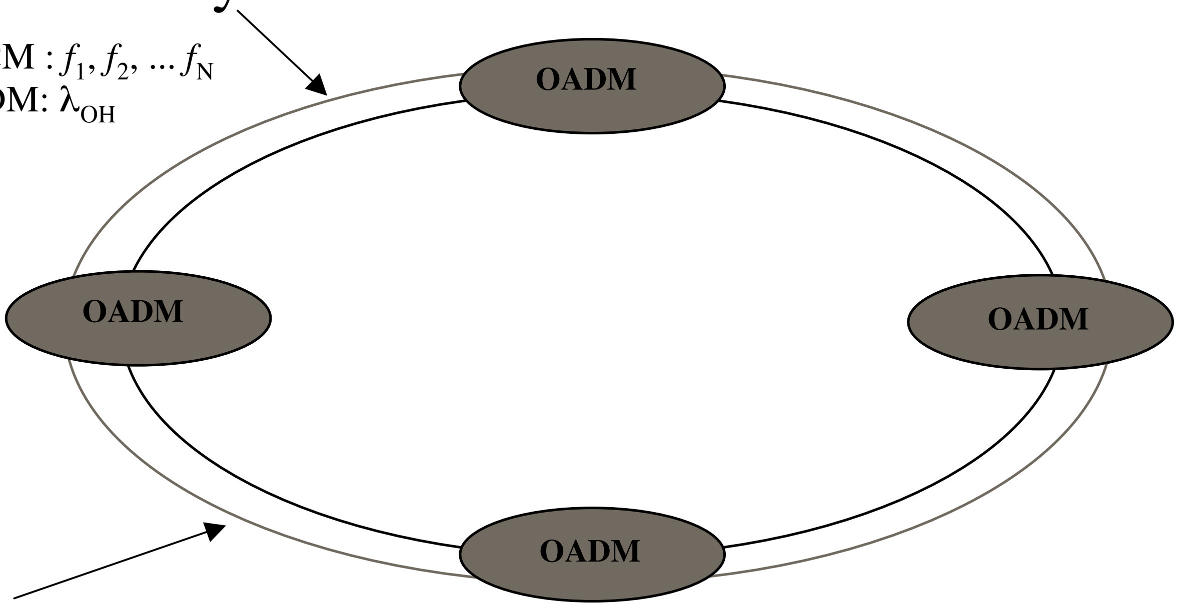
Lecture 6

8.4 Optical Network Management and Control

Network Monitoring and Control

- Measure the state of the links, nodes and data channels:
  - With minimal disturbance to the signals in the fiber
  - With minimal complexity in the measuring technique
  - With minimum prior knowledge of the information source or the data transport history
- Once we measure state or detect degradation, how do we
  - Reroute information
  - Inform appropriate network elements and entities of situation
- How is management and monitoring
  - Performed in a fast reconfigurable WDM all-optical network

Monitoring and Control Subnets



One or More Secondary Control Networks

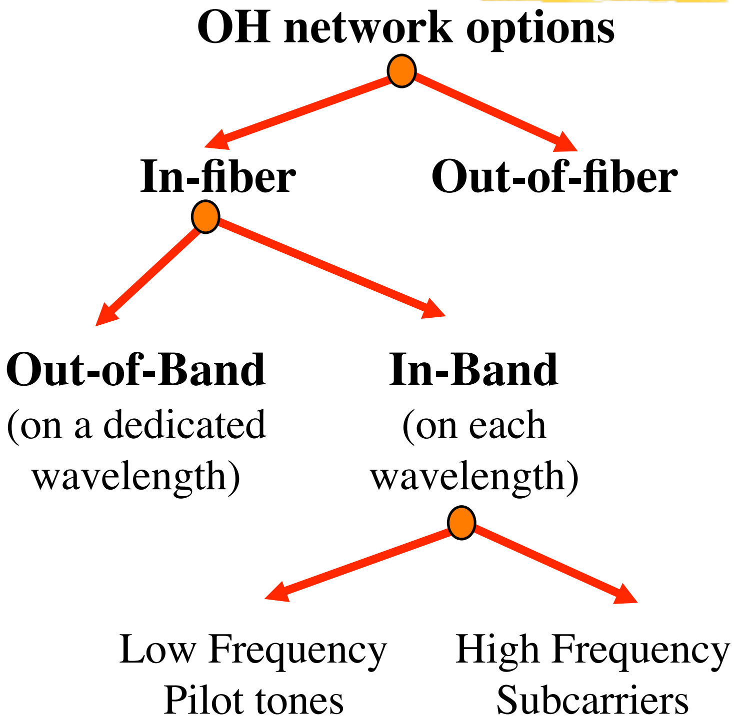
Out-of-band/In-Fiber SCM : $f_1, f_2, \dots f_N$
Out-of-band/In-Fiber TDM: λ_{OH}
Out-of-fiber: Ethernet

Primary WDM Network

$\lambda_1, \lambda_2, \dots \lambda_N$

Overhead Networks

- Operations and Maintenance (OAM)
  - It is usually implemented on an in-fiber, out-of-band wavelength, 1510 nm or 1310 nm
    - In this case, the OH channel does not traverse optical path with data since it is regenerated at each node.
  - It can also be sent on a totally different and separated structure (out-of-fiber solution)
    - The OH network should be extremely resilient
    - in case of catastrophic events, out-of-fiber OH may be very useful
- Monitoring (of the Optical link, path, etc)
  - Both In-band and out-of-band solutions are used
  - Typical: Low frequency pilot tones: 10-100 KHz at about 10% modulation depth of the digital signal.
  - Proposed: Optical subcarrier multiplexing: narrowband RF channel (in-band or out-of-band) at about 5% modulation depth



OH network options

In-fiber

Out-of-fiber

Out-of-Band
(on a dedicated wavelength)

In-Band
(on each wavelength)

Low Frequency Pilot tones

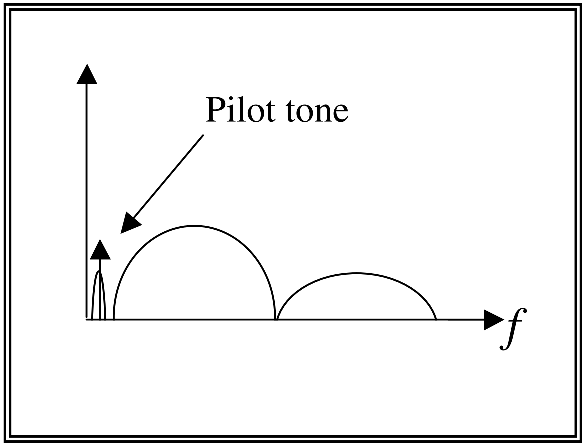
High Frequency Subcarriers

Monitoring Signaling and OAM

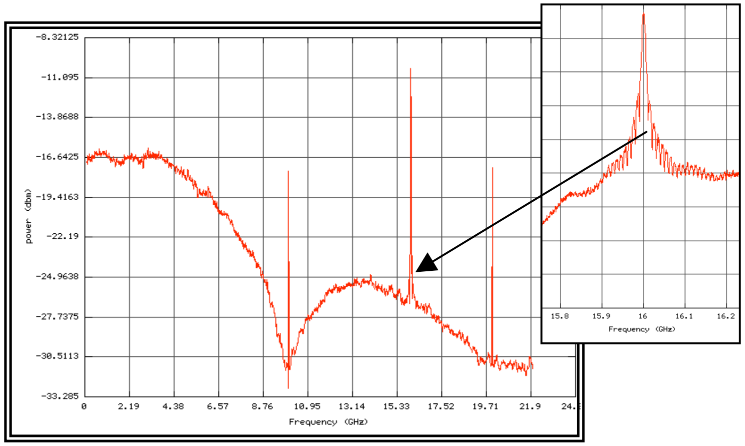
- Operations and Maintenance (OAM)
  - Overhead (OH) Channel: Out-of-band wavelength, 1510 nm or 1310 nm. Send measurement and fault information throughout network.
  - OH channel does not traverse optical path with data since it is regenerated at each node. Limited monitoring use, but can be used to report monitoring results.
- Monitoring
  - In band or out-of-band.
  - Low frequency pilot tones: 10-100 KHz at about 10% modulation depth of the digital signal.
  - Optical subcarrier multiplexing: narrowband RF channel (in-band or out-of-band) at about 5% modulation depth.

