Data Link Layer-5
18.11.2019

BLM 3051 Veri İletişimi
Wireless MAC & Switching

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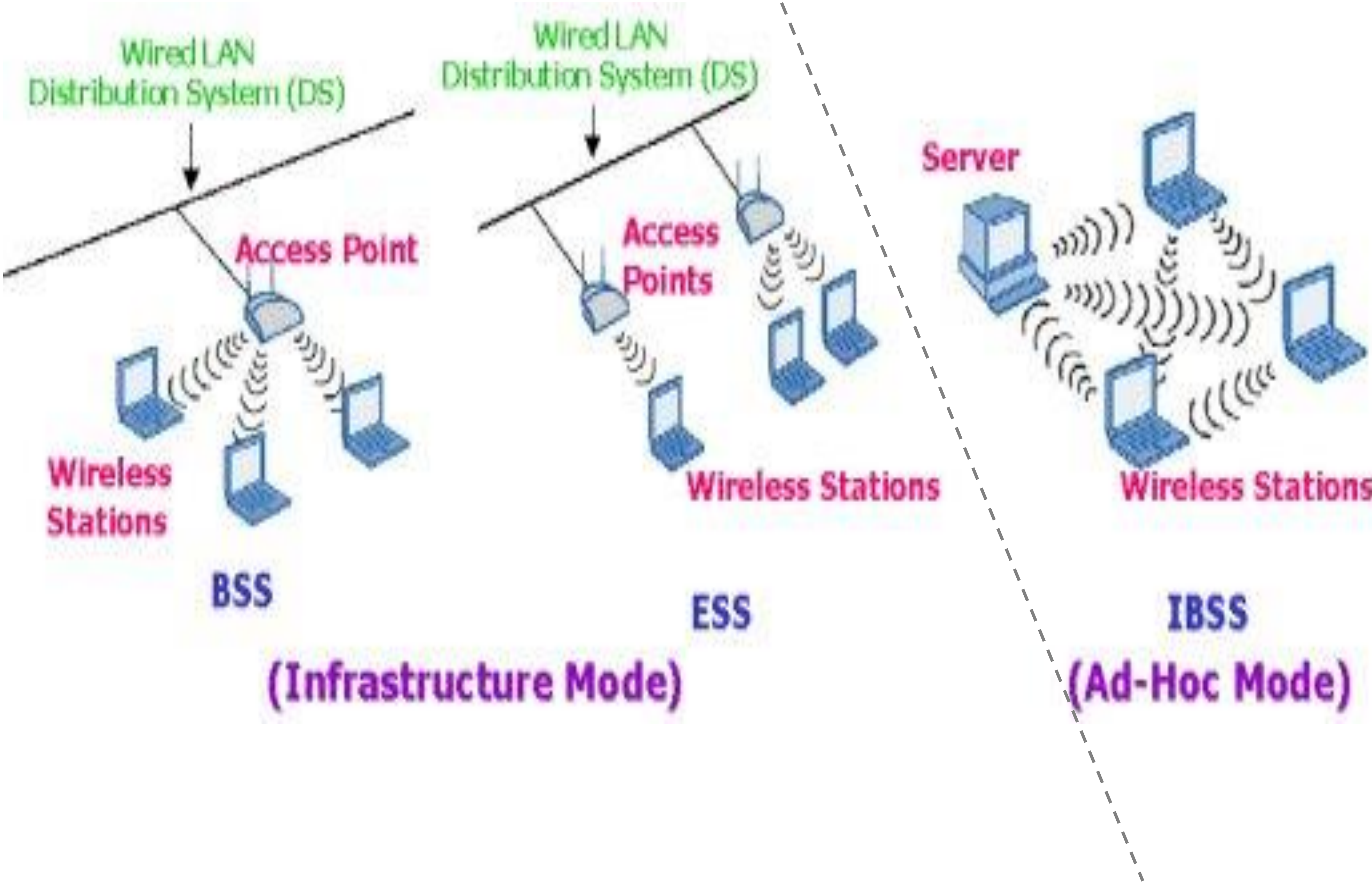
References:

- *Computer Networks*, Andrew Tanenbaum, Pearson, 5th Edition,2010.
- *Computer Networking, A Top-Down Approach Featuring the Internet*, James F.Kurose, Keith W.Ross, Pearson-Addison Wesley, 6th Edition, 2012.

.**BLG 337 Slides** from İTÜ prepared by Assoc. Prof.Dr. Berk CANBERK

Example: Wireless Architecture – Two Modes

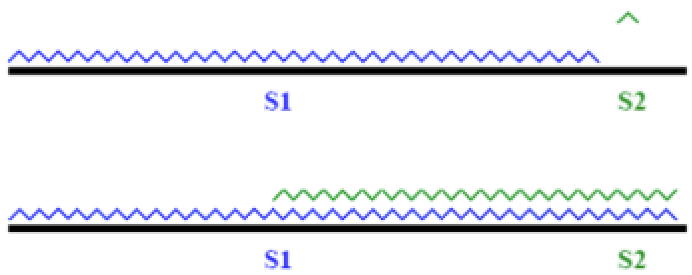


Review: Ethernet MAC

- **Ethernet CSMA/CD Algorithm**
  - NIC takes datagram from network layer, creates frame.
  - If NIC understands the channel idle, starts frame transmission.
  - If NIC senses channel busy, waits until channel idle, then transmits.
  - If NIC transmits entire frame without detecting another transmission, NIC has been successful with the frame.
  - If NIC detects another transmission while transmitting, aborts and sends jam signal.

Review: Ethernet MAC

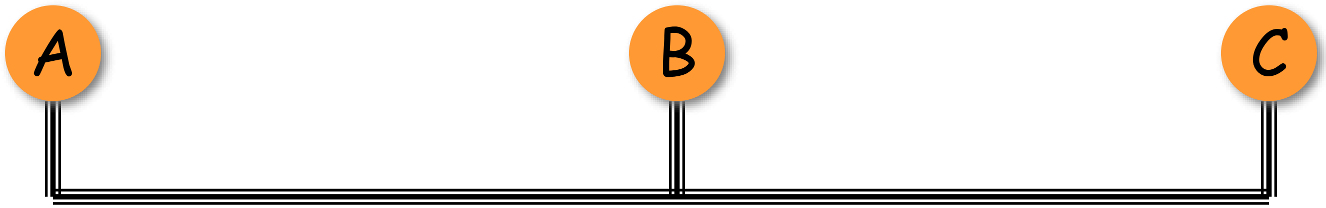
- **Ethernet CSMA/CD Algorithm**
  - **After aborting, NIC enters binary (exponential) backoff:**
    - after mth collision, NIC chooses K at random from {0,1,2, …, 2m-1}. NIC waits K·512 bit times, returns to Step 2
    - longer backoff interval with more collisions



- **Is detection of collusions possible on a wireless link?**

The Channel Access Problem

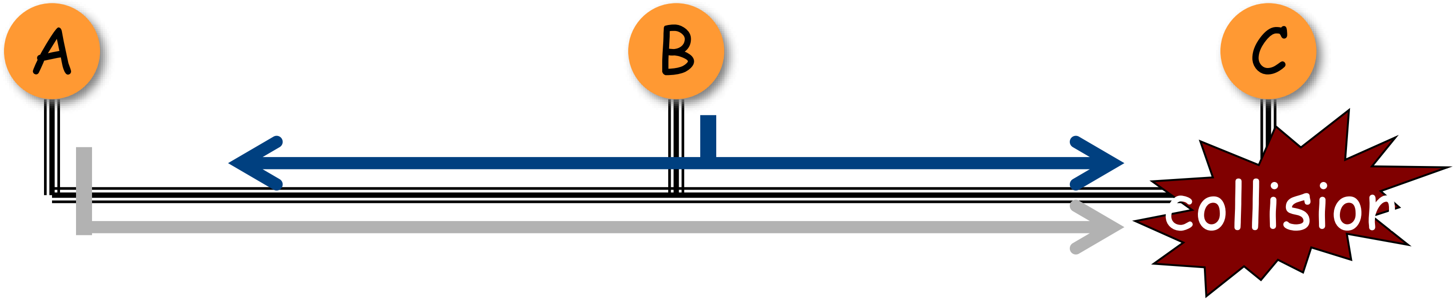
- Multiple stations share a channel



- Pairwise communication desired
  - **Simultaneous communication is not possible**
- MAC Protocols
  - **Suggests a scheme to schedule communication**
    - Maximize Number of communications
    - With real fairness btw all nodes.

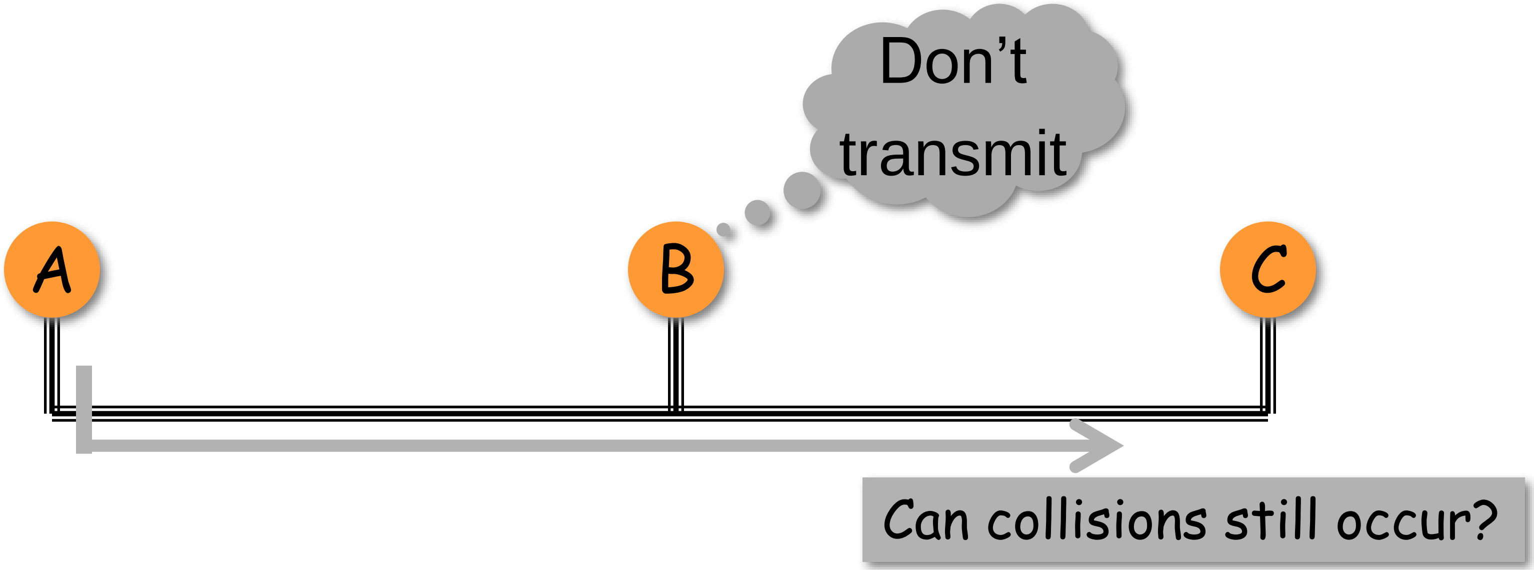
The Trivial Solution

- Send the packet without any planning!
  - **Many collusions: Weak system in high load!**



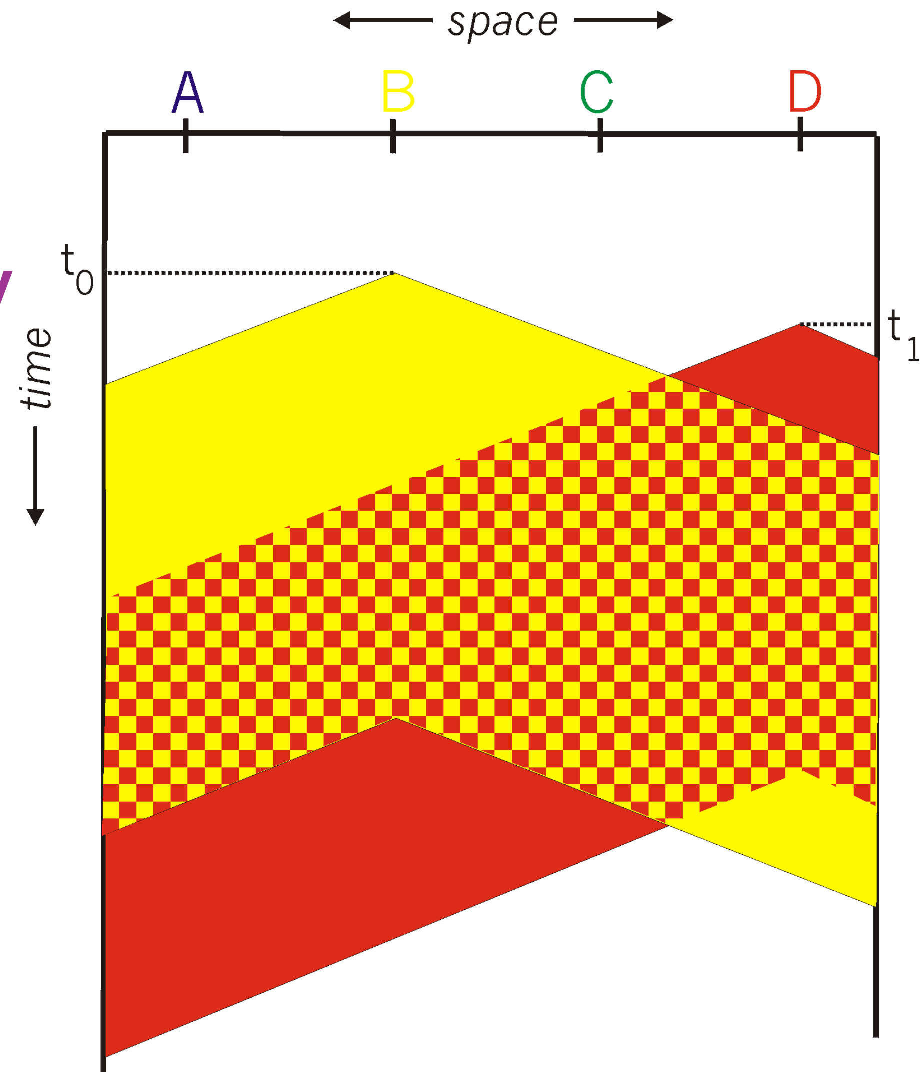
The Simple Resond

- Send the packet without any planning!
  - **Many collusions: Weak system in high load!**
- Listen before sending!
  - **CSMA**
  - **Differ transmission if signal is on channel**



