Module 20 : WDM Networks

Lecture : WDM Networks

Objectives

In this lecture you will learn the following

- Wavelength Routing
- Wavelength Management in a Router

Wavelength Routing:

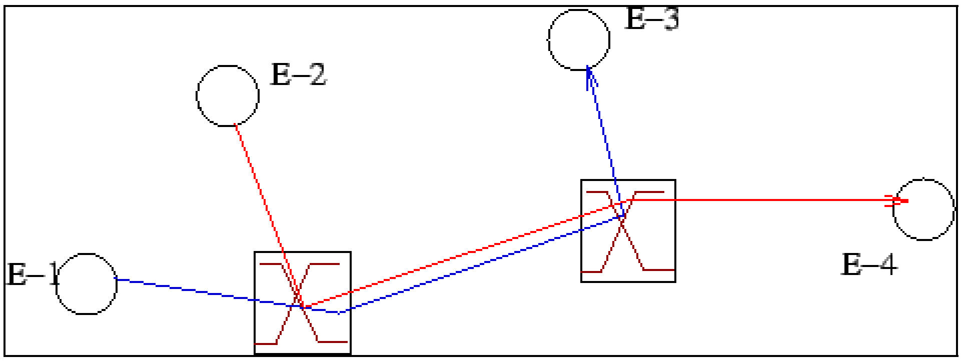
Distribution of data received at a central receiving station to their final destination is done by switches and routers. Though the terms *switching* and *routing* are used interchangeably, there are some differences about the way they work and the level of their operation. A switch is a dedicated service. For instance, an electro-mechanical switch connected to household electrical equipment provides a dedicated connectivity between the switch and the equipment. More advanced electronic switching (e.g. that used in a phone service) does not provide a dedicated physical connectivity but provides a dedicated time slot. Such circuits are called *virtual circuits.*

In **packet switching** , a message is divided into small segments called *packets* **.** Each packet is transmitted individually and may follow different paths to the destination. After all packets have arrived at the destination, they are re-assembled to form the original message. A packet has a header which identifies destination. **Routers** read the information on the header and decide on the best route for a packet based on the network condition.

Wavelength routing is a process in which arriving optical signals are directed to different output ports depending on the wavelength of the input. A network which uses this procedure is called a *wavelength routed network* **.** A wavelength router may be looked upon as a fixed wavelength demultiplexer which directs different wavelengths to different ports. A wavelength which is used for one destination is not available for another destination. Thus the device must also have wavelength converters in addition to optical cross connects. By changing the wavelength of an arriving input signal, one can change the destination port of the signal.

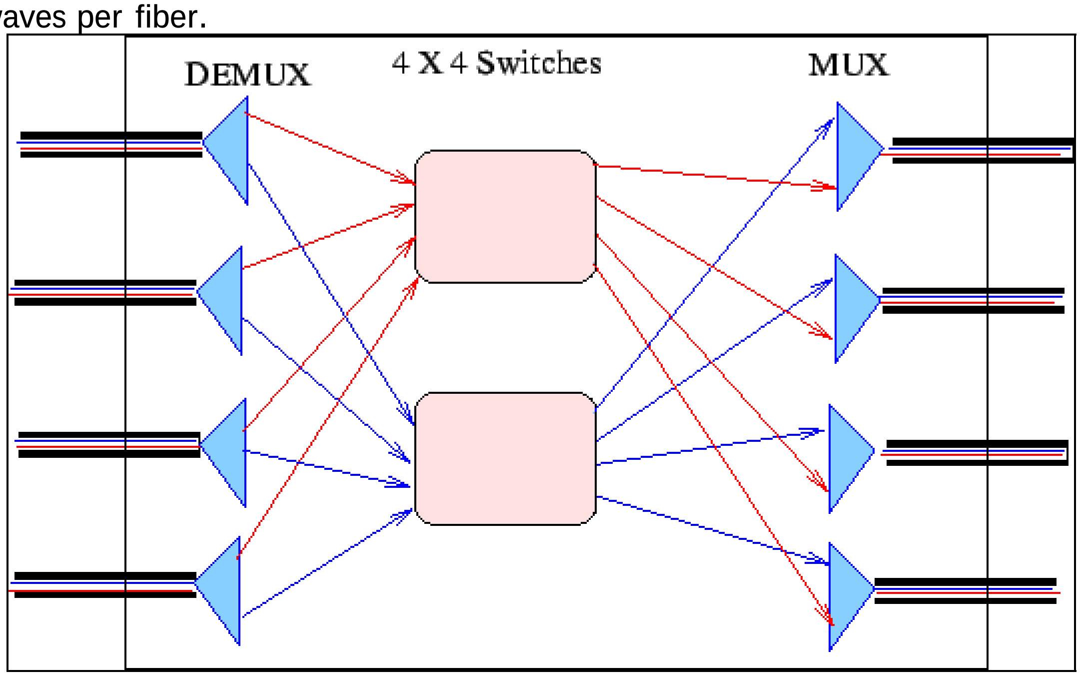
A wavelength routing network has *edge nodes* which provide interface between the optical layer and other systems such as IP routers, ATM switches etc. All switching inside the optical layer is done by OXCs which may work in conjunction with wavelength converters. Wavelength routing requires that a route must be defined in the network which connects a source (input) with the destination. Such an optical path is called a *light path* (also called a *clear path.* as the signal does not undergo any conversion from optical to electrical domain in its passage from the source to destination.)