Monitoring in Reconfigurable Networks

- Low frequency pilot tones
  - Support very low frequency modulation
  - Cannot carry information about fast reconfiguration events
  - Can be buried below low frequency cutoff of data channel
  - Supports data transparency



- Optical Subcarrier Tones
  - Support wideband modulation
  - Can detect information about fast reconfiguration events
  - Can be placed outside or inside baseband modulation
  - Supports data transparency

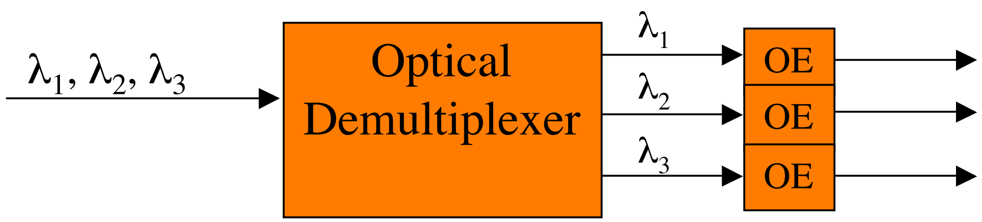


Monitoring Classes

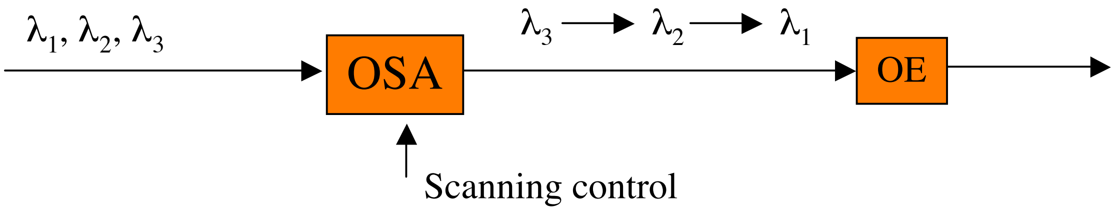
- Power Detection
  - Must distinguish between channel loss and “strings of zeros” transmission
- Frequency Monitoring
  - Must be within 1% of channel bandwidth
  - Stabilization of frequency dependent components
- Performance Monitoring
  - Difficult to use BER as direct measure
  - SNR and eye pattern statistics
  - Direct distortion measurement
  - Direct crosstalk measurement

