Lecture 9: Multiwavelength Optical Network Architectures

Stern and Bala (1999)
Multiwavelength Optical Networks
Chapter 3

Contents

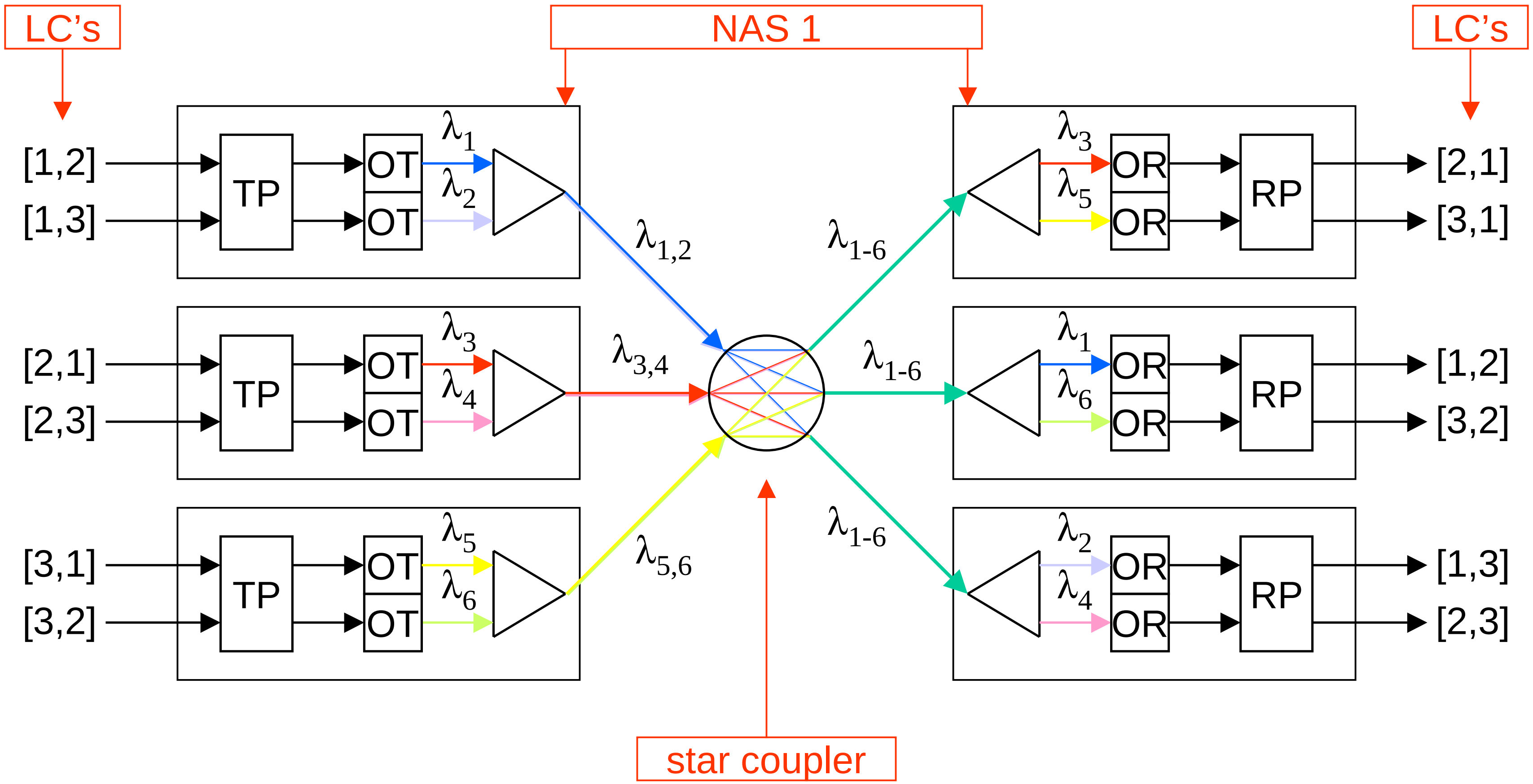
Static networks

- **Static network**, also called **broadcast-and-select network**, is such a purely optical shared medium network that
  - passive splitting and combining nodes are interconnected by fibers to provide static connectivity among some or all OT's and OR's
  - OT's broadcast and OR's select
- **Broadcast star network** is an example of such a static network:
  - star coupler combines all signals and broadcasts them to all OR's
    - static optical multicast paths from any station to the set of all stations
    - no wavelength selectivity at the network node
  - an optical connection is created by tuning the source OT and/or the destination OR to the same wavelength
  - thus, two OT's must operate at different wavelengths (to avoid interference)
    - this is called the **distinct channel assignment** constraint (DCA)
  - however, two OR's can be tuned to the same wavelength
    - by this way, optical multicast connections are created

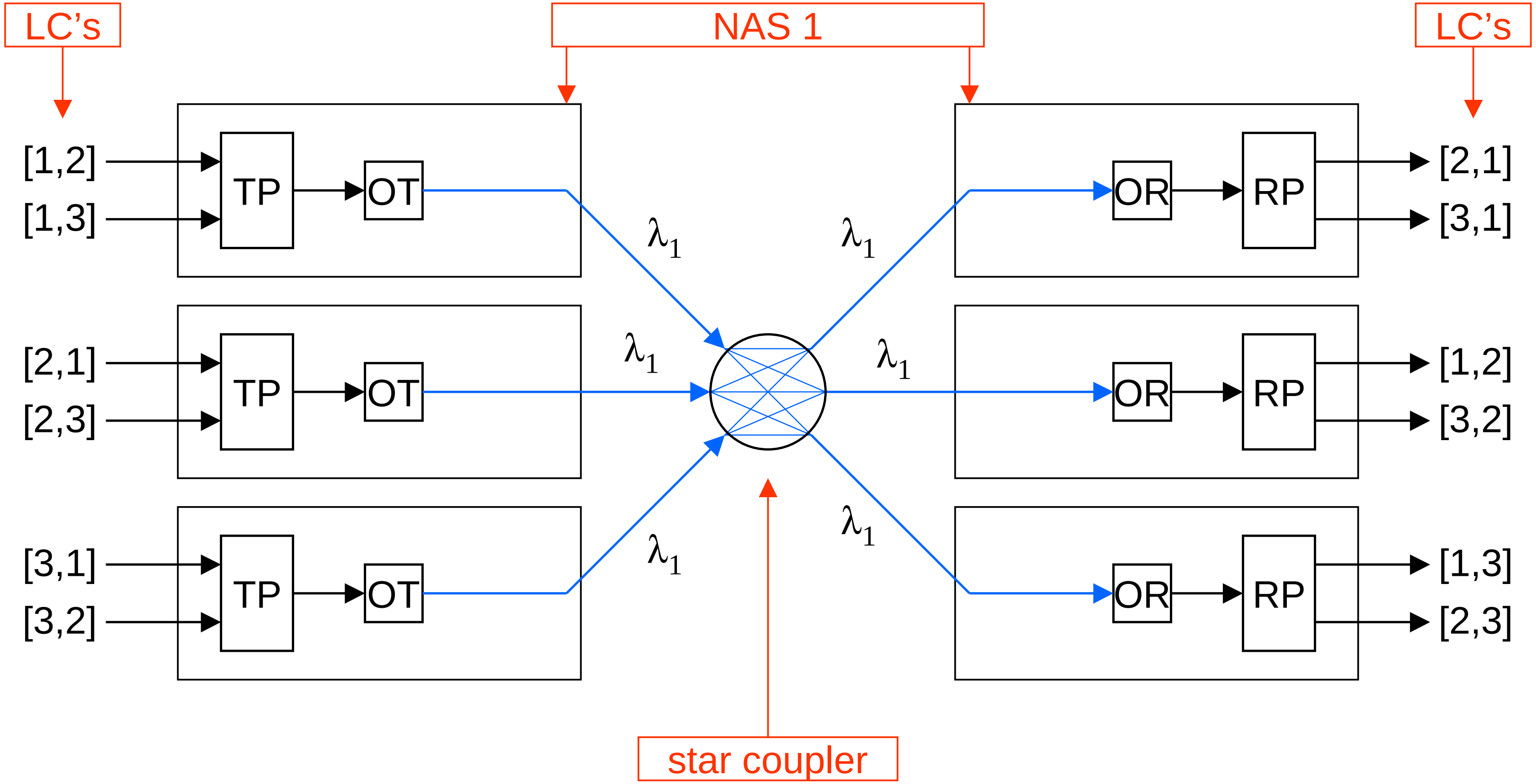
Realization of logical connectivity

- Methods to realize full point-to-point logical connectivity in a broadcast star with N nodes:
  - **WDM/WDMA**
    - whole λ-channel allocated for each LC
    - N(N-1) wavelengths needed (one for each LC)
    - N-1 transceivers needed in each NAS
  - **TDM/TDMA**
    - portion 1/(N(N-1)) of a λ-channel allocated for each LC
    - 1 wavelength needed
    - 1 transceiver needed in each NAS
  - **TDM/T-WDMA**
    - portion 1/(N-1) of a λ-channel allocated for each LC
    - N wavelengths needed (one for each OT)
    - 1 transceiver needed in each NAS, e.g. fixed OT and tunable OR (FT-TR), or tunable OT and fixed OR (TT-FR)