In the figure shown, the edge nodes are marked E-1 to E-5 which are connected by fibers to all optical portion of the network. Two optical paths, one from E-1 to E-3 and another from E-2 to E-4 are shown in the figure. A wavelength which is being used for one of the light paths is not available for another path. In the optical domain there is no conversion from photon signal to electrical signal.

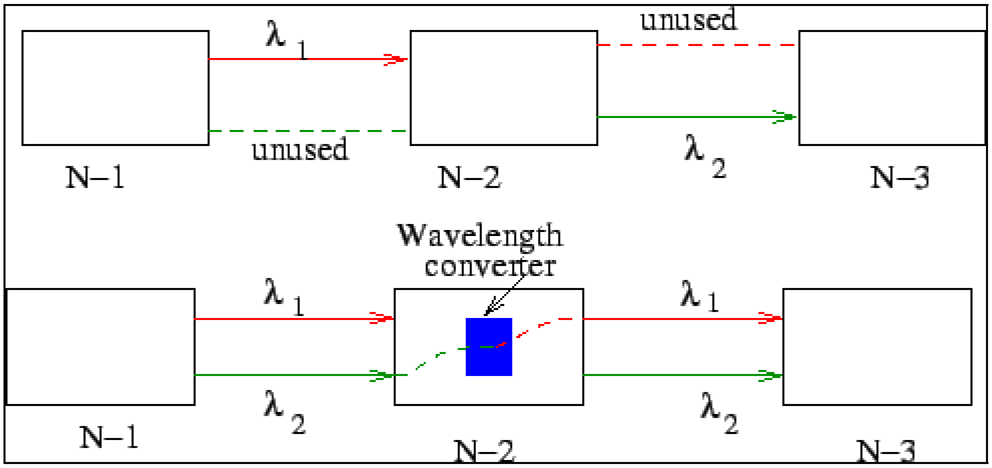


The implementation of wavelength routing is done as follows:

1. An OXC takes at each of its N input ports W signals of different wavelengths. If the signals can be directed to M output ports, the OXC acts essentially as W independent $N \times M$ switches. The figure shows equivalent switches for a 4×4 optical cross connect with 2 waves per fiber.

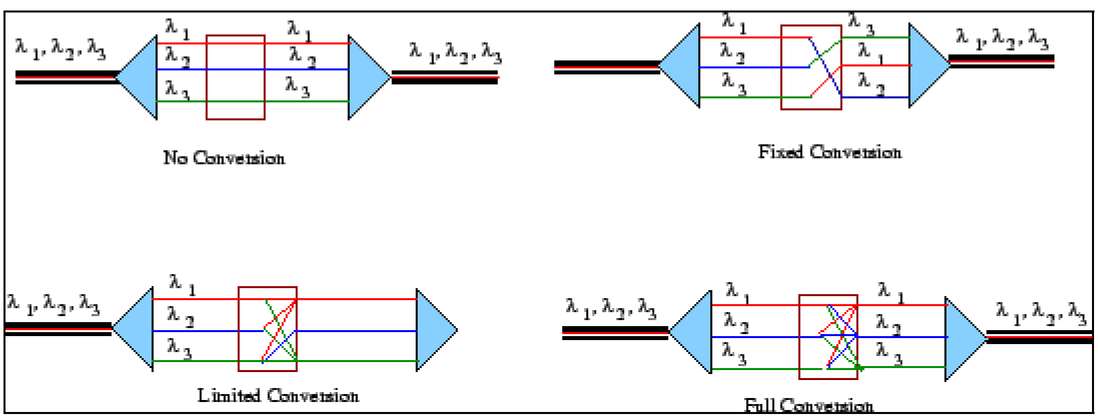


1. For a network not using wavelength converter, *wavelength continuit condition* requires that along any light path, the same wavelength must be used throughout. This is sometimes a restrictive condition because it does not allow establishment of a path between nodes even when a wavelength channel is available. Consider a case shown in the figure where two wavelengths λ_1 and λ_2 are available. There is one light path between N-1 and N-2 and a second light path between N-2 and N-3, the former using the wavelength λ_1 and the latter λ_2.



