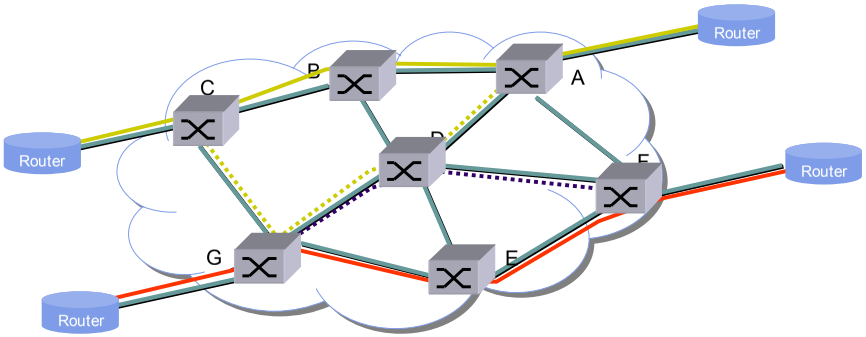
Mesh Topology Networks using SONET Cross-Connects

- Cross-Connects are nxn switches
- Interconnects SONET streams
- More flexible and efficient than rings
- Need mesh protection & restoration

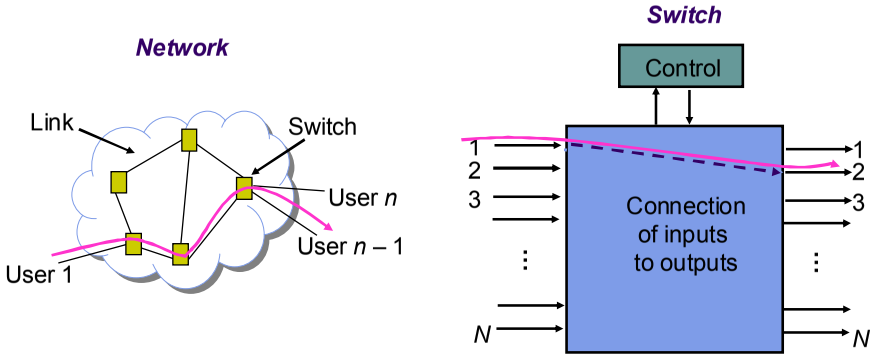


Circuit Switch Types

- Space-Division switches
  - Provide separate physical connection between inputs and outputs
  - Crossbar switches
  - Multistage switches
- Time-Division switches
  - Time-slot interchange technique
  - Time-space-time switches
- Hybrids combine Time & Space switching

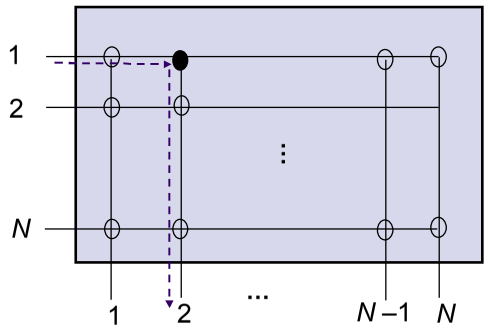
Network: Links & switches

- Circuit consists of dedicated resources in sequence of links & switches across network
- *Circuit switch* connects input links to output links



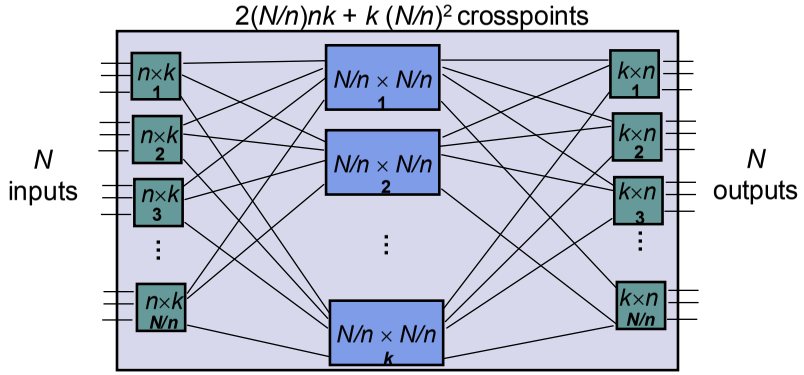
Crossbar Space Switch

- *N* x *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



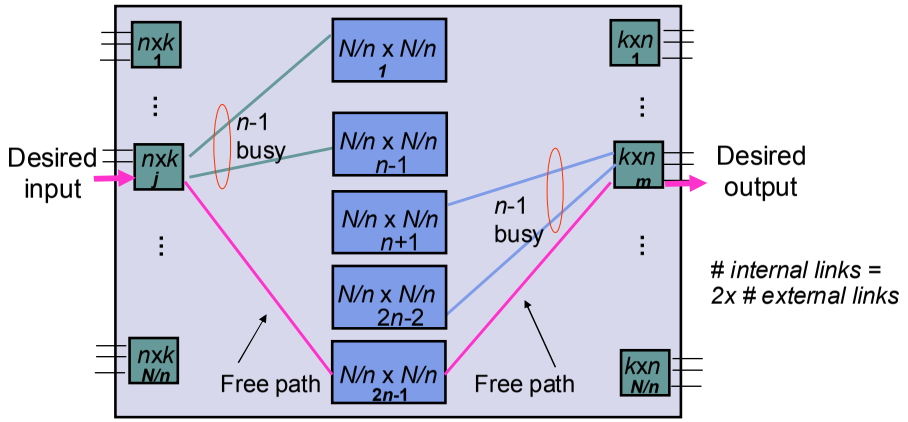
Multistage Space Switch

- 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?"