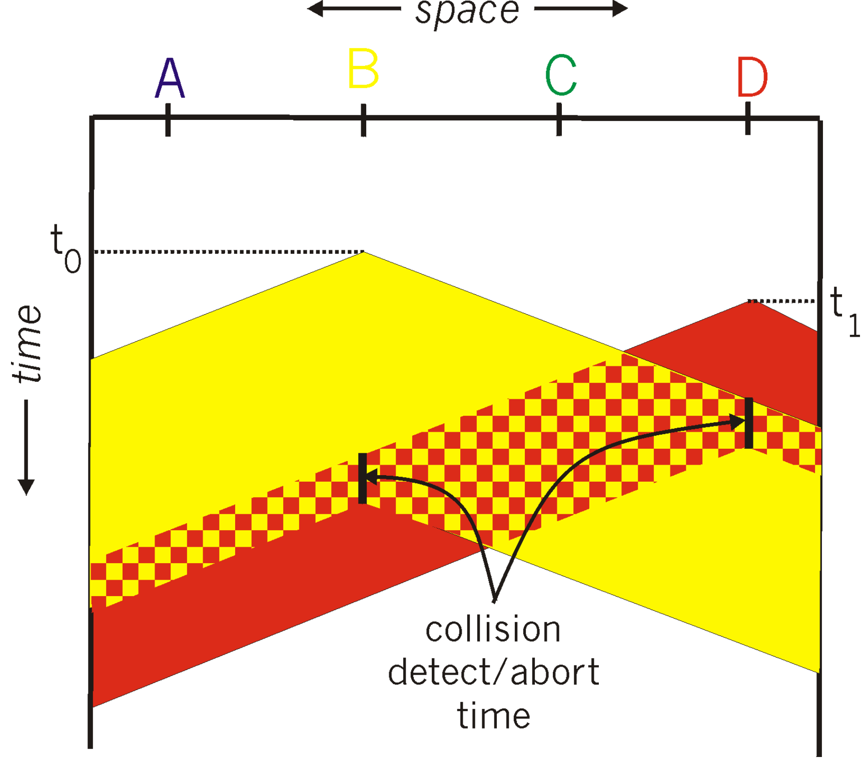
CSMA Collusions

- ✓ Collusions continues existing!
  - **Because of the non-zero propagation delay**
- ✓ If Collusion occurs:
  - **Entire packet transmission time wasted**
- ✓ Note:
  - **Role of distance & propagation delay in determining collision probability**



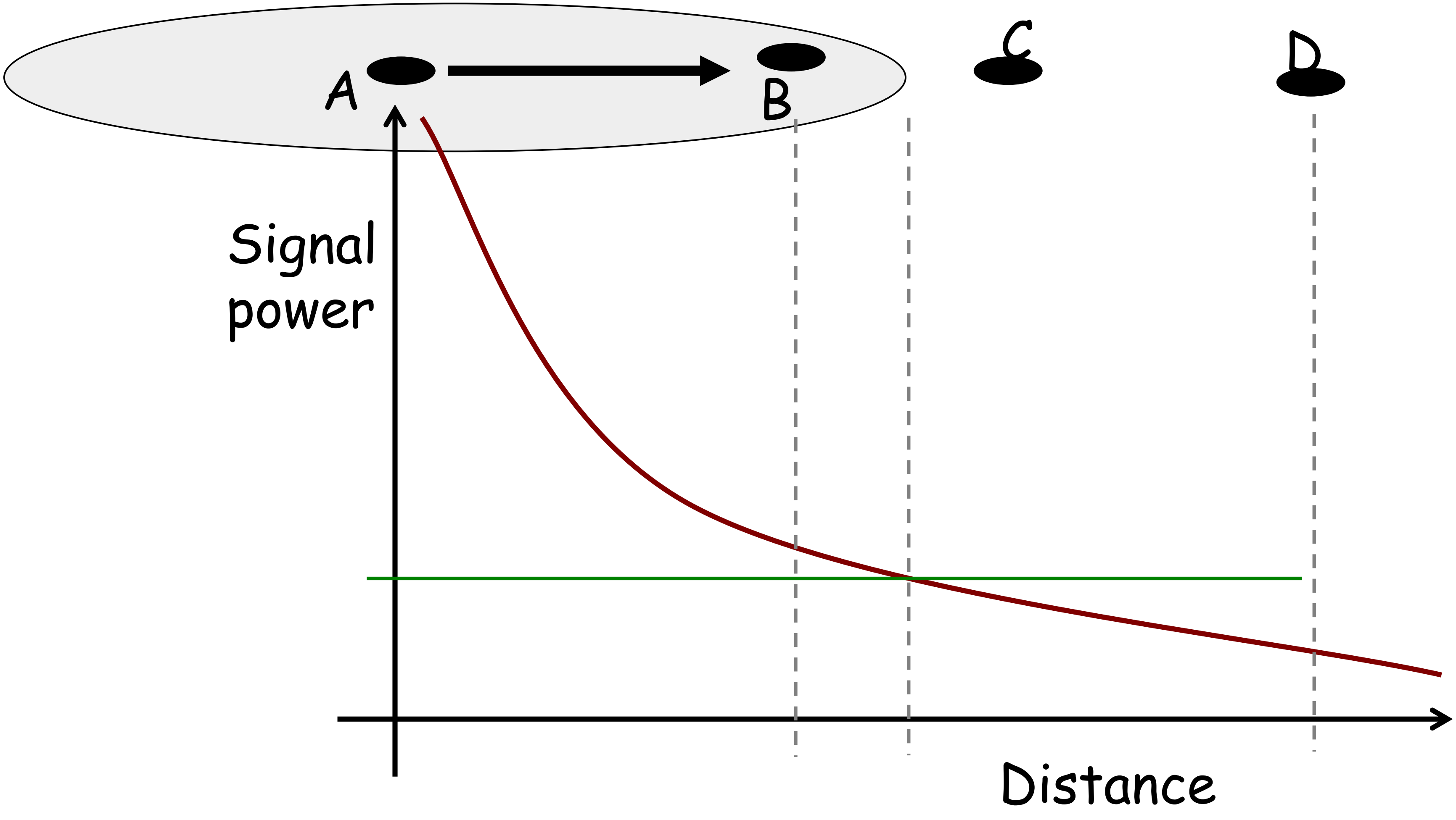
CSMA Collusions

- ✓ Continue listening the channel:
  - ○ **While transmitting**



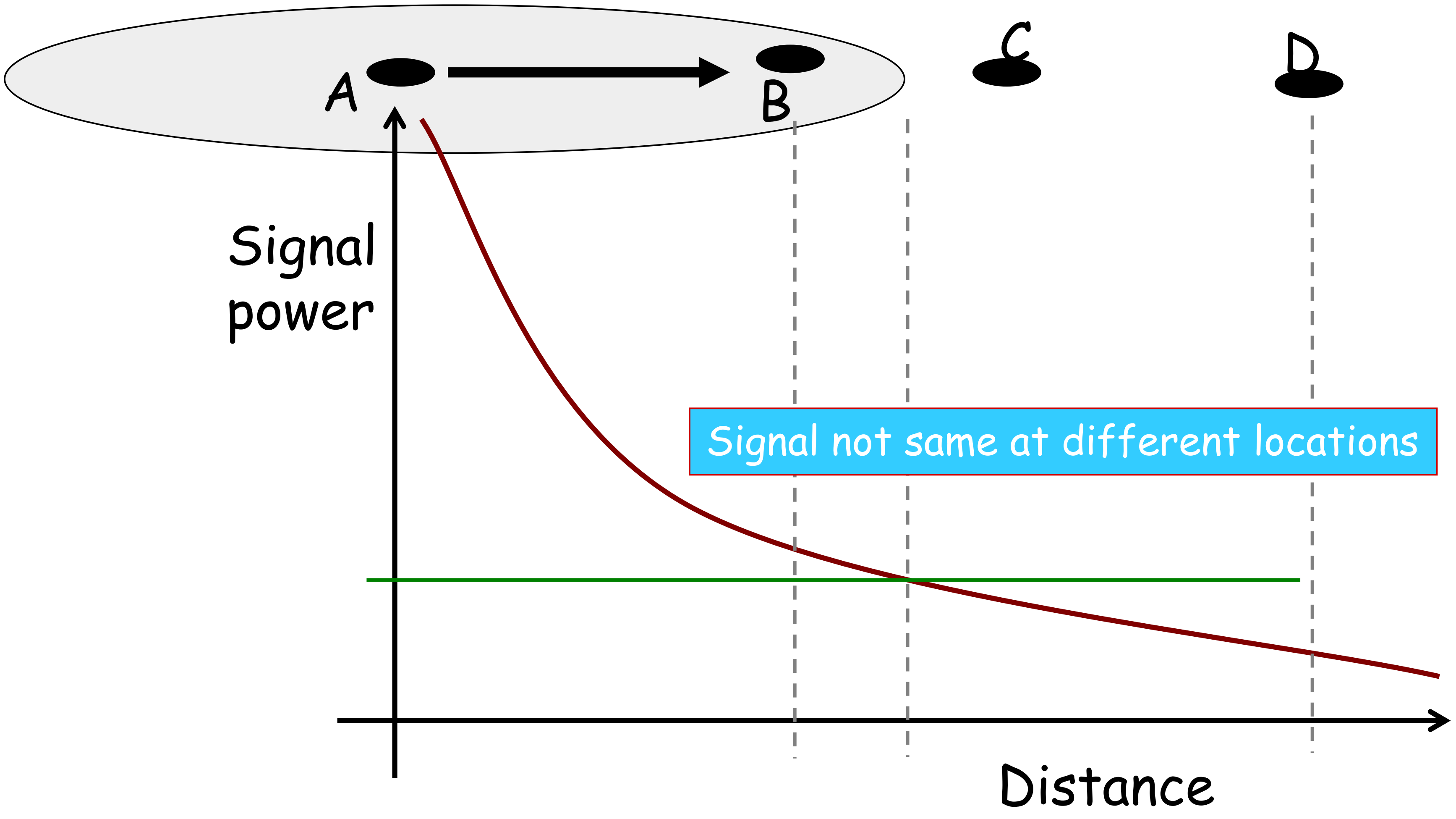
- ✓ If (Transmitted_Signal != Sensed_Signal)
  - ○ **Sender learns a collision occured**
  - ○ **Abort**

