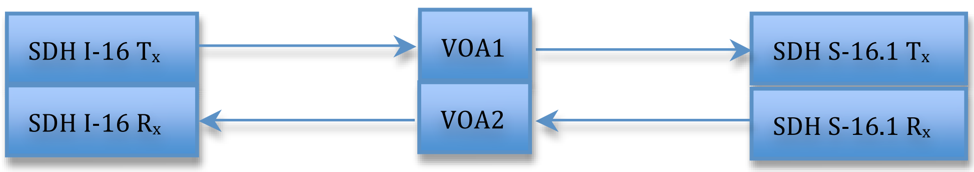
Homework 1 Solutions

Problem 6.1 (Ramaswami)

a. Path Layer
b. Line Layer
c. Link Layer
d. Section Layer
e. Physical Layer

Problem 6.3 (Ramaswami)

We have to connect a bi-directional link with SDH transponders, one with a I-16 interface and the other with a S-16.1 interface as shown below. We are allowed to use a variable optical attenuator (VOA) in each fiber path to make the links work between these two different interface standards.



We must connect the following transmitters and receivers for Link 1 and 2. The VOAs can be adjusted according to the link budgets.

	Link 1	**Link 2**
Transmitter Power (max)	-3 dBm	0 dBm
Transmitter Power (min)	-10 dBm	-5 dBm
Receiver Sensitivity (min)	-27 dBm	-18 dBm
Receiver Overload (min)	-27 dBm	-18 dBm
VOA Max	24 dB	18 dB
VOA Min	17 dB	13 dB

Problem 6.4 (Ramaswami)

a. Block size = 1KByte, link length = 1km
   - Block transmission duration = 8,000 bits /17 Mbps = 470.6 μs
   - Link latency = 1km/2x10^5 km/s = 5 μs
   - Throughput is 1 block/(transmission duration + link latency) = 1/(470.6 μs + 5 μs) = 2103 Blocks/sec = 14.54 MB/sec

b. Block size = 1KByte, link length = 10km
   - Block transmission duration = 8,000 bits /17 Mbps = 470.6 μs
   - Link latency = 1km/2x10^5 km/s = 50 μs
   - Throughput is 1 block/(transmission duration + round trip time) = 1/(470.6 μs + 50 μs) = 1921 Blocks/sec = 6.3 MB/Sec

c. Block size = 1KByte, link length = 100km

- Block transmission duration = 8,000 bits /17 Mbps = 470.6 μs
- Link latency = 1km/2x10^5 km/s = 500 μs
- Throughput is 1 block/(transmission duration + round trip time) = 1/(470.6 μs + 500 μs) = 1030 Blocks/sec = 944.5 kB/Sec

d. Block size = 4KByte, link length = 10km
- Block transmission duration = 32,000 bits /17 Mbps = 1880 μs
- Link latency = 1km/2x10^5 km/s = 50 μs
- Throughput is 1 block/(transmission duration + round trip time) = 1/(1880 μs + 50 μs) = 518 Blocks/sec = 11.93 MB/Sec

e. Block size = 4KByte, link length = 100km
- Block transmission duration = 32,000 bits /17 Mbps = 1880 μs
- Link latency = 1km/2x10^5 km/s = 500 μs
- Throughput is 1 block/(transmission duration + round trip time) = 1/(1880 μs + 500 μs) = 420 Blocks/sec = 3.24 MB/Sec

Problem 7.1 (Ramaswami)

Nodes A and B are next to each other in an all-optical OADM ring network. We do not have details of the other nodes or links in the network, we only know that the minimum received optical power is -30dBm at each OADM receiver (drop port), 0dBm at each OADM transmitter (add port), that adjacent channel crosstalk at the drop port receiver must be better than -15dB, and that the optical loss for add and drop is 0dB.

The problem assumes Node A adds wavelength λ_1 to the ring network and this lambda passes through Node B without being dropped while at the same time λ_2 has been transmitted at a upstream to Node A, is passed through Node A and then is dropped at Node B.

