S-72.3340 Optical Networks Course

Lecture 12: The Course Recap

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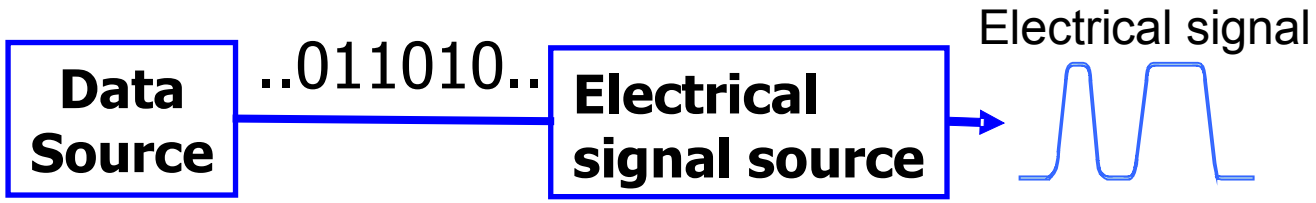
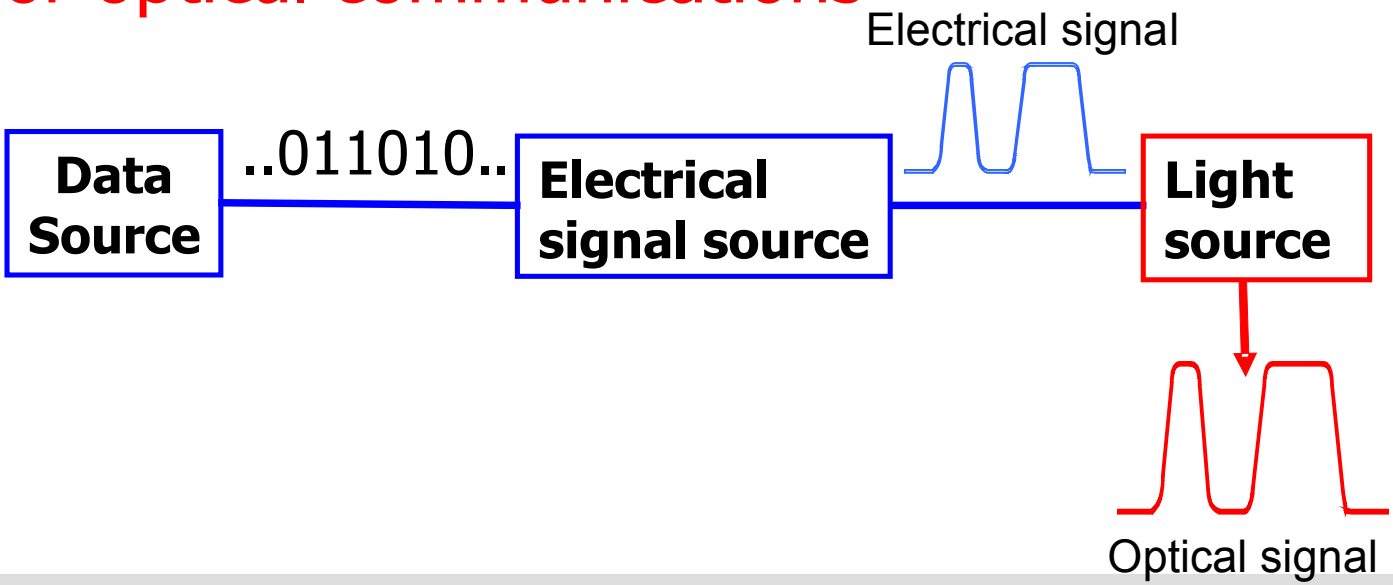
1. Introduction

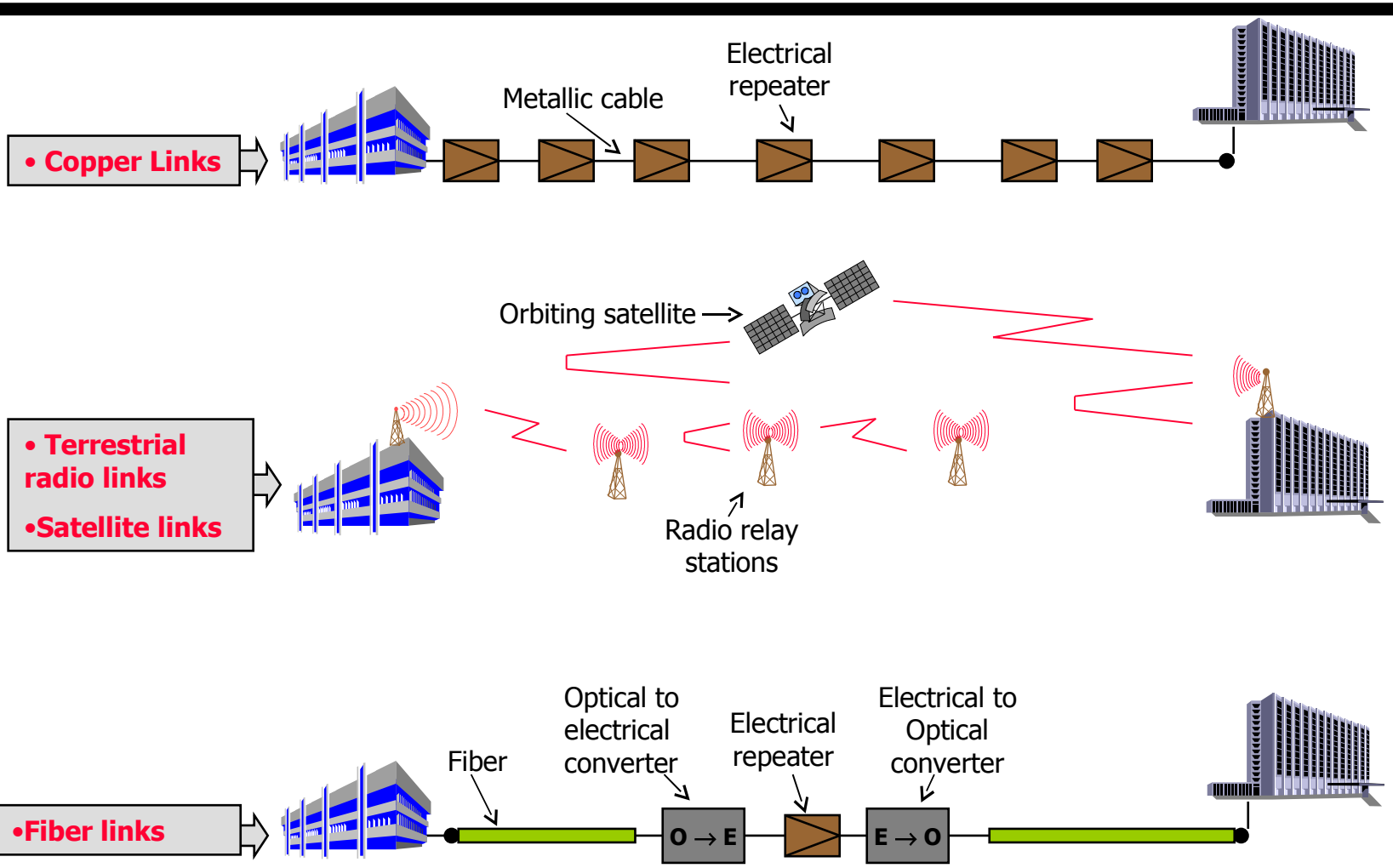
- Electrical communications



- Light or optical communications



1. Introduction



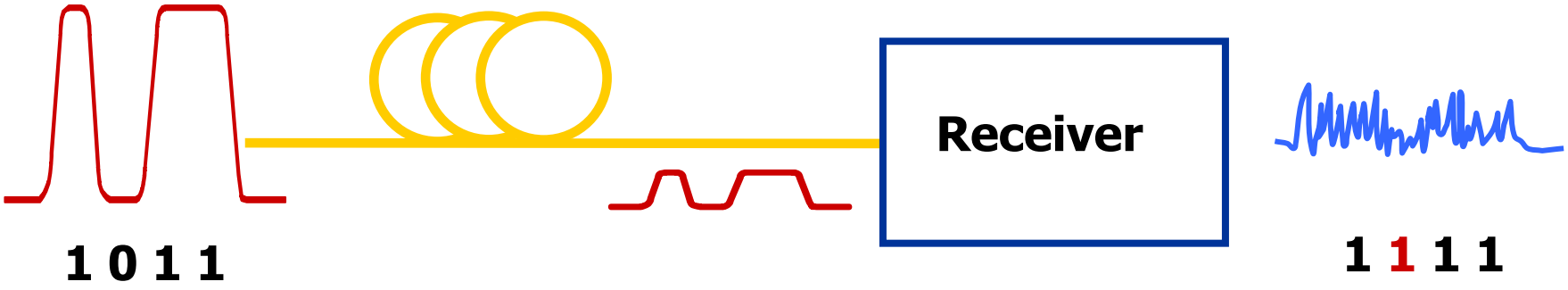
1. Introduction

- Advantages of the fiber transmission media
  - Low transmission loss (typically 0.2-0.5 dB/km)
  - Large information carrying capacity (multi Gbit/s)
  - Immunity to electromagnetic interference
  - More secure to eavesdropping or wiretapping
  - Smaller size and weight

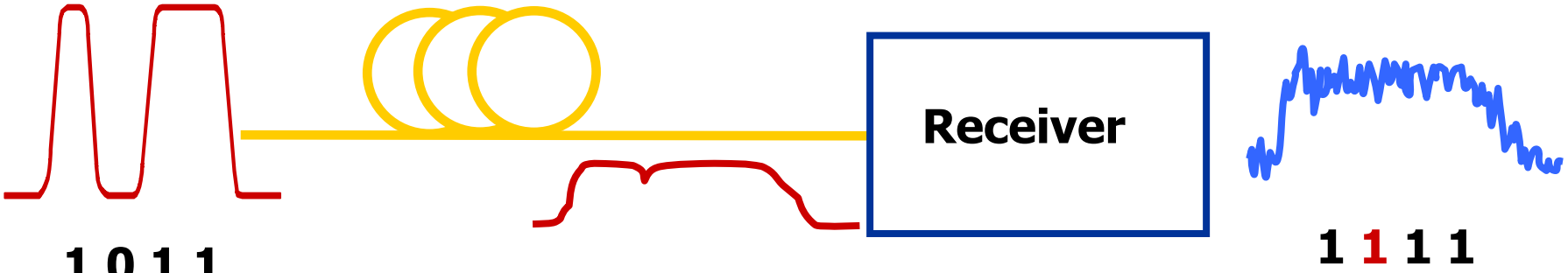
1. Introduction

- Link performance is limited by:

Loss

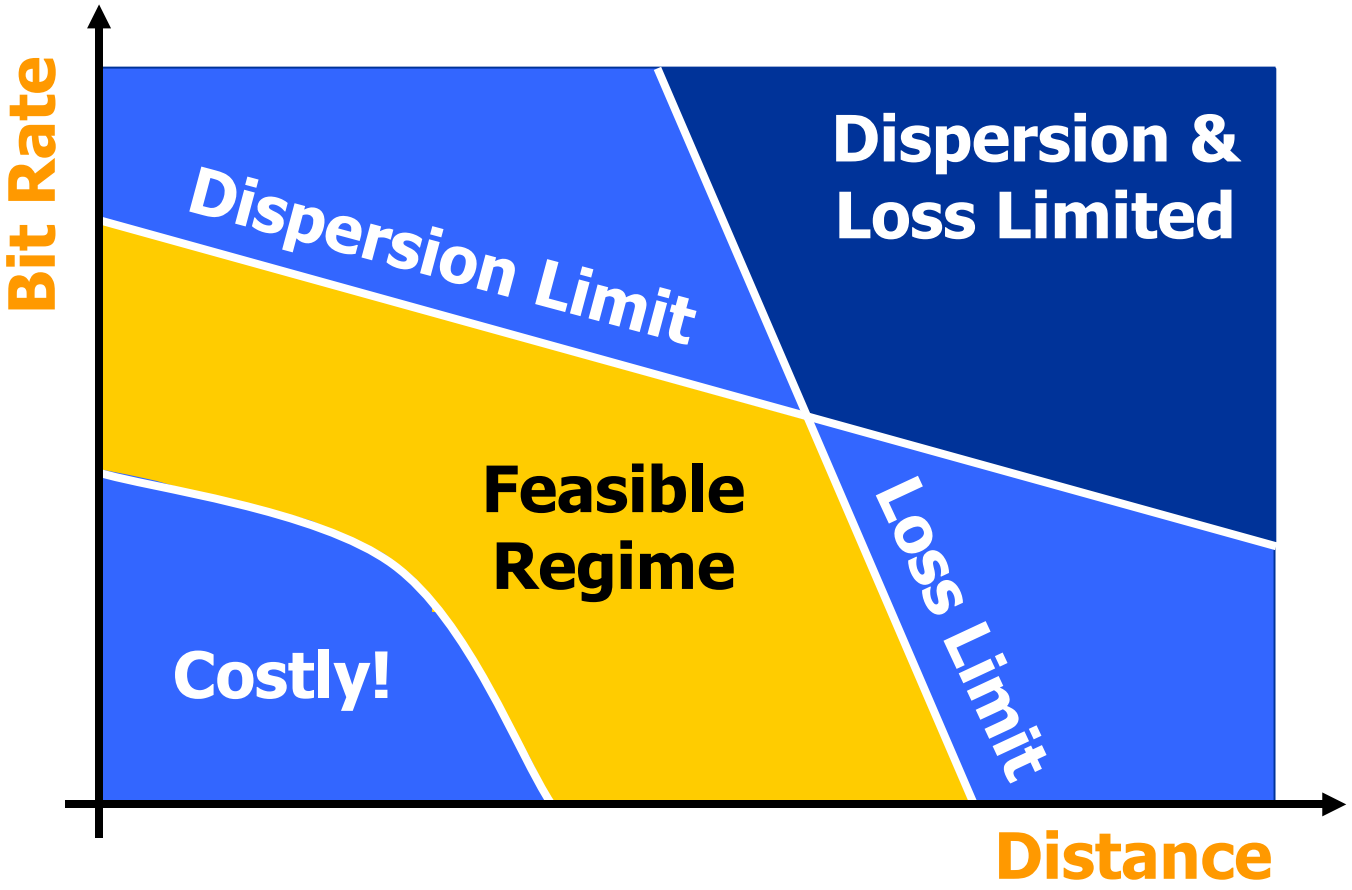


Spreading

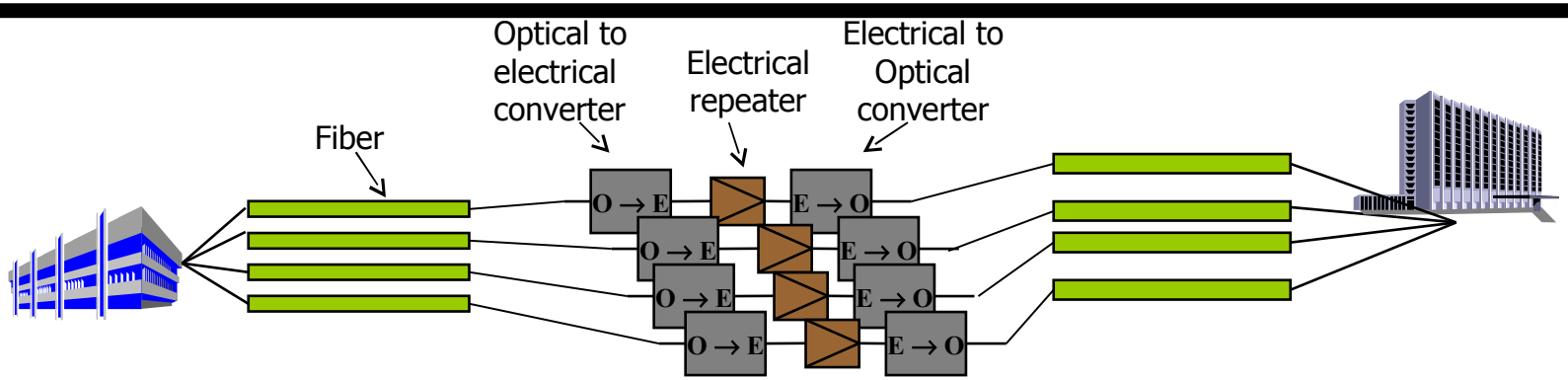


1. Introduction

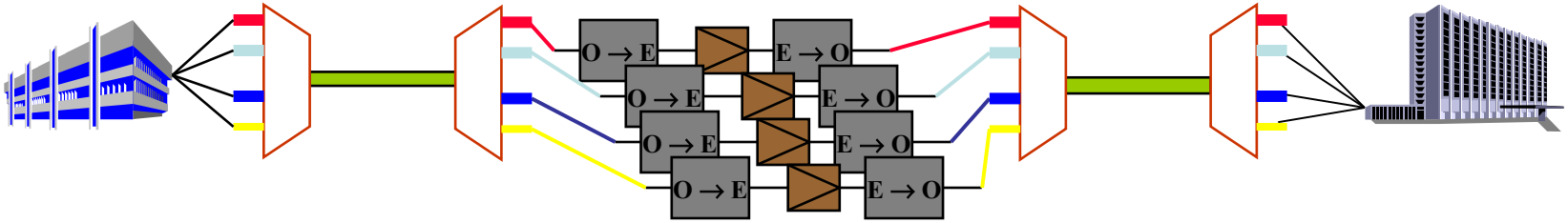
- Graphical representation of fiber limitations