Wireless Medium Access Control



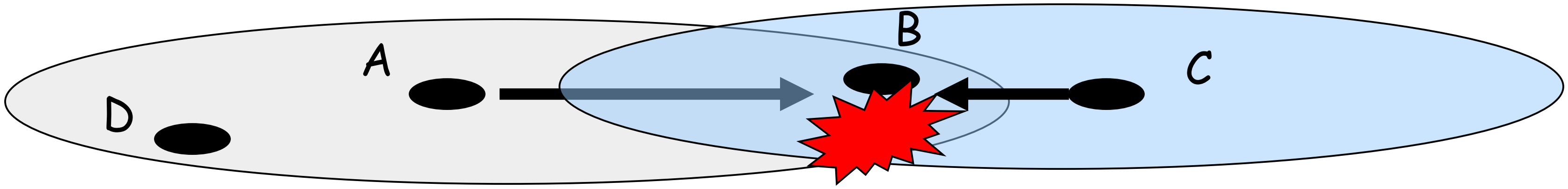
Wireless Media Disperse Energy

A cannot send and listen in parallel

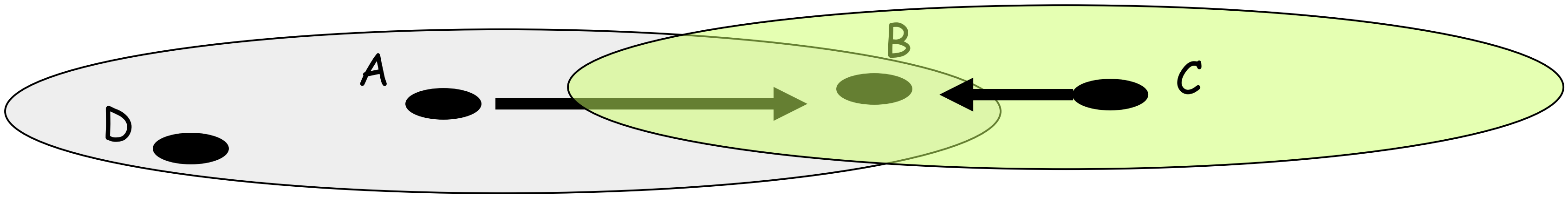


Collusion Detection Difficulty

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



Formulation of SINR

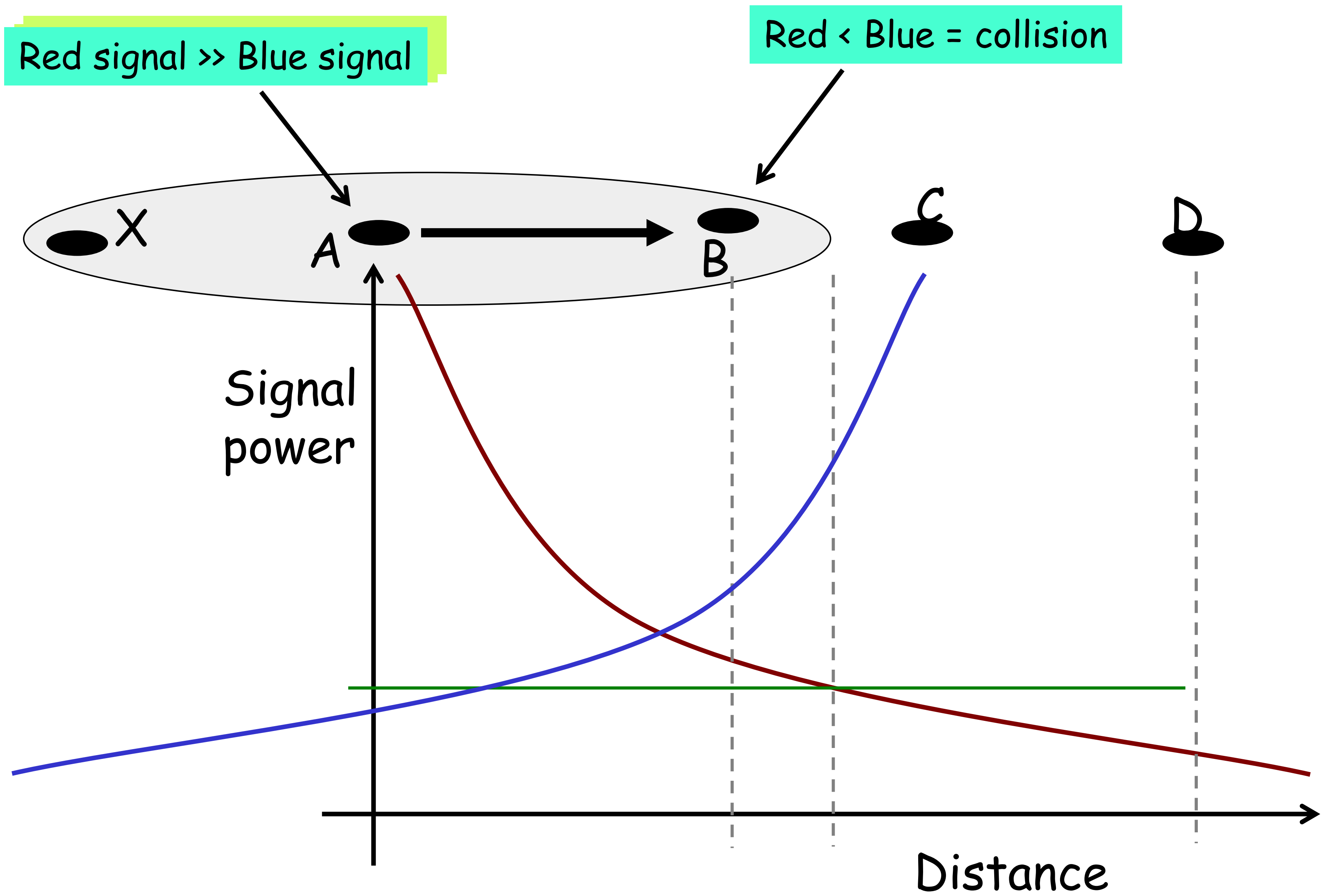


$$SINR = \frac{SignalOfInterest(SoI)}{Interference(I) + Noise(N)}$$

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

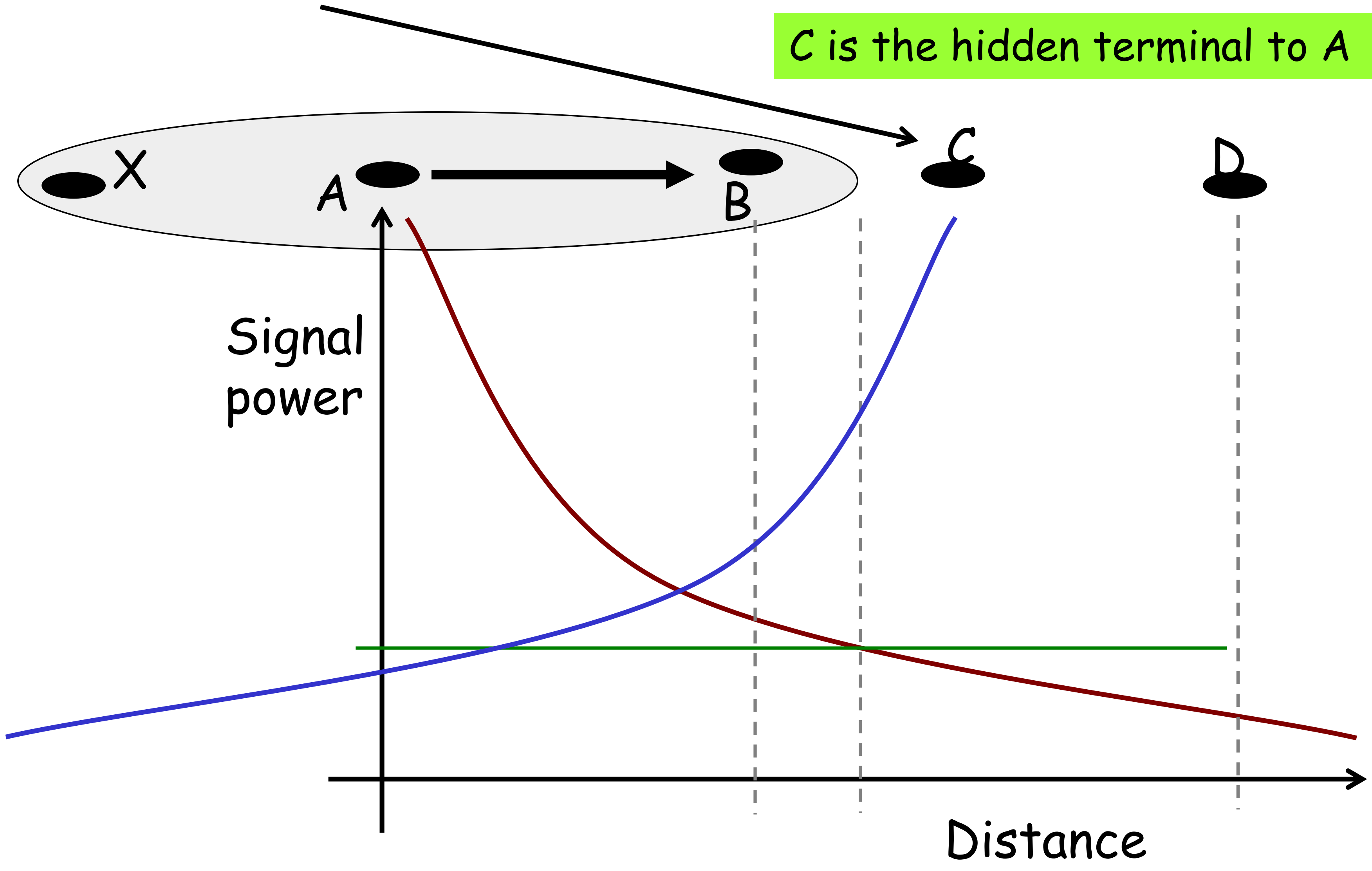
$$I_B^C = \frac{P^C_{transmit}}{d^a_{CB}}$$

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


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

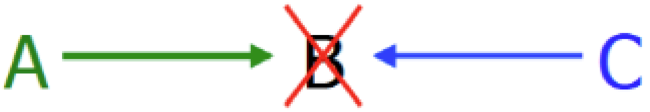
Important: C has not heard A, but can interfere at receiver B