We are asked to calculate the crosstalk suppression at each OADM to meet these requirements. At first lets assume there is no link loss, then

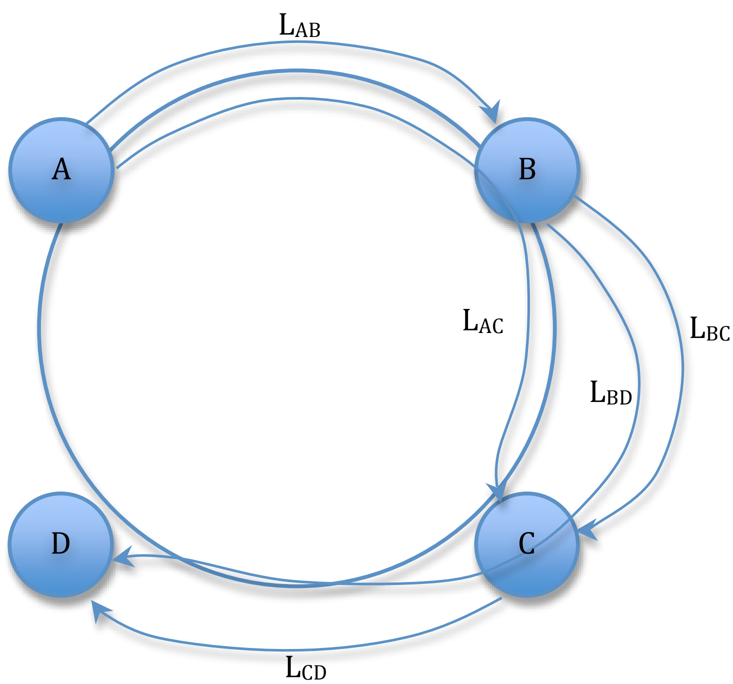
- Model the OADM at Node B as an optical filter that passes λ_1 to the Ring output link of Node B with zero loss and reflects λ_2 to the drop port receiver at Node B with zero loss. Consider the case where 0dBm at λ_1 is injected onto the ring at Node A and that λ_2 is dropped at node B at the minimum receiver sensitivity of -30dBm (note that independent of where λ_2 originates, the cumulative link and OADM through-going losses does not allow the dropped channel to decrease lower than the receiver sensitivity). Assuming that λ_2 is dropped with its highest cumulative loss (worst case), the optical power in λ_1 that is reflected by the filter at Node B and is received by the drop receiver recovering λ_1, the crosstalk power cannot exceed -45 dBm (15 dB down from the minimum received power) and the adjacent channel crosstalk suppression of the OADM must be -45dB or better. As the link loss increases between Nodes A and B, both the through-going and dropped signals at Node

B experience the same additional loss, and the OADM crosstalk requirements do not change.

- Now we consider the case where Node A adds a wavelength channel at λ_1, which is dropped at Node B, while Node B also adds a channel at wavelength λ_1 to the ring network. Since any crosstalk due to λ_1 from Node A passing through Node B and mixes with λ_1 added at node B (at the Node ring output and eventually downstream dropped port photodetector) will result in "coherent" crosstalk (same wavelength). The coherent crosstalk requirements are stricter (-30dB). The OADM crosstalk requirements, assuming worst-case received power (-30dBm) is -60dB. The link loss has a different effect in this problem than in the previous part. Since the channel added at Node A experiences the link loss, which decreases the signal that leaks through Node B and is coherently added to λ_1 added at Node B, the crosstalk requirements will relax linearly with the link loss (e.g. 10dB additional link loss will reduce OADM crosstalk requirements by 10dB).

Problem 7.2 (Ramaswami)

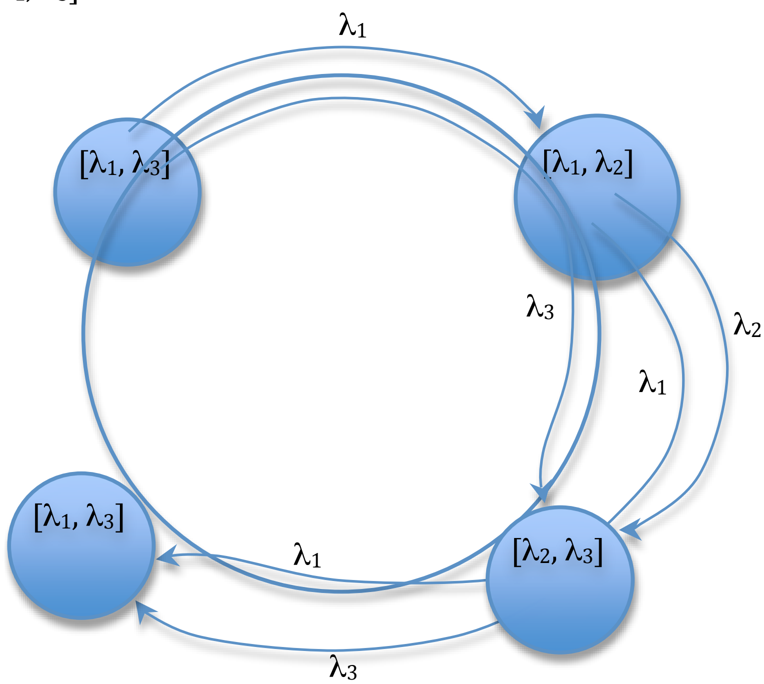
In this problem we are given OADMs with one of four possible drop configurations: [λ_1, λ_2], [λ_2, λ_3] or [λ_1, λ_3]. Lets also assume the add wavelengths for a given node are the same as the drop wavelengths. We need to set up lightpaths: L_{AB}, L_{BC}, L_{CD}, L_{AC}, and L_{BD}. This is illustrated in the following figure:



A possible routing wavelength assignment (RWA) using the possible OADM configurations is given in the following table, where there is no wavelength blocking on any particular link:

Lightpath	Link AB	Link BC	Link CD
L_{AB}	λ_1		
L_{BC}		λ_2	
L_{CD}			λ_3
L_{AC}	λ_3	λ_3	
L_{BD}		λ_1	λ_1

The OADM configurations would be: Node A - [λ_1, λ_3]; Node B - [λ_1, λ_2]; Node C - [λ_2, λ_3]; Node D - [λ_1, λ_3].

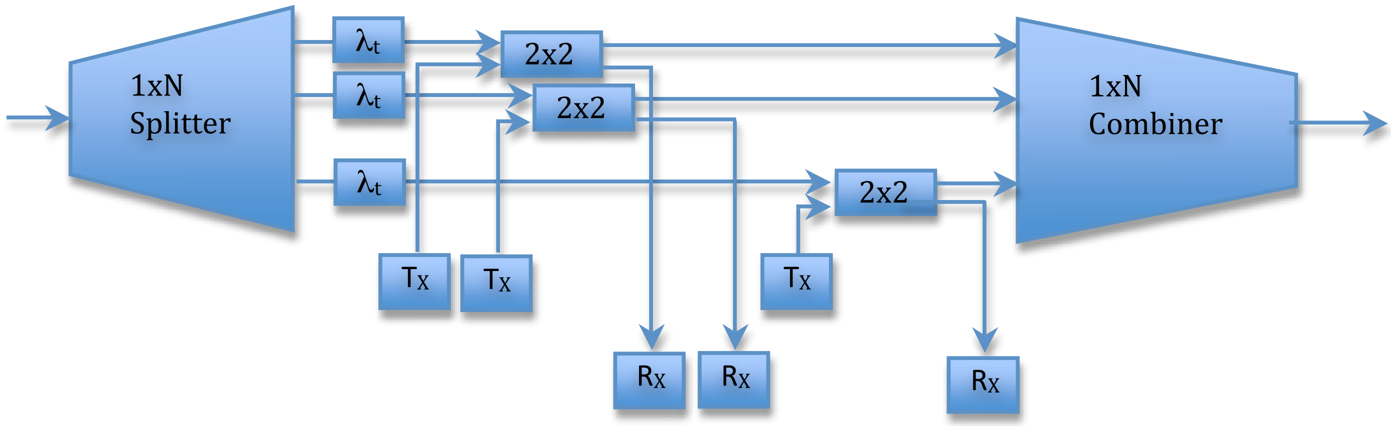


In the case where we need to replace AC and BD by AD and BC, we would need to change the node configurations to the following: Node A - [λ_1, λ_2]; Node B - [λ_2, λ_3]; Node C - [λ_2, λ_3]; Node D - [λ_1, λ_3] so that λ_1 can be used to setup a lightpath from A to D without blocking any of the other links/lightpaths.

Problem 7.4 (Ramaswami)

In this problem we are asked to use tunable optical filters, passive splitters/combiners and 2x2 optical switches to build a fully reconfigurable OADM in order to meet properties (1) and (2) and a special case of property (3) where the loss is fixed (but can be high) independent of how many channels are add/dropped.

The following configuration meets these requirements although at the expense of the splitter/combiner losses scaling as 3dB*Log_2N + excess losses.



Problem 7.5 (Ramaswami)

The following table can be used to compare the cost of the two hub node ring network configurations with four remote nodes. Assume each band is used to transmit in the opposite direction on a bidirectional to/from the hub node. Assume a regenerator can receive one wavelength (in one band) and re-transmit on another wavelength (in the other band). Assume each band demux only outputs on of the two bands.

	Configuration 1	**Configuration 2**
Remote Node	Band Demux ($20k/each) + 4*Regenerator ($10k/each)	SC-OADM ($10k/each)
Hub	2*Band Demux ($20k/each) + 8*Regenerator ($10k/each)	8*Regenerator ($10k/each)
Transmission Fiber		2*Optical Amplifiers ($30k/each)
Total Cost	4*[$20k +4*$10k] + 2*[$20k] + 8*[$10k] = **$360k**	4*[$10k] + 8*[$10k] + 2*[$20k] = **$160k**