Channel Equalization: Monitoring

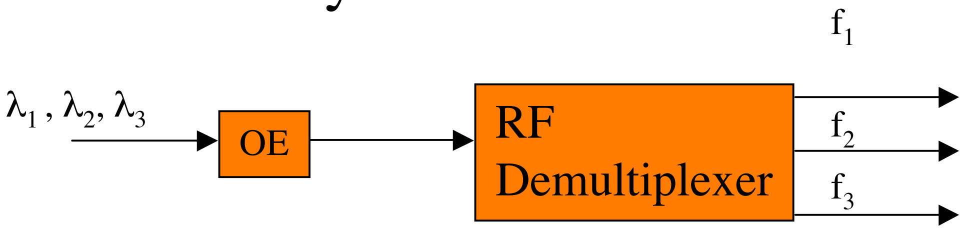
- Multichannel Optical Analyzer



- Optical Spectrum Analyzer

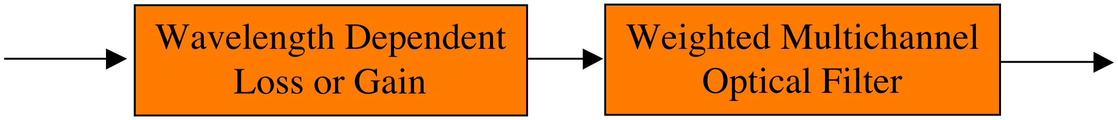


- RF Spectrum Analyzer



Channel Equalization: Control

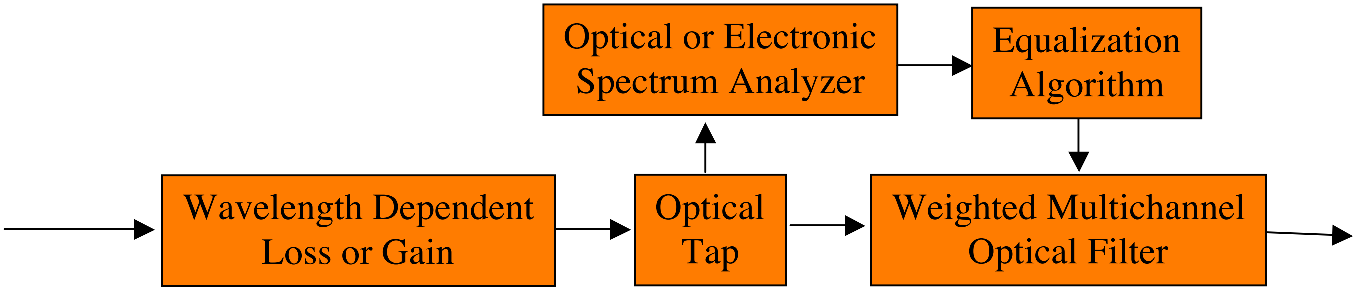
Static



Wavelength Dependent Loss or Gain

Weighted Multichannel Optical Filter

Dynamic: LC-Eq



Optical or Electronic Spectrum Analyzer

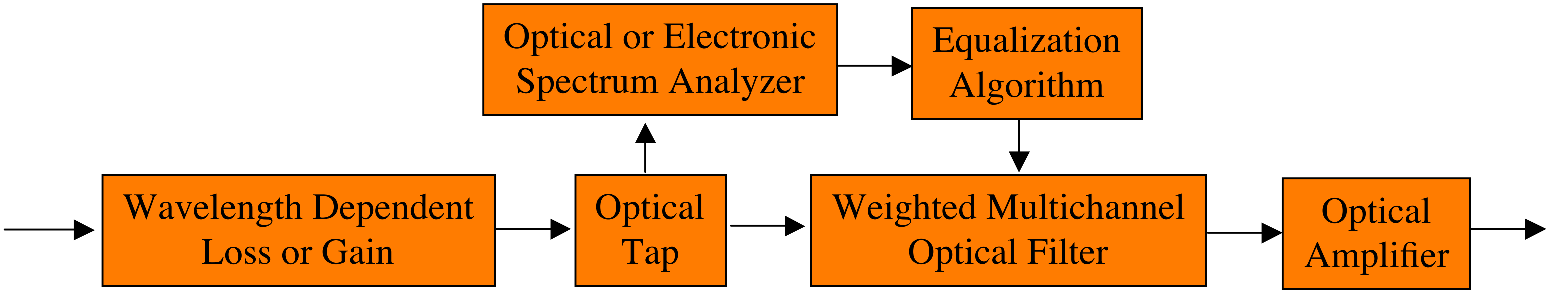
Equalization Algorithm

Wavelength Dependent Loss or Gain

Optical Tap

Weighted Multichannel Optical Filter

Dynamic: AGC



Optical or Electronic Spectrum Analyzer

Equalization Algorithm

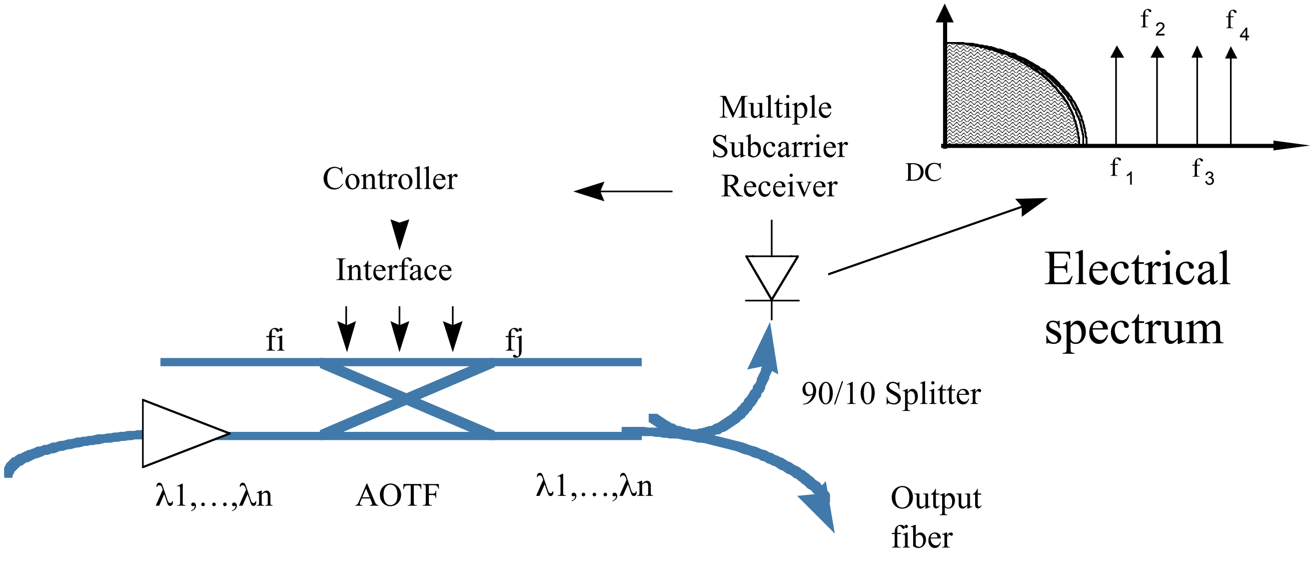
Wavelength Dependent Loss or Gain

Optical Tap

Weighted Multichannel Optical Filter

Optical Amplifier

Optical Subcarrier WDM Channel Equalization and Monitoring

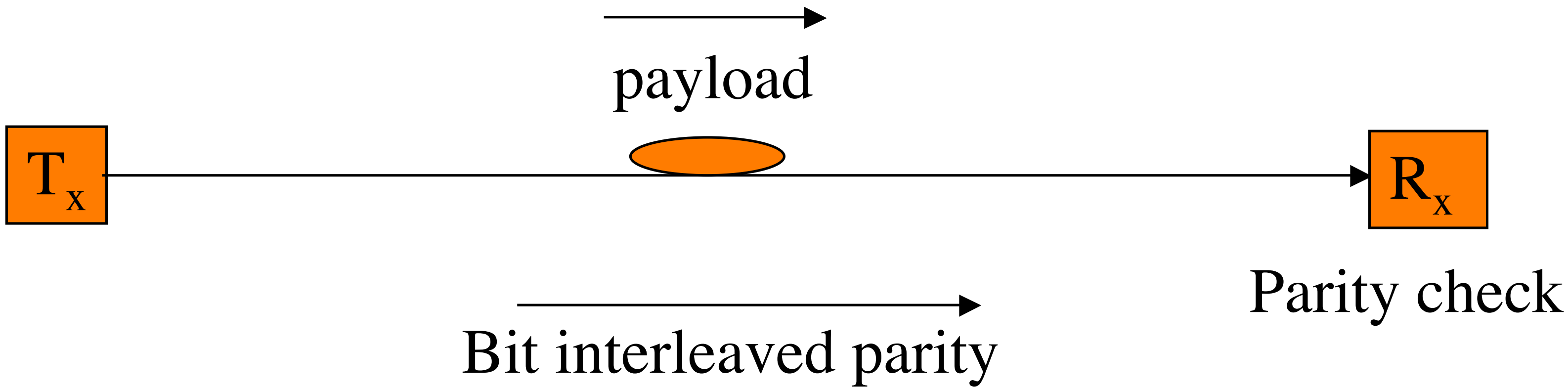


R. Gaudino and D. J. Blumenthal, OFC ‘98

OTN and SONET Monitoring

- The OTN and SONET monitoring functions are based on totally different approaches
  - SONET: the digital stream must be OEO converted
    - On the digital stream, fields are reserved to perform BER measurements
  - OTN: monitoring is done at the optical level
    - It is mainly non-intrusive: only a small fraction of optical power can be tapped
    - It is potentially
      - less expensive
      - very fast
    - It can be performed by a single system on the full set of WDM channels

Performance Monitoring in SDH Networks



payload

T_x

R_x

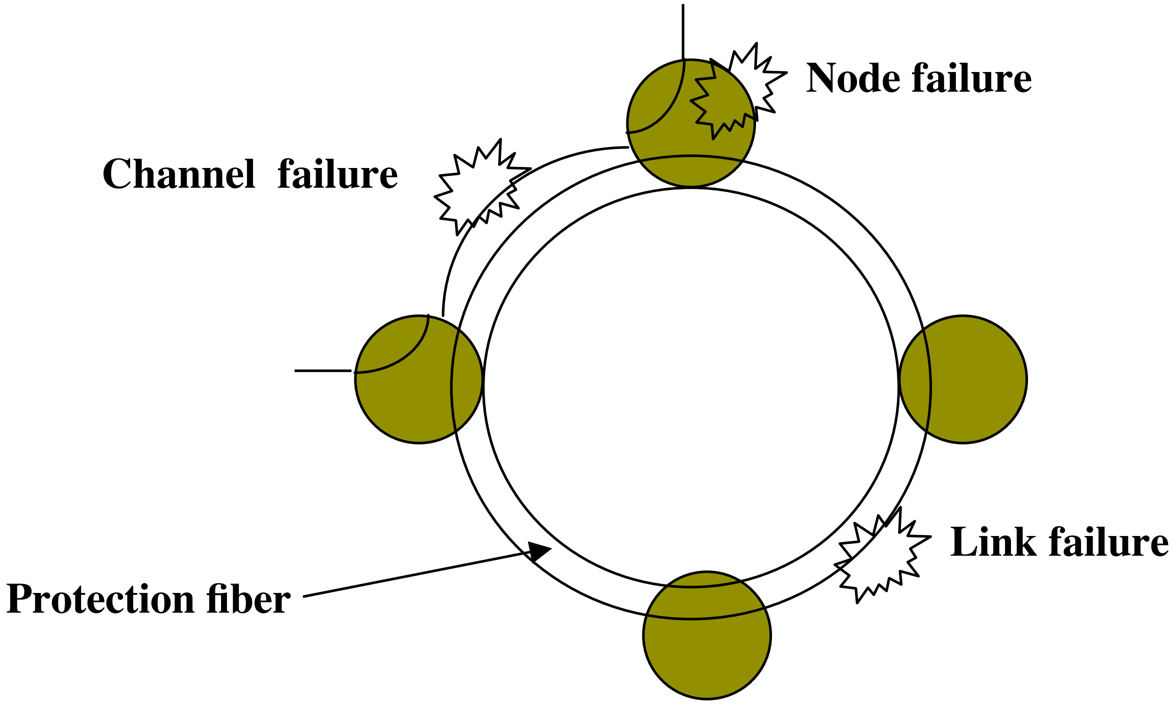
Parity check

Bit interleaved parity

Issue: Not transparent since framing is required to do parity check.

