Optical Networking System3

Interactive learning module

University Program
Photonics Curriculum Version 8.0

Outline

- The major objective of this interactive module is to illustrate several concepts in optical networking.

- The areas covered through the use of demonstrations are:
  - Network Capacity
  - Multiplexing of Services
  - Ring Topologies
  - Optical Switching
  - Optical Packet Networks
  - Network Protection

- Each topic is composed of three sections
  - Exercise description
  - Questions

Network Capacity

- The examples in this area demonstrate how the optical communications can support large transmission capacities by using two methods.
  - *"10G-40G upgrade ..."* increases single link speed
  - *"64x10 Gbps over 7500 km..."* using multiple wavelengths.

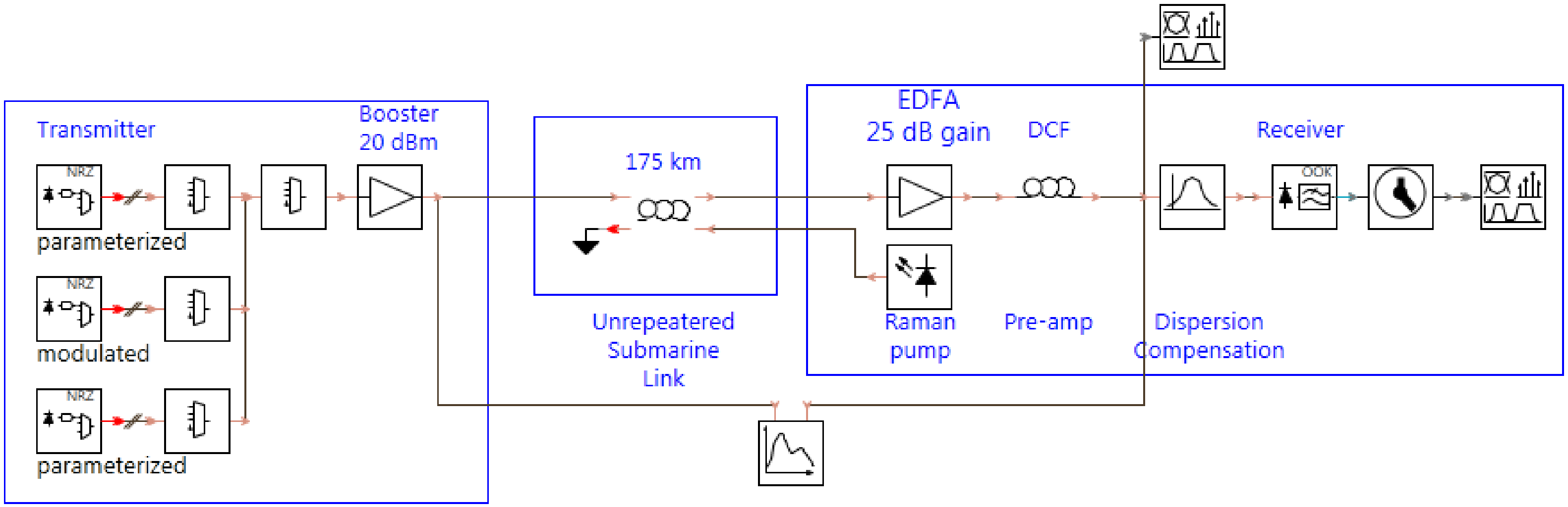
- Notice the techniques employed to compensate attenuation and dispersion problems to support long distances and large capacities.

10G-40G upgrade (1)

- The system compares the operation of a link using 10Gbps and upgrading to 40Gbps channels.
- Open the simulation file OS1-10G: here the bit rate per channel is 10Gbps
- Open the file and examine the system construction
- Execute the simulation (with the Raman pump off). Plot the output OSNR vs. frequency. What is the BER of the measured channel?
- Open the file OS1-40G: here the channels operate at 40Gbps. Proceed as in the previous case, and compare the cases with Raman pump on and off.
- **Question 1A:** What is the effect in the Optical SNR (OSNR) of the simple increase in transmission capacity?
- **Question 1B:** How can the OSNR be compensated for higher speeds?
- **Question 1C:** What is the effect on the output OSNR and BER of changing the booster output power and Noise Figure?

10G-40G Upgrade using Raman Amplifier

A 175 km unrepeatered link is shown below with a booster amplifier at the transmitter and pre-amp at the receiver.
The benefits of Raman amplification are shown, allowing an upgrade from 10 Gbps to 40 Gbps.
This is achieved by backward pumping the transmission fiber from the receiver terminal end.



1. Run the sweep.
   OSNR at the receiver is shown for the following cases:
   10 Gbps
   40 Gbps (6 dB drop in OSNR)
   40 Gbps with Raman pump ON (OSNR recovers)

   Without Raman amplification, a 6-dB OSNR degradation occurs due to the 6-dB increase in receiver bandwidth.
   With Raman gain, the OSNR improves at 40 Gbps, allowing an upgrade to 40 Gbps.
   This demo illustrates the benefits of distributed gain offered by Raman amplification.

