BLG 337E- Principles of Computer Communications

Assoc. Prof. Dr. Berk CANBERK

27/11/ 2018

-Wireless MAC and Switching-

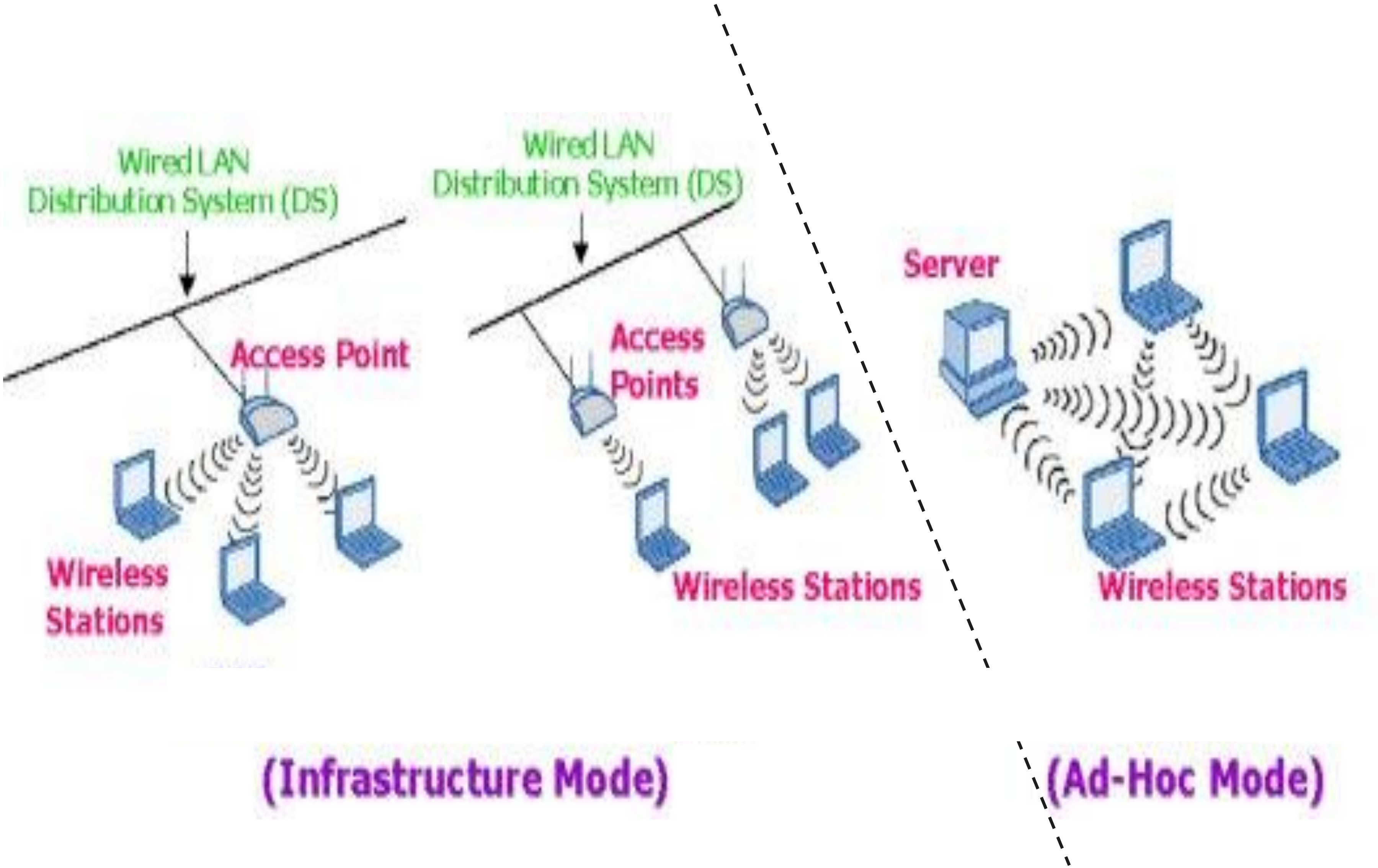
References:

Data and Computer Communications, William Stallings, Pearson-Prentice Hall, 9th Edition, 2010.

-*Computer Networking, A Top-Down Approach Featuring the Internet*, James F.Kurose, Keith W.Ross, Pearson-Addison Wesley, 6th Edition, 2012.

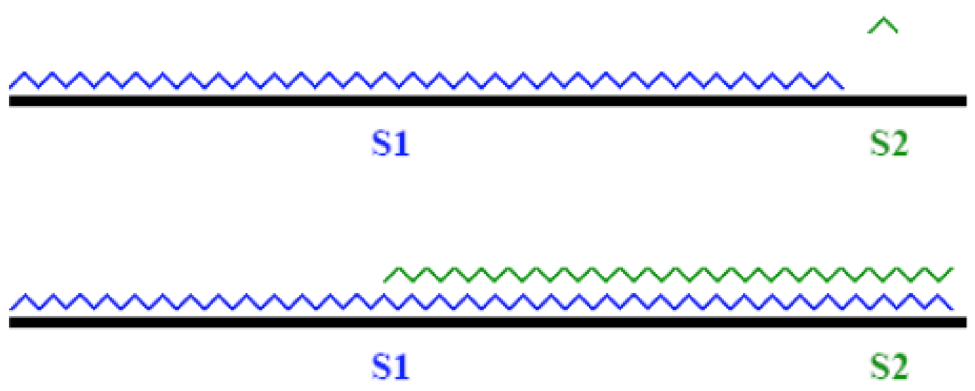
-Google!

Example: Wireless Architecture – Two modes



Review: Ethernet MAC

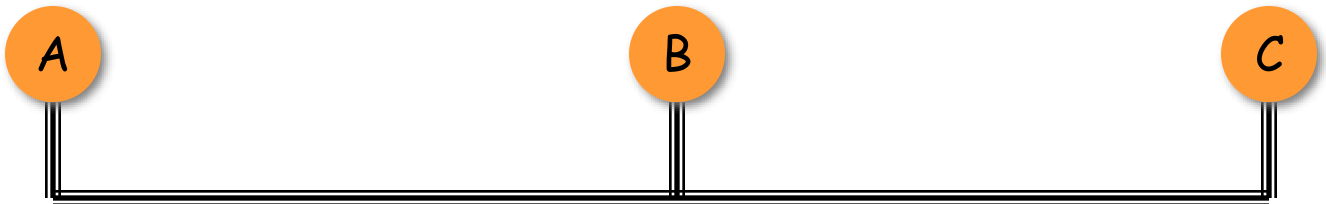
- CS (Carrier Sense): listen for others' transmissions before transmitting; defer to others you hear
- CD (Collision Detection): as you transmit, listen and verify you hear exactly what you send; if not, back off random interval, within exponentially longer range each time you transmit unsuccessfully



- Is CD possible on a wireless link? Why or why not?

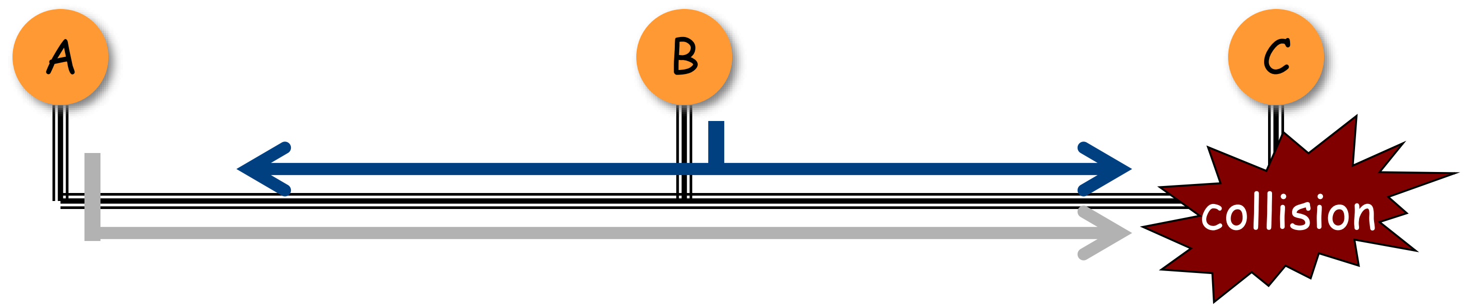
The Channel Access Problem

- Multiple nodes share a channel



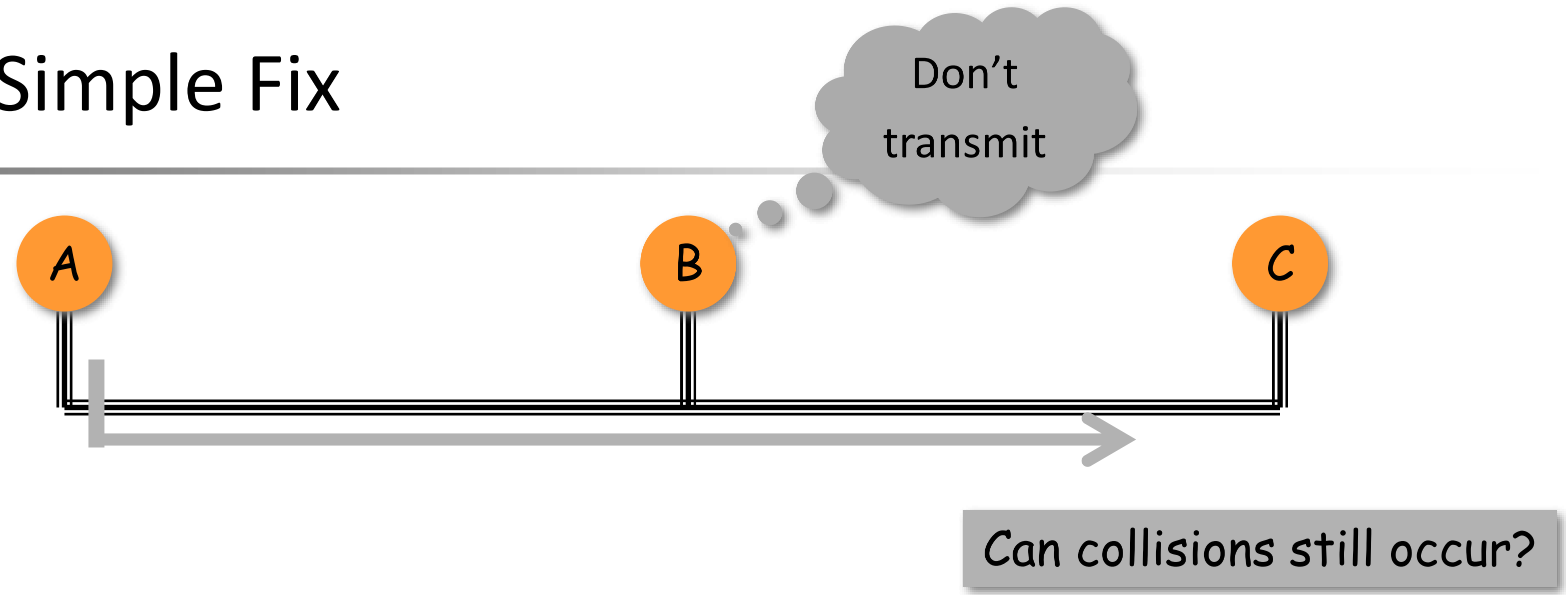
- Pairwise communication desired
  - Simultaneous communication not possible
- MAC Protocols
  - Suggests a scheme to schedule communication
    - Maximize number of communications
    - Ensure fairness among all transmitters

The Trivial Solution



- Transmit and watch!
  - Plenty of collisions --> poor throughput at high load

The Simple Fix



- Transmit and watch!
  - Plenty of collisions --> poor throughput at high load
- Listen before you talk
  - Carrier sense multiple access (CSMA)
  - Defer transmission when signal on channel

CSMA collisions

Collisions can still occur:

Propagation delay non-zero between transmitters

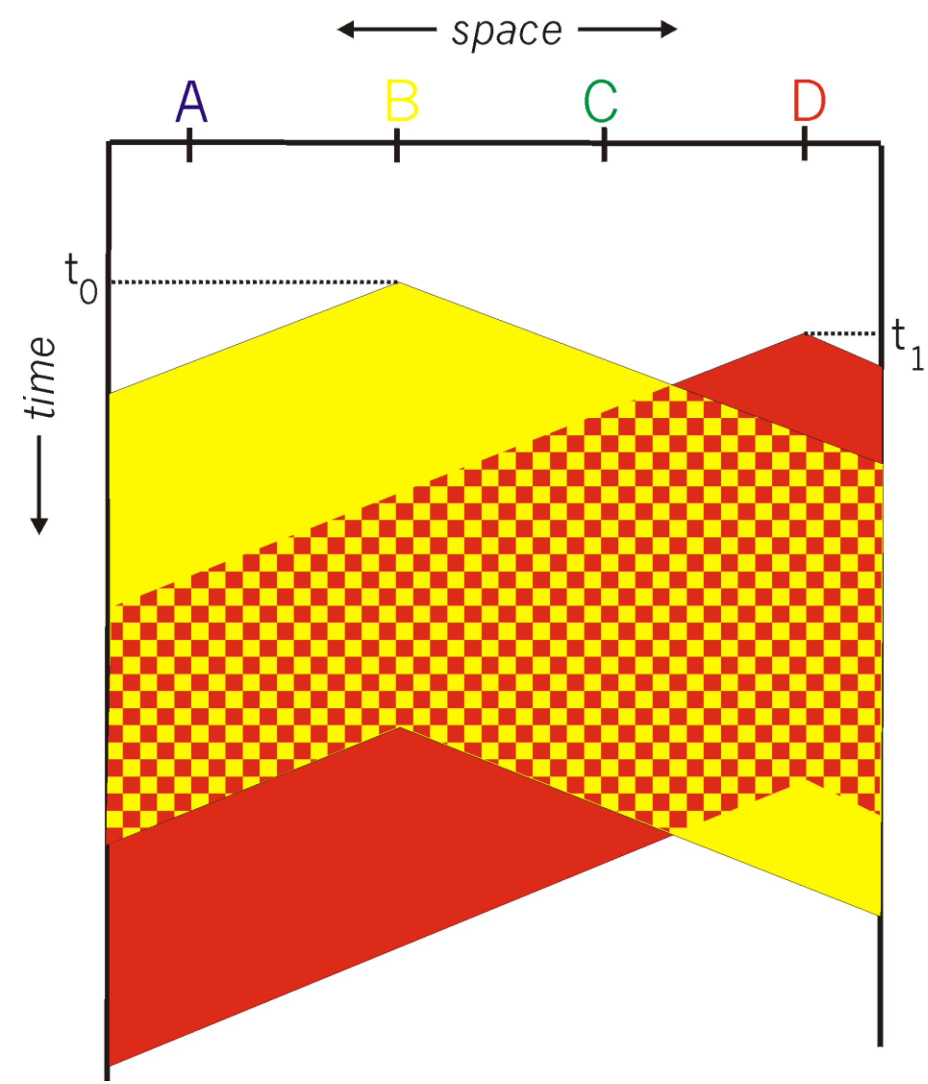
When collision:

Entire packet transmission time wasted

note:

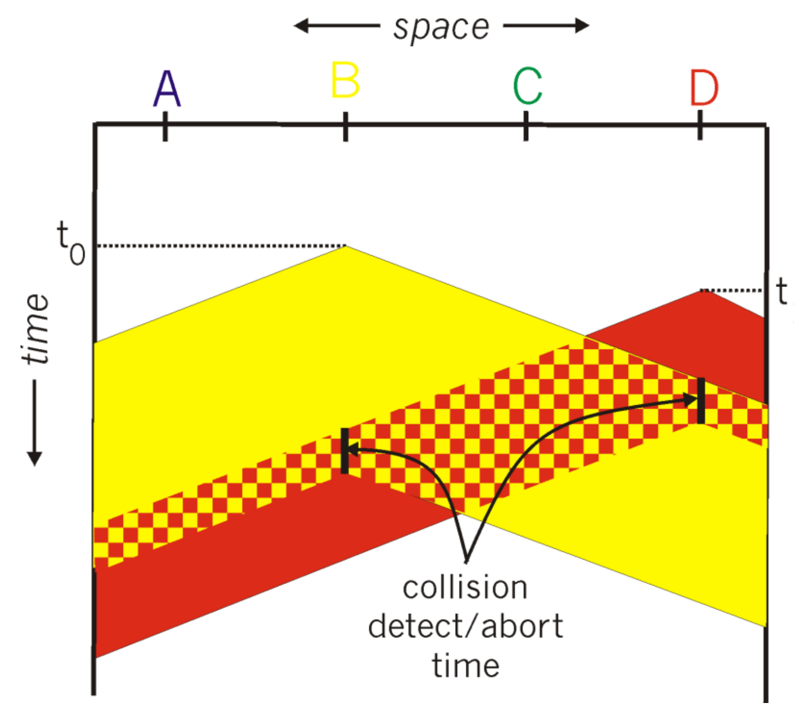
Role of distance & propagation delay in determining collision probability

spatial layout of nodes



CSMA/CD (Collision Detection)

- Keep listening to channel
  - While transmitting

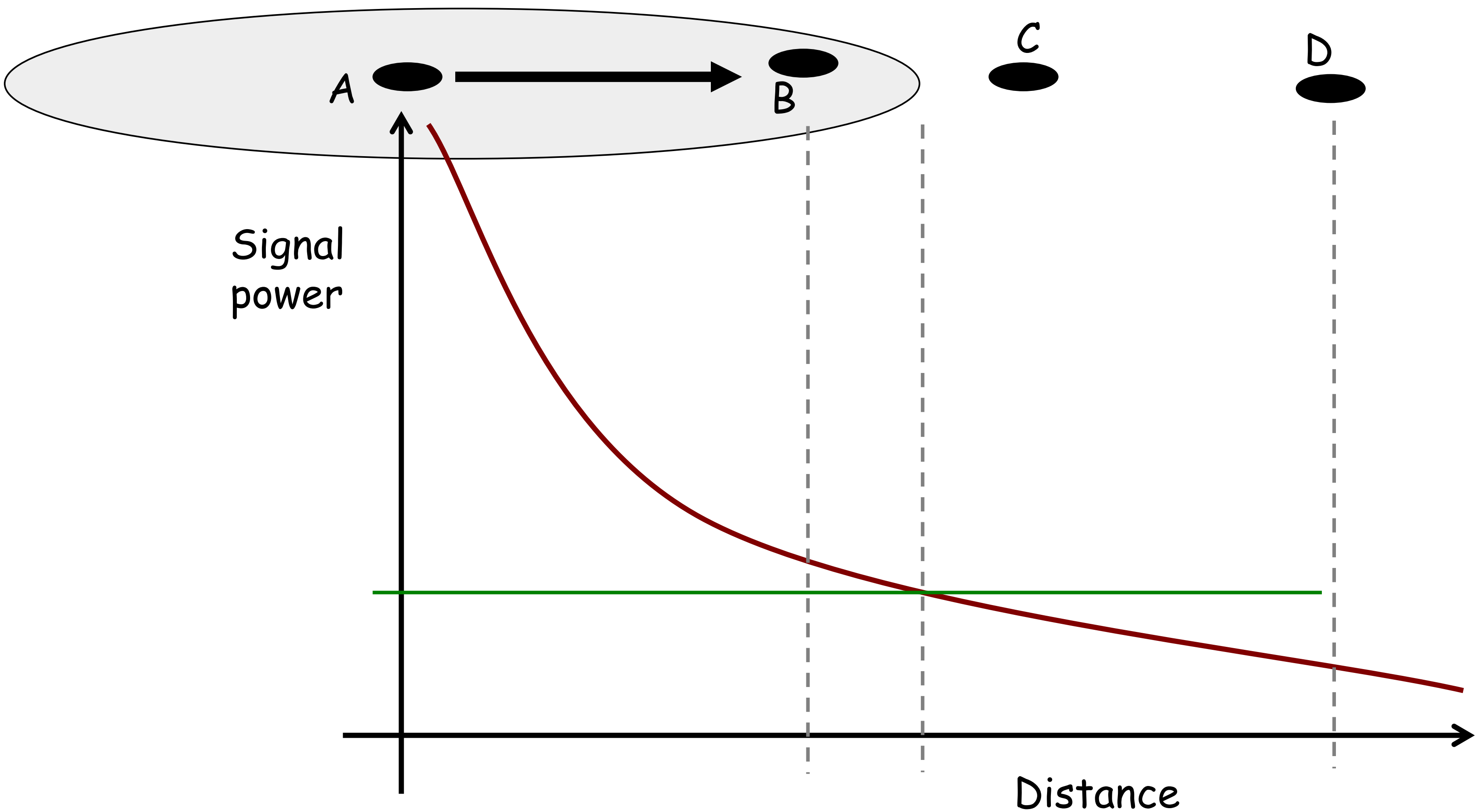


- If (Transmitted_Signal != Sensed_Signal)

  → Sender knows it's a **Collision**

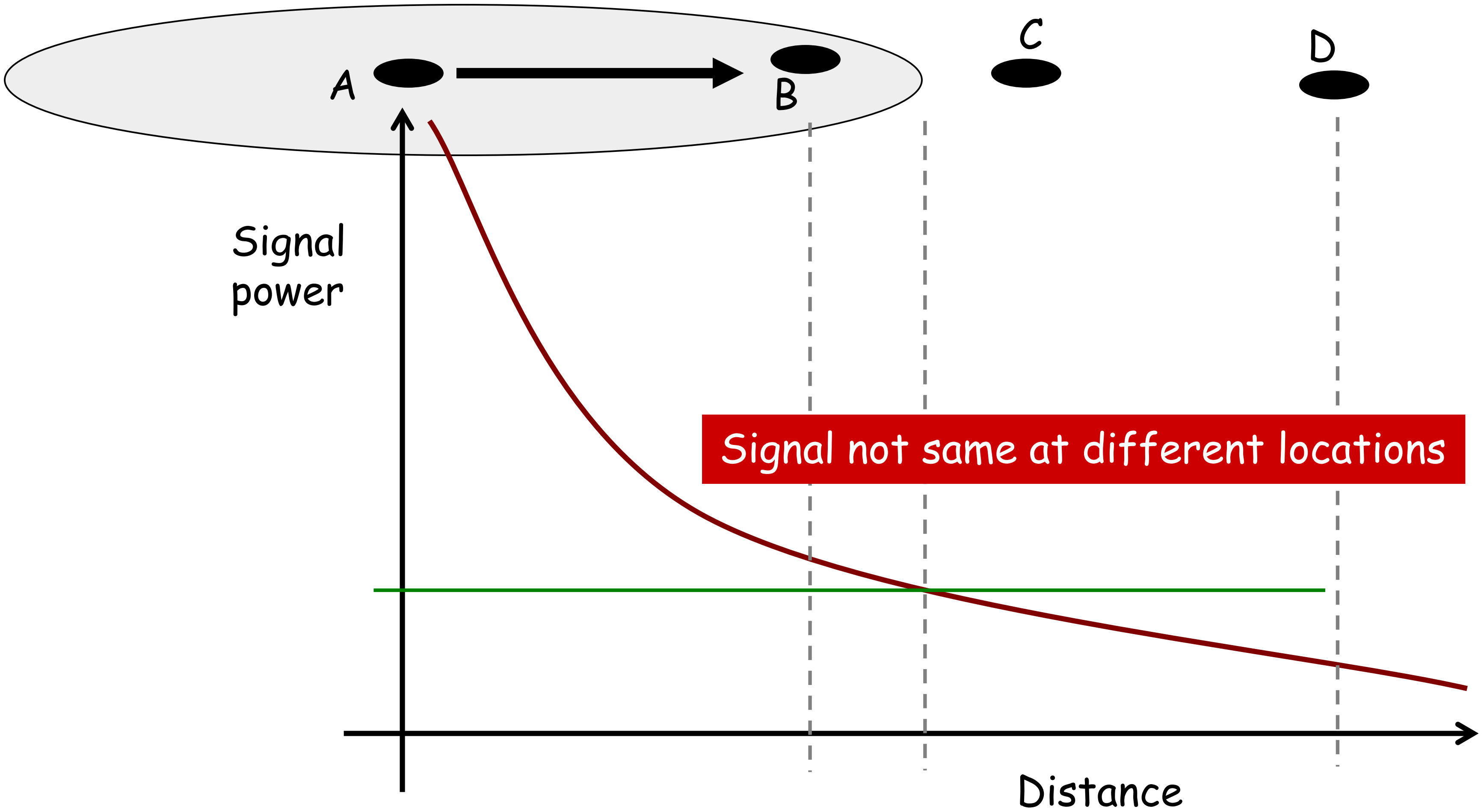
  → **ABORT**

Wireless Medium Access Control



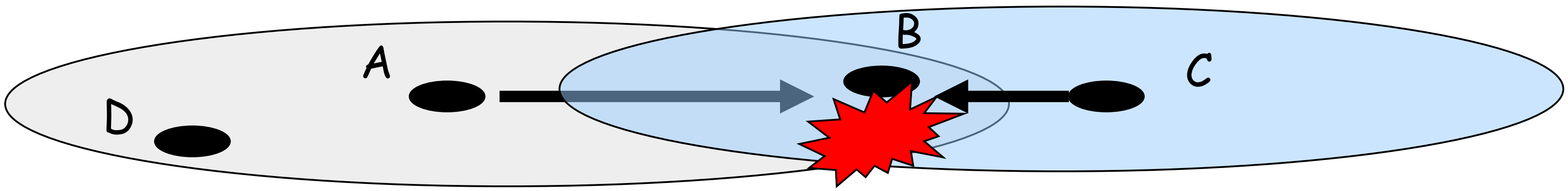
Wireless Media Disperse Energy

A cannot send and listen in parallel



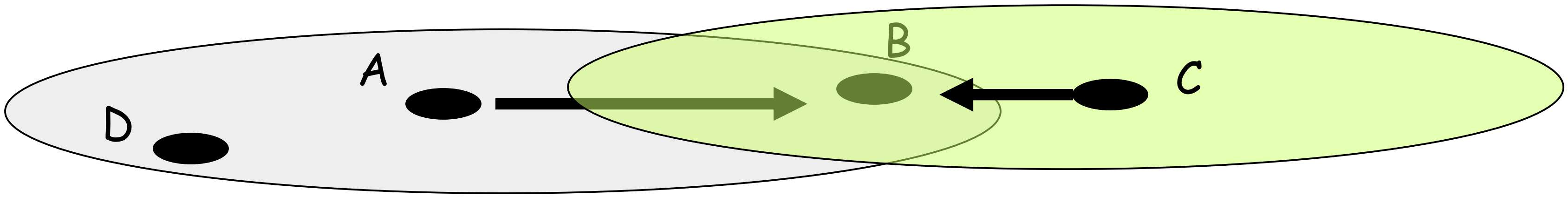
Signal not same at different locations

Collision Detection Difficult



- Signal reception based on SINR
  - Transmitter can only hear itself
  - Cannot determine signal quality at receiver

Calculating SINR



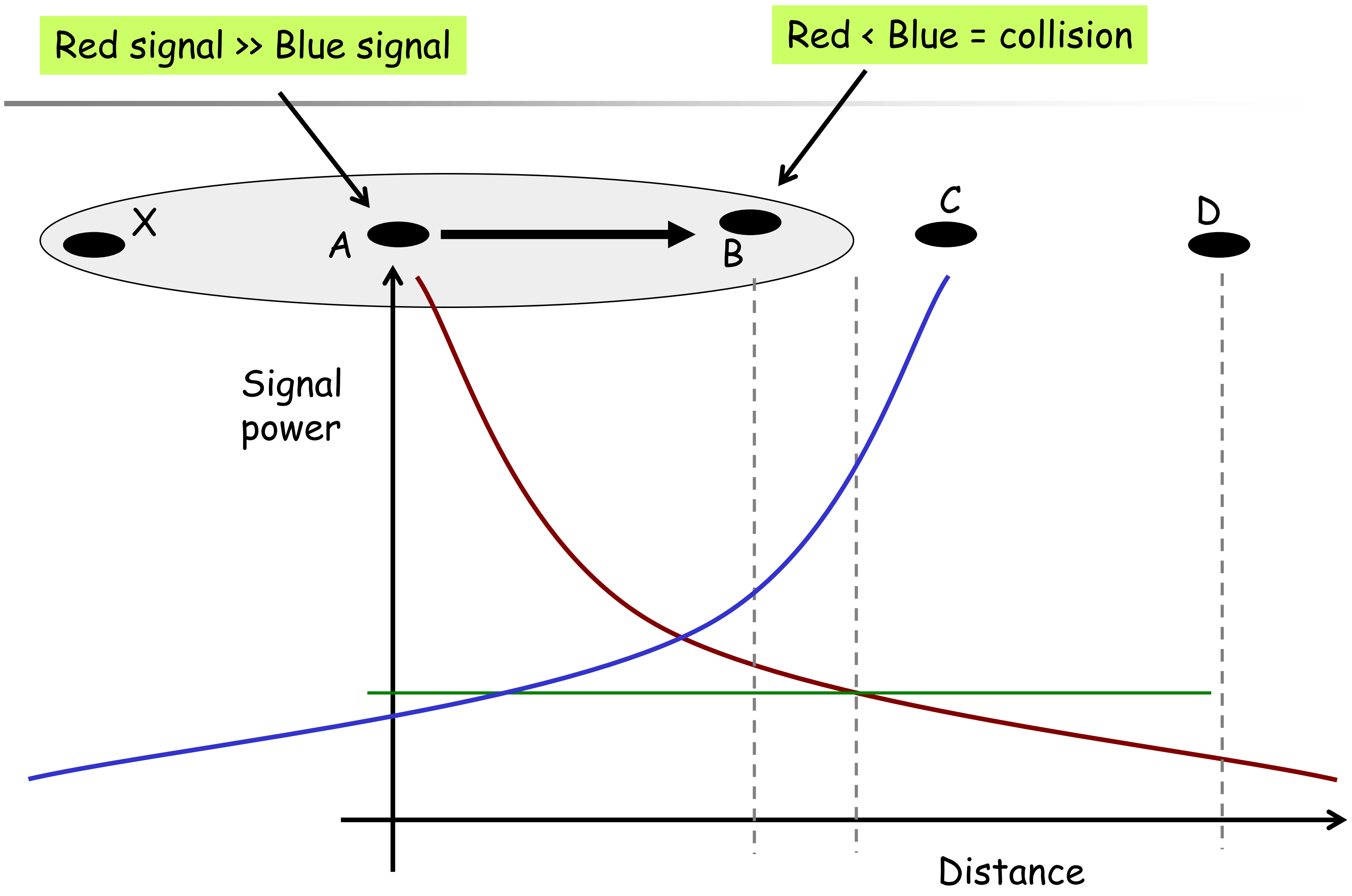
$$SINR = \frac{SignalOfInterest(SoI)}{Interference(I) + Noise(N)}$$

$$SoI_B^A = \frac{P^A_{transmit}}{d^a_{AB}}$$

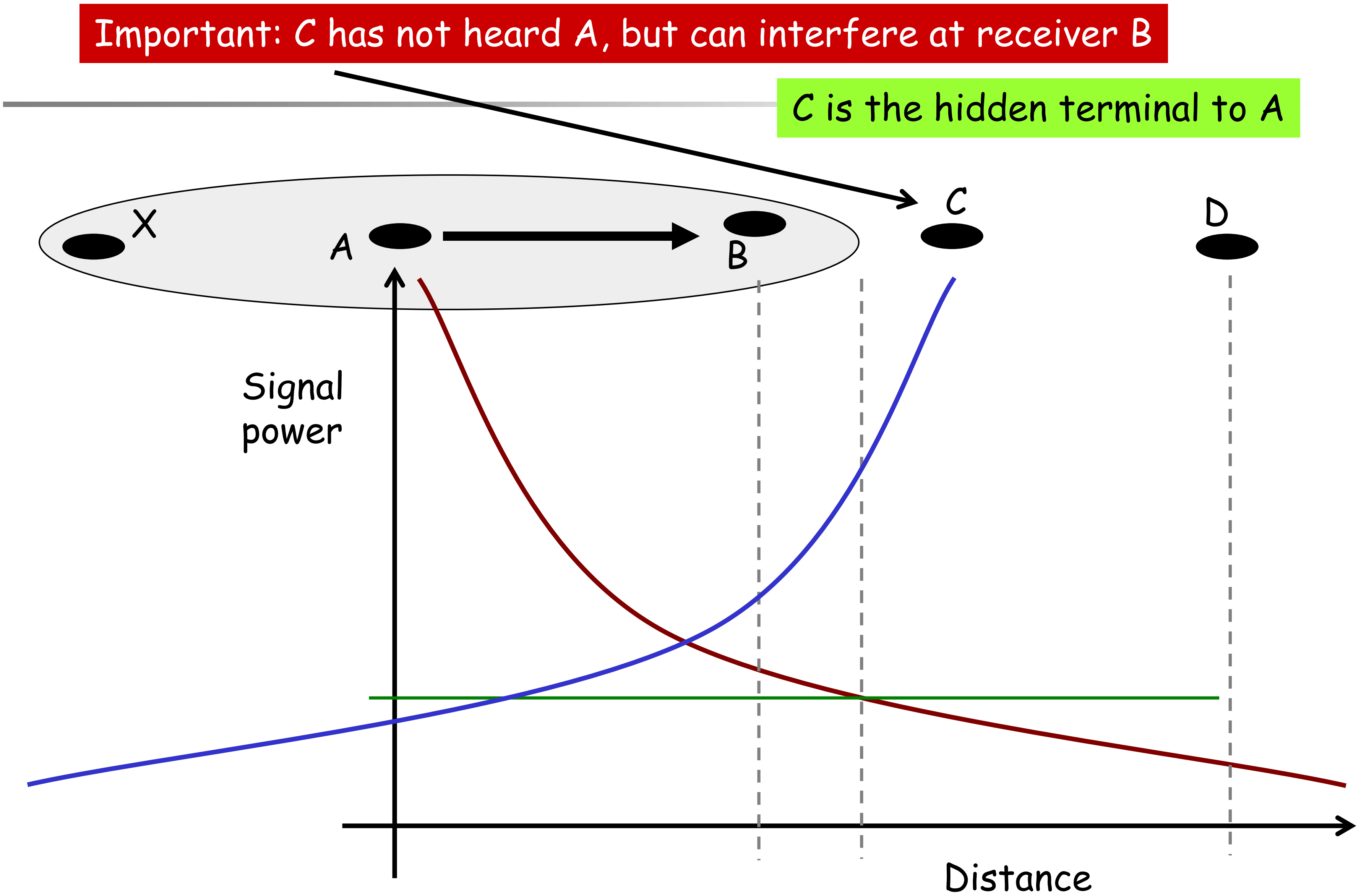
$$I_B^C = \frac{P^C_{transmit}}{d^a_{CB}}$$

$$\longrightarrow$$

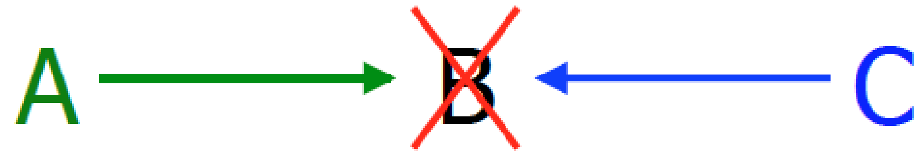
$$SINR_B^A = \frac{\frac{P^A_{transmit}}{d^a_{AB}}}{N + \frac{P^C_{transmit}}{d^a_{CB}}}$$