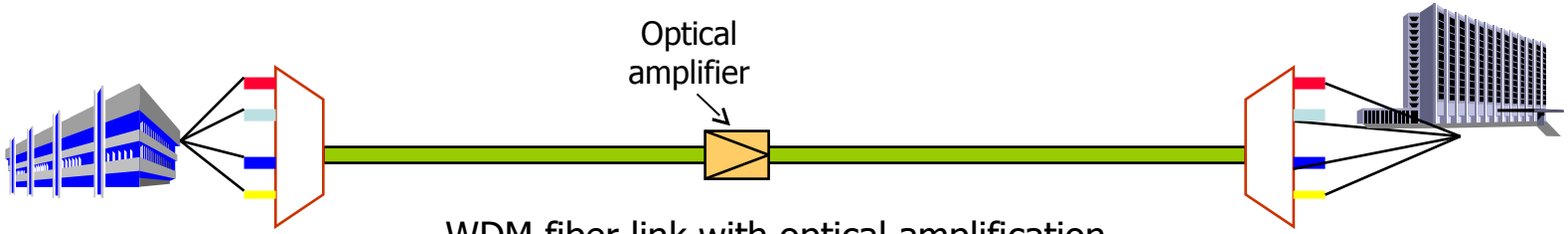
2. Wavelength-Division Multiplexing



Space-division multiplexing fiber link with electrical regeneration



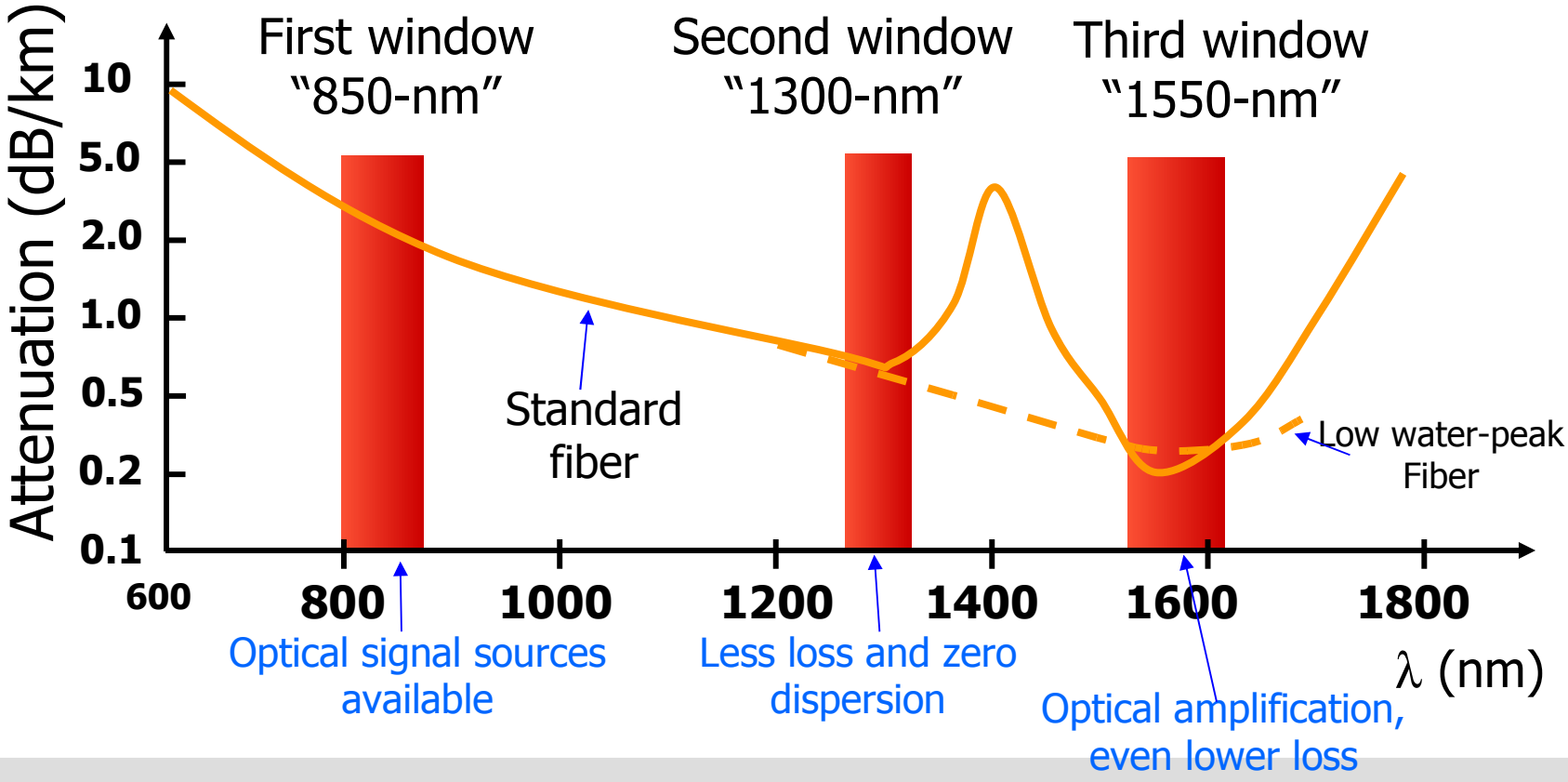
WDM fiber link with electrical regeneration



WDM fiber link with optical amplification

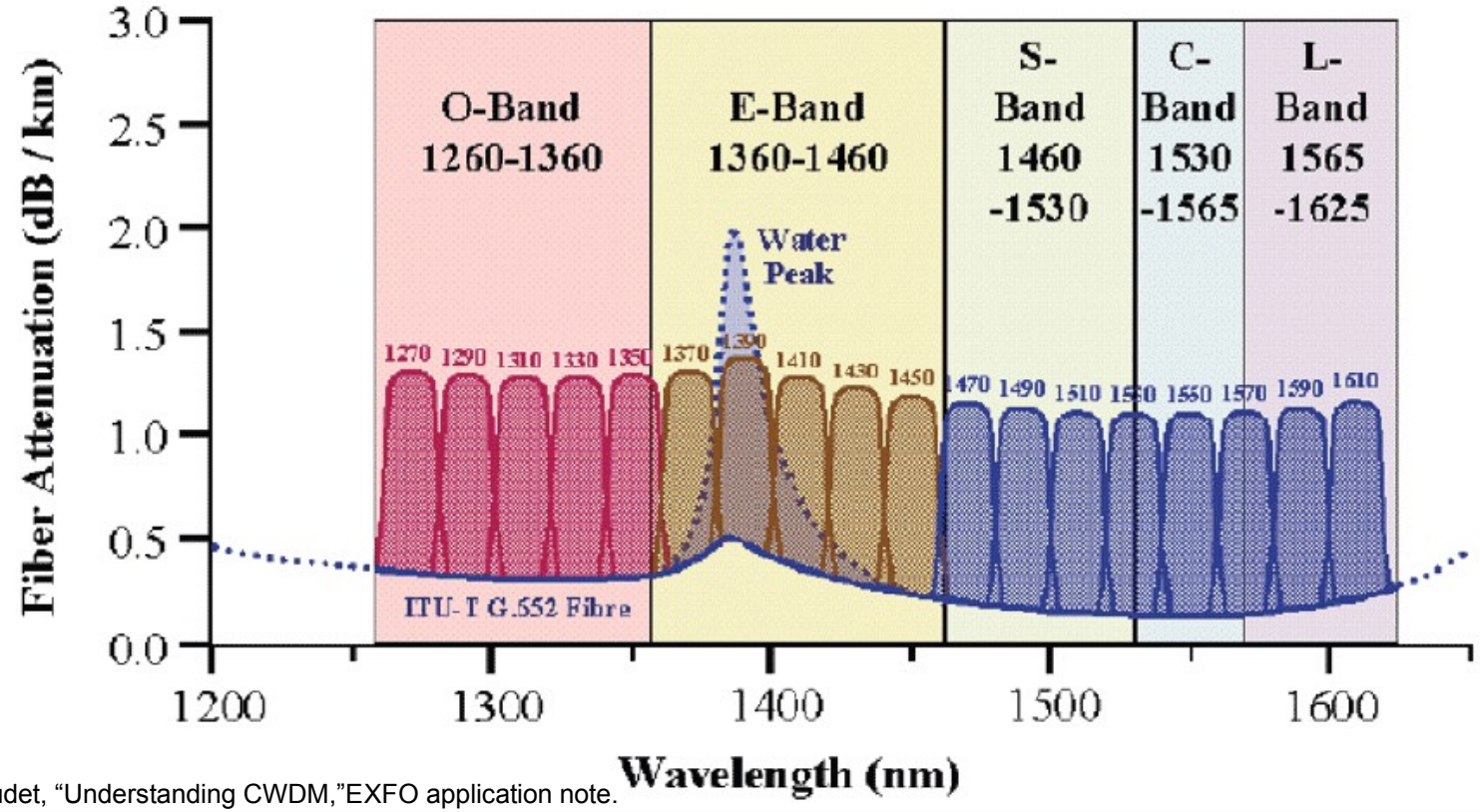
2. Wavelength-Division Multiplexing

- Amplified optical communications systems
  - Optical amplification enables WDM in 1550 nm window
  - Less attenuation than 850 nm and 1300 nm windows



2. Wavelength-Division Multiplexing

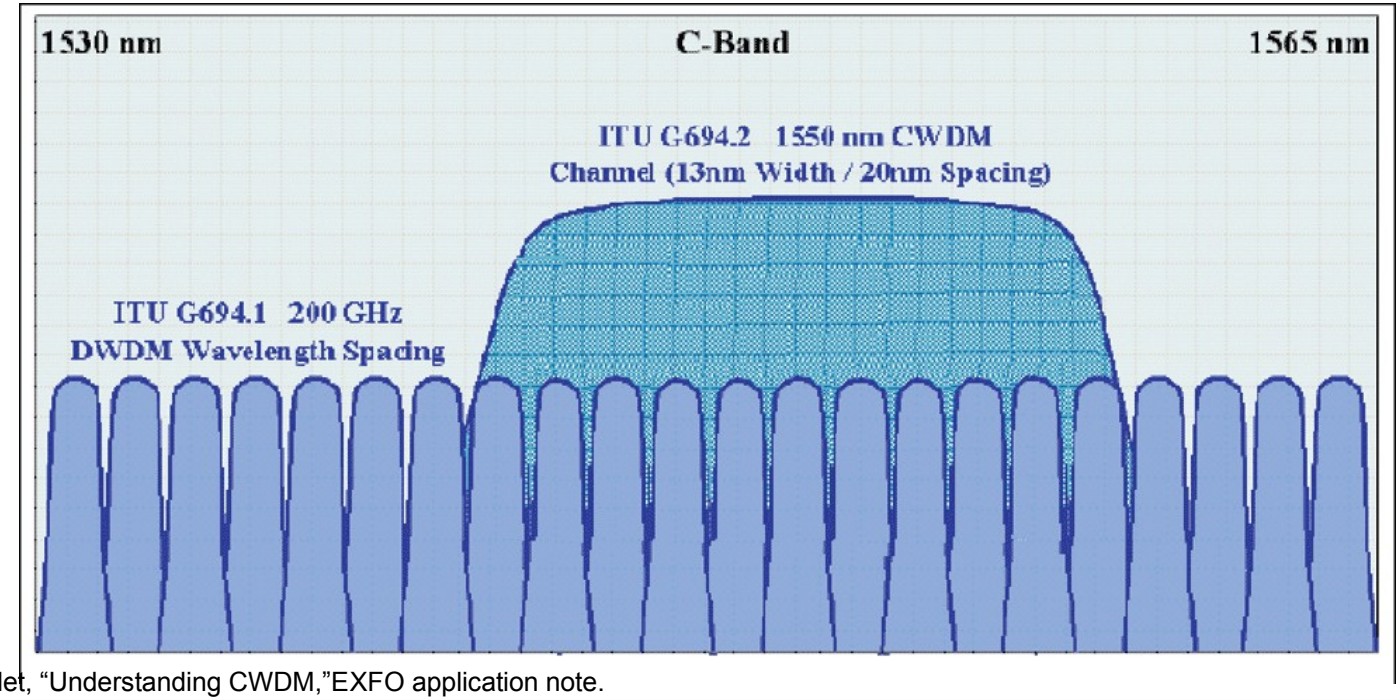
- Coarse WDM (CWDM)
  - ITU-T G.694.2/695 grid with 2500 GHz or 20 nm channel spacing
  - 18 channels spanning O-, E-, S-, C- and L-bands (1260-1625 nm)



Source: F. Audet, “Understanding CWDM,”EXFO application note.

2. Wavelength-Division Multiplexing

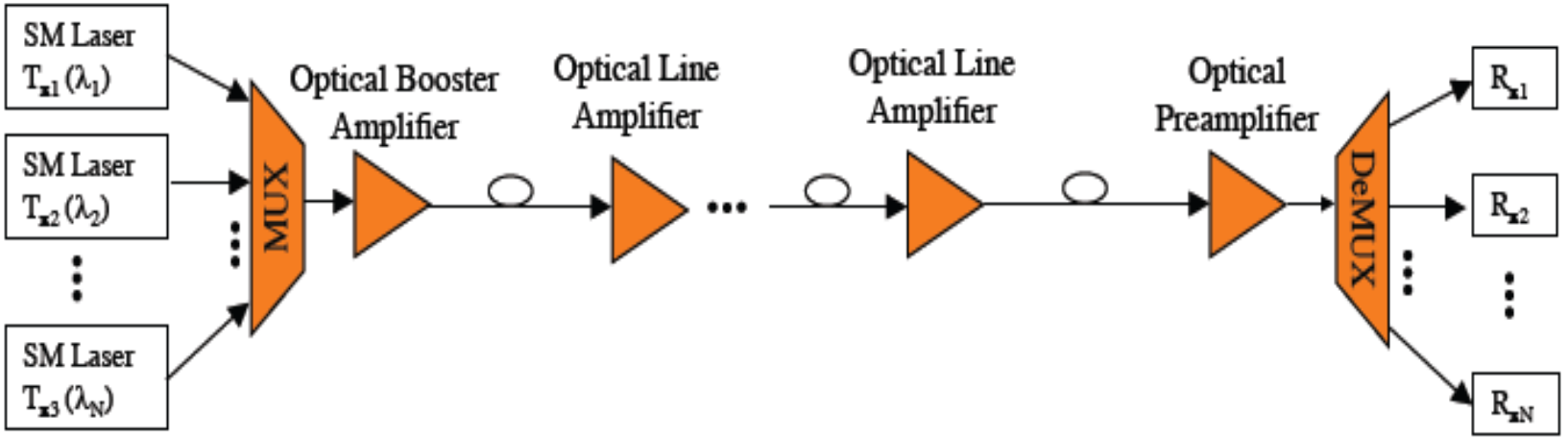
- DWDM enables many channels with amplification,
  - ...but requires stable transmitters and good filtering (sharp skirts and precise center frequency)
- CWDM simplifies filter and transmitter design (cheaper)
  - ...but no amplification and few channels



Source: F. Audet, “Understanding CWDM,”EXFO application note.