As only two wavelength are available, it is not possible to establish a light path between N-1 and N-3 (without violating continuity condition) though there is a free wavelength between each of the segments. However, if a wavelength converter is located at the node N-2, we may relax the continuity condition, as shown in the right hand figure.

The degree of wavelength conversion used in a given network depends on the traffic pattern in the network. The figure below illustrates different situations for a single input port and a single output port.



- A network may allow no conversion at all in which case all the wavelengths are routed as such to the output port.
- **Fixed wavelength conversion:** A signal entering a particular node with a wavelength λ_i always leaves the node with a

  pre-determined wavelength λ_j.
- **Limited wavelength conversion:** In this case, an input wavelength λ_i can be converted

  to any of a limited number of
  wavelengths. For instance, in the figure, λ_1 can be converted to either λ_1 or λ_3 but not to

  λ_2. Similarly, $\lambda - 2$ can be converted to λ_1 and λ_3 but cannot leave the node without conversion while λ_3 can be converted to any of the three wavelengths.

- **Full conversion:** This is the case where any of the input wavelengths can be converted to any of the permitted wavelengths.

Wavelength Management in a Router:

If the pattern of traffic in the network is known in advance and the variations take place over a long period of time, one can optimize network resources and arrive at a virtual network. Such a router is called a **static router.** The continuity condition is to be satisfied and only one wavelength may be used per route.
The problem of wavelength management incorporating continuity condition is same as working out a **Latin square** . A Latin square is an $N \times N$ matrix in which N distinct objects are placed such that no two elements of a given row (or of a column) have identical objects placed in them. (Students familiar with the game of *Sudoku* will notice the resemblance.) Mathematically, a Latin square is a matrix M defined as follows:

$$M = [a_{ij}] \ \ (1 \leq i, j \leq N)$$

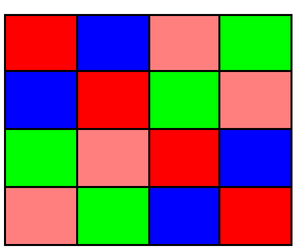
such that

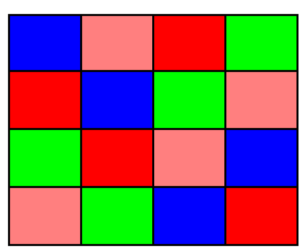
$$a_{ij} = a_{ik} \ \text{ for } \ j \neq k$$

$$a_{ij} = a_{kj} \ \text{ for } \ i \neq k$$

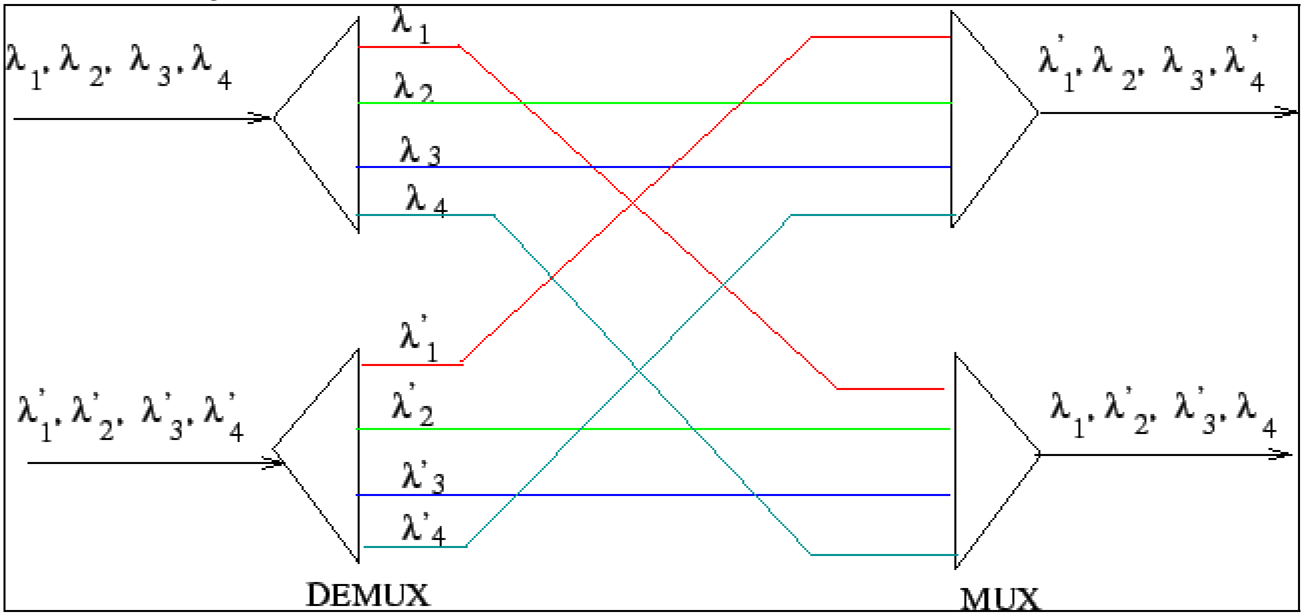
The number of distinct Latin squares grows exponentially with increasing N. For instance, there are only 12 squares of order 3, 576 of order 4 but over 5×10^{28} squares of order 9.