Red signal >> Blue signal
Red < Blue = collision
X
A
B
C
D
Signal power
Distance

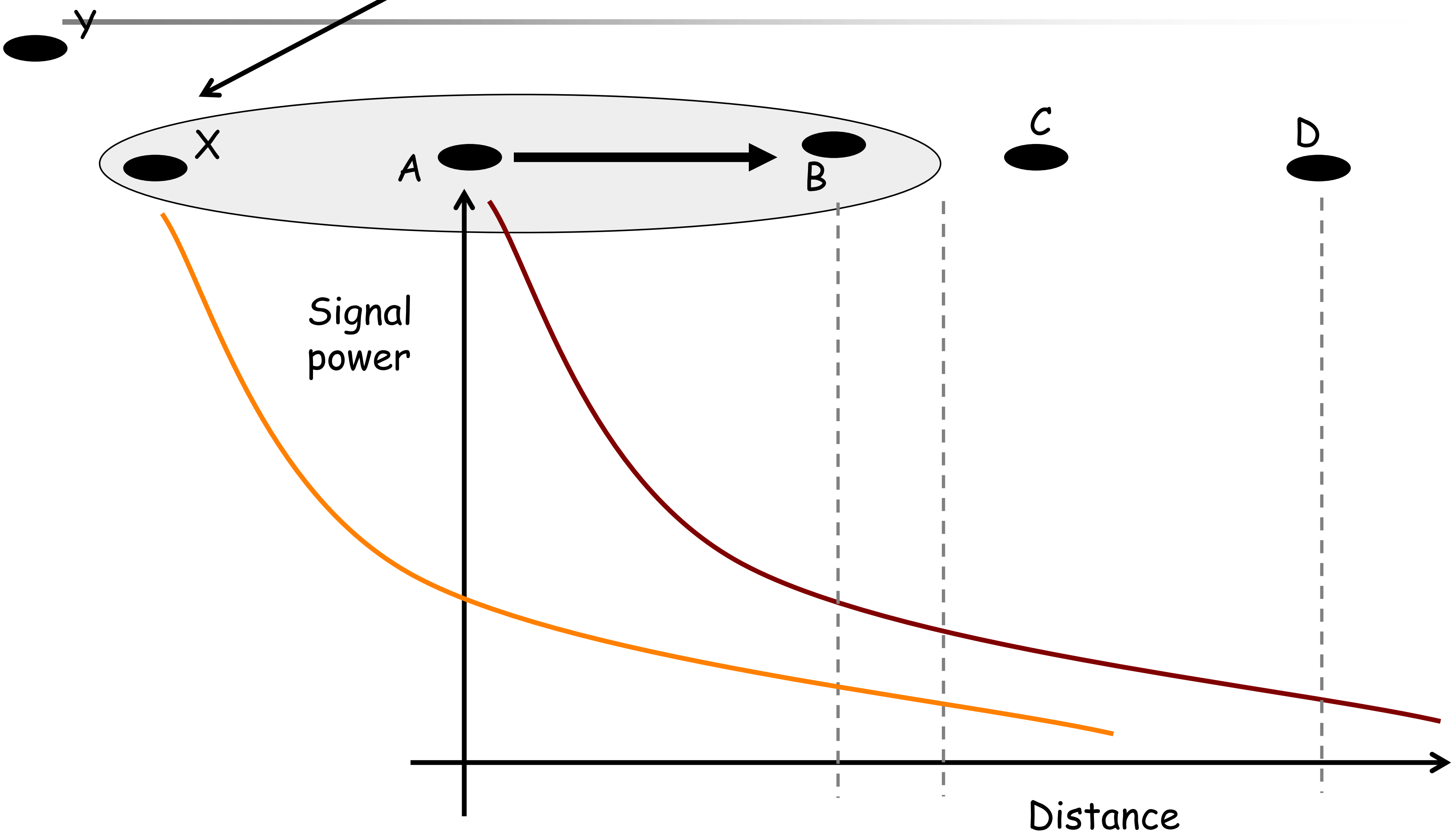

Important: C has not heard A, but can interfere at receiver B
C is the hidden terminal to A
X
A
B
C
D
Signal power
Distance

Hidden Terminal Problem



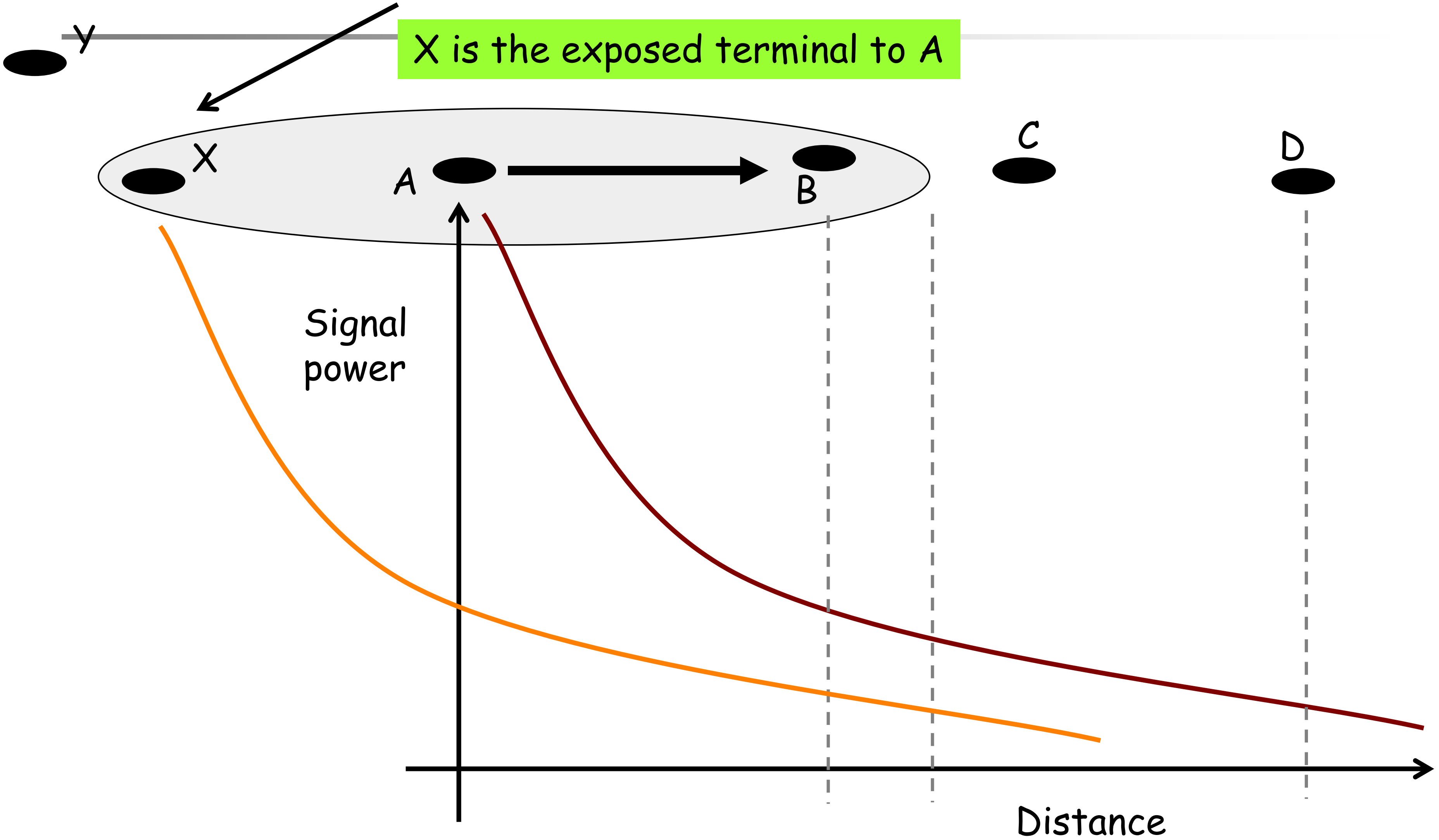
- Nodes placed a little less than one radio range apart
- CSMA: nodes listen to determine channel idle before transmitting
- C can't hear A, so will transmit while A transmits; result: collision at B
- Carrier Sense insufficient to detect all transmissions on wireless networks!
- Key insight: collisions are spatially located at receiver

Now, what should X do if it wants to transmit to Y ?



Important: X has heard A, but should not defer transmission to Y

X is the exposed terminal to A

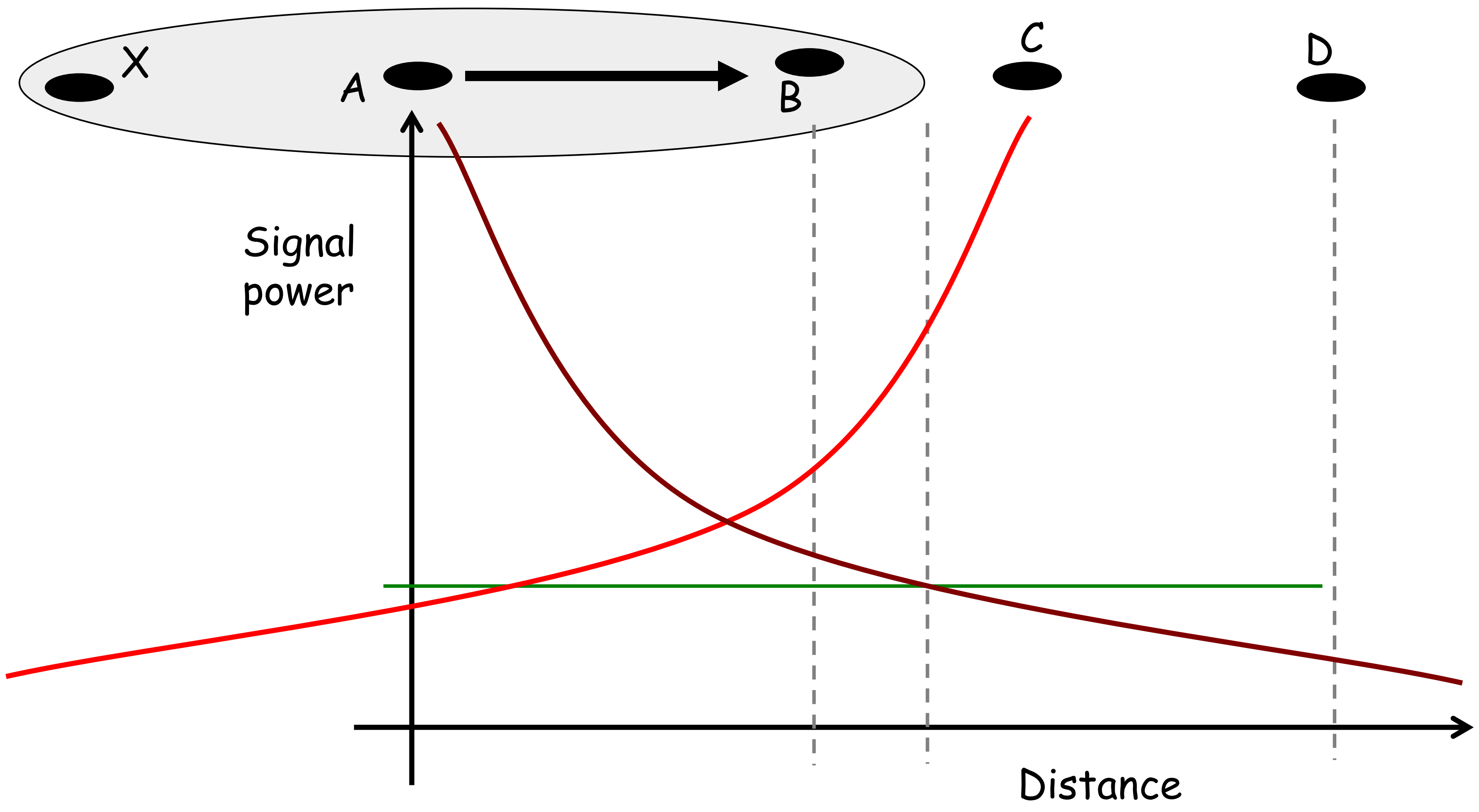


Exposed Terminal Problem

- B sends to A; C sends to a node other than B
- If C transmits, does it cause a collision at A?
- Yet C cannot transmit while B transmits to A!
- Same insight: collisions are spatially located at receiver
- One possibility: directional antennas rather than omnidirectional. Why does this help? Why is it hard?
- Simpler solution: use *receiver's* medium state to determine transmitter behavior

Here, the node letters are different from the previous slide!, this is another independent explanation!

How to prevent C from trasmitting?



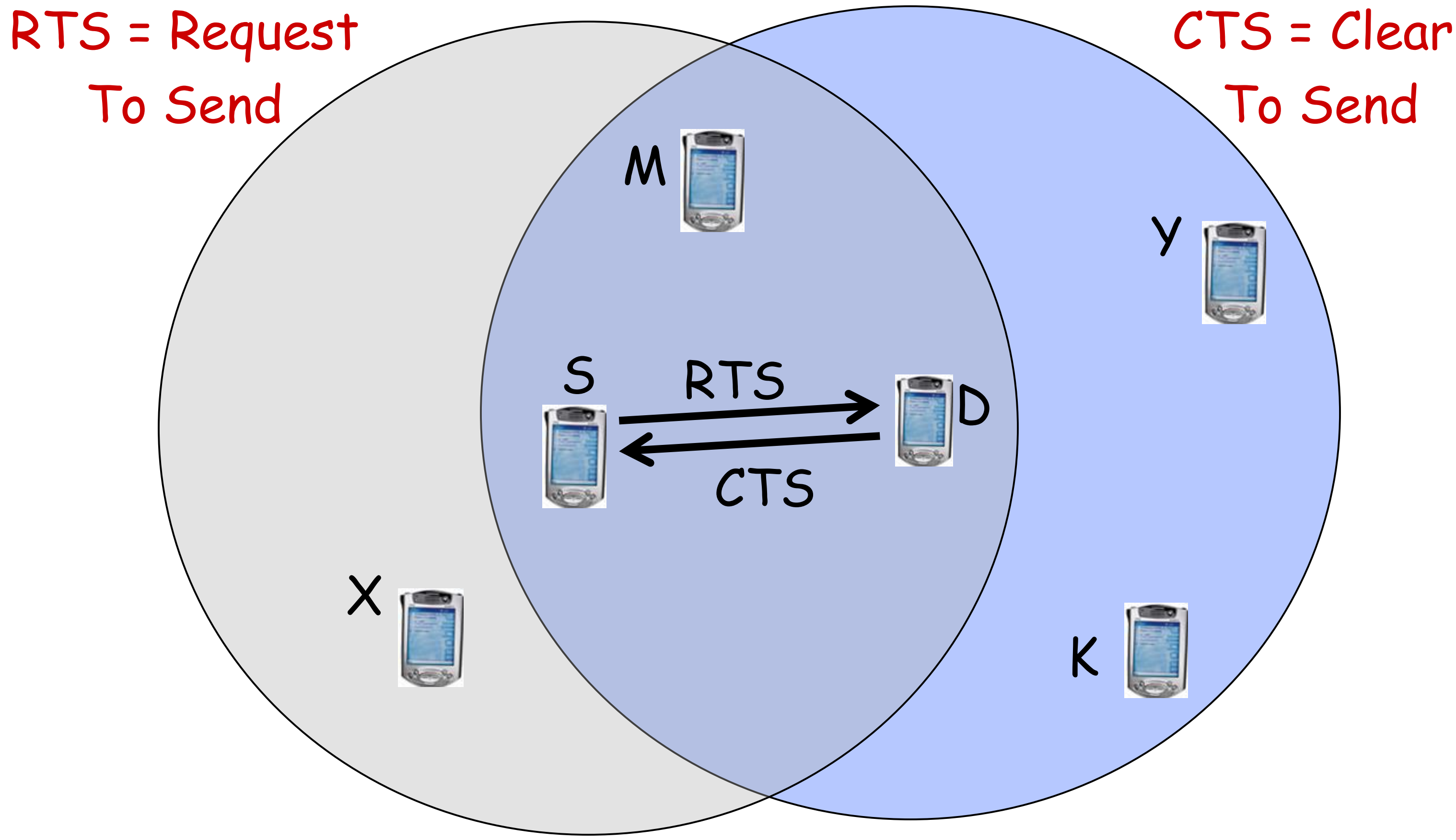
The Emergence of MACA, MACAW, & 802.11

- Wireless MAC proved to be non-trivial

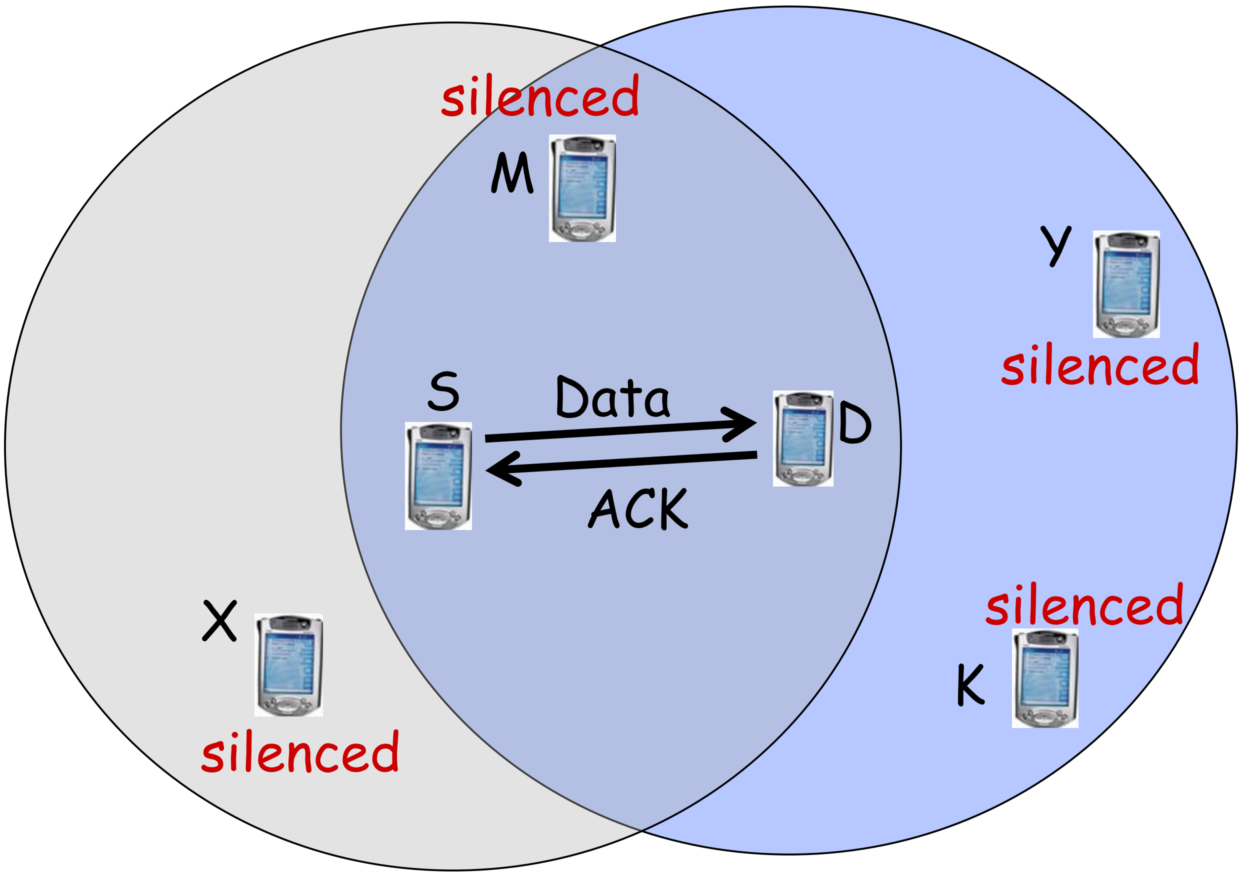
- 1992 - research by Karn (MACA)
- 1994 - research by Bhargavan (MACAW)

- Led to IEEE 802.11 committee
  - The standard was ratified in 1999

IEEE 802.11



IEEE 802.11



802.11 Steps

- All backlogged nodes choose a random number
- Each node counts down
  - Continue carrier sensing while counting down
  - Once carrier busy, freeze countdown
- Whoever reaches ZERO transmits RTS
  - Neighbors freeze countdown, decode RTS

802.11 Steps

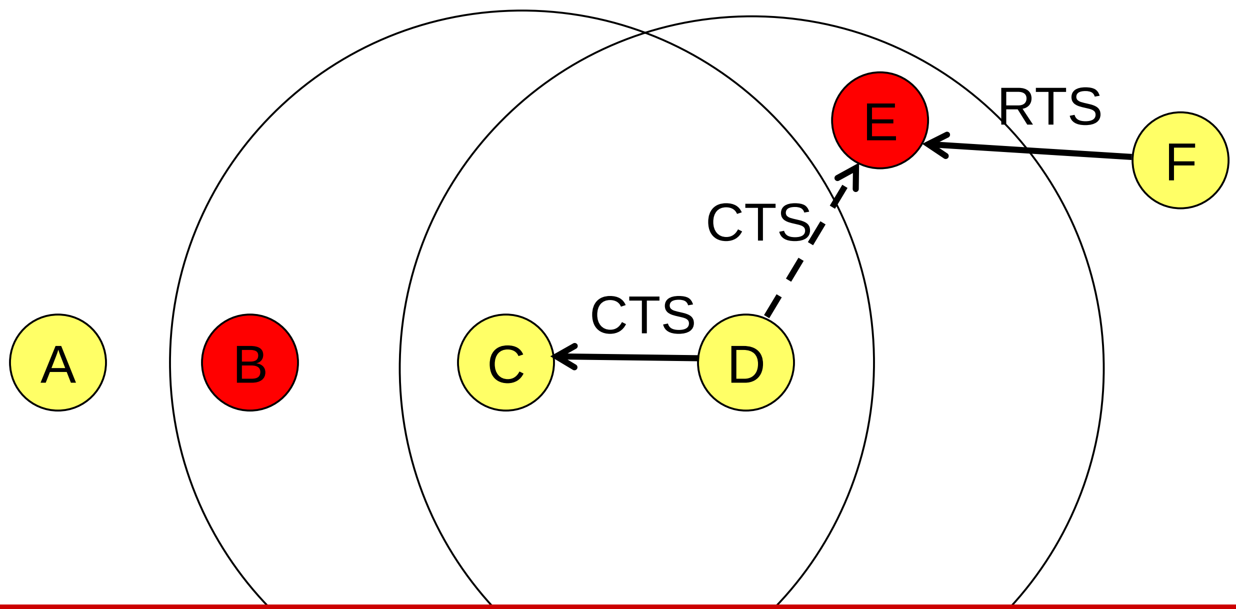
- Receiver replies with CTS

- Tx sends DATA, Rx acknowledges with ACK

- If RTS or DATA collides (i.e., no CTS/ACK returns)
  - Indicates collision
  - RTS chooses new random countdown number

RTS/CTS

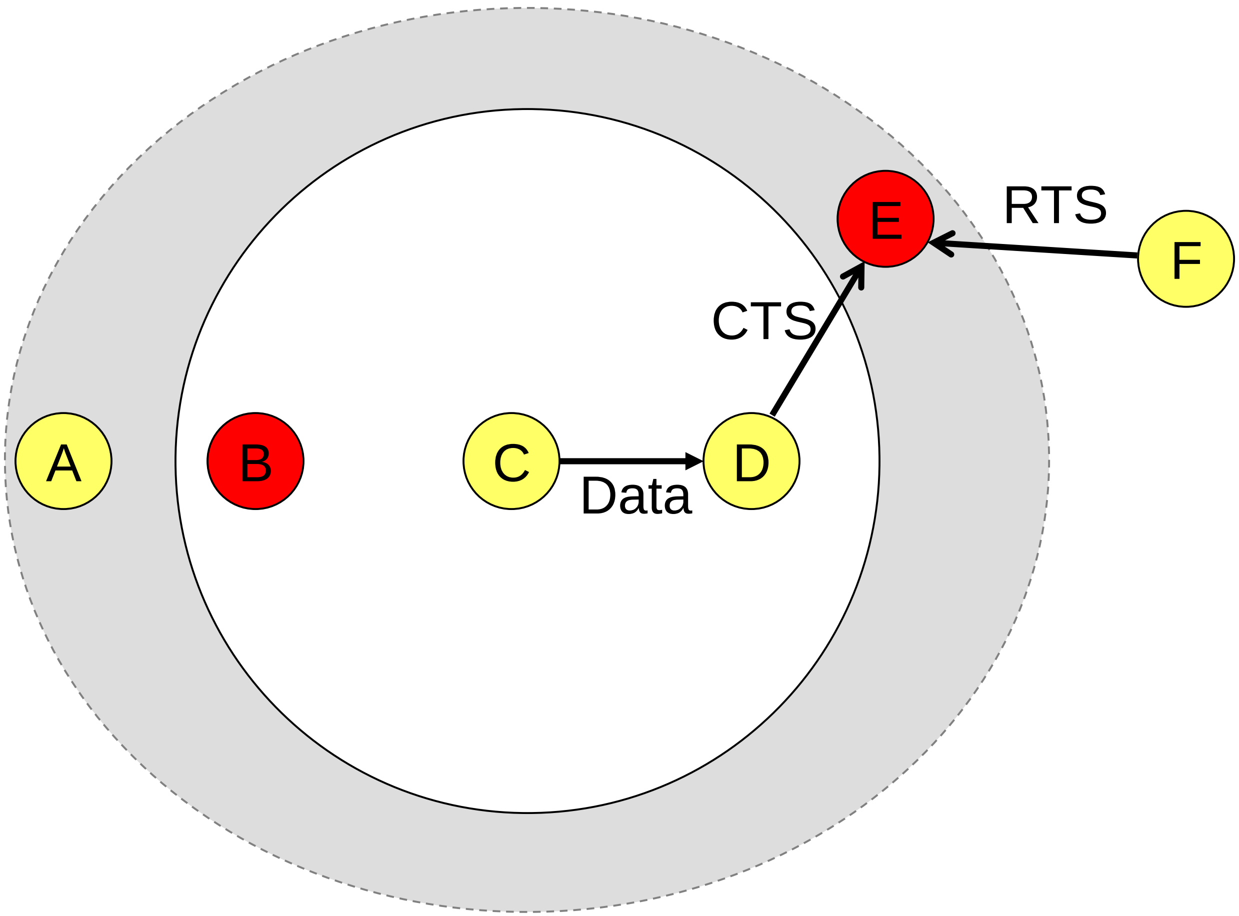
- Does it solve hidden terminals ?
  - Assuming carrier sensing zone = communication zone



E does not receive CTS successfully → Can later initiate transmission to D.
Hidden terminal problem remains.

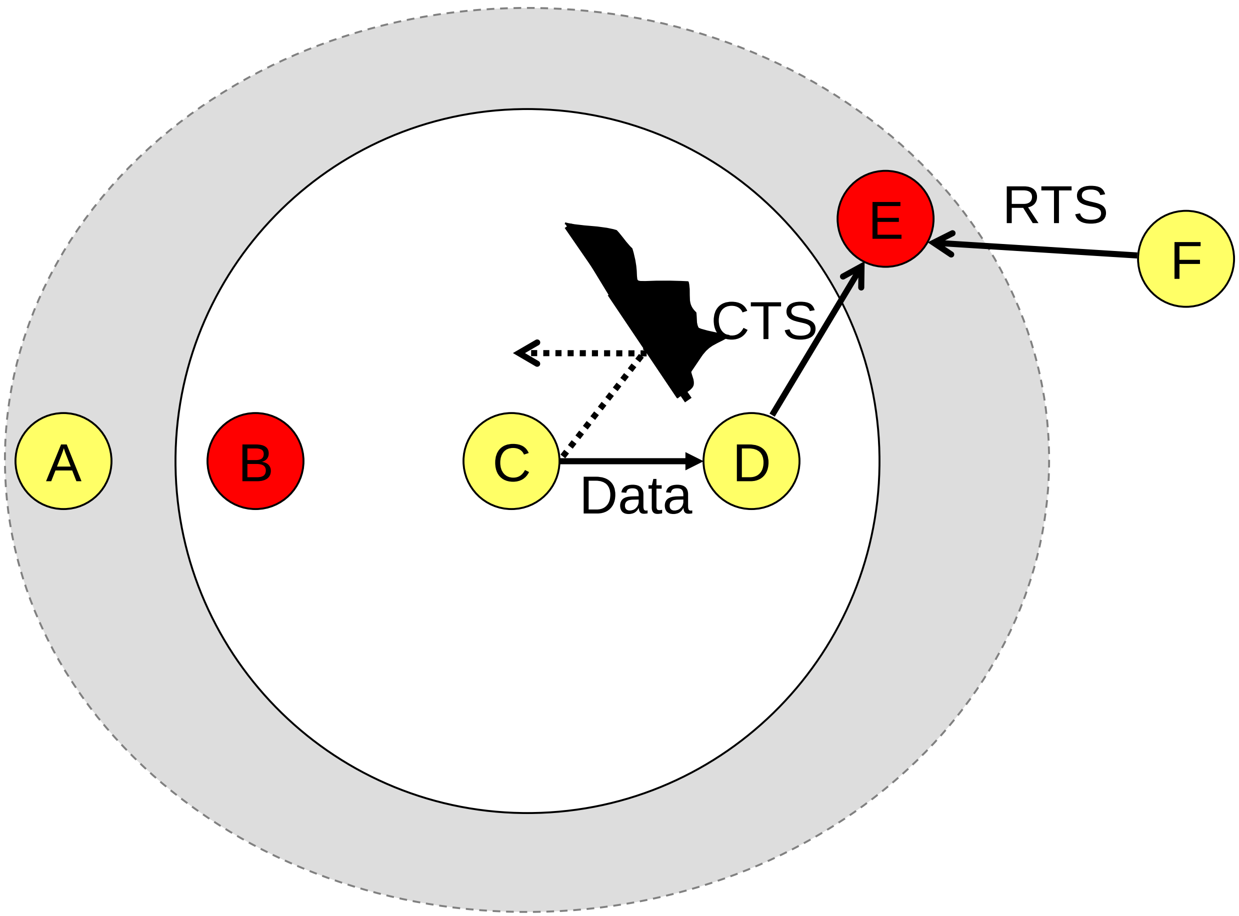
Hidden Terminal Problem

- How about increasing carrier sense range ??
  - E will defer on sensing carrier → no collision !!!



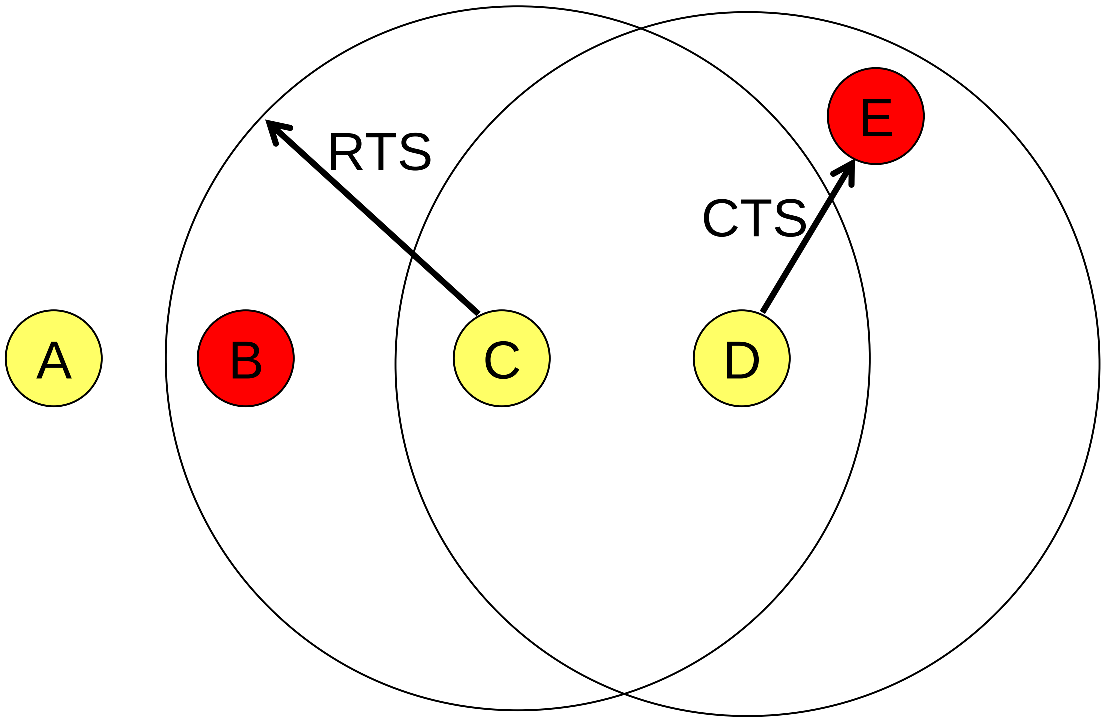
Hidden Terminal Problem

- But what if barriers/obstructions ??
  - E doesn’t hear C → Carrier sensing does not help



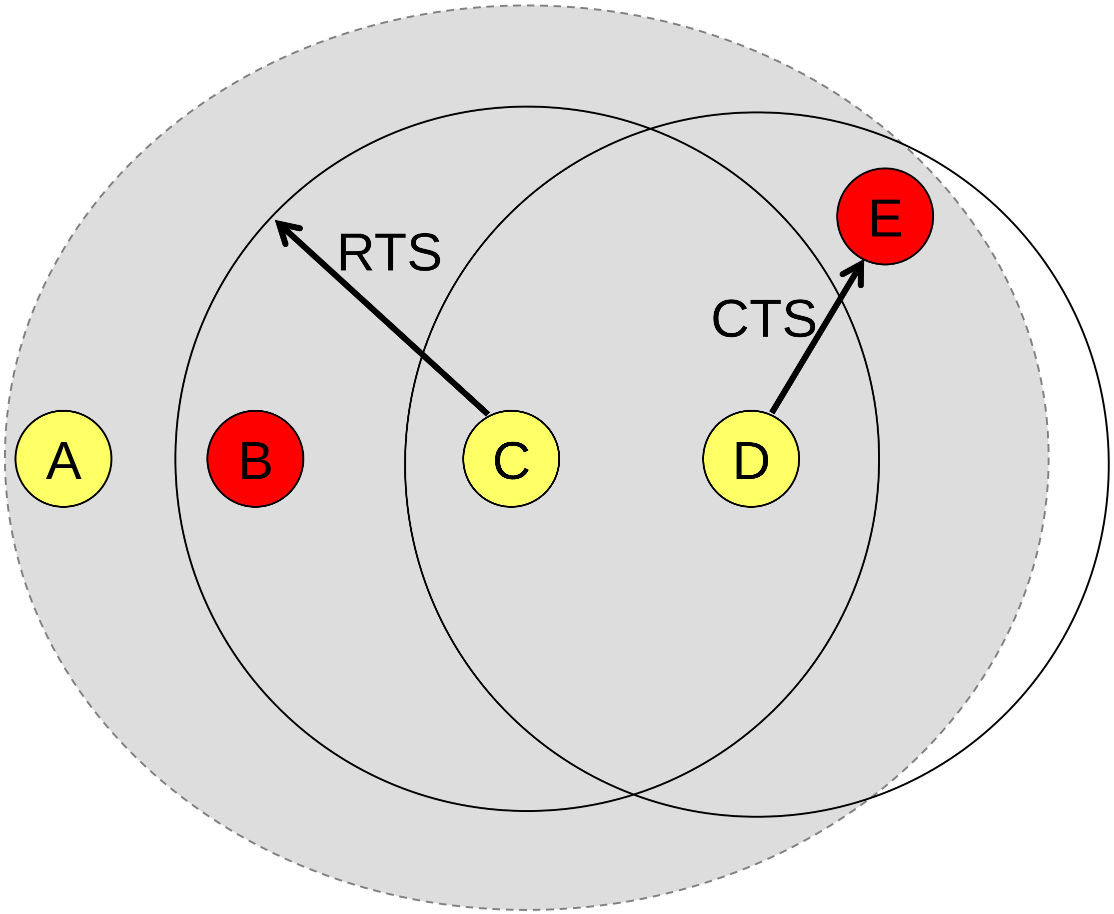
Exposed Terminal

- B should be able to transmit to A
  - RTS prevents this

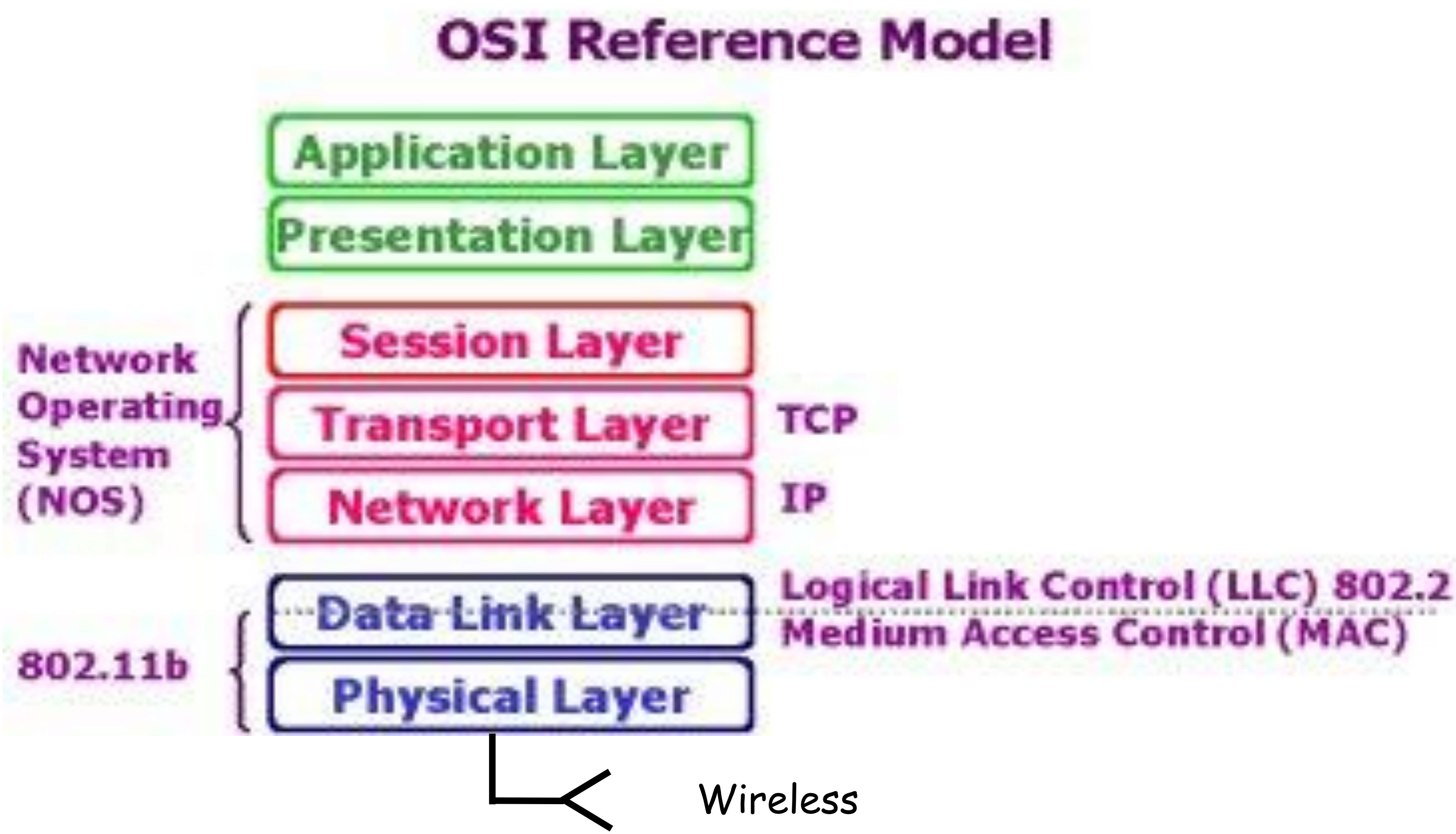


Exposed Terminal

- B should be able to transmit to A
  - Carrier sensing makes the situation worse