C is the hidden terminal to A

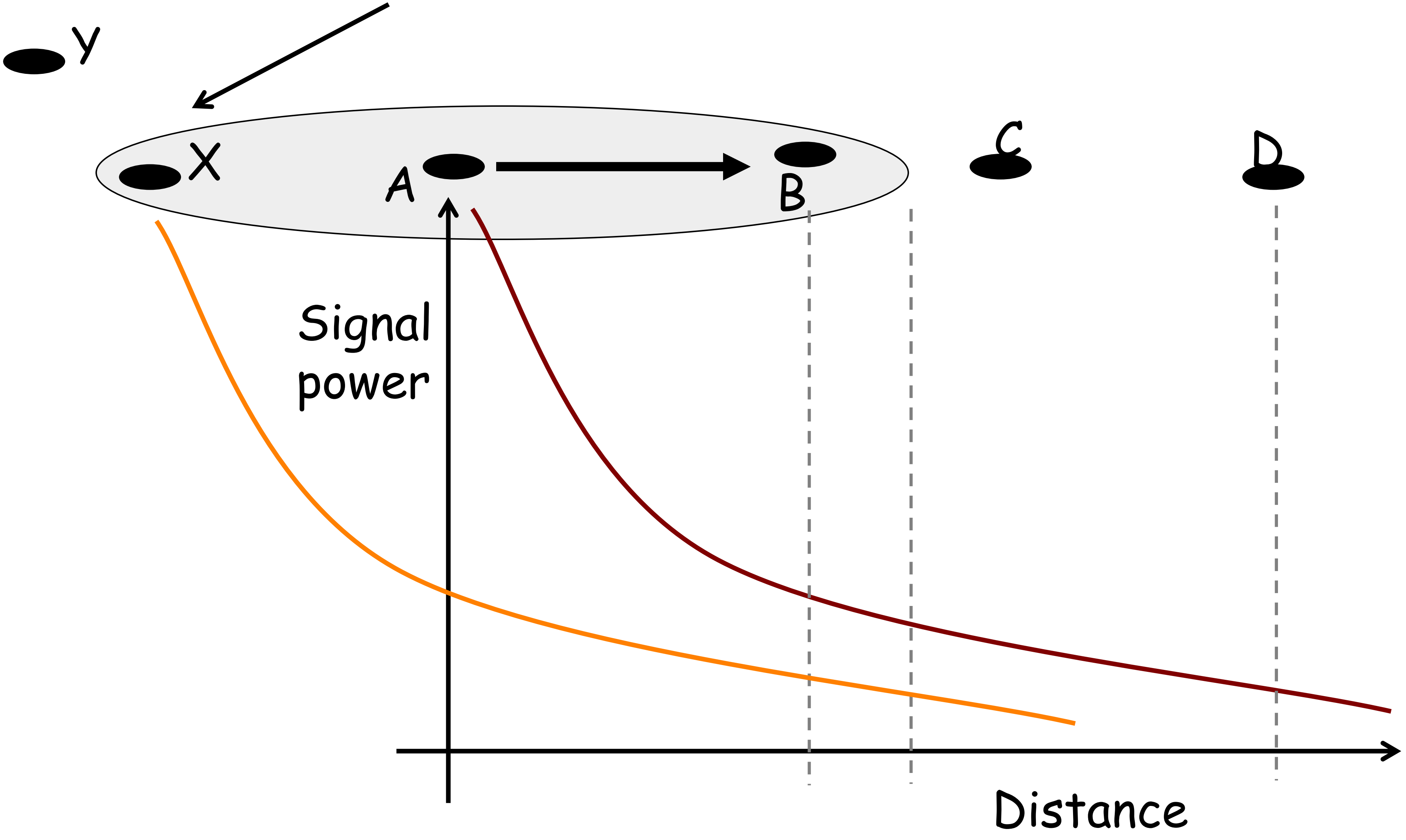


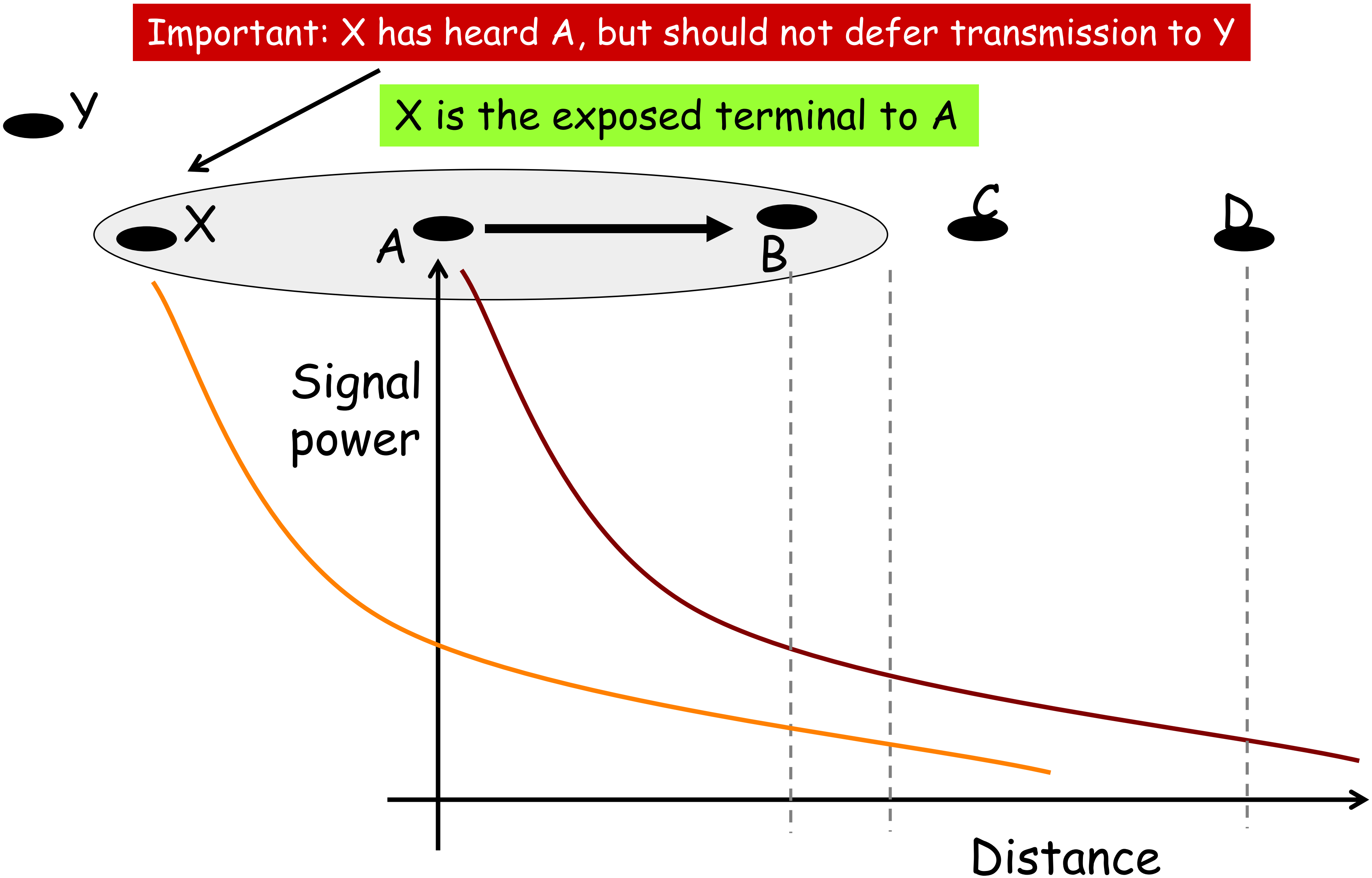
Hidden Terminal Problem

- Nodes placed a little less than one radio range apart.
- CSMA: nodes listen to channel to determine if it is idle or not.
- C can't hear A, so sends its packet while A sends, so that: collusion at B.
- **Carries Sense is not sufficient to detect all transmissions on wireless networks!**
- Note: Collusions are located at receiver.



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





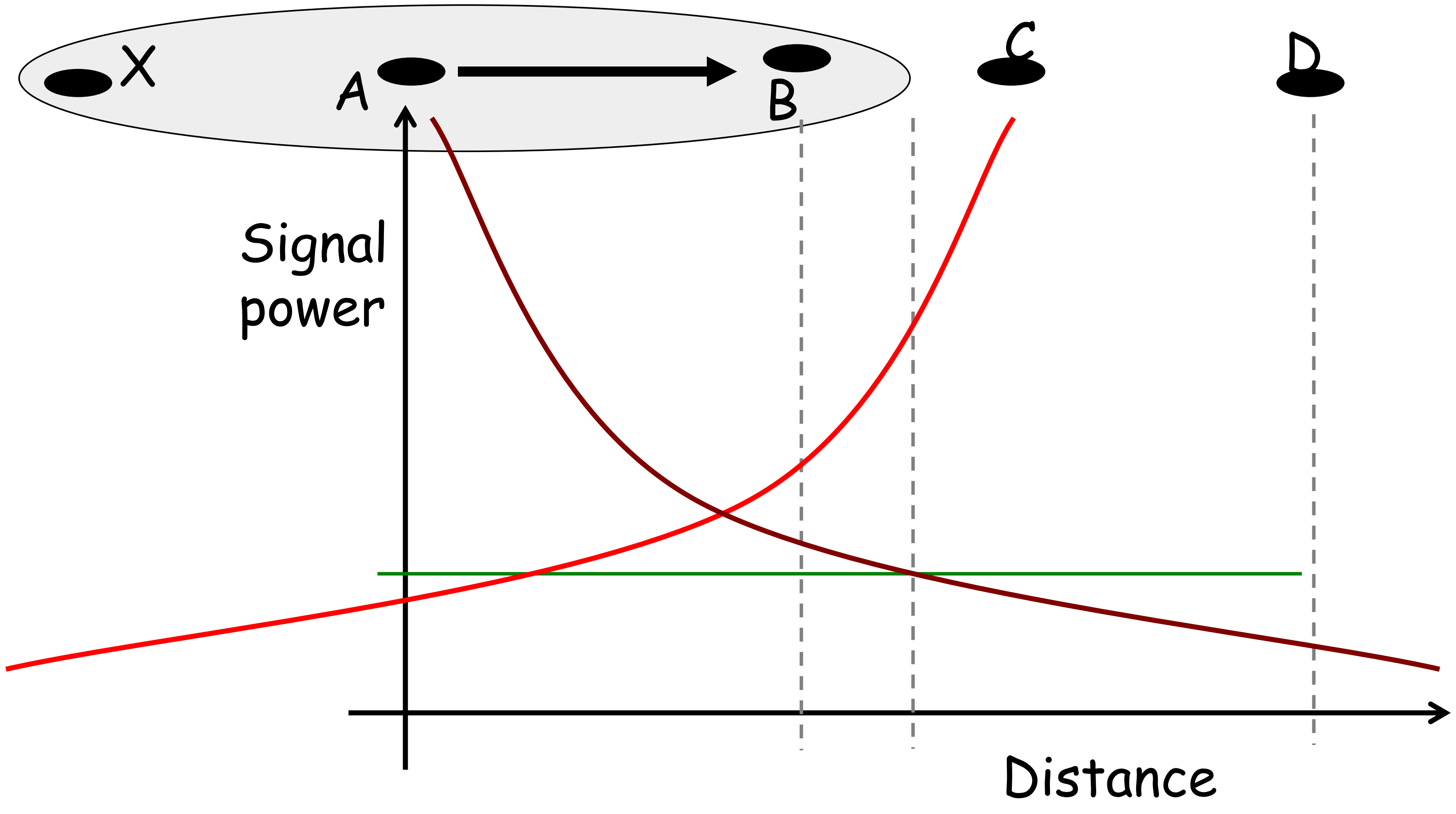
Important: X has heard A, but should not defer transmission to Y
X is the exposed terminal to A
Y
X
A
B
C
D
Signal power
Distance

Exposed Terminal Problem

- B sends to A; C sends to other than B.
- When C transmits, Does it cause a collusion at A?
- C cannot send packet while B transmits to A.
- Same Point: Collusions are located at receiver.
- One solution : directional anntennas instead of omnidirectional: **Why does this help and it is hard?**
- Simpler sc … nedium state to determine …

Exposed Terminal Problem:

How to prevent C from trasmitting?



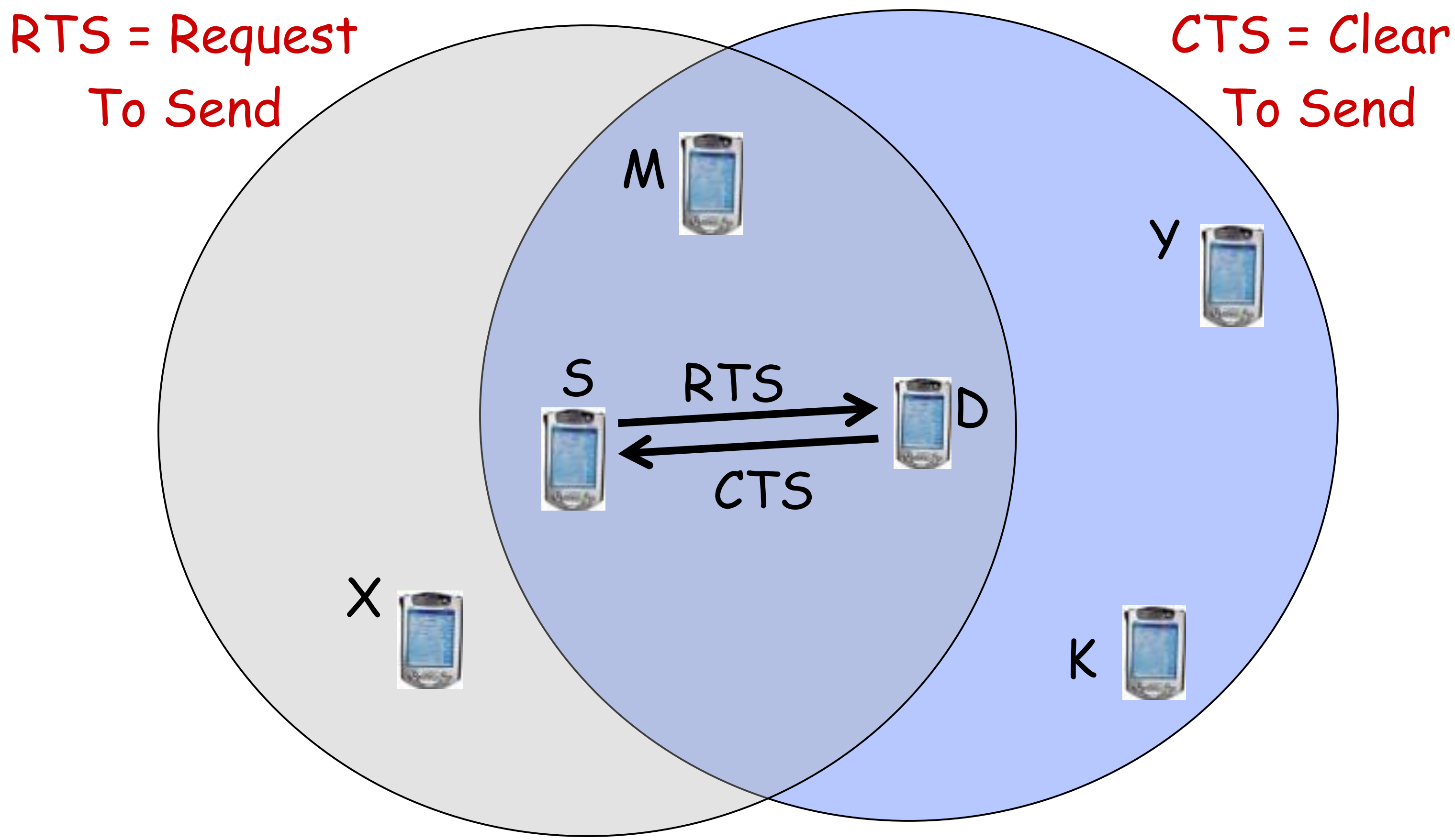
History of MACA, MACAW & 802.11

- ✓ Wireless MAC proved to be non-trivial

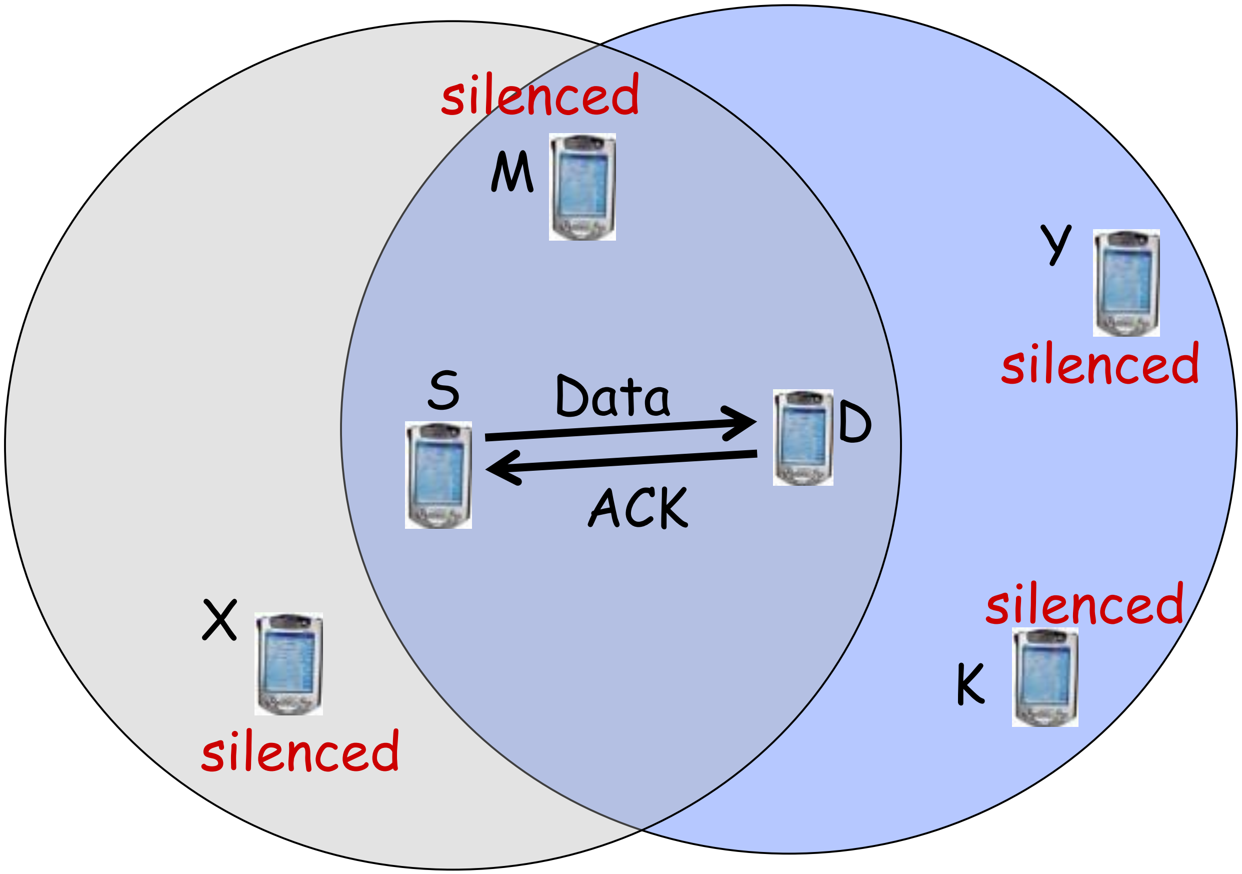
- ✓ 1992 - research by Karn (MACA)
- ✓ 1994 - research by Bhargavan (MACAW)

