


18-345 – Fall 08

Lecture 8

Circuit-Switching Networks 2

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Reading: Chapter 4



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Topics

- Multiplexing
- SONET
- Transport Networks
- Circuit Switches
- Telephone Network



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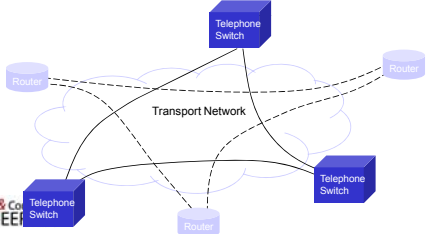

Transport Networks



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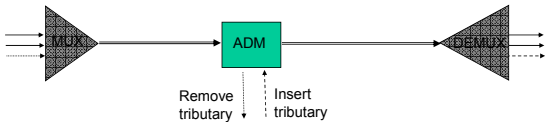
Transport Networks

- Backbone of modern networks
- Provide high-speed connections: Typically STS-1 up to OC-192
- Clients: large routers, telephone switches, regional networks
- Very high reliability required because of consequences of failure
 - 1 STS-1 = 783 voice calls; 1 OC-48 = 32000 voice calls;





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SONET ADM Networks



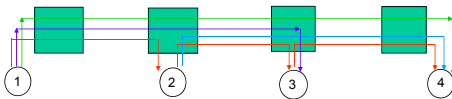
- SONET ADMs: the heart of existing transport networks
- ADMs interconnected in linear and ring topologies
- SONET signaling enables fast restoration (within 50 ms) of transport connections



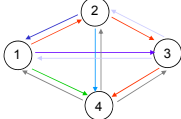

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Linear ADM Topology

- ADMs connected in linear fashion
- Tributaries inserted and dropped to connect clients



- Tributaries traverse ADMs transparently
- Connections create a *logical* topology seen by clients
- Tributaries from right to left are not shown

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1+1 Linear Automatic Protection Switching

- Simultaneous transmission over diverse paths
- Monitoring of signal quality
- Fast switching in response to signal degradation
 - Selector simply chooses the better line
- 100% redundant bandwidth

T = Transmitter
W = Working line
R = Receiver
P = Protection line

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1:1 Linear APS

- Transmission on working fiber
- Signal for switch to protection route in response to signal degradation
- Can carry extra (preemptible traffic) on protection line

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1:N Linear APS

- Transmission on diverse routes; protect for 1 fault
- Reverts to original working channel after repair
- More bandwidth efficient

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SONET Rings

- ADMs can be connected in ring topology
- Clients see *logical* topology created by tributaries

Three ADMs connected in physical ring topology

Logical fully connected topology

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SONET Ring Options

- 2 vs. 4 Fiber Ring Network
- Unidirectional vs. bidirectional transmission
- Path vs. Link protection
- Spatial capacity re-use & bandwidth efficiency
- Signaling requirements

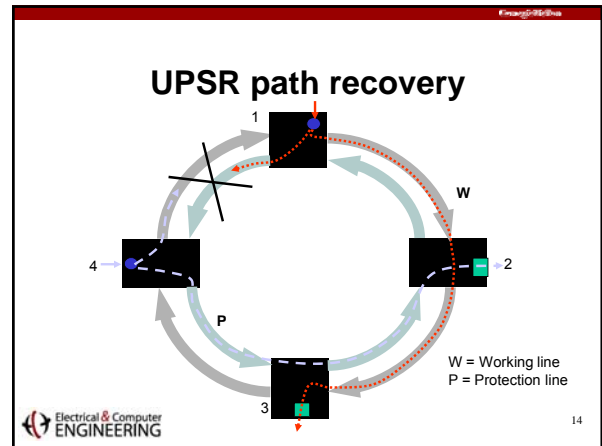
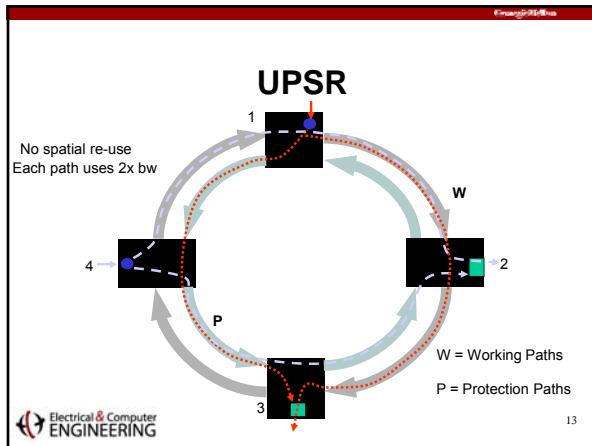
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Two-Fiber Unidirectional Path Switched Ring