2. Wavelength-Division Multiplexing

- A typical amplified WDM link includes:
  - Optical transmitters and receivers (1 each per wavelength)
  - Wavelength multiplexer and demultiplexers
  - Optical amplifiers
    - Boost amplifier: to increase the output power
    - Line amplifier: to compensate for fiber losses
    - Preamplifier: to improve receiver sensitivity

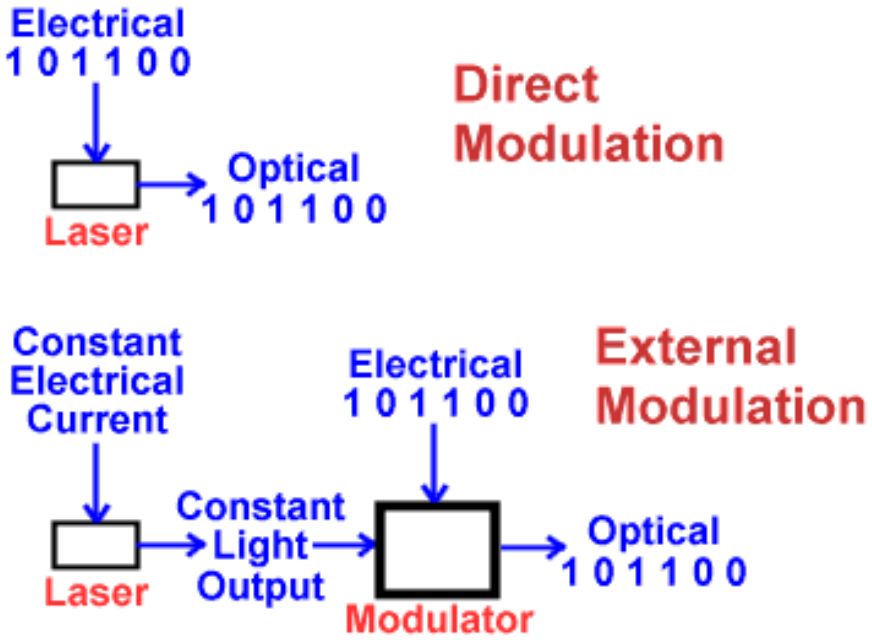


2. Modulation/Demodulation

- Two popular optical modulation schemes
  - On-off keying (OOK) modulation
  - Subcarrier modulation (SCM)

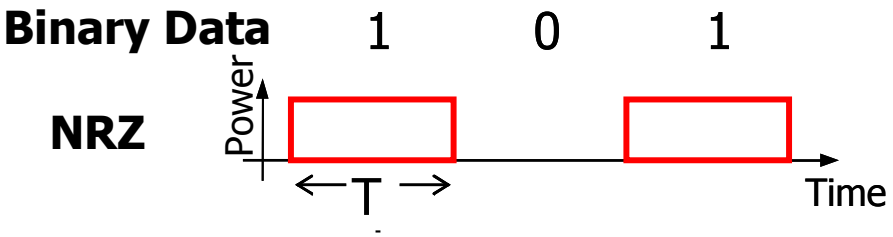
2.1 On-Off Keying (OOK) Modulation

- It is possible to directly or externally modulate (i.e. turn off and on) a light source (laser or LED)
  - Direct modulation ⇒ simple, chirp
  - External modulation ⇒ more complex, less chirp

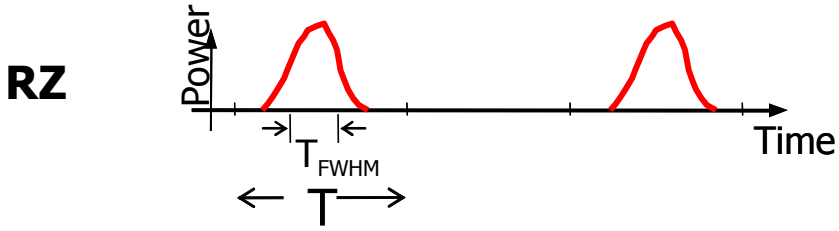


2.1 On-Off Keying (OOK) Modulation

- Non-Return-to-Zero (NRZ) format



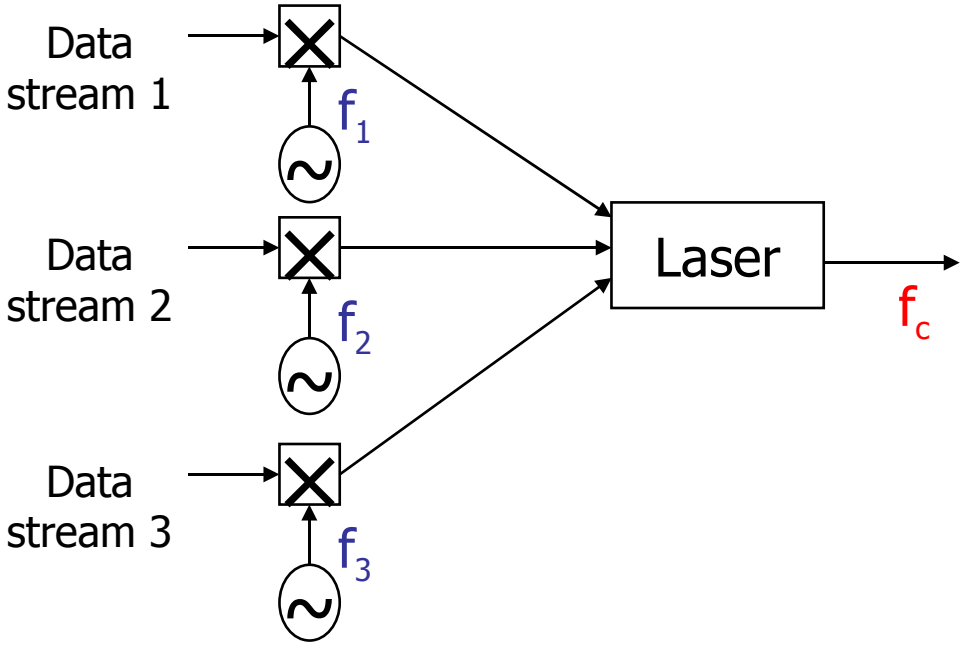
- Return-to-Zero (RZ) format

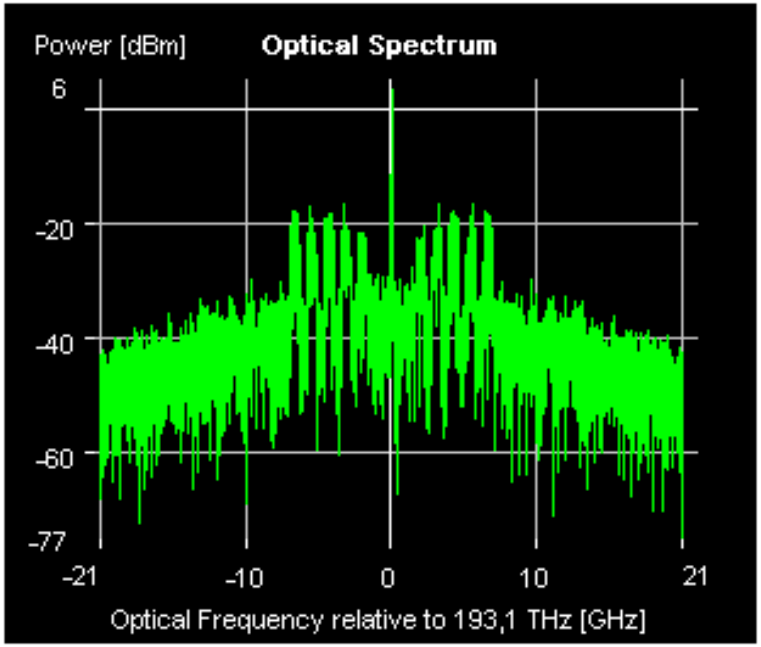


Duty Cycle = T_{FWHM}/T where T_{FWHM} is full width at half maximum of power

2.2 Subcarrier Modulation

- Subcarrier modulated (SCM) systems
  - Multiplex multiple data streams onto one optical signal
  - Each data stream assigned a unique subcarrier frequency
    $\Rightarrow$ subcarrier multiplexing





5 signal subcarrier multiplexing

2.3 Demodulation

- Data signal recovery is a two step process
  - (1) Recovering the clock
  - (2) Determining whether a "0" or "1" bit was sent in a bit interval ⇨ direct detection

2.3 Demodulation

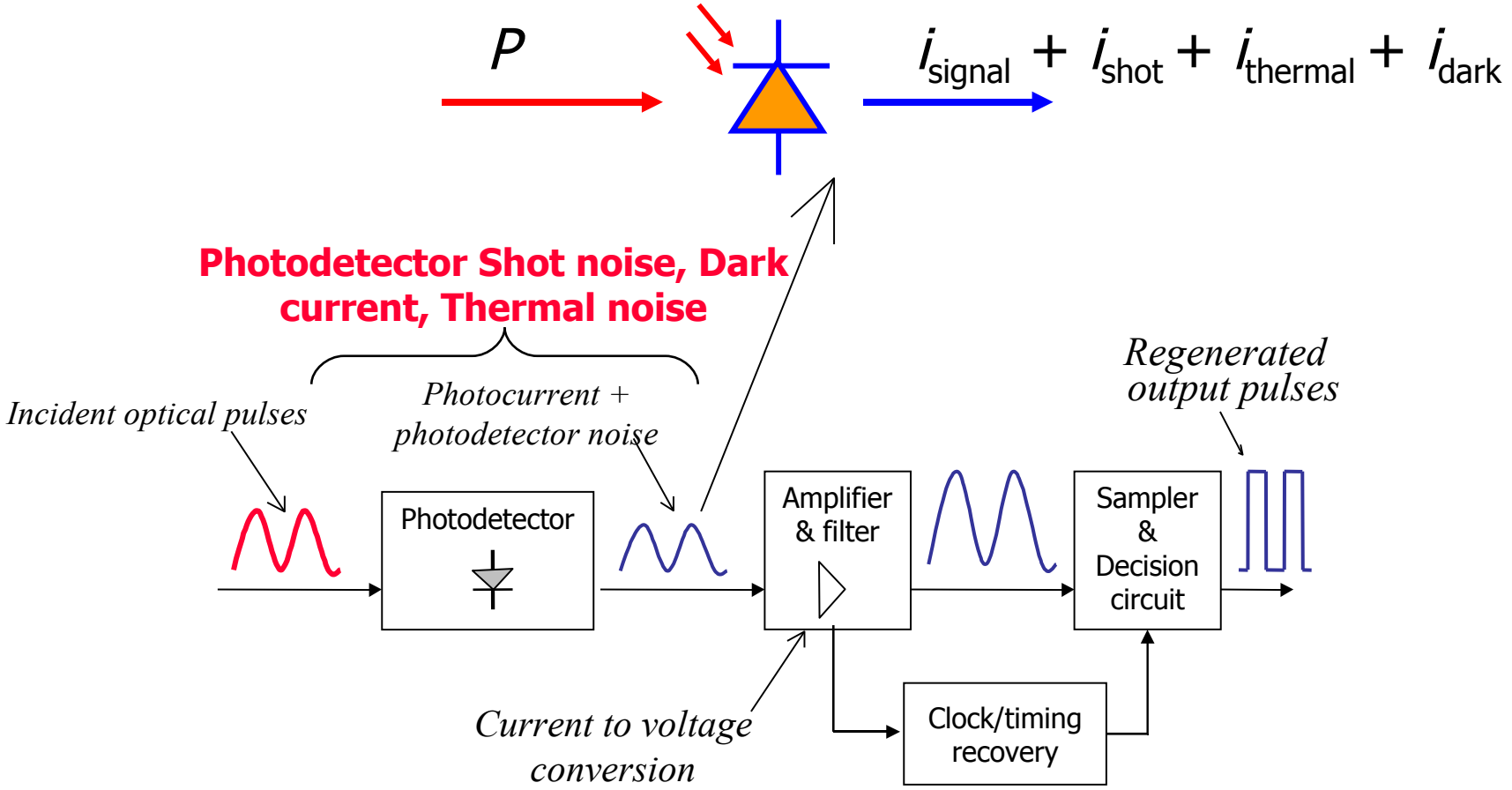


Figure: Block diagram showing various functions and noise components in a receiver

2.3 Demodulation

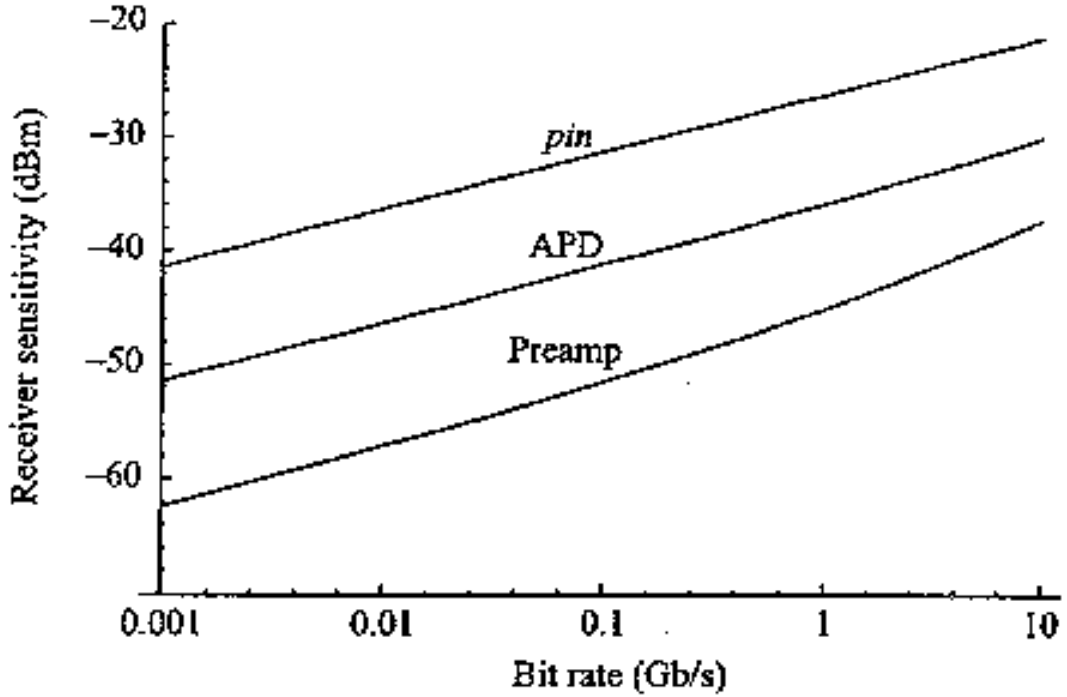
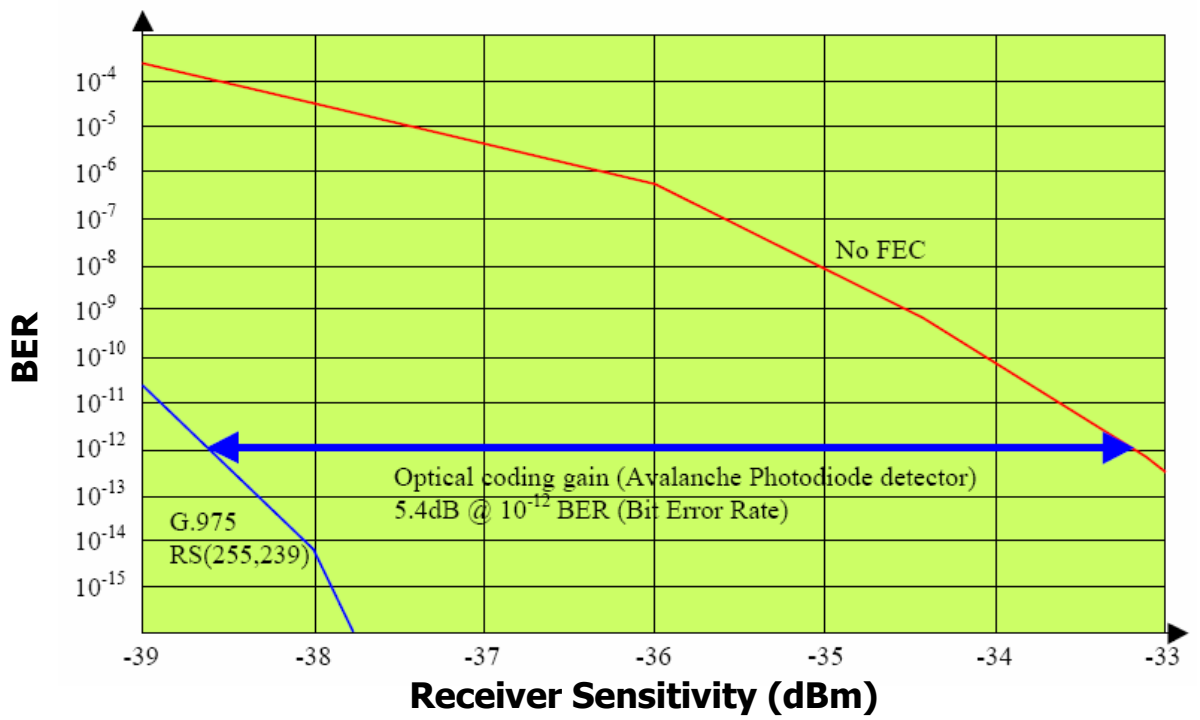


Figure 4.4 Sensitivity plotted as a function of bit rate for typical *pin*, APD, and optically preamplified receivers. The parameters used for the receivers are described in the text.