8.5 Survivability, Protection and Restoration

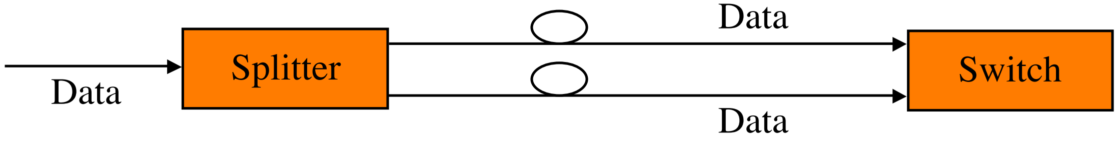
Survivability and Restoration



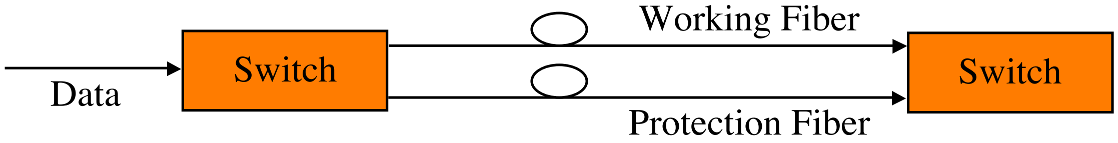
- **Protection** techniques involve redundant capacities within the network.
- **Survivability** is the ability to deliver service during failures.
- **Restoration time** is the amount of time to recover from a failure.

Protection Switching

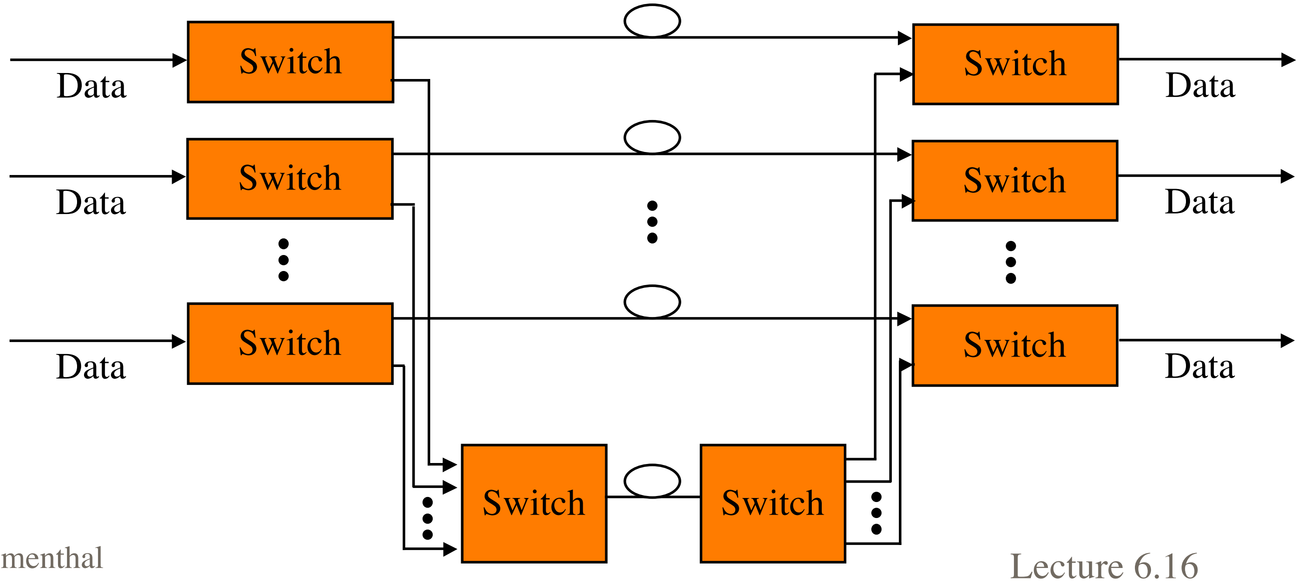
- 1 + 1 Protection



- 1:1 Protection



- 1:N Protection

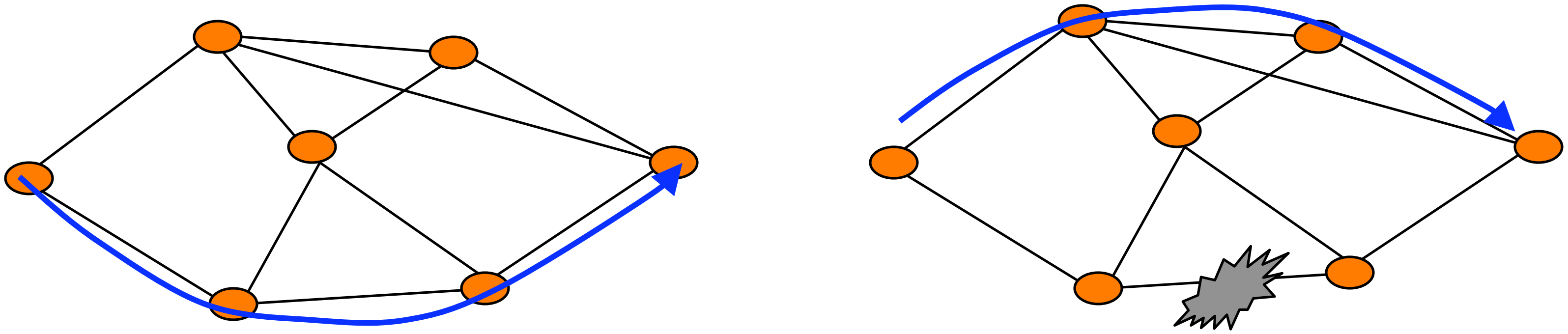


Protection and Topologies

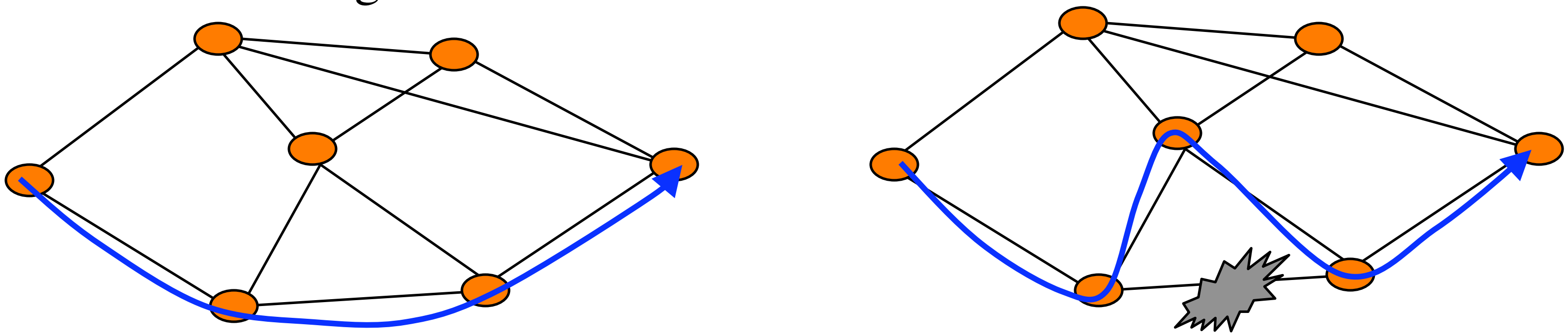
- 1+1 or 1:1 strategies are typically suited for multi-fiber ring architectures
  - The solution proposed for OTN are very similar to those used in SONET, and are based on loopback capabilities
- 1:N is suited for mesh architectures
  - It offers the best use of bandwidths, but it is much more complex to be implemented
- The solution for the near-term seems to be 1:1 on rings, while the long term solution will probably be 1:N over optical meshes

Path and Line Switching

- Two protection strategies
  - Path switching:

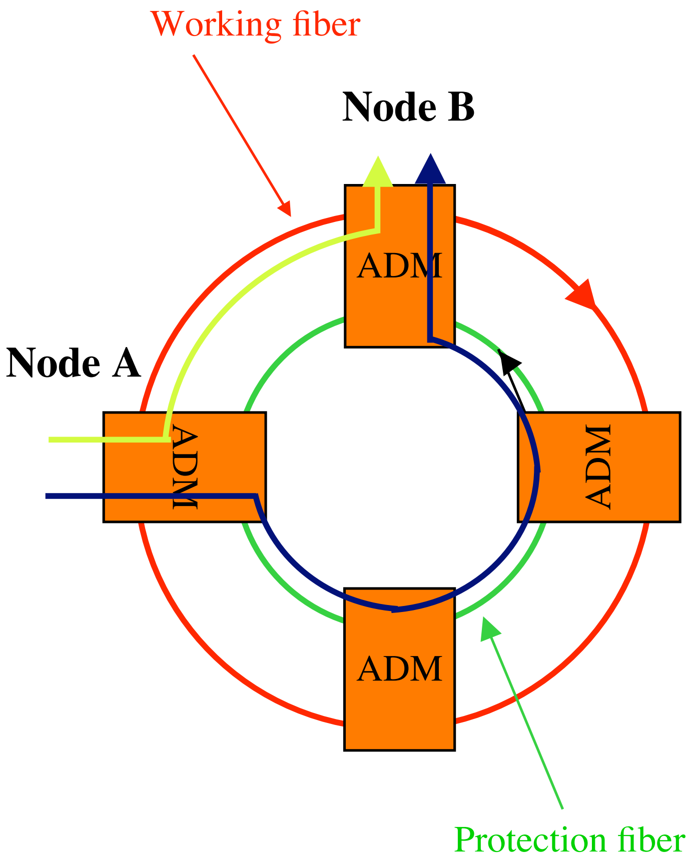


  - Line switching



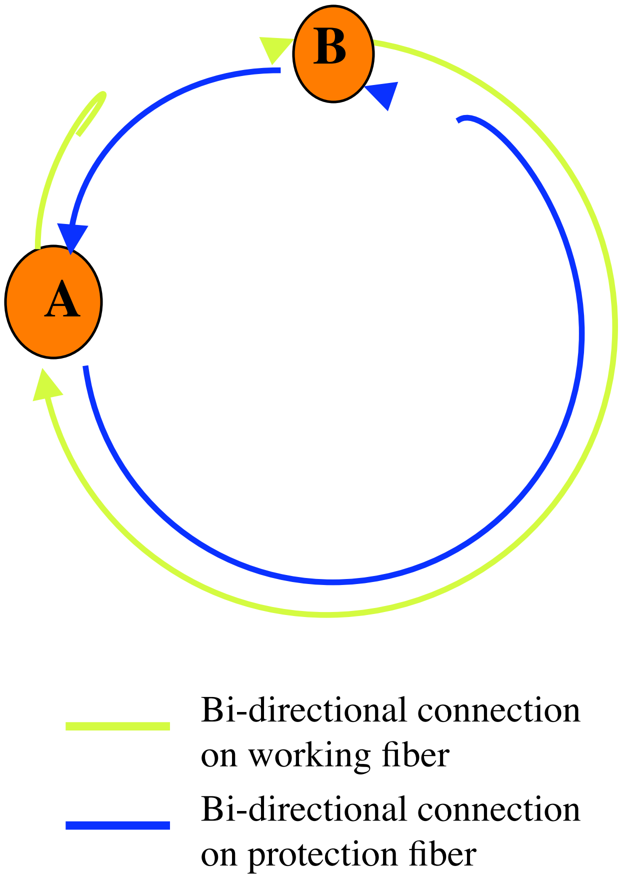
Protection in Optical Rings - UPSR

- Unidirectional Path-Switched Rings (UPSRs)
  - It is directly derived from SONET, but can be directly applied in optics
- It is a 1+1 protection on a dual fiber ring
- The figure shows a connection from node A to node B
- Under normal operating conditions, the SAME traffic is sent simultaneously on the working and protection fibers
- Node B receives normally two copies of the same channel
- In case of a (single) link failure, one of the two copies is still available



Two-fiber UPSR

- The allocated protection capacity is equal to the working capacity
- A bi-directional connection on a two fibers UPSR completely uses a wavelength in both rings (working and protection)
- Its main drawback is the fact that, if a bi-directional connection between two nodes is needed, no spatial reuse is possible
  - i.e., the same wavelength is NOT available for any other bi-directional (and protected connection)

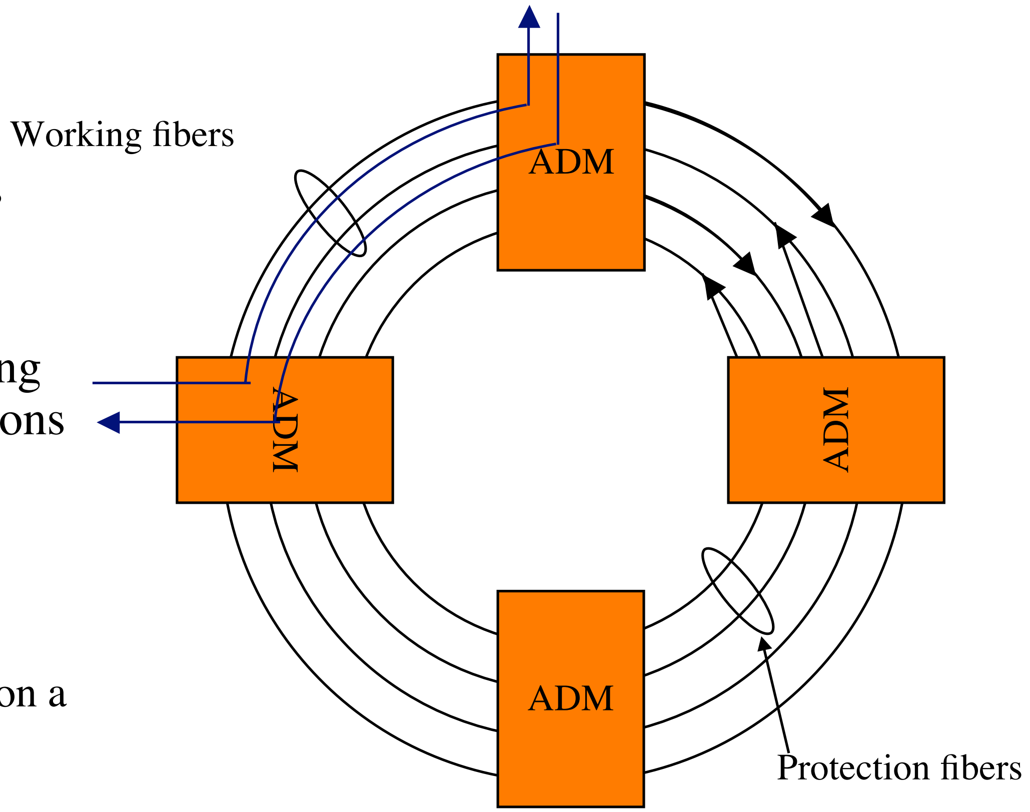


Two-fiber UPSR

- The USPR approach is quite simple, and is often implemented in local exchange or access network
- It is attractive for simplicity, and thus lower cost,
  - The only required action, in case of failure, is at the receiver
  - The length of the ring determines the minimum restoration time of the system
- If most of the links are unidirectional, than spatial reuse is possible
  - This is often in access networks, where one one acts as a hub

