OPTICAL NETWORKING

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OPTICAL NETWORKING

❖ OUTLINE

- Introduction
- First Generation Optical Networks
  - Fiber Distributed Data Interface (FDDI)
  - Synchronous Optical Network/Synchronous Digital Hierarchy (SONET/SDH)
- Second Generation Optical Networks
  - Wavelength Division Multiplexing (WDM)
  - Optical Networking Components
  - Wavelength Routing Networks

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OPTICAL NETWORKING

❖ INTRODUCTION-ONE

- ❖ Advantages of Optical Transmission
  - ❖ Large bandwidth permits high data transmission, which also supports the aggregation of voice, video, and data
  - ❖ Technological improvements are occurring rapidly, often permitting increased capacity over existing optical fiber
  - ❖ Immunity to electromagnetic interference reduces bit error rate and eliminates the need for shielding within or outside a building
  - ❖ Glass fiber has low attenuation, which permits extended cable transmission distance
  - ❖ Light as a transmission medium provides the ability for the use of optical fiber in dangerous environments
  - ❖ Optical fiber is difficult to tap, thus providing a higher degree of security than possible with copper wire
  - ❖ Light weight and small diameter of fiber permit high capacity through existing conduits

OPTICAL NETWORKING
❖ INTRODUCTION-TWO

- ❖ Disadvantages of Optical Transmission
  - ❖ Cable splicing:
    - ❖ Welding or fusing: you must clean each fiber end, then align and carefully fuse the ends using an electric arc.
      - ❖ Time consuming
      - ❖ Least amount of signal loss between joined elements.
    - ❖ Gluing
      - ❖ Bonding material that matches the refractive index of the core of the fiber.
      - ❖ Time consuming
      - ❖ Higher loss of signal power than fusing.
    - ❖ mechanical connectors
      - ❖ Considerably facilitate the joining of fibers,
      - ❖ More signal loss than do the other two methods
      - ❖ Can reduce the span of the fiber to a smaller distance.

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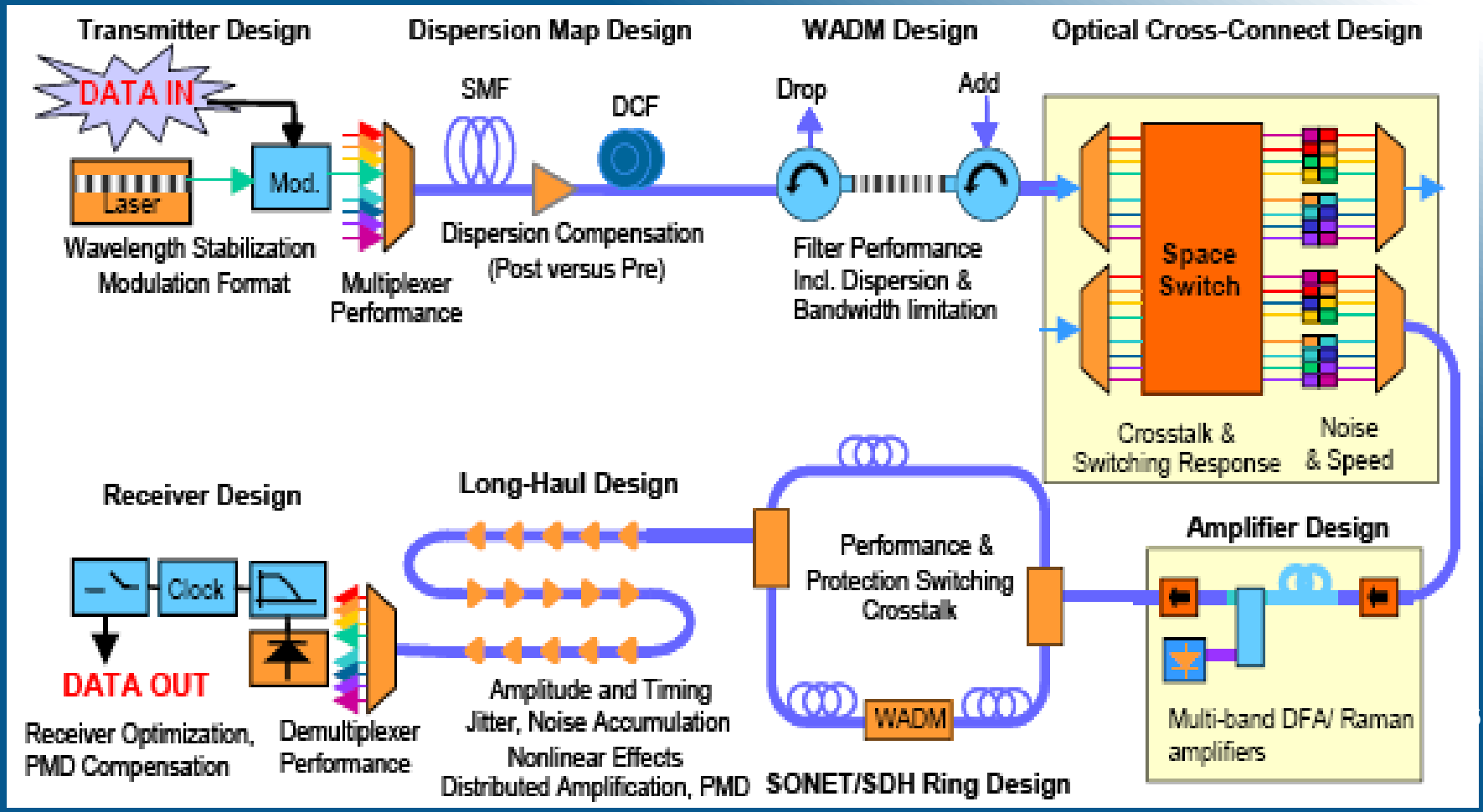
- INTRODUCTION-THREE
  - Schematic Outline of Optical Network