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

IEEE 802.11 Details



IEEE 802.11 Details



IEEE 802.11 Steps

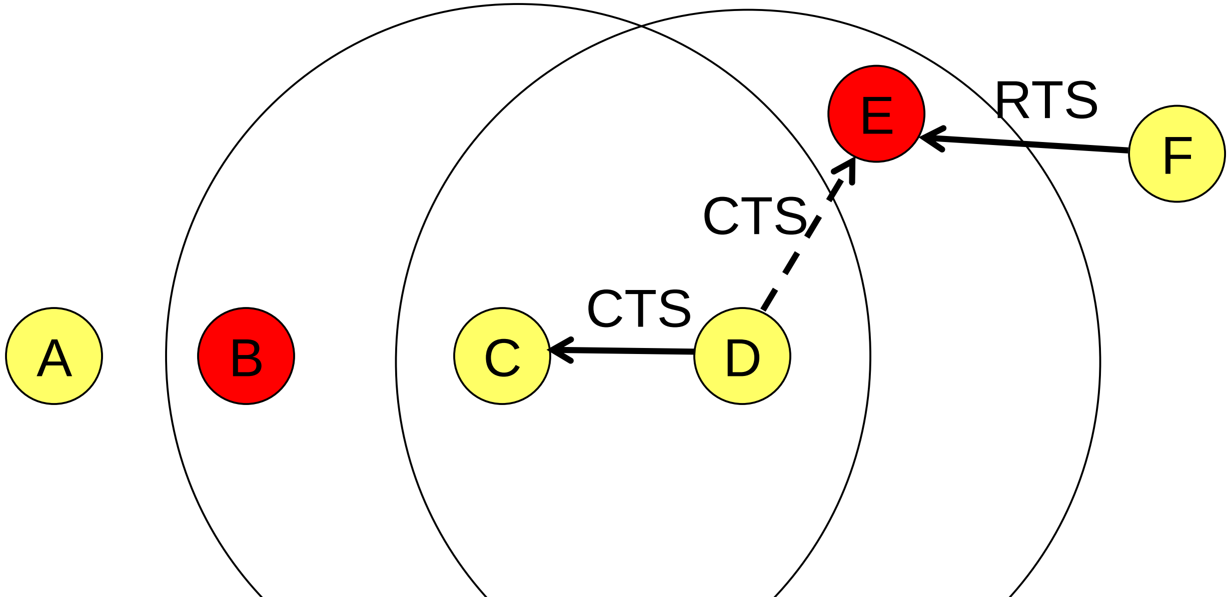
- All backlogged nodes choose a random number
- Each station counts down.
  - Continue carrier sensing while counting down
  - Once carrier busy, freeze countdown
- Who reaches ZERO sends RTS
  - Neighbors freeze countdown, decode RTS

IEEE 802.11 Steps

- Receiver replies with CTS
- Tx sends DATA, Rx informs with ACK
- When RTS or DATA collides (i.e., no CTS/ACK returns)
  - Indicates collision
  - RTS chooses a new random countdown number

RTS/CTS

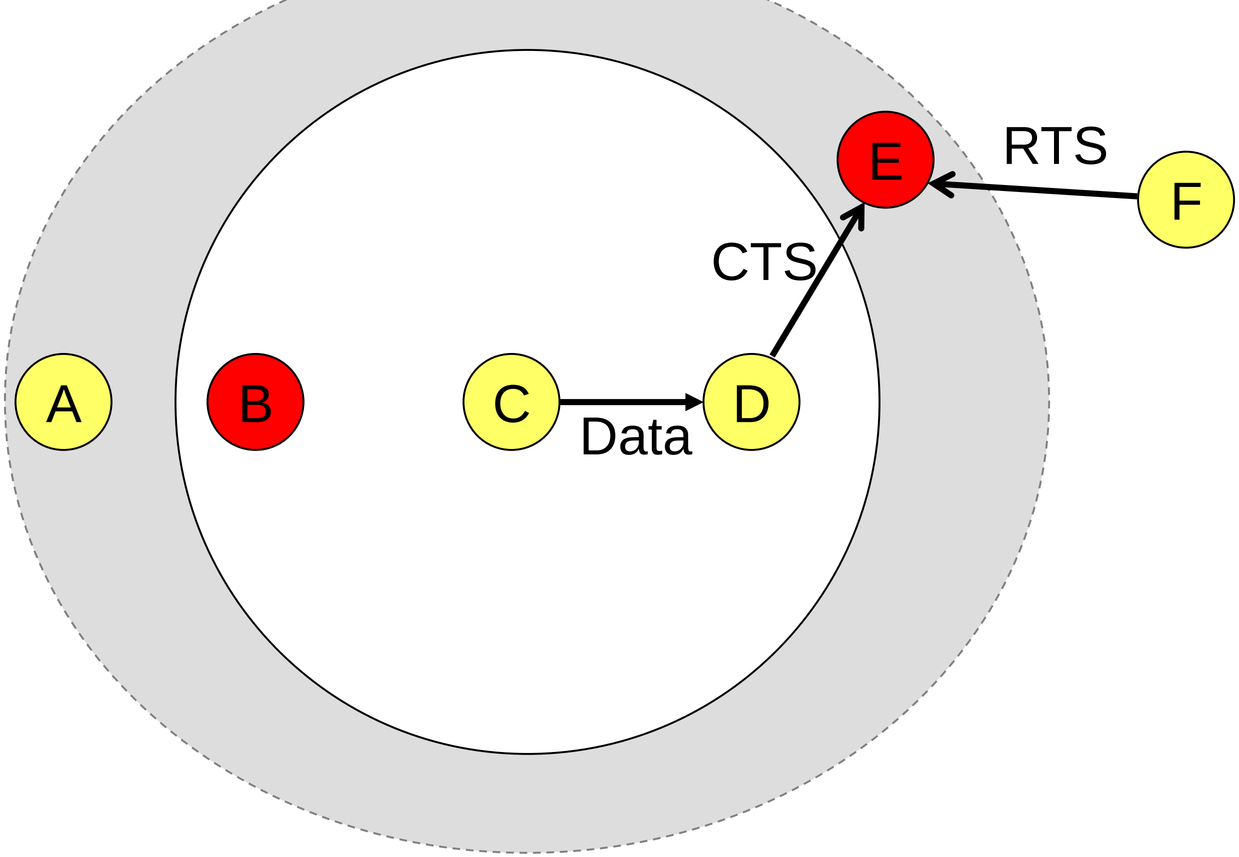
- **Does it solve hidden terminals ?**
  - Assuming carrier sensing zone = communication zone



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

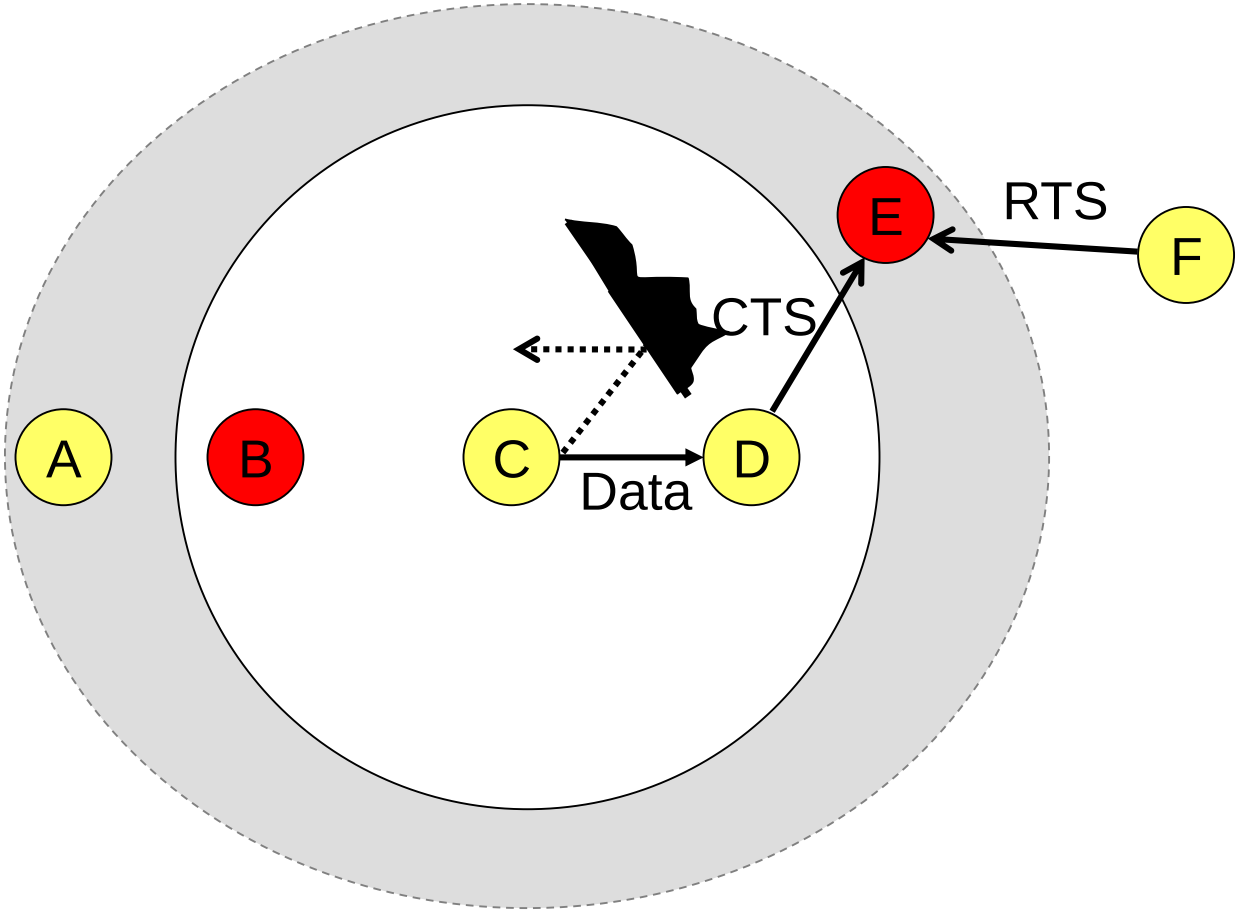
Hidden Terminal Problem

- **How about increasing carrier sense range ??**
  - E will defer [illegible] carrier → no collision !!!