Protection in Optical Rings: BLSRs

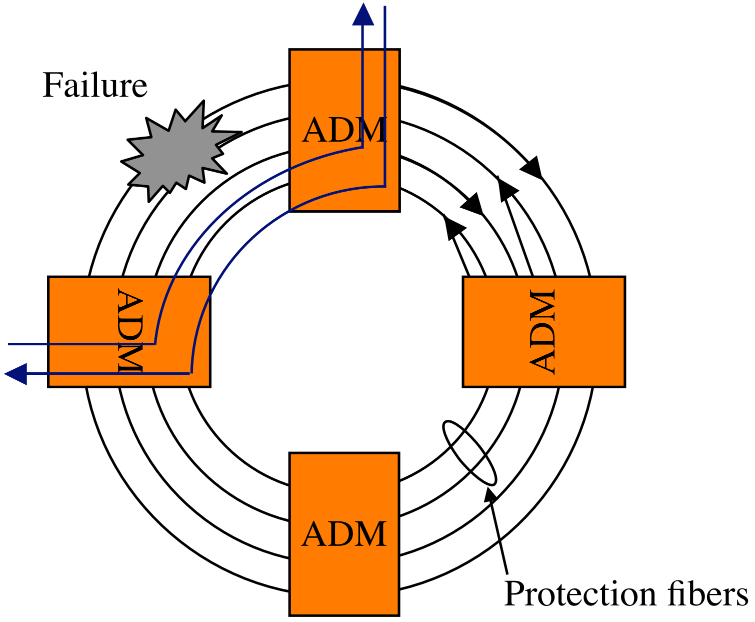
- Four-fibers Bi-directional Line-Switched Rings (4-BLSRs)
  - Two fibers used as working fibers
  - Two fibers used as protection fibers
- The graph shows a bi-directional connection between A and B
- Note that in this architecture, working traffic can be carried on both directions along the link (clockwise and counterclockwise)
- This allows spatial reuse
  - It can be shown that this is the maximum spatial reuse achievable on a ring



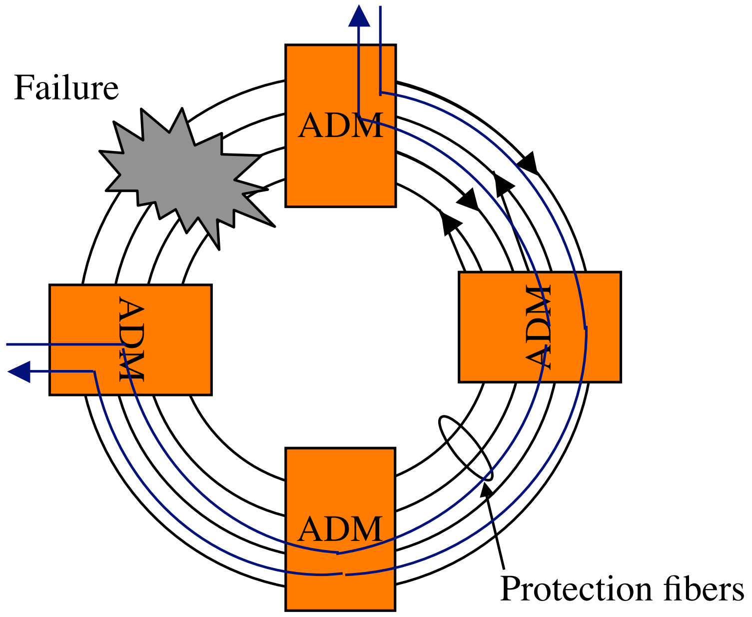
Protection in BLSR/4

- 1:1 protection is usually implemented on BLSR/4
- Two options are available
  - Span protection
  - Line protection

Span Protection in a BLSR/4

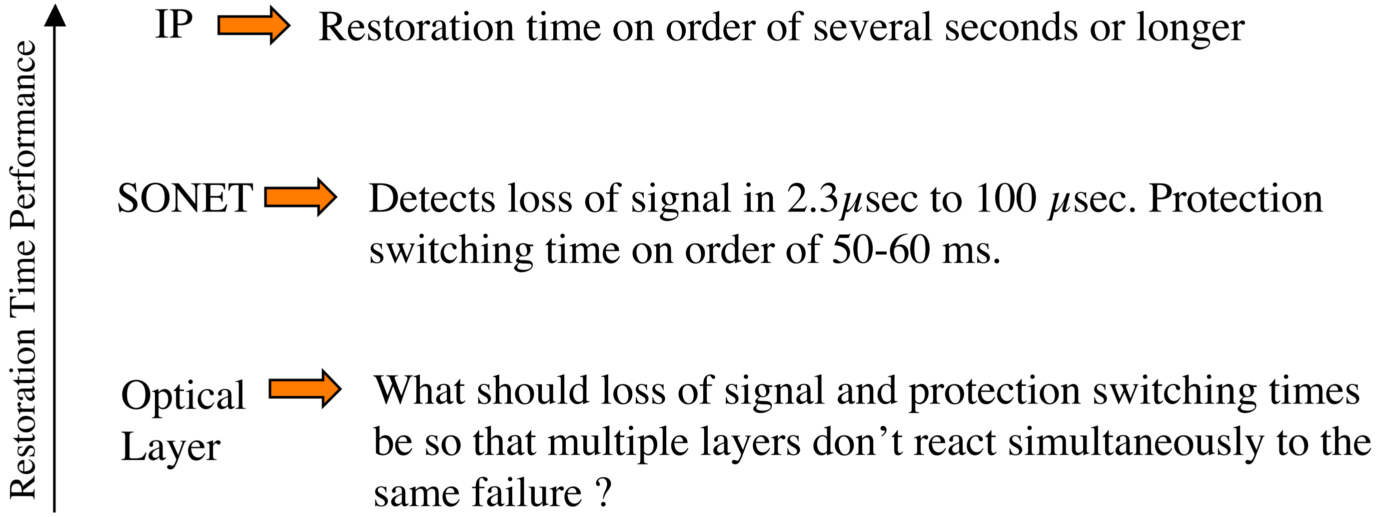


Line Protection in a BLSR/4



Protection Interworking Between Layers

- Different layers will have different protection mechanisms, each with unique restoration time constants
- Some networking architecture may not have any protection mechanism so may rely on an optical layer to do protection switching
- Protection switching in one layer should not negatively impact protection in other layers