2. Vary booster and Pre-amp Gain and Noise Figure and note the effect on OSNR.

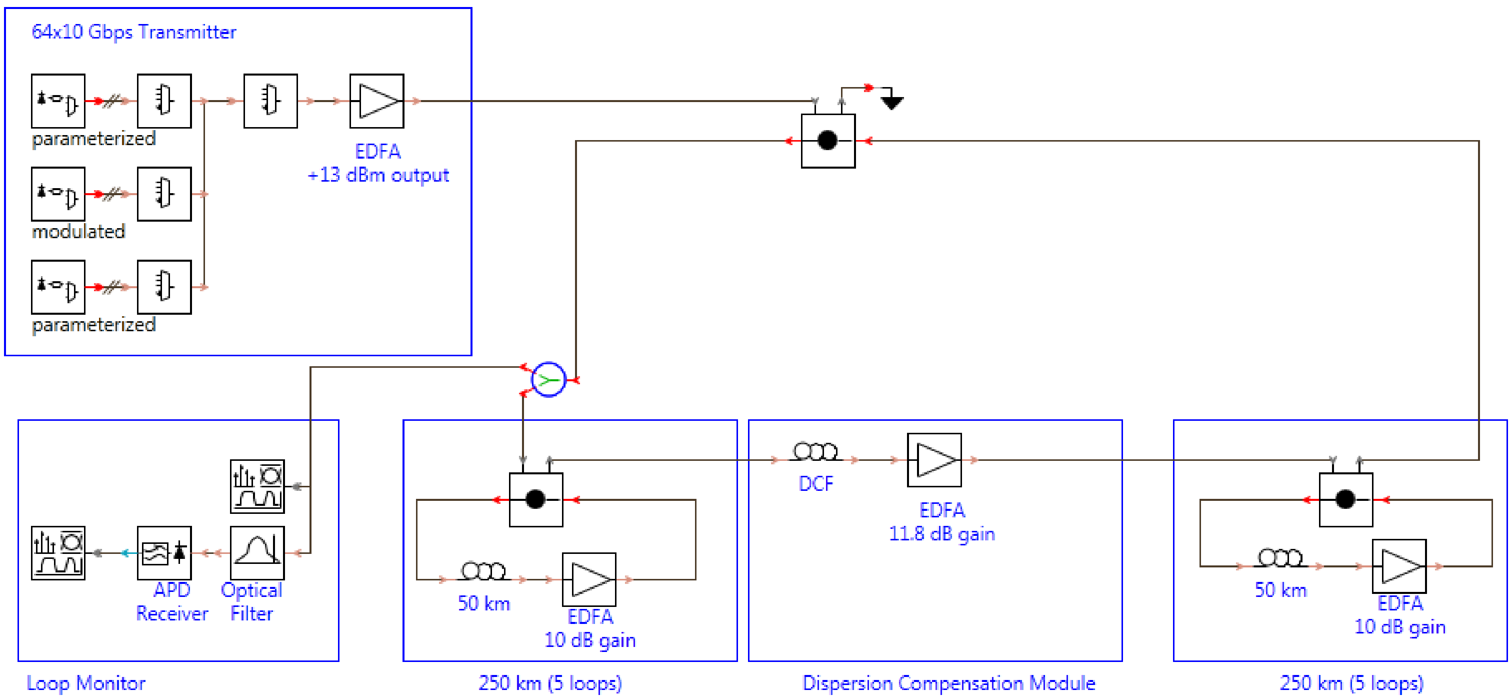
64x10 Gbps Over 7500 km (1)

- The system demonstrates the operation of a system with 64 channels 10 Gbps each. The transmission covers 7500 km.
- Open the simulation file OS2 and examine the system construction. Notice the use of loops to simplify the model and avoid repeated segments
- Execute the simulations following the instructions on the page.
- **Question 2A:** What is the effect of the nonlinearities in the link quality? What is the optimal power (dBm) at the transmitter output?
- **Question 2B:** Why a DCF fiber is needed? What is the optimal value of dispersion for the DCF? What is the effect of the dispersion slope of the DCF?

64x10 Gbps Over 7500 Km (2)

64x10 Gbps over 7500 km

The degradation of Optical Signal to Noise Ratio in a dispersion-compensated 64-channel 10 Gbps NRZ WDM system is shown over 7500 km. Nonlinear effects are turned off to enable fast simulation times.



Instructions

1) Run demo. The loop monitor displays the optical spectrum at the input of every loop iteration, together with the eye diagram of the middle modulated channel.

2) For a more realistic simulation including non-linear effects, change global parameter "NonlinearIndex Enabled" to 1. Simulation times will increase.
Vary the transmitter amplifier output power and observe the impact of non-linear effects on the received eye.
Investigate the effect of dispersion by changing the DCF fiber dispersion. Increase dispersion slope and see how this affects the eye.
Change optical filter bandwidths at the receiver and observe the critical importance of optical filtering.

Multiplexing of services, Mixed Metro (1)

- This model shows how several services can be mixed in the same transmission system for application in a metropolitan access network.
- Open the simulation file OS3
- Examine the system construction.
- Execute the simulations following the instructions on the page.

- **Question 3A:** Which is the wavelength band allocated for the 2.5 and 10 Gbps channels according to the model and which is the spectrum shown in the OSA? Are they the same?
- **Question 3B:** Increase the fiber length from 50 km up to 100 km, and discuss which channels (bit rate) are most degraded as the length is increased.
- **Question 3C:** Is it possible to improve the maximum transmission distance with respect to point 3B by varying the input power?

Mixed Service Metro System (2)

Mixed Services Metro System
40 Channel x 2.5 Gbit/s 25-GHz Spacing
10 channel x 10 Gbit/s 100-GHz Spacing

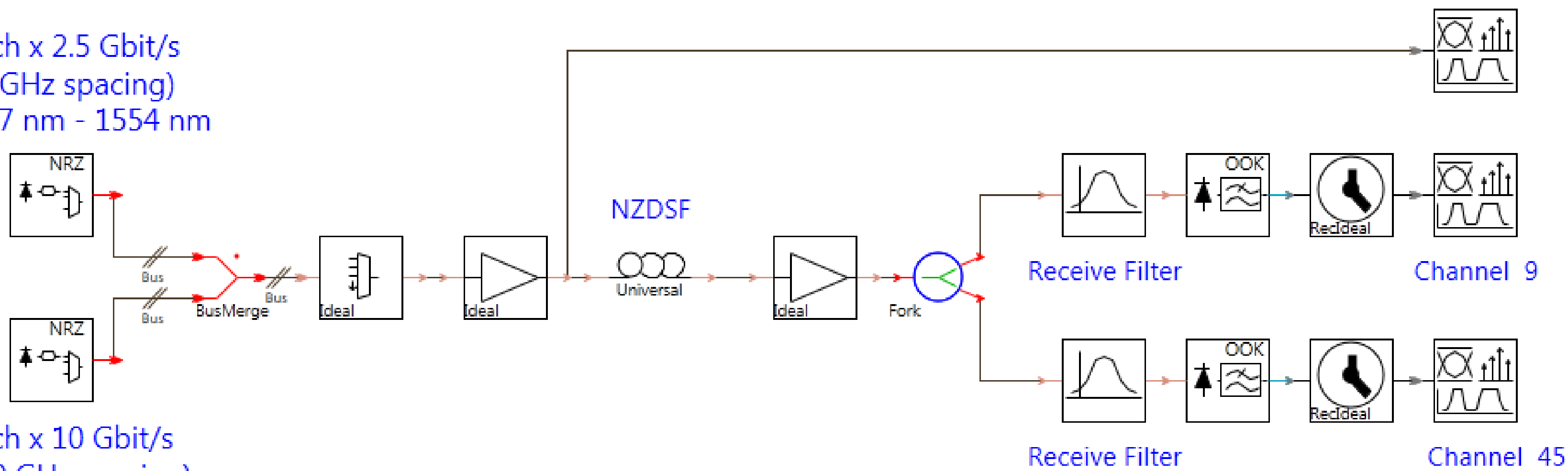
1538-1554 nm (C-band)

This demonstrates the ability to simulate the system with several different data rates.

The data rates may be defined globally, or within individual transmitters.
Global variables can be added for as many data rates as required.

All data rates must be different by factors of 2^n.