* For optically preamplified receiver, a noise figure of 6dB assumed
* Optical bandwidth B_o =50 GHz

2.3 Demodulation

- Also performance improvements with electrical DSP techniques
  - Equalizers
  - Error detection and correction (forward error correction)



Source: G. Barlow, "A G.709 Optical Transport Network Tutorial," Innocor white paper.

3. Transmission System Engineering

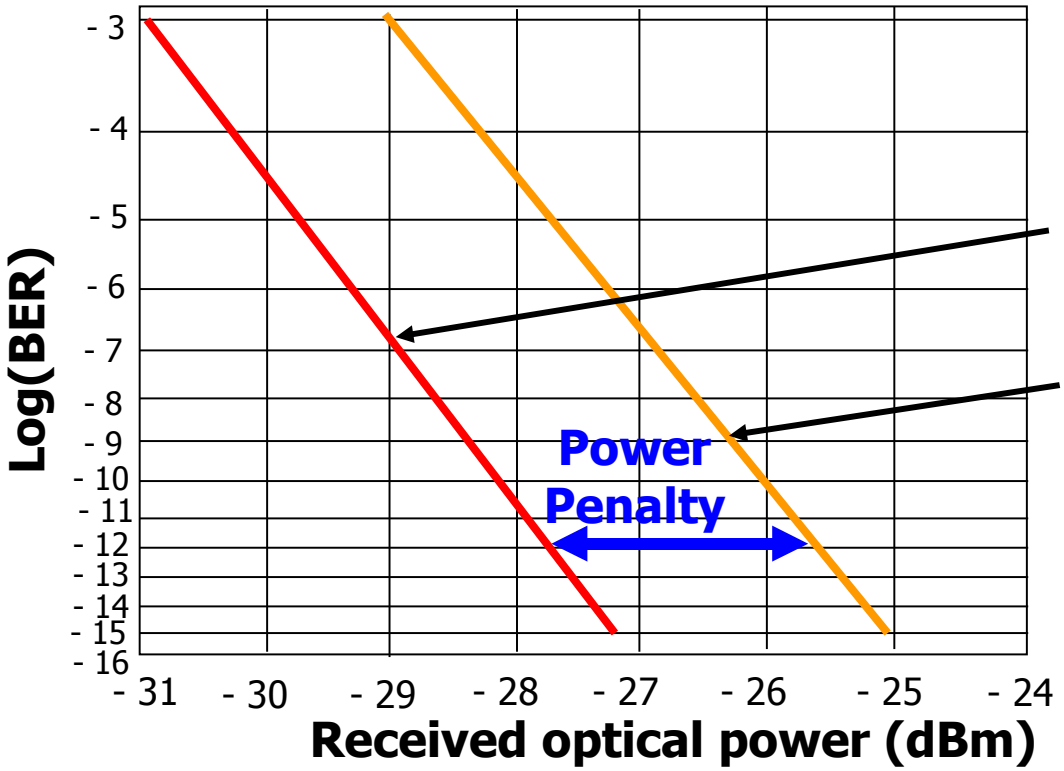
- Link power budget

Item	Value	dB value
Transmitter: *1a) Average output power*	1.0 mW	0.0 dBm
Channel: *2a) Propagation losses* (10 km)	0.2 dB/km	-20.0 dB
Receiver: *3a) Signal power at receiver* *3b) Receiver sensitivity*		-20.0 dBm -30.0 dBm
Link Margin (Power Margin)	= (3a – 3b)	+10.0 dB

VPIsystems™

3. Transmission System Engineering

- Power penalty analysis



VPIsystems®

3. Transmission System Engineering

- Power penalty analysis

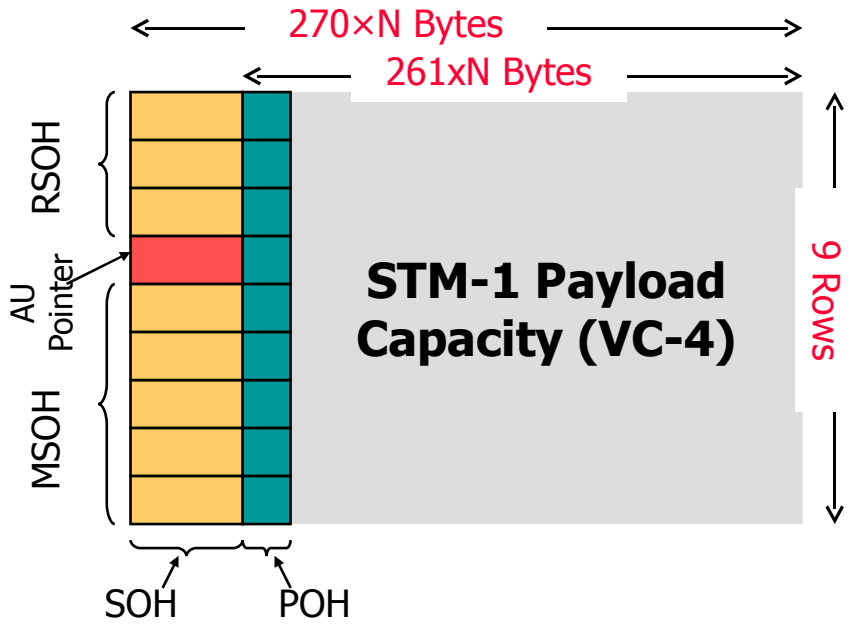
Impairment	Allocation (dB)
Ideal Q-factor	17
Transmitter	1
Crosstalk	1
Dispersion	2
Nonlinearities	1
Polarization dependent losses	3
Component ageing	3
System margin	3
Required Q-factor	31

4. SDH/SONET

- Dominant standard for optical transmission and multiplexing for high-speed signals
  - Single master clock ⇒ synchronous multiplexing
    - Easier and cheaper multiplexers and demultiplexers
  - Extensive management information
  - Standard optical interfaces enable interoperability
  - Network topologies and protection switching for high availability service
  - Basic transmission rates
    - SDH ⇒ 155 Mb/s STM-1 (synchronous transport module-1)
    - SONET ⇒ 51.48 Mb/s (STS-1)

4. SDH/SONET

- Layer (except physical layer) has associated overhead bytes
  - POH for path layer, MSOH for multiplexer section layer and RSOH for regenerator section layer



STM-N frame structure

4. SDH/SONET

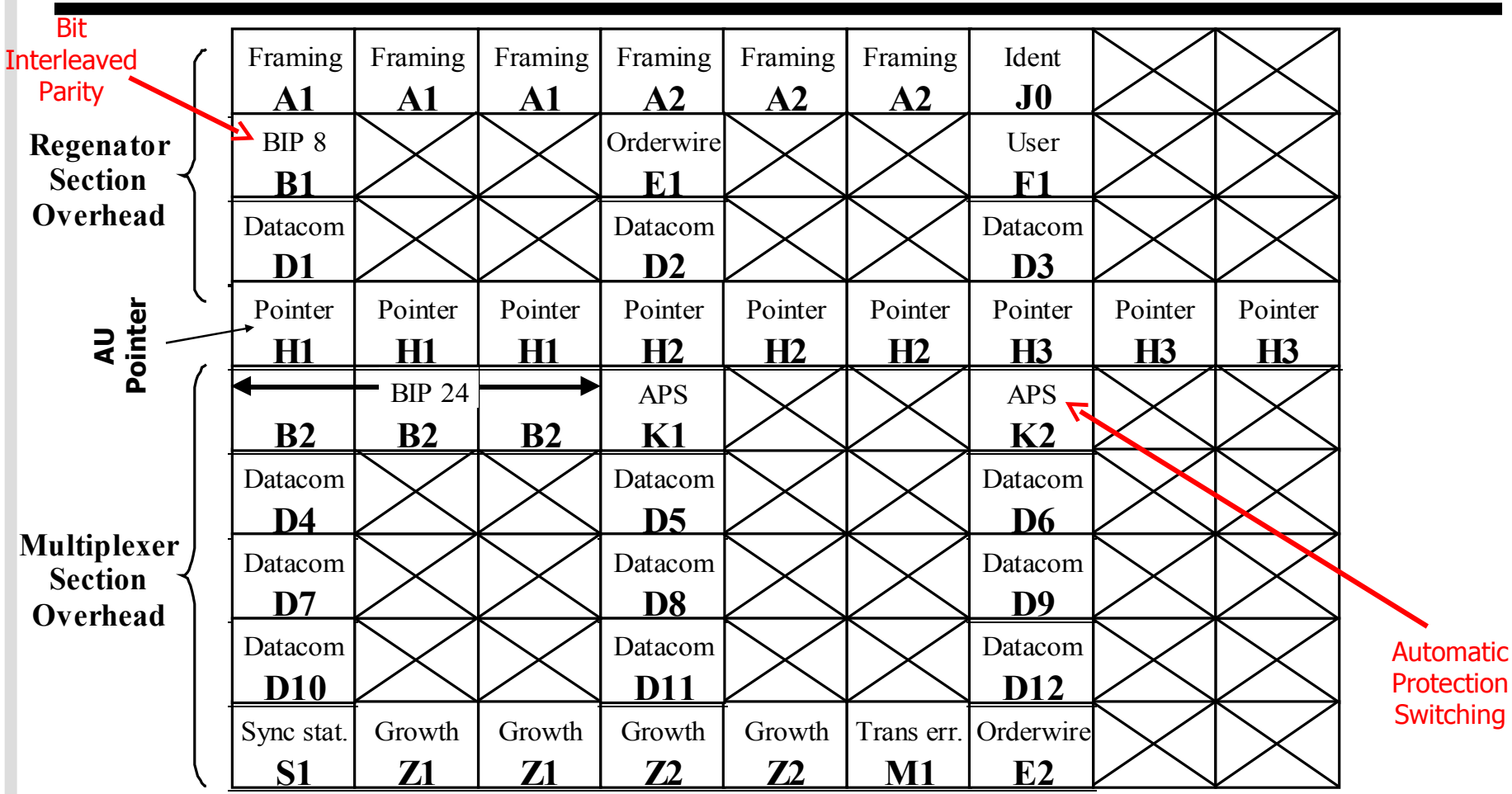
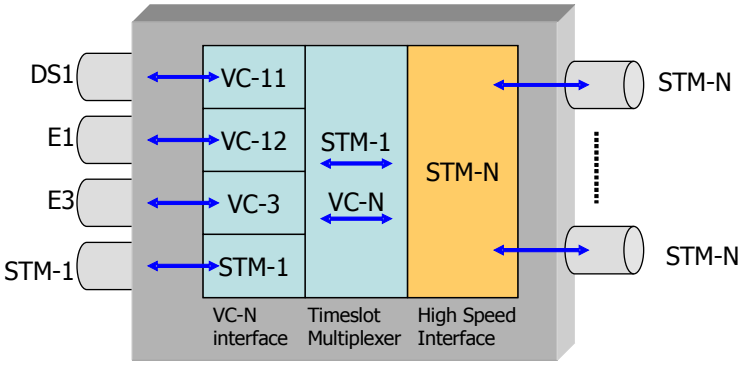


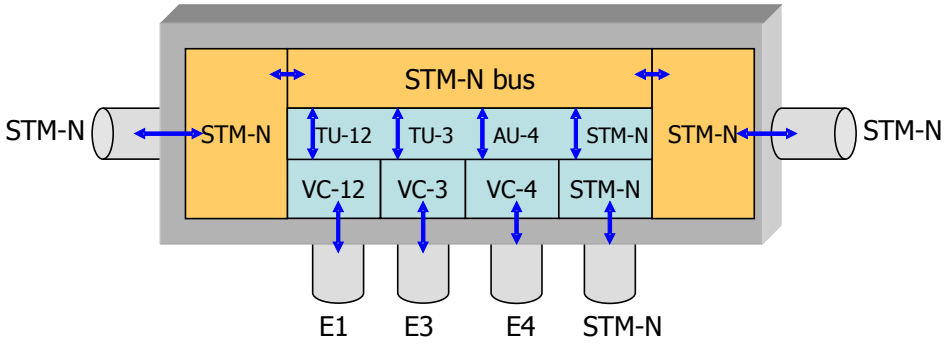
Figure: SDH section overhead bytes. Crossed bytes are auxiliary bytes

4. SDH/SONET

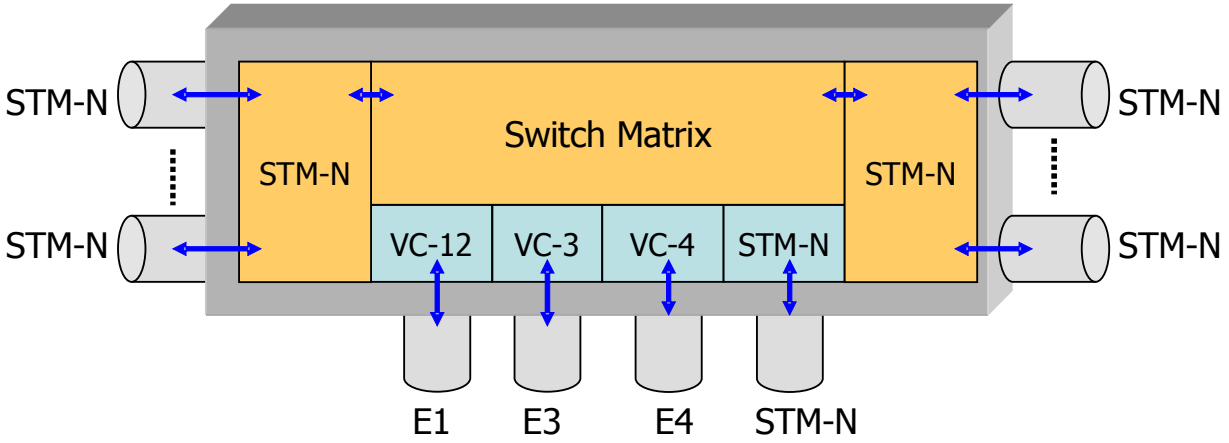
Path Terminating Equipment used in the SDH networks



Terminal Multiplexer



Add/Drop Multiplexer

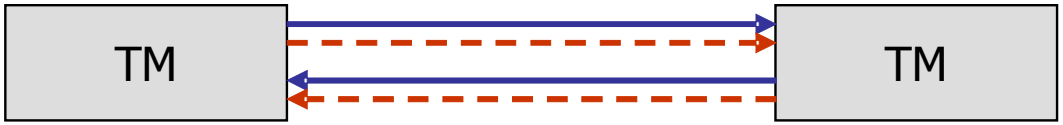


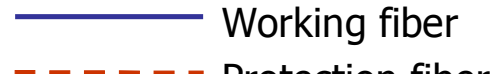
Digital Cross-Connect System

4. SDH/SONET

Resilient SDH network topologies

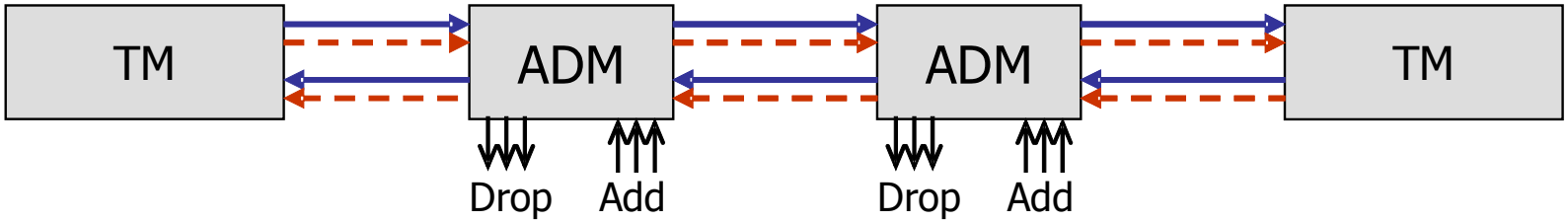
Point-to-point configuration





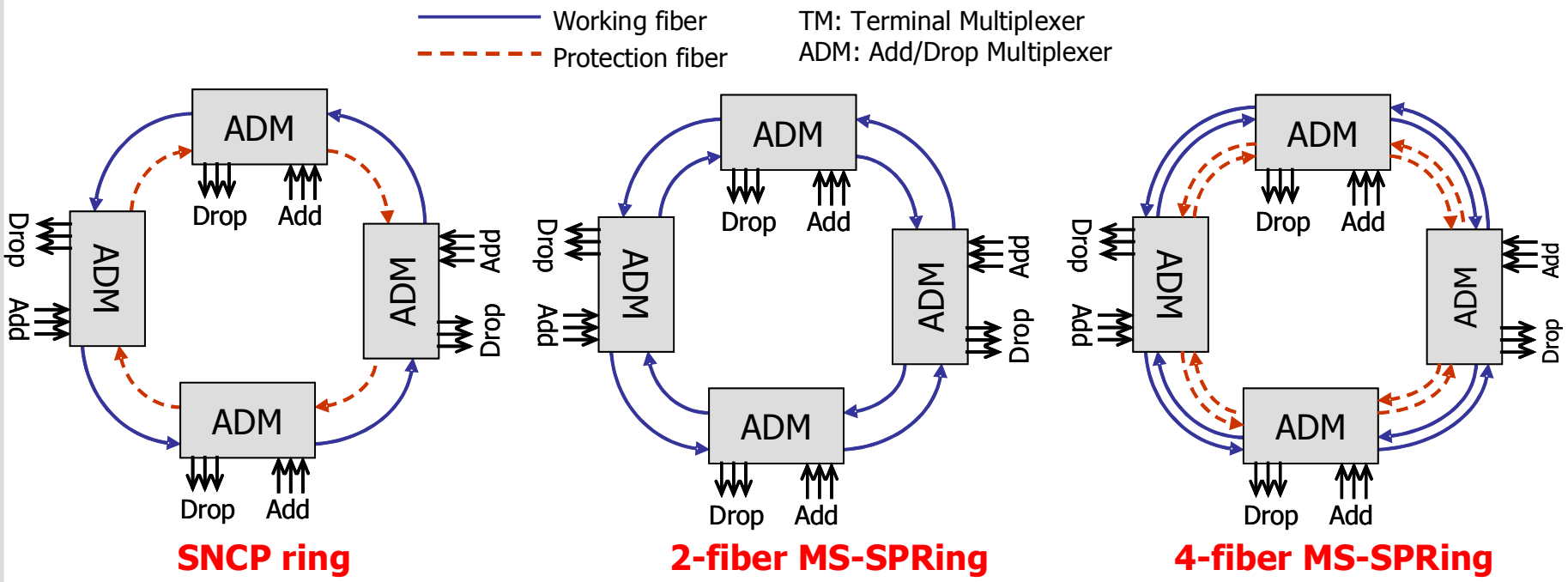
TM: Terminal Multiplexer
ADM: Add/Drop Multiplexer