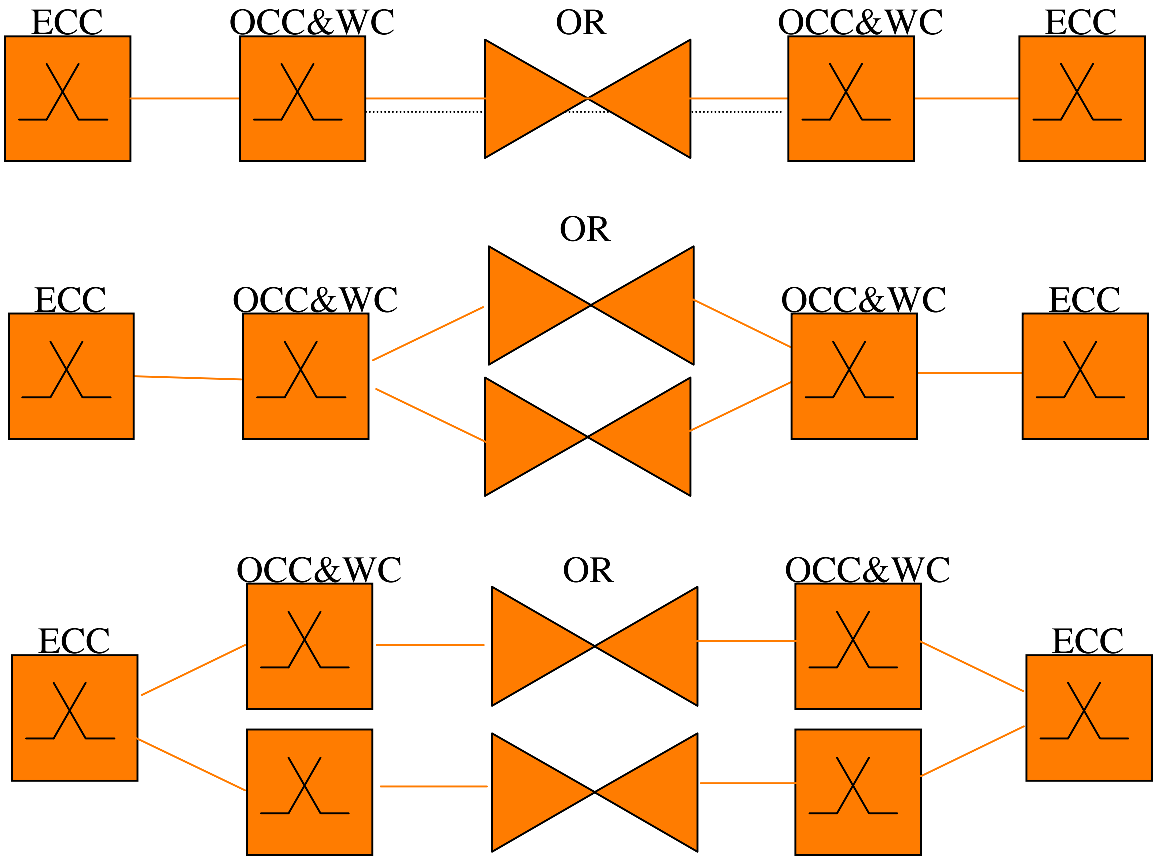


IP → Restoration time on order of several seconds or longer

SONET → Detects loss of signal in 2.3μsec to 100 μsec. Protection switching time on order of 50-60 ms.

Optical Layer → What should loss of signal and protection switching times be so that multiple layers don't react simultaneously to the same failure ?

Protection Switching



Optical Regenerator Section Protection

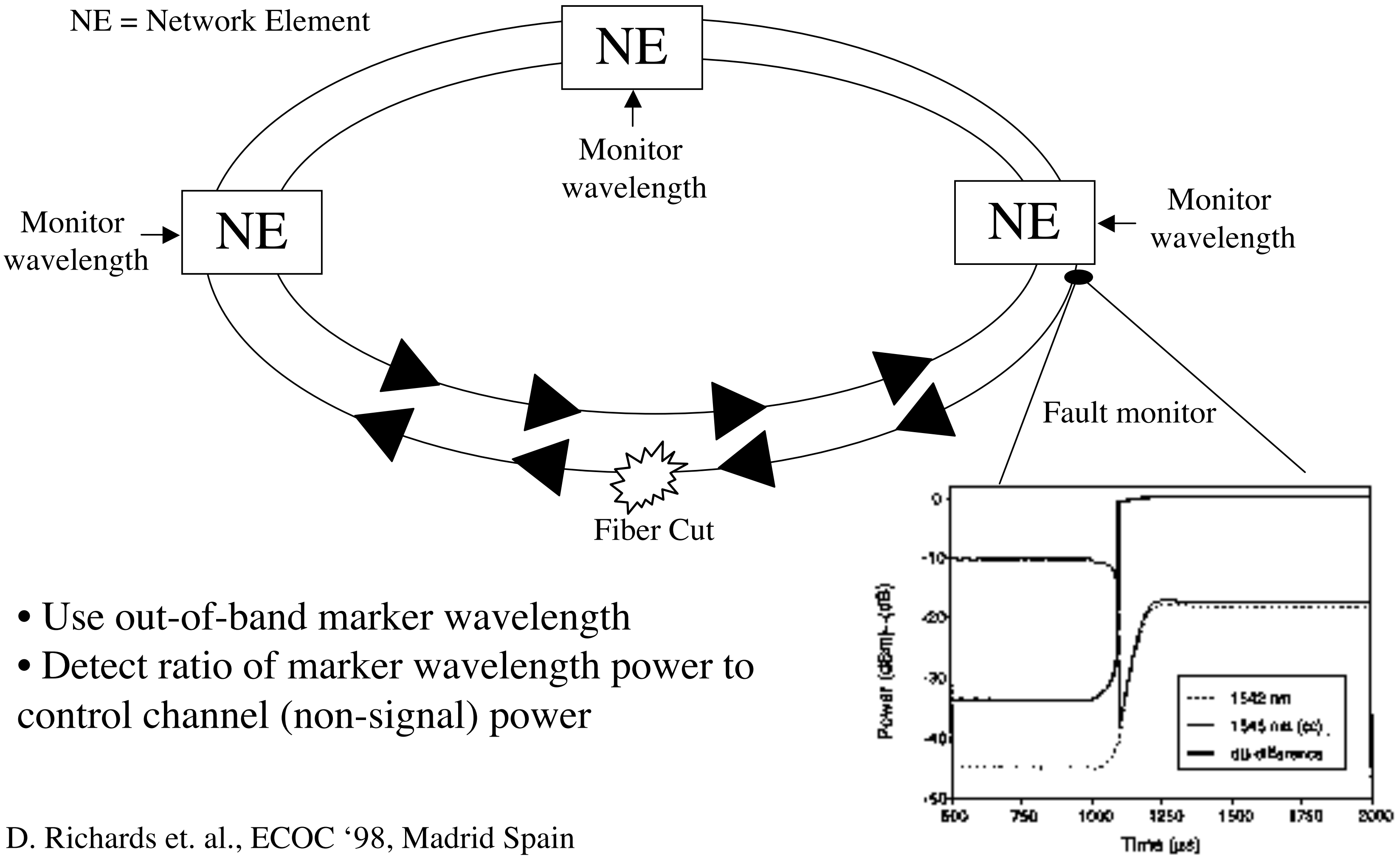
Optical Multiplexer Section Protection

Optical Path Section Protection

Fast Transients with Cascaded EDFAs

- Power transients in surviving channels due to cross gain saturation in EDFAs due to
  - Wavelength channels added or dropped
  - Network reconfigurations
  - Link, node or amplifier failures
- Speed of power transients proportional to number of amplifiers (Zyskind, OFC ‘96)
  - 1/N x 10s of microseconds for chain of N amplifiers
- Error bursts will occur if
  - Receiver dynamic range exceeded
  - Fiber nonlinearity thresholds exceeded

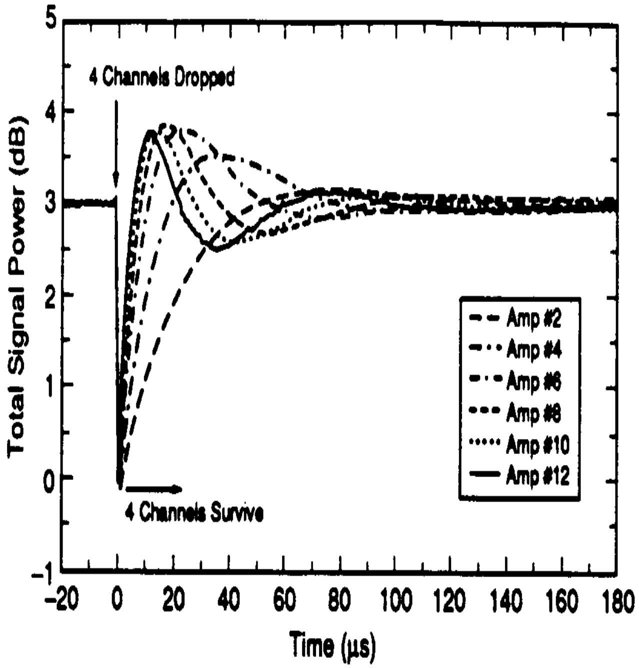
Detecting Fiber Cuts



- Use out-of-band marker wavelength
- Detect ratio of marker wavelength power to control channel (non-signal) power