40 ch x 2.5 Gbit/s
(25 GHz spacing)
1547 nm - 1554 nm



10 ch x 10 Gbit/s
(100 GHz spacing)
1538 nm - 1545 nm

Ring Topologies

- Most optical networks are deployed using ring topologies establishing protection mechanisms.
- One of the most common design problems in ring topologies is the routing of optical channels.

We will examine two cases

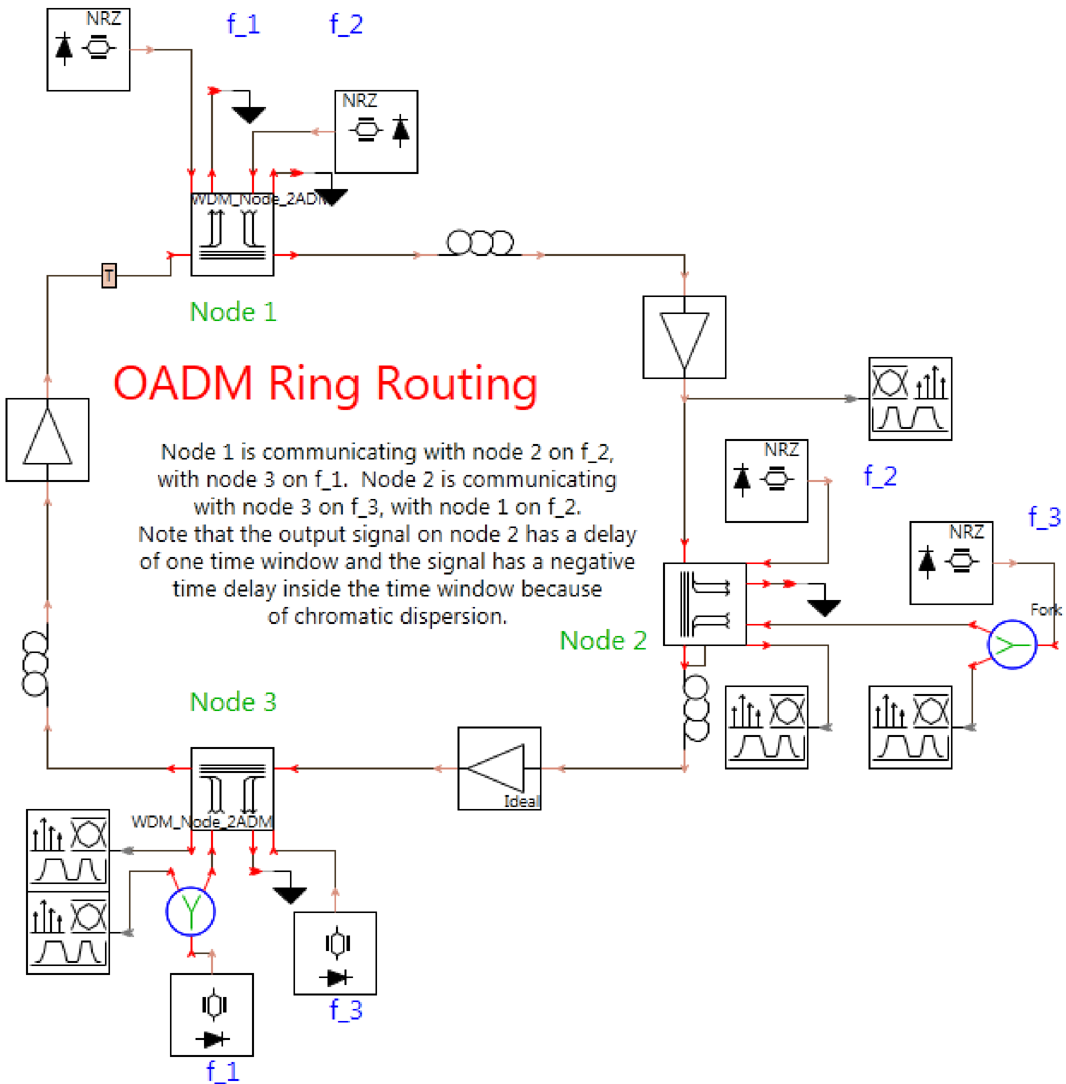
- Single Ring Routing
- Three Rings with OXC & ADM

Ring Routing (1)

- The first system is a unidirectional ring created by using point-to-point fiber segments between Add Drop Multiplexers (ADMs).
- Open the simulation file OS4
- Examine the construction, in particular locate the ADMs.
- Execute the simulation.

- **Question 4A:** How is the signal routed from the entry points to the exits?
- **Question 4B:** Is the communication between end nodes unidirectional or bidirectional?
- **Question 4C:** How many wavelengths are occupied in each fiber segment, and how many are added / dropped in each node?
- Question 4D: What is the effect of increasing the fiber lengths from 80 km to 120 km?