Broadcast star using WDM/WDMA



Broadcast star using TDM/TDMA



Effect of propagation delay on TDM/TDMA

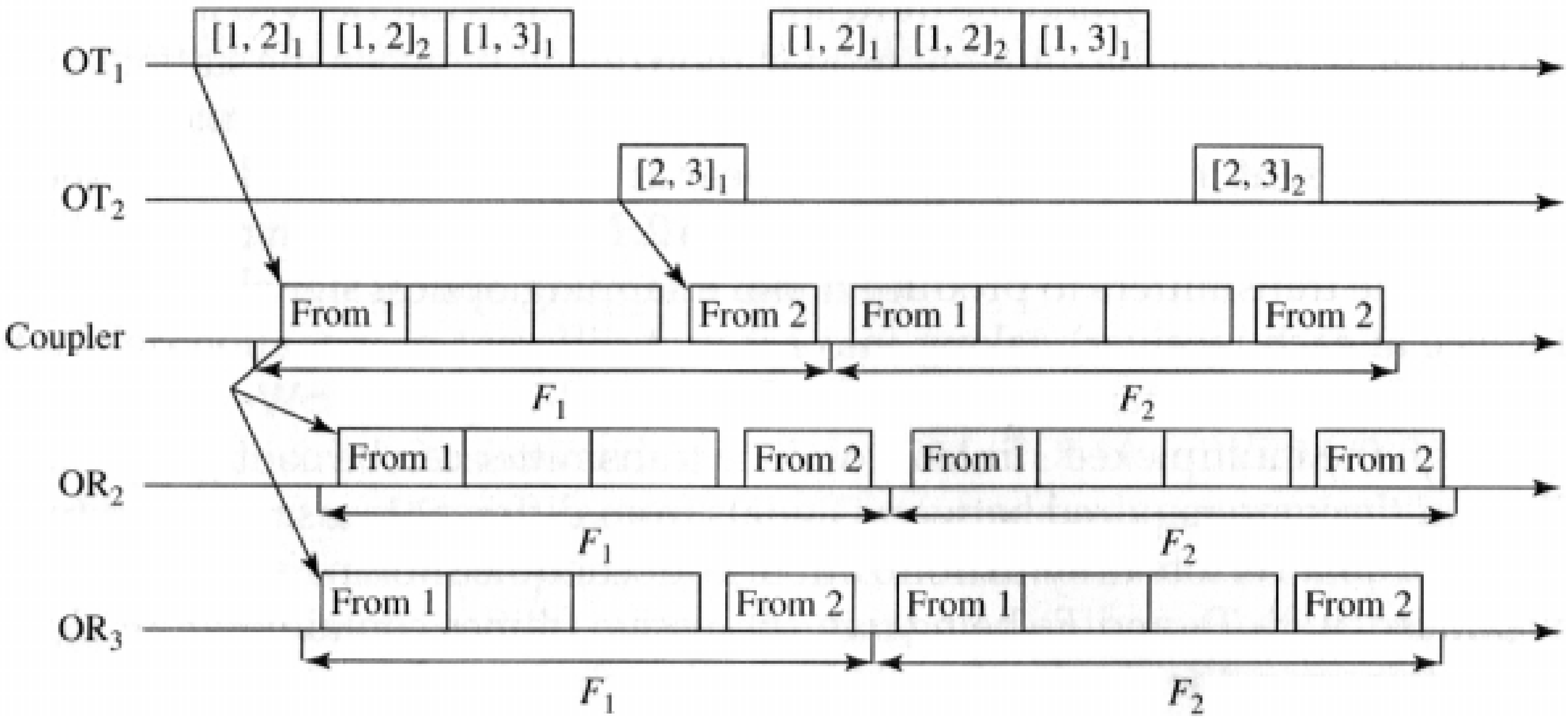
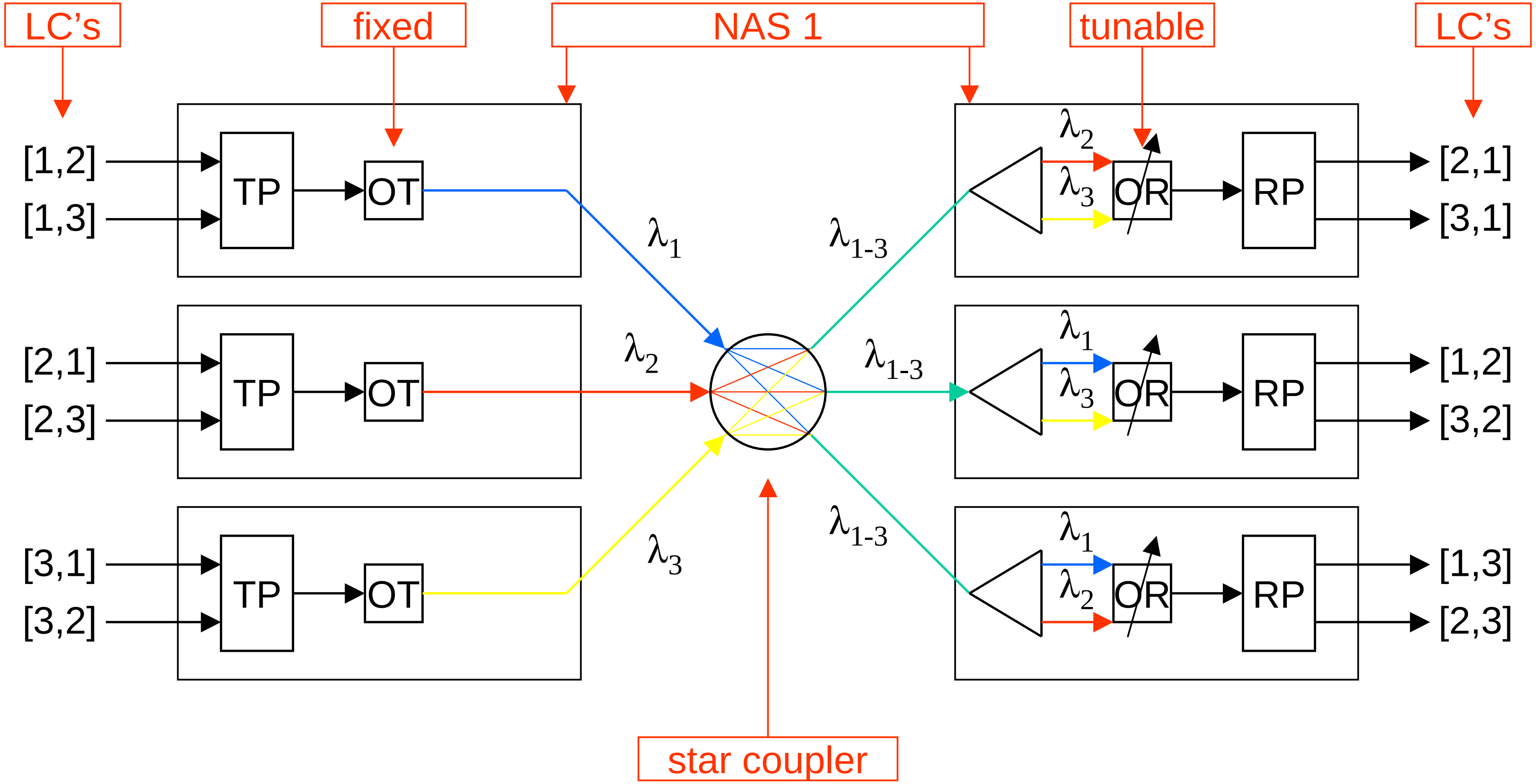
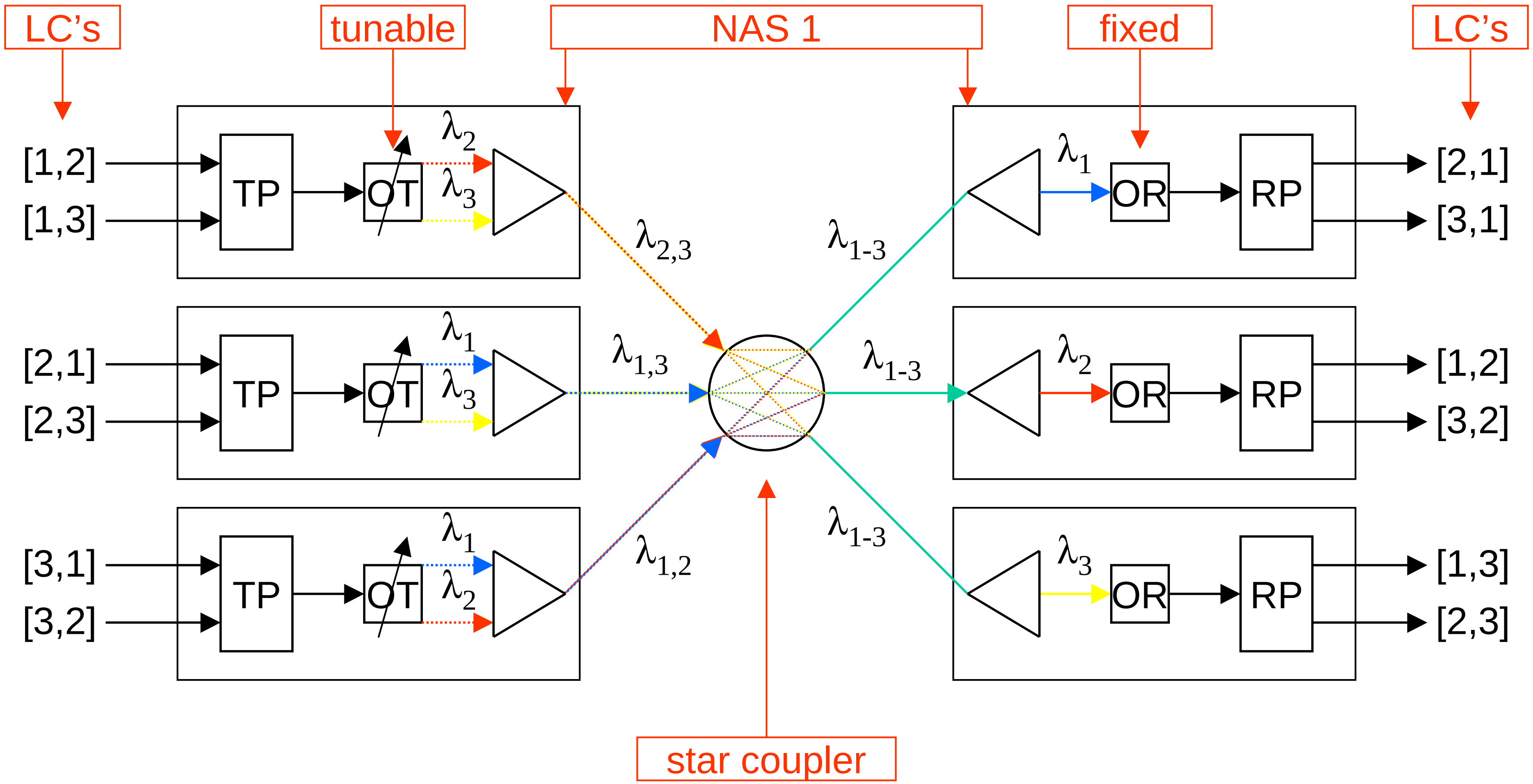


FIGURE 3.7 A TDM/TDMA schedule.

Broadcast star using TDM/T-WDMA in FT-TR mode



Broadcast star using TDM/T-WDMA in TT-FR mode



Channel allocation schedules for circuit switching

WDM/WDMA

λ_1	[1,2]	[1,2]	[1,2]	[1,2]
λ_2	[1,3]	[1,3]	[1,3]	[1,3]
λ_3	[2,1]	[2,1]	[2,1]	[2,1]
λ_4	[2,3]	[2,3]	[2,3]	[2,3]
λ_5	[3,1]	[3,1]	[3,1]	[3,1]
λ_6	[3,2]	[3,2]	[3,2]	[3,2]

frame

TDM/T-WDMA with FT-TR

λ_1	[1,2]	[1,3]	[1,2]	[1,3]
λ_2	[2,3]	[2,1]	[2,3]	[2,1]
λ_3	[3,1]	[3,2]	[3,1]	[3,2]

frame

TDM/T-WDMA with TT-FR

λ_1	[2,1]	[3,1]	[2,1]	[3,1]
λ_2	[3,2]	[1,2]	[3,2]	[1,2]
λ_3	[1,3]	[2,3]	[1,3]	[2,3]

frame

Channel allocation schedule (CAS) should be
- **realizable** = only one LC per each OT and timeslot
- **collision-free** = only one LC per each λ and timeslot
- **conflict-free** = only one LC per each OR and timeslot

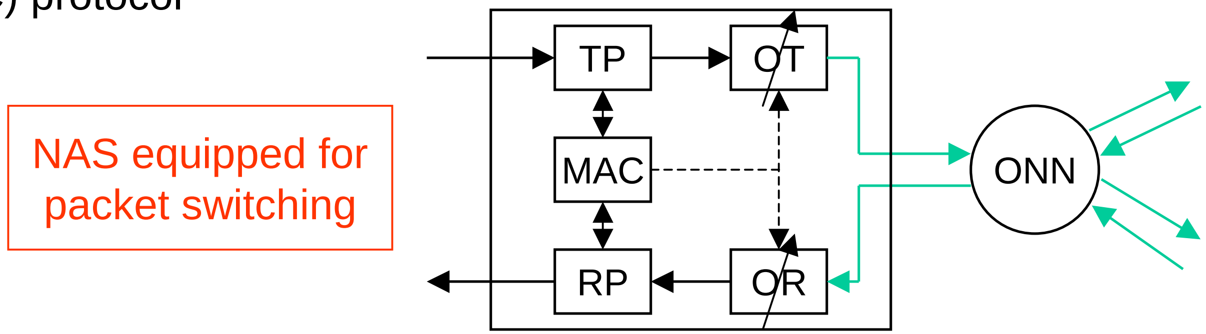
TDM/TDMA

λ_1	[1,2]	[1,3]	[2,1]	[2,3]	[3,1]	[3,2]	[1,2]	[1,3]	[2,1]	[2,3]	[3,1]	[3,2]

frame

Packet switching in the optical layer

- **Fixed capacity allocation** produced by periodic frames is well adapted to stream-type traffic. However, in the case of bursty packet traffic this approach may produce a very poor performance.
- By implementing **packet switching in the optical layer**, it is possible to maintain a very large number of LC's simultaneously using **dynamic capacity allocation**.
  - Packets are processed in TP's/RP's of the NAS's (but **not** in ONN's)
  - TP's can schedule packets based on instantaneous demand
  - As before, broadcast star is used as a **shared medium**
  - Control of this shared optical medium requires a Medium Access Control (MAC) protocol



Additional comments on static networks

- The broadcast-and-select principle **cannot be scaled** to large networks for three reasons:
  - **Spectrum use**: Because all transmissions share the same fibers, there is no possibility of optical spectrum reuse; so the required spectrum typically grows at least proportionally to the number of transmitting stations.
  - **Protocol complexity**: Synchronization problems, signaling overhead, time delays, and processing complexity all increase rapidly with the number of stations and the number of LC's.
  - **Survivability**: There are no alternate routes in case of a failure. Furthermore, a failure at the star coupler can bring the whole network down.
- For these reasons, a practical limit on the number of stations in a broadcast star is approximately 100

Contents

- Static networks
- Wavelength Routed Networks (WRN)
- Linear Lightwave Networks (LLN)
- Logically Routed Networks (LRN)