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- FIRST GENERATION OPTICAL NETWORKS

OPTICAL NETWORKING

- FIBER DISTRIBUTED DATA INTERFACE (FDDI)

- Dates back to the early 1980s
- FDDI uses token-passing scheme
- Uses two fiber pairs, each operating at 100 Mbits/s.
- Data rates approaching 90% of its 100 MB/s operating rate
- FDDI was, and in some locations still is, commonly used at the Internet Service Provider (ISP) peering points that provide interconnections between ISPs.
- Relatively expensive

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❖ FIBER DISTRIBUTED DATA INTERFACE (FDDI)

- ❖ FDDI is defined as the two bottom layers of the seven-layer OSI reference model
- ❖ It provides a transport facility for higher-level protocols such as TCP/IP

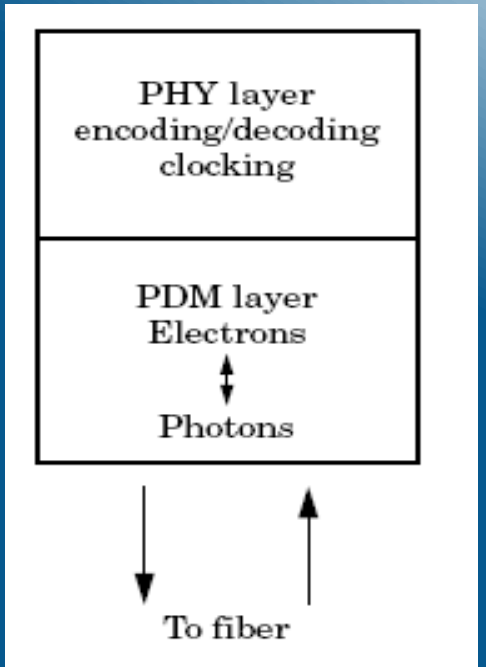
OSI Reference Model

7	Application
6	Presentation
5	Session
4	Transport
3	Network
2	Data Link
1	Physical

- Physical layer is subdivided into:
  - physical-medium-dependent (PMD) sublayer defines the details of the fiber-optic cable used
  - the physical (PHY) layer specifies encoding/decoding and clocking operation

LAN Standards

FDDI	Ethernet	Token Ring



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FDDI 4B/5B CODING

- The selection of the 4B/5B coding was based on the need to reduce the signaling level from 200 MHz to a 125-MHz rate (cost reduction)
- Each bit is encoded using non-returnto-zero-inversion (NRZI) transmission
- Because 4 bits are encoded into 5 bits, this means there are 16, 4-bit patterns.
- Those patterns were selected to ensure that a transition is present at least twice for each 5-bit code.
  - DC balance: important for thresholding at receiver
  - For some input data sequences the worst case DC unbalance is 10%
- Because 5-bit codes are used, the remaining symbols provide special meanings or represent invalid symbols.
- Special symbols
  - I symbol is used to exchange handshaking between neighboring stations,
  - J and K symbols are used to form the Start Delimiter for a packet,
    - which functions as an alert to a receiver that a packet is arriving

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FDDI FIBER SPECIFICATIONS

- **OPTICAL FIBER SUPPORT**
  - FDDI can support **62.5/125**-, 50/125-, and 100/140-µm multimode fiber sizes. Maximum distance 2 Km.
  - FDDI also supports the use of single-mode fiber,
  - Long-distance transmission (up to 40 Km)
  - FDDI single-mode fiber is commonly specified as 8/125, 9/125, and 10/125.
- **OPTICAL TRANSMITTER**
  - 850, 1300, and 1550 nm
  - 850 and 1300 nm for multimode fiber
  - 1300 and 1500 nm for single-mode fiber
  - For single-mode fiber laser diodes must be used
- **ATTENUATION**
  - For multimode fiber
  - PMD standard specifies a power budget of 11.0 dB
  - Maximum cable attenuation is 1.5 dB/km at 1300 nm.
  - single-mode fiber
  - power budget extends from 10 to 32 dB