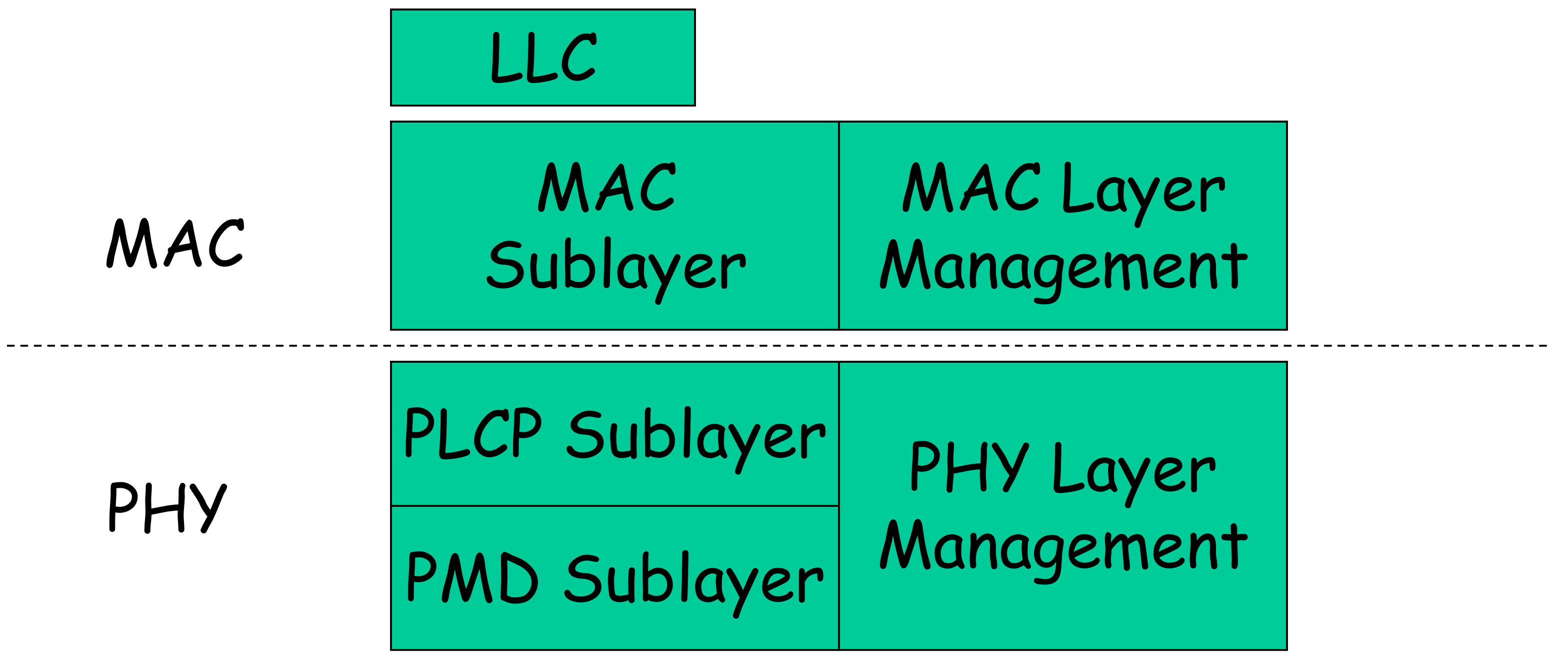


IEEE 802.11 in OSI Model



802.11 Scope & Modules

To develop a MAC and PHY spec for wireless connectivity for fixed, portable and moving stations in a local area



Applications

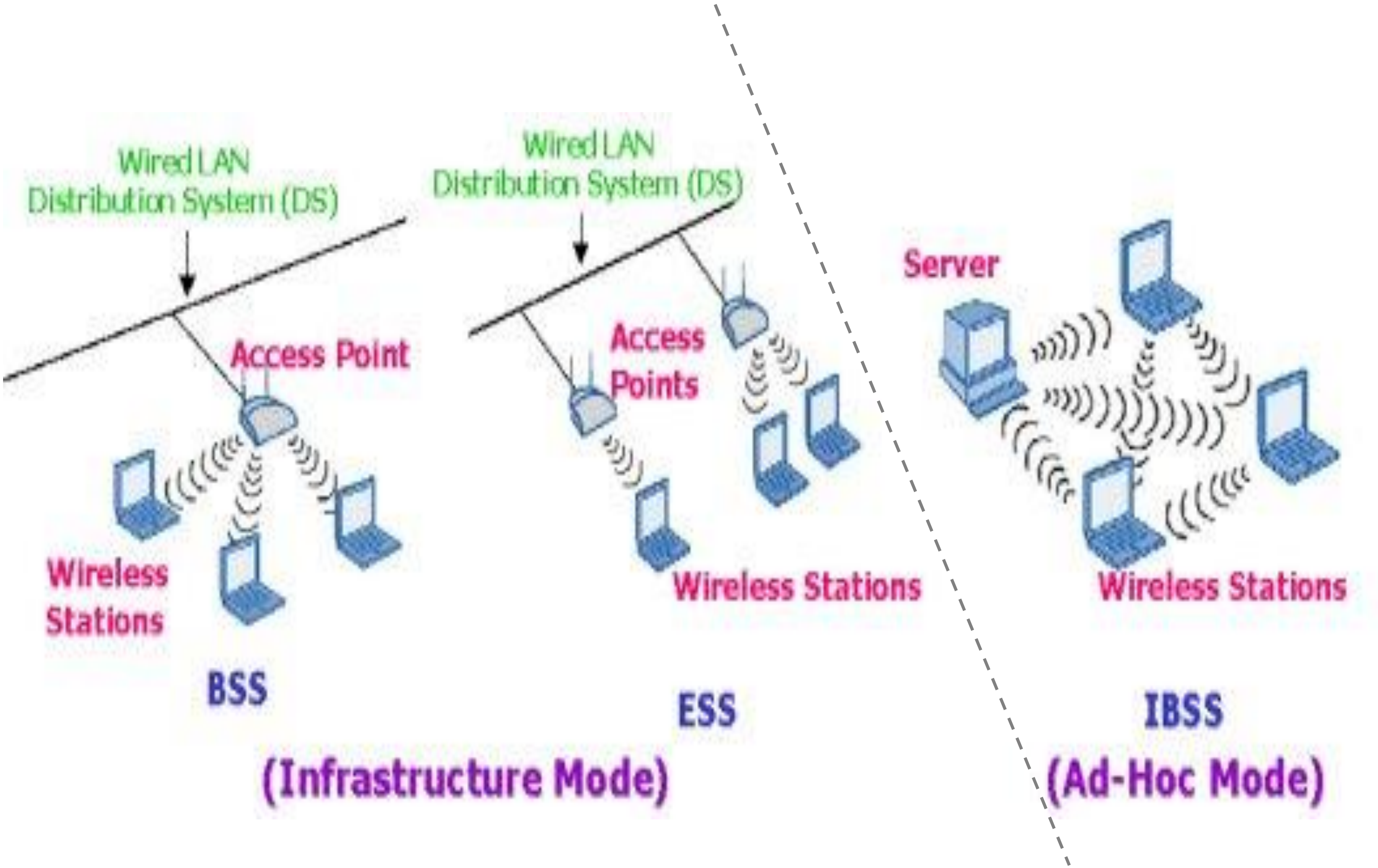
Single Hop

- Home networks
- Enterprise networks (e.g., offices, labs, etc.)
- Outdoor areas (e.g., cities, parks, etc.)

Multi-hops

- Adhoc network of small groups (e.g.,aircrafts)
- Balloon networks (SpaceData Inc.)
- Mesh networks (e.g., routers on lamp-posts)

802.11 Architecture – Two modes



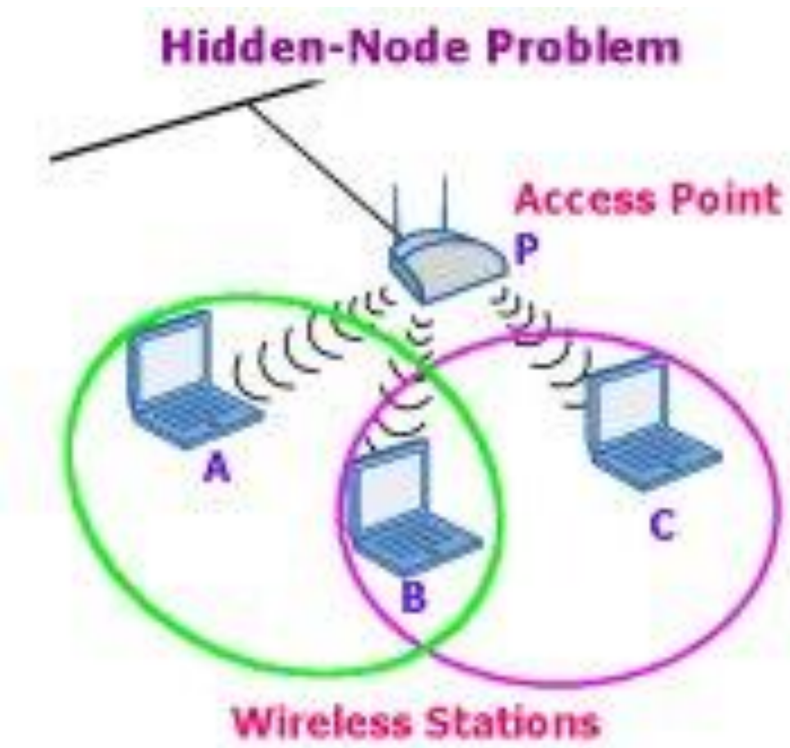
802.11 MAC

- **CSMA/CA based protocol**
  - Listen before you talk
  - CA = Collision avoidance (prevention is better than cure !!)

- **Robust for interference**
  - Explicit acknowledgment requested from receiver
    - for unicast frames
  - Only CSMA/CA for Broadcast frames

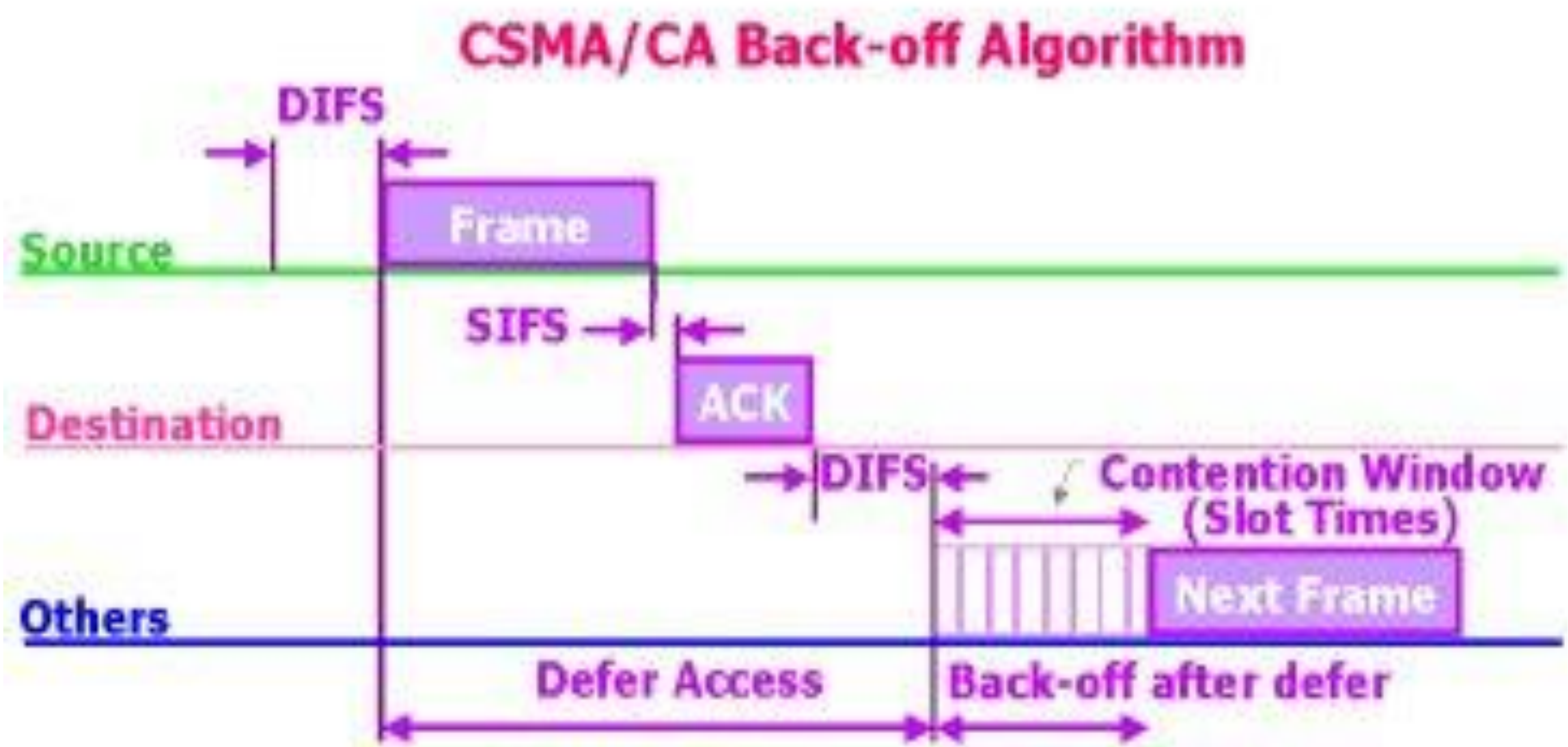
- **Optional RTS/CTS offers Virtual Carrier Sensing**
  - RTS/CTS includes duration of immediate dialog
  - Addresses hidden terminal problems

802.11 MAC

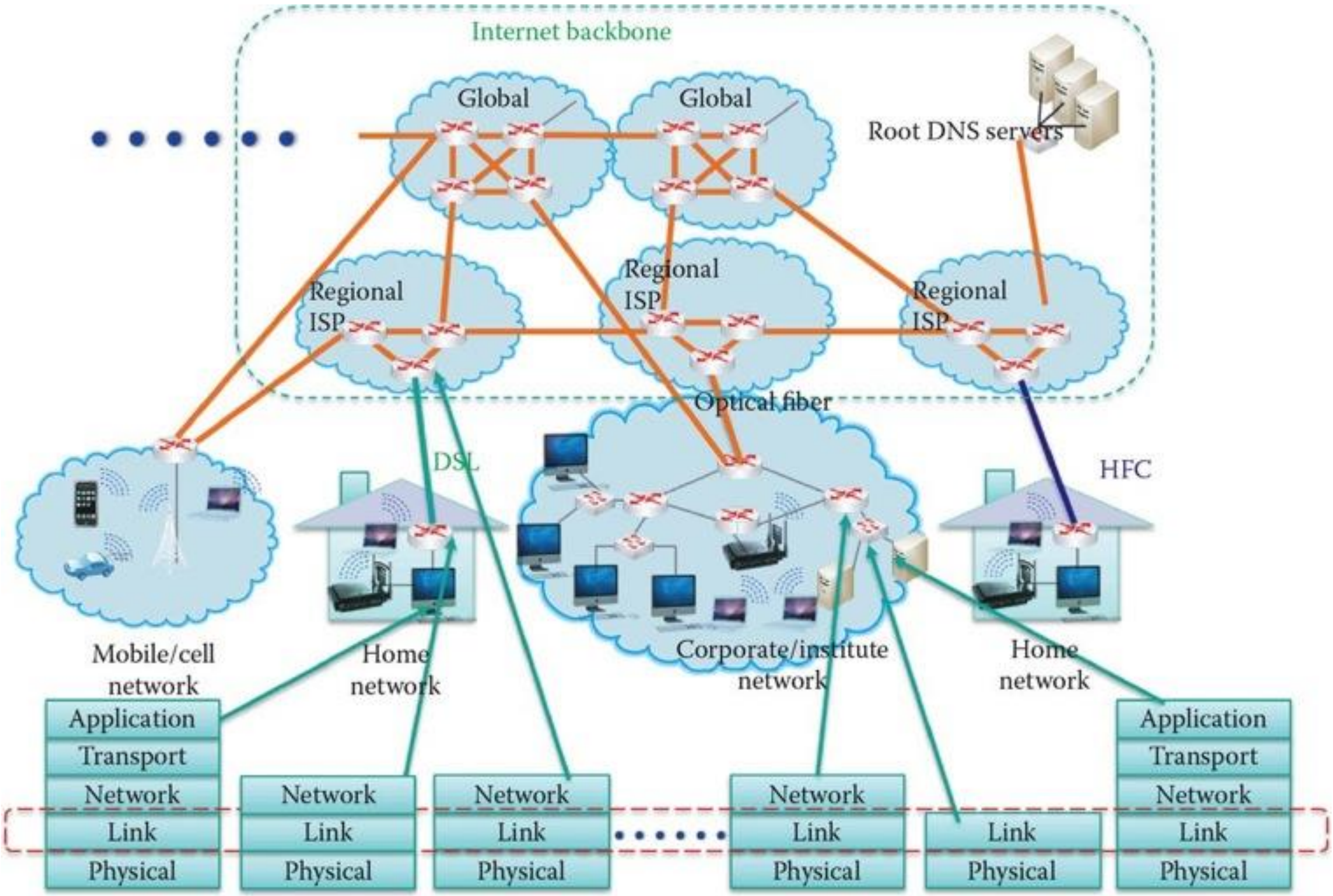

Hidden-Node Problem
Access Point
P
A
B
C
Wireless Stations


4-Way Handshake
(RTS/CTS)
Access Point
Station
RTS
(Request To Send)
CTS
(Clear To Send)
Data
ACK

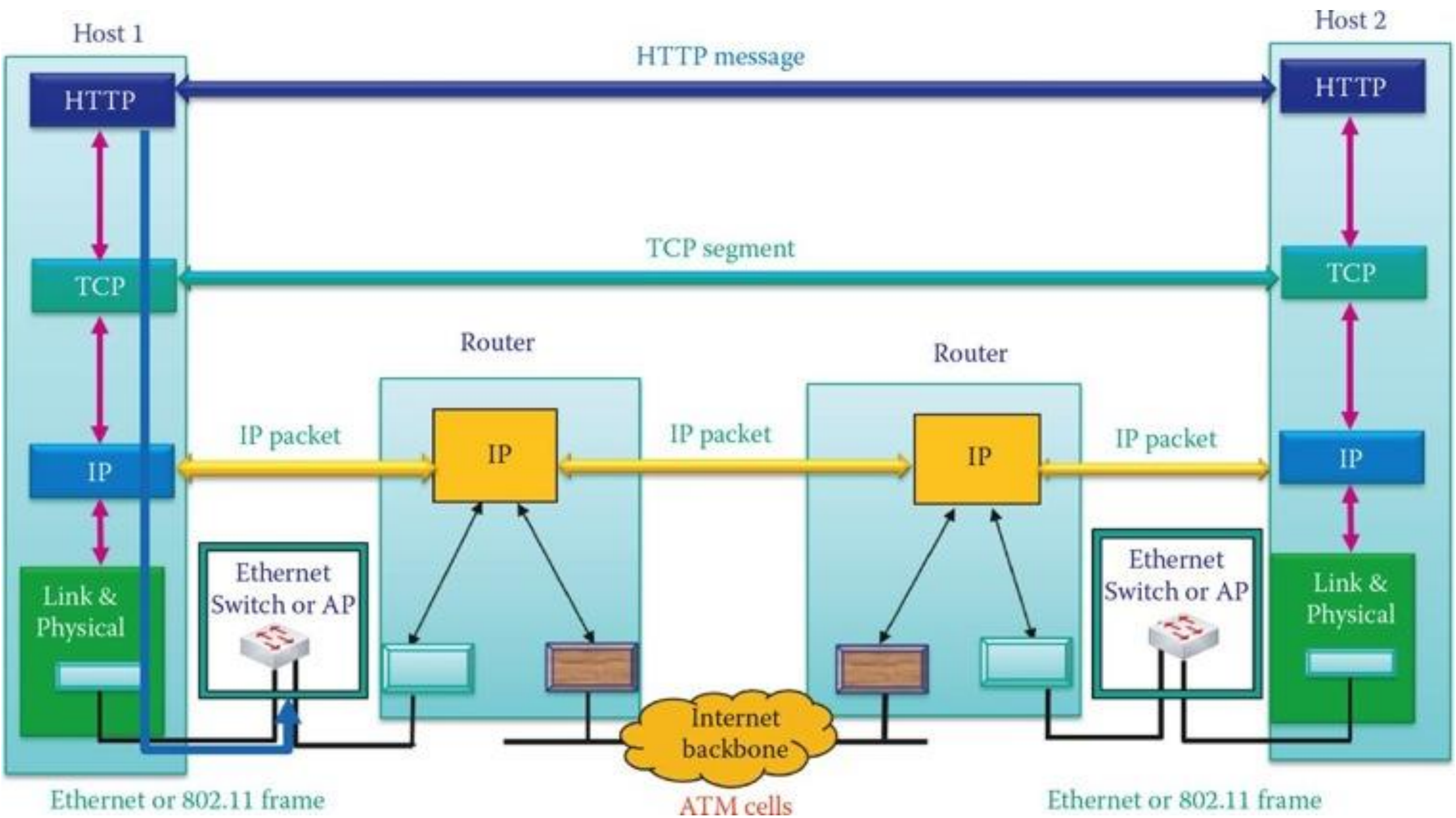
Physical Carrier Sense & Backoff



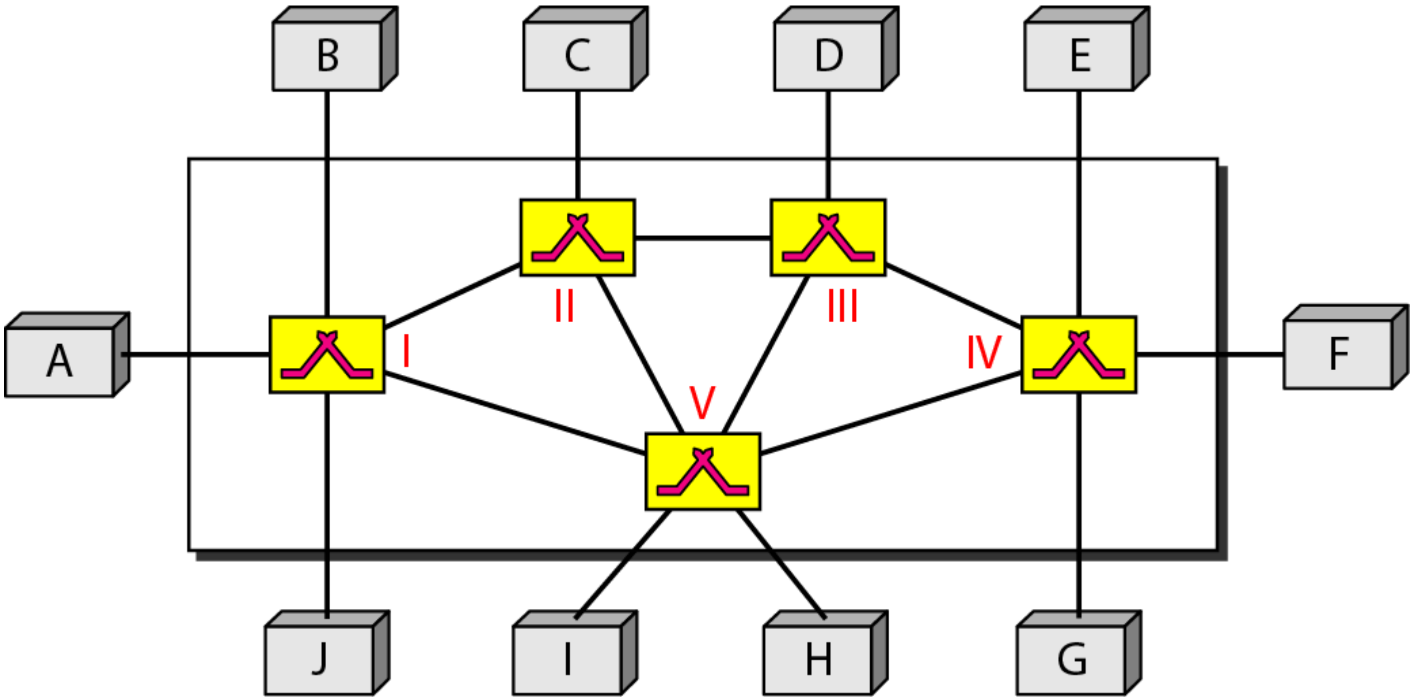
Overal Internet Architecture



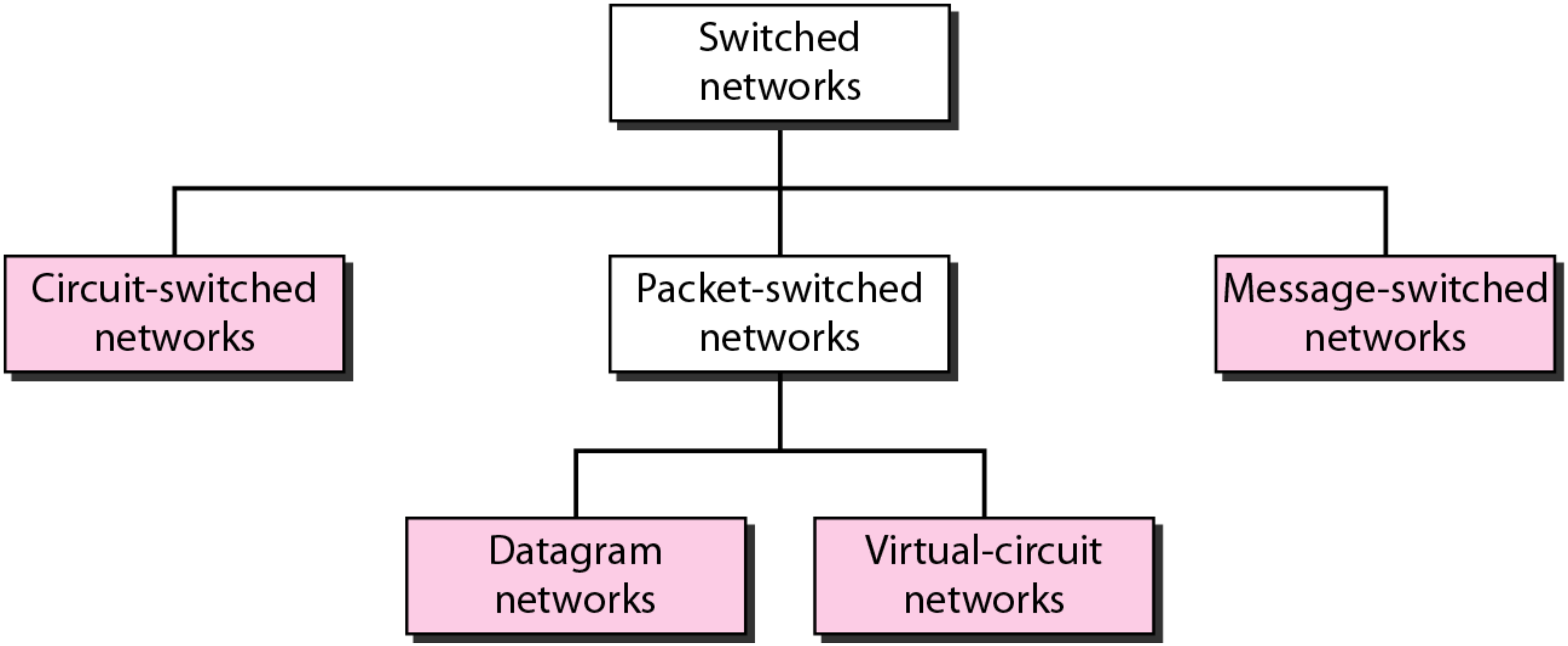
MAC Architecture



Switched network



Taxonomy of switched networks



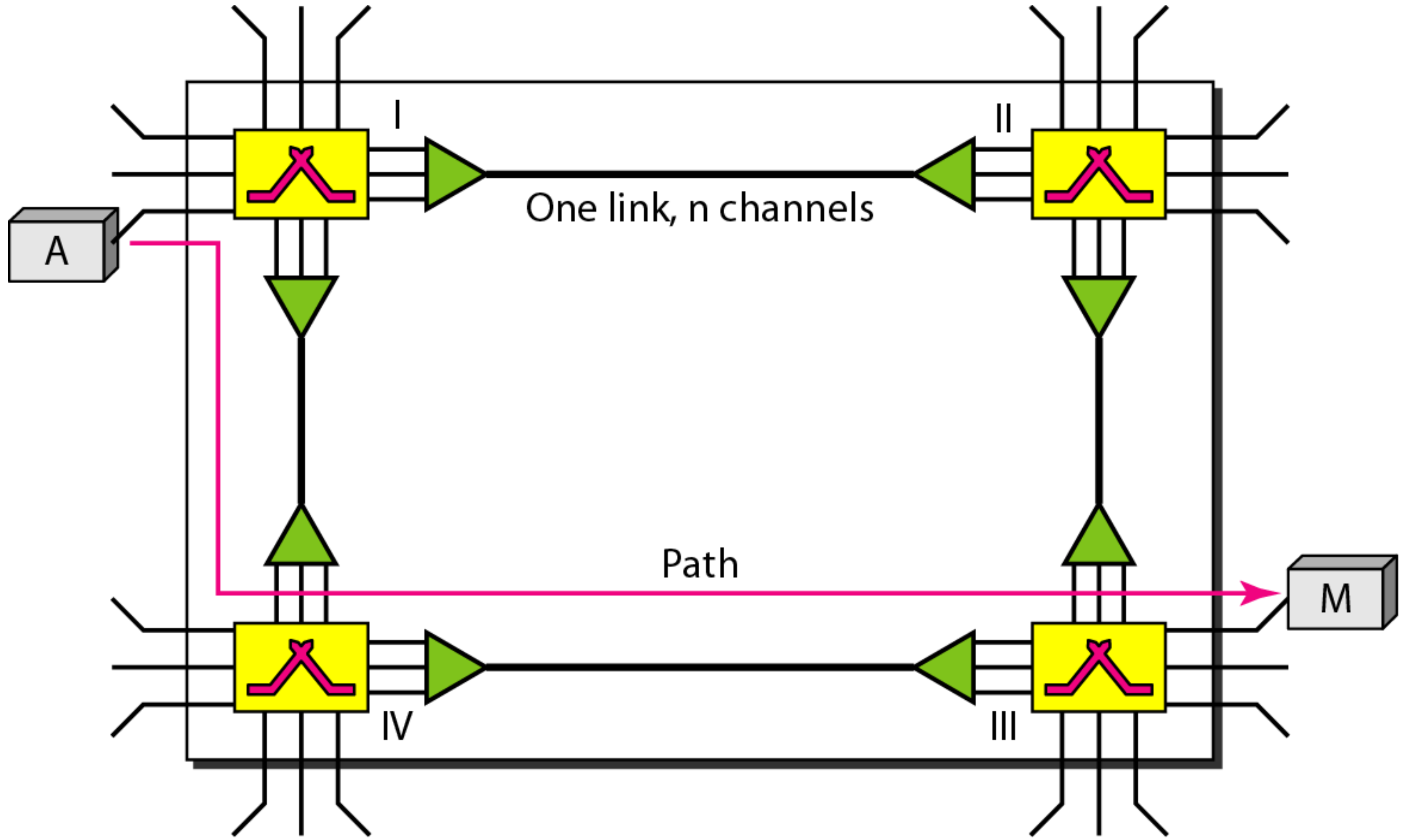
CIRCUIT-SWITCHED NETWORKS

A circuit-switched network consists of a set of switches connected by physical links.

A connection between two stations is a dedicated path made of one or more links.

However, each connection uses only one dedicated channel on each link. Each link is normally divided into n channels by using FDM or TDM.