D. Richards et. al., ECOC ‘98, Madrid Spain

Fast Power Transients in Optically Amplified WDM Networks



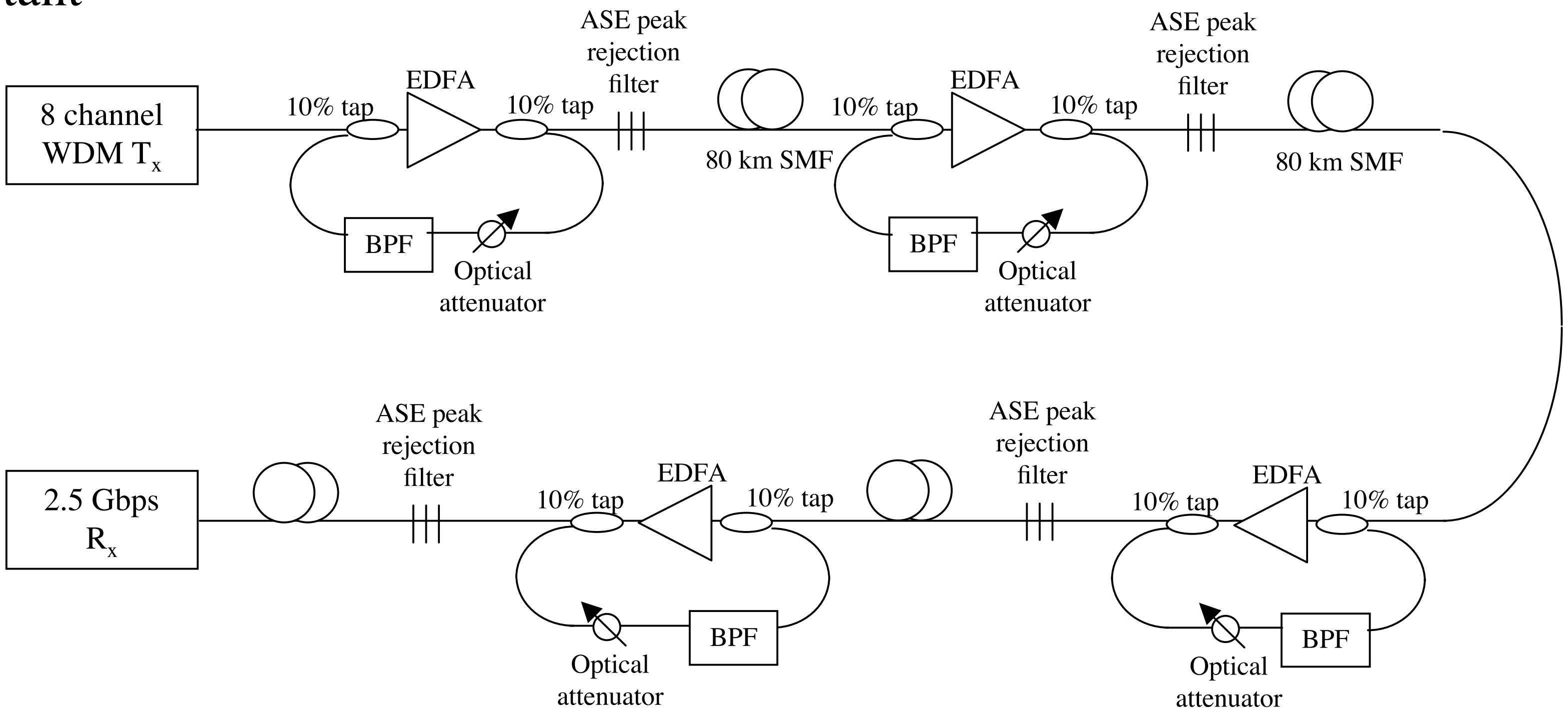
Measured output power as a function of time after 2, 4, 6, 8, 10, and 12 EDFA's. At time t = 0 one laser is blocked, corresponding to loss of 4 of 8 signal channels.

J. L. Zyskind et.al., OFC’96, PD31-2

- Adding or dropping channels in a WDM Network which contains N Erbium Doped Fiber Amplifiers, either in nodes or regenerators, would cause a power fluctuation in the surviving channels, sometimes even doubling the power in EDFAs farther down the chain.
- Typical time scales for gain changes in EDFAs are of the order of tens of microseconds.
- To limit performance penalties, power fluctuations should be limited to 1dB.
- Response times of the EDFAs should be 100 - 200 ns.
- Solution: Dynamic gain control or gain clamping

Stabilization with Gain Clamped EDFAs

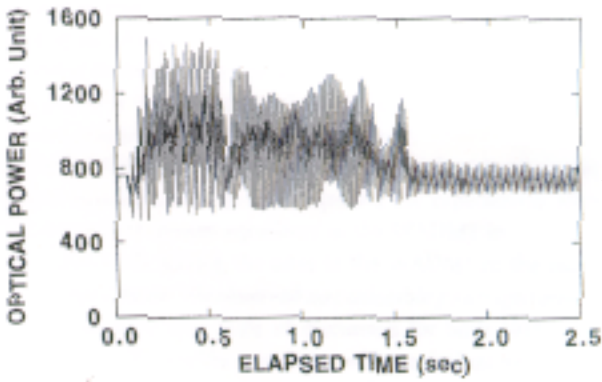
∍Address problem of channel add/drop rates on order of EDFA gain relaxation oscillation frequency and gain clamped amplifier loop time constant



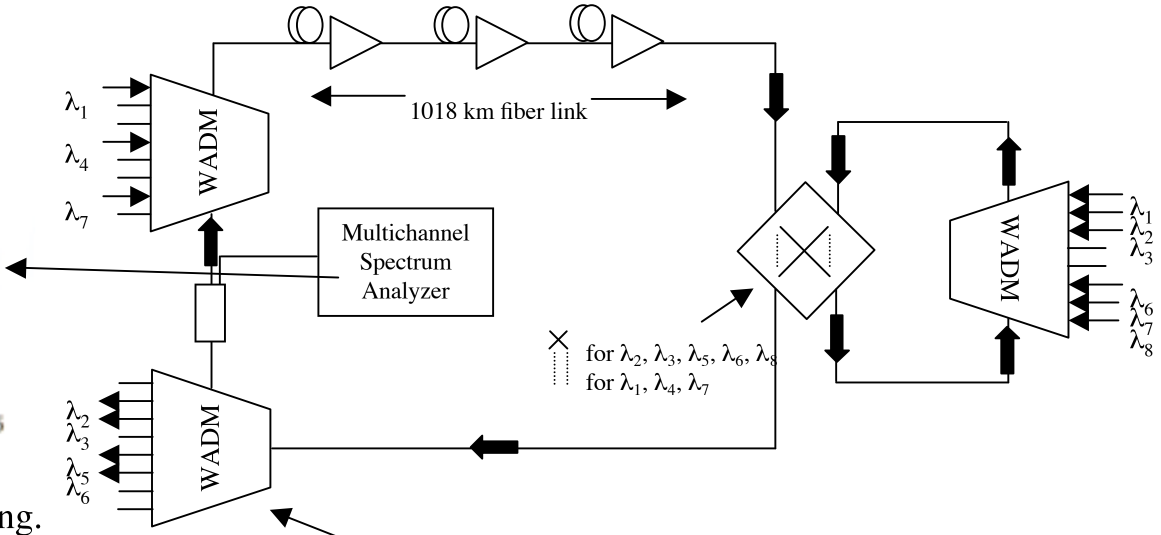
S. Y. Kim et. al., Electron. Letts., Aug. 1997

Power Fluctuations in Cascaded Channel Power Equalizers

State 1: 1,4,and 7 only through EDFA link	State 2: Add 2,3,5 and 6 to EDFA link



Channel 7 without EDFA gain clamping.
Gain clamping greatly reduces effect.



Array of (8) 2x2 switches followed by array of (8) automatic channel power equalizers

S. J. B. Yoo et. al., OFC ‘98