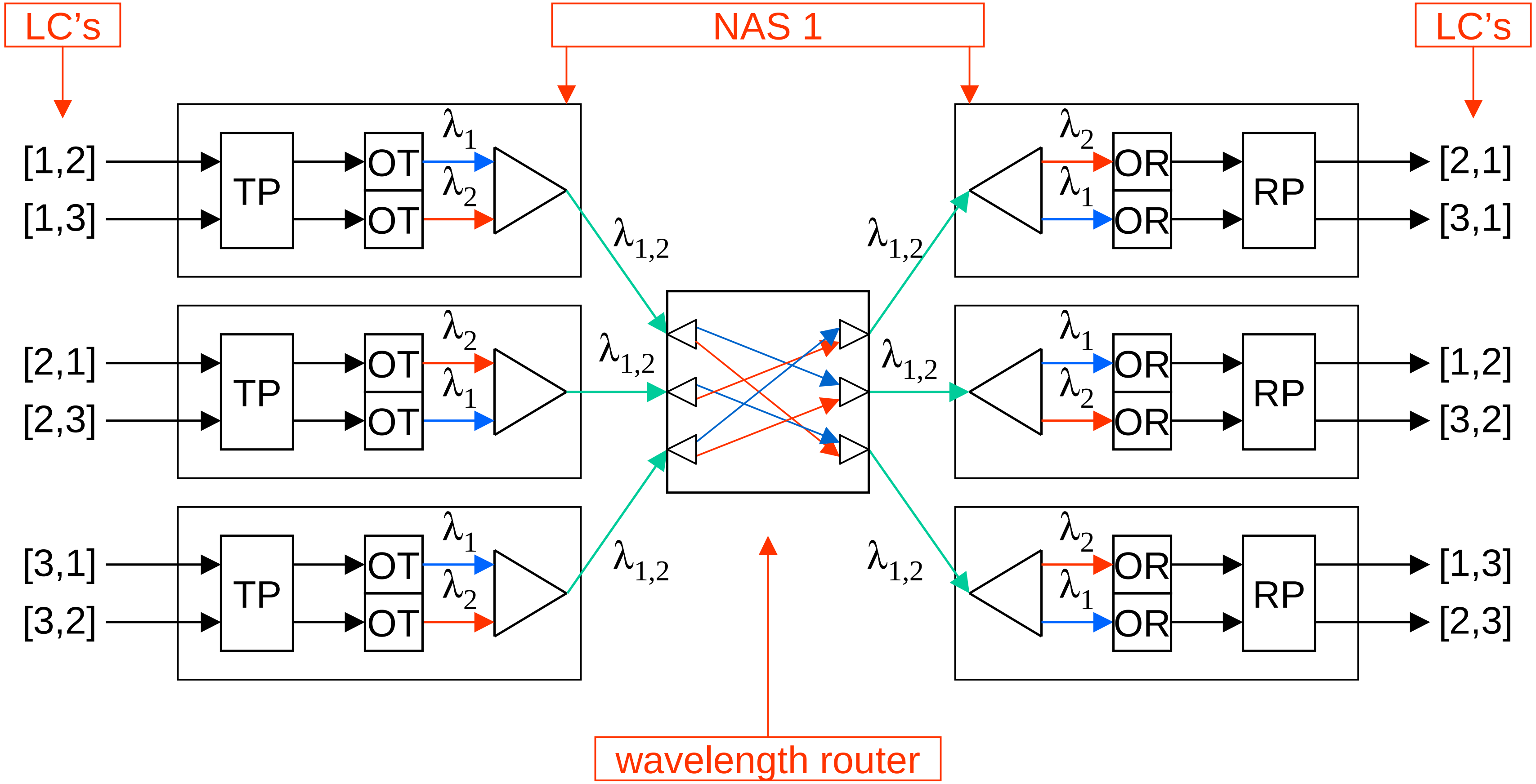
Wavelength Routed Networks (WRN)

- **Wavelength routed network** (WRN) is such a purely optical network that
  - each λ-channel can be recognized in the ONN's (= wavelength selectivity) and routed individually
  - ONN's are typically wavelength selective crossconnects (WSXC)
    - then the network is **dynamic** (allowing **switched** connections)
    - a static WRN (allowing only **dedicated** connections) can be built up using static wavelength routers
- All optical paths and connections are **point-to-point**
  - each point-to-point LC corresponds to a point-to-point OC
  - full point-to-point logical/optical connectivity among N stations requires N-1 transceivers in each NAS
  - multipoint logical connectivity only possible by several point-to-point optical connections using WDM/WDMA

Static wavelength routed star

- Full point-to-point logical/optical connectivity in a static wavelength routed star with N nodes can be realized by
  - **WDM/WDMA**
    - whole λ-channel allocated for each LC
    - N-1 wavelengths needed
      - thus, the spectrum reuse factor is N
        (= N(N-1) optical connections / N-1 wavelengths)
    - N-1 transceivers needed in each NAS

Static wavelength routed star using WDM/WDMA

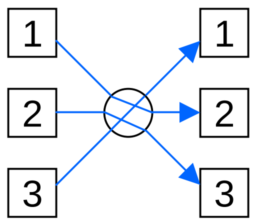


Routing and channel assignment

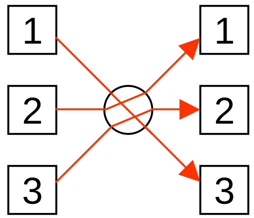
- Consider a WRN equipped with WSXC’s (or wavelength routers)
  - so, no wavelength conversion possible
- Establishing an optical connection requires
  - channel assignment
  - routing
- **Channel assignment** (executed in the λ-channel sublayer) involves
  - allocating an available wavelength to the connection and
  - tuning the transmitting and receiving station to the assigned wavelength
- **Routing** (executed in the optical path sublayer) involves
  - determing a suitable optical path for the assigned λ-channel and
  - setting the switches in the network nodes to establish that path

Channel assignment constraints

- The following two channel assignment constraints apply to WRN's
  - **Wavelength continuity**: The wavelength of each optical connection remains the same on all links it traverses from source to destination
    - This is unique to transparent optical networks, making routing and wavelength assignment a more challenging task than the related problem in conventional networks.

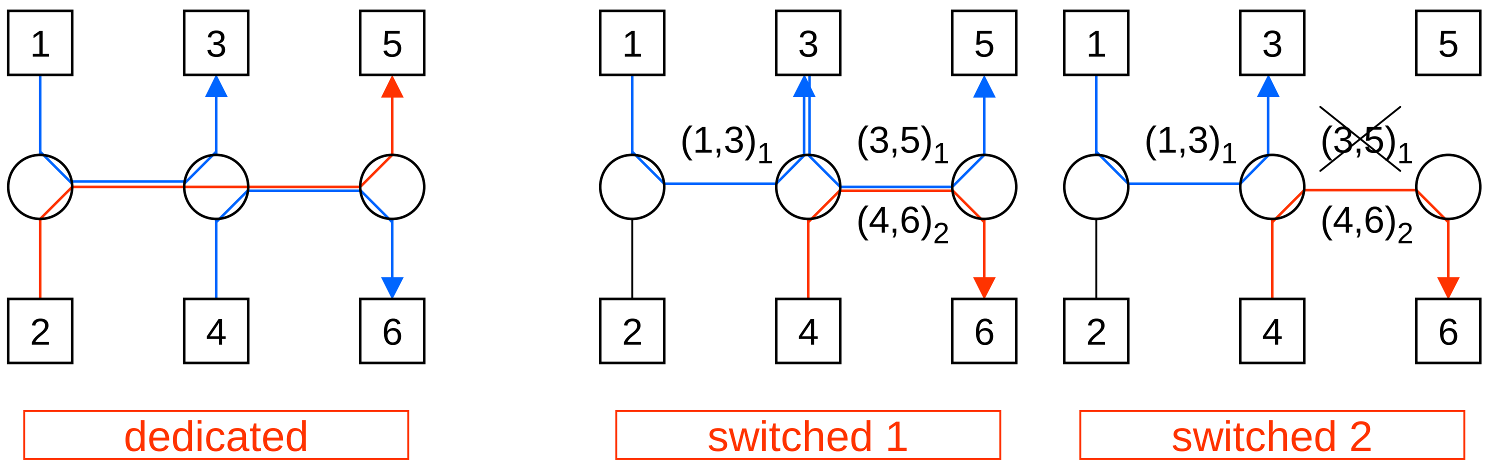


  - **Distinct channel assignment** (DCA): All optical connections sharing a common fiber must be assigned distinct λ-channels (that is, distinct wavelengths).
    - This applies to access links as well as internodal links.
    - Although the DCA is necessary to ensure distinguishability of signals on the same fiber, it is possible (and generally advantageous) to **reuse** the same wavelength on **fiber-disjoint paths**



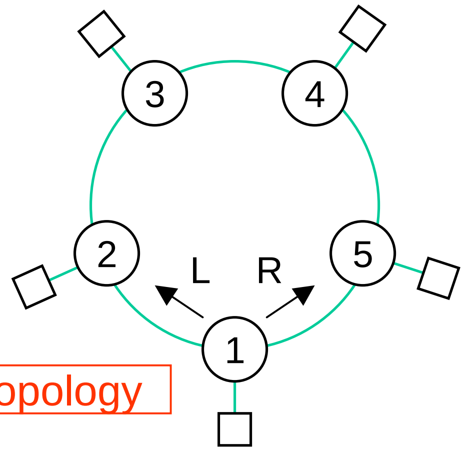
Routing and channel assignment problem

- **Routing and channel assignment** (RCA) is the fundamental control problem in large optical networks
  - Generally, the RCA problem for **dedicated** connections can be treated off-line, so that computationally intensive optimization techniques are appropriate.
  - On the other hand, RCA decisions for **switched** connections must be made rapidly, and hence suboptimal heuristics must normally be used.



Example: Bidirectional ring with elementary NAS's

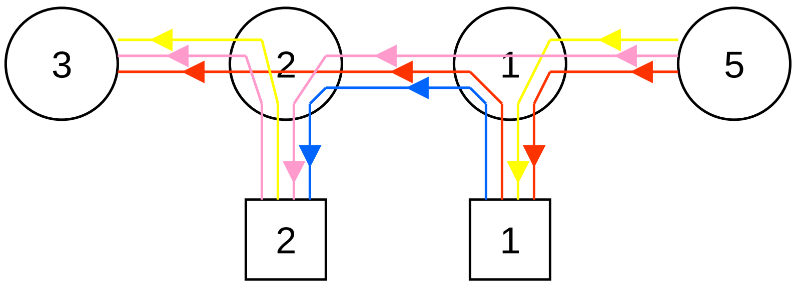
- Consider a bidirectional ring of 5 nodes and stations with single access fiber pairs
- Full point-to-point logical/optical connectivity requires
  - 4 wavelengths
    - thus, the spectrum reuse factor is 20/4 = 5
  - 4 transceivers in each NAS



physical topology

	1	2	3	4	5
1	--	1L	2L	3R	4R
2	1R	--	3L	4L	2R
3	3R	4R	--	2L	1L
4	4L	2R	1R	--	3L
5	2L	3L	4R	1R	--

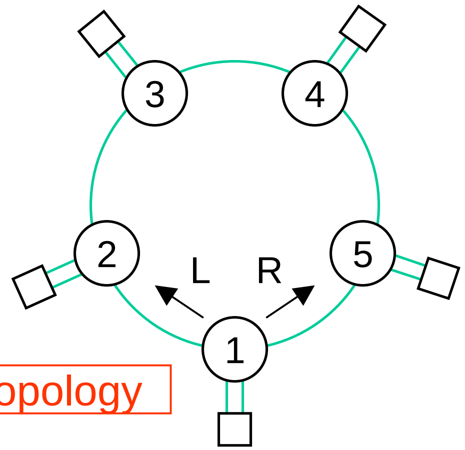
RCA



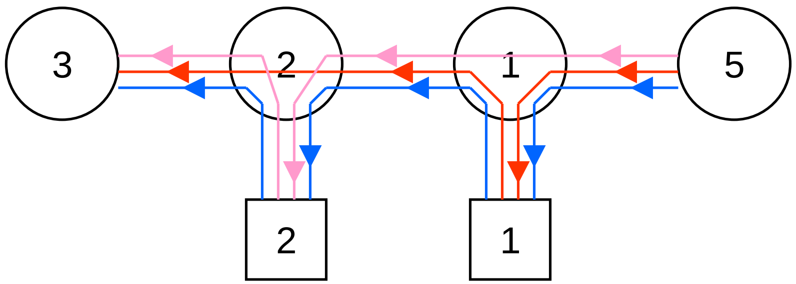
Fiber from ONN1 to ONN2

Example: Bidirectional ring with nonblocking NAS's

- Consider then a bidirectional ring of 5 nodes and stations with two access fiber pairs
- Full point-to-point logical/optical connectivity requires
  - 3 wavelengths
    - the spectrum reuse factor is now 20/3 = 6.67
  - 4 transceivers in each NAS



physical topology



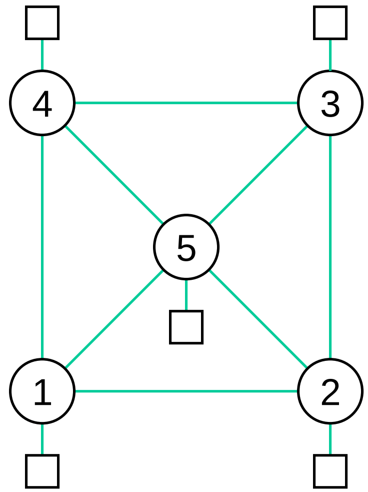
Fiber from ONN1 to ONN2

	1	2	3	4	5
1	--	1L	2L	2R	1R
2	1R	--	1L	3L	3R
3	2R	1R	--	2L	1L
4	2L	3R	2R	--	3L
5	1L	3L	1R	3R	--

RCA

Example: Mesh network with elementary NAS's

- Consider a mesh network of 5 nodes and stations with single access fiber pairs
- Full point-to-point logical/optical connectivity requires
  - 4 wavelengths
    - the spectrum reuse factor is 20/4 = 5
  - 4 transceivers in each NAS
  - despite the richer physical topology, no difference with the corresponding bidirectional ring (thus, the access fibers are the bottleneck)

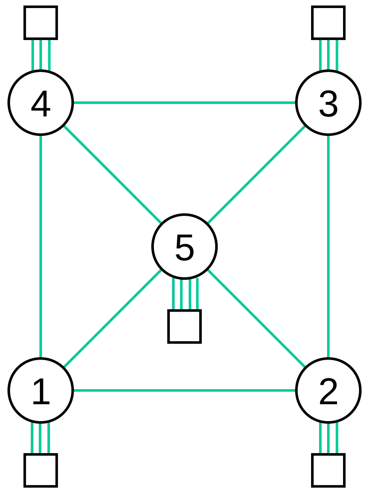


physical topology

RCA?