A trivial circuit-switched network

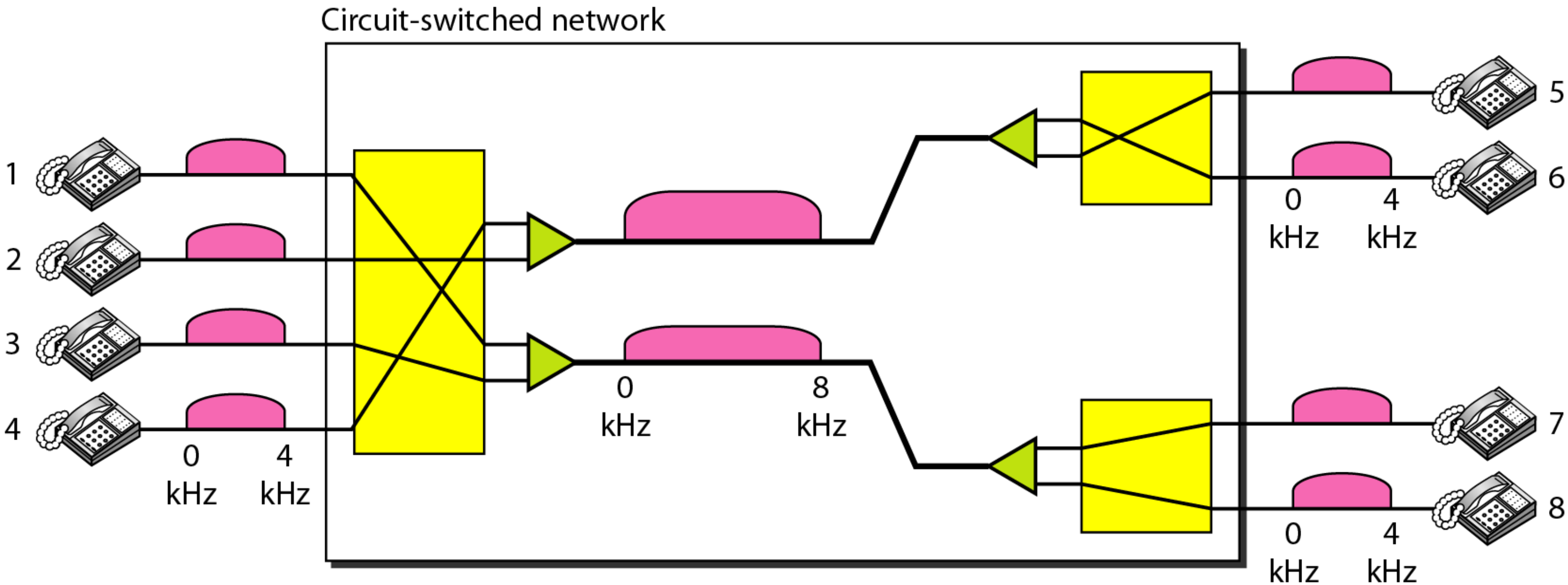


Example

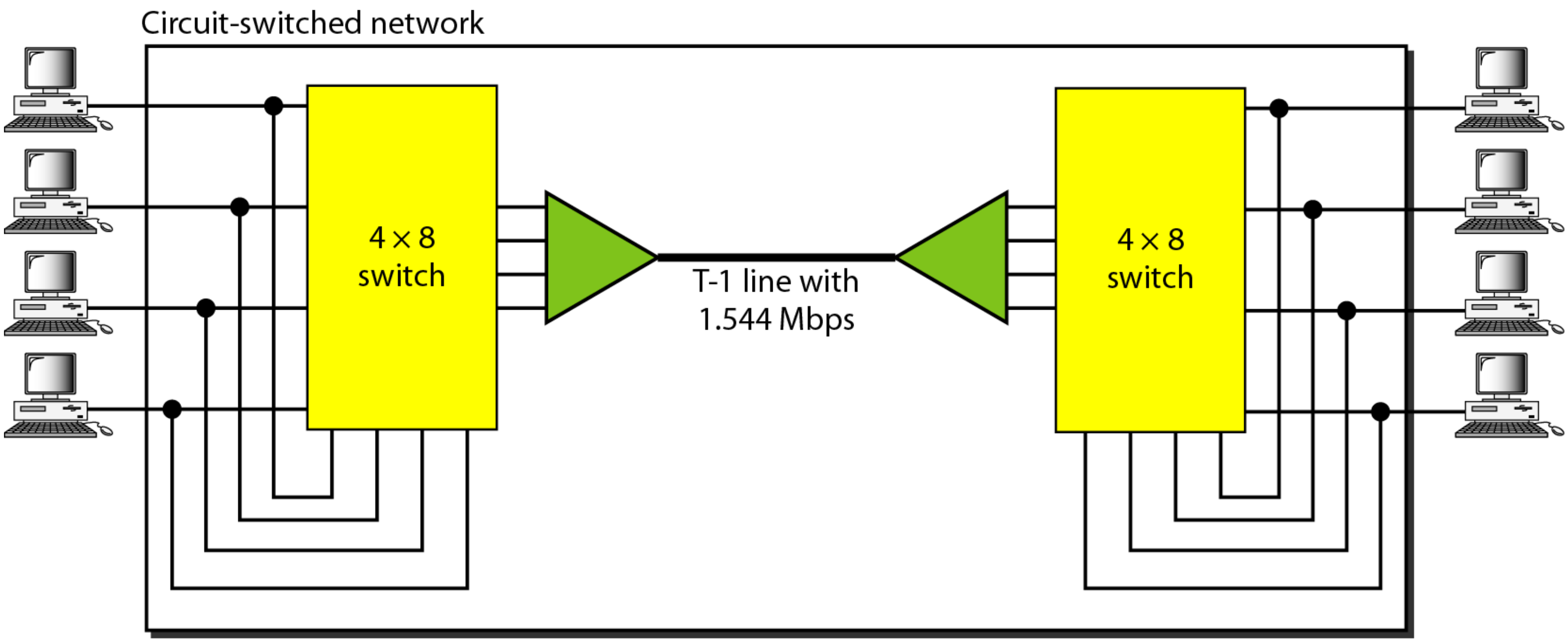
As a trivial example, let us use a circuit-switched network to connect eight telephones in a small area. Communication is through 4-kHz voice channels. We assume that each link uses FDM to connect a maximum of two voice channels. The bandwidth of each link is then 8 kHz.

Telephone 1 is connected to telephone 7; 2 to 5; 3 to 8; and 4 to 6. Of course the situation may change when new connections are made. The switch controls the connections.

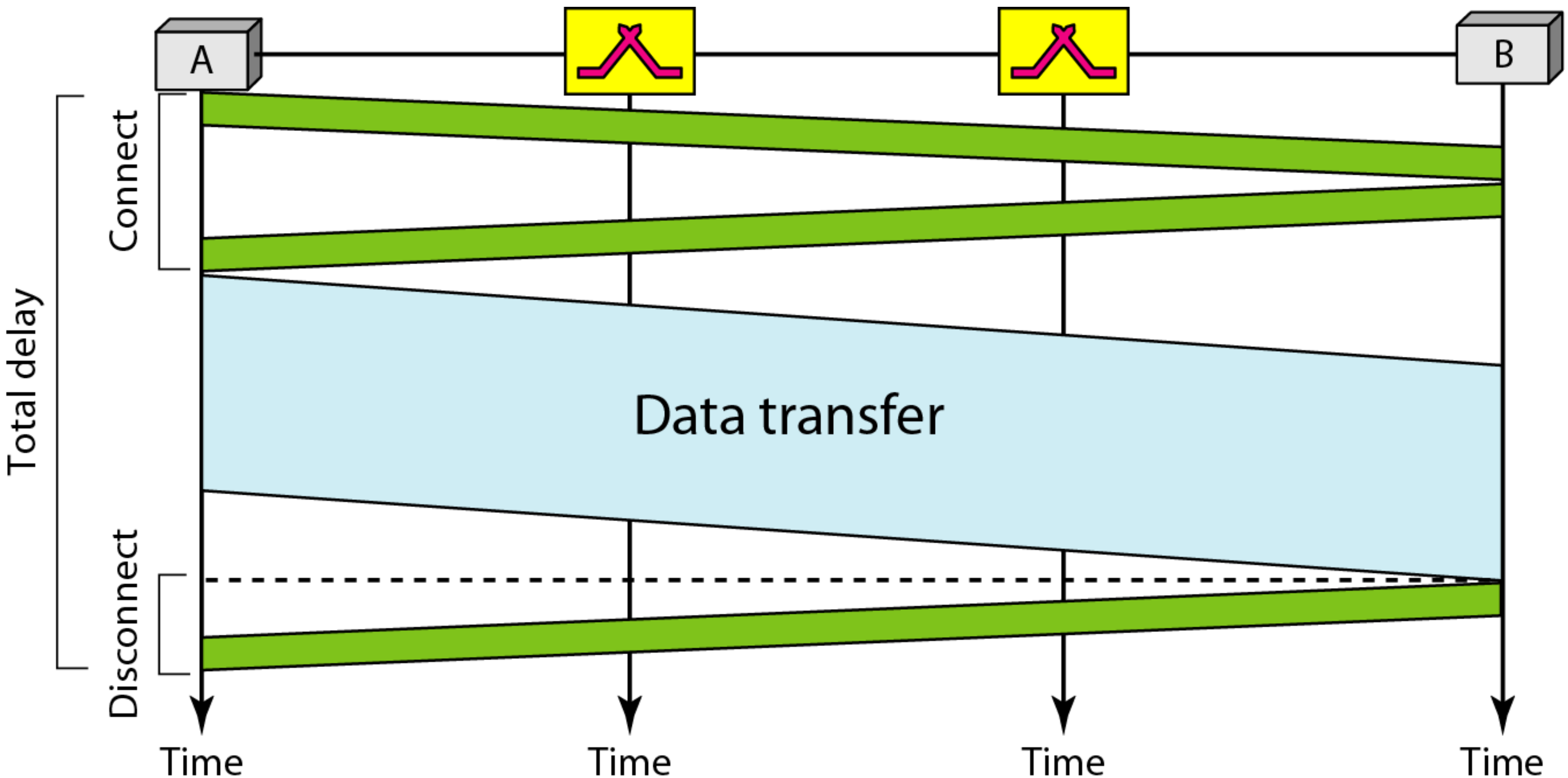
Circuit-switched network 1



Circuit-switched network 2



Delay in a circuit-switched network

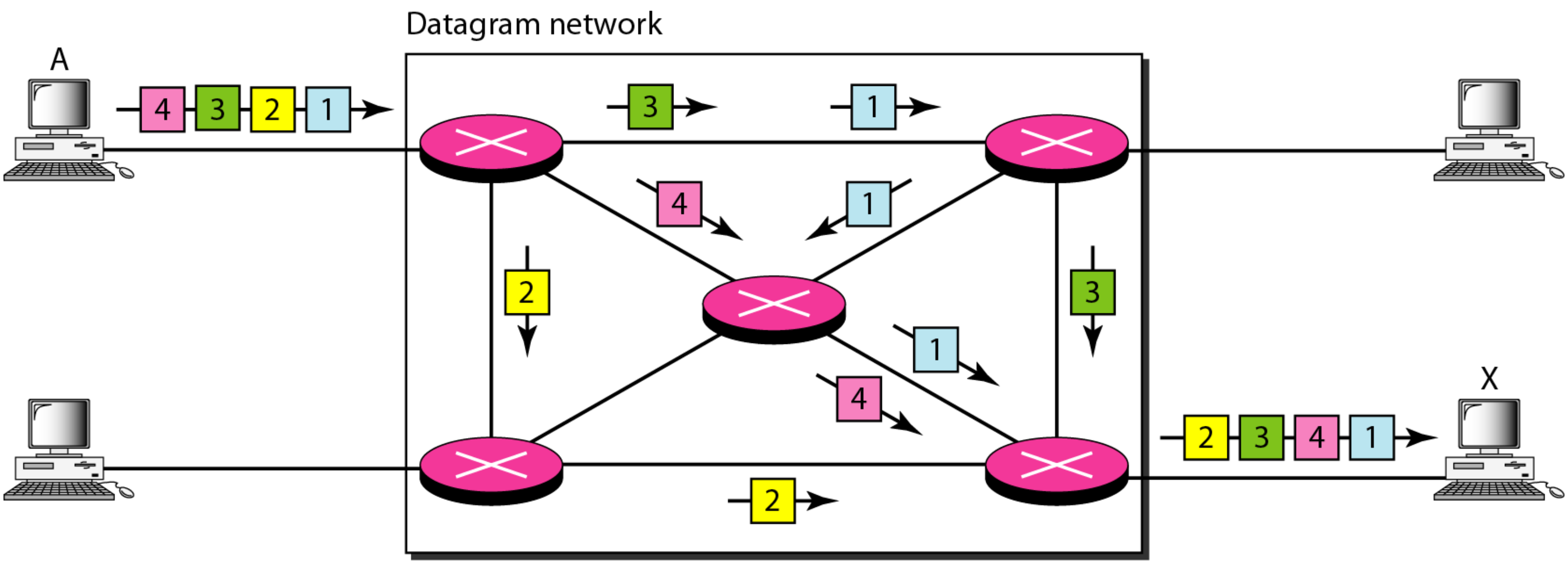


DATAGRAM NETWORKS

In data communications, we need to send messages from one end system to another.

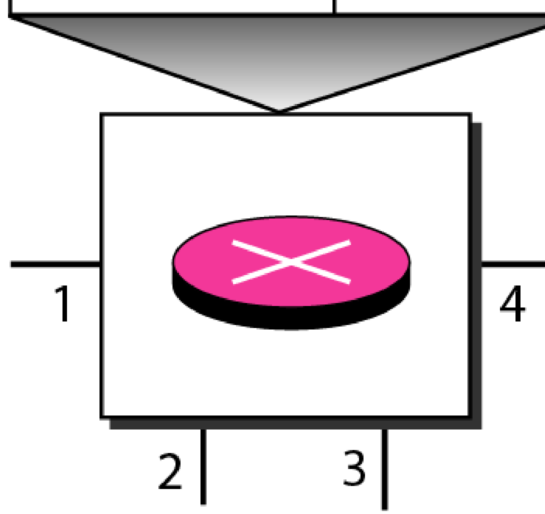
If the message is going to pass through a packet-switched network, it needs to be divided into packets of fixed or variable size.
The size of the packet is determined by the network and the governing protocol.

A datagram network with four switches (routers)



Routing table in a datagram network

Destination address	Output port
1232	1
4150	2
⋮	⋮
9130	3

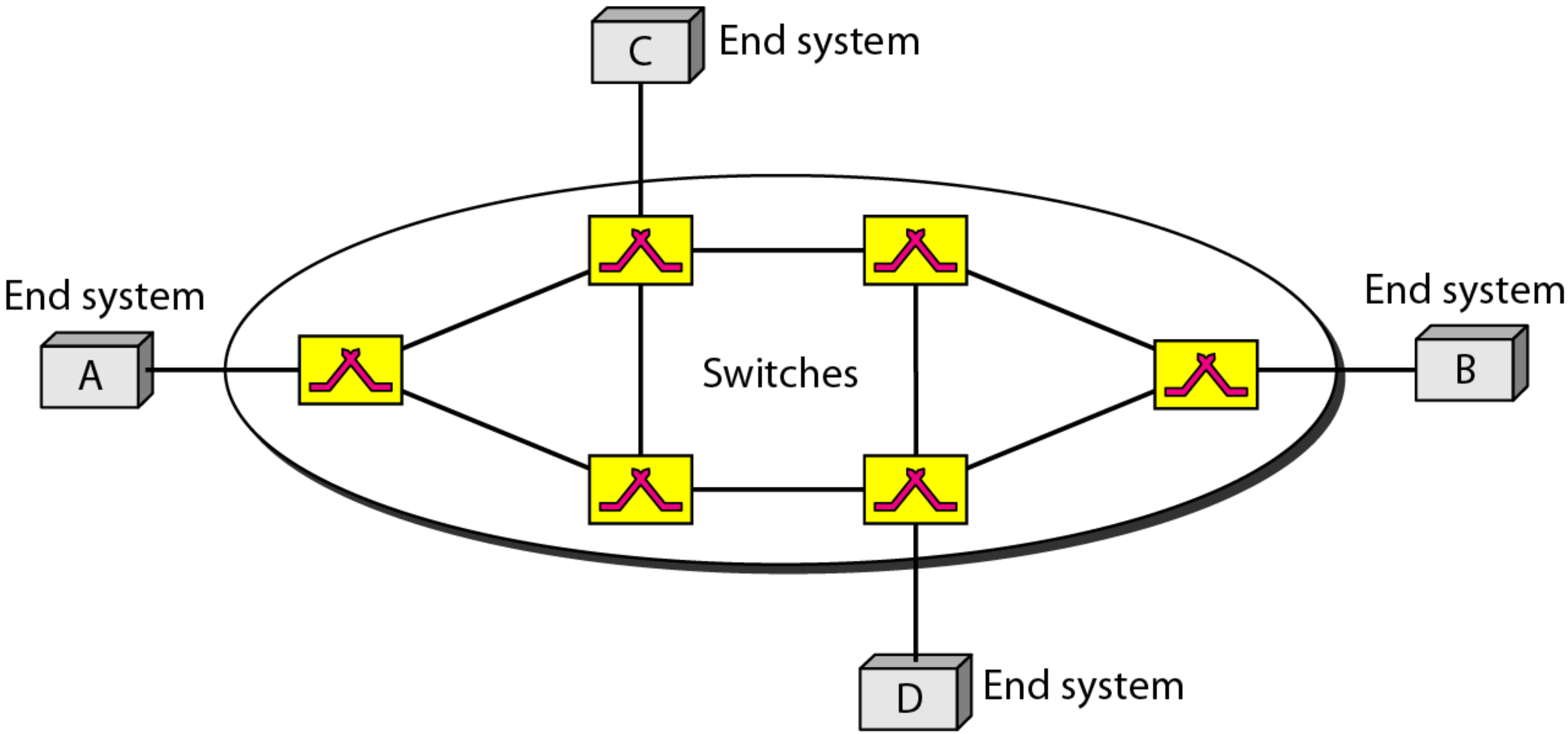


VIRTUAL-CIRCUIT NETWORKS

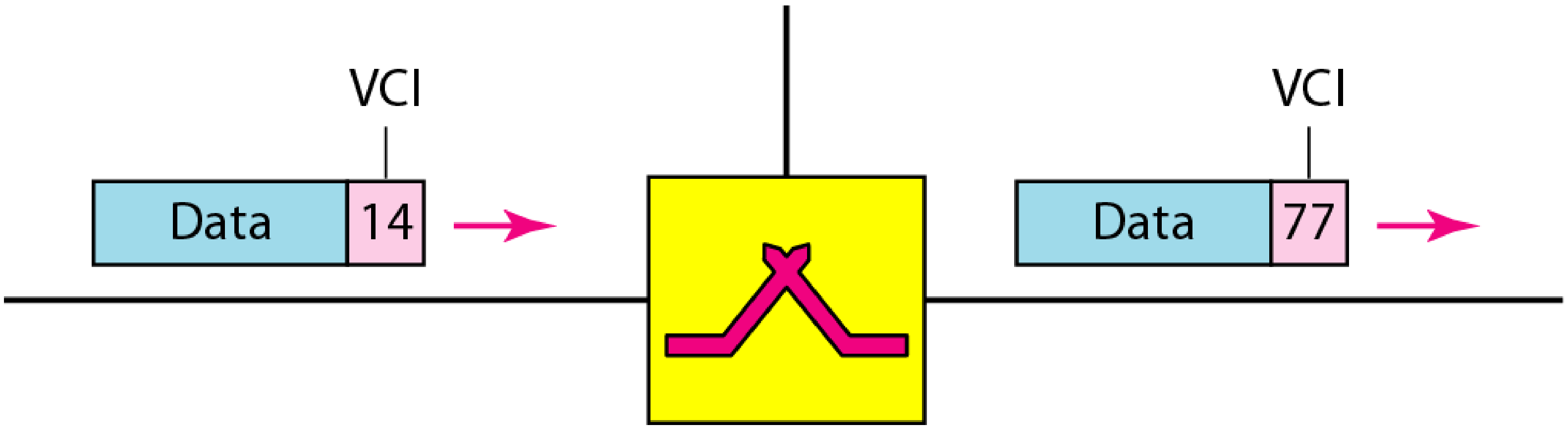
A virtual-circuit network is a cross between a circuit-switched network and a datagram network.

It has some characteristics of both.

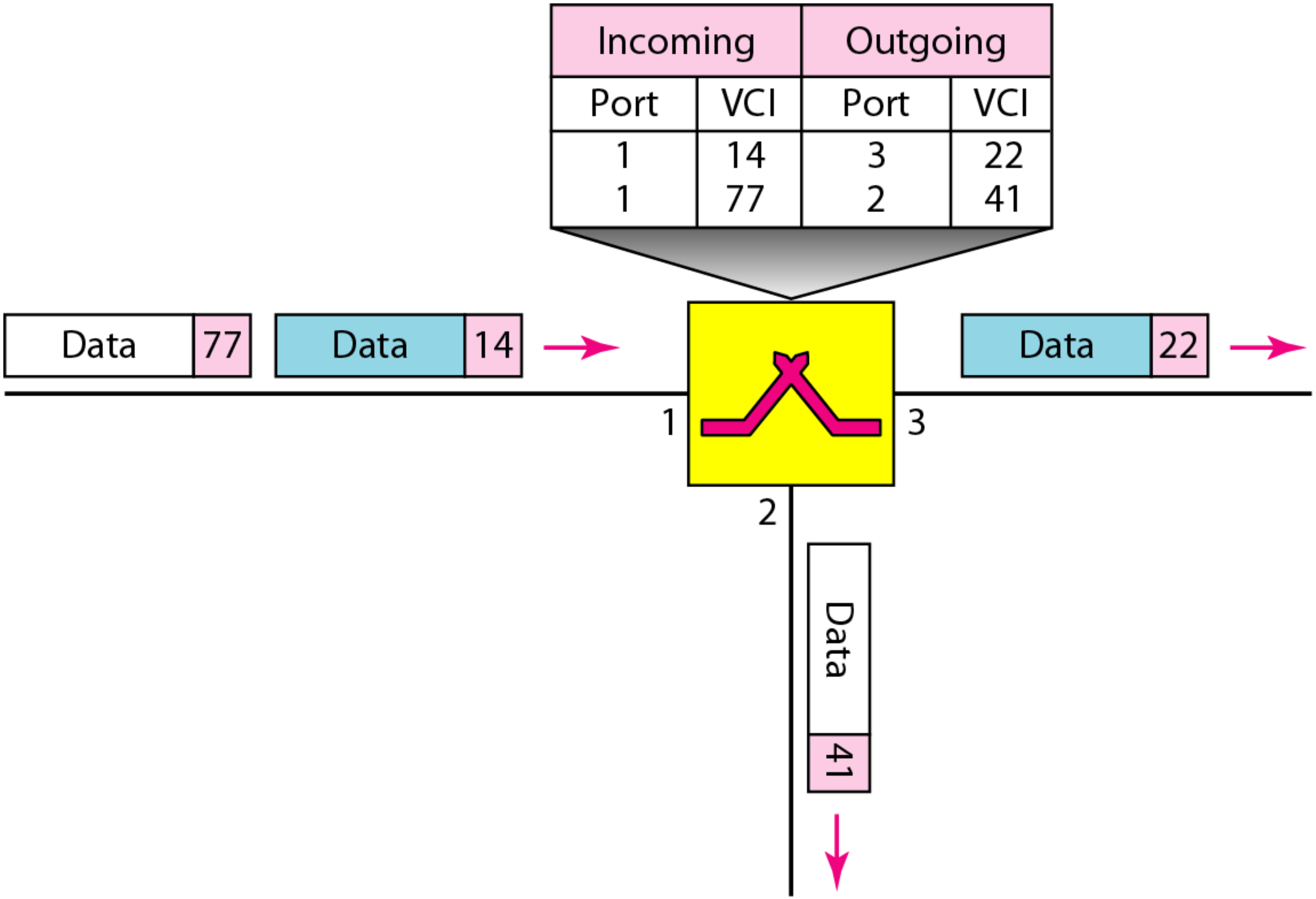
Virtual-circuit network



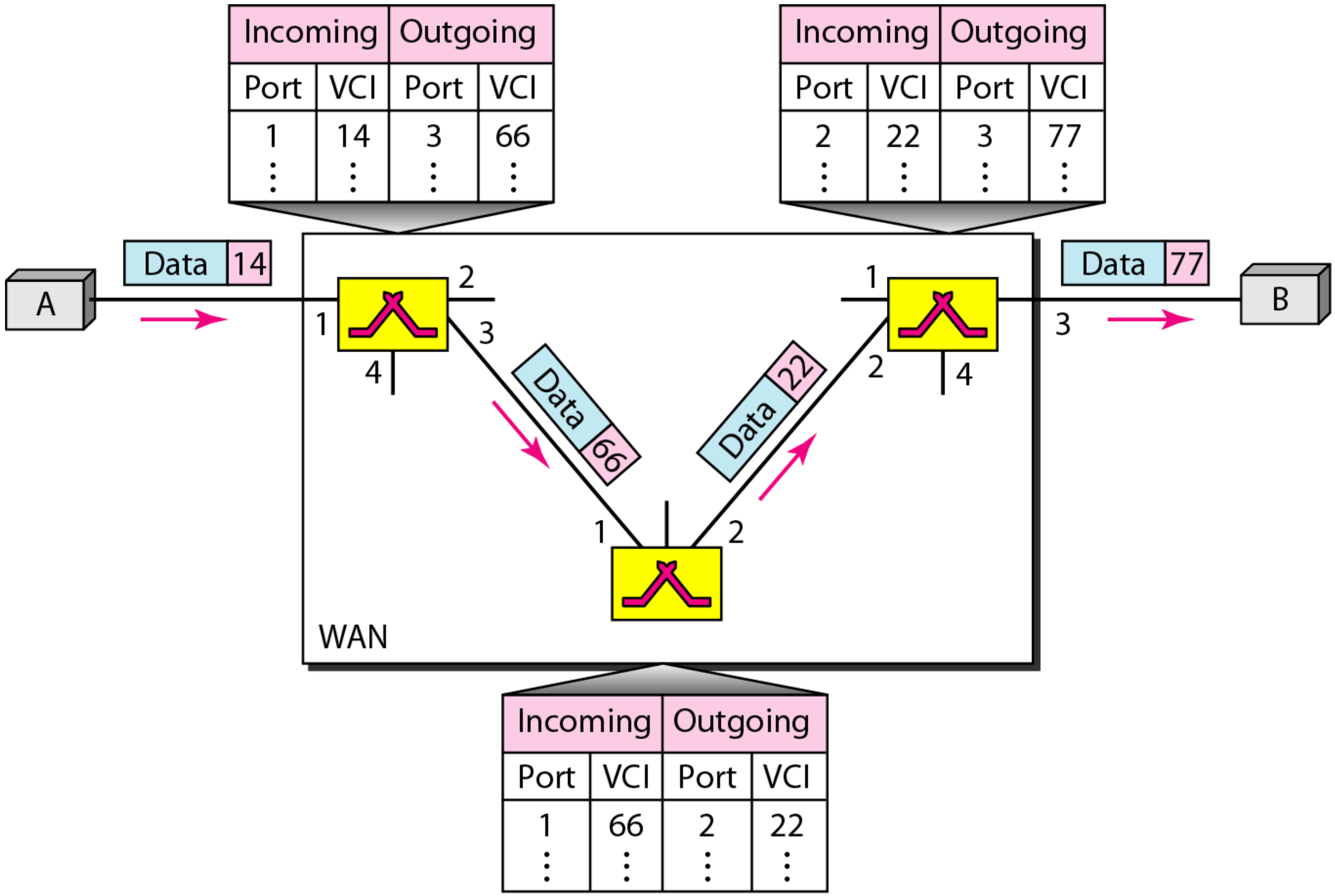
Virtual-circuit identifier



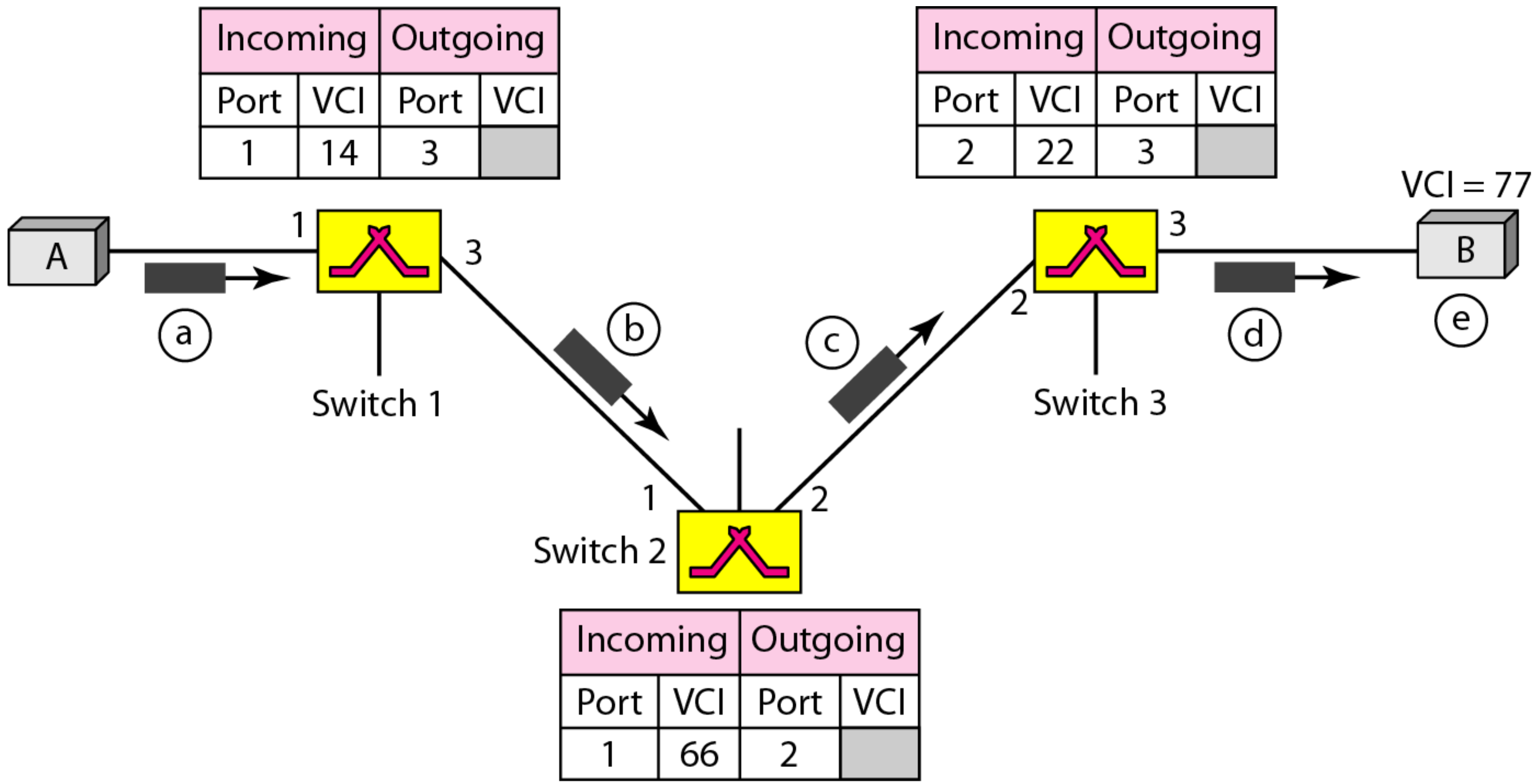
Switch and tables in a virtual-circuit network



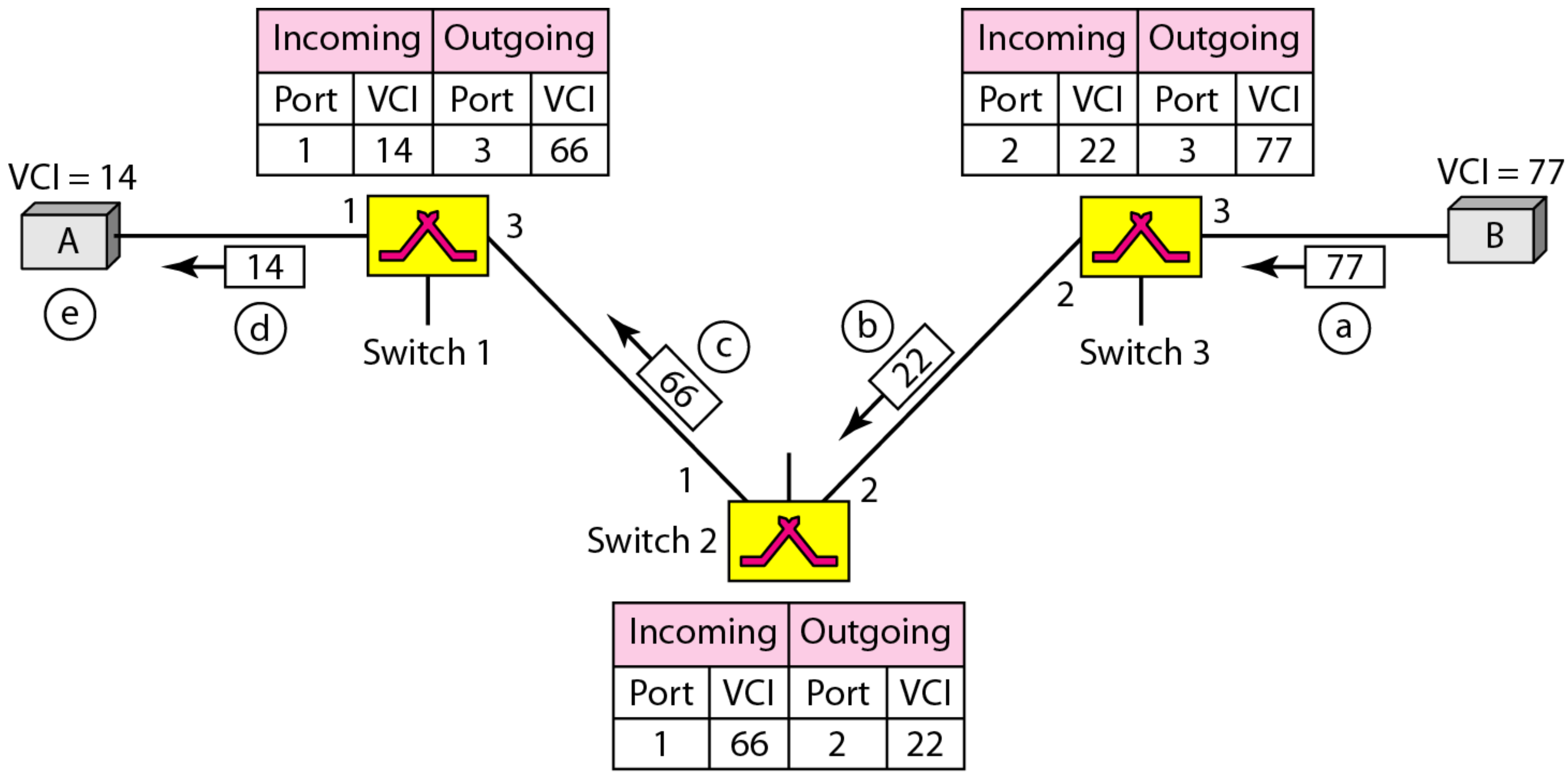
Source-to-destination data transfer in a virtual-circuit network



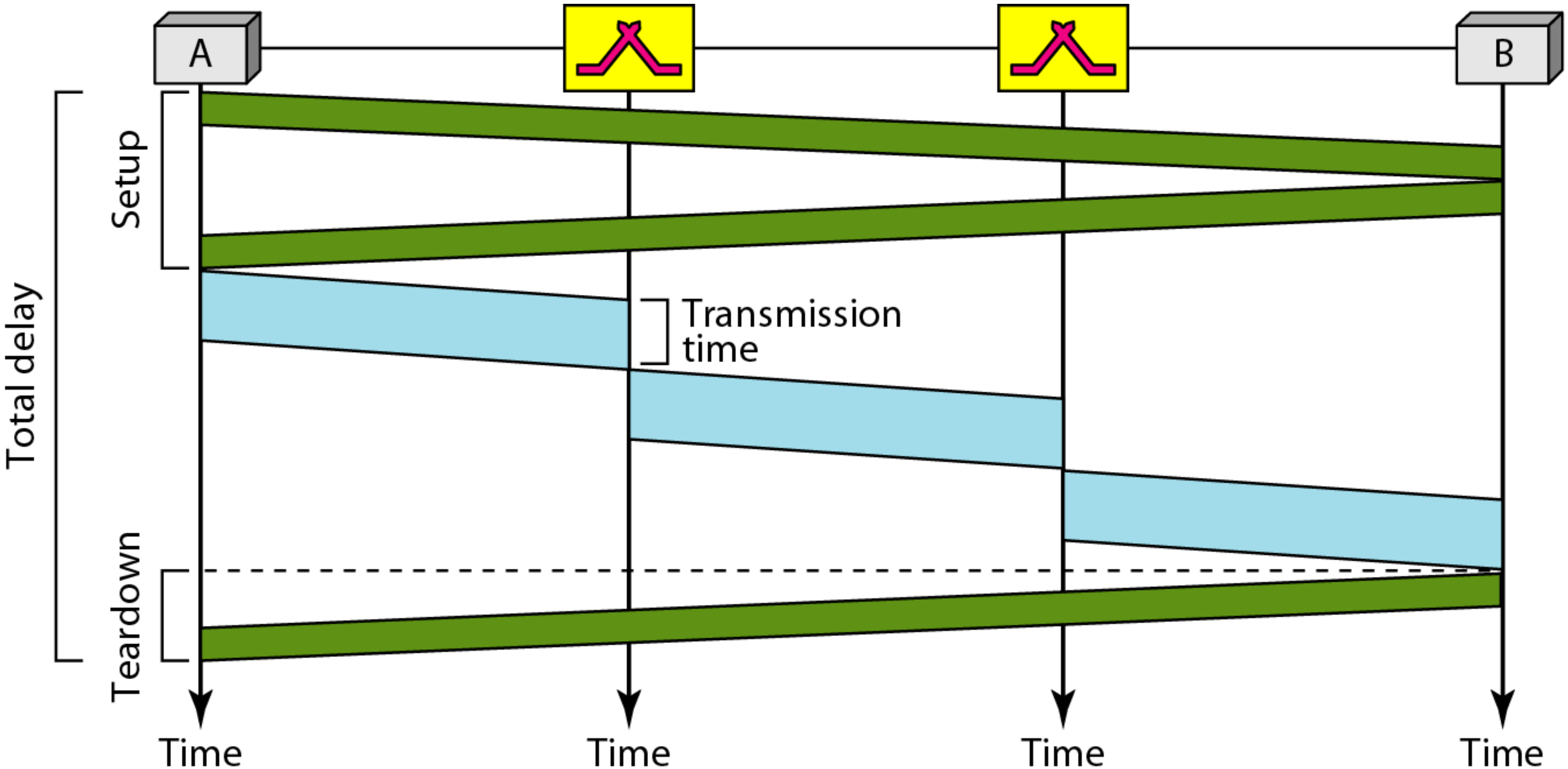
Setup request in a virtual-circuit network