Examples of two Latin square of order 4 are given below.





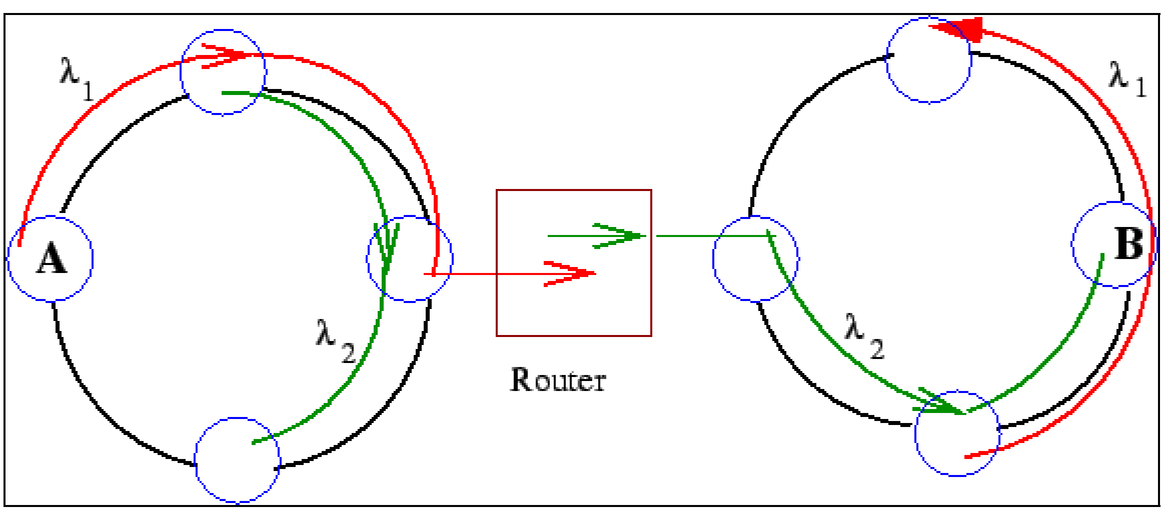
We may think of the matrix as one whose columns represent input ports and the rows the output ports. Exactly one wavelength (as indicated by different colour in the table) from each input port will be routed to each output port. The wavelength used by the router from port i to port j is given by the colour scheme of the (i, j) element of the table. Note that if two signals of the same wavelength arrive at two different ports, they will be directed to two distinct output ports. For instance, if the scheduling is done by the left hand side figure in which the same wavelength (blue) arrive at both input port 1 as well as 2, the former will be routed to output port 1 and the latter to 2. The same physical wavelength being used for different I-O connection is known as **wavelength re-use** . The figure shows a typical static wavelength router.



If the network condition changes frequently, a static routing is not helpful. One needs to then use dynamic switching of wavelength. In the following figure, two WDM rings are connected to a wide area network. Each ring can transmit in two wavelengths λ_1 and λ_2.

Problem arises if the node A of the left LAN wishes to communicate with the node B of the right LAN. As the wavelength λ_1 at which node A transmits is in active use in another channel of the right LAN, a dynamic

switching of wavelength has to take place.



References:

1. S. V. Kartalopoulos, DWDM - Networks, Devices and Technology, Wiley, N.J. (2003)
2. R. Ramaswami and K. N. Sivarajan, Optical Networks , Academic Press, Sandiego (1998)
3. Jeff Hecht, Understanding Fiber Optics, 5th Edn. Prentice Hall (2006)

Recap

In this lecture you have learnt the following

- Wavelength Routing
- Wavelength Management in a Router

Congratulations, you have finished Module 20. To view the next lecture select it from the left hand side menu of the page