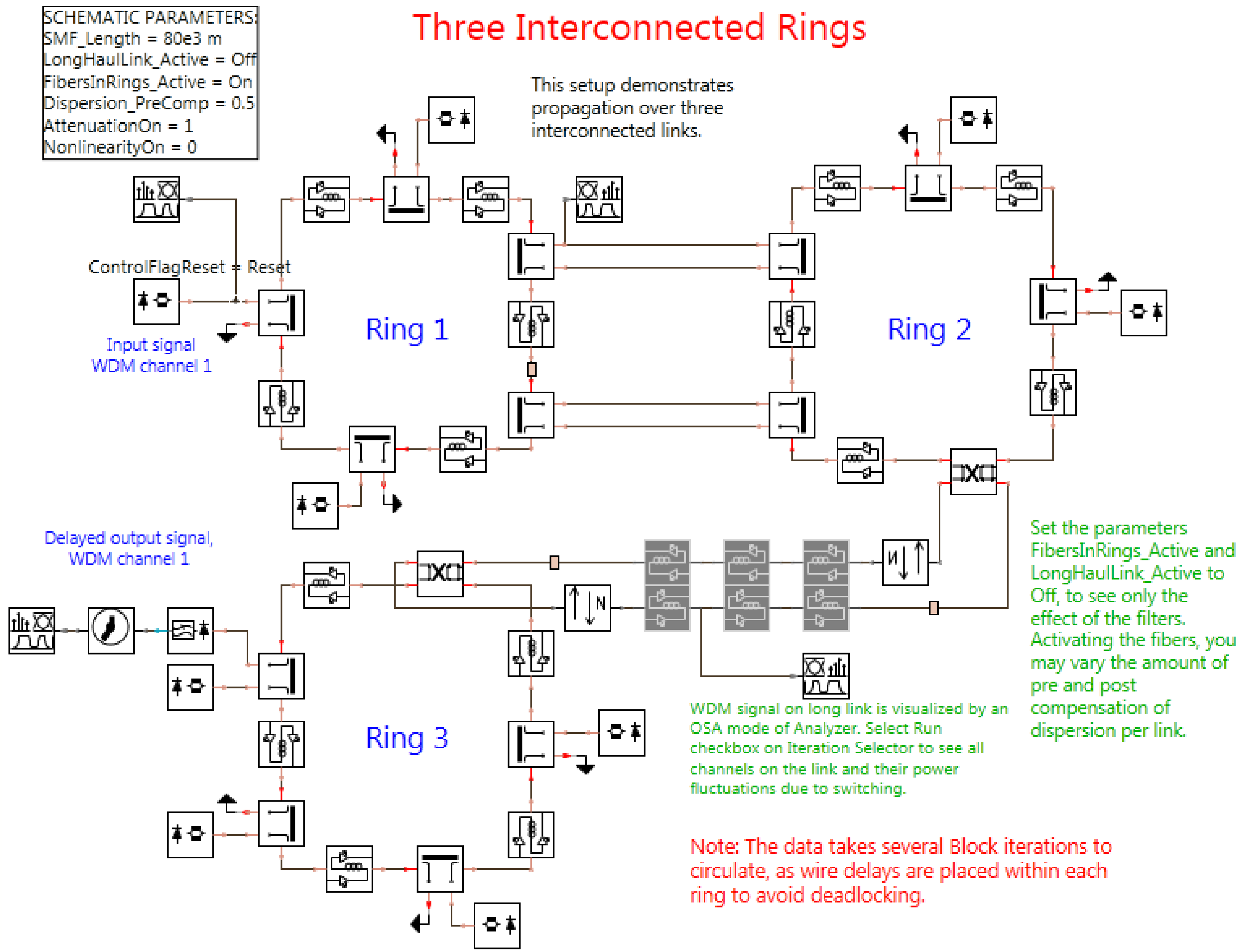
Ring Routing (2)



3x Ring with OXC & ADM (1)

- The second ring system consists of three rings linked by ADMs and Optical Cross Connects (OXCs).
- Open the simulation file OS5 and examine the construction, in particular identify the ADMs.
- Execute the simulation.
- **Question 5A:** How many wavelengths are extracted in each ADM?
- **Question 5B:** How many channels can be exchanged between ring 1 and ring 2?
- **Question 5C:** How many channels can be exchanged between ring 3 and ring 2?
- **Question 5D:** How is the signal routed from the entry points to the exits?
- **Question 5E:** Set the parameters FibersInRings_Active and LongHaulLink_Active to Off, to see only the effect of the filters. Activating the fibers, you may vary the amount of pre and post compensation of dispersion per link and discuss the results.

3x Ring with OXC & ADM (2)



Optical Switching (1)

- Complex optical systems are impractical to implement with simple ADMs. Optical switches or cross connects allow greater flexibility. The next simulation demonstrates the operation of an OXC.
- The WDM cross connect has two input fibers and two outputs. Each fiber carries 4 different wavelengths.
- Open the simulation file OS6 and examine the construction, in particular look inside the OXC and internal modules (see next pages).
- Execute the simulation.

- **Question 6A:** Inside the OXC which are the functions of the *demux* and *mux* devices?
- **Question 6B:** The switch fabric is made of multiple smaller blocks. How many 2x2 switching blocks are in total in this switch?
- **Question 6C:** Why do we need frequency converters?

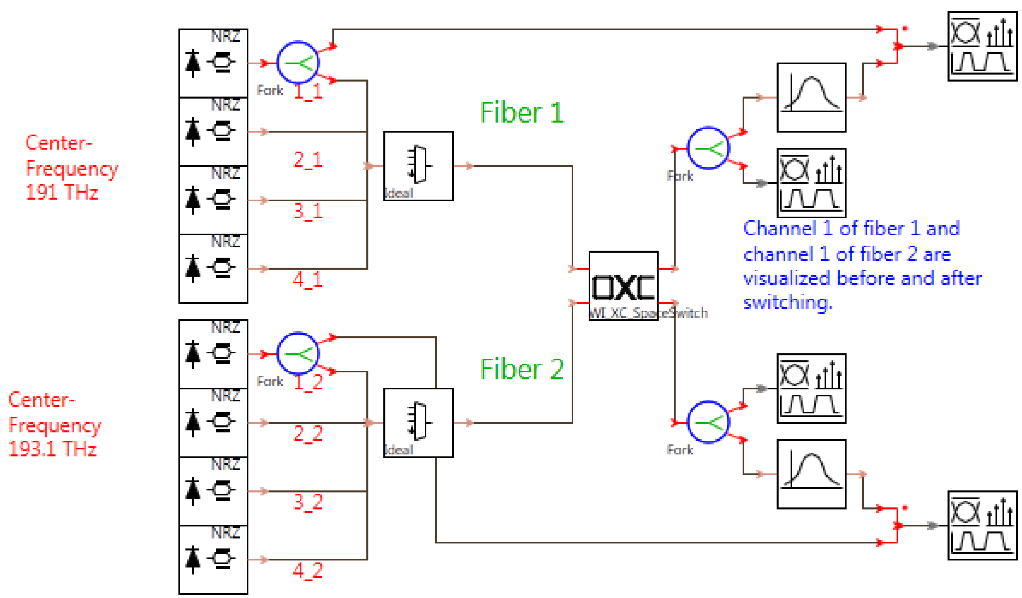
WDM Cross connect (2)