Example: Mesh network with nonblocking NAS's

- Consider a mesh network of 5 nodes and stations with three/four access fiber pairs
- Full point-to-point logical/optical connectivity requires
  - only 2 wavelengths
    - the spectrum reuse factor is 20/2 = 10
  - 4 transceivers in each NAS



physical topology

RCA?

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- Static networks
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Linear Lightwave Networks (LLN)

- **Linear lightwave network** (LLN) is such a purely optical network that
  - nodes perform (only) strictly linear operations on optical signals
- This class includes
  - both static and wavelength routed networks
  - but also something more
- The most general type of LLN has **waveband selective LDC** nodes
  - LDC performs controllable optical signal dividing, routing and combining
  - these functions are required to support **multipoint optical connectivity**
- Waveband selectivity in the nodes means that
  - the optical path layer routes signals as **bundles** that contain all λ-channels within one waveband
- Thus, all layers of connectivity and their interrelations must be examined carefully

Routing and channel assignment constraints

- The two constraints of WRN's need also be satisfied by LLN's
  - **Wavelength continuity**: The wavelength of each optical connection remains the same on all links it traverses from source to destination
  - **Distinct channel assignment** (DCA): All optical connections sharing a common fiber must be assigned distinct λ-channels
- Additionally, the following two routing constraints apply to LLN's
  - **Inseparability**: Channels combined on a single fiber and situated within the same waveband cannot be separated within the network
    - this is a consequence of the fact that the LDC's operate on the aggregate power carried within each waveband
  - **Distinct source combining** (DSC):Only signals from distinct sources are allowed to be combined on the same fiber
    - DSC condition forbids a signal from splitting, taking multiple paths, and then recombining with itself
    - otherwise, the combined signals would interfere with each other, garbling their information

Inseparability

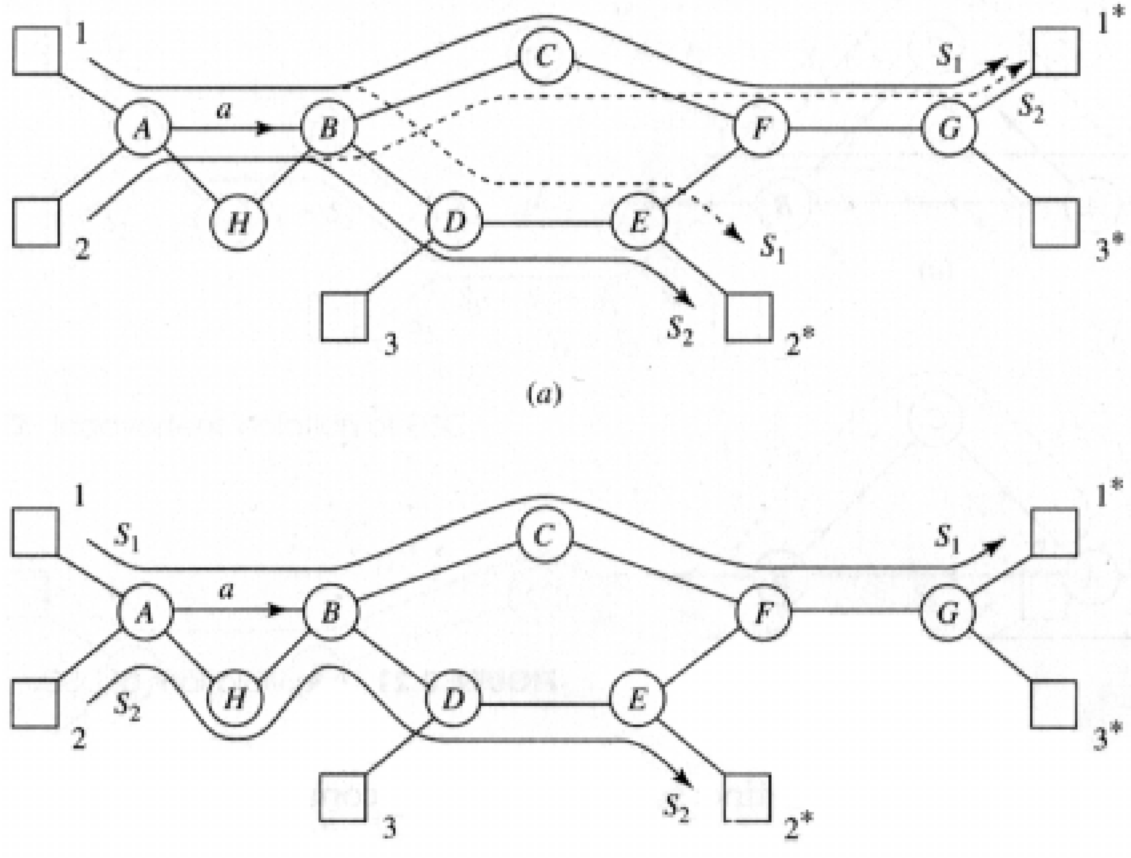


FIGURE 3.20 Inseparability.

Two violations of DSC

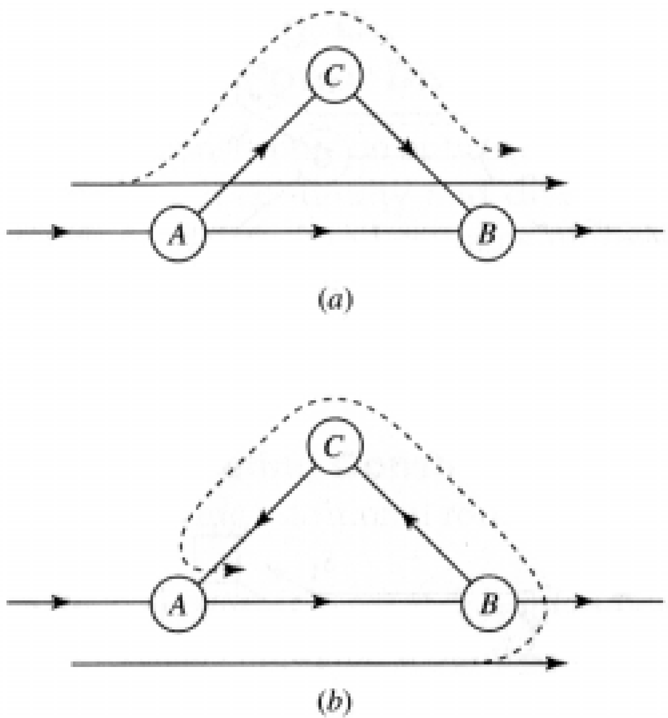


FIGURE 3.21 Two violations of DSC.

Inadvertent violation of DSC

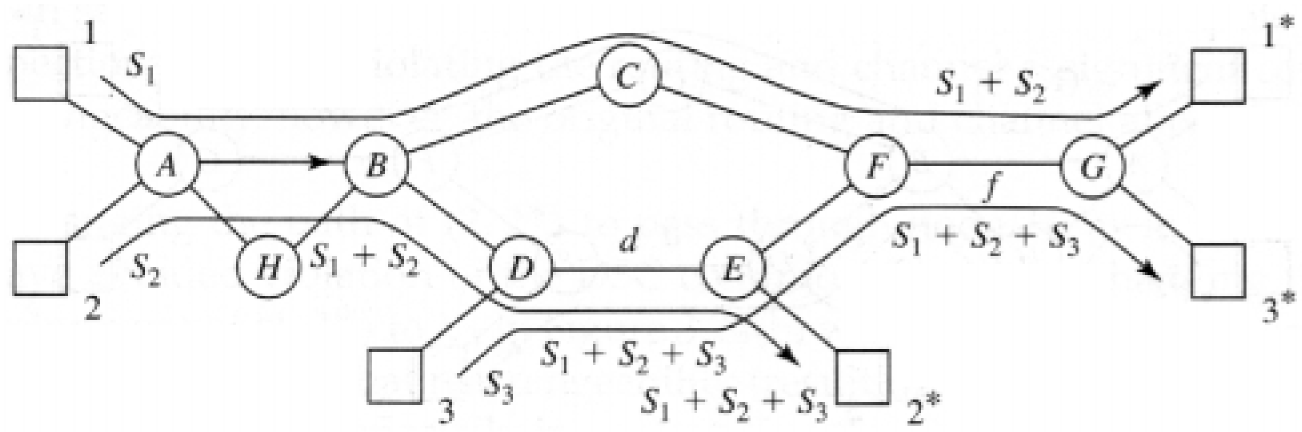


FIGURE 3.22 Inadvertent violation of DSC.

Avoidance of DSC violations

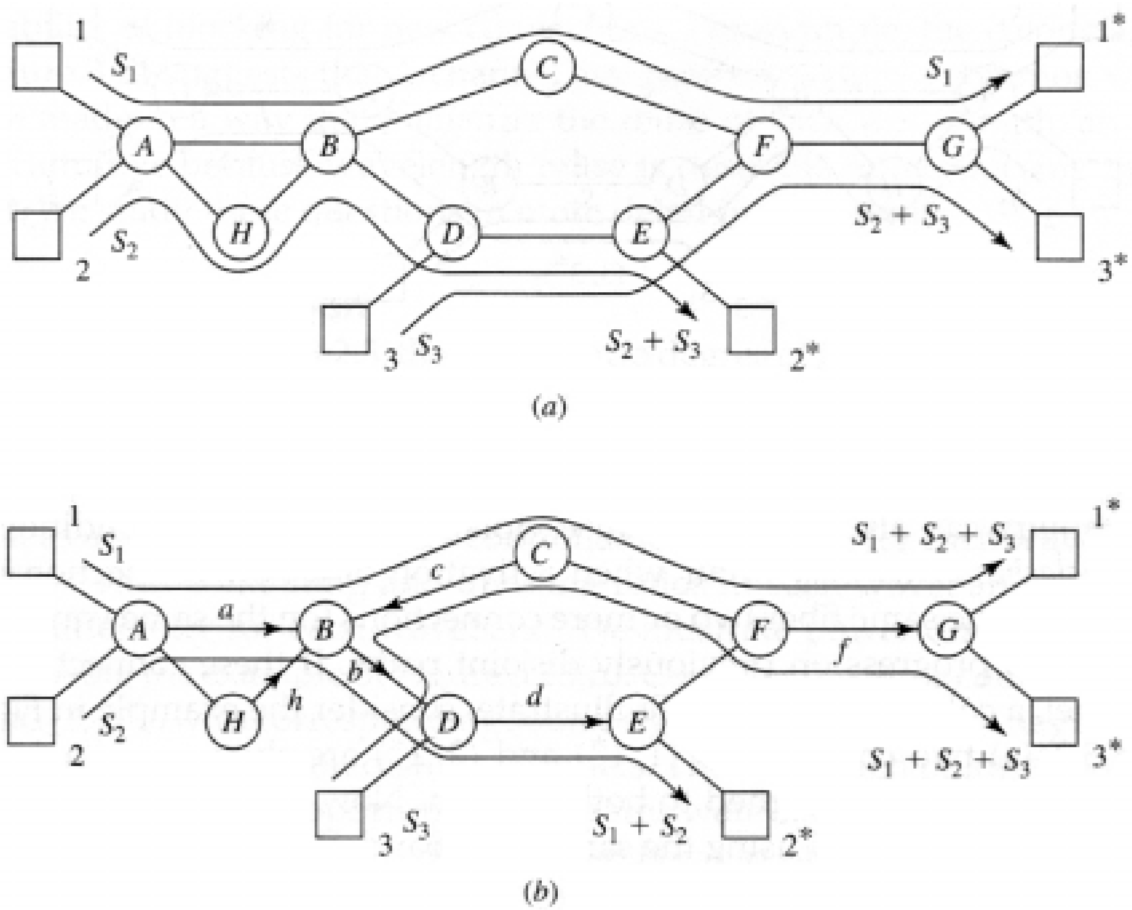


FIGURE 3.23 Avoidance of DSC violations.