Two fibers transmit in opposite directions

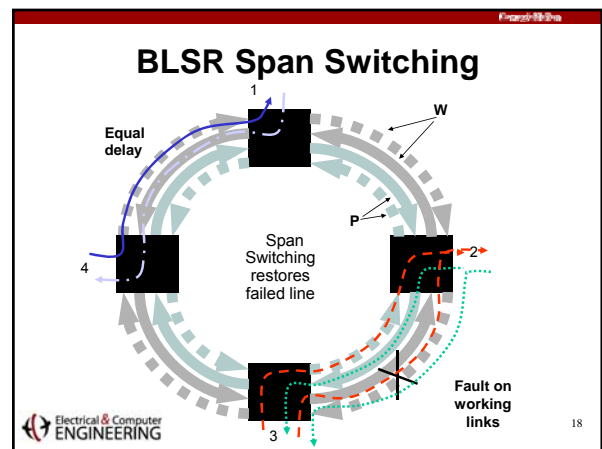
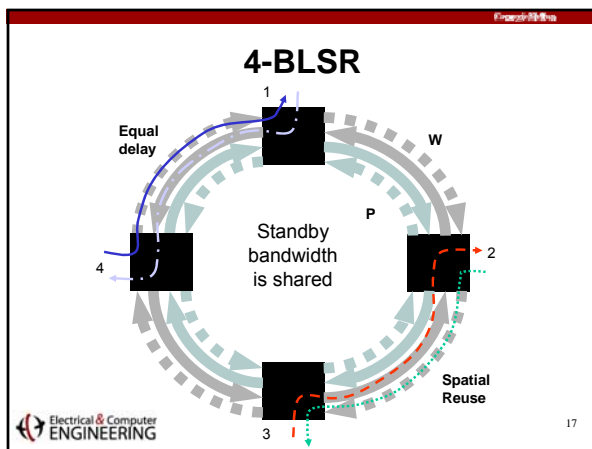
- Unidirectional
 - Working traffic flows clockwise
 - Protection traffic flows counter-clockwise (and it is always flowing)
 - 1+1 like
- Selector at receiver does *path protection switching* on detection of failure