WDM Cross-Connect

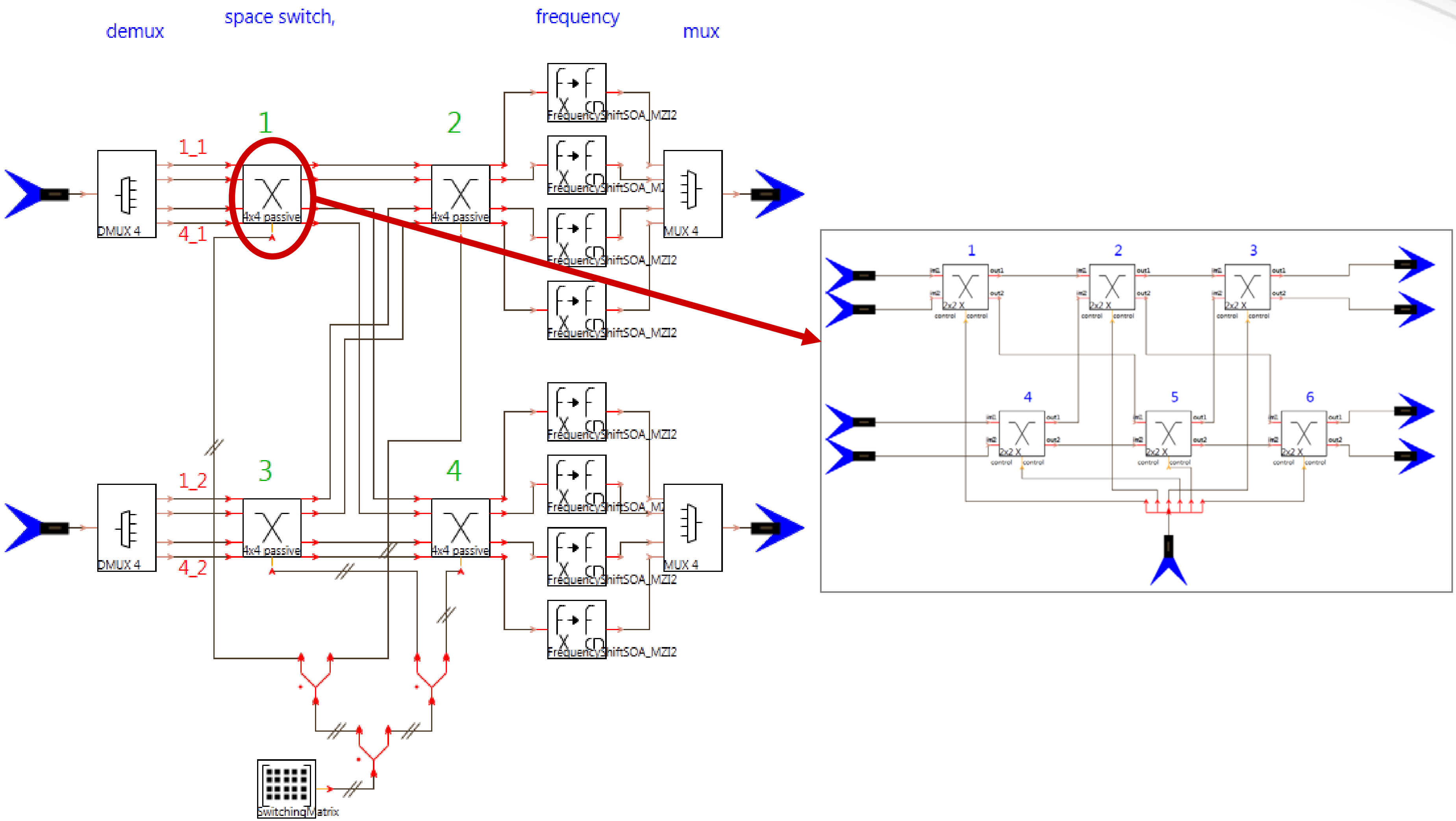
Two frequency channels from one input are switched to any frequency of the other output. This is done by a 4x6 switching matrix which controls the space switches inside the OXC.

Switching matrix	Output behavior: output 1	output 2
0 1 0 0 1 0	1_2	1_1
0 1 0 0 1 0	2_2	2_1
0 0 0 0 0 0	3_1	3_2
0 0 0 0 0 0	4_1	4_2

Switching matrix	output 1	output 2
0 0 0 0 0 0	1_1	1_2
0 0 0 0 0 0	2_1	2_2
0 1 0 0 1 0	3_2	3_1
0 1 0 0 1 0	4_2	4_1



WDM Cross connect (3)



Optical Packet Networks (1)

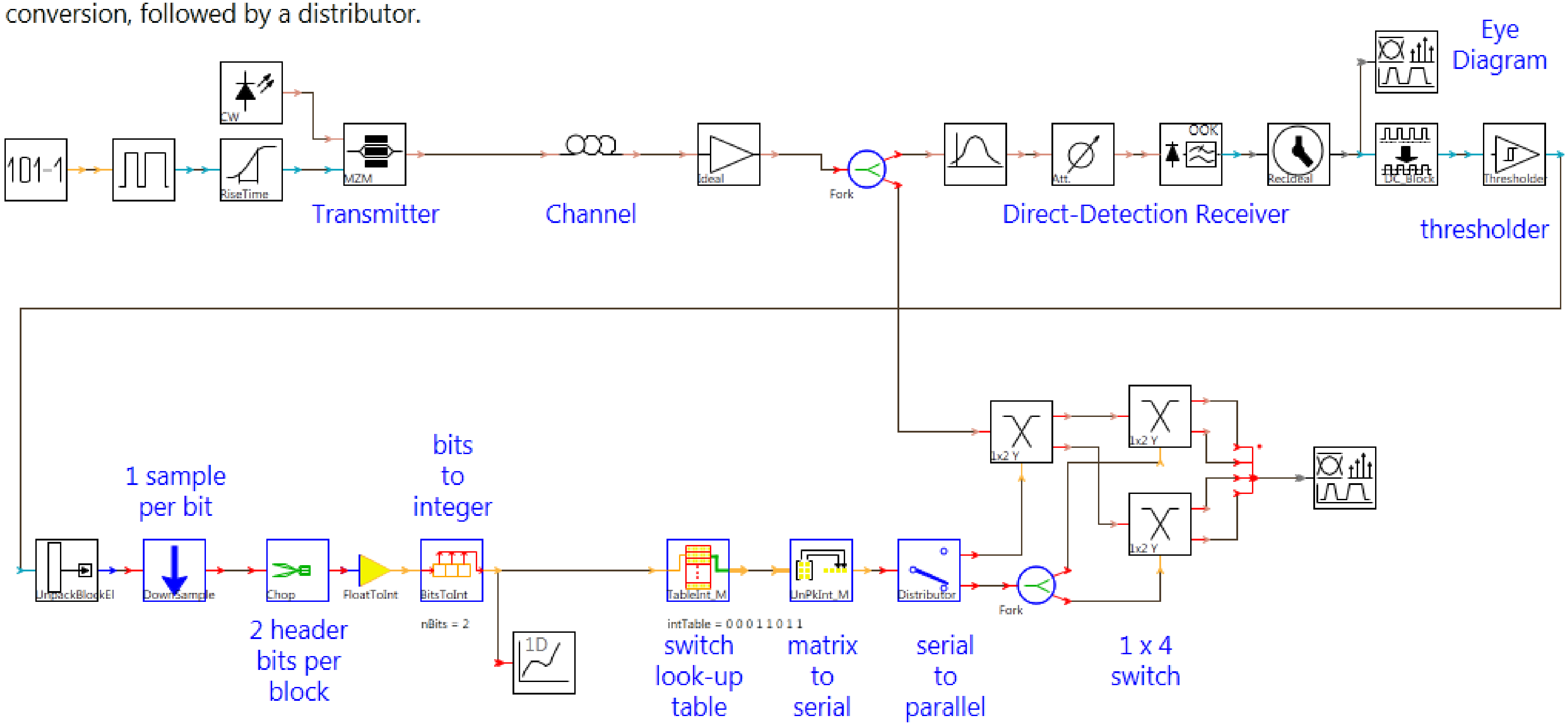
- Optical packets are still under research. The major difficulty consists of holding the packet while the header is processed.
- One of the proposed approaches consists in identifying the destination by the initial bits of the packet. The arriving packet is copied in two paths, one will be directed toward the switch fabric while the other is sent to a header processor.
- The example shows how the packet can be sent to one of four ports using two bits at the beginning of the header. The signal processing in this example is ideal and doesn't consume time.
- Open the simulation file OS7 and examine the construction, in particular the signal processing of the header.
- Execute the simulation.