Linear add/drop configuration



4. SDH/SONET

Resilient SDH network topologies



5. Multiservice Optical Networks

- Multiservice networks provide more than one distinct communications service type
  - Voice, data, Internet etc.
  - Over a common physical infrastructure e.g. fiber
- Increased prominence of data-centric protocols
  - ATM, IP/MPLS, Ethernet, SAN protocols etc.
- SDH originally defined to carry voice traffic
  - Unsuitable for asynchronous packet-switched bursty data traffic
  - Four-fold capacity increase increments (e.g. from STM-1 to STM-4) $\Rightarrow$ Inflexible provision of capacity to users

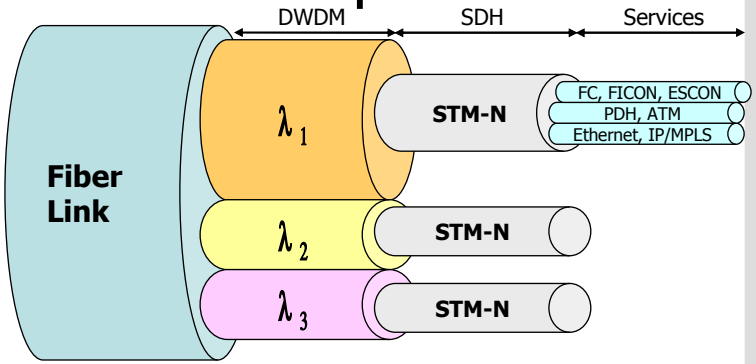
5. Multiservice Optical Networks

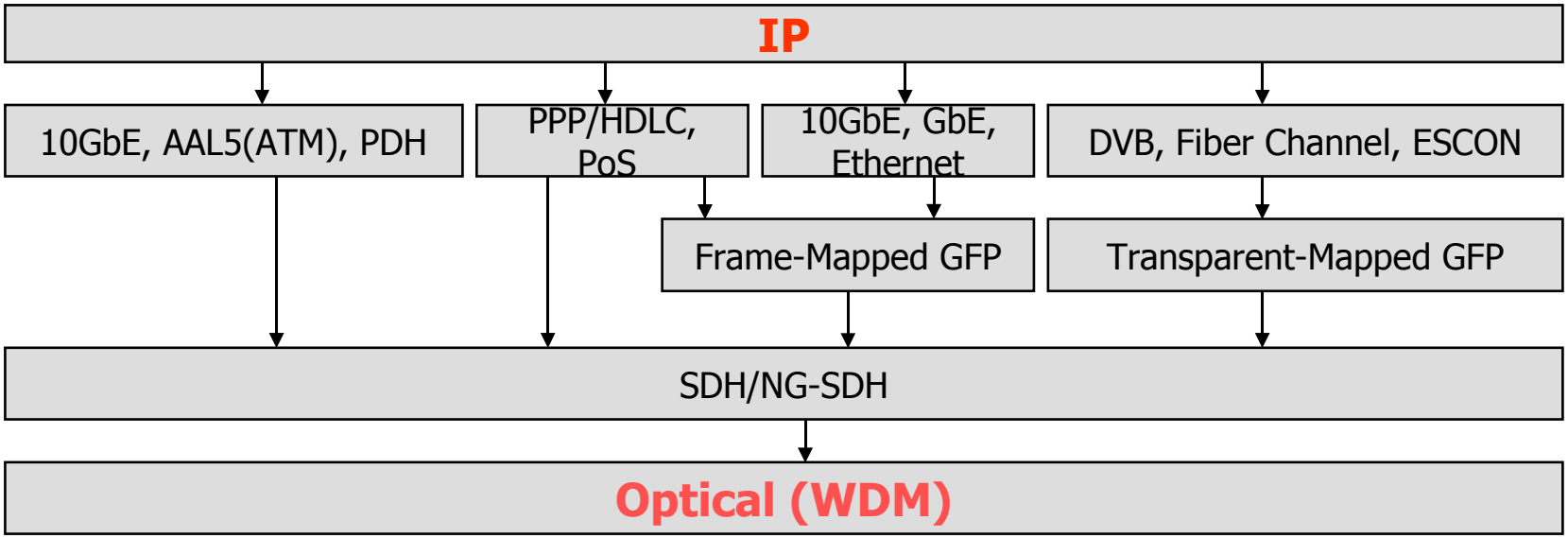
- Upgrade current systems with next-generation SDH/SONET (NG-SDH) solutions
  - Virtual Concatenation (ITU-T G.7043)
  - Link Capacity Adjustment Scheme (ITU-T G.7042)
  - Generic Framing Procedure (ITU-T G.7041)

- These upgrades only needed at source and destination terminal equipment of required service
  - Intermediate equipment do not need to be aware and can interoperate with upgraded equipment
  - Enables operater to make only partial network upgrades on as-needed basis

5. Multiservice Optical Networks

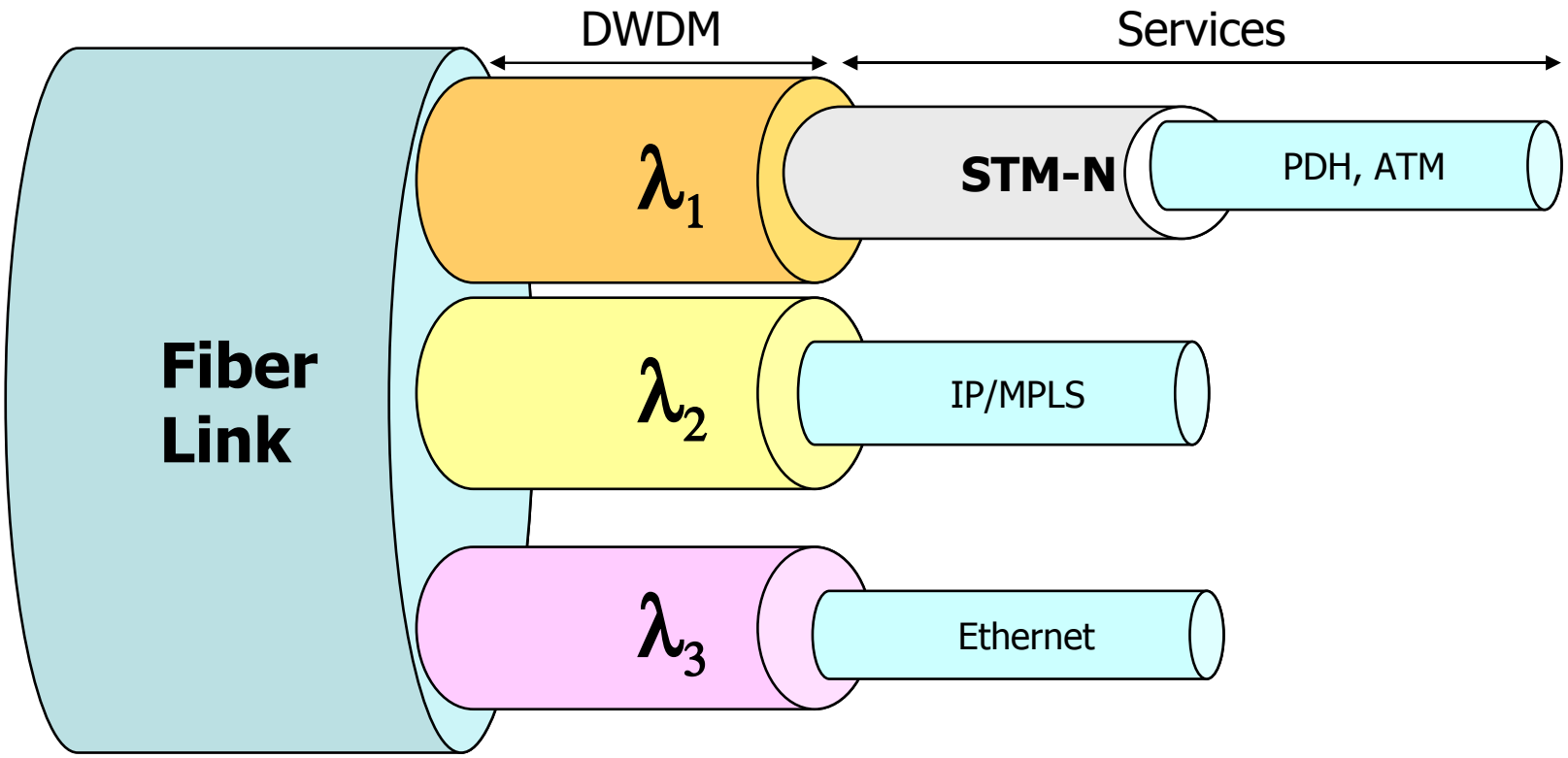
- Example ways of transporting IP packets over optical (WDM) networks via SDH/NG-SDH





5. Multiservice Optical Networks

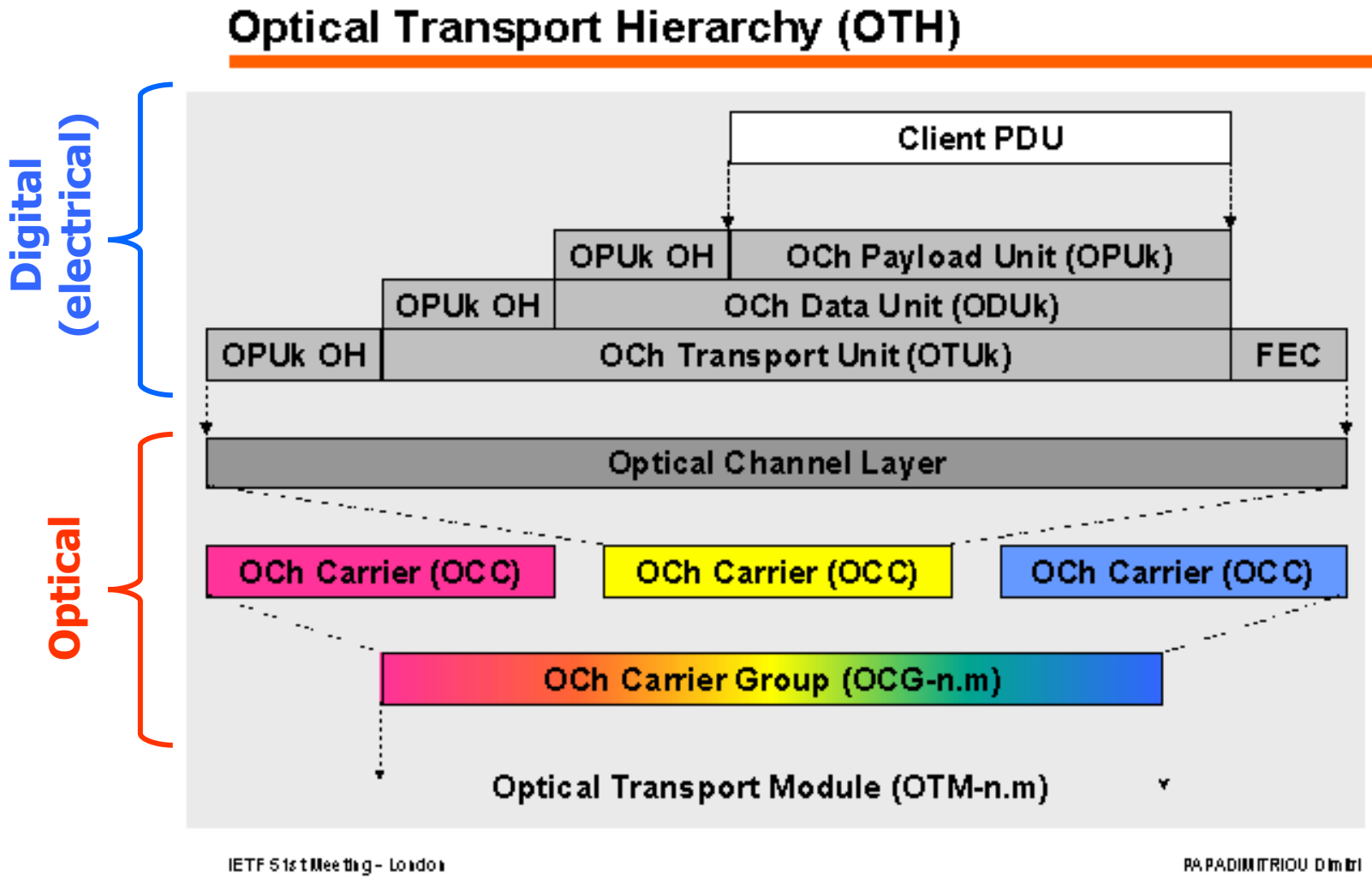
- Optical WDM network with open interfaces simplifies direct access to fiber capacity sharing by different clients



5. Multiservice Optical Networks

- Optical Transport Network (OTN) ITU-T G.709, G.872
  - Truly global standard unlike SDH/SONET
  - Enables SDH-like Operations, Administration, Maintenance and Provisioning for WDM networks
    - Reduces the requirement to run every service through SDH/SONET to benefit from the management features
  - More efficient multiplexing, provisioning, and switching of high-bandwidth (≥ 2.5 Gbit/s) services
  - Improved multivendor and inter-carrier interoperability
  - Forward error correction (FEC) from the beggining
  - Less complex than NG-SDH ⇒ easier to manage

5. Multiservice Optical Networks



5. Multiservice Optical Networks

- Multiservice provisioning platforms e.g. Cisco's ONS 15454

Cisco ONS 15454

- Supported interfaces
  - Electrical (DS1, E1, E3, STM-1E etc.)
  - SDH (up to STM-64)
  - CWDM and DWDM (OTN)
  - Ethernet (up to GbE)
  - SAN (Fiber Channel and FICON)
  - Video (D1 video, HDTV)
- Cross-connection levels
  - DS1/E1 up to STM-64