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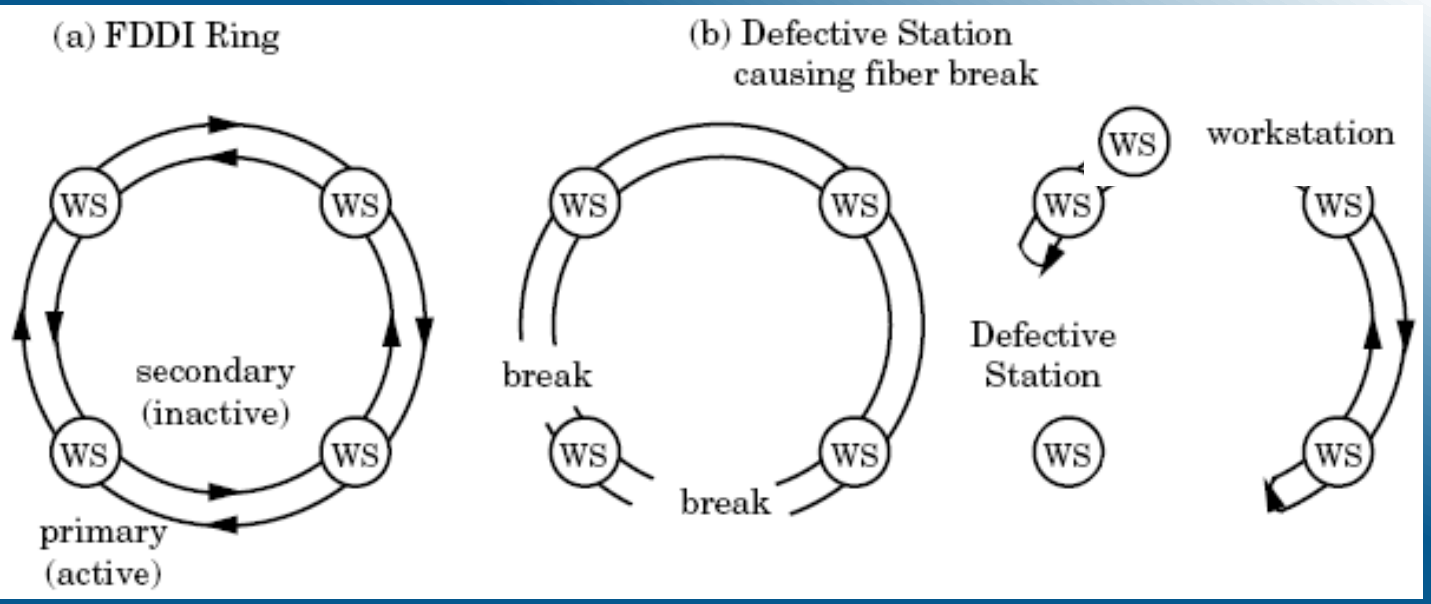
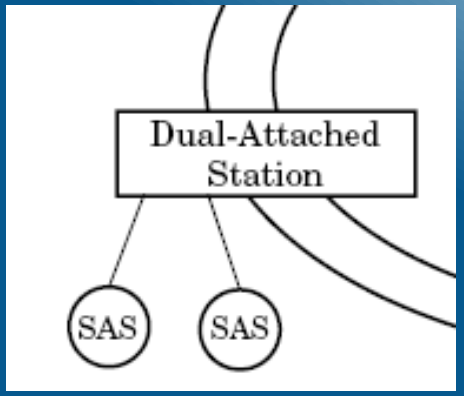
- FDDI RING STRUCTURE



- FDDI backbone consists of two separate fiber-optic rings,
  - *primary ring:* active
  - *secondary ring:* "on hold,"
- Station Types
  - Class A:dual-attachment stations, Class B: single-attachment station.



OPTICAL NETWORKING

- SONET/SDH(1)

  DESIGN IDEAS OF SONET

- **S**ynchronous **O**ptical **NET**work
- Designed for ***optical*** transport (high bitrate)
- **Direct** mapping of lower levels into higher ones
- Carry all PDH types in **one** universal hierarchy
  - ITU version = **S**ynchronous **D**igital **H**ierarchy
  - different terminology but interoperable
- Overhead doesn't increase with rate
- OAM designed-in from beginning

OPTICAL NETWORKING

❖ SONET/SDH(1)
STANDERDIZATION

The original Bellcore proposal:

- hierarchy of signals, all multiple of basic rate (50.688)
- basic rate about 50 Mbps to carry DS3 payload
- bit-oriented mux
- mechanisms to carry DS1, DS2, DS3

Many other proposals were merged into 1987 draft document (rate 49.920)

In summer of 1986 CCITT express interest in cooperation

- needed a rate of about 150 Mbps to carry E4
- wanted byte oriented mux

Initial compromise attempt

- byte mux
- US wanted 13 rows * 180 columns
- CEPT wanted 9 rows * 270 columns

Compromise!

- US would use basic rate of 51.84 Mbps, 9 rows * 90 columns
- CEPT would use three times that rate - 155.52 Mbps, 9 rows * 270 columns

OPTICAL NETWORKING

- SONET/SDH(1)

- Current transmission and multiplexing standard for high speed signals
  - North America: Synchronous Optical Network (SONET)
  - Europe, Japan and rest of the world: Synchronous Digital Hierarchy (SDH)
- Prior to SONET and SDH: Plesiochronous Digital Hierarchy (PDH)
  - 4KHz sampled at 8KHz quantized at 8 bits per sample → 64kb/s

Transmission rates for PDH

Level	North America [Mb/s]		Europe [Mb/s]		Japan [Mb/s]
0	DS0	0.064		0.064	0.064
1	DS1/T1	1.544	E1	2.048	1.544
2	DS2/T2	6.312	E2	8.448	6.312
3	DS3/T3	44.736	E3	34.368	32.064
4		139.264	E4	139.264	97.728

OPTICAL NETWORKING

SONET/SDH(2)