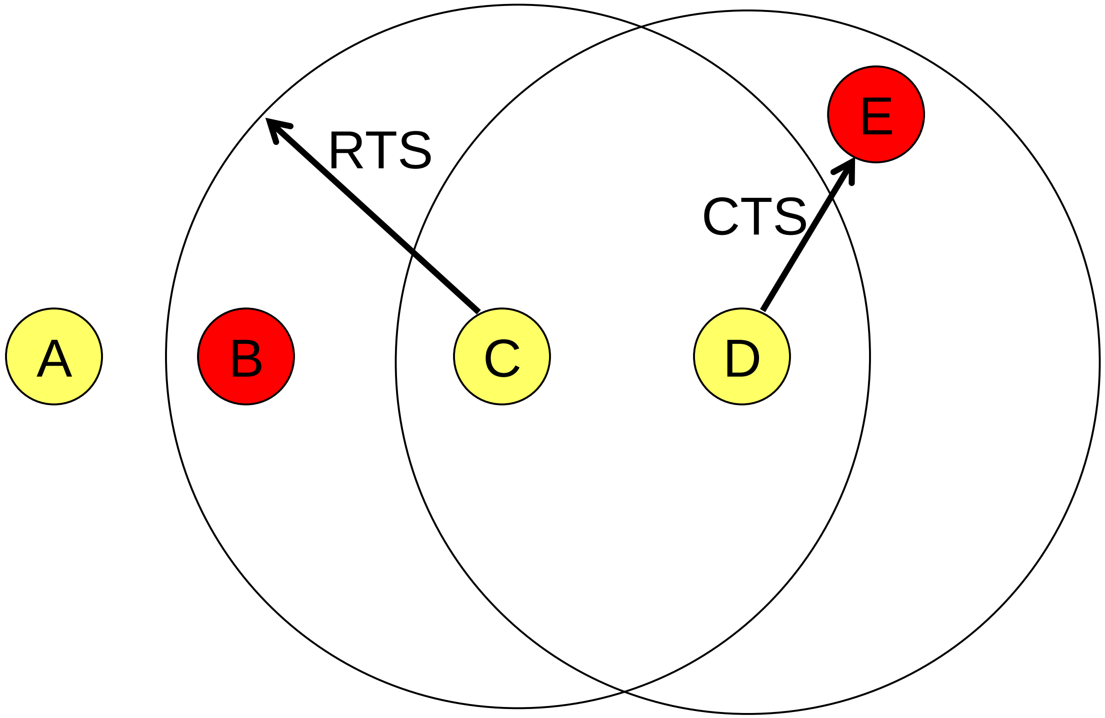
Hidden Terminal Problem

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



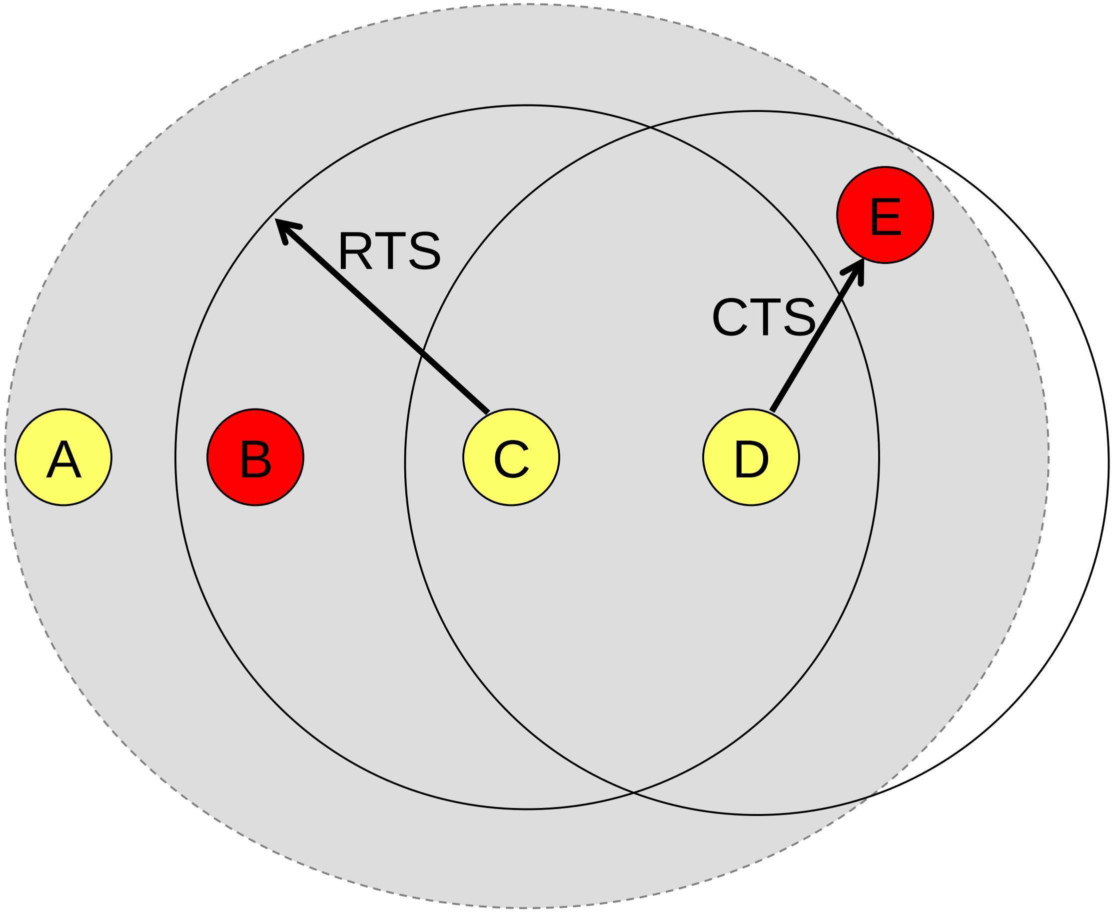
Exposed Terminal

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

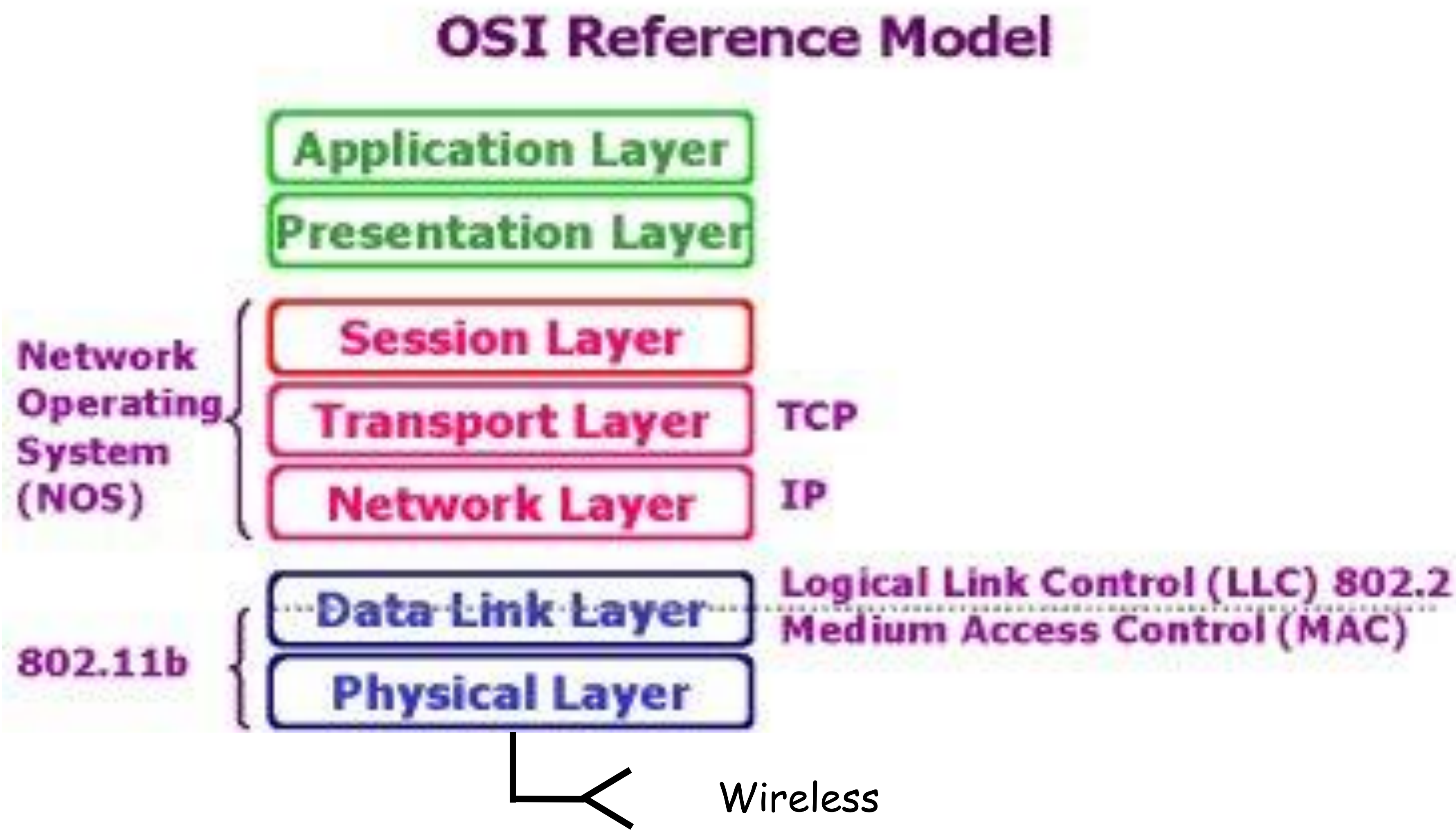


Exposed Terminal

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

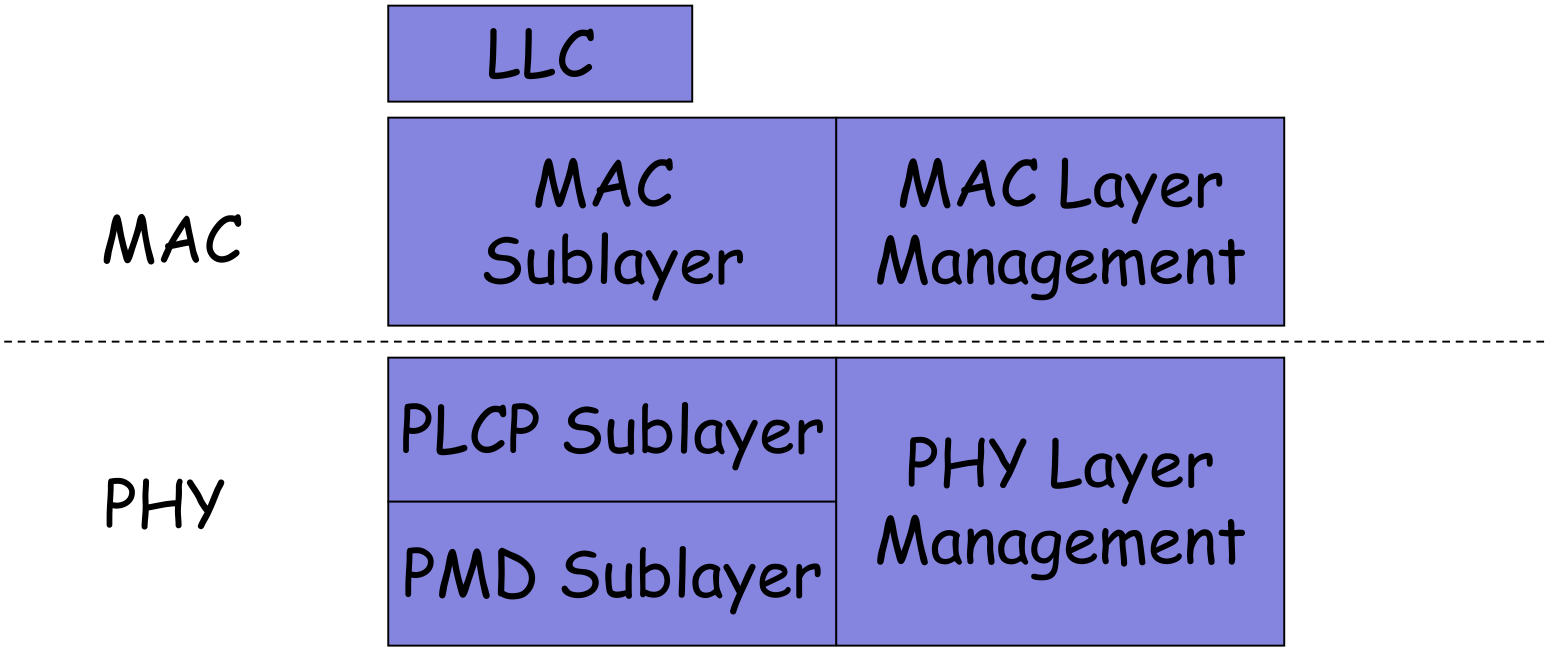


IEEE 802.11 in OSI Model



802.11 in OSI Scope & Modules

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

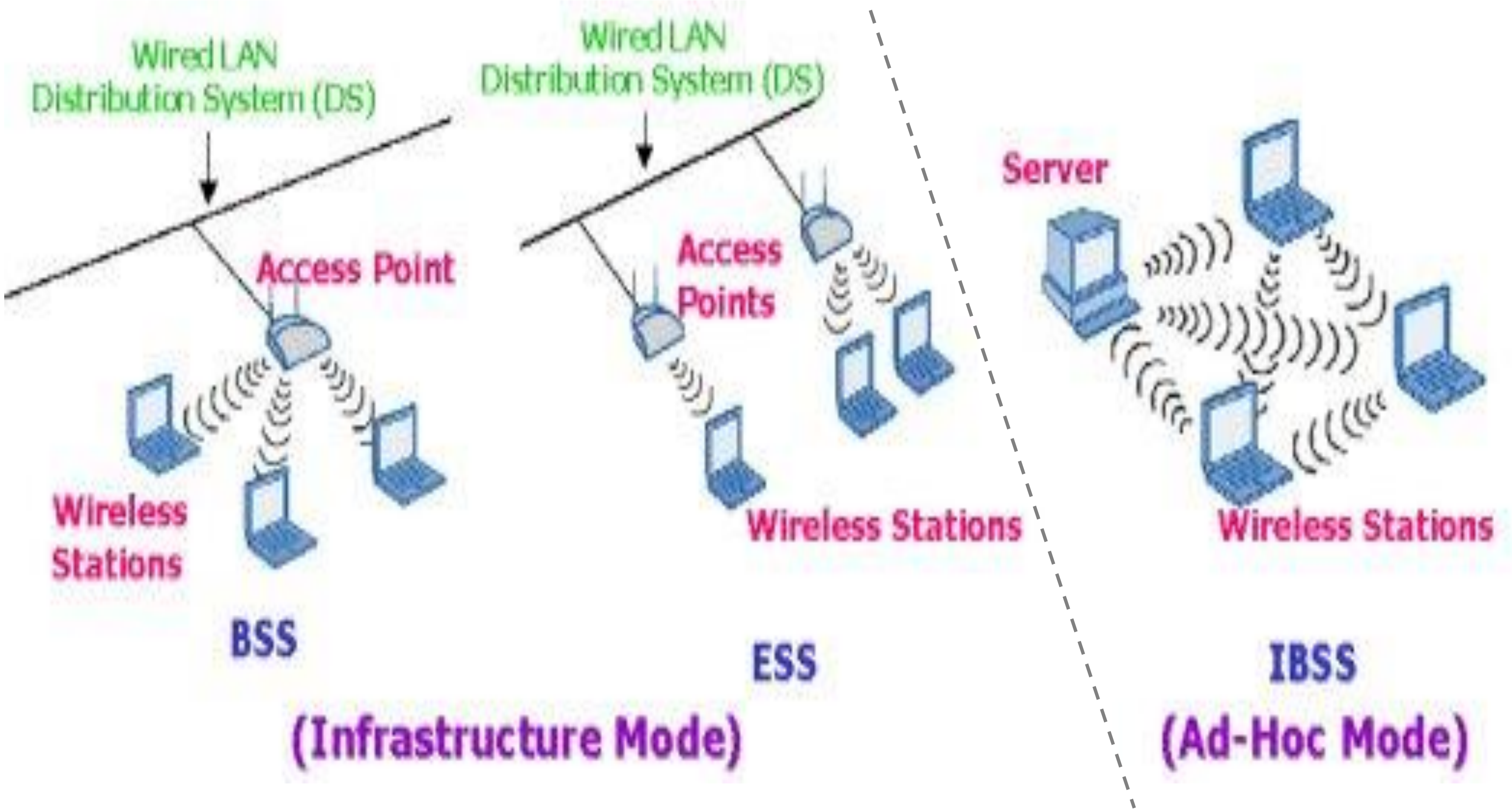


802.11 Applications

- 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

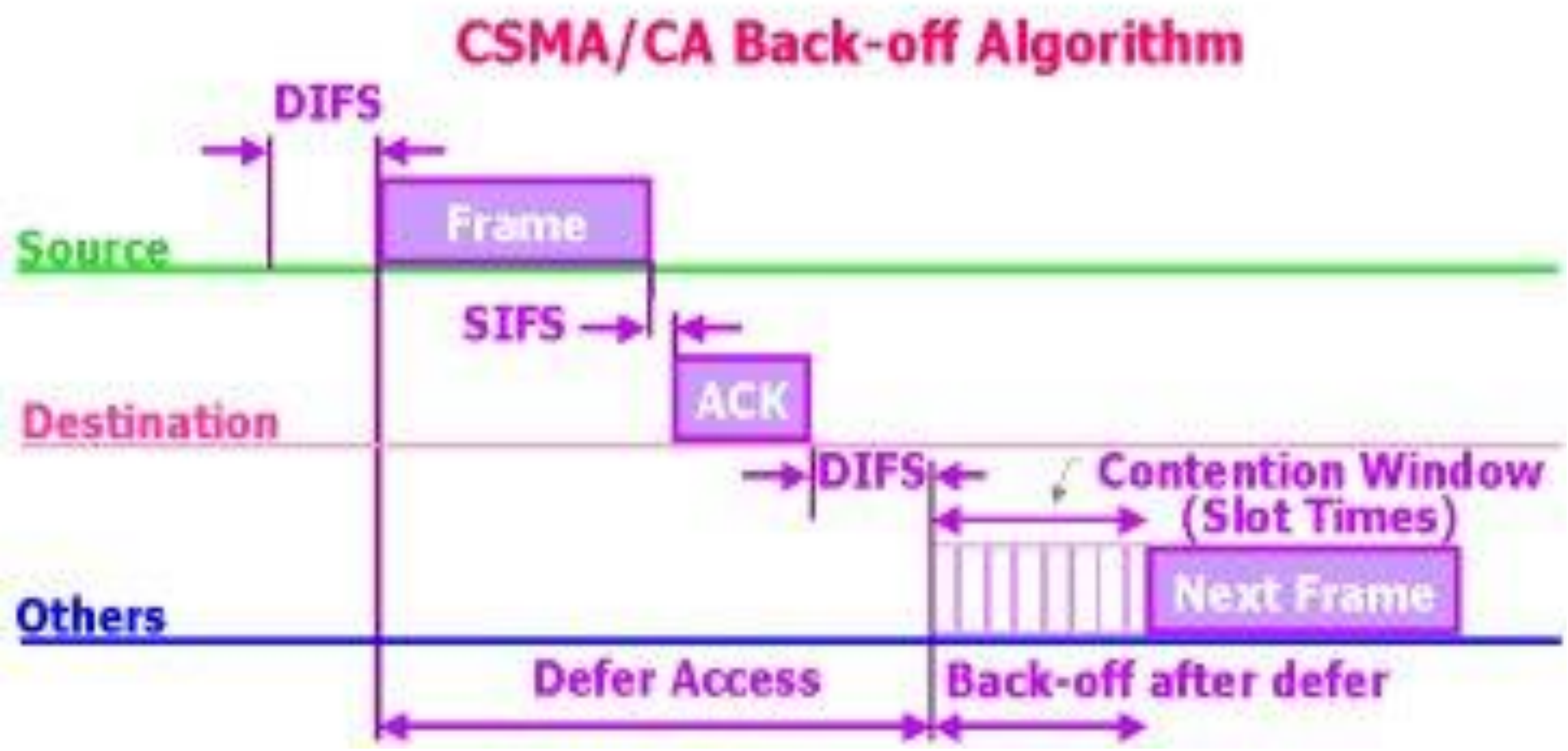
- **Optional RTS/CTS offers Virtual Carrier Sensing**
  - RTS/CTS includes duration of immediate dialog
  - Addresses hidden terminal problems