5. Multiservice Optical Networks

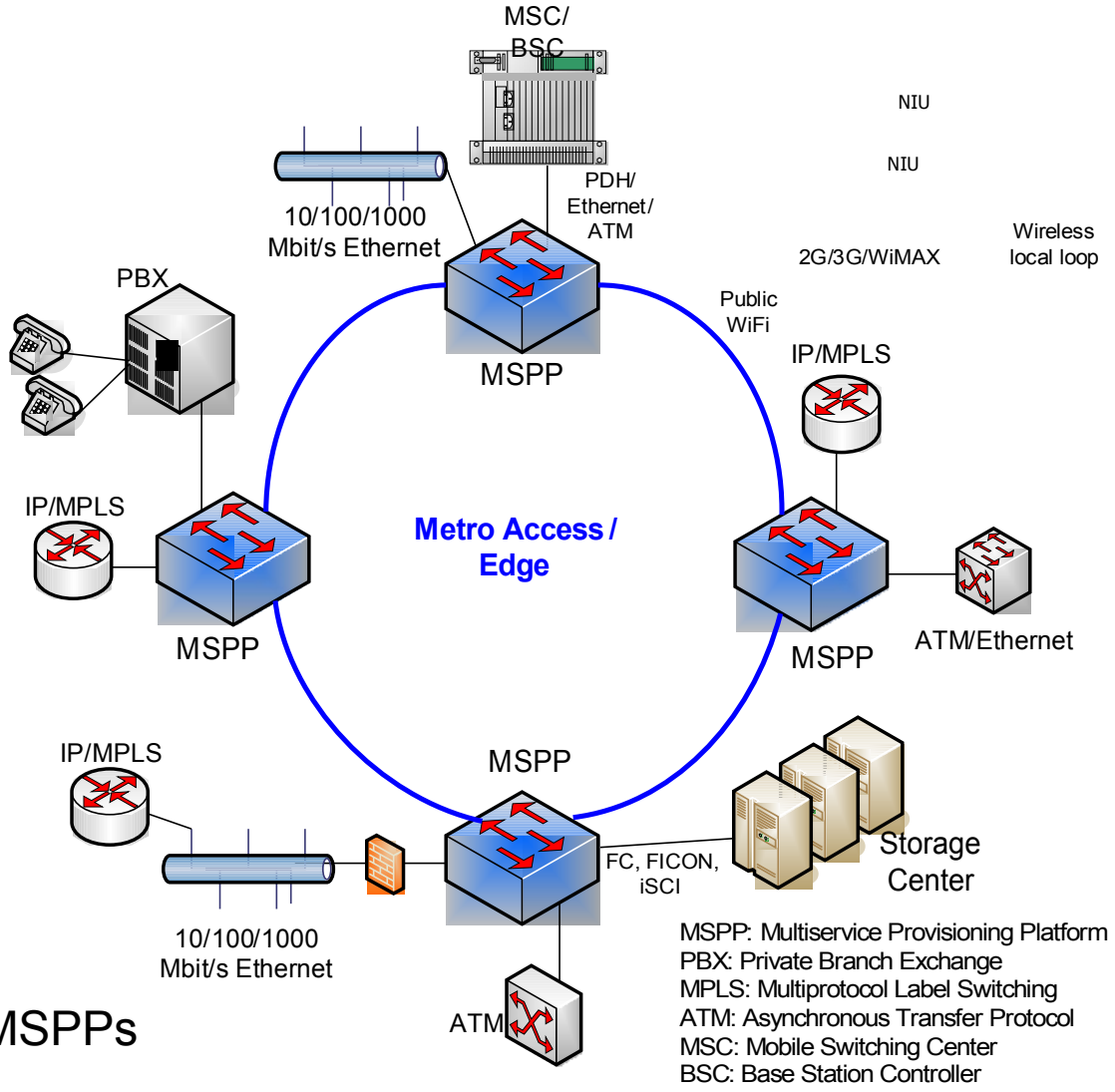
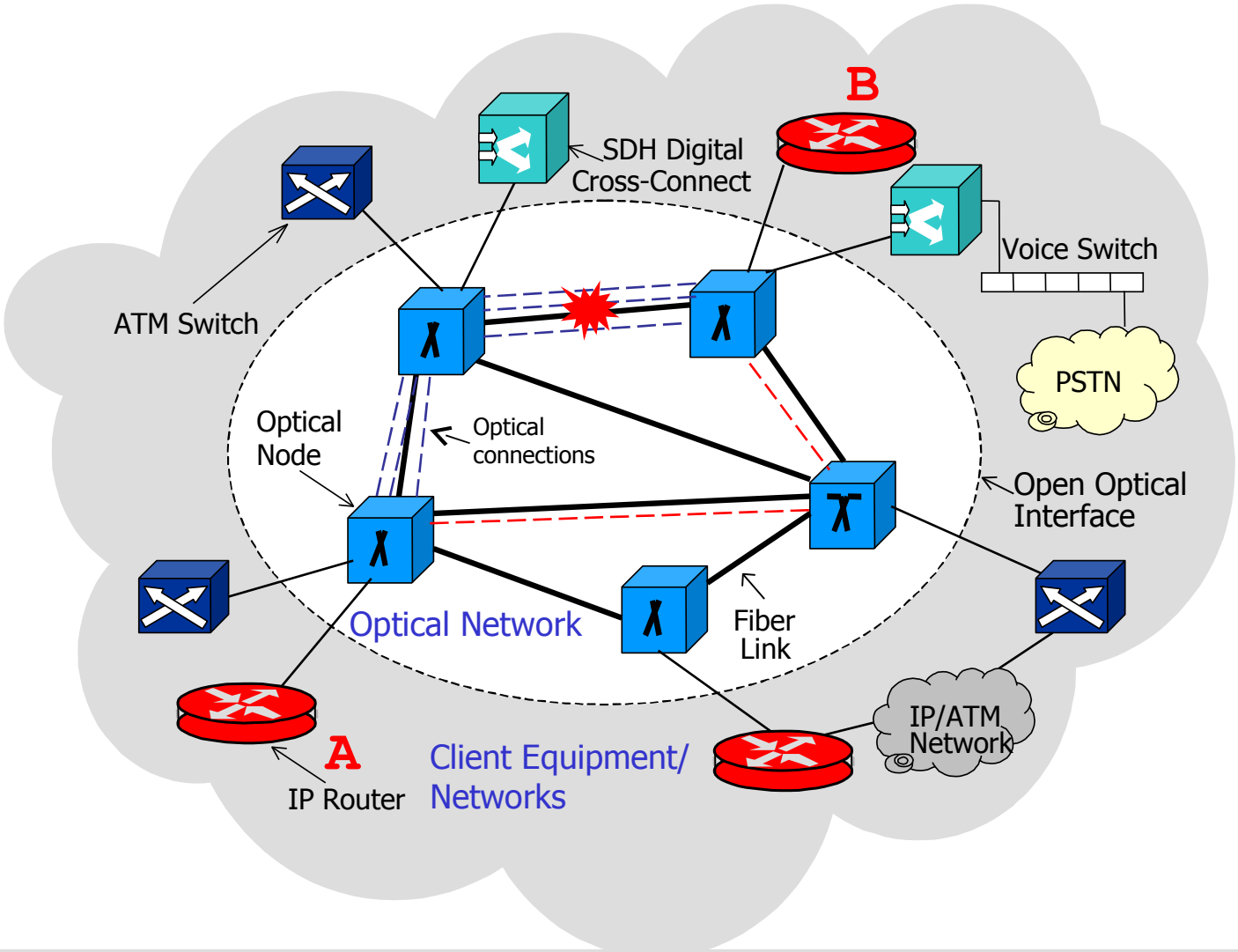


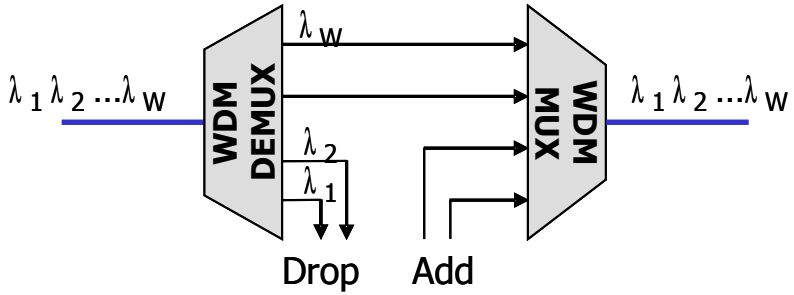
Figure: Example service mix supported by deployment of MSPPs

7. Optical Network Design



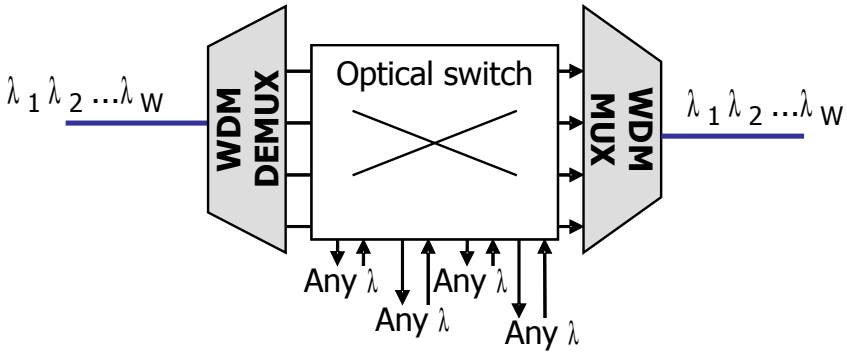
7. Optical Network Design

Example fixed OADM



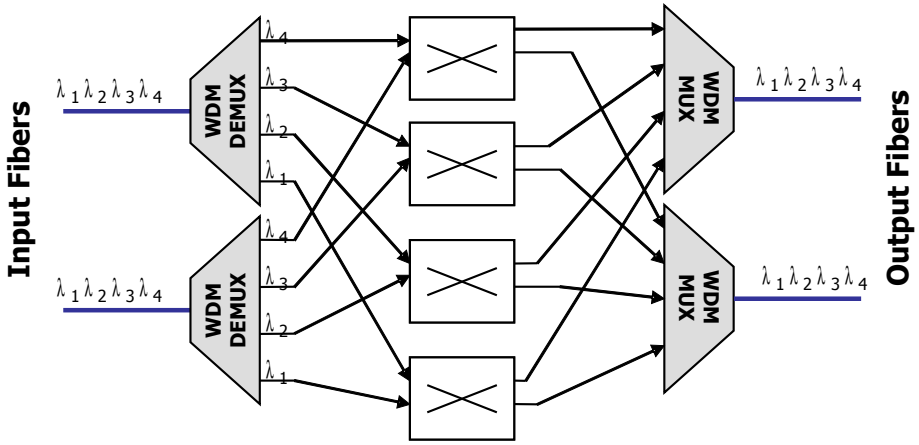
(a) Parallel

Example reconfigurable OADM



(b) Fully tunable OADM using a large multiport optical switch

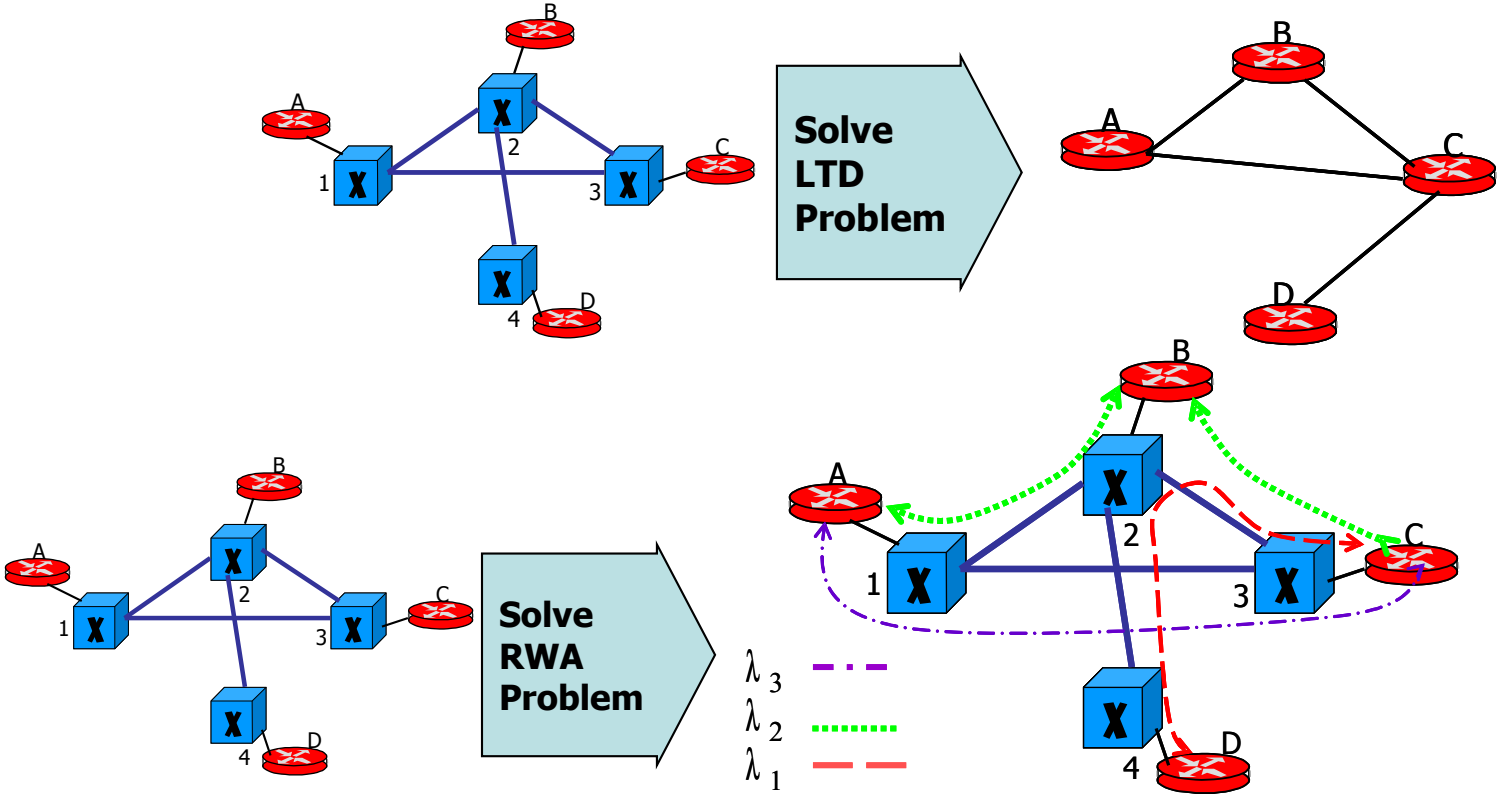
Example fixed OXC



The example OXC scaled to handle 4 wavelength channels on each fiber port

7. Optical Network Design

- A WDM network may be realized by solving:
  - Physical topology design (PTD) problem
  - Lightpath topology design (LTD) problem
  - Routing and wavelength assignment (RWA) problem



8. Test and Measurement

- Example: Acterna MTS-8000 Tester

Source: ACTERNA

Fiber characterization
- OTDR/Power meter
- CD/PMD Testing
- Connection checklist tester

CWDM/DWDM Testing
- OSA (OSNR, LED/laser/EDFA test)
- Q-factor meter

Digital Test Modules
- SDH (up to STM-64)
- PDH
- Ethernet (up to 10GbE)

Talk set (communication & file transfer)

Software tools (result post-processing, report generation)