- PDH versus SONET/SDH
  - Multiplexing
    - PDH: Difficult to pick low bit rate stream from high bit rate stream
    - In PDH, clocks of lower bit streams are not perfectly synchronous
      - Higher rates are not integral multiples of 64Kb/s
        - Bit stuffing needed
        - Mulltiplexers and Demultiplexers complicated
    - In SONET/SDH a master clock is used→MUX and DEMUX much easier
  - Management
    - Unlike PDH, SONET/SDH standards are rich of management and traffic performance monitoring information
  - Interoperability
    - SONET/SDH define standard optical interfaces
    - PDH: different vendors define different line coding, optical interfaces,...
  - Networking
    - SONET/SDH: Service restoration time is less than 60 ms
    - PDH: restoration time is several seconds to minutes

OPTICAL NETWORKING

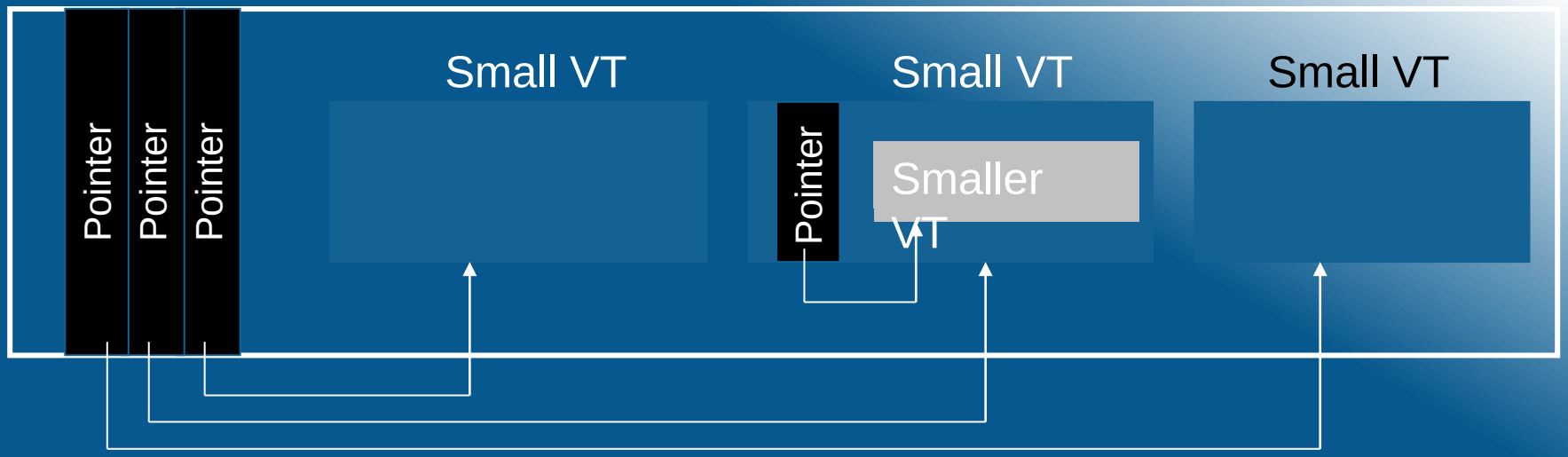
SONET/SDH(3)

- SONET/SDH
  - Lower speed PDH is mapped into *synchronous payload envelope* (SPE), or *synchronous container* in SDH
  - Path overhead bytes are added to the SPE
    - Path overhead unchanged during transmission
    - Allows PDH monitoring end-to-end
  - SPE+path overhead = *virtual tributary* VT (*container* in SDH)
  - VT may be placed at different points within a frame (125 *μs*)
  - Many small VTs can be multiplexed into a larger VT (see next slide)
  - The overhead of each VT includes a pointer to smaller VTs multiplexed into the payload of the larger VT
  - This hierarchical structure simplifies extraction of low speed stream from high speed stream

OPTICAL NETWORKING

- SONET/SDH(4)