- **Question 7A:** For the eight packets in the simulation which is the sequence of ports selected?
- **Question 7B:** What could be the problem if the packet arrives at the switch fabric before the header is processed?
- **Question 7C:** How can this problem be solved?

Packet Header Recognition (2)

Packet Header Recognition

This schematic shows how the first two bits of each block (a block represents a packet) can be used to select the destination of an optical packet. The circuit uses Signal Processing modules extensively, and implements a look-up table using a Table function for matrices. The index of the table is derived by turning the serial bits into an integer. The selected matrix is converted into parallel drives for the switches using a Martix-Vector conversion, followed by a distributor.



Network Protection

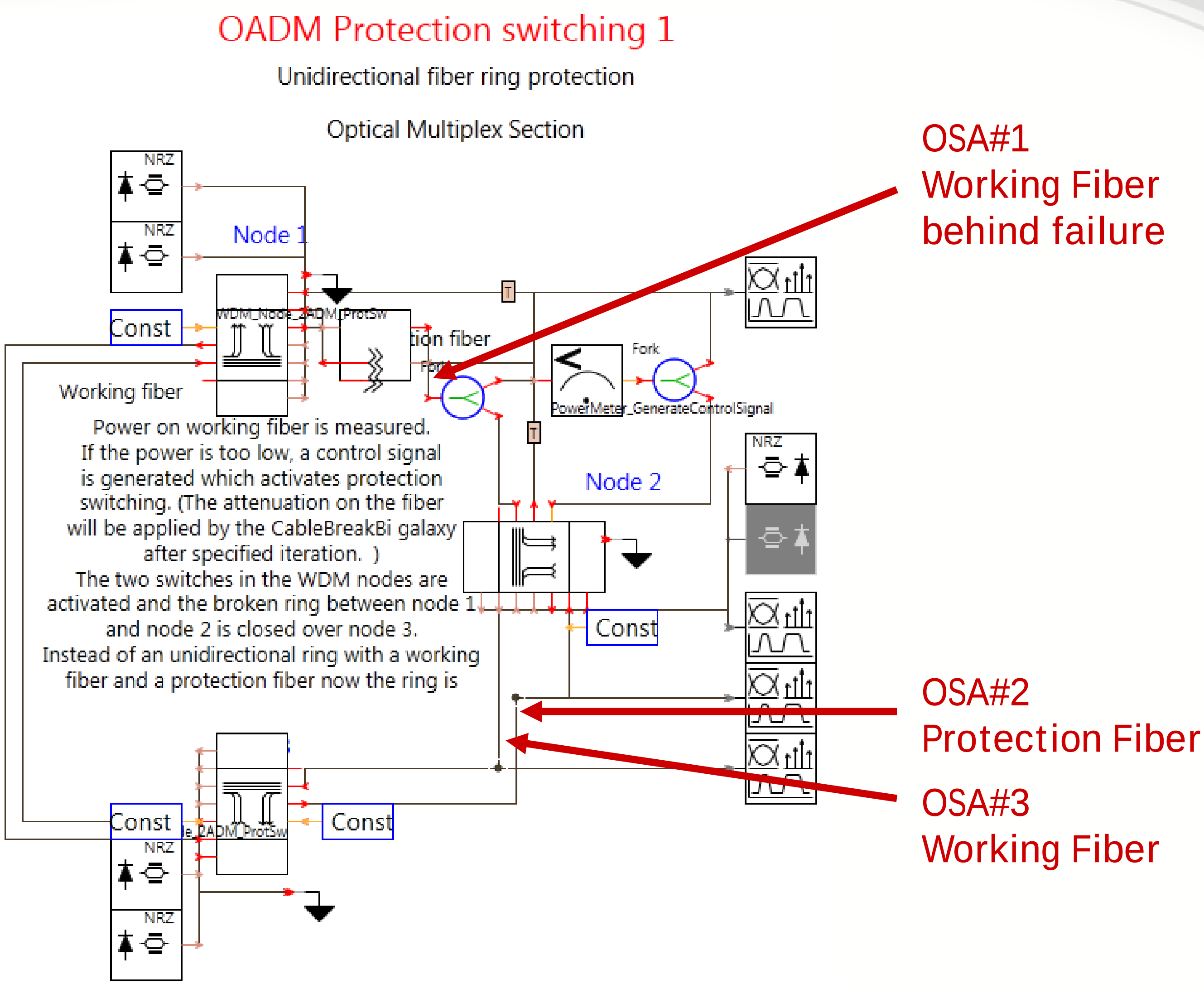
- One of the major concerns for optical networks is the reliability due to the large volumes of information that is carried through them.
- Most optical system designs include a mechanism to automatically protect the traffic in case of failure.
- The most common protection is to have a ring topology and redirect the traffic in the opposite direction after a failure.
- The examples shown present two variations of ring protection techniques.
  - OADM Protection Switching 1
  - OADM Protection Switching 2

OADM Protection Switching 1 (1)