8. Test and Measurement

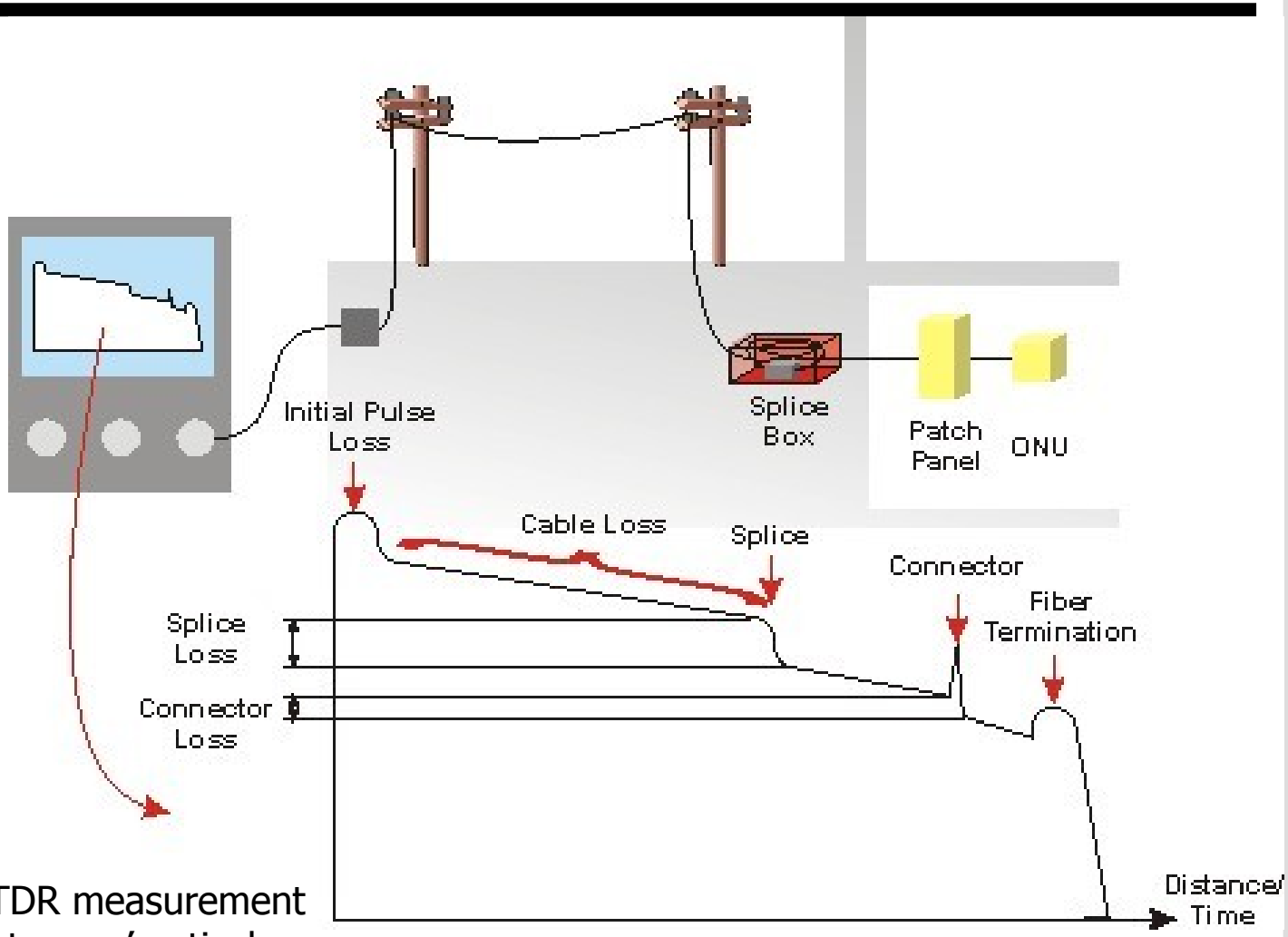
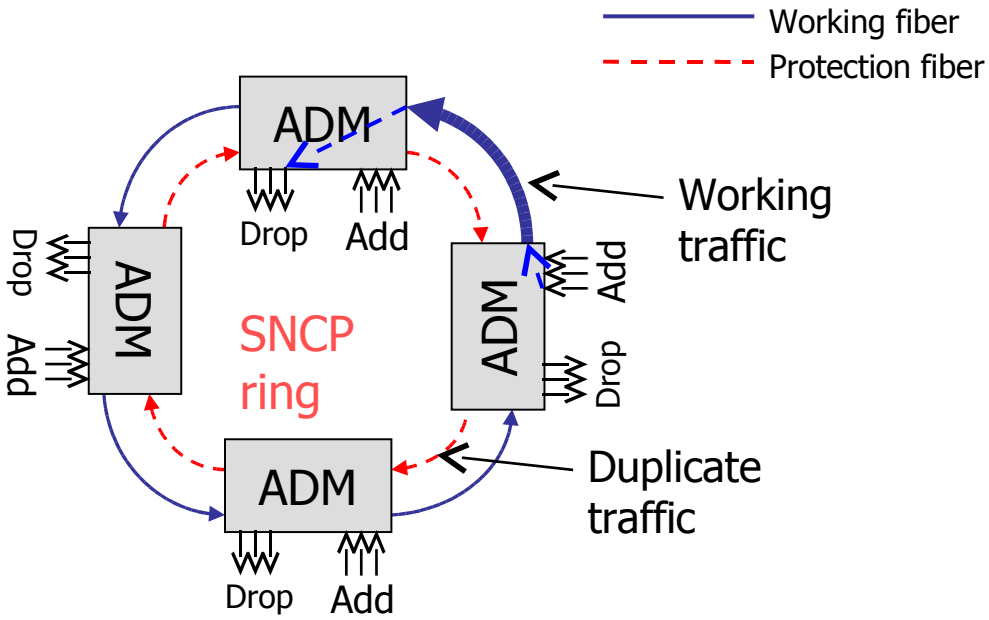


Figure: Example OTDR measurement for a fiber link to customers' optical termination unit (ONU)

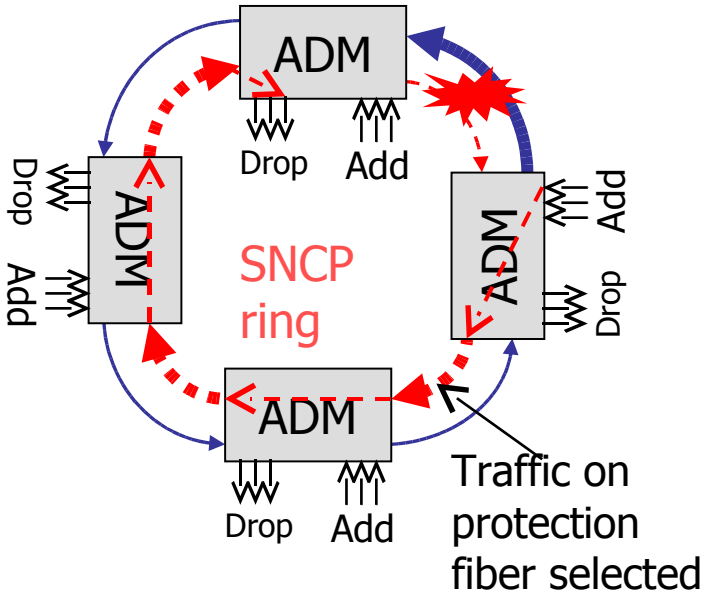
Source: "Introduction to Optical Communications," by L. Hart, Althos Publishing

9. Network Management and Survivability

- Subnetwork connection protection (SNCP) rings



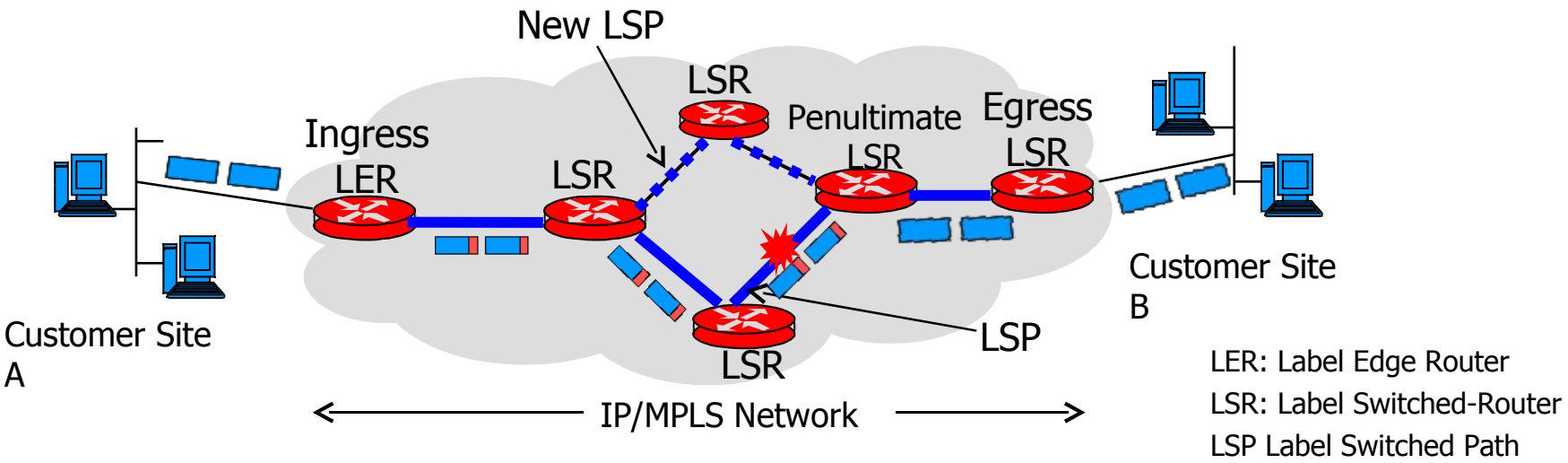
Before Failure



After Failure

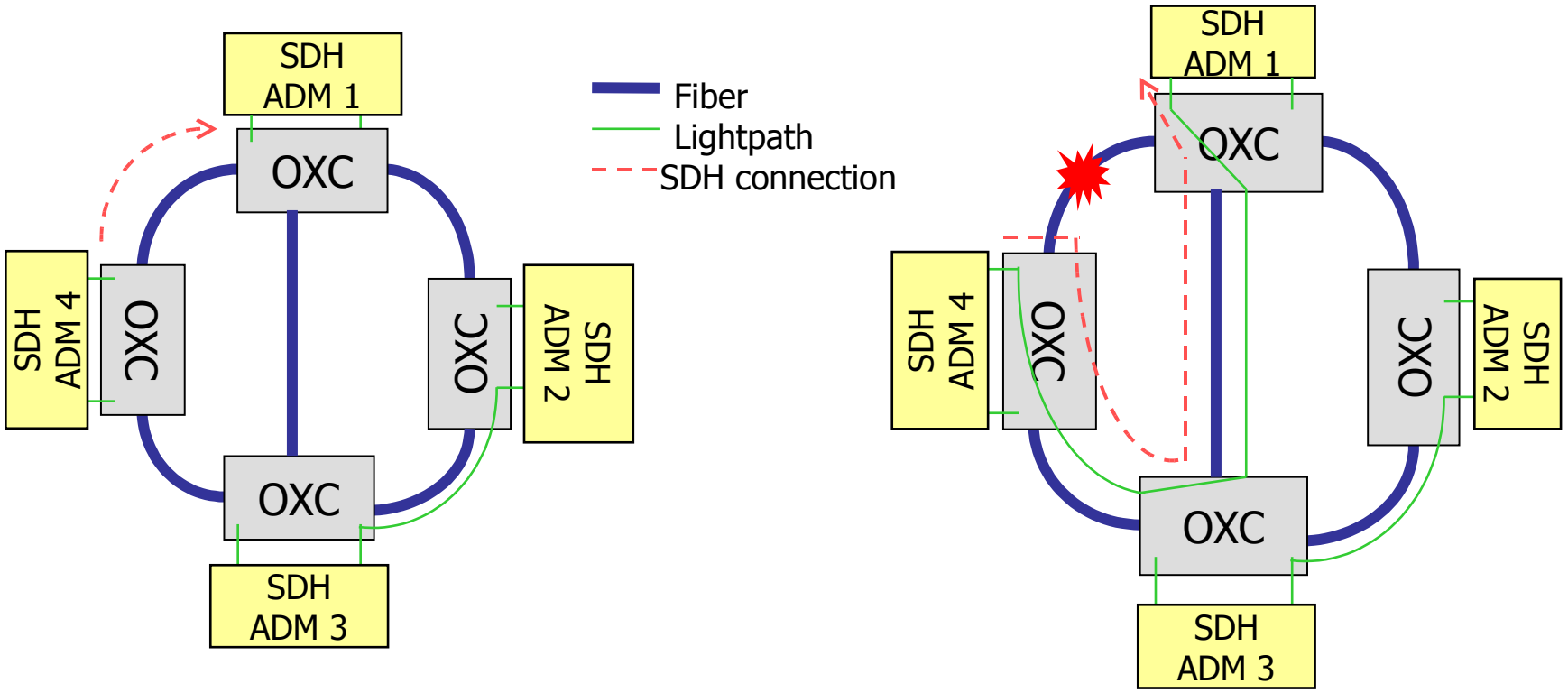
9. Network Management and Survivability

- IP/MPLS network protection schemes
  - When failure detected packets could be rerouted on new setup LSP



9. Network Management and Survivability

- Example of SDH protection involving optical layer



(a) Normal operation before failure. SDH connection realized using lightpaths provided by optical layer between ADMs

(c) Fiber fails and OXCs perform optical layer restoration and reroute lightpath. SDH carries on with normal operation awaiting another failure

9. Network Management and Survivability

- Classical network management constitutes "FCAPS" functions
  - Fault management: detecting failures and isolating failed component
  - Configuration management: managing orderly network changes e.g. equipment addition/removal
  - Accounting management: billing and developing component lifetime histories
  - Performance management: monitoring and managing various network performance metrics
  - Security management: user authentication, control access to network elements, user data protection etc.
  - Safety management: (specifically for optical networks) ensure that optical radiation conforms to eye safety requirements.

9. Network Management and Survivability

- Interaction between optical and client layers (IP, SDH etc.) is important aspect of connection management protocols
- Different control plane models proposed for interconnecting optical layer control plane and client layer control plane
  - Overlay model
  - Overlay+ model
  - Augmented (dynamic overlay) model
  - Peer model

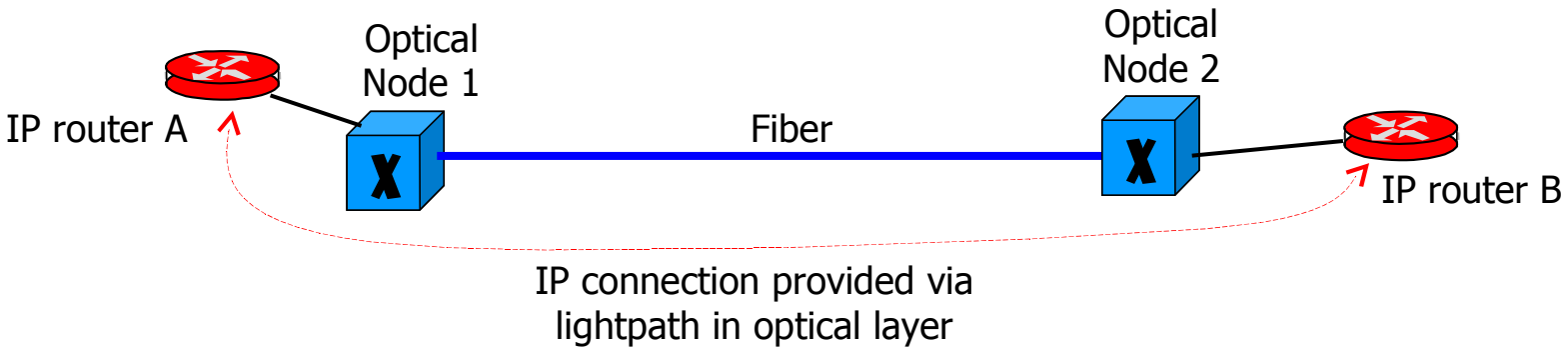


Figure: Example of client layer connection provision via the optical layer

10. Deployment Considerations

- Selected fiber cable deployment method depends on various factors
  - Geographical topography of an area
  - Availability of rights-of-way
  - Time constraints
  - Operator's business strategy

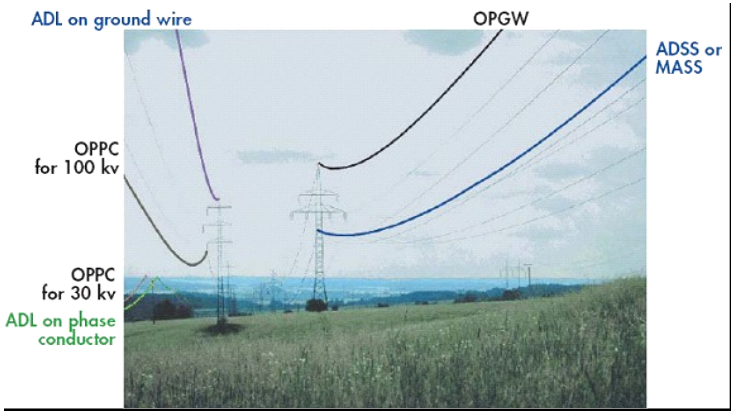
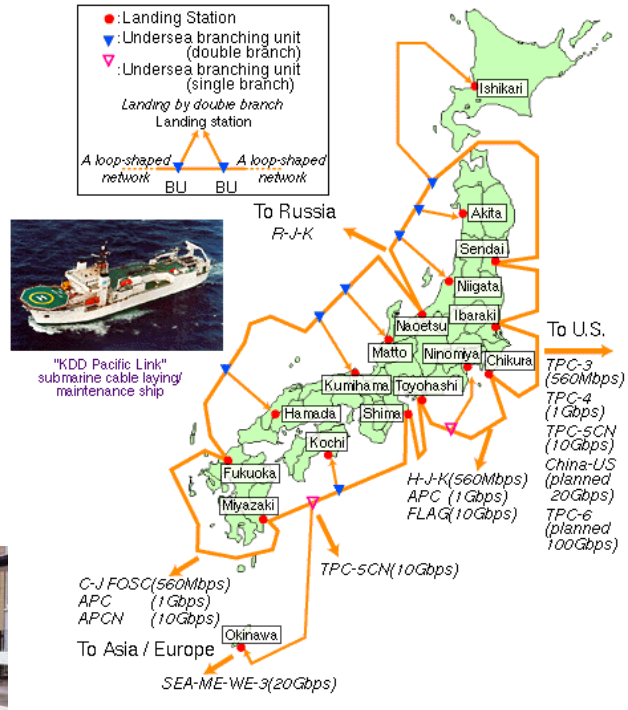