Color clash

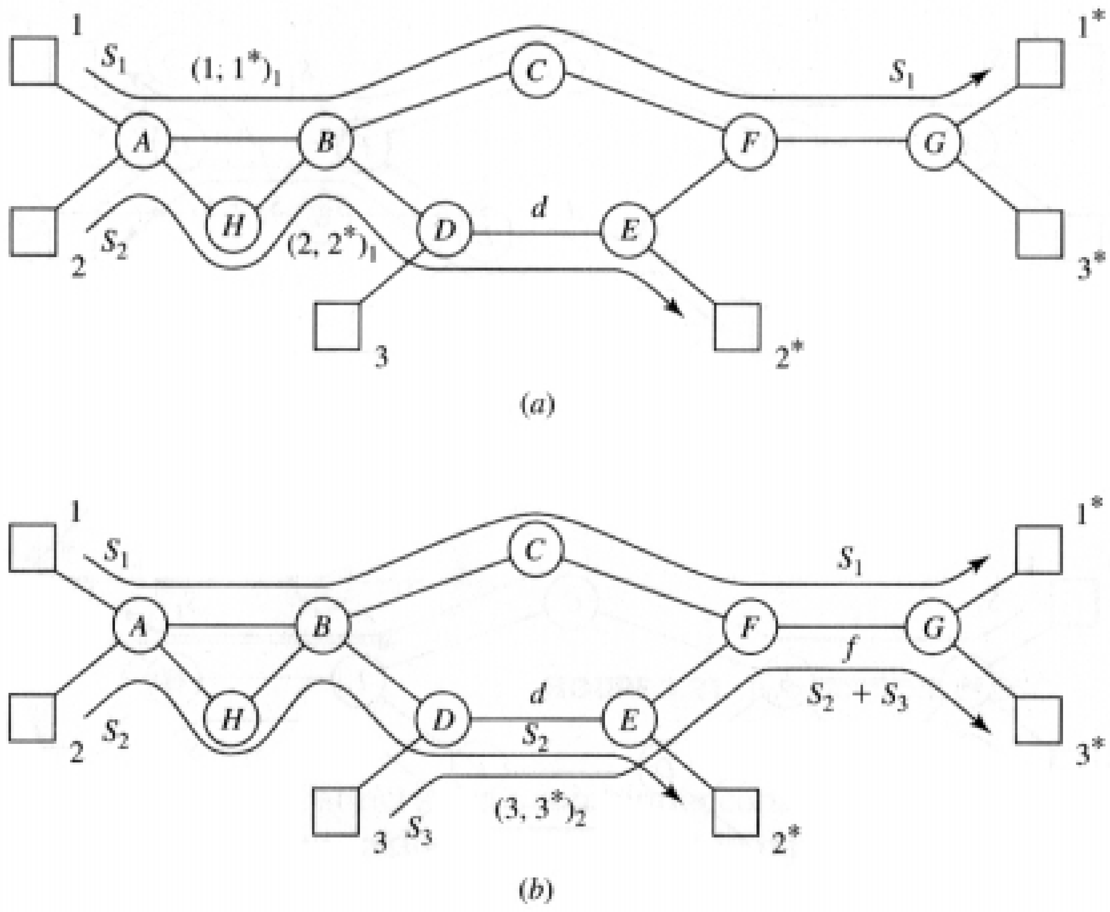


FIGURE 3.24 Color clash.

Power distribution

- In an LDC it is possible to specify combining and dividing ratios
  - these ratios determine how power from the sources is distributed to the destinations
  - combining and dividing ratios can be set differently for each waveband
- How should these ratios be chosen?
- The **objective** could be
  - to split each source's power equally among all destinations it reaches, and
  - to combine equally all sources arriving at the same destination
- The resultant end-to-end power transfer coefficients are independent of
  - the routing paths through the network,
  - the number of nodes they traverse, and
  - the order in which signals are combined and split
- They depend only on
  - the number of destinations for each source and
  - the number of sources reaching each destination

Illustration of power distribution

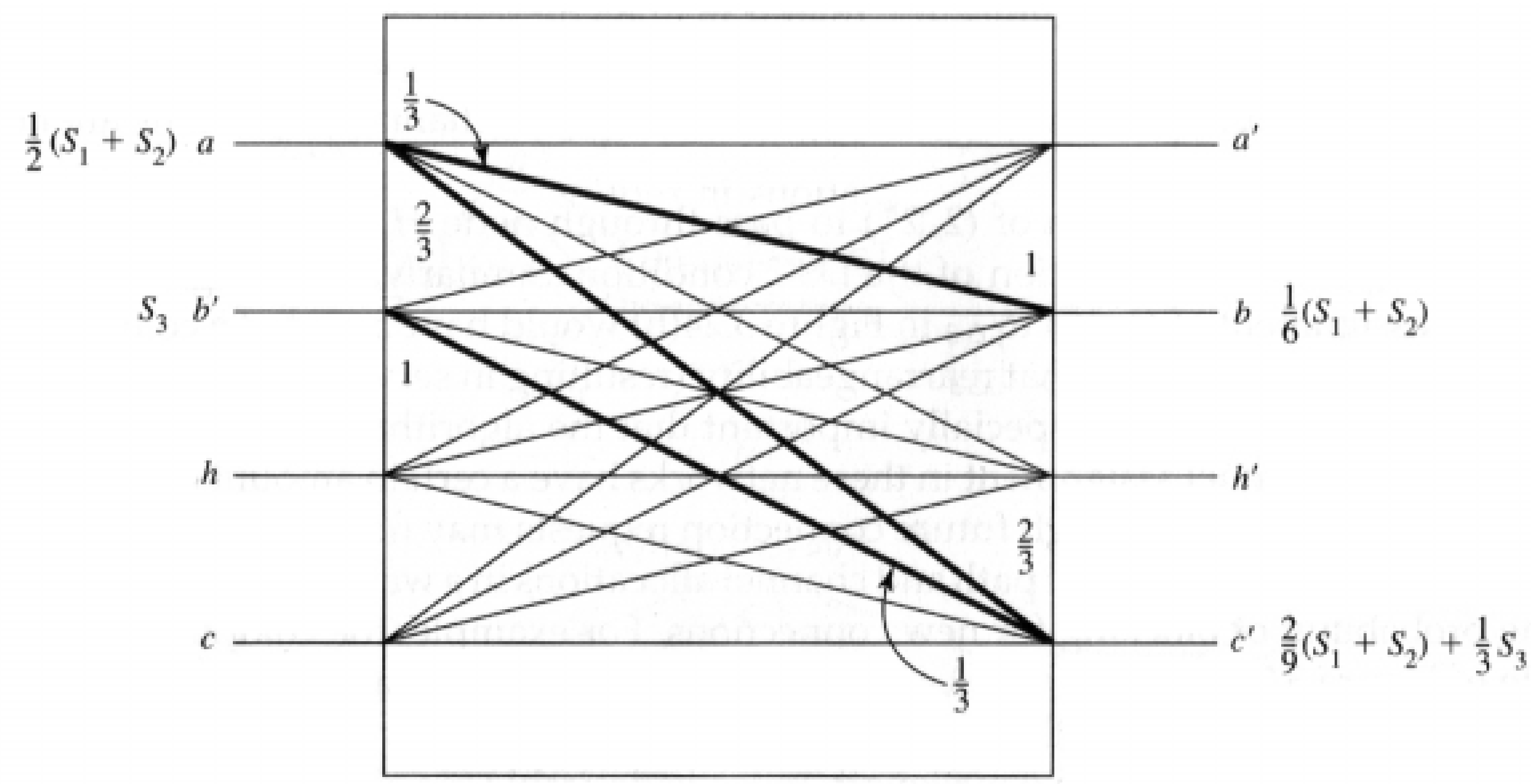


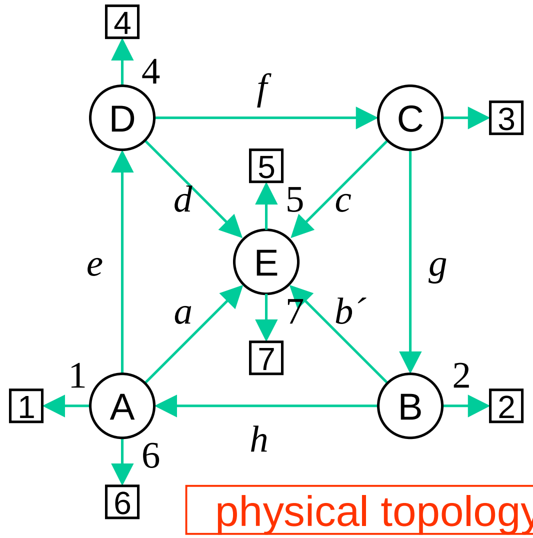
FIGURE 3.25 Illustration of power distribution. Node B in Figure 3.23(b).

Multipoint subnets in LLN's

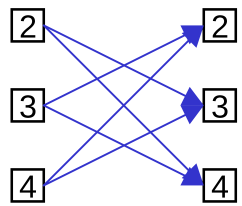
- Attempts to set up several point-to-point optical connections within a common waveband leads to unintentional creation of multipoint optical paths
  - Thus, complications in routing, channel assignment and power distribution
- On the other hand, waveband routing leads to more efficient use of the optical spectrum
- In addition, the multipoint optical path capability is useful when creating intentional multipoint optical connections
  - Thus, LLN's can deliver a high degree of logical connectivity with minimal optical hardware in the access stations
  - This is one of the fundamental advantages of LLN's over WRN's
- Multipoint optical connections can be utilized when creating a full logical connectivity among specified clusters of stations within a larger network
  - Such fully connected clusters are called **multipoint subnets** (MPS)

Example: Seven stations on a mesh

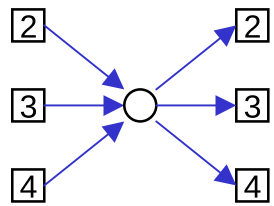
- Consider a network containing seven stations interconnected on an LLN with a mesh physical topology and bidirectional fiber links
  - Notation for fiber labeling: *a* and *a´* form a fiber pair with opposite directions
- The set of stations {2,3,4} should be interconnected to create an MPS with full logical connectivity
- This can be achieved e.g. by creating an **optical path on a single waveband** in the form of a tree joining the three stations (**embedded broadcast star**)



physical topology



LCG



LCH

Realization of the MPS by a tree embedded in mesh

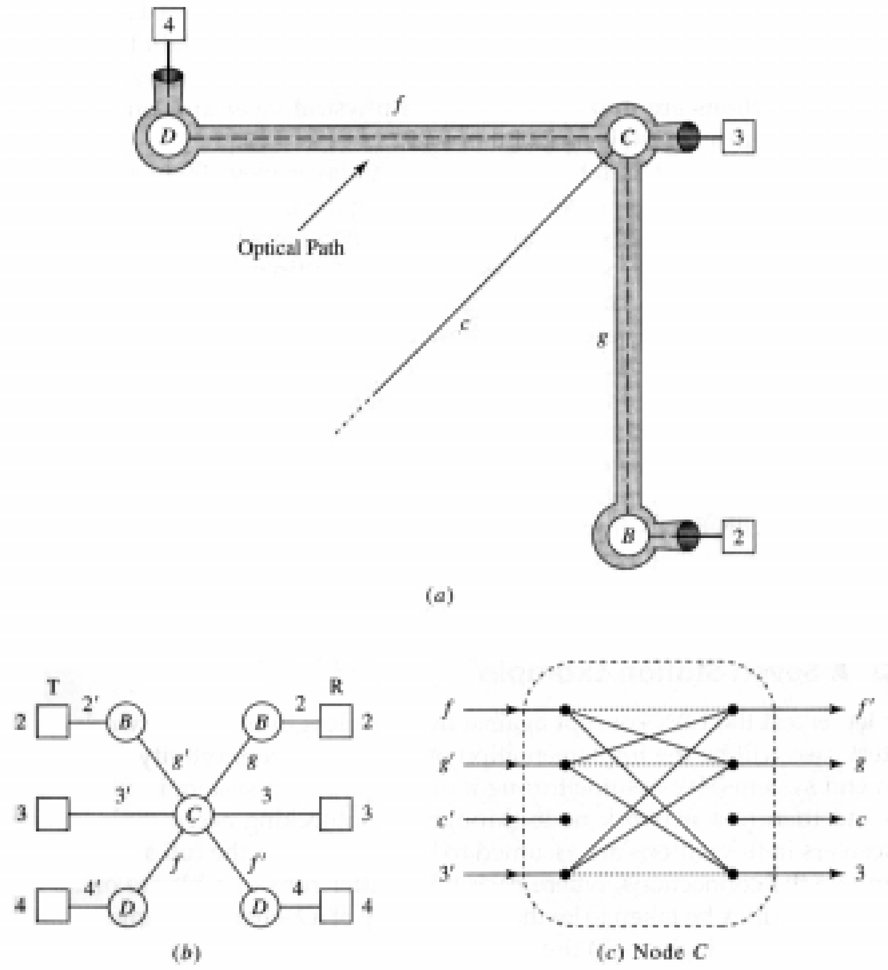


FIGURE 3.27 Tree embedded in mesh.