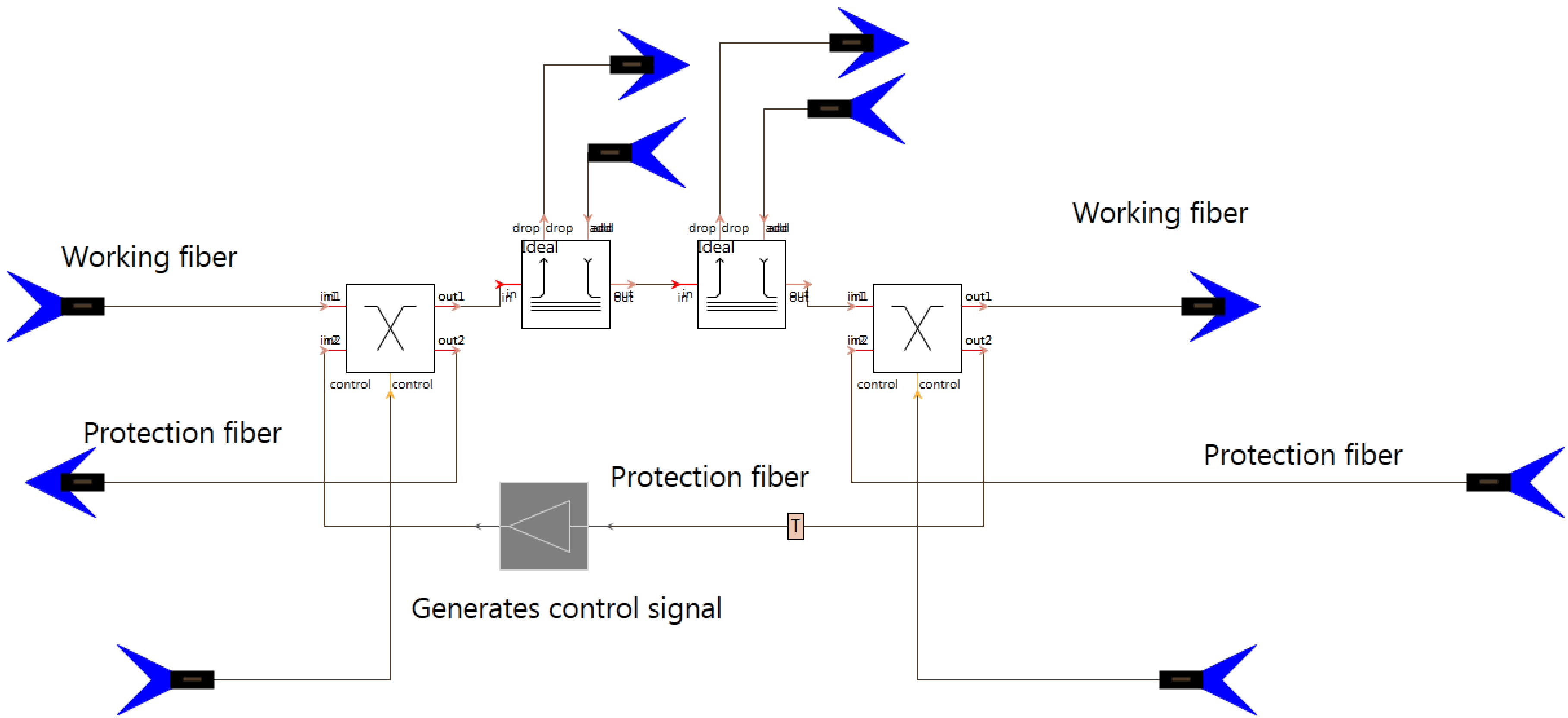
- The first example of protection shows a unidirectional ring that has a second fiber used only for protection.
- Open the simulation file OS9 and examine the construction, in particular look inside the ADMs. Also notice the location of the *SignalAnalyzer* **(OSA)** points.
- Run the simulation and examine the OSA results.

- **Question 8A:** How many channels were occupied in the protection fiber before and after the failure?
- **Question 8B:** How many channels were occupied in the working fiber behind the fiber cut, before and after the failure?
- **Question 8C:** How many channels were occupied in the working fiber away from the cut, before and after the failure?
- **Question 8D:** How is the signal protected during a failure?

OADM Protection Switching 1 (2 System)



OADM Protection Switching 1 (3 ADM node)



OADM Protection Switching 2 (1)

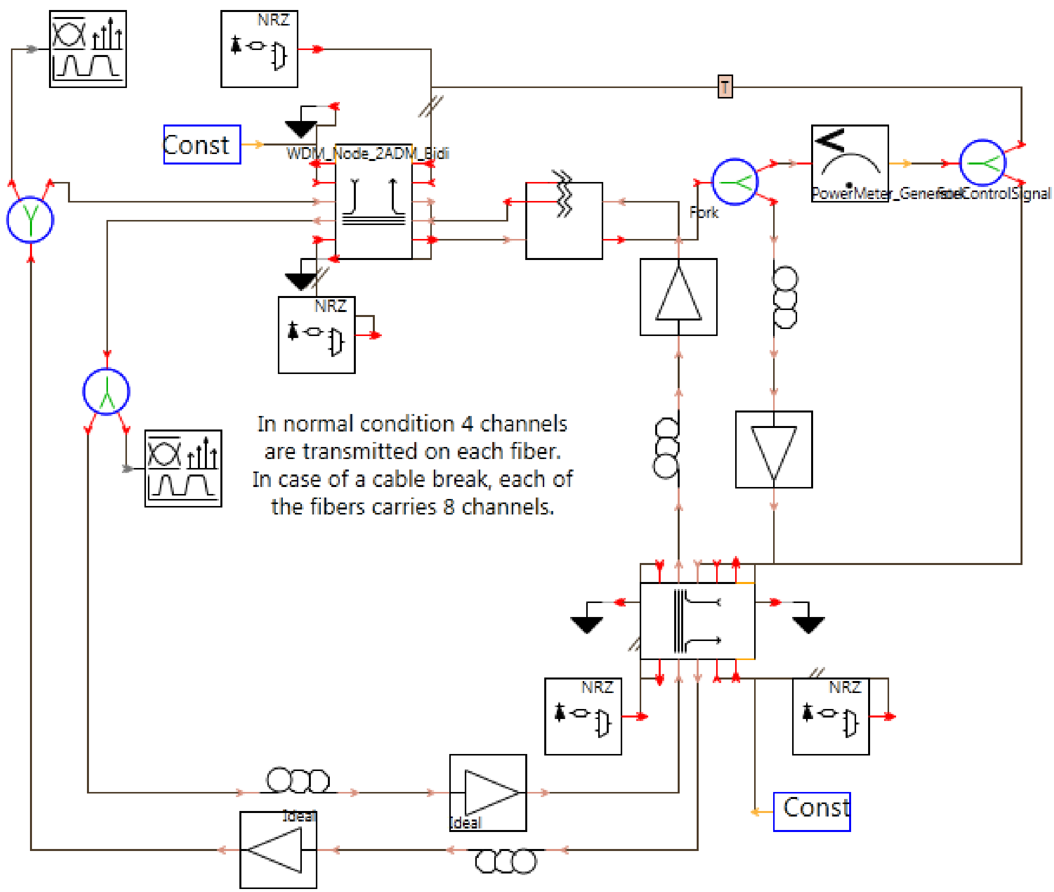
- The second example of protection shows a bidirectional ring that uses both fibers at half capacity. The other half is reserved for protection.
- Open the simulation file OS9 and examine the construction, in particular look inside the ADMs. Also notice the location of the OSA points.
- Run the simulation and examine the OSA results.