802.11 MAC

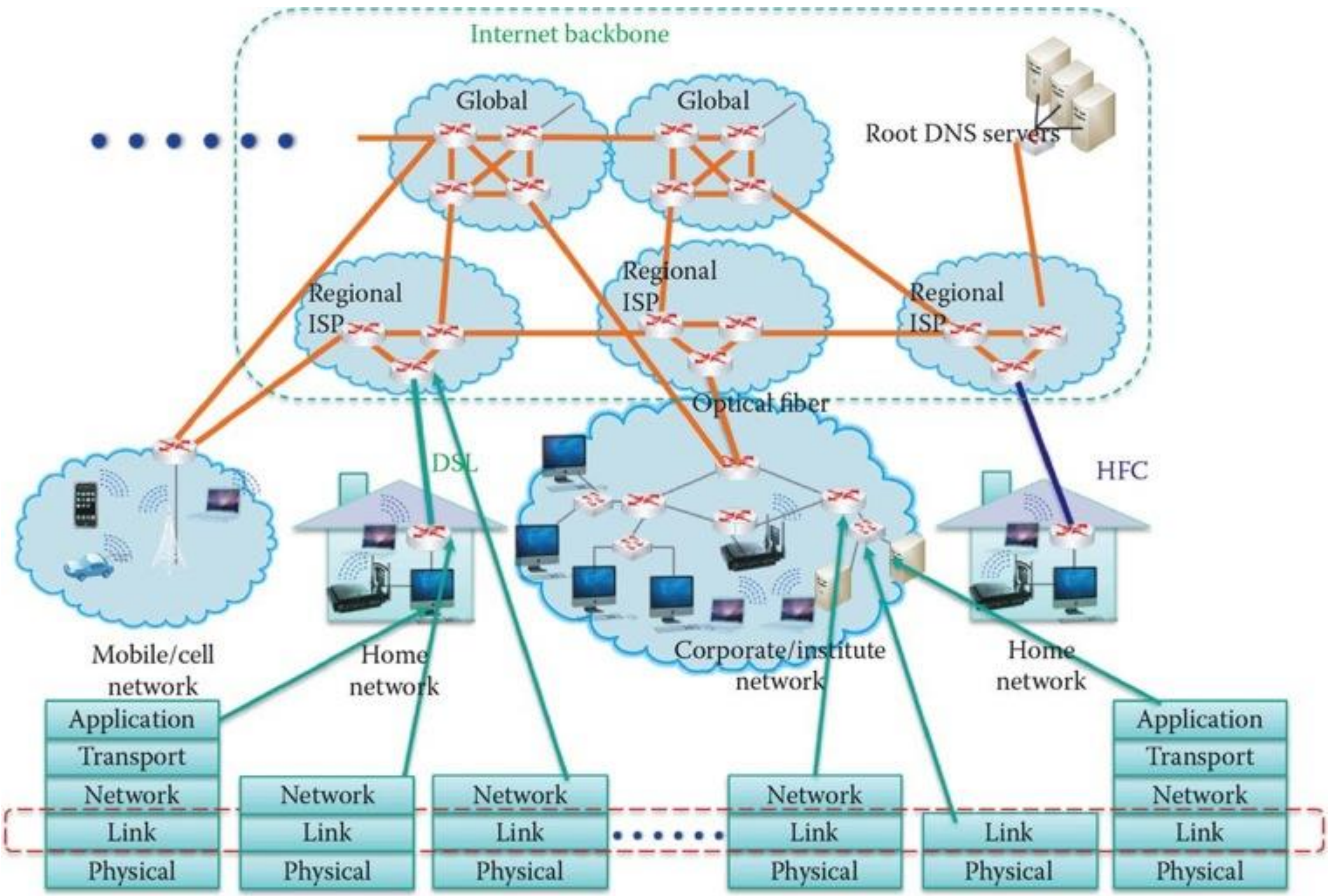

Hidden-Node Problem
Access Point
P
A
B
C
Wireless Stations


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

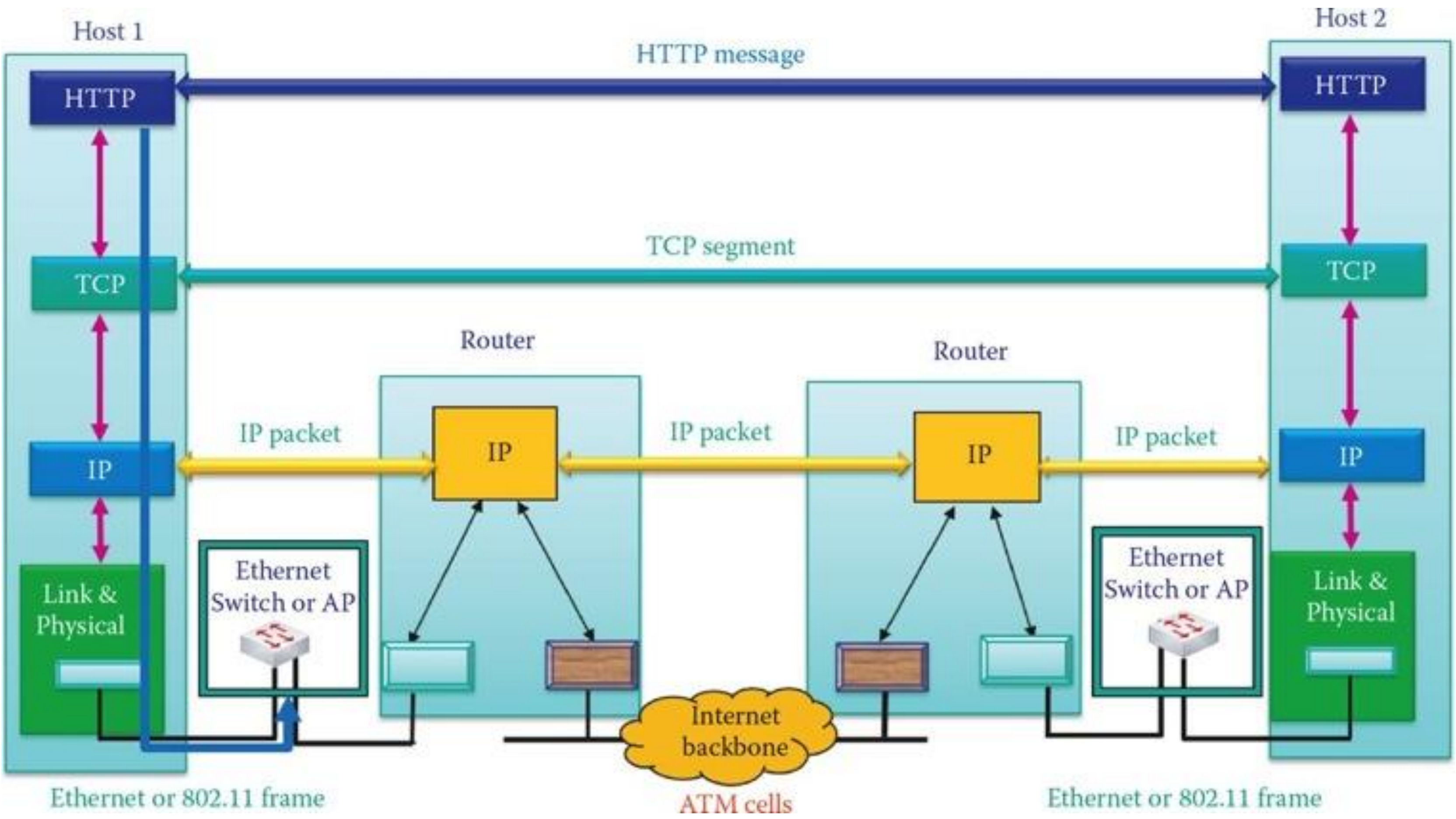
802.11 Physical Carrier Sense & Backoff



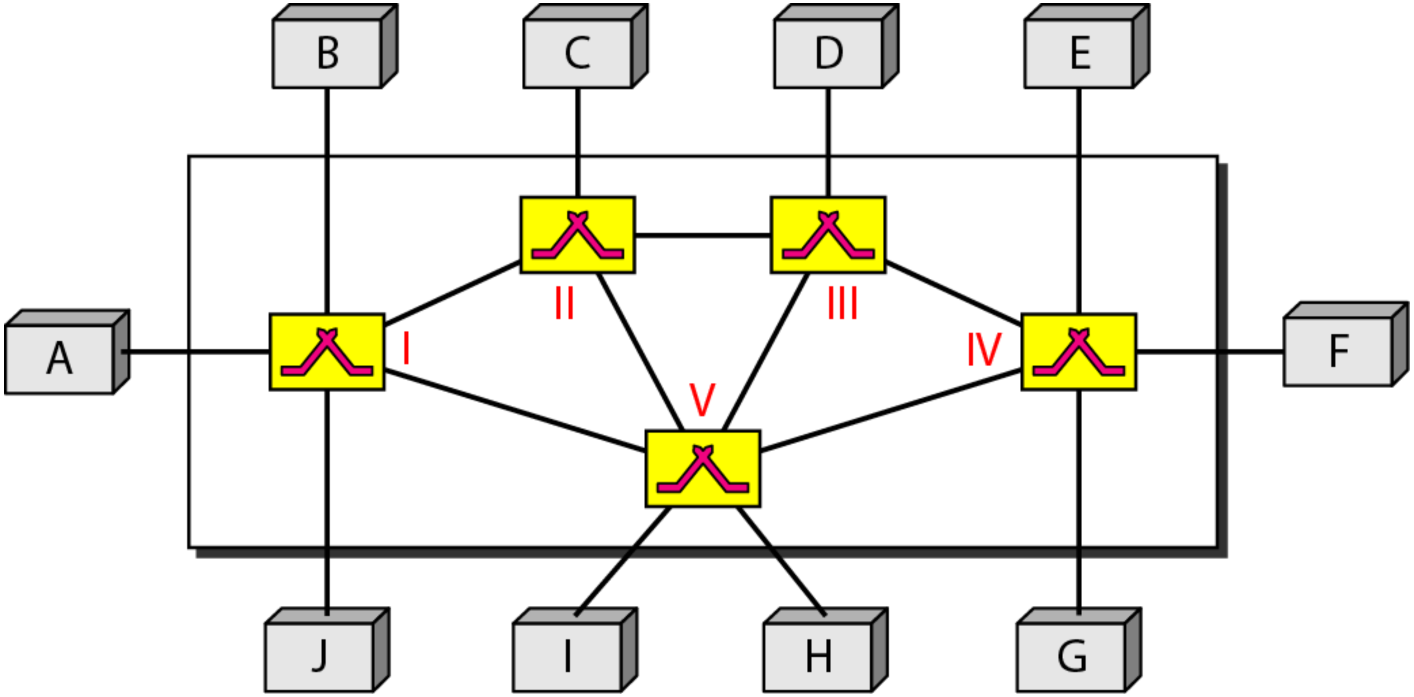