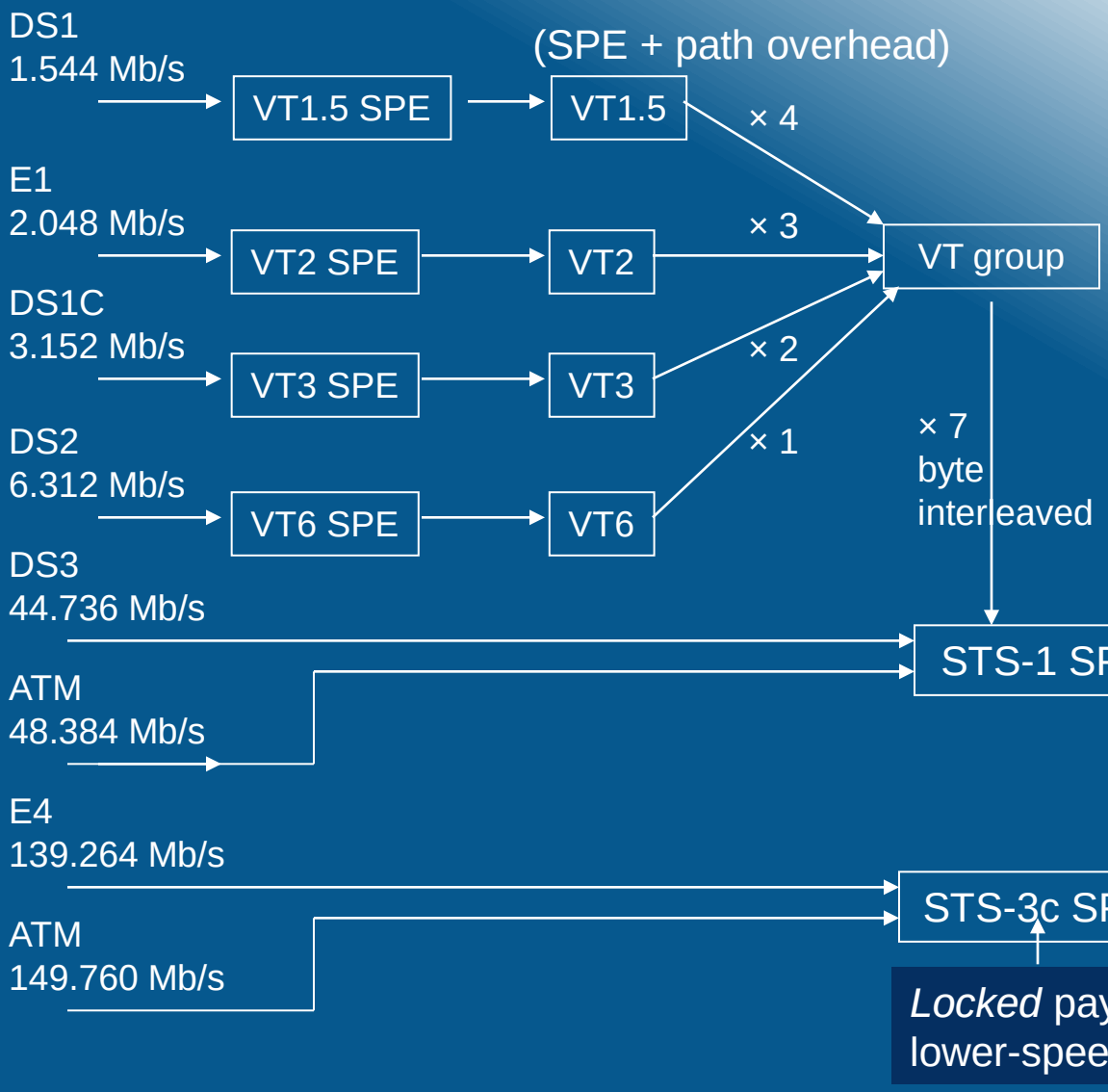
Hierarchical multiplexing structure employed in SONET and SDH



- In SONET: VTs with four sizes
  - VT1.5, VT2, VT3, VT6 that carry 1.5, 2, 3, 6 Mb/s PDH streams
  - VT group = 4 VT1.5s or 3 VT2s or 2 VT3s or a single VT6
  - Basic SONET SPE (STS-1) = 7 VT groups = 51.84 Mb/s
  - STS-*N* = *N* × STS-1 (byte interleaved) *STS = Synchronous Transport Signal*
  - STM-*1* = *synchronous Transport Module* = 155 MB/s

OPTICAL NETWORKING

- SONET/SDH(5)



OC for Optical Carrier

SONET Signal	SDH signal	Bit rate [Mb/s]
STS-1		51.84
STS-3 (OC-3)	STM-1	155.52
STS-12 (OC-12)	STM-4	622.08
STS-24		1244.16
STS-48 (OC-48)	STM-16	2488.32
STS-192 (OC-192)	STM-64	9953.28