Setup acknowledgment in a virtual-circuit network

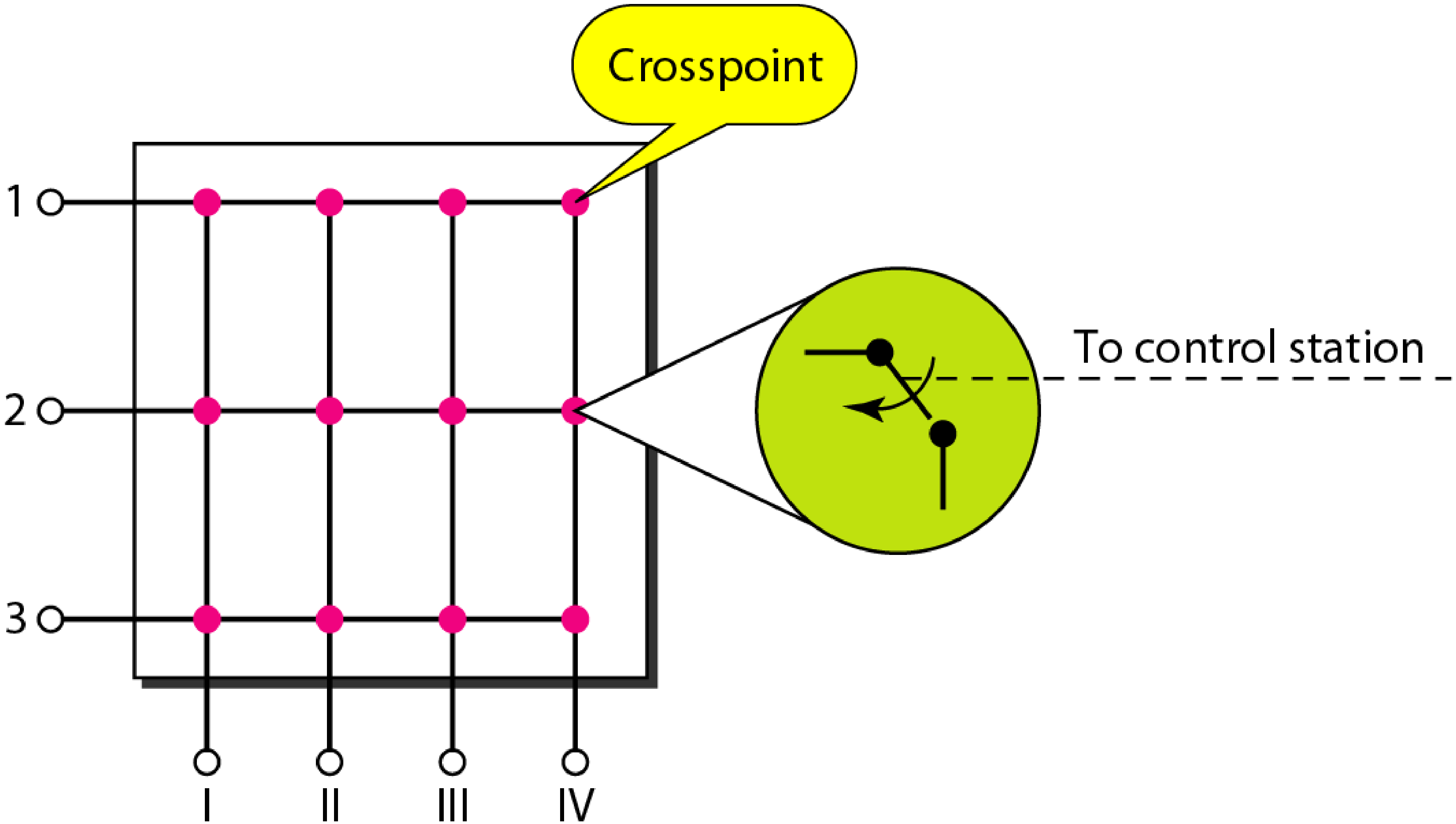


Delay in a virtual-circuit network

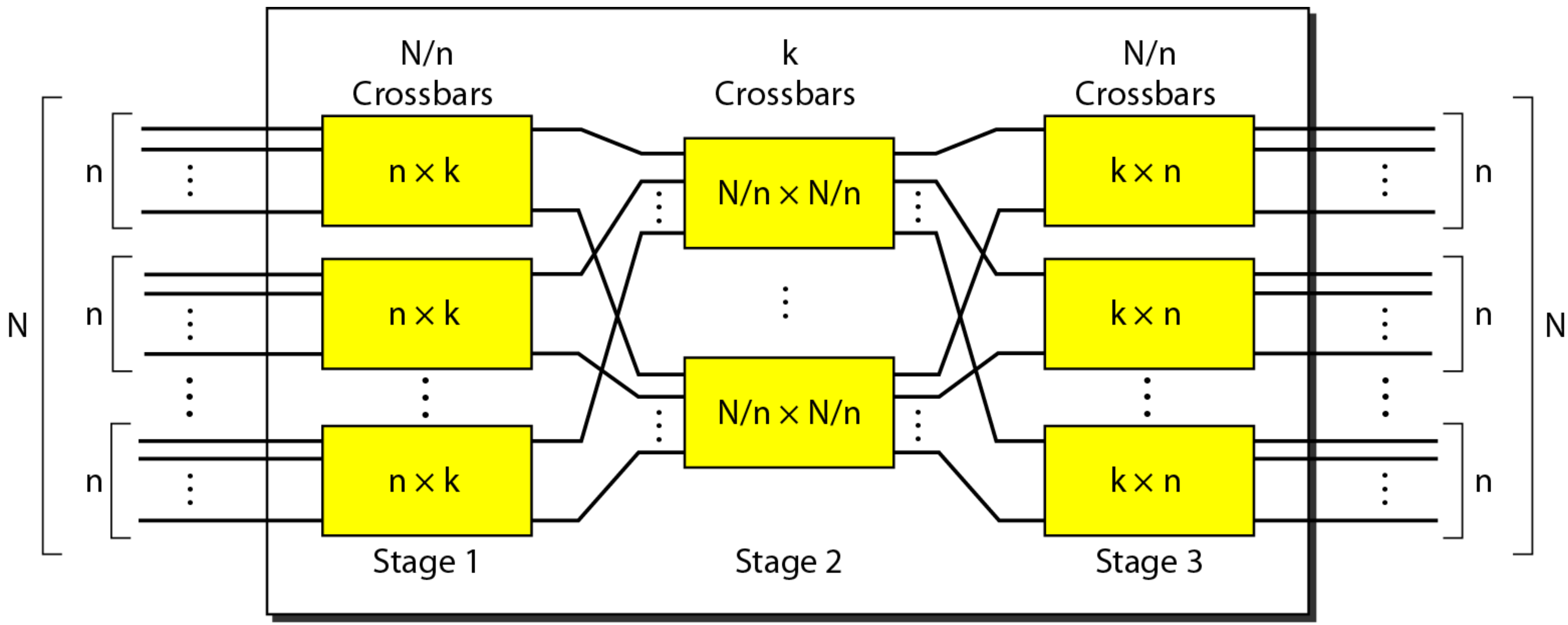


Structure of a Switch

Crossbar switch with three inputs and four outputs



Multistage switch



In a three-stage switch, the total
number of crosspoints is

$$2kN + k(N/n)^2$$

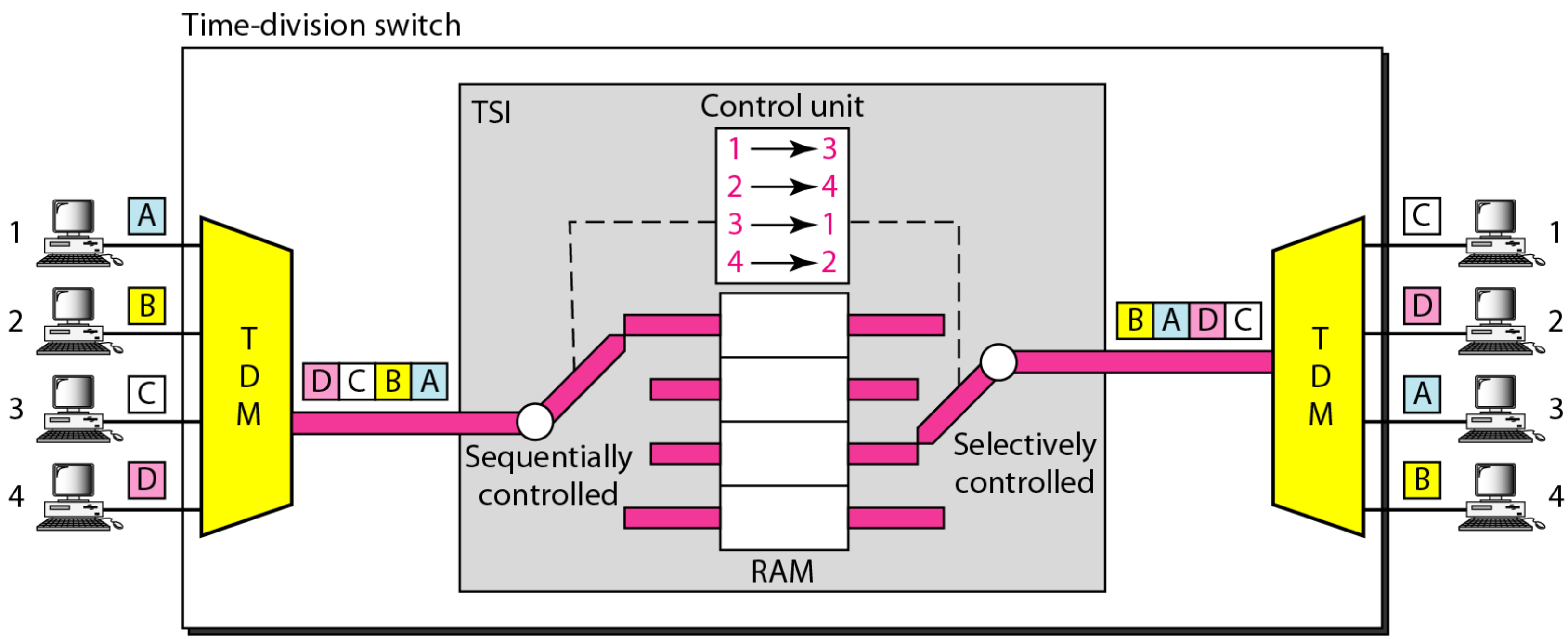
which is much smaller than the number of crosspoints in a single-stage switch (N^2).

Design a three-stage, 200 × 200 switch (N = 200) with k = 4 and n = 20.

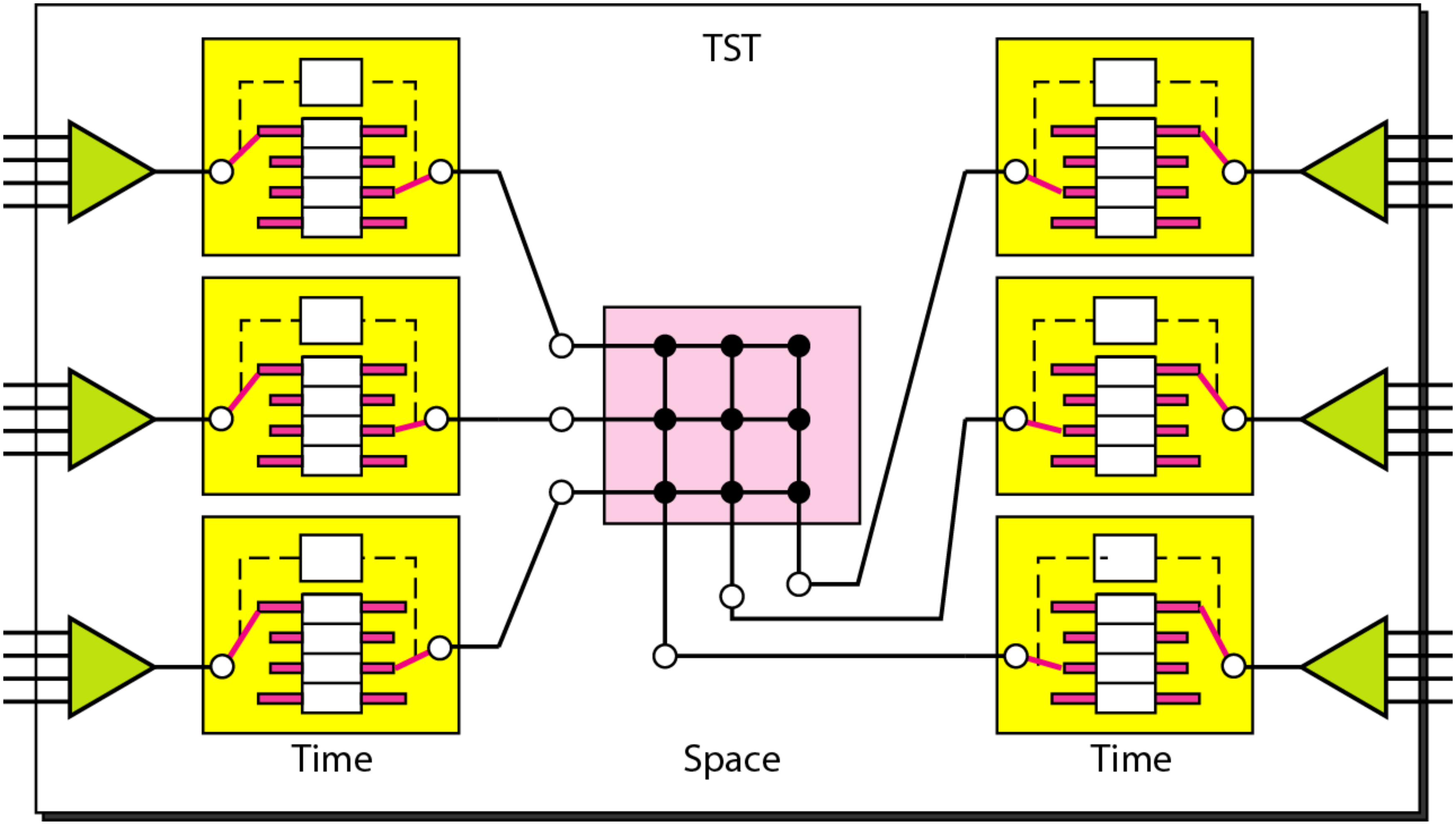
Solution

In the first stage we have N/n or 10 crossbars, each of size 20 × 4. In the second stage, we have 4 crossbars, each of size 10 × 10. In the third stage, we have 10 crossbars, each of size 4 × 20. The total number of crosspoints is $2kN + k(N/n)^2$*, or 2000 crosspoints. This is 5 percent of the number of crosspoints in a single-stage switch (200 × 200 = 40,000).*

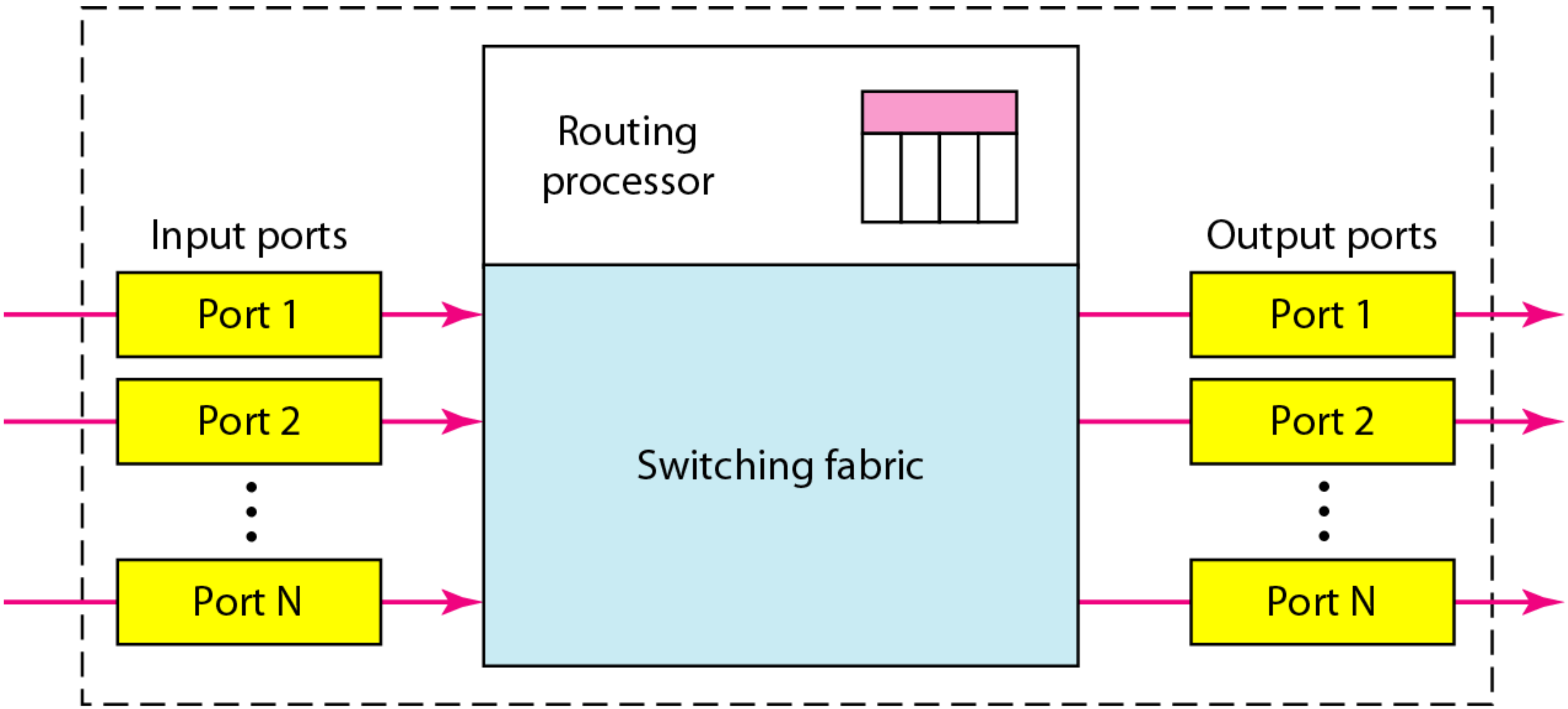
Time-slot interchange



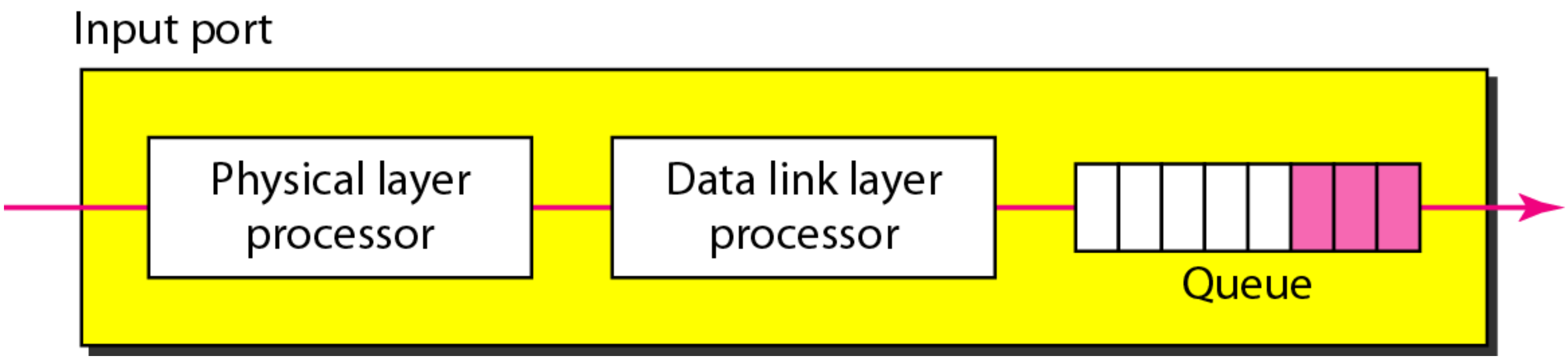
Time-space-time switch



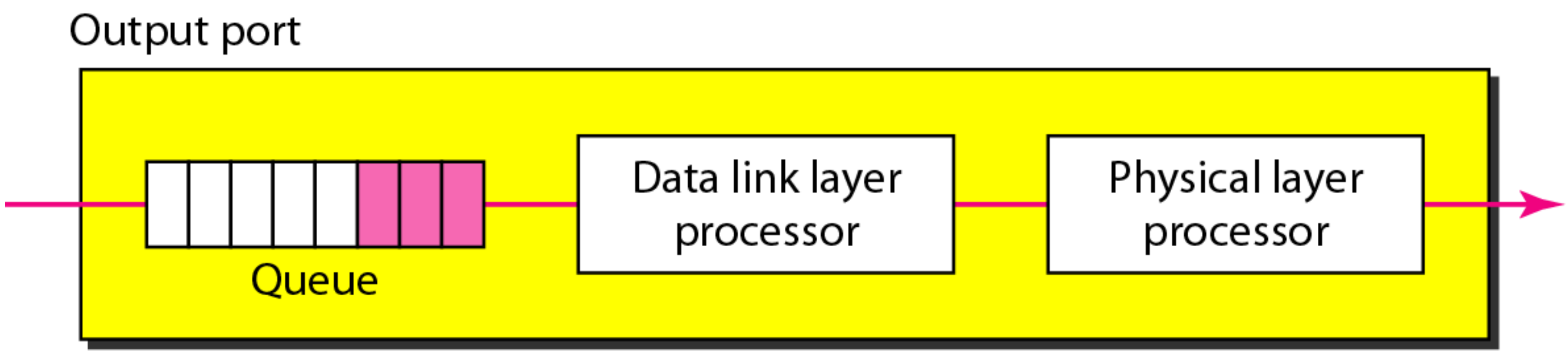
Packet switch components



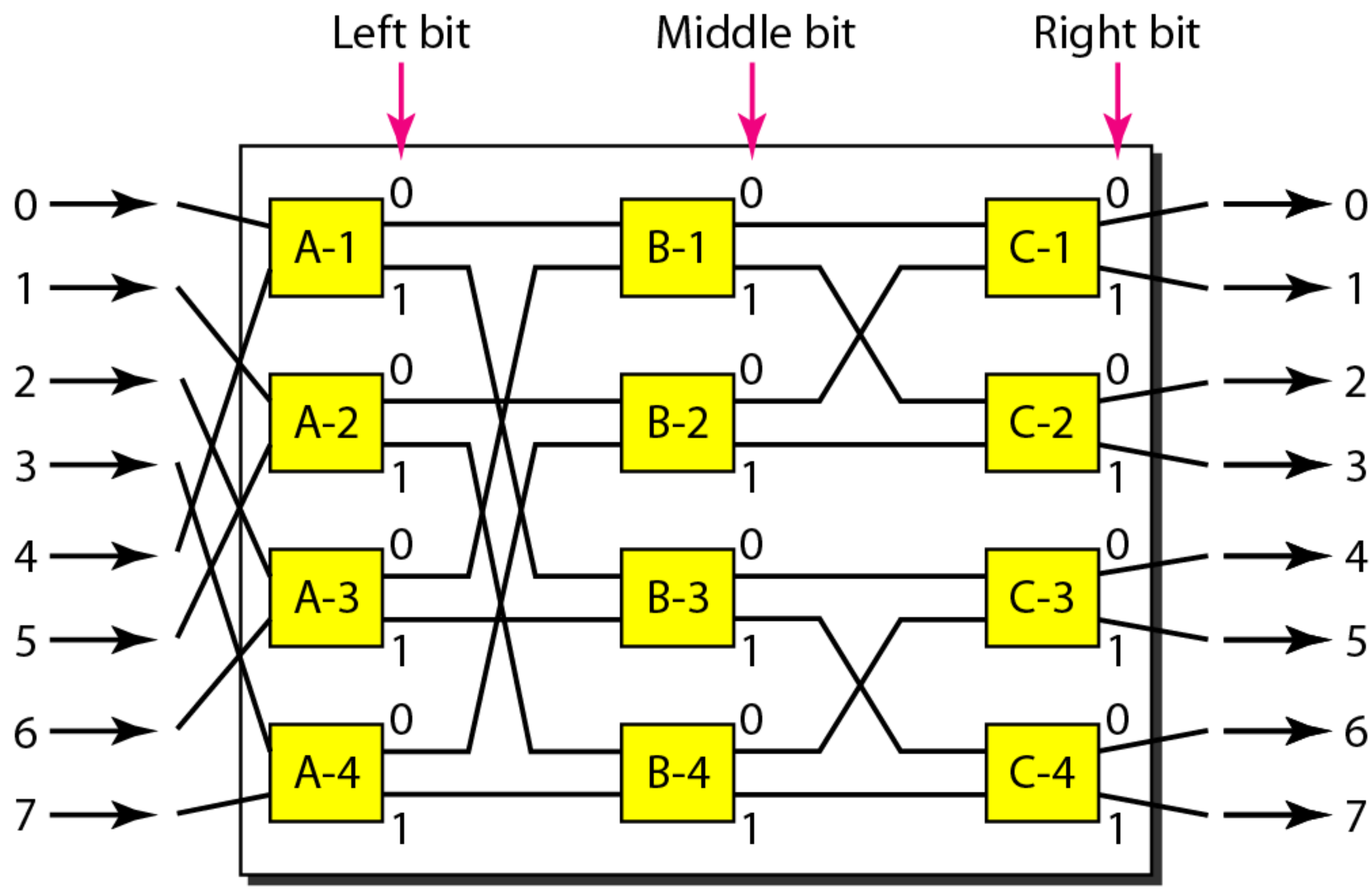
Input port


Input port
Physical layer processor
Data link layer processor
Queue

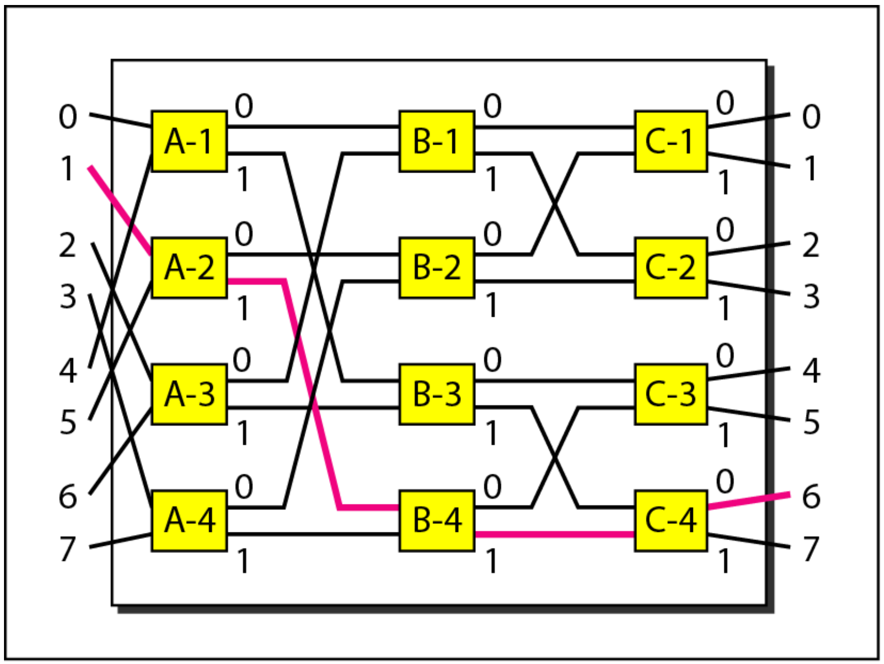
Output port


Output port
Queue
Data link layer processor
Physical layer processor

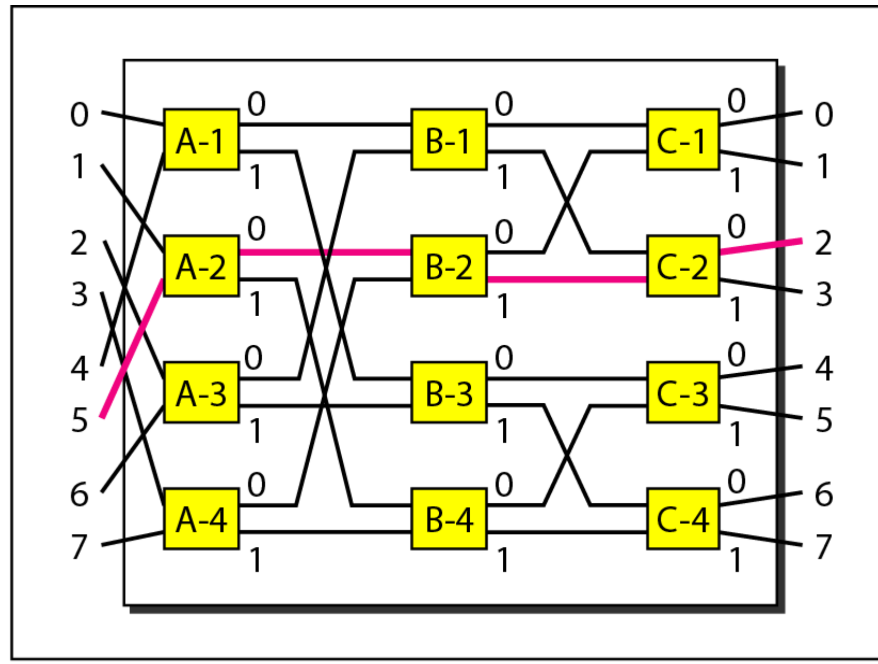
A banyan switch



Examples of routing in a banyan switch



a. Input 1 sending a cell to output 6 (110)



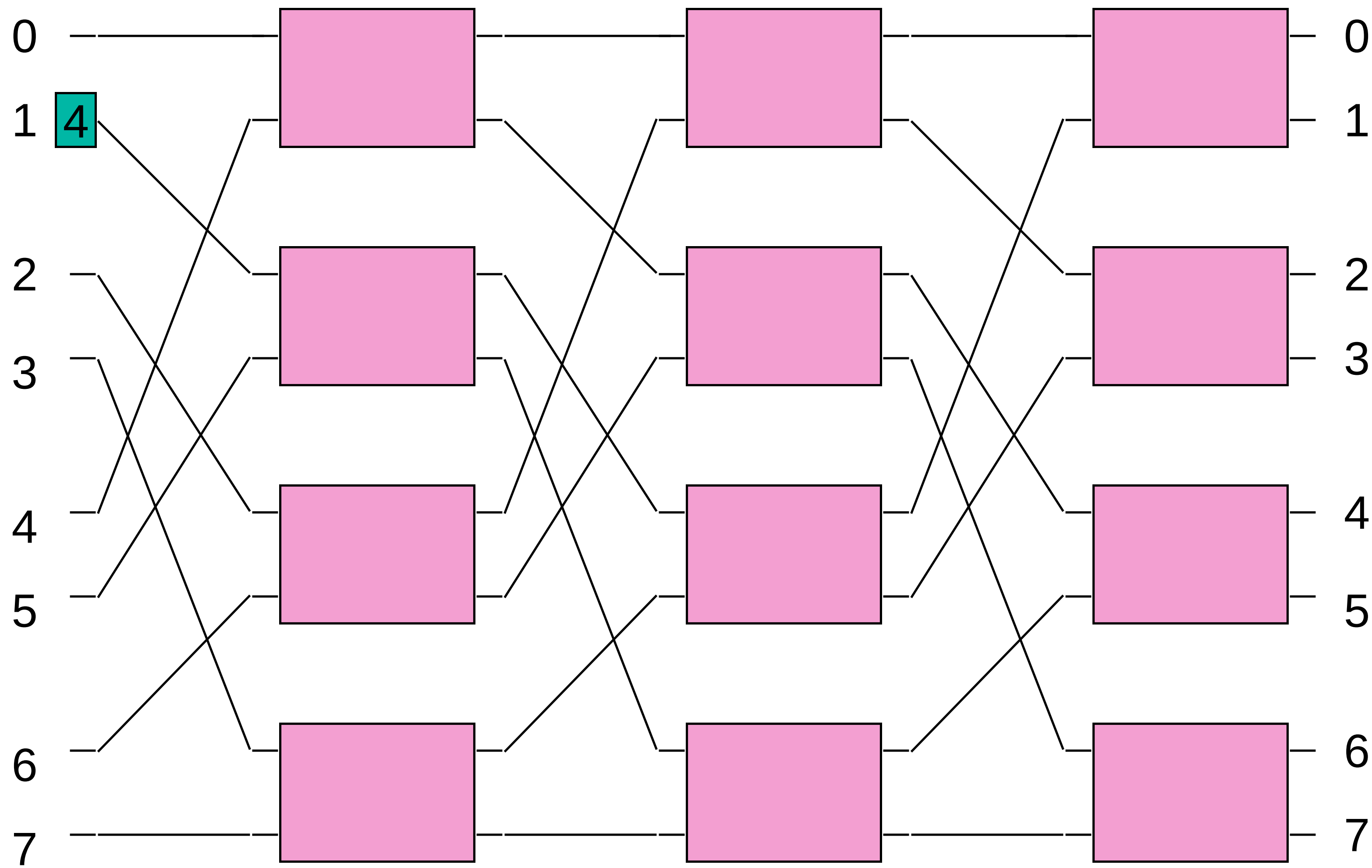
b. Input 5 sending a cell to output 2 (010)

Self Routing

- Omega network has <u>self-routing property</u>
- The path for a cell to take to reach its destination can be determined directly from its <u>routing tag</u> (i.e., destination port id)
- <u>Stage k</u> of the MIN looks at <u>bit k</u> of the tag
- If <u>bit k is 0</u>, then send cell out <u>upper port</u>
- If <u>bit k is 1</u>, then send cell out <u>lower port</u>
- Works for every possible input port (really!)