- **Question 9A:** How many channels were occupied in each fiber before the failure?
- **Question 9B:** How many channels were occupied in each fiber after the failure?
- **Question 9C:** How is the signal protected during a failure?

OADM Protection Switching 2 (2 System)

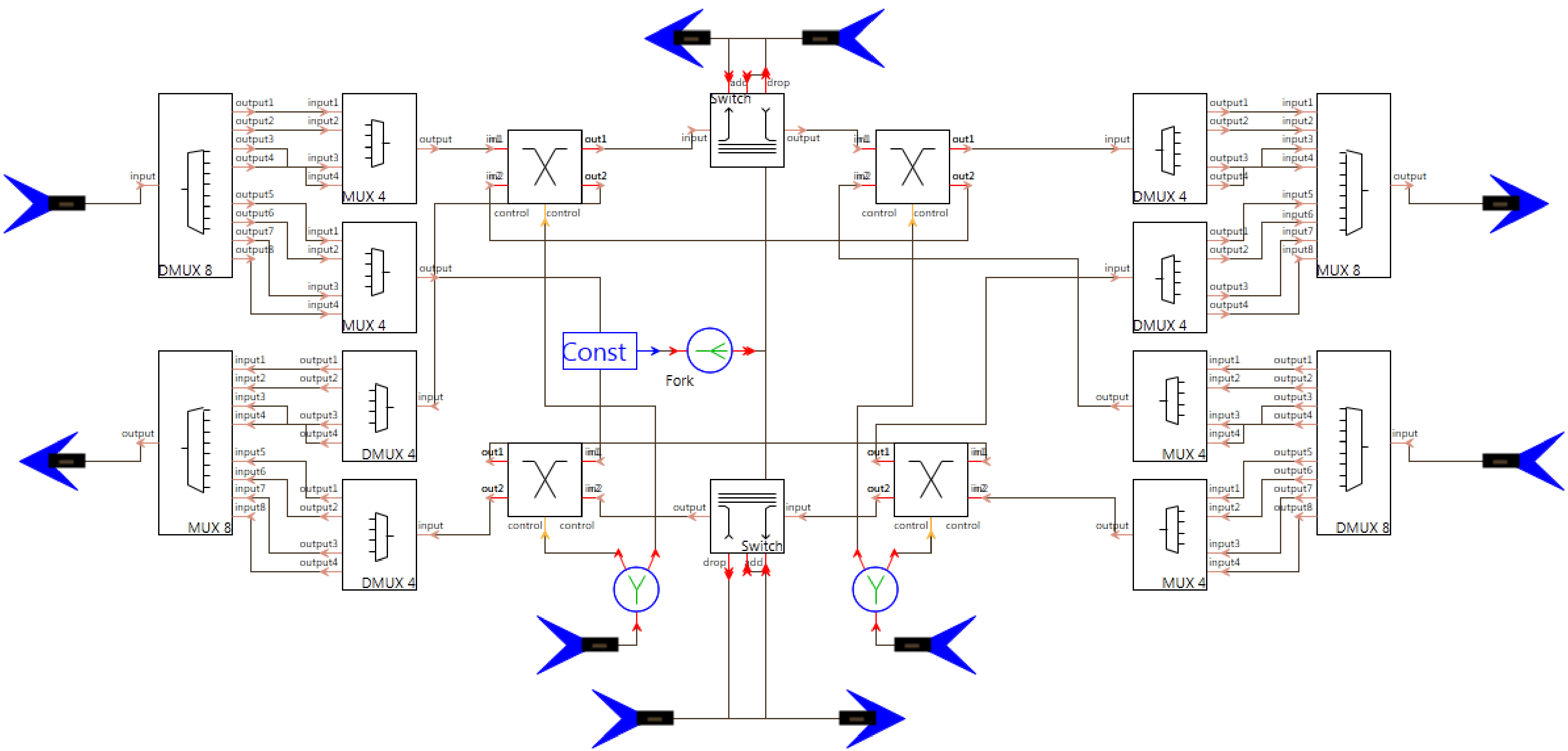
OADM Protection Switching 2

Protection switching



In normal condition 4 channels are transmitted on each fiber. In case of a cable break, each of the fibers carries 8 channels.

OADM Protection Switching 2 (3 ADM module)



Summary

This module illustrated the following Optical Networking Concepts:

- General Networking concepts
- Optical network technology components
- Types of optical networks
- Protection Mechanisms
- Design Issues

More information is available in the *Lecture Module*

Bibliography

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Glossary

A800	Advanced 800 service	**LAN**	Local Area Network	**ROI**	Return Over Investment
ADM	Add-Drop Multiplexer	**LD**	Long Distance service	**SDH**	Synchronous Digital Hierarchy
API	Application Interface	**MEMS**	Micro Electro-Mechanical System	**SDS**	Switched Digital Services
ATM	Asynchronous Transfer Mode	**MPLS**	Muti-Protocol Label Switching	**SLA**	Service Level Agreement
CATV	Cable Television	**MZI**	Mach – Zehnder Interferometer	**SOA**	Semiconductor Optical Amplifier
CDMA	Code Division Multiple Access	**OC1, OC3, OC12, OC48, …**	North American synchronous digital frame formats	**SONET**	Synchronous Optical Network
CPE	Costumer Premises Equipment	**OEO**	Optical – Electrical – Optical	**STM1, STM4, STM16, …**	ITU synchronous digital frame formats
DSL	Digital Subscriber Loop	**OLT**	Optical Line Terminal	**T1, T2, T3, …**	North American digital frame formats
DWDM	Dense WDM	**OOO**	Optical – Optical – Optical	**TDM**	Time Division Multiplexing
E1, E2, E3, …	ITU Digital frame formats (International)	**OXC**	Optical cross-connect	**TNM**	Telecommunications Network Management
EDFA	Erbium Doped Fiber Amplifier	**PDA**	Personal Digital Assistant	**VNS**	Virtual Network Service (voice)
FDM	Frequency Division Multiplexing	**PL / LP**	Private Line	**VPN**	Virtual Private Network (data)
FR	Frame Relay	**POP**	Point Of Presence	**WAN**	Wide Area Network
HDTV	High Definition Television	**POTS**	Plain old Telephone Service	**WDM**	Wavelength Division Multiplexing
ISDN	Integrated Services Digital Network	**PSTN**	Public Switched Telephone Network	**xDSL**	Any standard DSL variation
ITU	International Telecommunications Union	**RF**	Radio Frequency		