Figure: Fiber cables deployed on power transmission lines (source: Alcatel)



10. Deployment Considerations

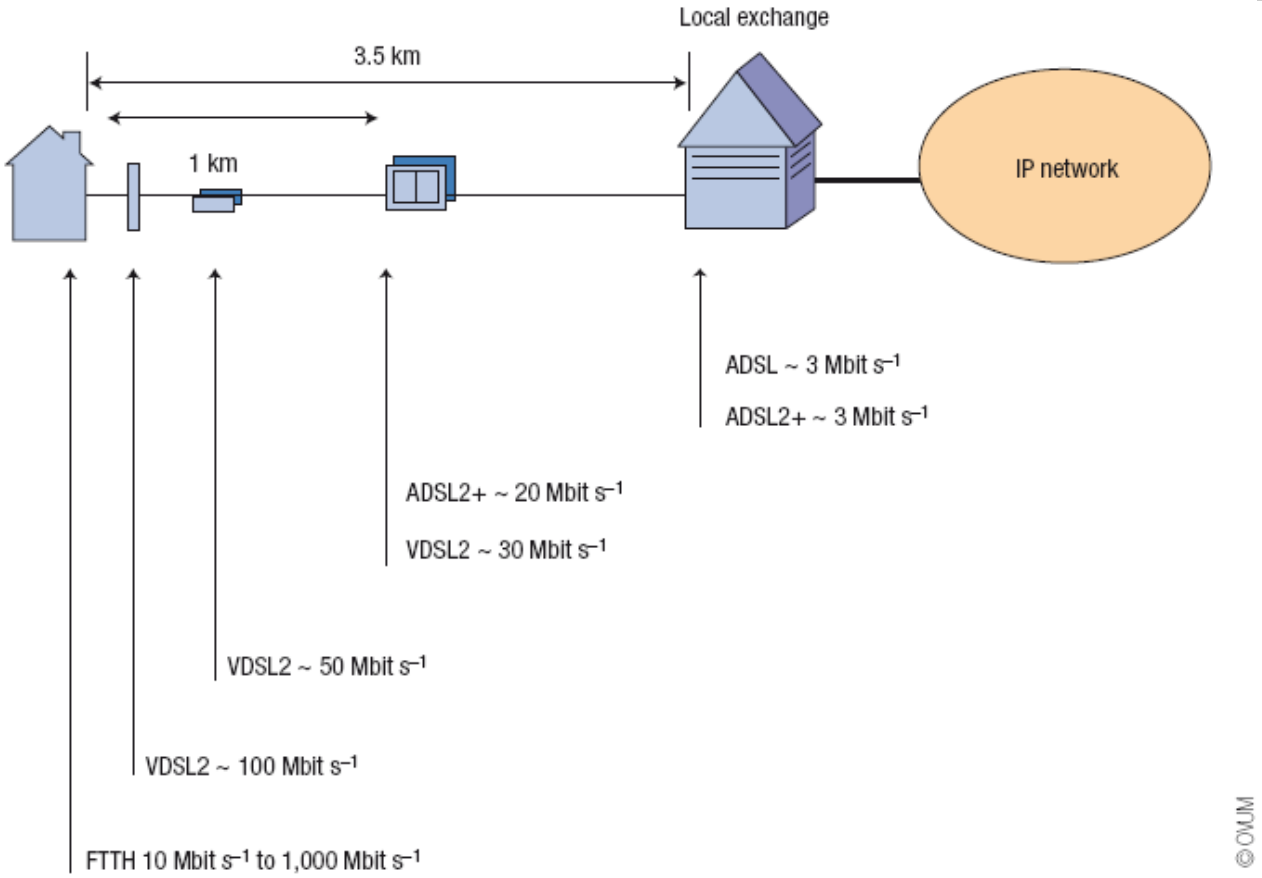


Figure 1 Decreasing copper-loop lengths, increasing bandwidth. Fibre-to-the-home (FTTH) provides a bandwidth pipe that is capable of providing data-transfer speeds of 10 to 1,000 Mbit s^{-1} direct to the user. In contrast, VDSL and ADSL technologies that use existing telephone wiring are limited both in terms of their transmission distance and data speeds. IP stands for Internet protocol.

10. Deployment Considerations

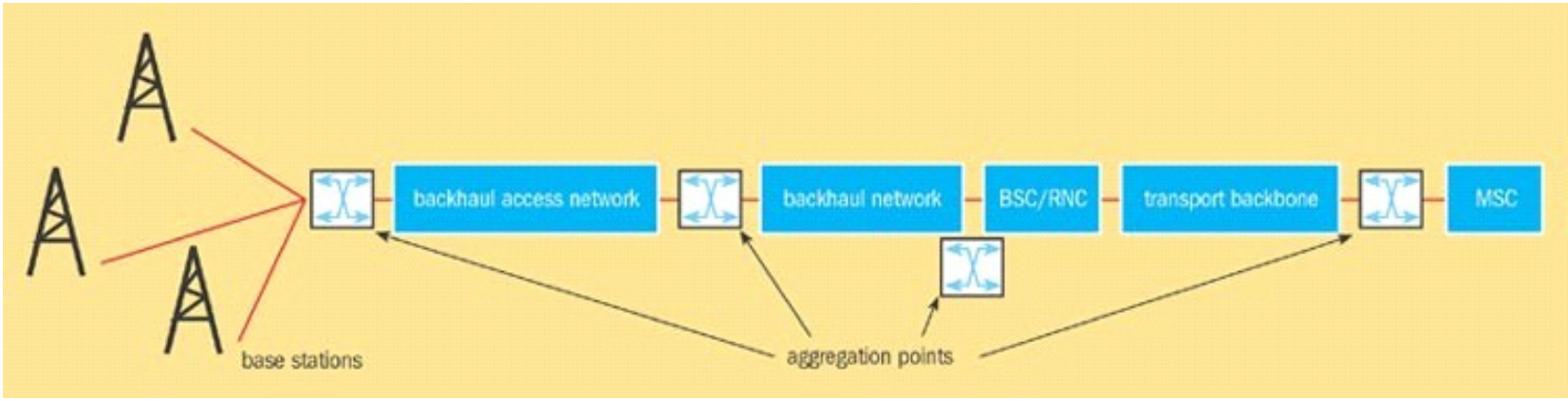
- Fiber-optic communications now used in diverse areas

2006 BMW X5

Flexray

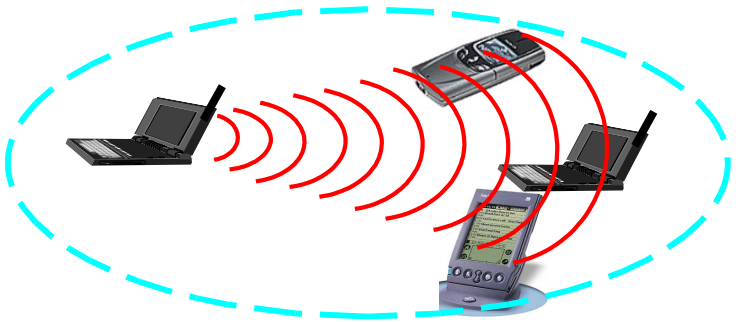
- Example: Avionics Full-Duplex Ethernet/ARINC 664 standard
  - 10 Mb/s (Copper), 100 Mb/s (Copper or Fiber), GbE (future)
  - Planned for A380s, 787s

Airbus A380



10. Deployment Considerations

- Wireless or free space optics communications now also available



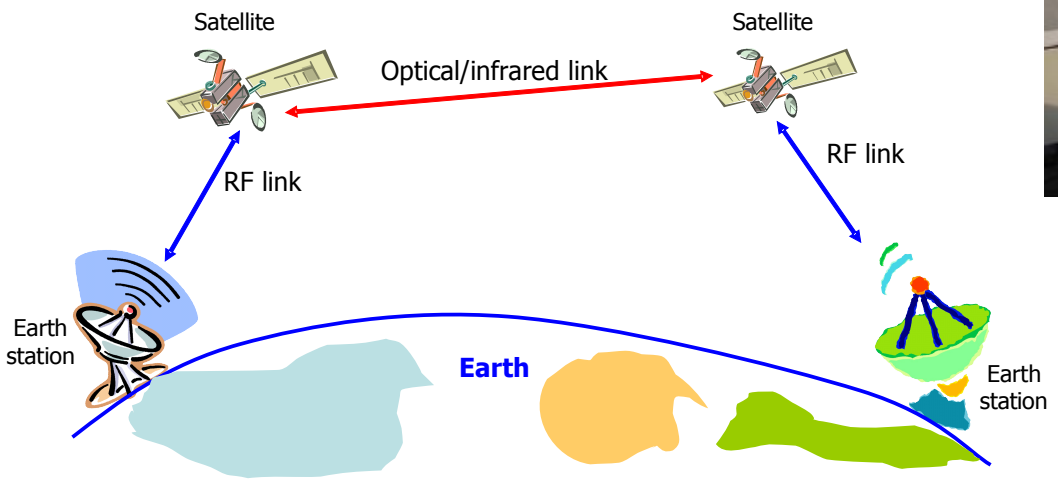
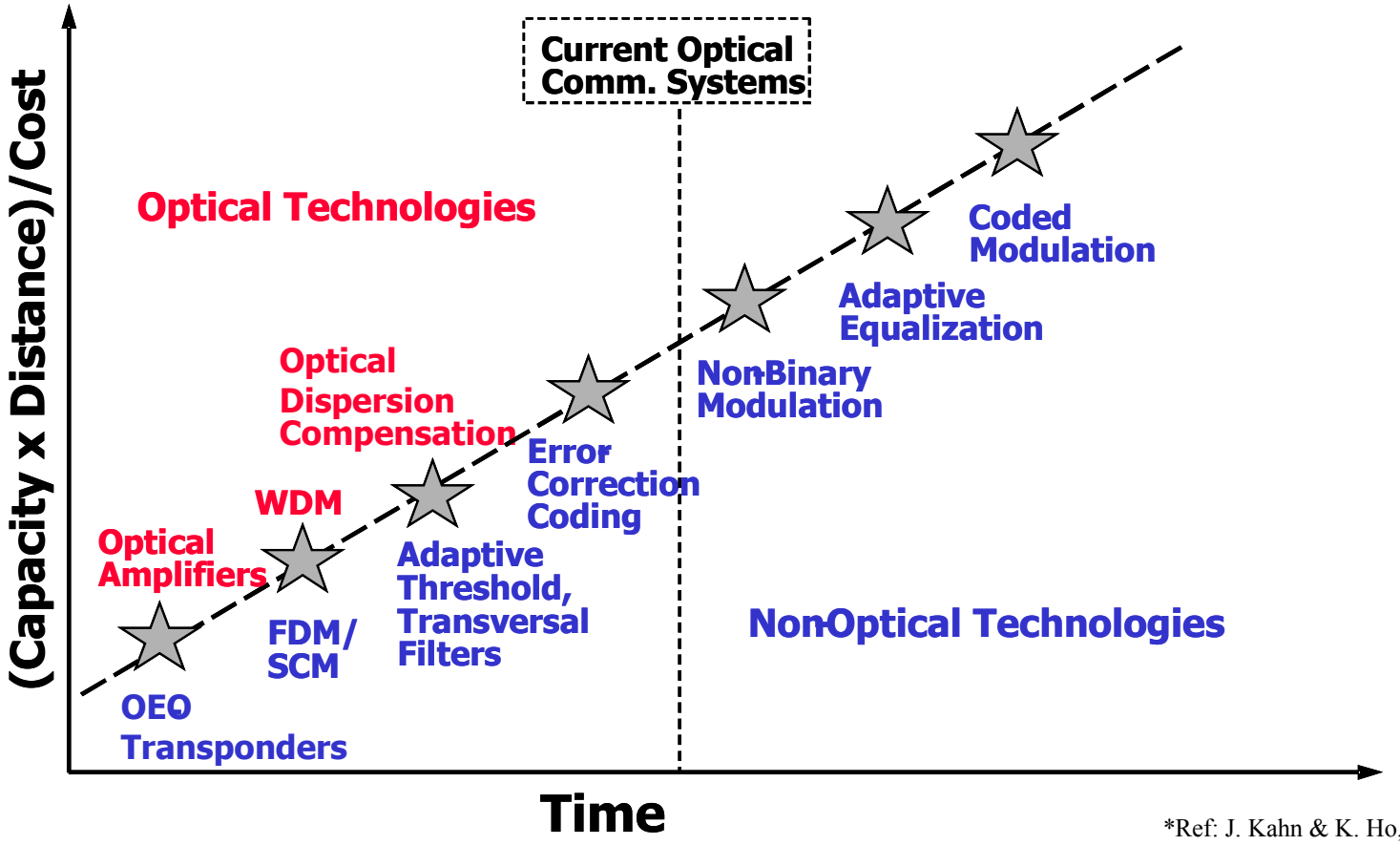


Figure: Rooftop FSO installation

Sources: Waseda University, Hamamatsu Photonics, IEEE/ConTEL conference

11. Future Directions of Optical Net.



*Ref: J. Kahn & K. Ho, Proceedings of SPIE, Vol. 4872, July 2005

11. Future Directions of Optical Net.

- Still need for optical digital signal processing (> 40 Gb/s) with photonic integrated circuits

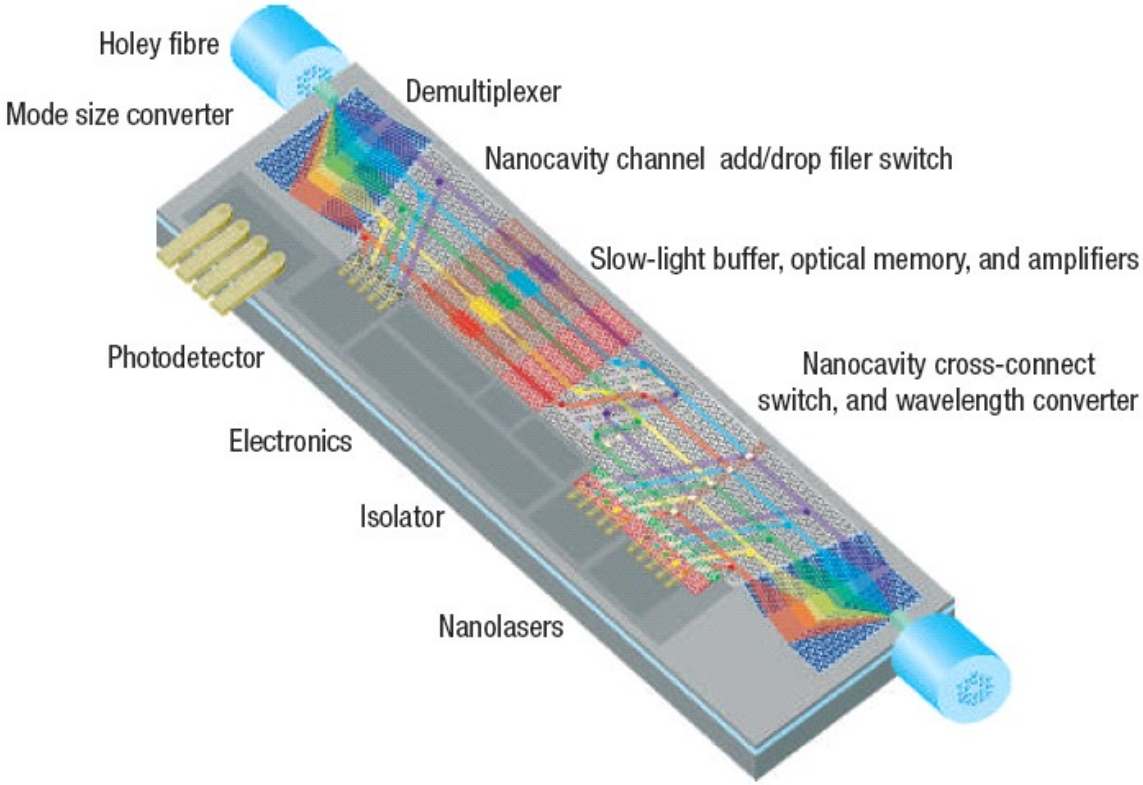


Figure: A typical photonic crystal PIC envisioned for the future (source: Nature Photonics, pp. 11, Jan 2007).

About the Exam

- **Please note that YOU CAN ONLY DO ONE(1) EXAM. That is if you do Exam A, you will not do Exam B, OR if you do Exam B you will not do Exam A.**
  - **Exam A: Day: Ma/Mon 14.05.2007, Time: 13-16, Place: S1,S4**
  - **Exam B: Day: Ke/Wed 16.05.2007, Time: 16-19, Place: S4**
- Each exam will have five questions, whereby Question 1 is compulsory, and you can choose to do any three out of Questions 2 to 5.

Thank You and Good luck!