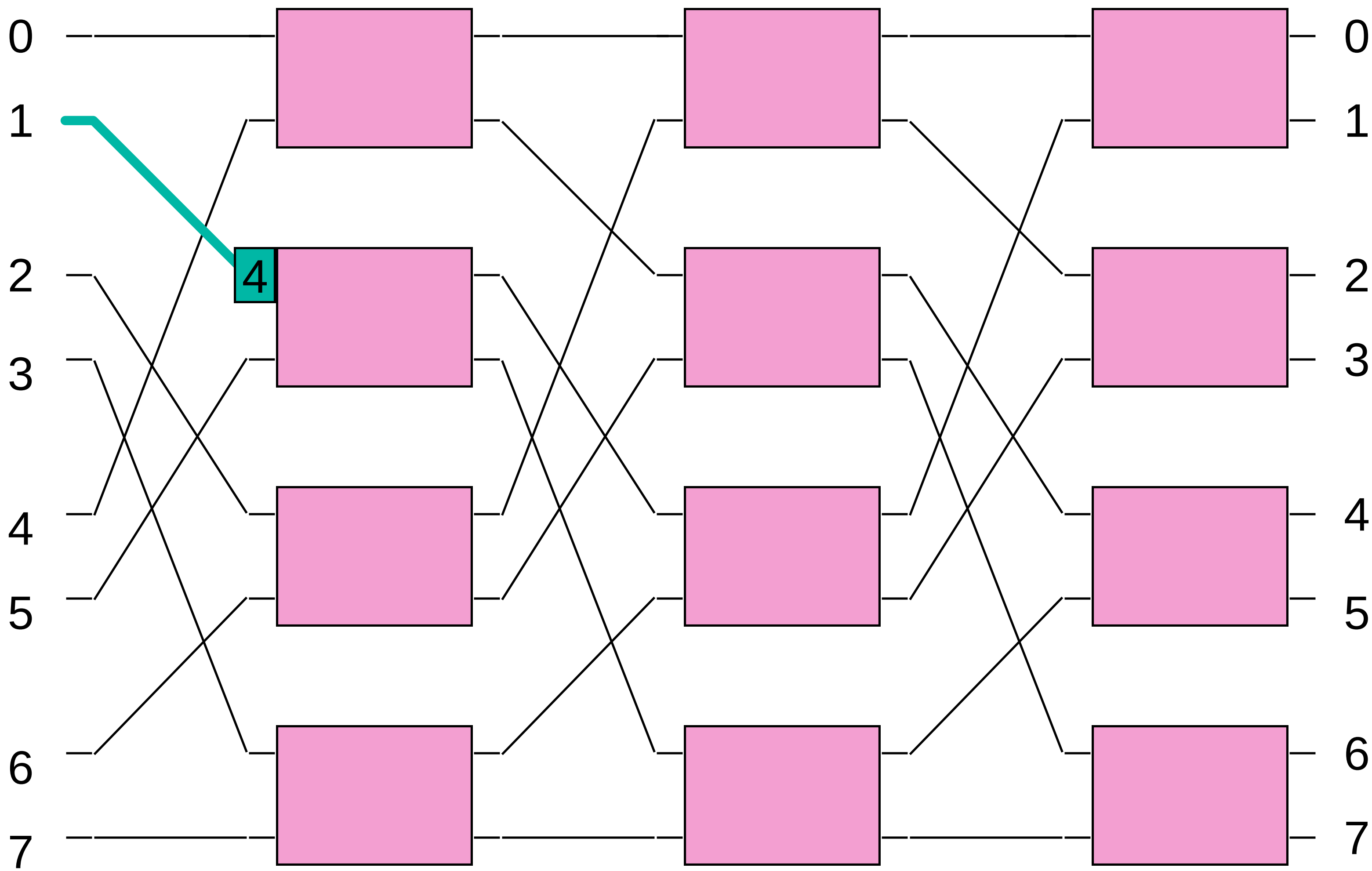
Example of Self Routing

Cell destined for output port 4 (= 100_2)



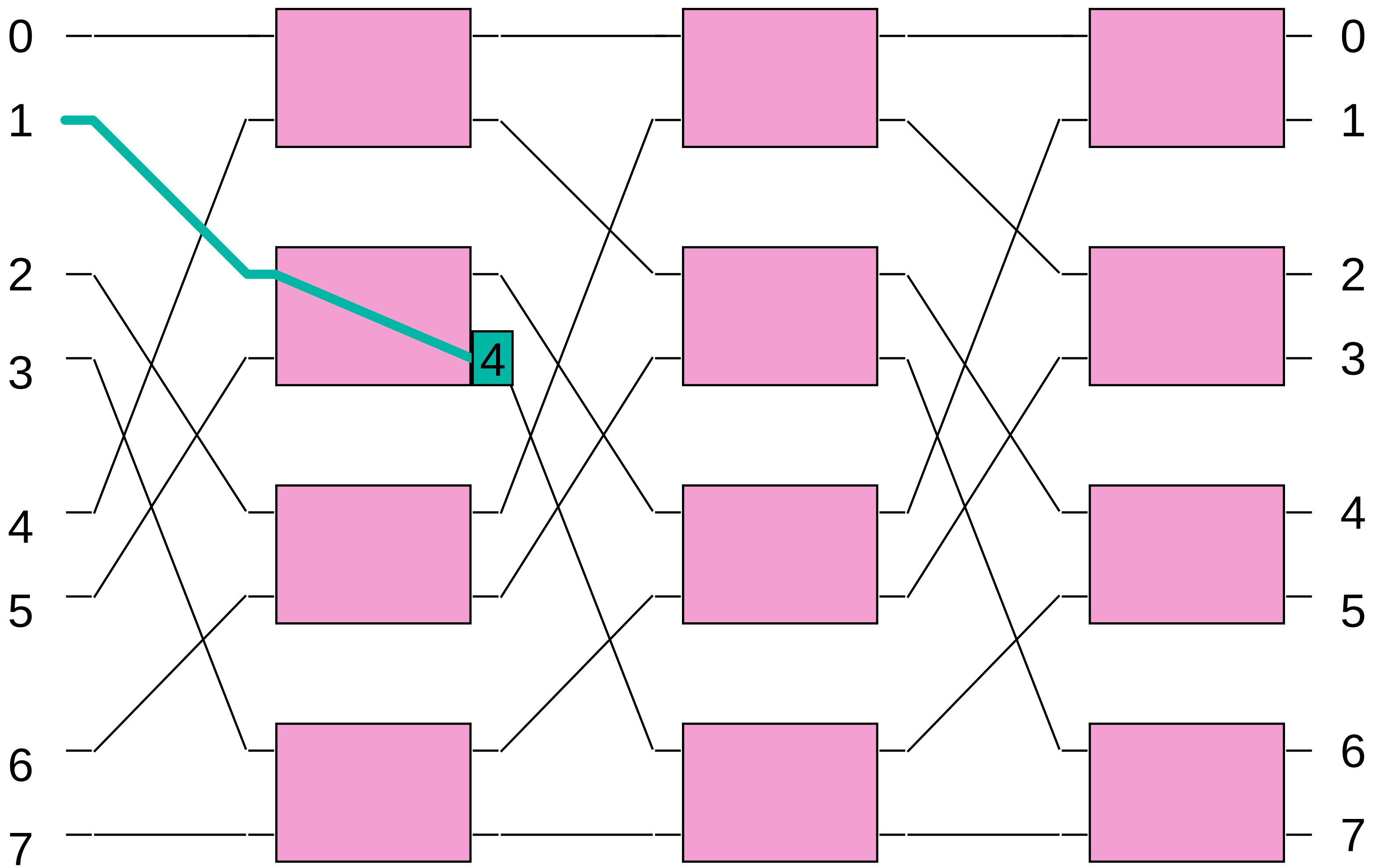
Example of Self Routing

Cell destined for output port 4 (= 100_2)



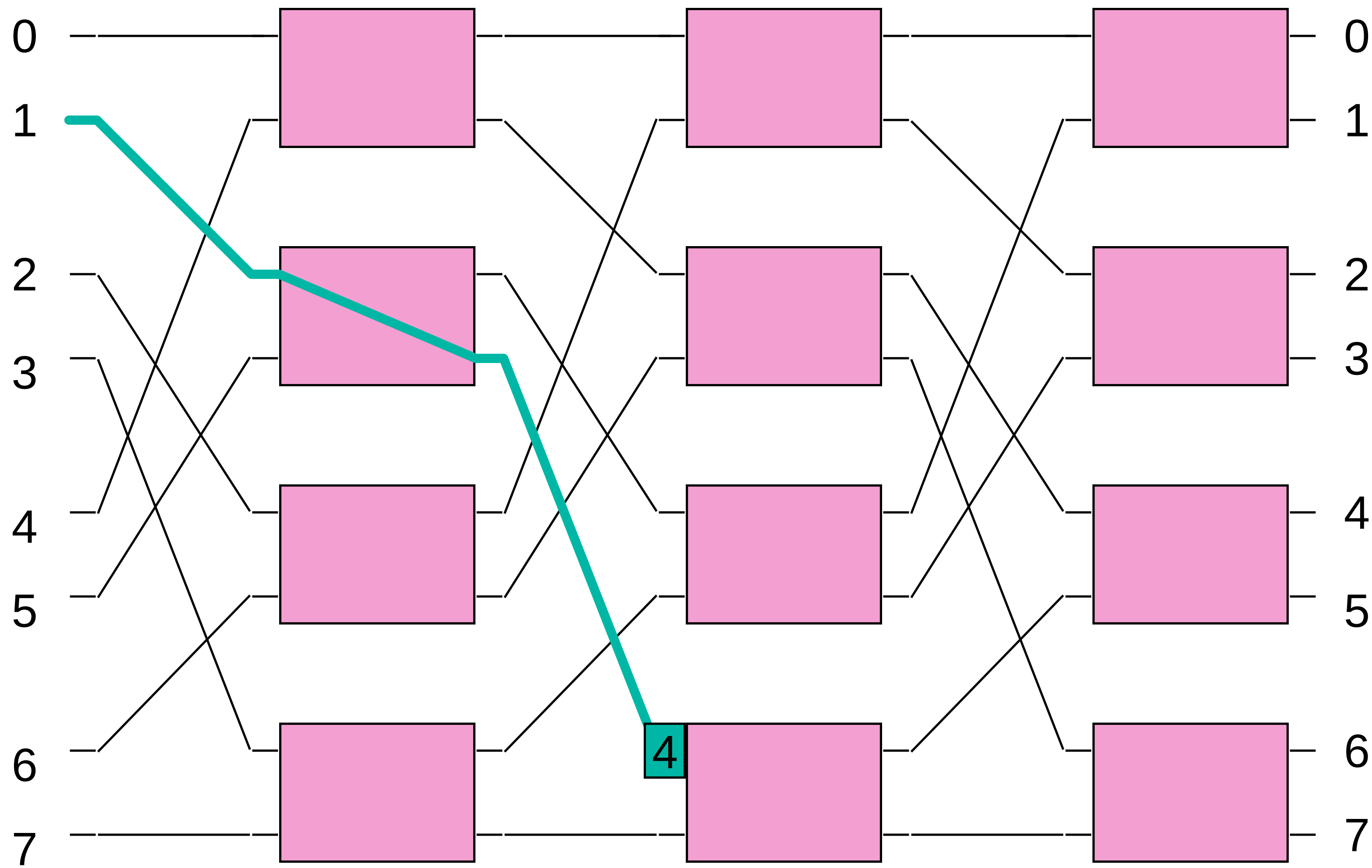
Example of Self Routing

Cell destined for output port 4 (= 100_2)



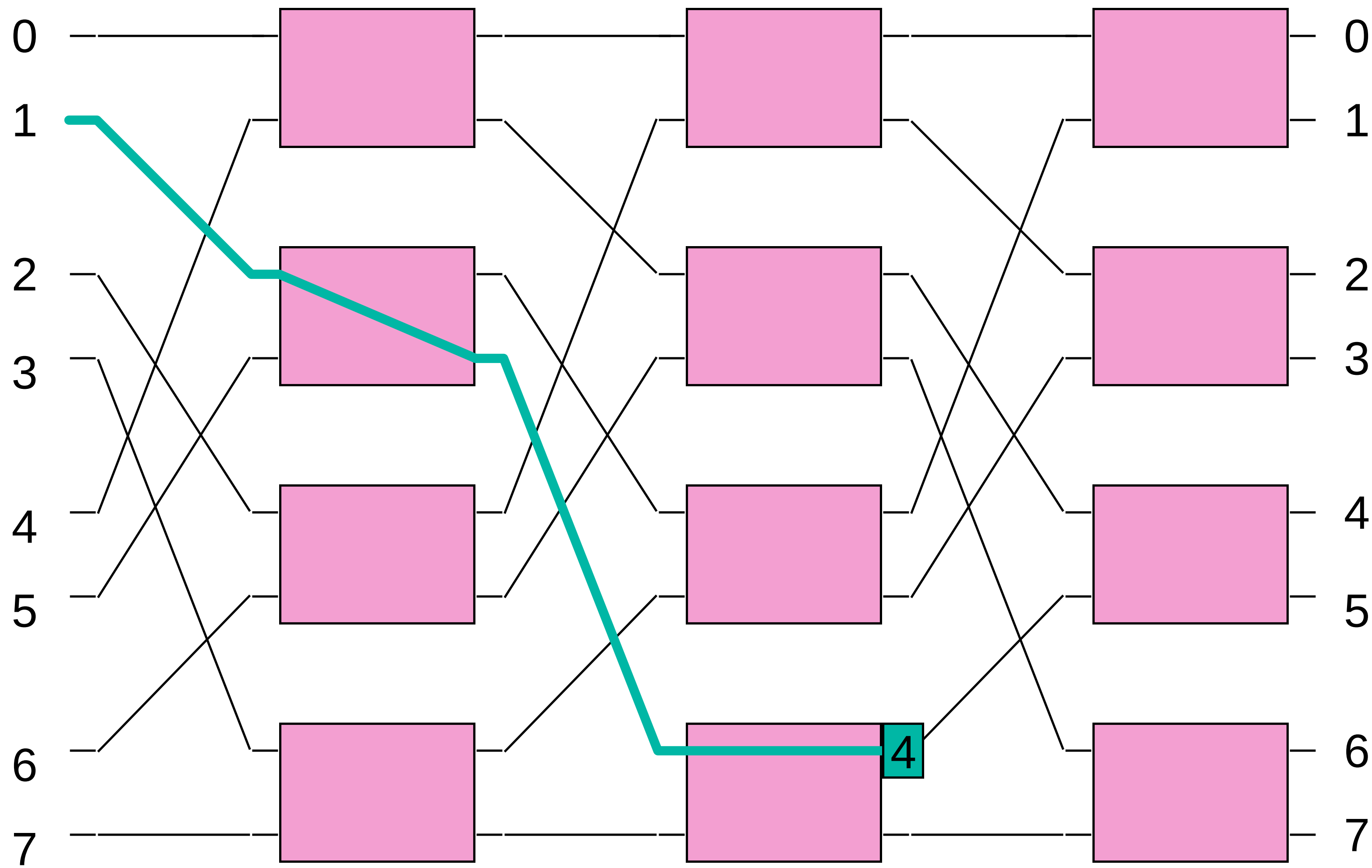
Example of Self Routing

Cell destined for output port 4 (= 100_2)



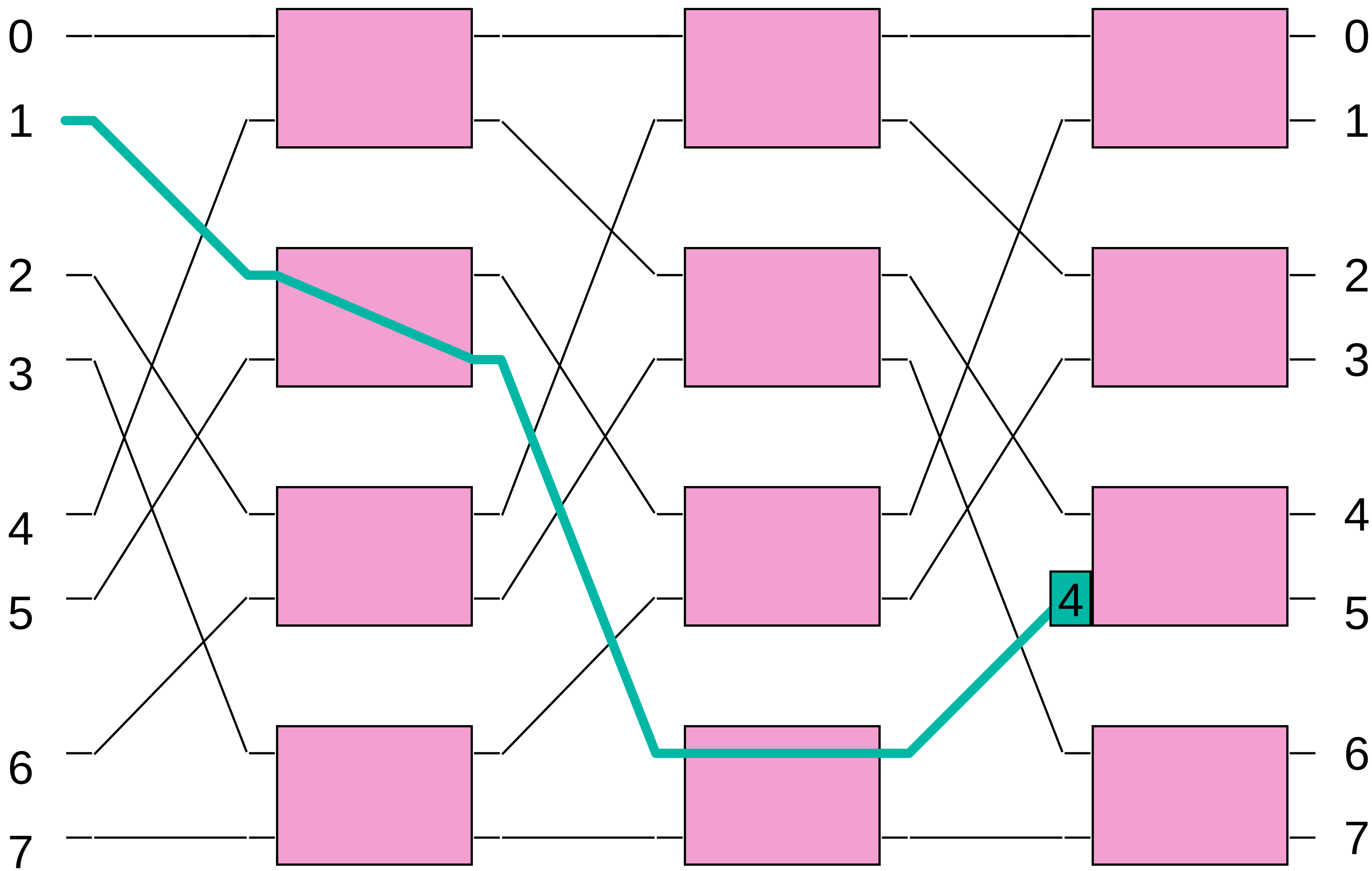
Example of Self Routing

Cell destined for output port 4 (= 100_2)



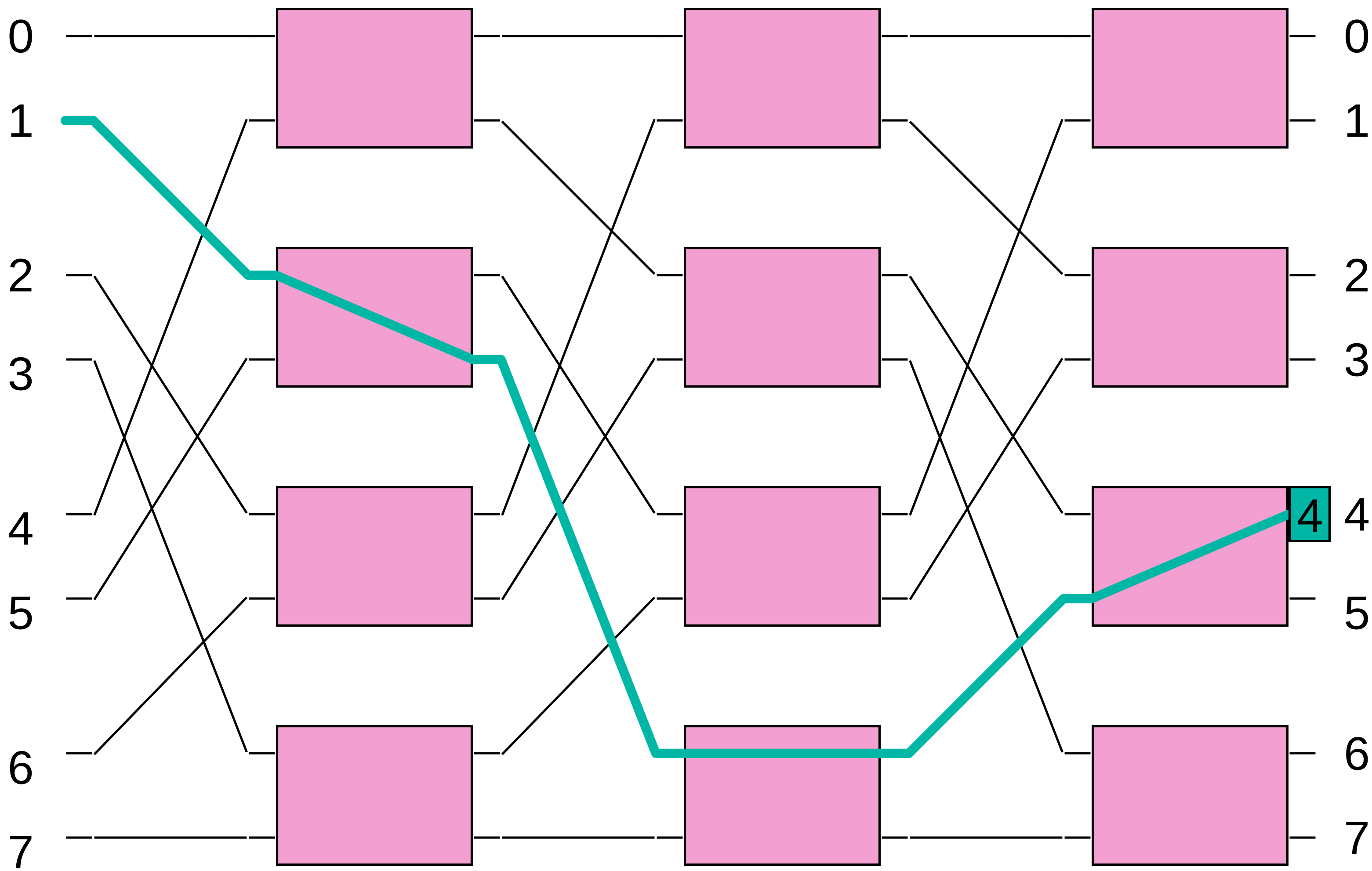
Example of Self Routing

Cell destined for output port 4 (= 100_2)



Example of Self Routing

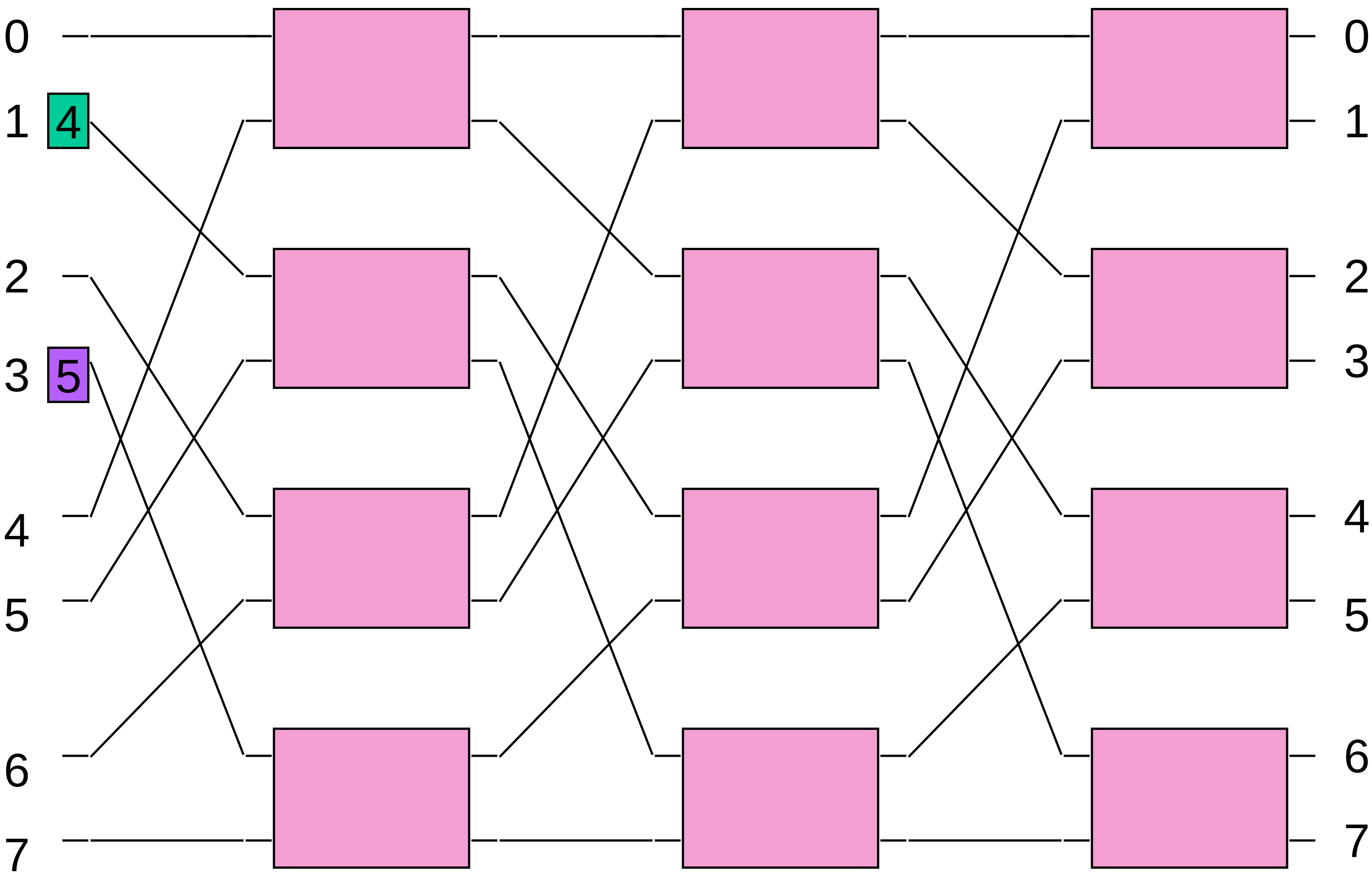
Cell destined for output port 4 (= 100_2)



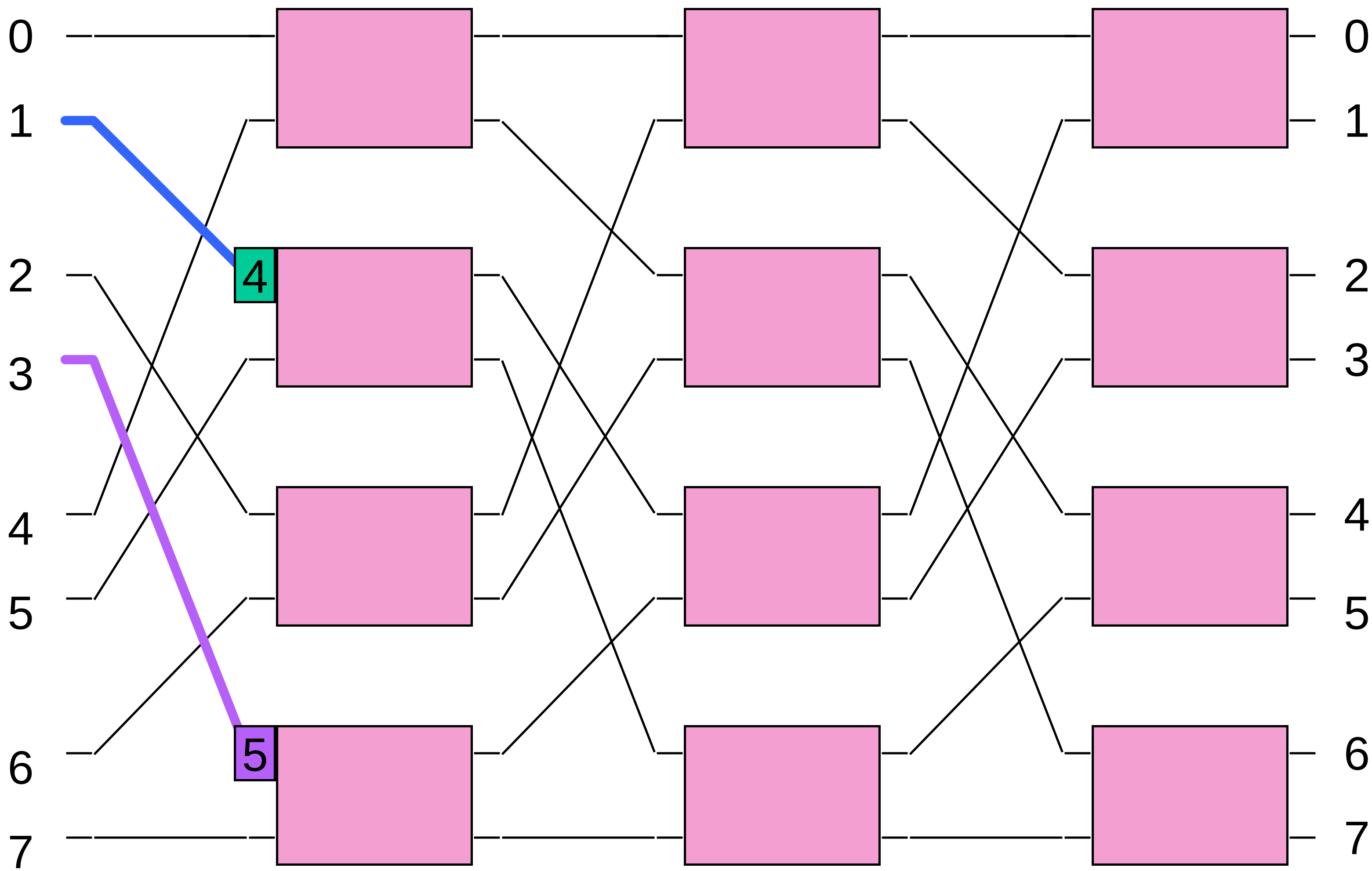
Path Contention

- The omega network has the problems as the delta network with output port contention and path contention
- Again, the result in a bufferless switch fabric is <u>cell loss </u>(one cell wins, one loses)
- Path contention and output port contention <u>can seriously degrade the achievable throughput of the switch</u>