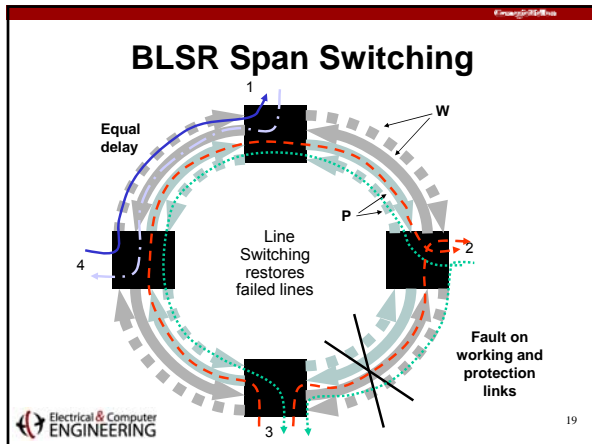
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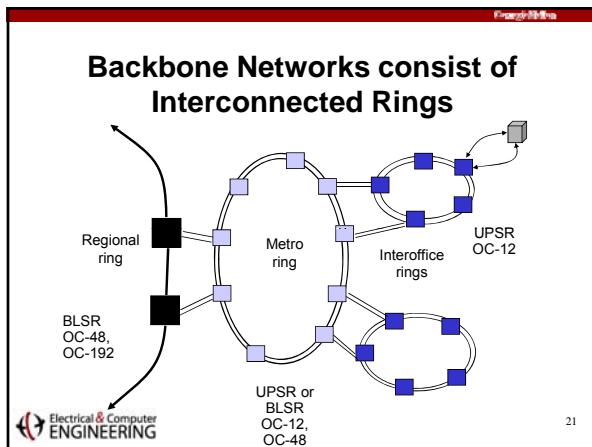
- ### UPSR Properties
- Low complexity
 - Fast path protection
 - No spatial re-use
 - Suitable for lower-speed access networks
 - Different delay between W and P path
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- ### Four-Fiber Bidirectional Line Switched Ring
- 1 working fiber pair plus 1 protection fiber pair
 - Bidirectional
 - Working traffic & protection traffic use *same route* in working pair
 - 1:N like
 - *Line* restoration provided by either:
 - Restoring a failed span
 - Switching the line around the ring
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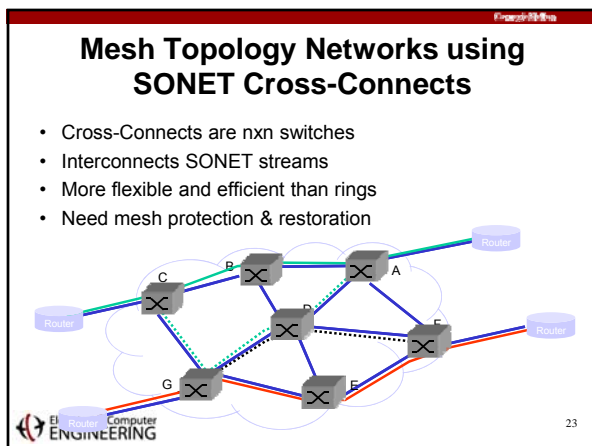