Clos Non-Blocking Condition: *k=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=2n-1***, there is another path left to connect desired input to desired output



Minimum Complexity Clos Switch

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

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

Differentiate with respect to n:

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

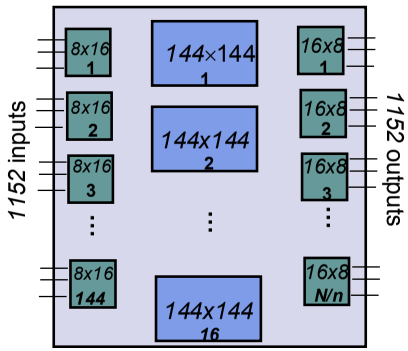
The minimized number of crosspoints is then:

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

This is lower than N^2 for large N

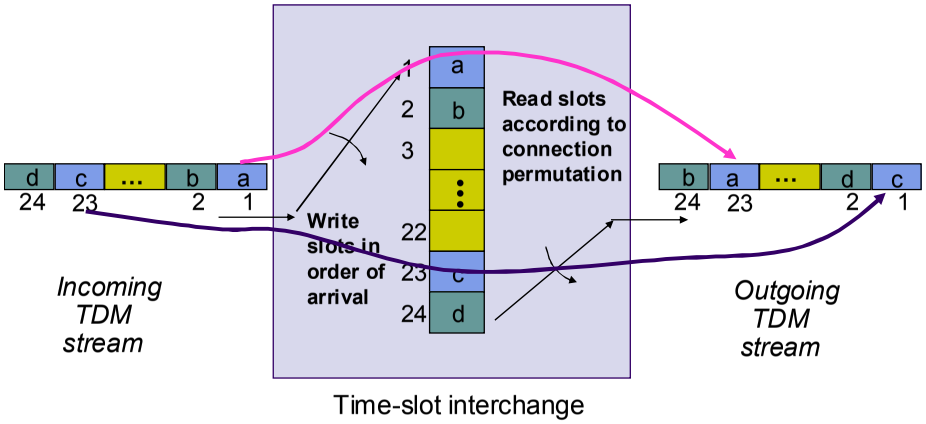
Example: Clos Switch Design

- 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 centre stage
  - 144 16x8 in third stage
  - Aggregate Throughput: 3.6 Tbps!
  - Note: the 144x144 crossbar can be partitioned into multiple smaller switches



Time-Slot Interchange (TSI) Switching

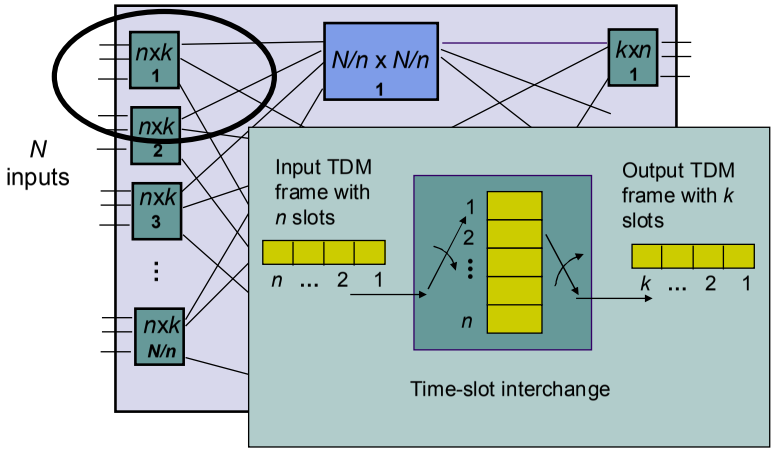
- Write bytes from arriving TDM stream into memory
- Read bytes in permuted order into outgoing TDM stream
- Max # slots = 125 μsec / (2 x memory cycle time)