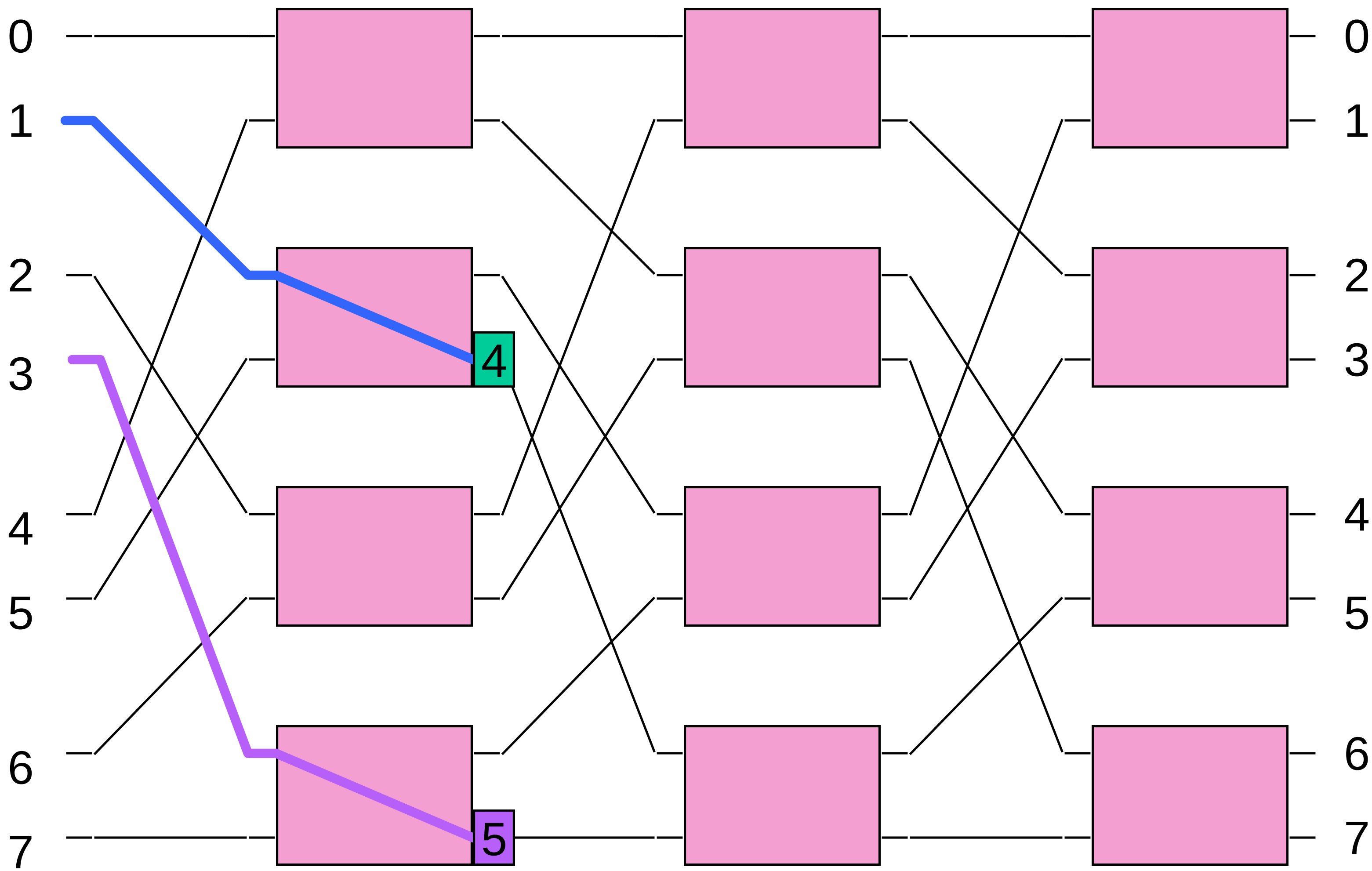
Path Contention



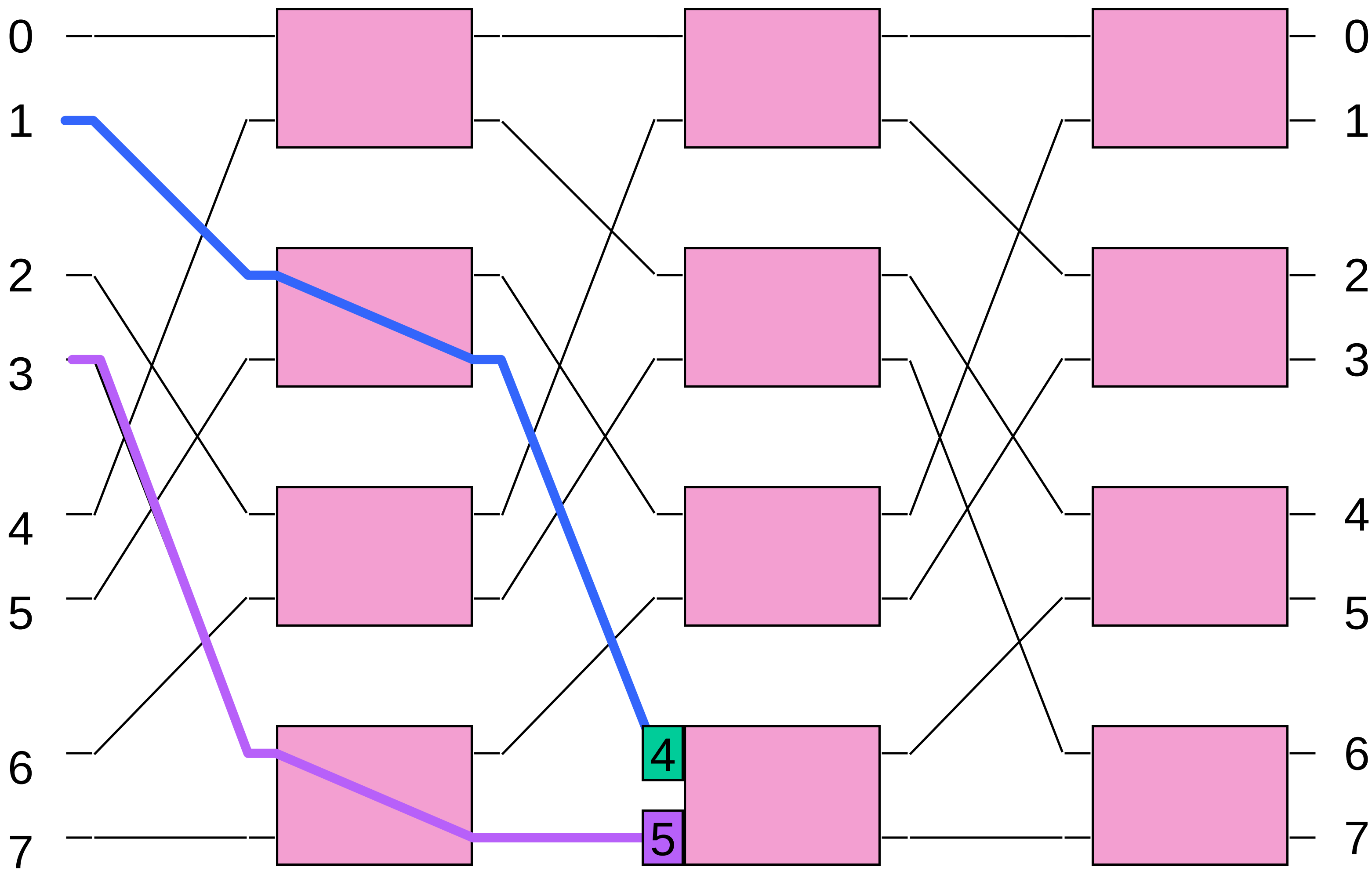
Path Contention



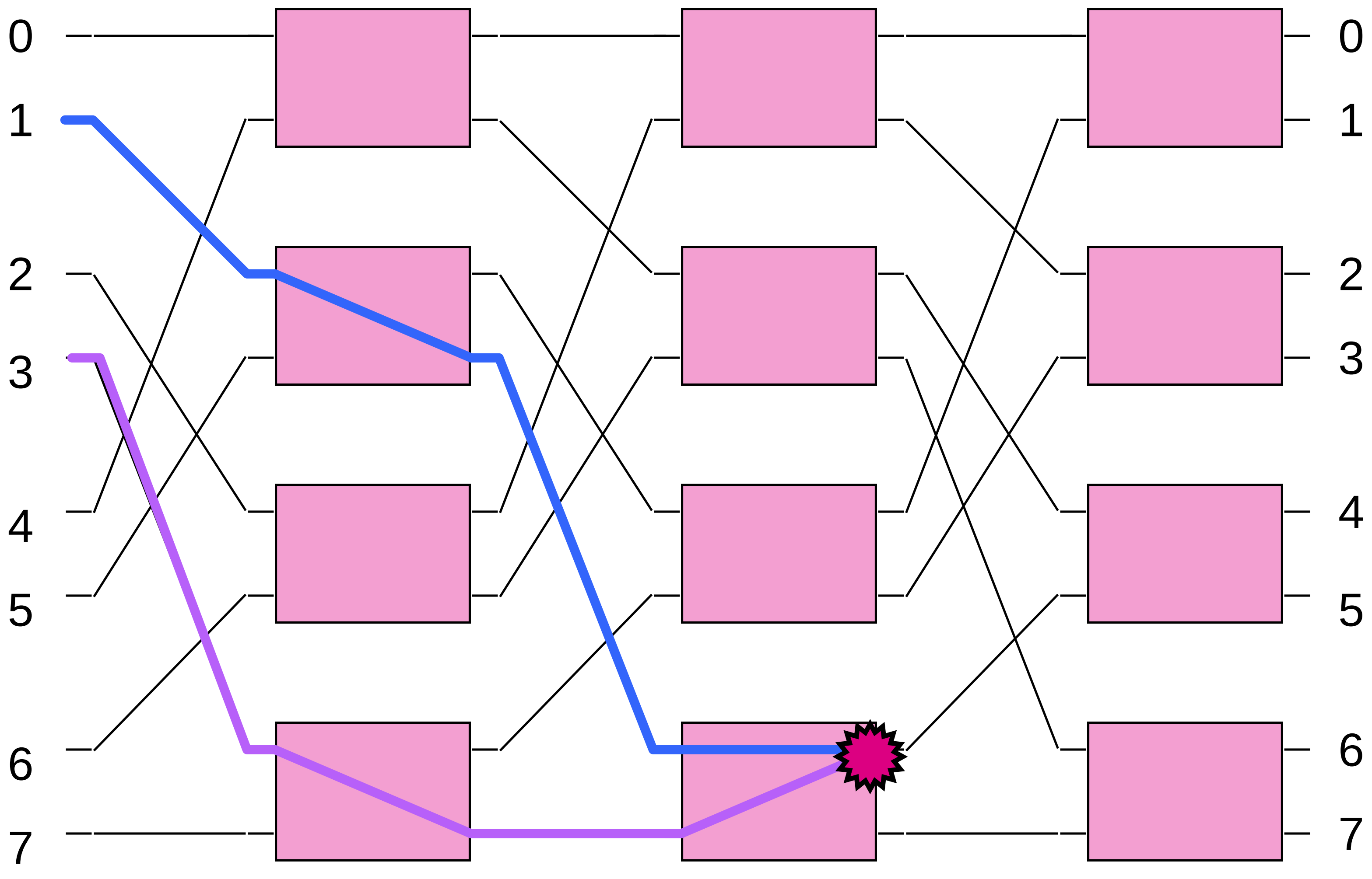
Path Contention



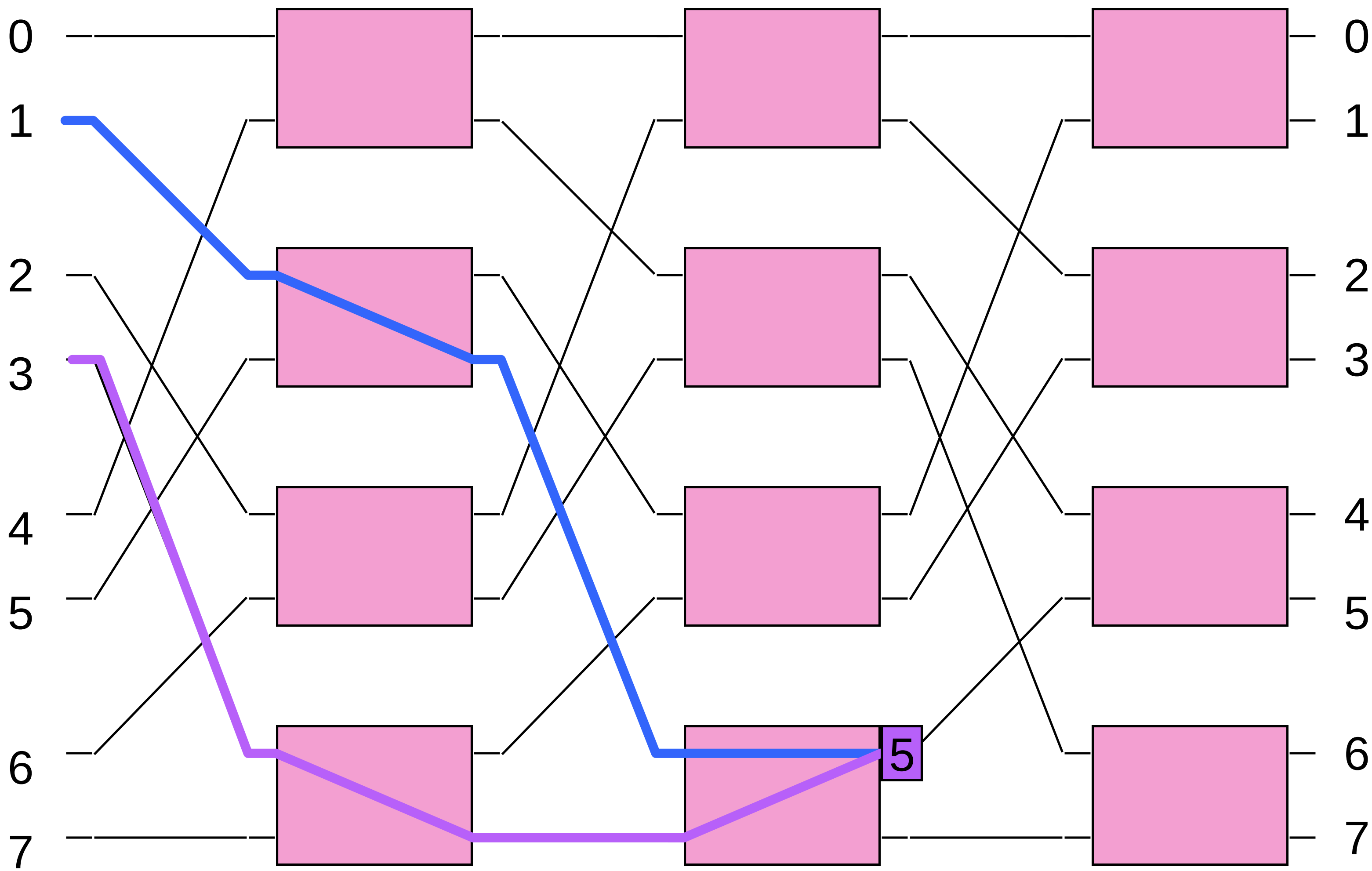
Path Contention



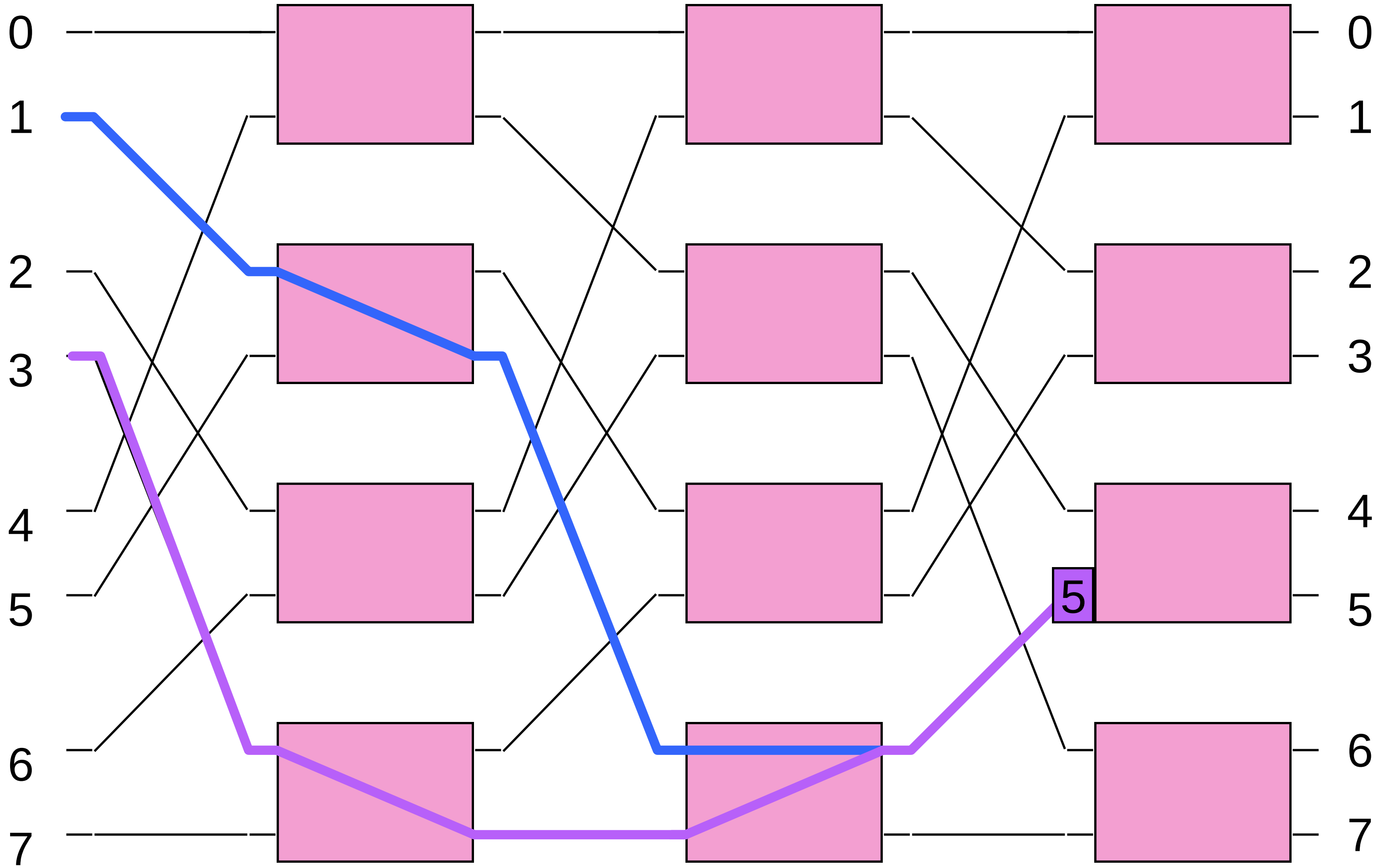
Path Contention



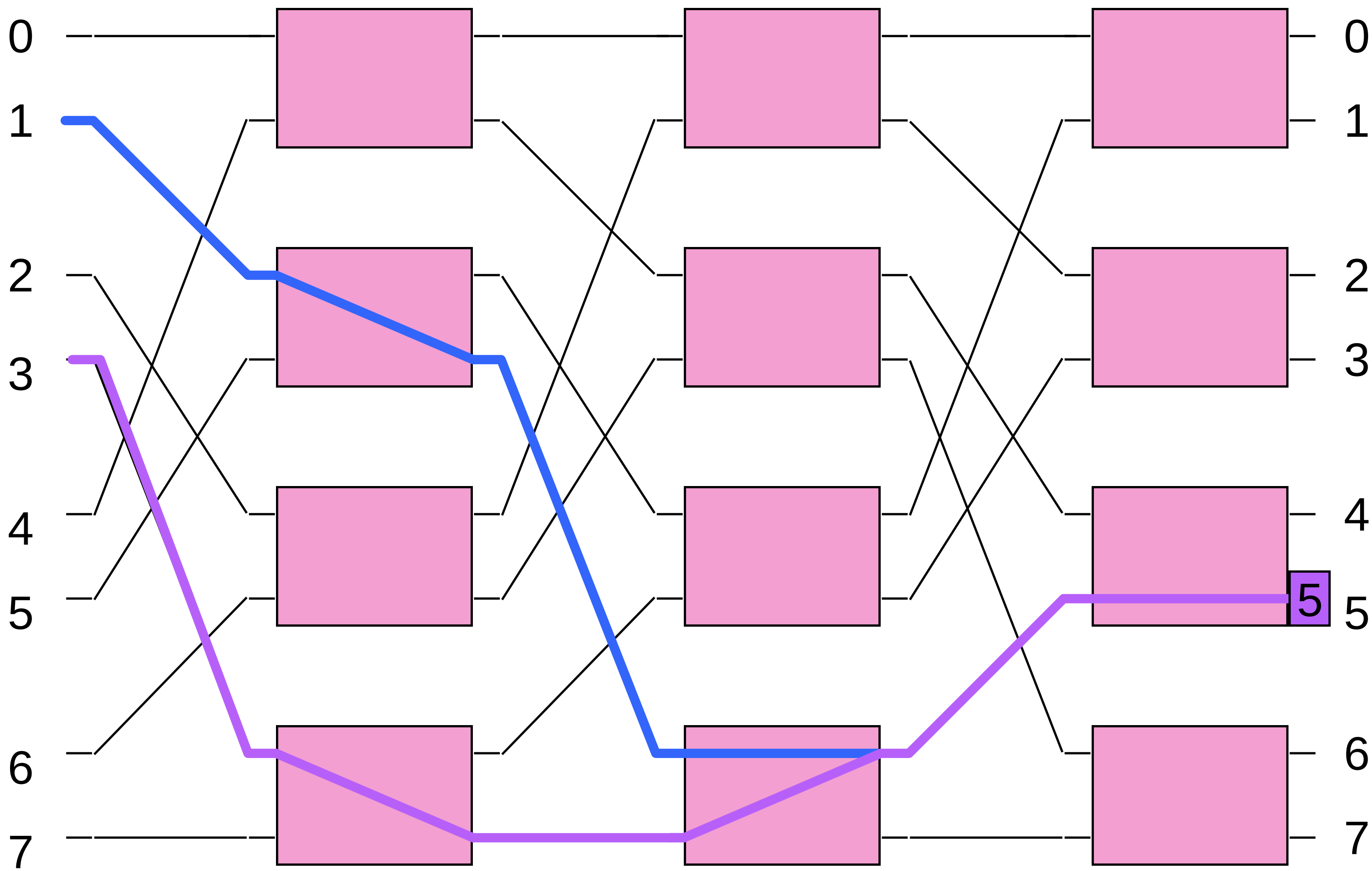
Path Contention



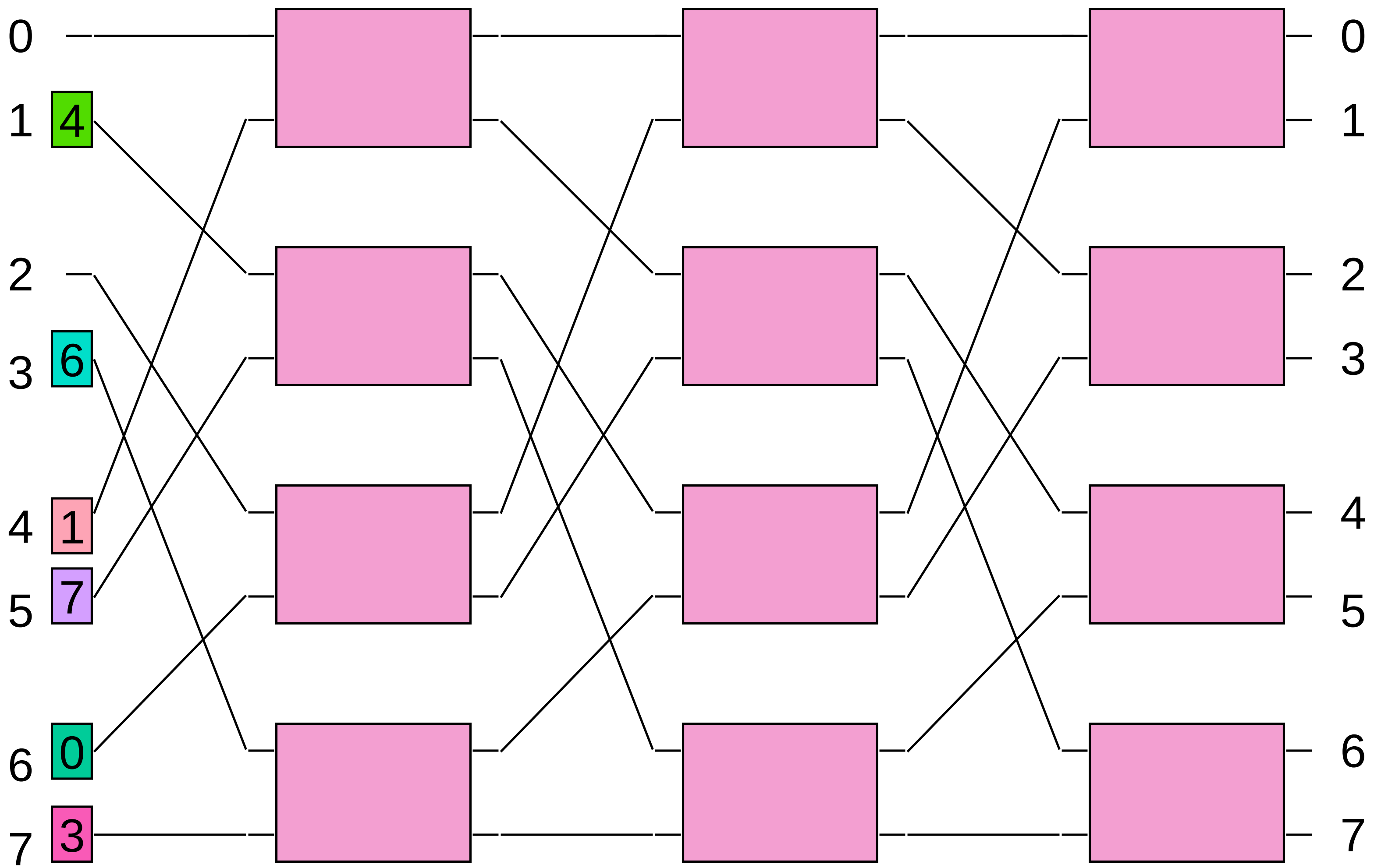
Path Contention



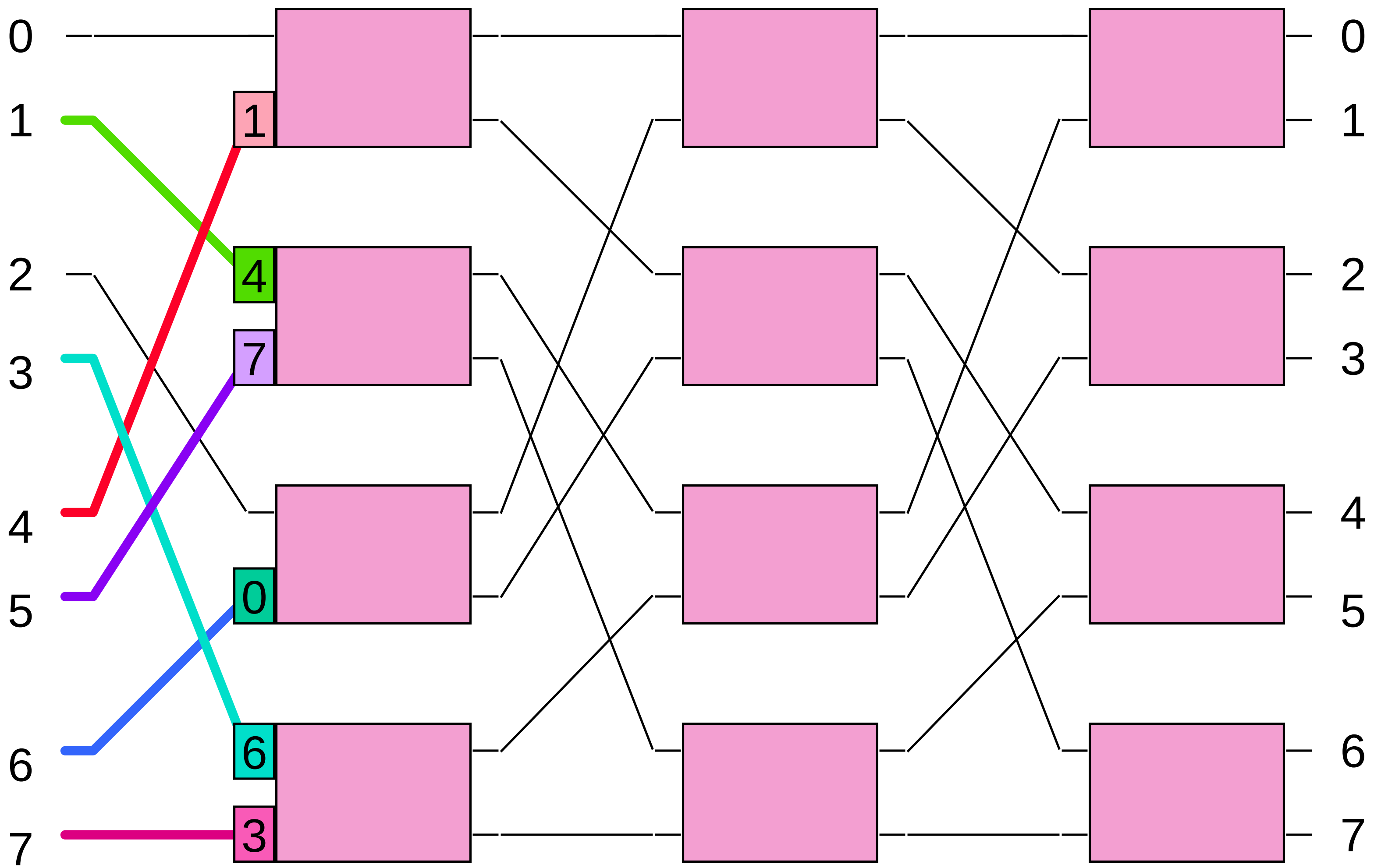
Path Contention



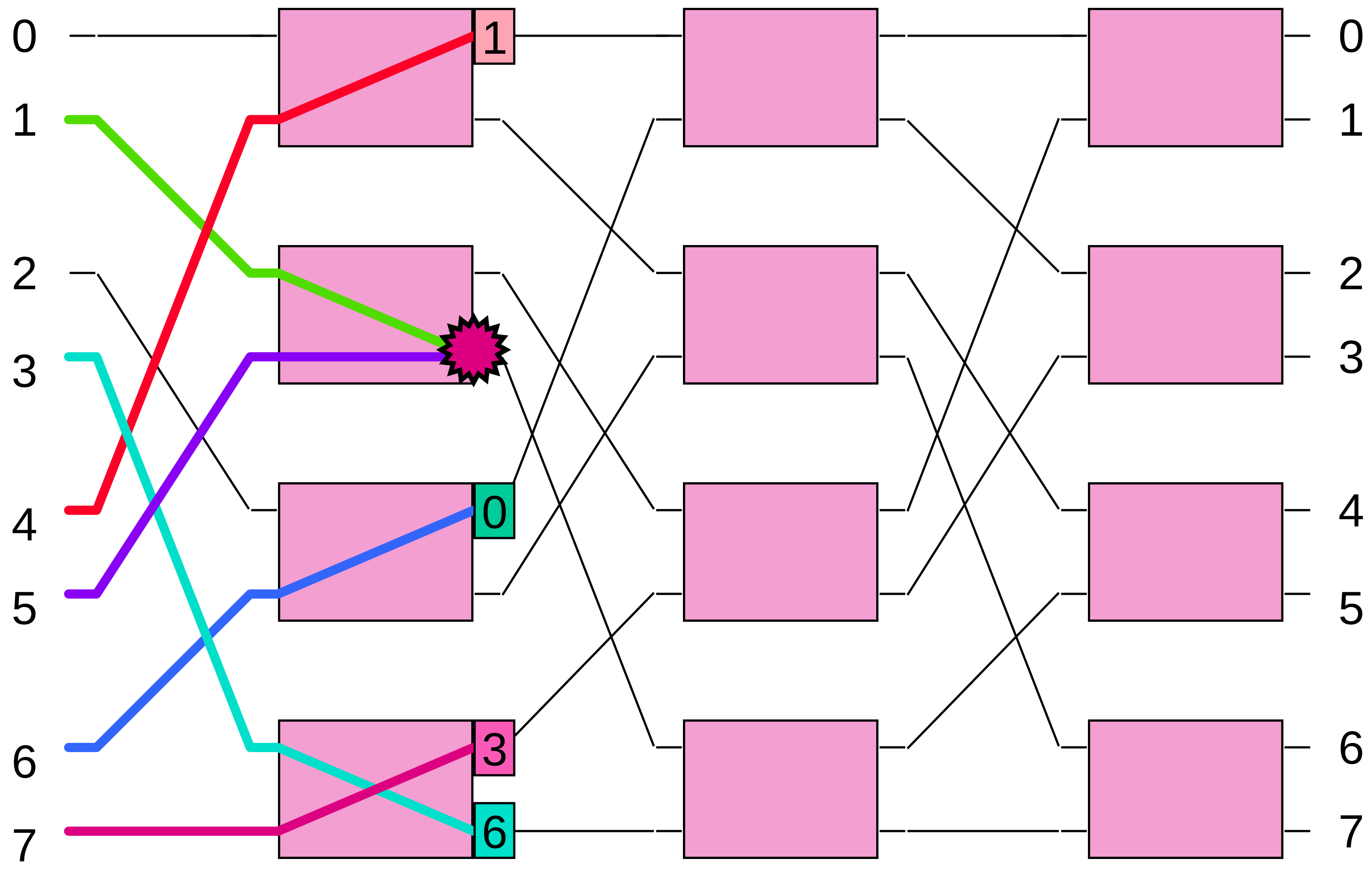
Performance Degradation



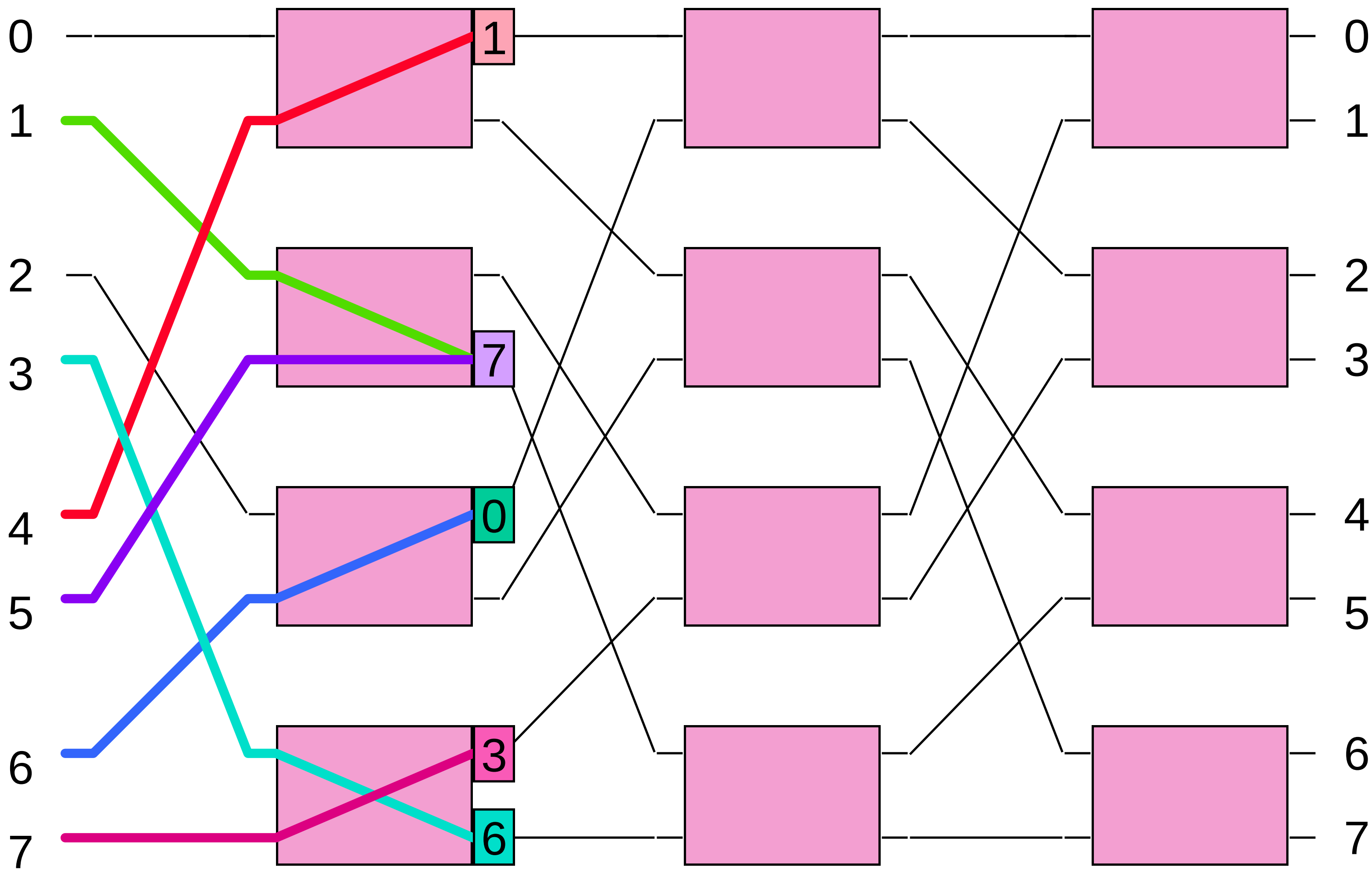
Performance Degradation



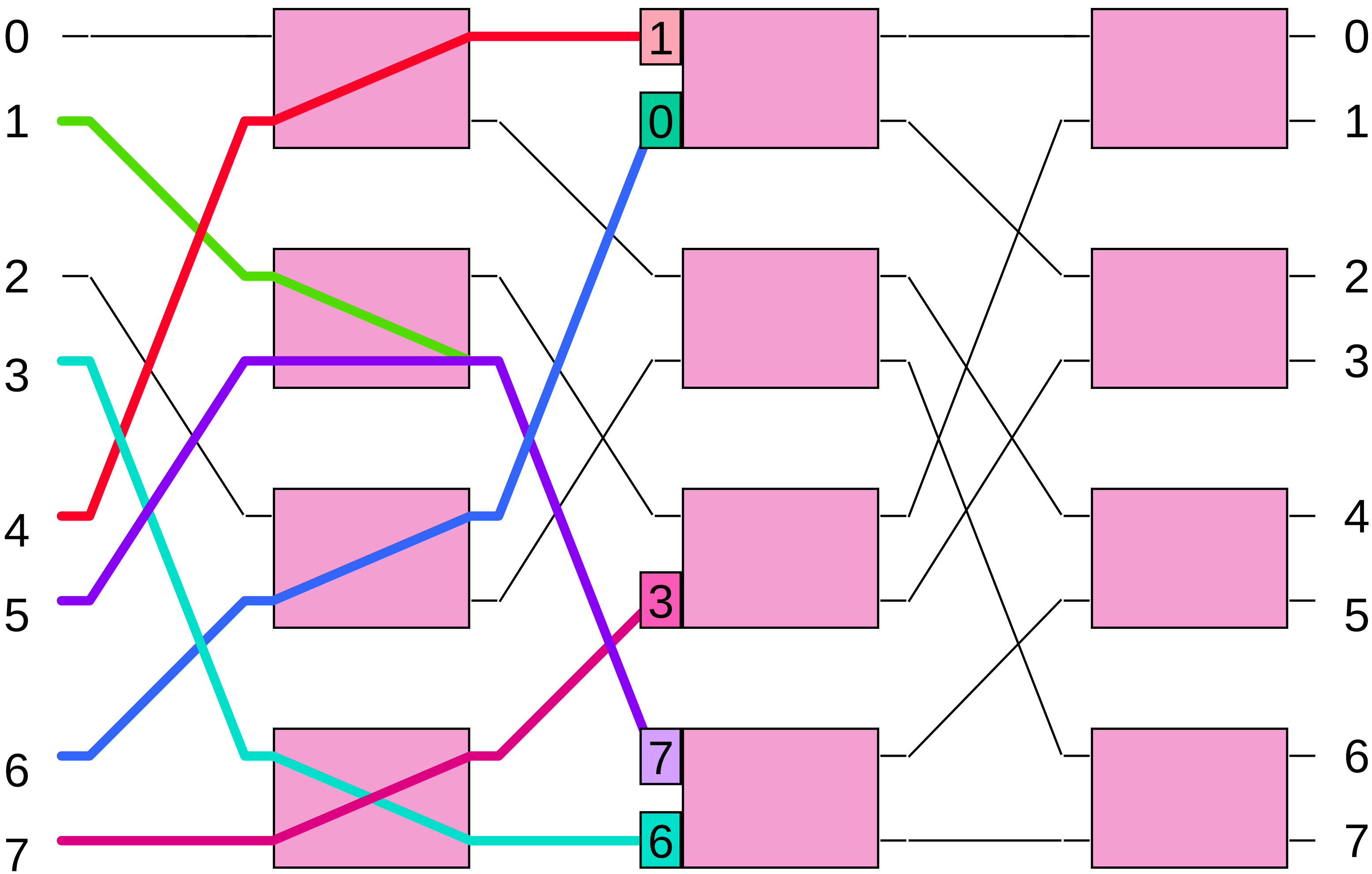
Performance Degradation



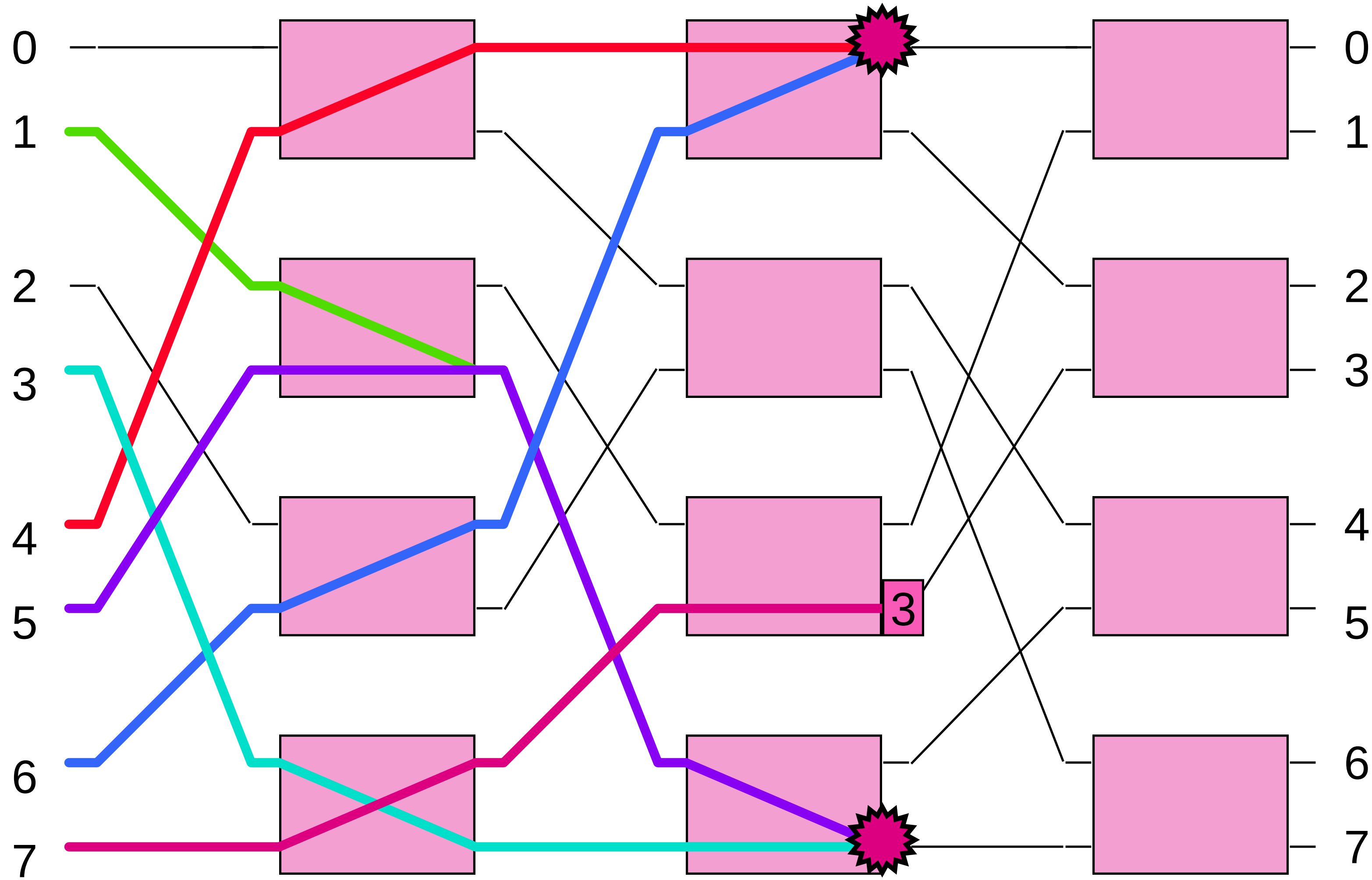
Performance Degradation



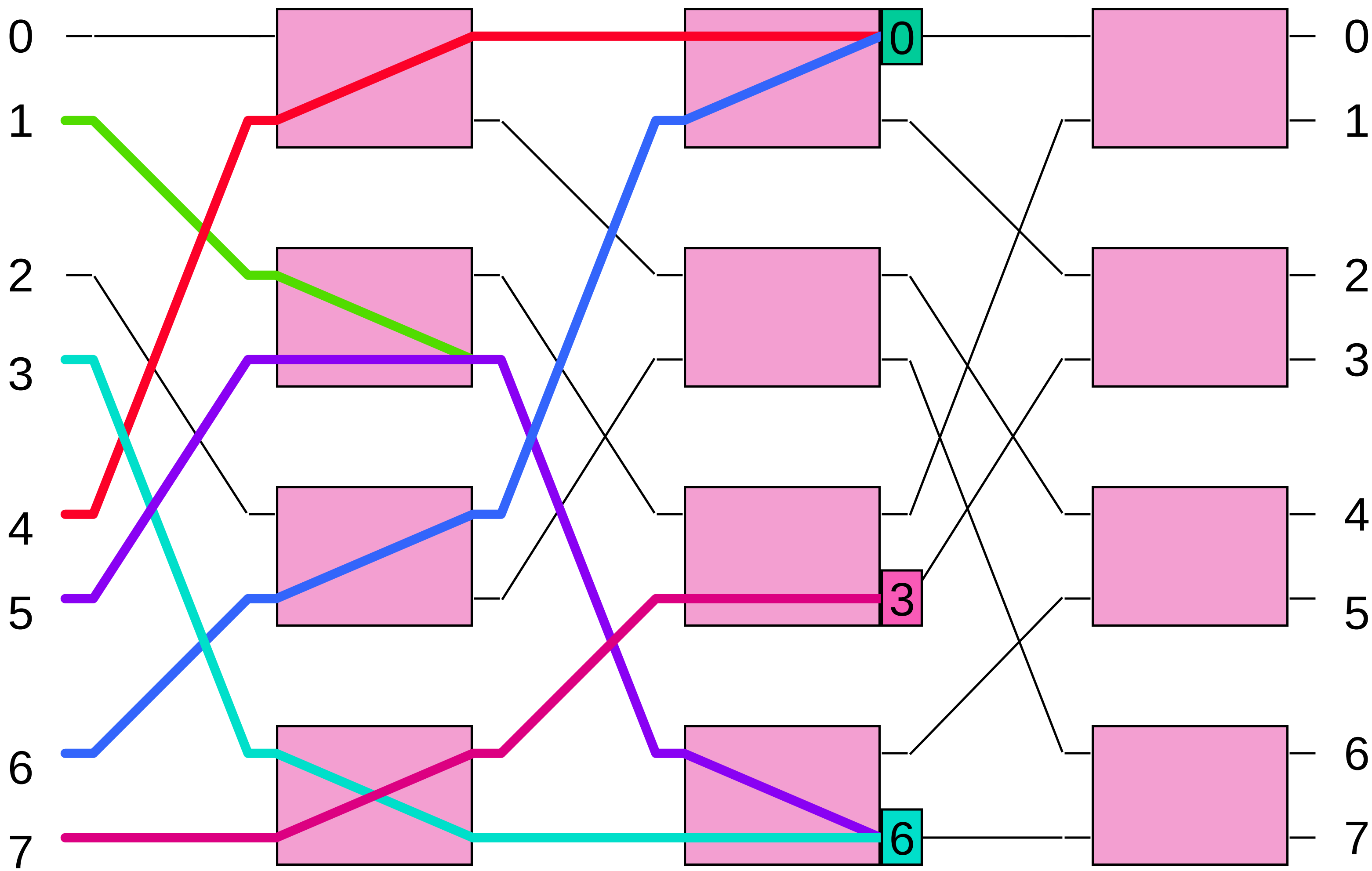
Performance Degradation



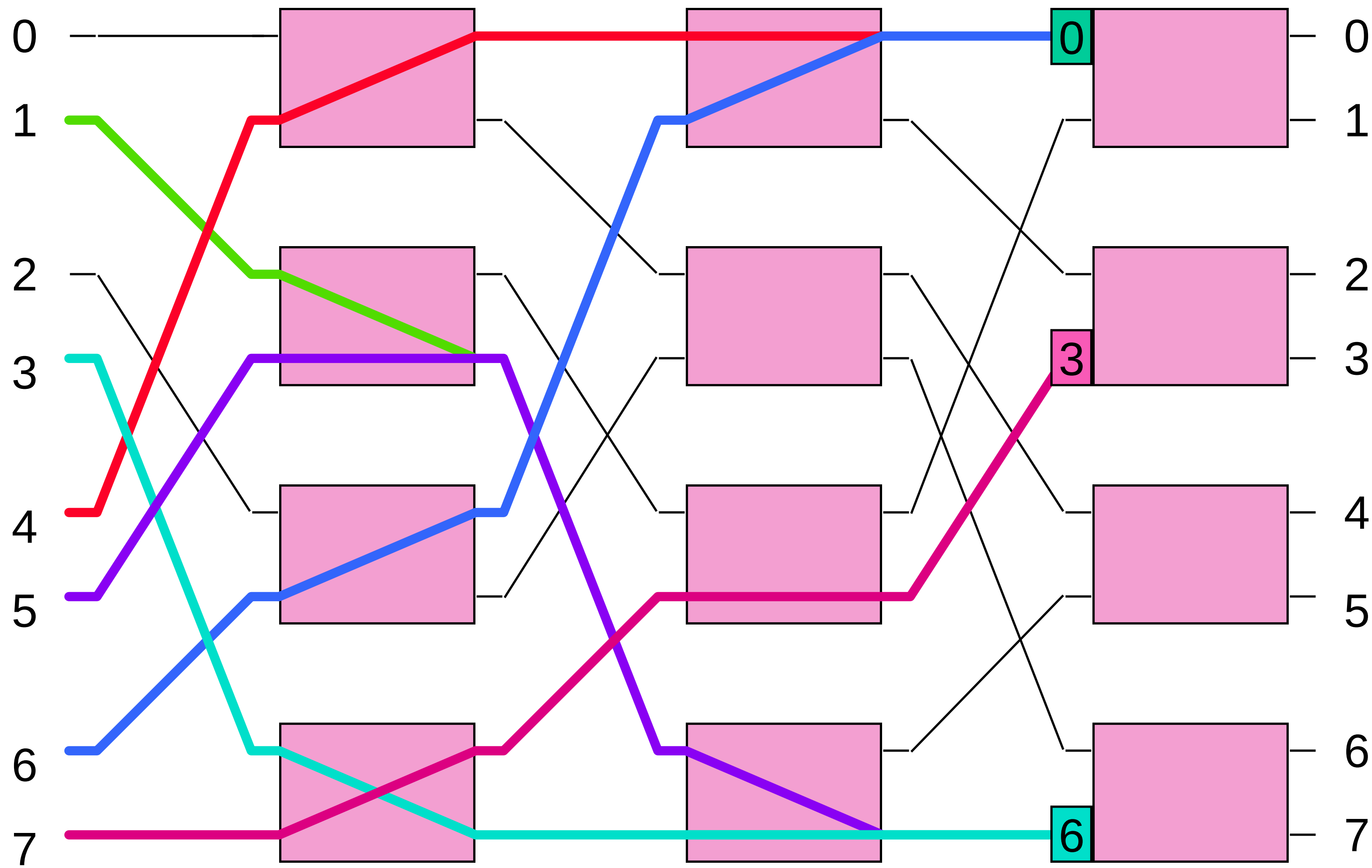
Performance Degradation