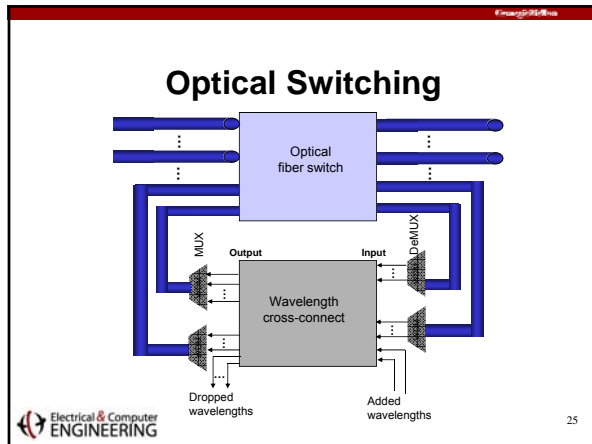
- ### 4-BLSR Properties
- High complexity: signaling required
 - Fast line protection for restricted distance (1200 km) and number of nodes (16)
 - Spatial re-use; higher bandwidth efficiency
 - Suitable for high-speed backbone networks
 - Multiple simultaneous faults can be handled
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- ### The Problem with Rings
- Managing bandwidth can be complex
 - Increasing transmission rate in one span affects all equipment in the ring
 - Introducing WDM means stacking SONET ADMs to build parallel rings
 - Distance limitations on ring size implies many rings need to be traversed in long distance
 - End-to-end protection requires ring-interconnection mechanisms
- Managing 1 ring is simple;
Managing many rings is very complex*
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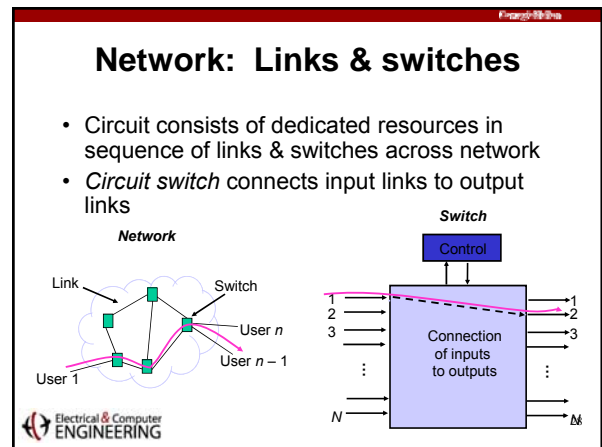
- ### From SONET to WDM
- | | |
|---|---|
| <p>SONET</p> <ul style="list-style-type: none"> • combines multiple SPEs (Synchronous Payload Envelopes) into high speed digital stream • ADMs and crossconnects interconnected to form networks • SPE paths between clients form logical topology • High reliability through protection switching | <p>WDM</p> <ul style="list-style-type: none"> • combines multiple wavelengths into a common fiber • Optical ADMs can be built to insert and drop wavelengths in same manner as in SONET ADMs • Optical crossconnects can also be built • All-optical backbone networks will provide end-to-end wavelength connections • Protection schemes for recovering from failures are being developed to provide high reliability in all-optical networks |
|---|---|
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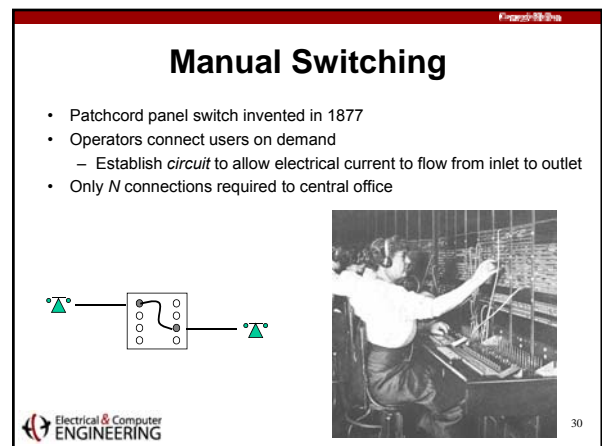
- ## Topics
- Multiplexing
 - SONET
 - Transport Networks
 - Circuit Switches
 - Telephone Network
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Circuit Switches

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- ## Circuit Switch Types
- Evolution of Switching System:
 - Manual operators
 - Step-by-step switch (Strowger switch)
 - Crossbar switch
 - Space-Division switches
 - Crossbar switches
 - Multistage switches
 - Time-Division switches
 - Time-slot interchange technique
 - Time-space-time switches
 - Hybrids combine Time & Space switching
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Step-by-step (Strowger) Switch

- Electromagnetic switch
- Sequence of dialed numbers selects output line

The diagram illustrates the path of a signal through a 4-digit step-by-step switch. It starts at a 'Line Selector' which routes the signal to the '1st selector'. This selector has 10 contacts (0-9) and routes the signal to the '2nd selector', which also has 10 contacts (0-9). The signal then passes through a 'connector group' which has 100 contacts (00-99). The sequence of dialed numbers is 4, 6, 8, and 5, which is shown as the signal path through the selectors and connector group.

Dialing a number 4685 in a 4-digit Step by Step

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Step-by-step (Strowger) Switch

The diagram shows a detailed view of the rightmost selector. It features a 'Tooth bank level' and a 'Vertical rod' that moves up and down. The selector has 'Fixed contacts' and 'Movable contacts' that can connect to one of 100 different points of fixed contacts, each leading to a different line.