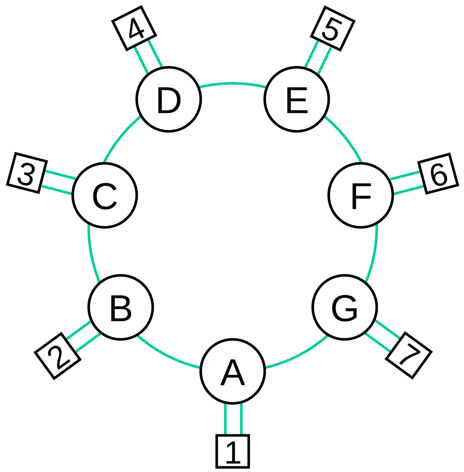
Contents

- Static networks
- Wavelength Routed Networks (WRN)
- Linear Lightwave Networks (LLN)
  - Seven-station example
- Logically Routed Networks (LRN)

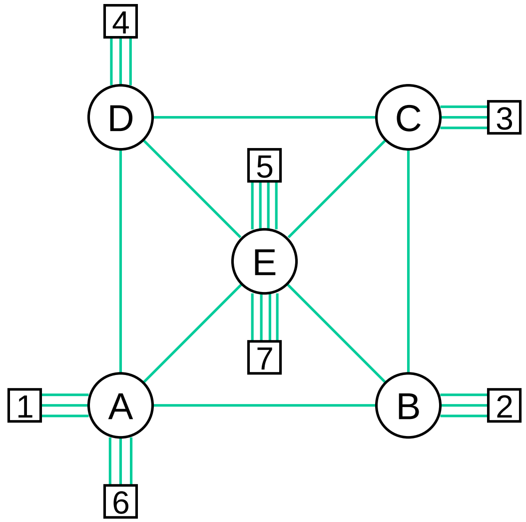
Seven-station example

- **Assume**:
  - nonblocking access stations
  - each transmitter runs at a bitrate of R_0
- **Physical topologies** (PT):
  - **bidirectional ring**
  - **mesh**
  - **multistar** of seven physical stars
- **Logical topologies** (LT):
  - **fully connected** (point-to-point logical topology with 42 edges)
    - realized using **WRN**
  - **fully shared** (hypernet logical topology with a single hyperedge)
    - realized using a **broadcast-and-select network** (LLN of a single MPS)
  - **partially shared** (hypernet of seven hyperedges)
    - realized using **LLN** of seven MPS's

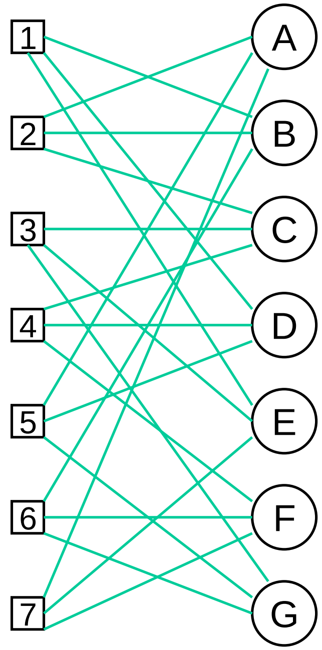
Physical topologies



ring



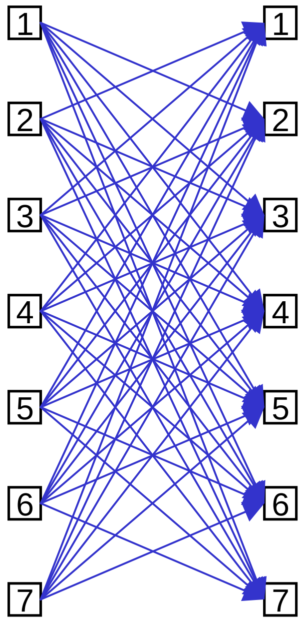
mesh



multistar

Fully connected LT: WRN realizations

- **Ring** PT:
  - 6 λ's with spectrum reuse factor of 42/6 = 7
    - RCA?
  - 6 transceivers in each NAS
    $\Rightarrow$ network capacity = 7*6 = 42 R_0
- **Mesh** PT:
  - 4 λ's with spectrum reuse factor of 42/4 = 10.5
    - RCA?
  - 6 transceivers in each NAS
    $\Rightarrow$ network capacity = 7*6 = 42 R_0
- **Multistar** PT:
  - 2 λ's with spectrum reuse factor of 42/2 = 21
    - RCA?
  - 6 transceivers in each NAS
    $\Rightarrow$ network capacity = 7*6 = 42 R_0



LCG

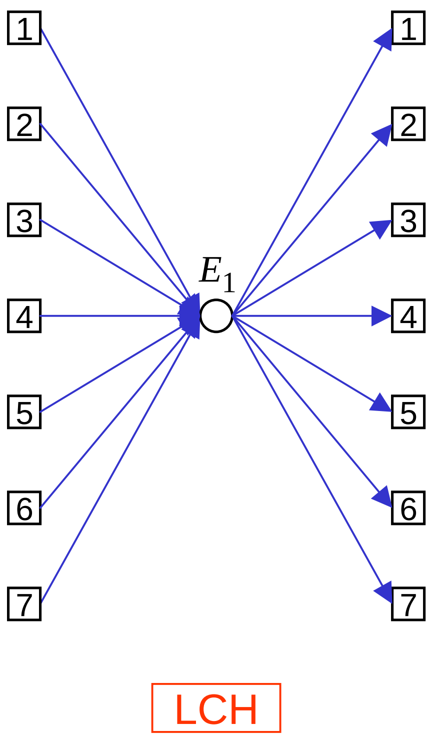
Fully shared LT: Broadcast and select network realizations

- Any PT
- **WDM/WDMA**:
  - 42 λ's with spectrum reuse factor of 1
  - 6 transceivers in each NAS

    $\Rightarrow$ network capacity = 7*6 = 42 R_0
- **TDM/T-WDMA** in FT-TR mode:
  - 7 λ's with spectrum reuse factor of 1
  - 1 transceiver in each NAS

    $\Rightarrow$ network capacity = 7*1 = 7 R_0
- **TDM/TDMA**:
  - 1 λ with spectrum reuse factor of 1
  - 1 transceiver in each NAS

    $\Rightarrow$ network capacity = 7*1/7 = 1 R_0

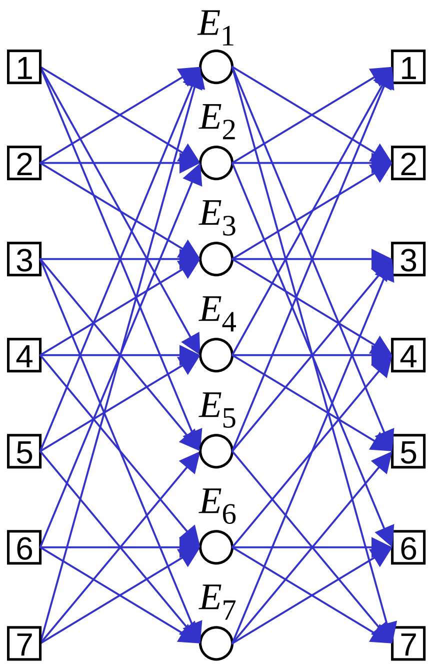


Partially shared LT: LLN realizations

- **Note**: Full logical connectivity among **all** stations
- **Mesh** PT using **TDM/T-WDMA** in FT-TR mode:
  - 2 wavebands with spectrum reuse factor of 7/2 = 3.5
    - RCA?
  - 3 λ's per waveband
  - 3 transceivers in each NAS

    $\Rightarrow$ network capacity = 7*3 = 21 R_0
- **Multistar** PT using **TDM/T-WDMA** in FT-TR mode:
  - 1 waveband with spectrum reuse factor of 7/1 = 7
    - RCA?
  - 3 λ's per waveband
  - 3 transceivers in each NAS

    $\Rightarrow$ network capacity = 7*3 = 21 R_0



LCH

Contents

Logically Routed Networks (LRN)

- For small networks, high logical connectivity is reasonably achieved by purely optical networks. However, when we move to larger networks, the transparent optical approach soon reaches its limits.
  - For example, to achieve the full logical connectivity among 22 stations on a bidirectional ring using wavelength routed point-to-point optical connections 21 transceivers are needed in each NAS and totally 61 wavelengths. Economically and technologically, this is well beyond current capabilities.
- Thus, we must turn to electronics (i.e. logically routed networks)
- **Logically routed network** (LRN) is such a hybrid optical network that
  - performs logical switching (by **logical switching nodes** (LSN)) on top of a transparent optical network
  - LSN's create an extra layer of connectivity between the end systems and the NAS's

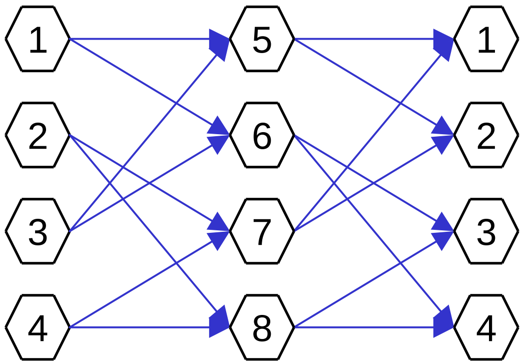
Two approaches to create full connectivity

- **Multihop networks** based on point-to-point logical topologies
  - realized by **WRN**'s
- **Hypernets** based on multipoint logical topologies
  - realized by **LLN**'s

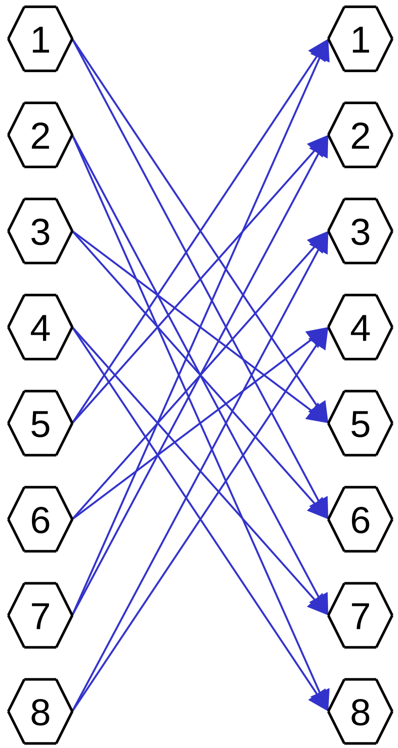
Point-to-point logical topologies

- In a point-to-point logical topology,
  - a hop corresponds to a logical link between two LSN’s
  - maximum throughput is inversely proportional to the average hop count
- One of the **objectives** of using logical switching on top of a transparent optical network is
  - to reduce the cost of the station equipment (by reducing the number of optical transceivers and the complexity of optics) while maintaining high network performance
- Thus, we are interested in logical topologies that
  - achieve a small average number of logical hops at a low cost (i.e., small node degree and simple optical components)
- An example is a **ShuffleNet**
  - for example, an eight-node ShuffleNet has 16 logical links and an average hop count of 2 (if uniform traffic is assumed)
  - these networks are scalable to large sizes by adding stages and/or increasing the degree of the nodes