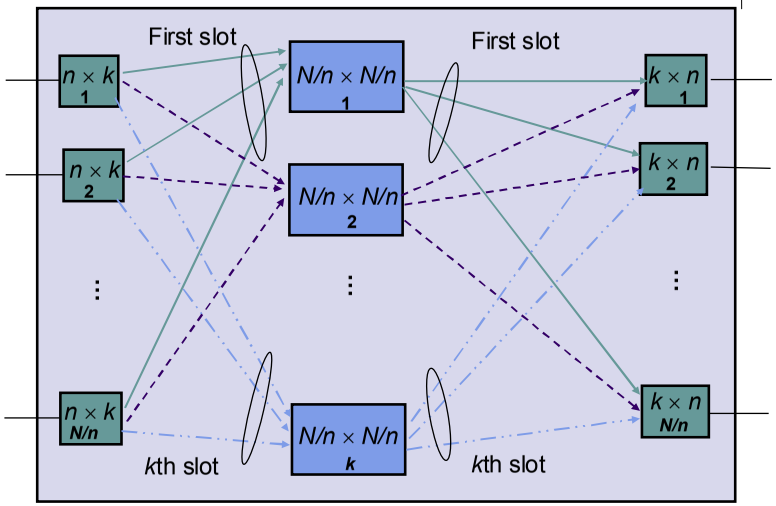
Time-slot interchange

Time-Space-Time Hybrid Switch

- Use TSI in first & third stage; Use crossbar in middle
- Replace n input x k output space switch by TSI switch that takes n-slot input frame and switches it to k-slot output frame

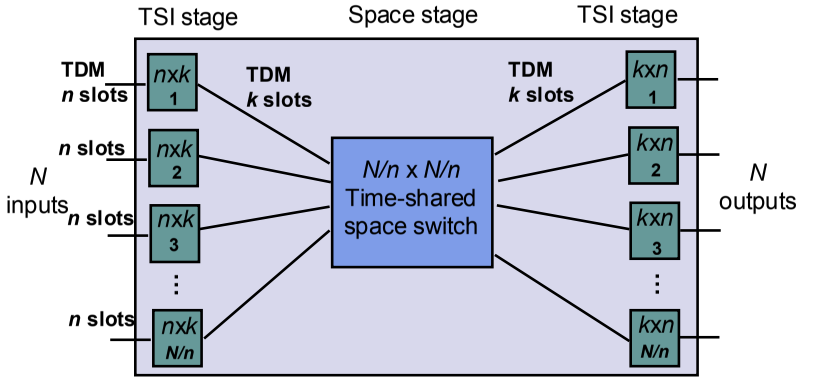


Flow of time slots between switches



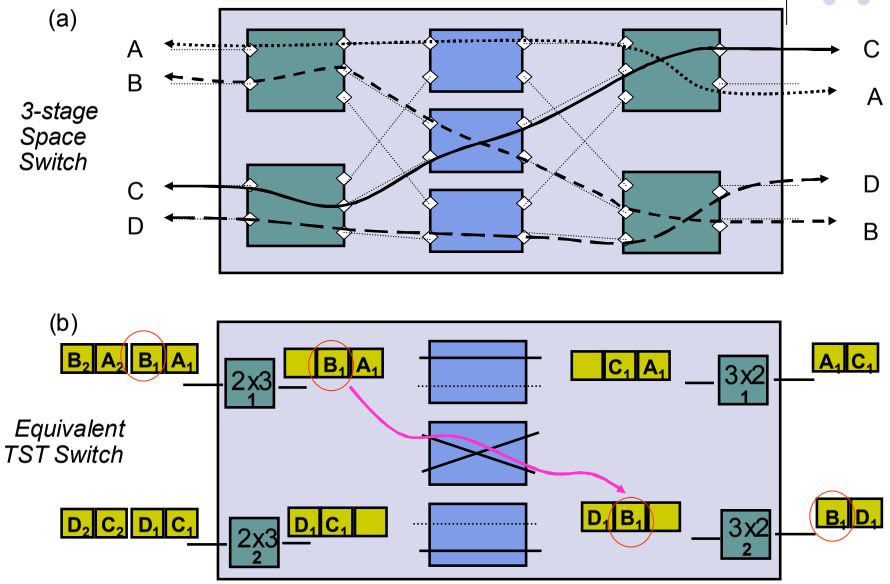
- Only one space switch active in each time slot

Time-Share the Crossbar Switch



- Interconnection pattern of space switch is reconfigured every time slot
- Very compact design: fewer lines because of TDM & less space because of time-shared crossbar

Example: A→3, B→4, C→1, D→3



Example: T-S-T Switch Design

For N = 960

- Single stage space switch ~ 1 million crosspoints
- T-S-T
  - Let n = 120 N/n = 8 TSIs
  - $k = 2n - 1 = 239$ for non-blocking
  - Pick k = 240 time slots
  - Need 8x8 time-multiplexed space switch

For N = 96,000

- T-S-T
  - Let n = 120 k = 239
  - N / n = 800
  - Need 800x800 space switch

Available TSI Chips circa 2002

- OC-192 SONET Framer Chips
  - Decompose 192 STS1s and perform (restricted) TSI
- Single-chip TST
  - 64 inputs x 64 outputs
  - Each line @ STS-12 (622 Mbps)
  - Equivalent to 768x768 STS-1 switch