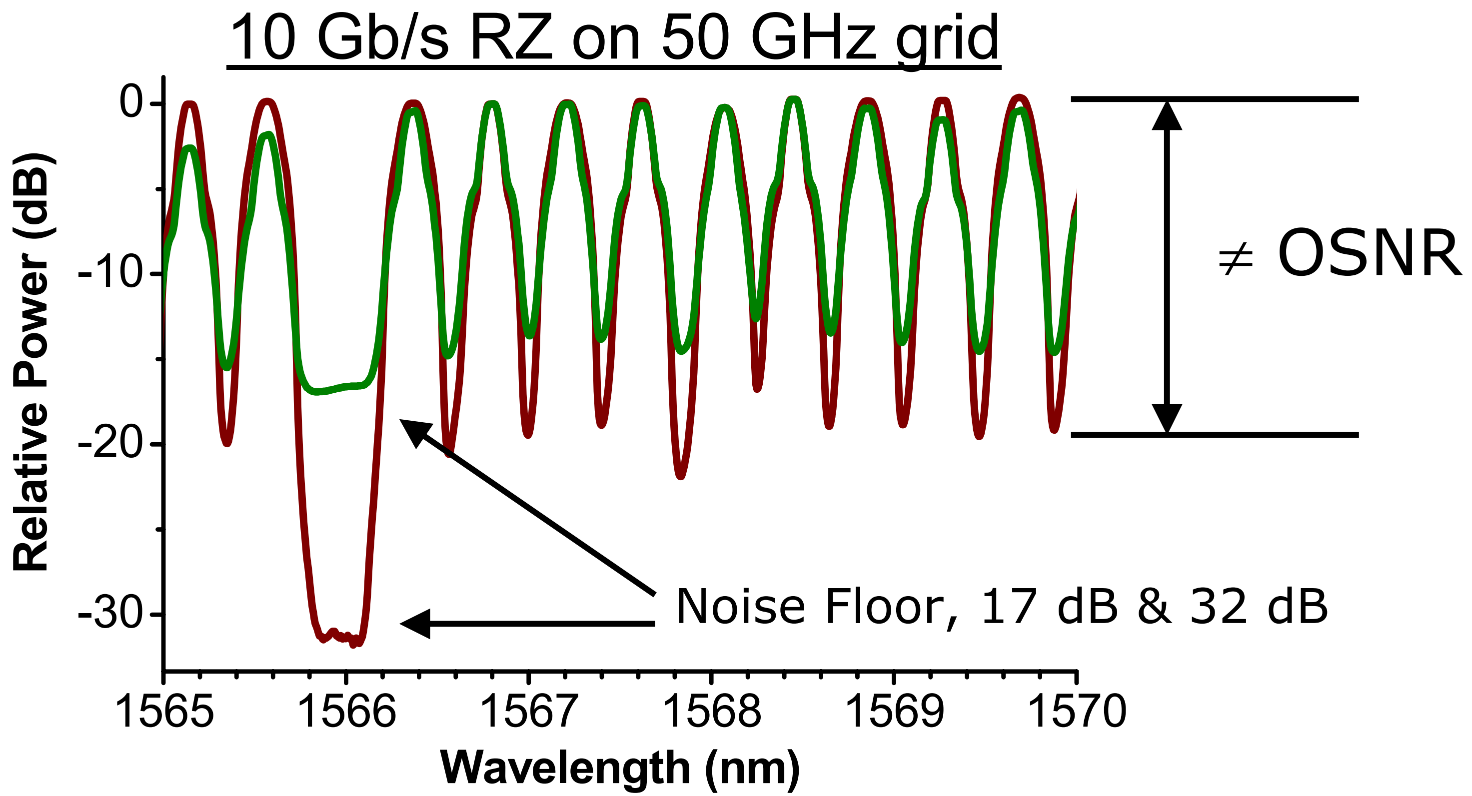
• Fault management: Q-factor natural replacement for BER

• Regeneration applications: solutions tied to regeneration technologies & provide BER trend



Back-Up Slides

Is spectral OSNR useful?



Problems:

- **Tight channel spacing: overlapping spectra**
- **Per-channel OSNR (OADM/OXC networks)**
- **Filters modify spectra (OADM/OXC)**
- **Poor coverage: MPI, pump RIN transfer, FWM**

Lucent Technologies
Bell Labs Innovations

Is spectral OSNR useful?

Yes, under following constraints:

- OSNR-degradation is only impairment of interest or major impairment
- Channels are widely spaced in wavelength
  - Or spectral regions reserved for monitoring
- Used for amplifier monitoring (not channel monitoring)
  - Don’t follow channels through ROADM/OXC