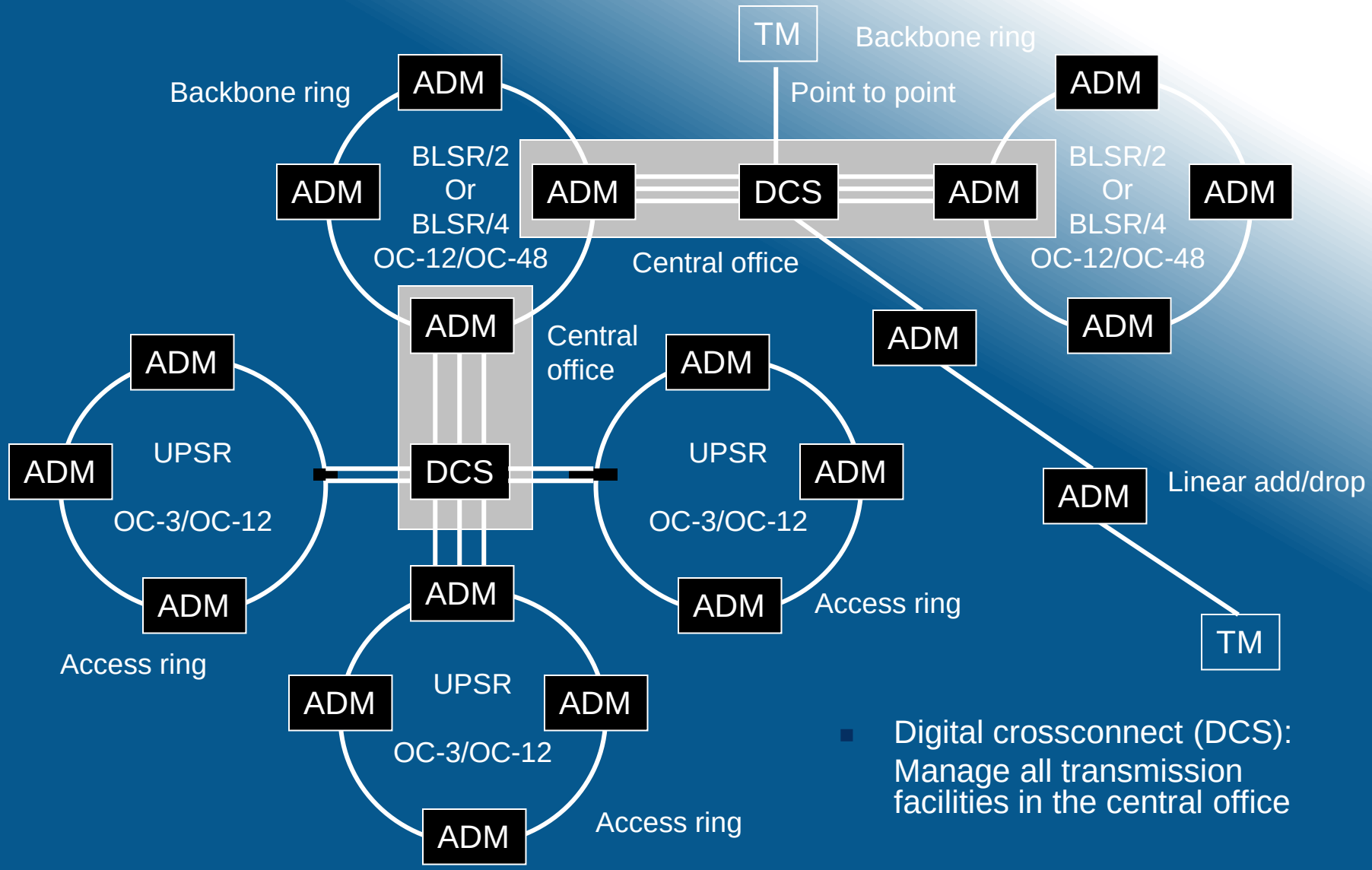
OPTICAL NETWORKING

- SONET/SDH(6)

- SONET/SDH network configurations
  - Point-to-point
    - Node at ends
      - Terminal Multiplexers (TM)
      - Line Terminating Equipment (LTE)
  - Linear
    - Inserting add/drop multiplexers (ADM) between TM in point-to point-links.
    - Allows insertion or extraction of smaller traffic at mid-points
  - Rings
    - ADM with added function of protection: High level of availability
    - Unidirectional path-switched rings (UPSRs)
    - Bidirectional line-switched rings (BLSRs)
      - Two fibers BLSR/2, four fibers BLSR/4

OPTICAL NETWORKING

- SONET/SDH(7)



- Digital crossconnect (DCS): Manage all transmission facilities in the central office

OPTICAL NETWORKING

- SONET/SDH(8)

  SONET/SDH LAYERS(1)

- Path layer: End-to-end connections
- Line layer:
  - Multiplexes a numer of path-layer connection into a single link
  - Responsible for protection switching
- Section layer: Links consist of sections
  - Present at each regenerator

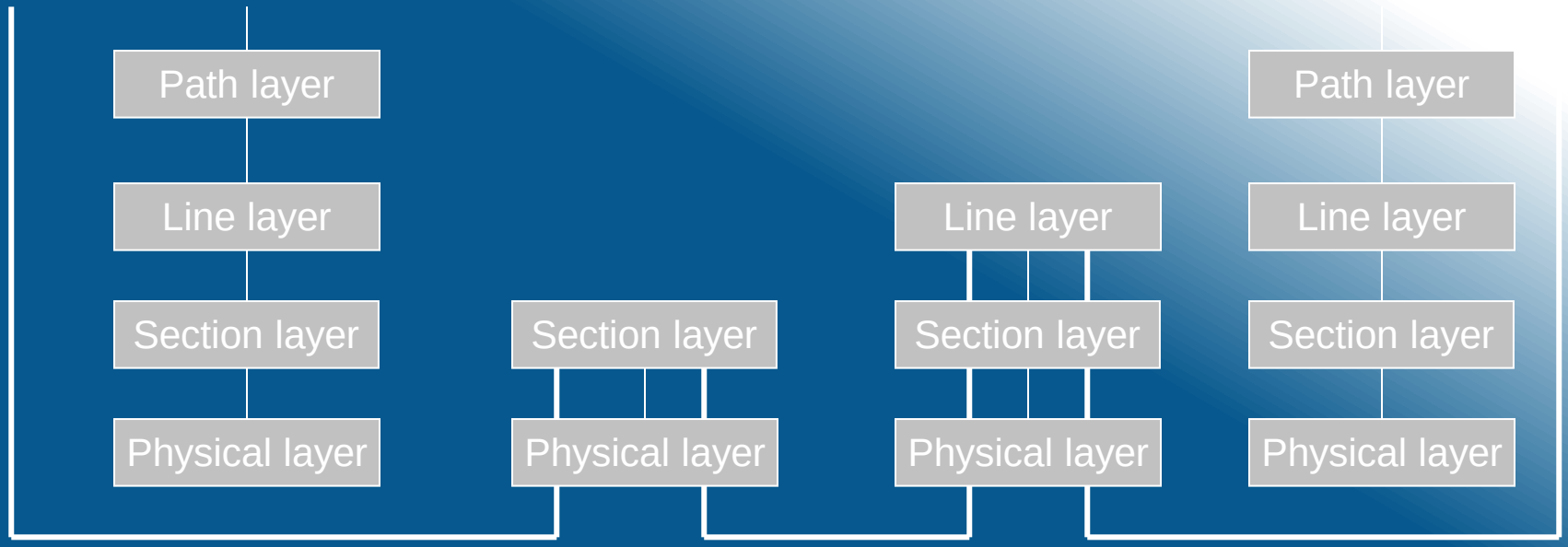
OPTICAL NETWORKING

- SONET/SDH(8)
  SONET/SDH LAYERS(2)