Detailed view of rightmost selector from previous slide

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Crossbar Switch

The diagram shows a crossbar switch with a 'Switch fabric' represented as a grid. 'INPUT' lines enter from the left and 'OUTPUT' lines exit from the bottom. A box labeled 'Electro mechanical control logic for making contacts' is connected to the switch fabric.

- Entire phone number is available before processing
- Key idea: control function is separated from switching fabric.
 - So, can implement sophisticated logic
- Logical addresses possible
 - > independent of physical line numbers

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Crossbar Switch

A photograph of a physical crossbar switch assembly, showing a grid of components on a printed circuit board.

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Stored-Program Control Switches

- SPC switches (1960s)
 - Crossbar switches with electromechanical (relay) crossbars
 - Computer program controls process of making contact
- Computer program allows customized features such as call forwarding, call waiting, three-way calling, etc.
- Computer program simplifies administrative and maintenance tasks.

The diagram shows an SPC switch with a grid of crossbars. A box labeled 'SPC' is connected to the grid. 'Control' lines enter from the left and 'Signaling Message' lines enter from the right. The grid is shown with arrows indicating the flow of control and signaling messages.

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Crossbar Space Switch

- $N \times N$ array of crosspoints
- Connect an input to an output by closing a crosspoint
- Nonblocking: Any input can connect to idle output
- Complexity: N^2 crosspoints

The diagram shows an $N \times N$ array of crosspoints. The input lines are labeled 1, 2, ..., N and the output lines are labeled 1, 2, ..., N-1, N. A crosspoint is shown at the intersection of input line 1 and output line 2, with a dot indicating it is closed.

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Multistage Space Switch

- Large switch built from multiple stages of small switches
- The n inputs to a first-stage switch share k paths through intermediate crossbar switches
- Larger k (more intermediate switches) means more paths to output
- In 1950s, Clos asked, "How many intermediate switches required to make switch nonblocking?"

$2(N/n)nk + k(N/n)^2$ crosspoints

N inputs N outputs

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Clos Non-Blocking Condition: $k \geq 2n-1$

- Request connection from last input to input switch j to last output in output switch m
- Worst Case: All other inputs have seized top $n-1$ middle switches AND all other outputs have seized next $n-1$ middle switches
- If $k \geq 2n-1$, there is another path left to connect desired input to desired output

Desired input Desired output

Free path Free path

internal links = $2 \times$ # external links

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Minimum Complexity Clos Switch

$C(n)$ = number of crosspoints in Clos switch

$$= 2Nk + k\left(\frac{N}{n}\right)^2 = 2N(2n-1) + (2n-1)\left(\frac{N}{n}\right)^2$$

Differentiate with respect to n :

$$0 = \frac{\partial C}{\partial n} = 4N - \frac{2N^2}{n^2} + \frac{2N^2}{n^3} \approx 4N - \frac{2N^2}{n^2} \implies n \approx \sqrt{\frac{N}{2}}$$

The minimized number of crosspoints is then:

$$C^* = (2N + \frac{N^2}{N/2})\left(2\left(\frac{N}{2}\right)^{1/2} - 1\right) \approx 4N \sqrt{2N} = 4\sqrt{2} N^{1.5}$$

This is lower than N^2 for large N

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Example: Clos Switch Design

- Circa 2002, Mindspeed offered a Crossbar chip with the following specs:
 - 144 inputs x 144 outputs, 3.125 Gbps/line
 - Aggregate Crossbar chip throughput: 450 Gbps
- Clos Nonblocking Design for 1152x1152 switch
 - $N=1152, n=8, k=16$
 - $N/n=144$ 8x16 switches in first stage
 - 16 144x144 in center stage
 - 144 16x8 in third stage
 - Aggregate Throughput: 3.6 Tbps!

1152 inputs 1152 outputs

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Summary

- Multiplexing
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