Eight-node ShuffleNet



logical topology



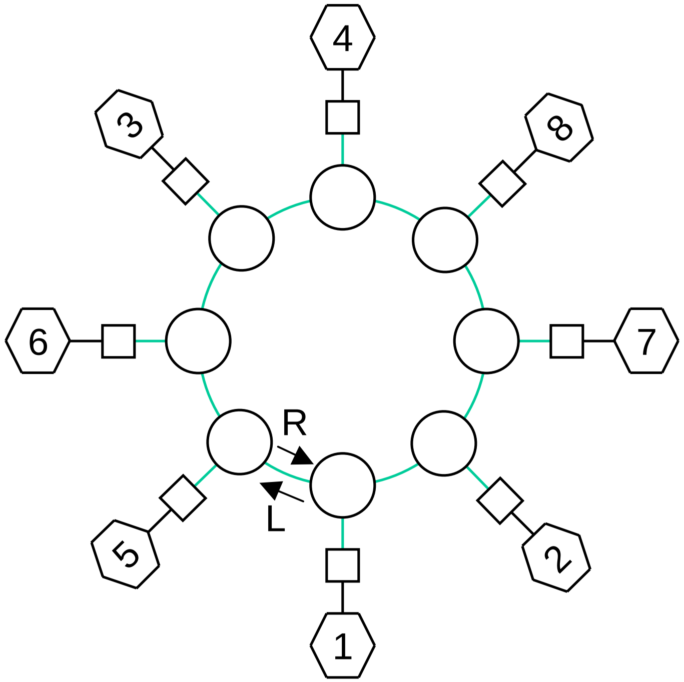
LCG

ShuffleNet embedded in a bidirectional ring WRN

- **Bidirectional ring WRN** with elementary NAS's
  - 2 λ's with spectrum reuse factor of 16/2 = 8
  - 2 transceivers in each NAS
  - average hop count = 2
    $\Rightarrow$ network cap. = 8*2/2 = 8 R_0

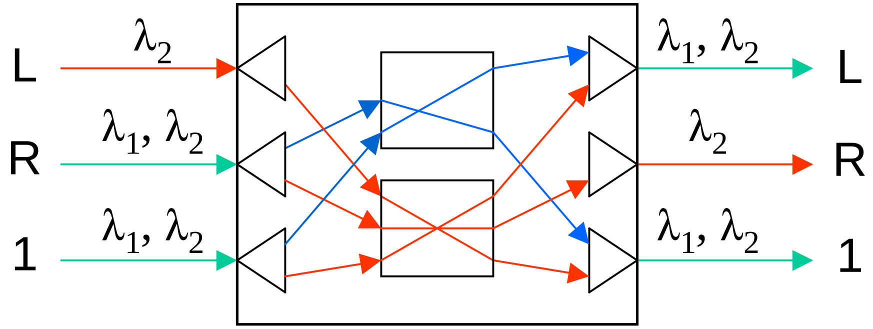
	1	2	3	4	5	6	7	8
1	--	--	--	--	1L	2L	--	--
2	--	--	--	--	--	--	1R	2R
3	--	--	--	--	2R	1R	--	--
4	--	--	--	--	--	--	2L	1L
5	1R	2R	--	--	--	--	--	--
6	--	--	1L	2L	--	--	--	--
7	2L	1L	--	--	--	--	--	--
8	--	--	2R	1R	--	--	--	--

RCA

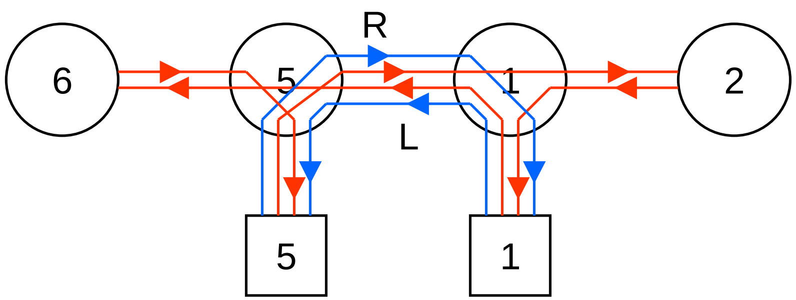


Note: station labeling!

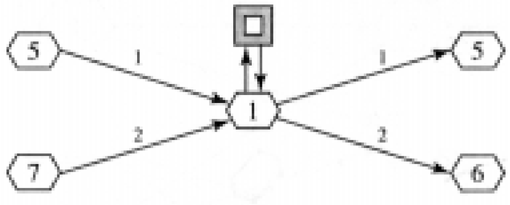
Details of a ShuffleNet node



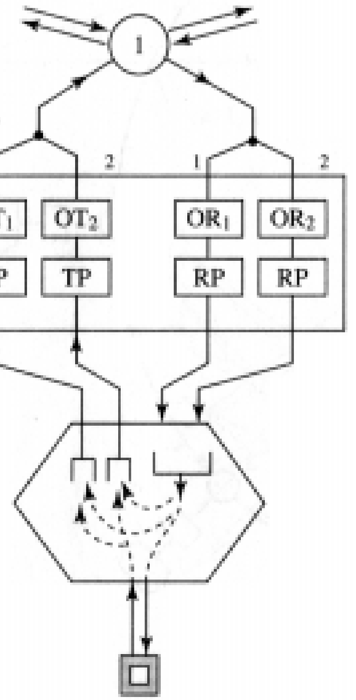
ONN1



Fibers between ONN5 and ONN1



(a)

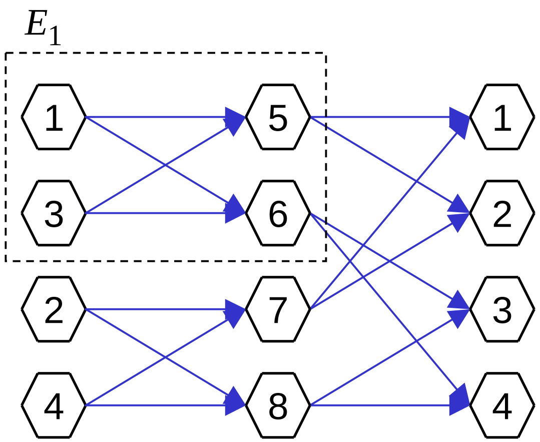


(b)

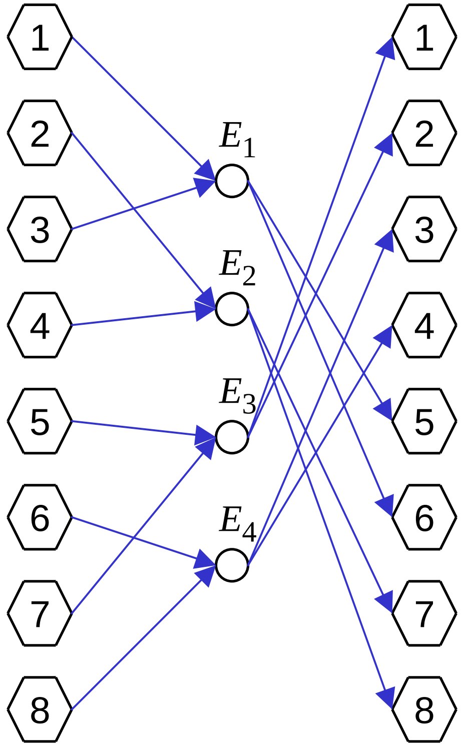
Multipoint logical topologies

- High connectivity may be maintained in transparent optical networks while economizing on optical resource utililization through the use of **multipoint connections**.
- These ideas are even more potent when combined with logical switching.
- For example, a ShuffleNet may be modified to a **Shuffle Hypernet**.
  - An eight-node Shuffle Hypernet has 4 hyperarcs
  - Each hyperarc presents a directed MPS that contains 2 transmitting and 2 receiving stations
  - An embedded directed broadcast star is created to support each MPS
  - For a directed star, a (physical) tree is found joining all stations in both the transmitting and receiving sets of the MPS
  - Any node on the tree can be chosen as a root
  - The LDC’s on the tree are set to create optical paths from all stations in the transmitting set to the root node, and paths from the root to all receiving stations

Eight-node Shuffle Hypernet



transformation



LCH

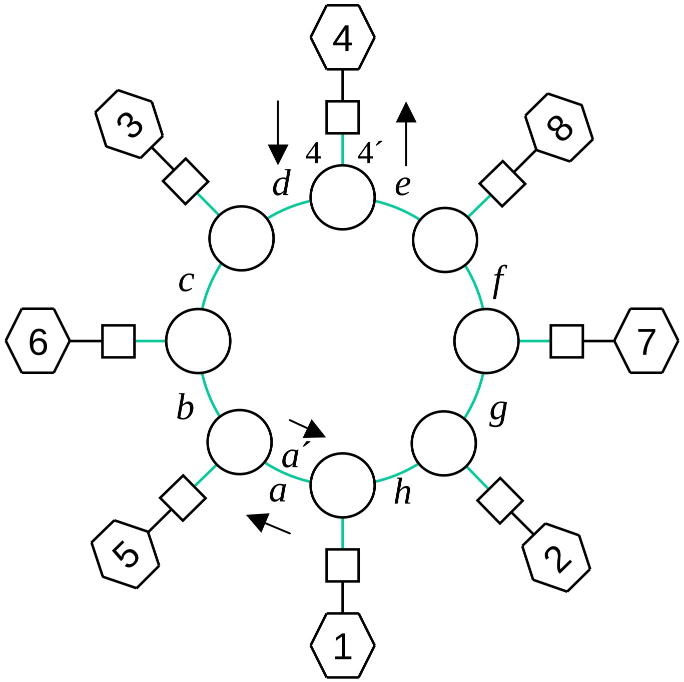
Shuffle Hypernet embedded in a bidirectional ring LLN

- **Bidirectional ring LLN** with elementary NAS's using **TDM/ T-WDMA** in FT-TR mode
  - 1 waveband with spectrum reuse factor of 4/1 = 4
  - 2 λ's per waveband
  - 1 transceiver in each NAS

  $\Rightarrow$ network cap. = 8*1/2 = 4 R_0

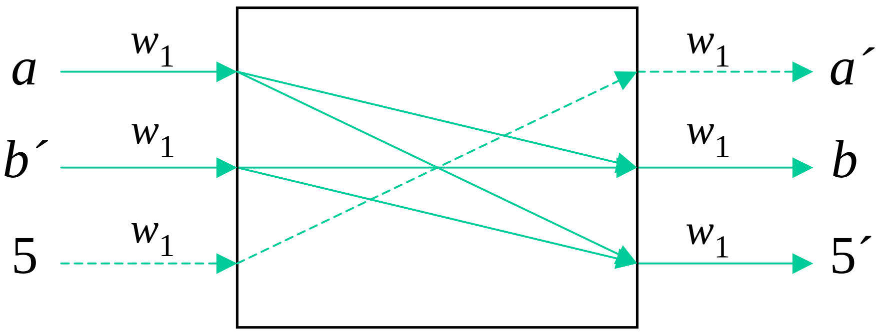
	inbound fibers	root	outbound fibers	wave-band
E_1	a, b', c'	ONN5	b	1
E_2	e, f', g'	ONN8	f	1
E_3	g, a', h'	ONN2	h	1
E_4	c, d', e'	ONN3	d	1

RCA

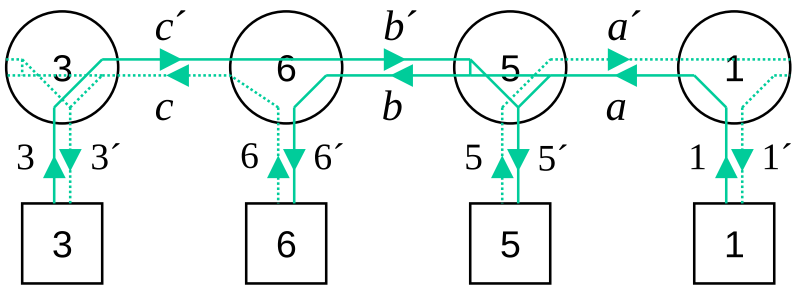


Note: station and fiber labeling!