- SONET was designed with definite layering concepts
- Physical layer – optical fiber (linear or ring)
  - when exceed fiber reach – regenerators
  - regenerators are not mere amplifiers,
  - regenerators use their own overhead
  - fiber between regenerators called section (regenerator section)
- Line layer – link between SONET muxes (**A**dd/**D**rop **M**ultiplexers)
  - input and output at this level are **V**irtual **T**ributaries (**VC**s)
  - actually 2 layers
    - lower order VC (for low bitrate payloads)
    - higher order VC (for high bitrate payloads)
- Path layer – end-to-end path of client data (tributaries)
  - client data (payload) may be
    - PDH
    - ATM
    - packet data

OPTICAL NETWORKING

- SONET/SDH(9)
  - SONET/SDH LAYERS(3)

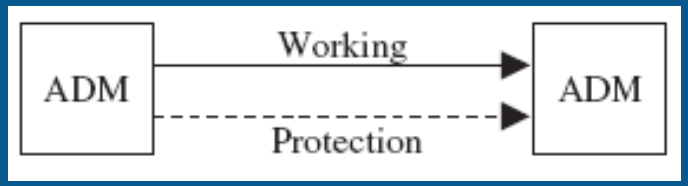


OPTICAL NETWORKING

- SONET/SDH(10)
  SELF-HEALING SONET/SDH RING(ONE)

- Causes for a ring to go down:
  - Failure of a fiber link:
    - Fiber is accidentally cutoff
    - The transmission or receiver equipment on the fiber link fail.
    - SONET/SDH device fails (rare)
- Services automatically restored: using the *automatic protection switching (APS)* protocol.
  - The time to restore the services has to be less than 60 msec.

- Link protection:
  - *Dedicated 1 + 1,*



    - The two devices are connected with two different fibers.
    - The SONET/SDH signal is split and simultaneously transmitted over both fibers.
    - The destination selects the best of the two signals based on their quality.
    - The working and protection fibers have to be *diversely routed*

OPTICAL NETWORKING

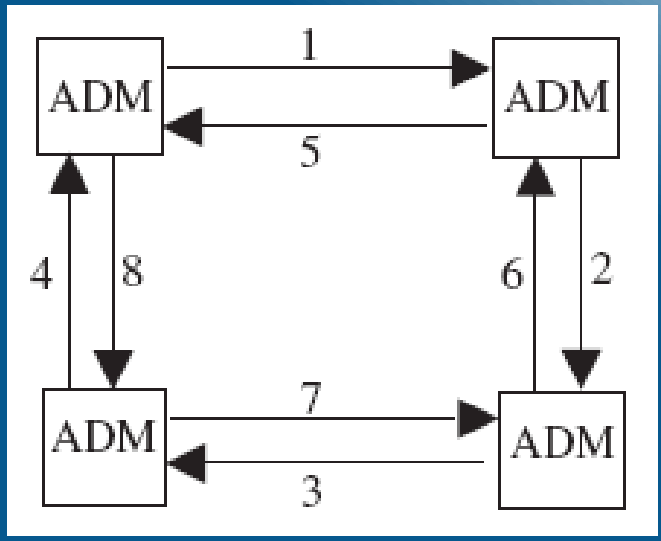
- SONET/SDH(11)
  SELF-HEALING SONET/SDH RING(TWO)

- Link protection:
  - 1:1 scheme,
    - Two diversely routed fibers: a *working fiber* and a *protection fiber*.
    - The signal is transmitted over the working fiber.
    - If this fiber fails, then the source and destination both switch to the protection fiber.
  - The 1:*N* scheme
    - Generalization of the 1:1 scheme,
    - *N* working fibers are protected by a single protection fiber.
    - Only one working fiber can be protected at any time.
    - Once a working fiber has been repaired, the signal is switched back, either automatically or manually, from the protection fiber to the working fiber.

OPTICAL NETWORKING

- SONET/SDH(12)
  - SELF-HEALING SONET/SDH RING(THREE)

- Self-healing SONET/SDH ring architectures are distinguished by
  - *Number of fibers*: A SONET/SDH ring can consist of either two or four fibers. the working and protection rings are *route diverse*.
  - *Direction of transmission*: A SONET/SDH ring can be *unidirectional* or *bidirectional*.
  - *Line or path switching*: Protection on a SONET/SDH ring can be at the level of a *line* or a *path*.
    - *Line* is a link between two SONET/SDH devices and might include regenerators.
    - A *path* is an end-to-end connection between the point where the SPE originates and the point where it terminates.
    - *Line switching* restores all of the traffic that pass through a failed link
    - *Path switching* restores some of the connections that are affected by a link failure.