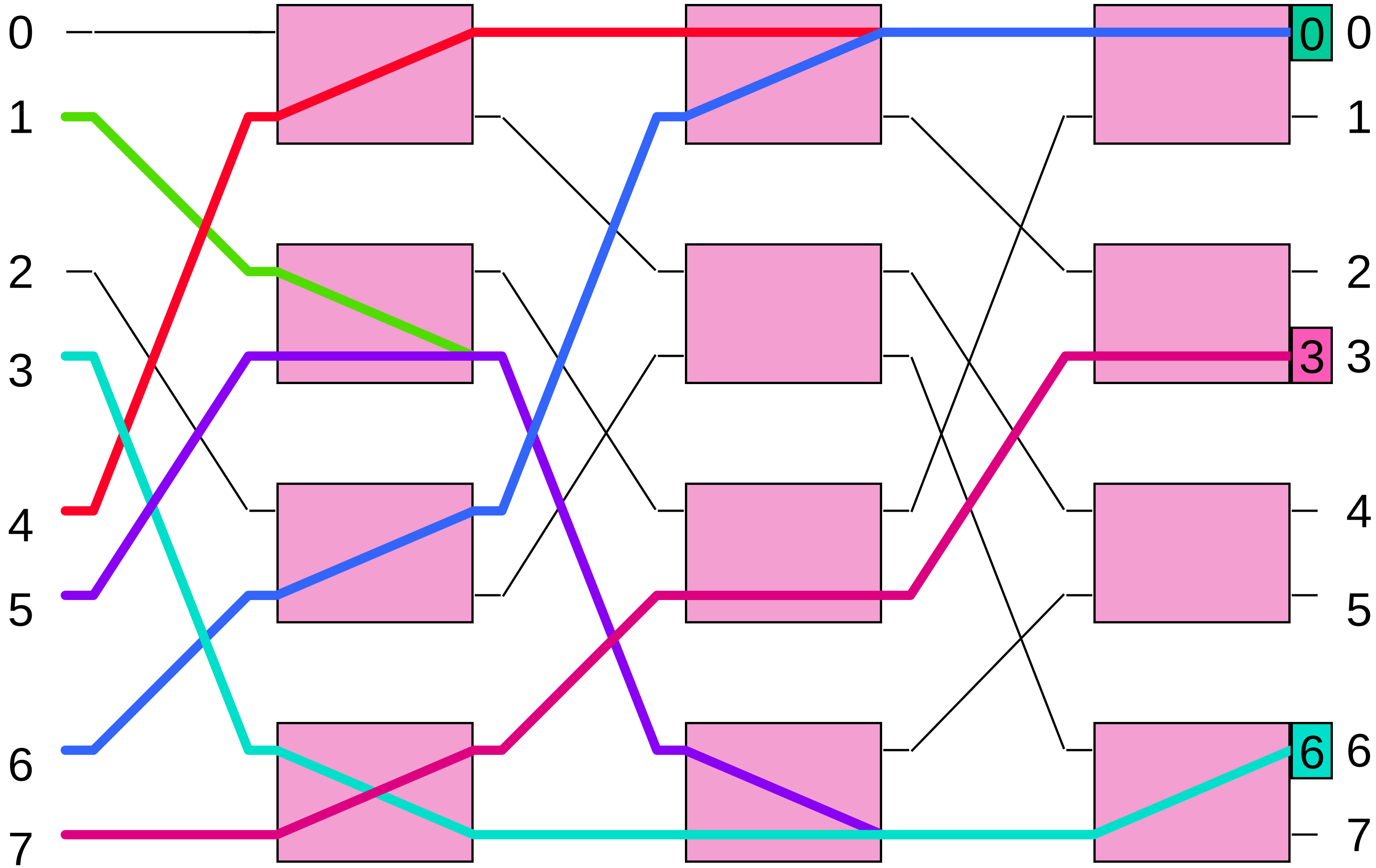
Performance Degradation



Performance Degradation



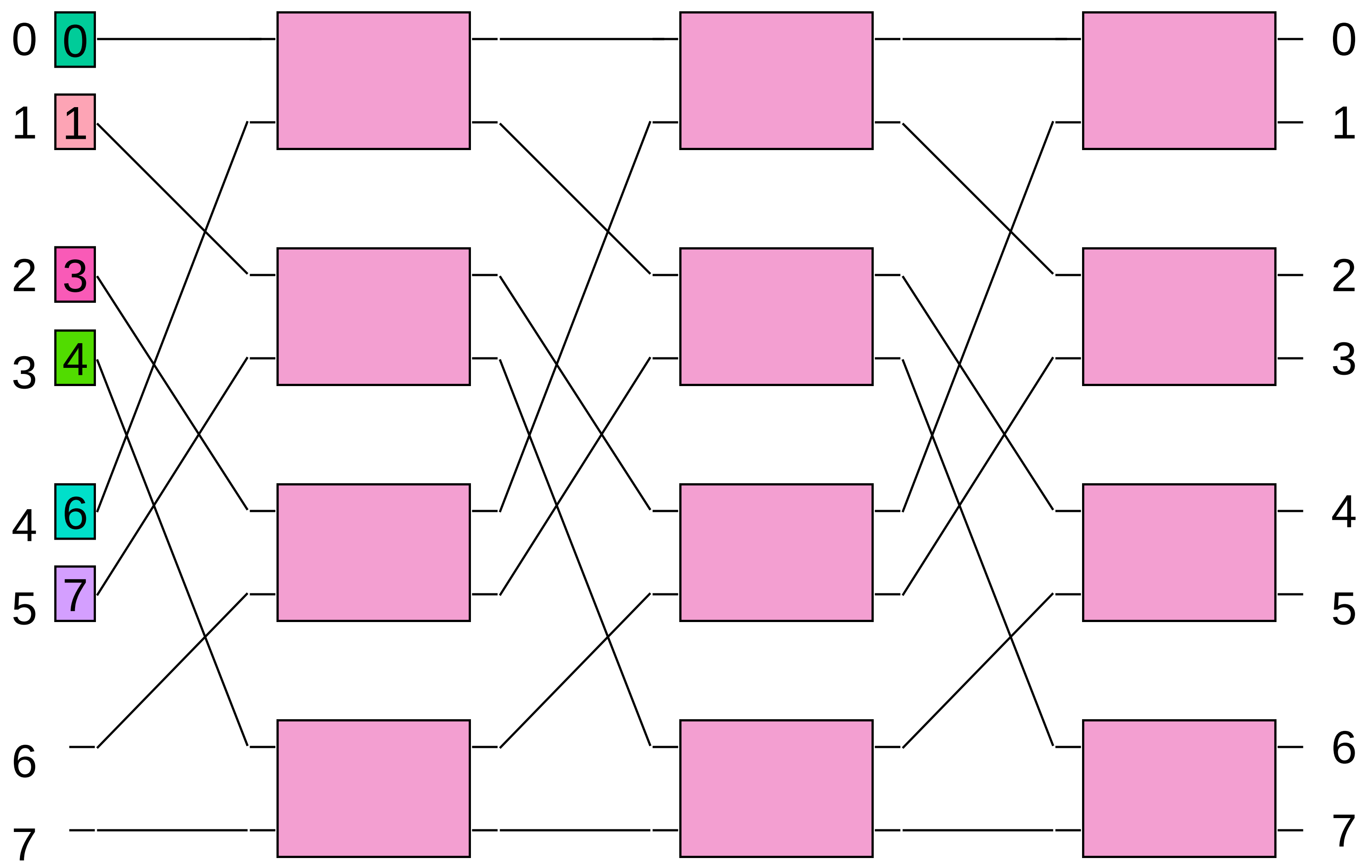
Performance Degradation



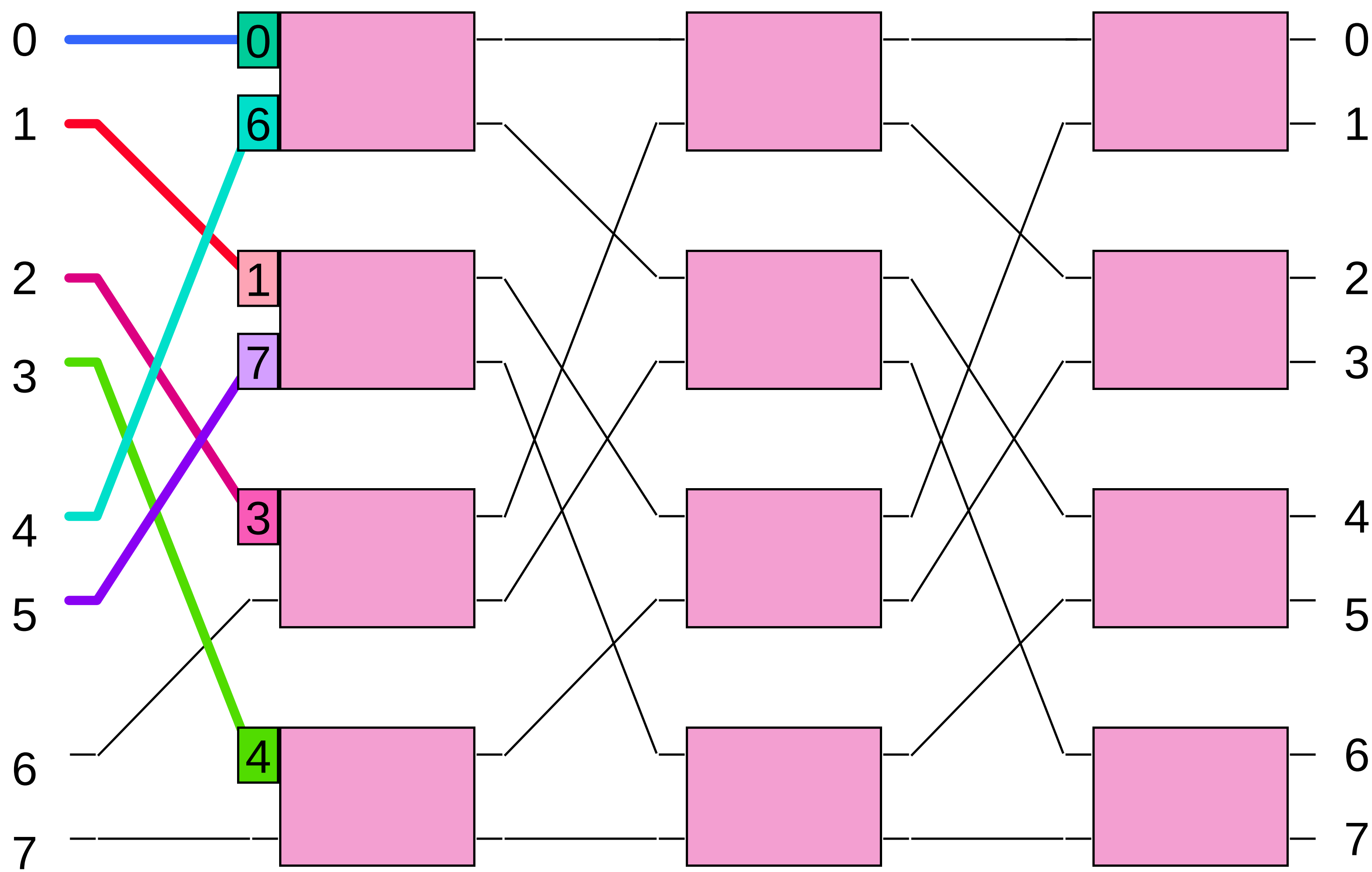
A Solution: Batcher Sorter

- One solution to the contention problem is to sort the cells into monotonically increasing order based on desired destination port
- Done using a bitonic sorter called a Batcher
- Places the M cells into gap-free increasing sequence on the first M input ports
- Eliminates duplicate destinations

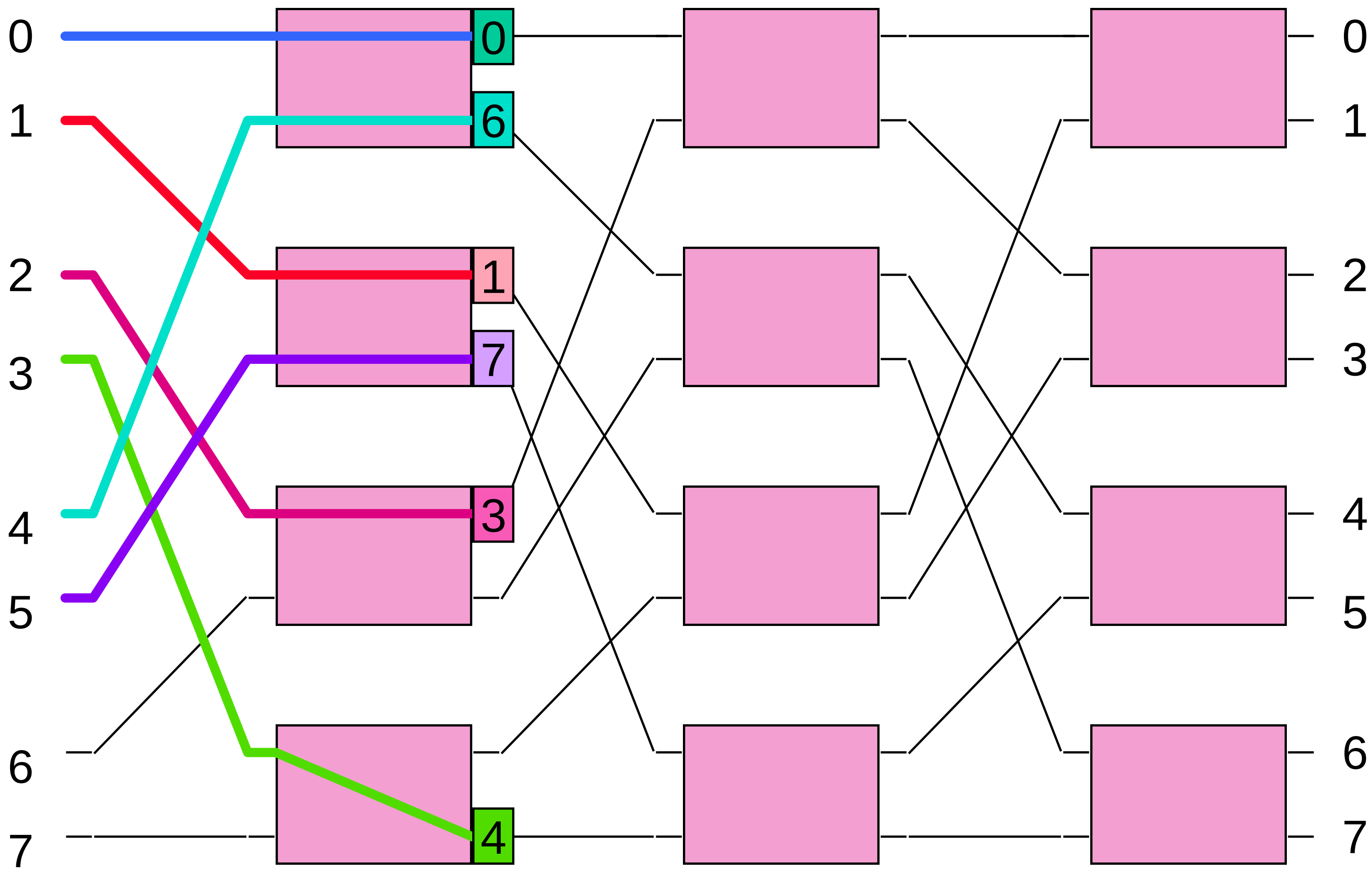
Batcher-Banyan Example



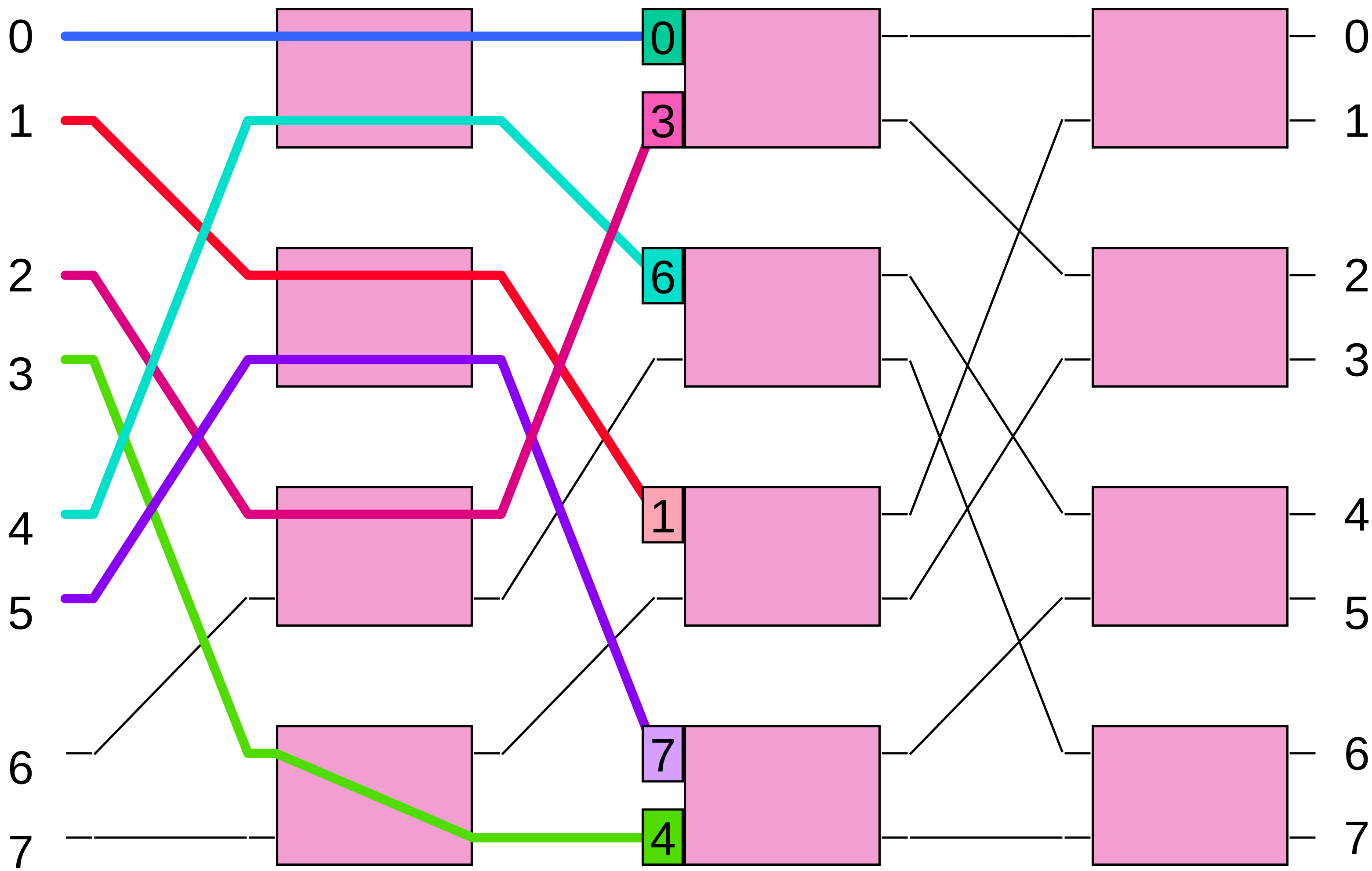
Batcher-Banyan Example



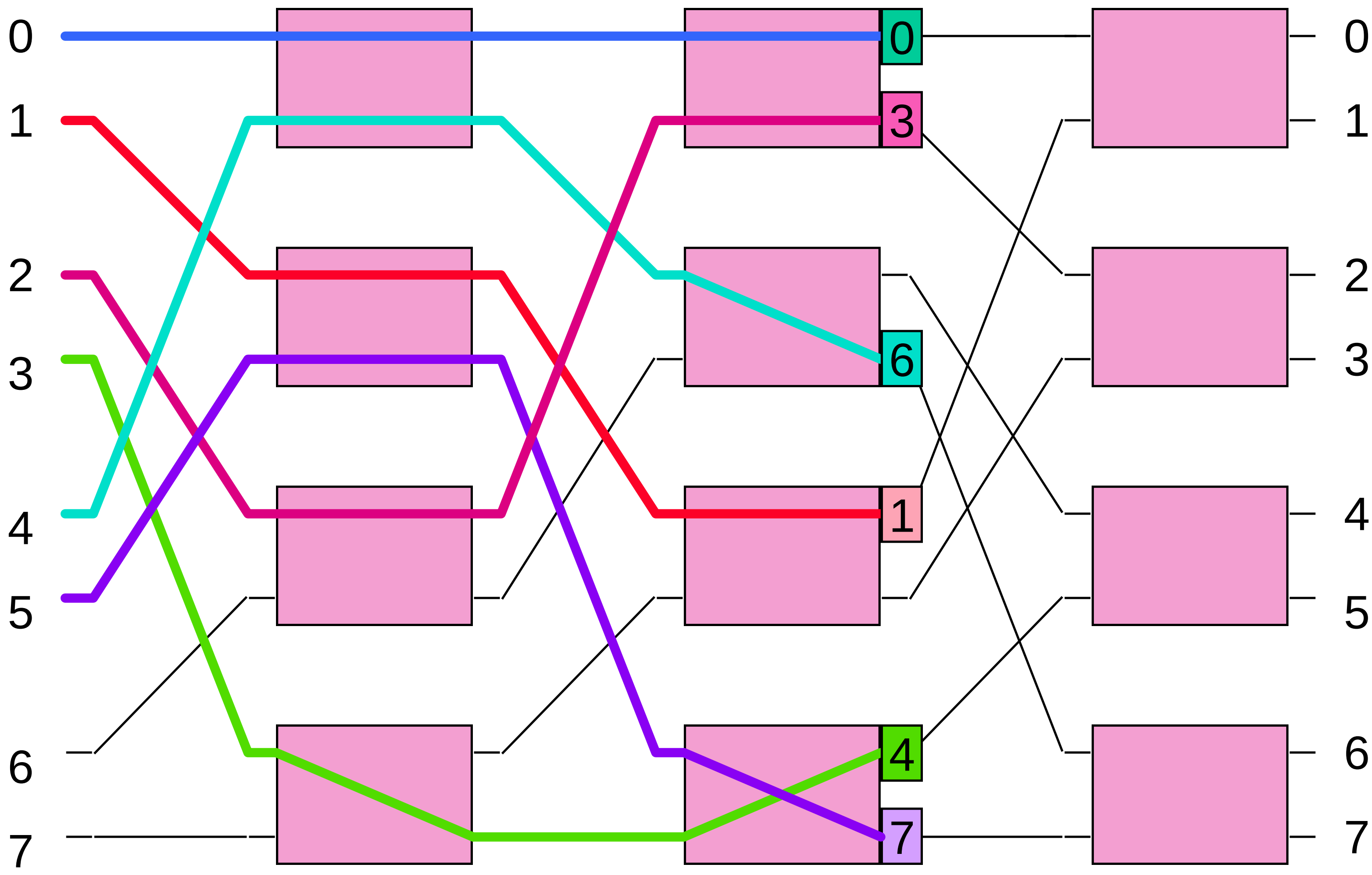
Batcher-Banyan Example



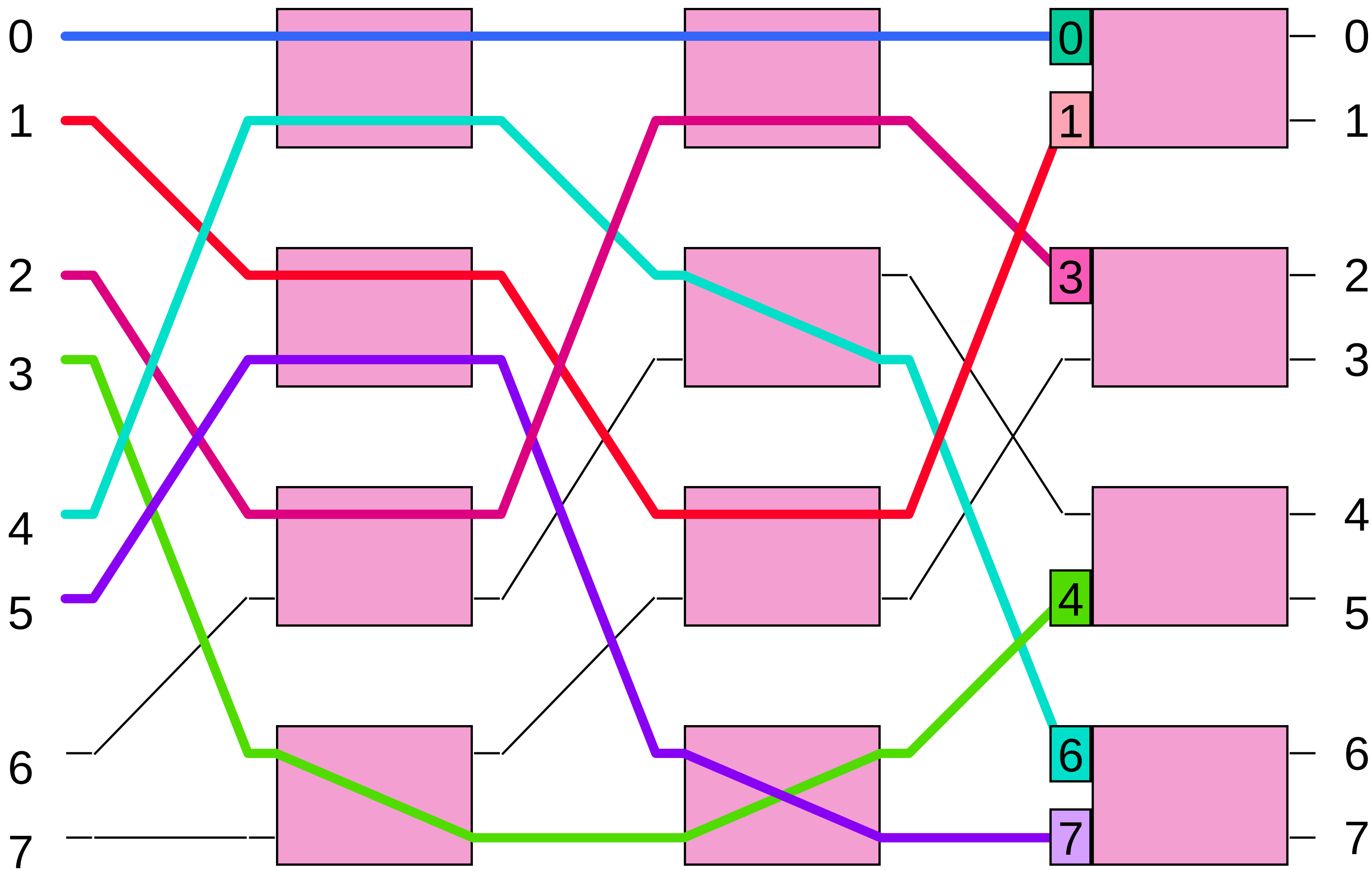
Batcher-Banyan Example



Batcher-Banyan Example



Batcher-Banyan Example



Batcher-Banyan Example