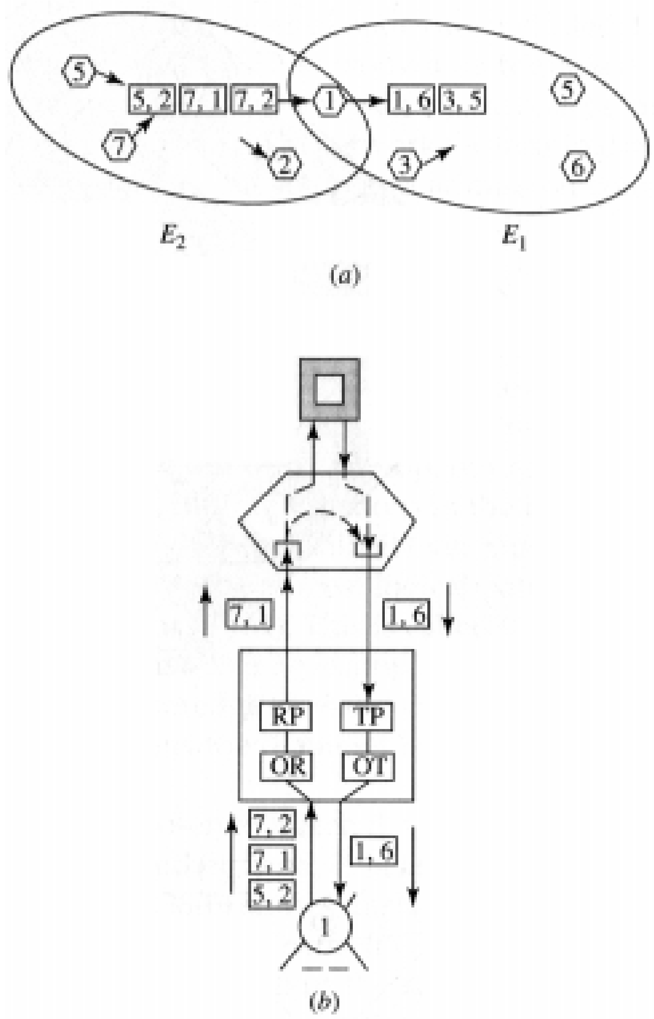
Details of node in Shuffle Hypernet



ONN5



Fibers between ONN3 and ONN1



Contents

- Static networks
- Wavelength Routed Networks (WRN)
- Linear Lightwave Networks (LLN)
- Logically Routed Networks (LRN)
  - Virtual connections: an ATM example

Virtual connections: an ATM example

- Recall the problem of providing full connectivity among five locations
  - This time, suppose each location contains a number of end systems that access the network through an ATM switch. The interconnected switches form a transport network of 5*4 = 20 VP’s.
- The following five designs are now examined and compared:
  - **Stand-alone ATM star**
  - **Stand-alone ATM bidirectional ring**
  - **ATM over a network of SONET cross-connects**
  - **ATM over a WRN**
  - **ATM over a LLN**
- Traffic demand:
  - Each VP requires 600 Mbps (≈ STS-12)
- Optical resources:
  - The λ-channels and the transceivers run at rate 2.4 Gbps (≈ STS-48)

Stand-alone ATM networks

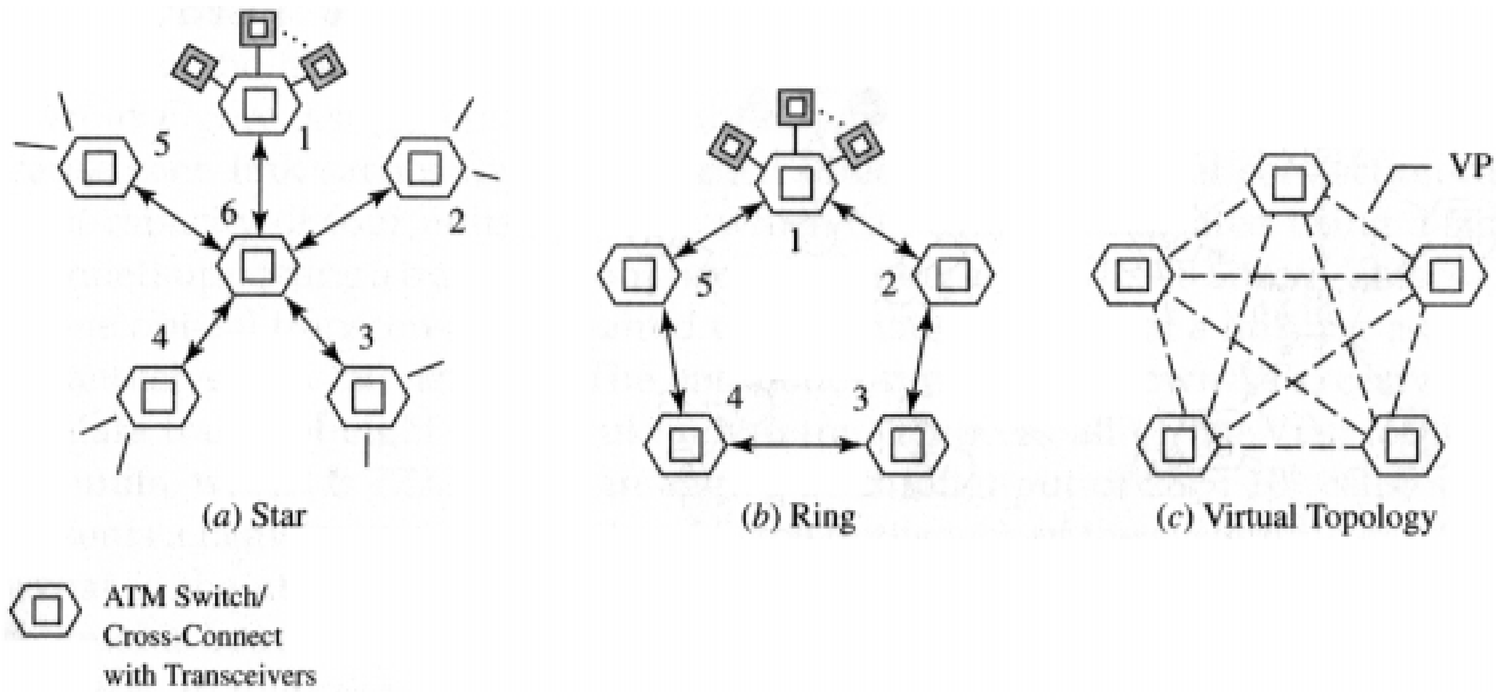


FIGURE 3.40 ATM stand-alone networks.

Embedded ATM networks
Figure 3.41, p. 160

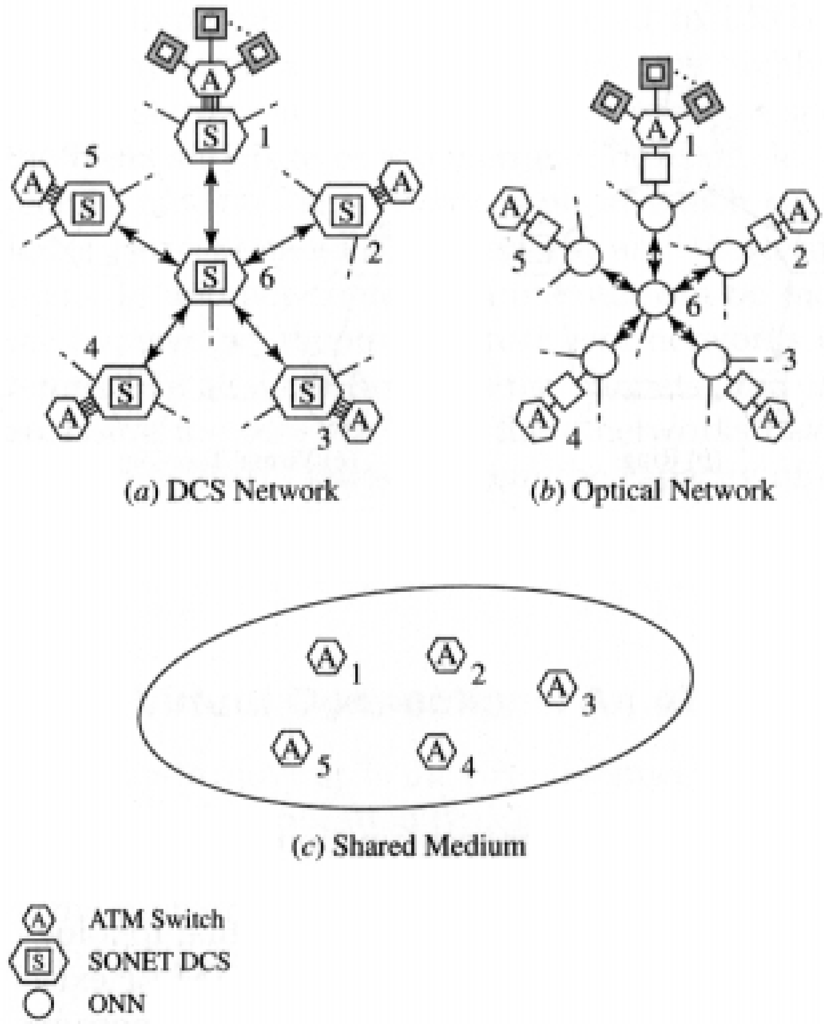


FIGURE 3.41 Embedded ATM network.

Case 1: Stand-alone ATM star

- The fiber links are connected directly to ports on the ATM switches, creating a point-to-point optical connection for each fiber
  - each link carries 4 VP's in each direction $\Rightarrow$ each optical connection needs 2.4 Gbps, which can be accomodated using a single λ-channel
  - thus, one optical transceiver is needed to terminate each end of a link, for a total of 10 transceivers in the network
- Processing load is unequal:
  - the end nodes process their own 8 VP's carrying 4.8 Gbps
  - center node 6 processes all 20 VP's carrying 12.0 Gbps $\Rightarrow$ **bottleneck**
- Inefficient utilization of fibers, since
  - even though only one λ-channel is used, the total bandwidth of each fiber is dedicated to this system
- Poor survivability, since
  - if any link is cut, then the network is cut in two
  - if node 6 fails, the network is completely distroyed

Case 2: Stand-alone ATM bidirectional ring

- Again, the fiber links are connected directly to ports on the ATM switches, creating a point-to-point optical connection for each fiber
  - assuming shortest path routing, each link carries 3 VP's in each direction $\Rightarrow$ each optical connection needs 1.8 Gbps, which can be accomodated using a single λ-channel (leaving 25% spare capacity)
  - again, 1 optical transceiver is needed to terminate each end of a link, for a total of 10 transceivers in the network
- Equal processing load:
  - each ATM node processes its own 8 VP's and 2 additional transit VP's carrying an aggregate traffic of 6.0 Gbps
- Thus,
  - no processing bottleneck,
  - the same problem with optical spectrum allocation as in case 1,
  - but better survivability, since the network can recover from any single link cut or node failure by rerouting the traffic

Case 3: ATM embedded in DCS network

- ATM end nodes access DCS’s through 4 electronic ports
- The fiber links are now connected to ports on the DCS’s, creating a point-to-point optical connection for each fiber
  - each link carries 4 VP’s in each direction $\Rightarrow$ each optical connection needs 2.4 Gbps, which can be accomodated using a single λ-channel
  - again, 1 optical transceiver is needed to terminate each end of a link
- Processing load is lighter:
  - ATM nodes process their own 8 VP’s carrying 4.8 Gbps
  - but it is much simpler to perform VP cross-connect functions at the STS-12 level than at the ATM cell level (as was done in case 1)
- A trade-off must be found btw optical spectrum utilization and costs
  - the more λ-channels on each fiber (to carry “background” traffic), the more (expensive) transceivers are needed
- Survivability and reconfigurability are good
  - since alternate paths and additional bandwidth exist in the DCS network

Case 4: ATM embedded in a WRN

- The DCS's are now replaced by optical nodes containing WSXC's
- Each ATM end node is connected electronically to an NAS
- Each VP in the virtual topology must be supported by
  - a point-to-point optical connection occupying one λ-channel
  - thus, 4 tranceivers are needed in each NAS (and totally 20 transceivers)
  - however, no tranceivers are needed in the network nodes
- With an optimal routing and wavelength assignment,
  - the 20 VP's can be carried using 4 wavelengths (= 800 GHz)
- Processing load is very light,
  - due to optical switching (without optoelectronic conversion at each node)
  - Note: ATM nodes still process their own 8 VP's carrying 4.8 Gbps
- As in case 3, survivability and reconfigurability are good
  - since alternate paths and additional bandwidth exist in the underlying WRN

Case 5: ATM embedded in an LLN

- The WSXC's are now replaced by LDC's
- A single waveband is assigned to the ATM network, and the LDC's are set to create an embedded tree (MPS) on that waveband
  - the 20 VP's are supported by a single hyperedge in the logical topology
  - since each λ-channel can carry 4 VP's,
    5 λ-channels are needed totally, all in the same waveband (= 200 GHz)
  - only 1 tranceiver is needed in each NAS (and totally 5 transceivers) using TDM/T-WDMA in FT-TR mode
- Processing load is again very light,
  - due to optical switching (without optoelectronic conversion at each node)
  - Note: ATM nodes still process their own 8 VP's carrying 4.8 Gbps
- As in cases 3 and 4, survivability and reconfigurability are good
  - since alternate paths and additional bandwidth exist in the underlying LLN

Comparison of ATM network realizations

TABLE 3.5 Comparison of ATM Network Realizations

Case	Optical Spectrum Usage	No. of Optical Transceivers	Node Processing Load	Other
1	Very high	10	Very high	Poor survivability
2	Very high	10	High	—
3	Lowest	10	Medium	High DCS cost
4	Medium	20	Very low	—
5	Low	5	Very low	Rapid tunability required, optical multicast possible

THE END