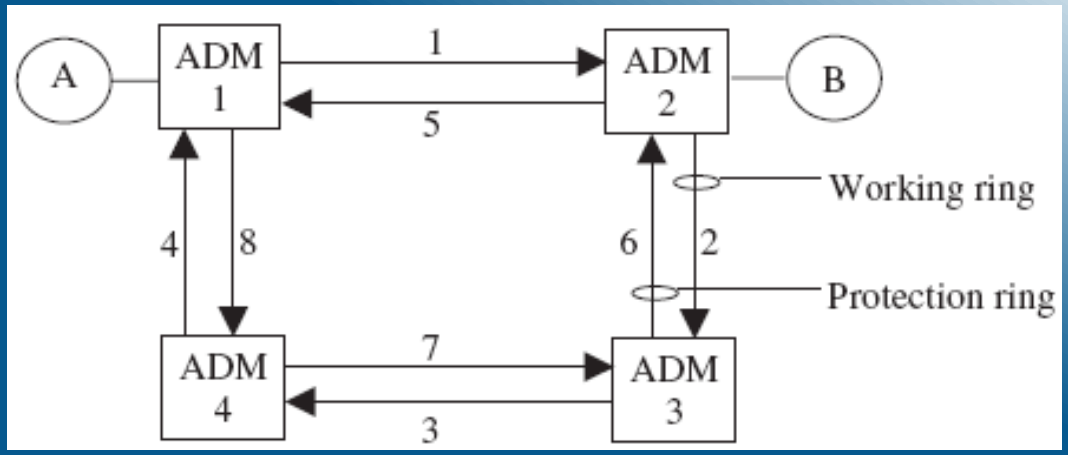


OPTICAL NETWORKING

- SONET/SDH(13)

  SELF-HEALING SONET/SDH RING(FOUR)

- **Two-fiber Unidirectional Path Switched Ring (2F-UPSR)**
  - Example: The working ring consists of fibers 1, 2, 3, and 4; the protection ring consists of fibers 5, 6, 7, and 8.
  - Unidirectional: A transmits to B over fiber 1 (working), and B transmits to A over fibers 2, 3, and 4 (working).
  - Protection: path level using 1 + 1

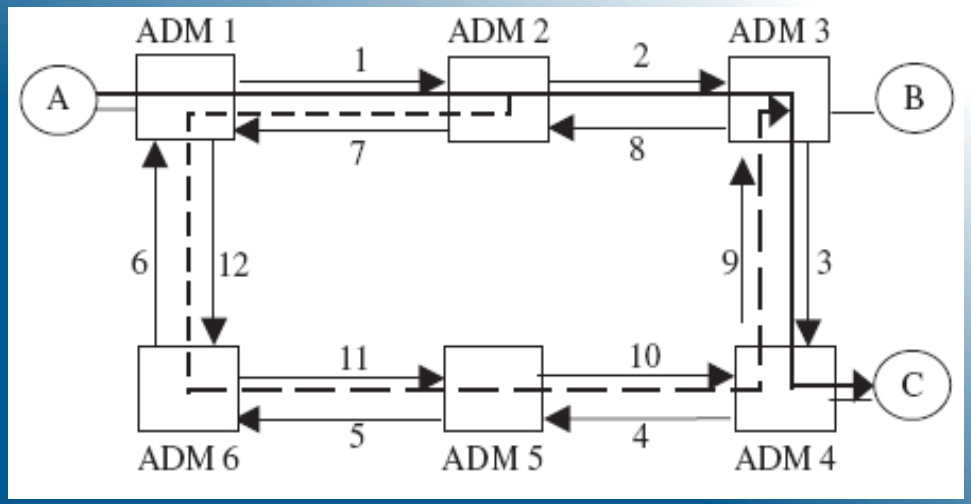


  - Simple ring architecture: Used as a metro edge ring to interconnect PBXs and access networks to a metro core ring.
  - Typical transmission speeds are OC-3/STM-1 and OC-12/STM-4.
  - Disadvantage:The maximum amount of traffic it can carry is equal to the traffic it can carry over a single fiber.

OPTICAL NETWORKING

- SONET/SDH(14)
  SELF-HEALING SONET/SDH RING(FIVE)

- **Two-fiber Bidirectional Line Switched Ring (2F-BLSR)**
  - Used in metro core rings.
  - Example:
    - Clockwise transmission (Ring 1): Fibers 1, 2, 3, 4, 5 and 6.
    - Counter-clockwise transmission (Ring 1): Fibers 7, 8, 9, 10, 11, and 12.
    - Rings 1 and 2 carry working and protection traffic.



  - Assume: each fiber is OC-12/STM-4. Then, two OC-3/STM-1s are allocated to working traffic and the other two to protection traffic.
  - Since only two OC-3/STM-1s can be used for working traffic, the maximum capacity that the 2F-BLSR can carry over both Rings 1 and 2 is OC-12/STM-4.
  - The capacity allocated to protection traffic on either Rings 1 and 2 can be used to carry low priority traffic.

OPTICAL NETWORKING

- SONET/SDH(15)
  SELF-HEALING SONET/SDH RING(SIX)

- **2F-BLSR**
  - Bidirectional:
    - Ring 1 or Ring 2, depending on the route of the shortest path to the destination.
    - A transmits to B over the working part of fibers 1 and 2 of Ring 1,
    - B transmits to A over the working part of fibers 8 and 7 of Ring 2.
  - Fiber 2 fails:
    - line switching: Traffic over fiber 2 automatically switched to the protection part of Ring 2.
    - All of the traffic will be rerouted to ADM 3 over the protection part of Ring 2 using fibers 7, 12, 11, 10, and 9.
    - From there, the traffic continue on following the original path of the connection.
    - Consider a connection from A to C (solid line).
    - When fiber 2 fails, the traffic from A will be rerouted (dotted line).
    - At ADM 3, it will be routed back to ADM 4 over fiber 3.