Overall Internet Architecture



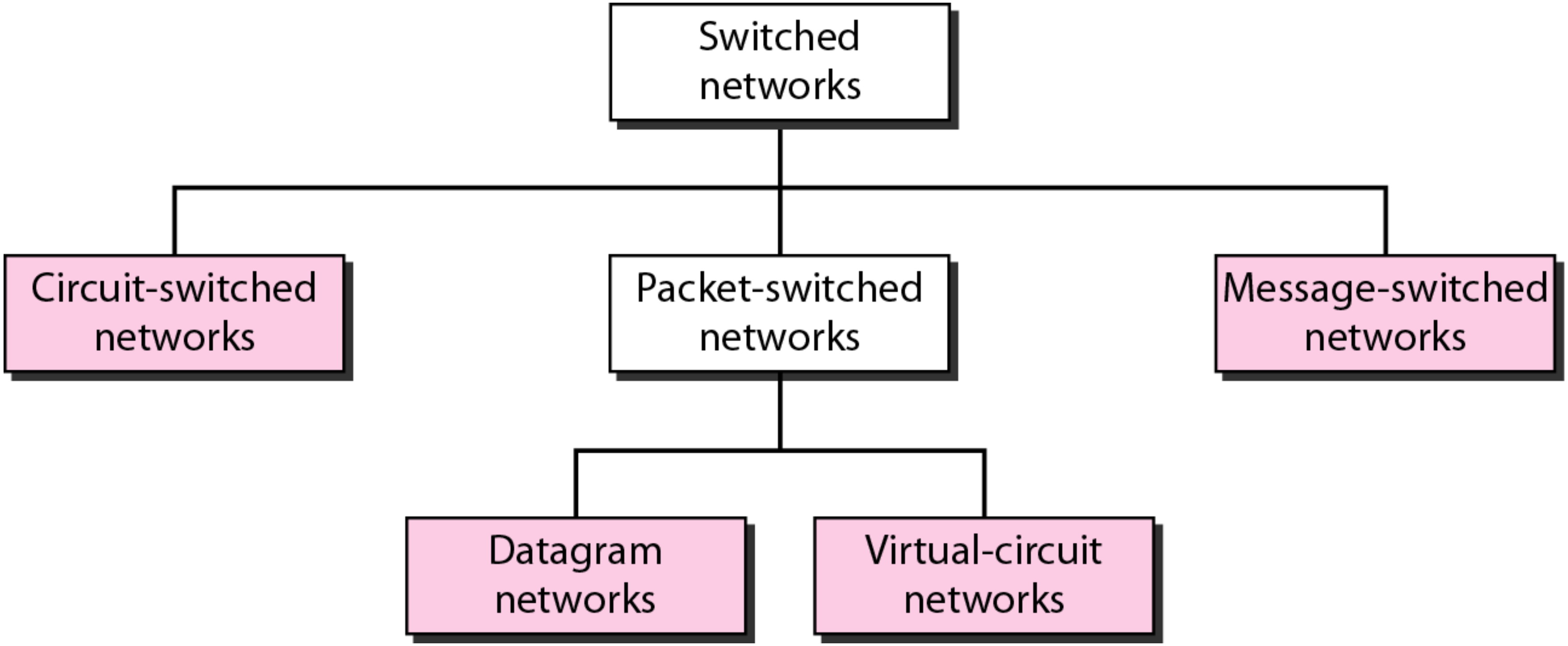
MAC Architecture



Switched Network



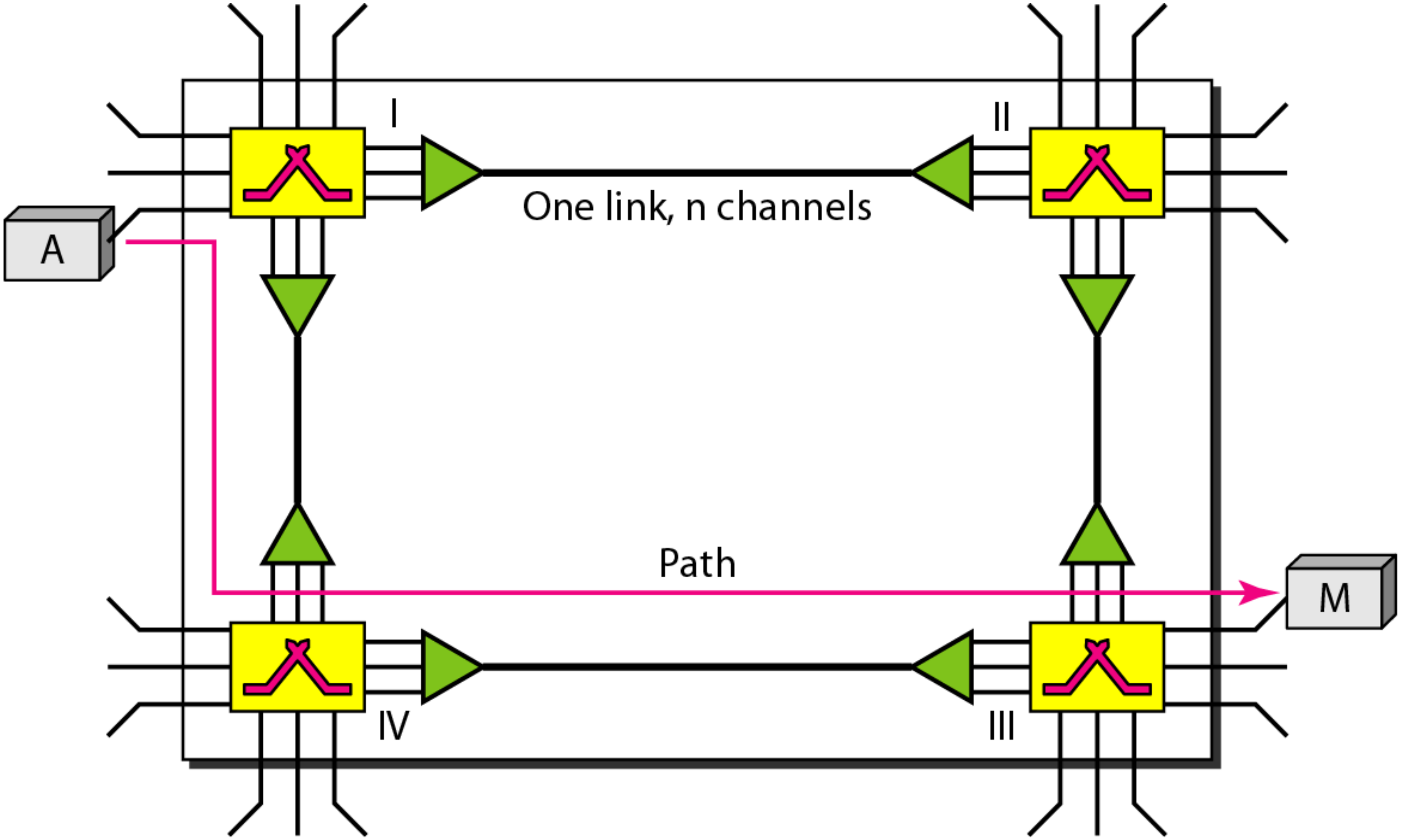
Taxonomy of switched networks



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.

Circuit Switched Networks

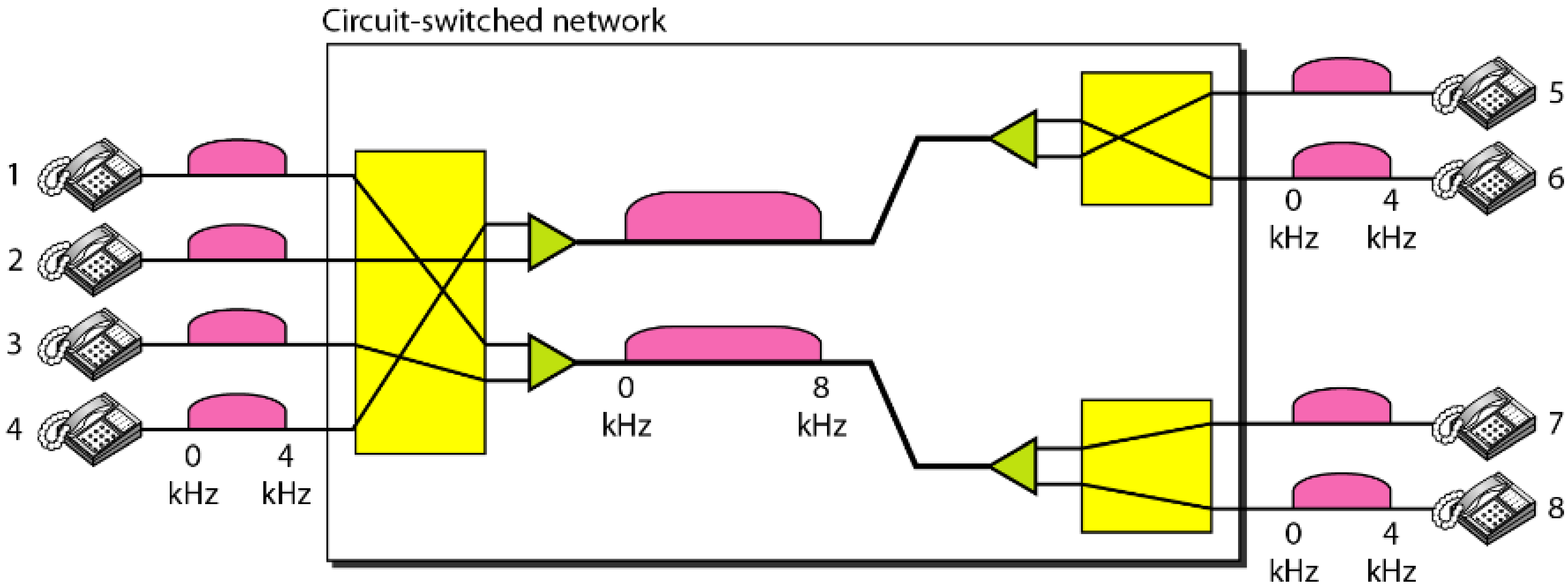


Example

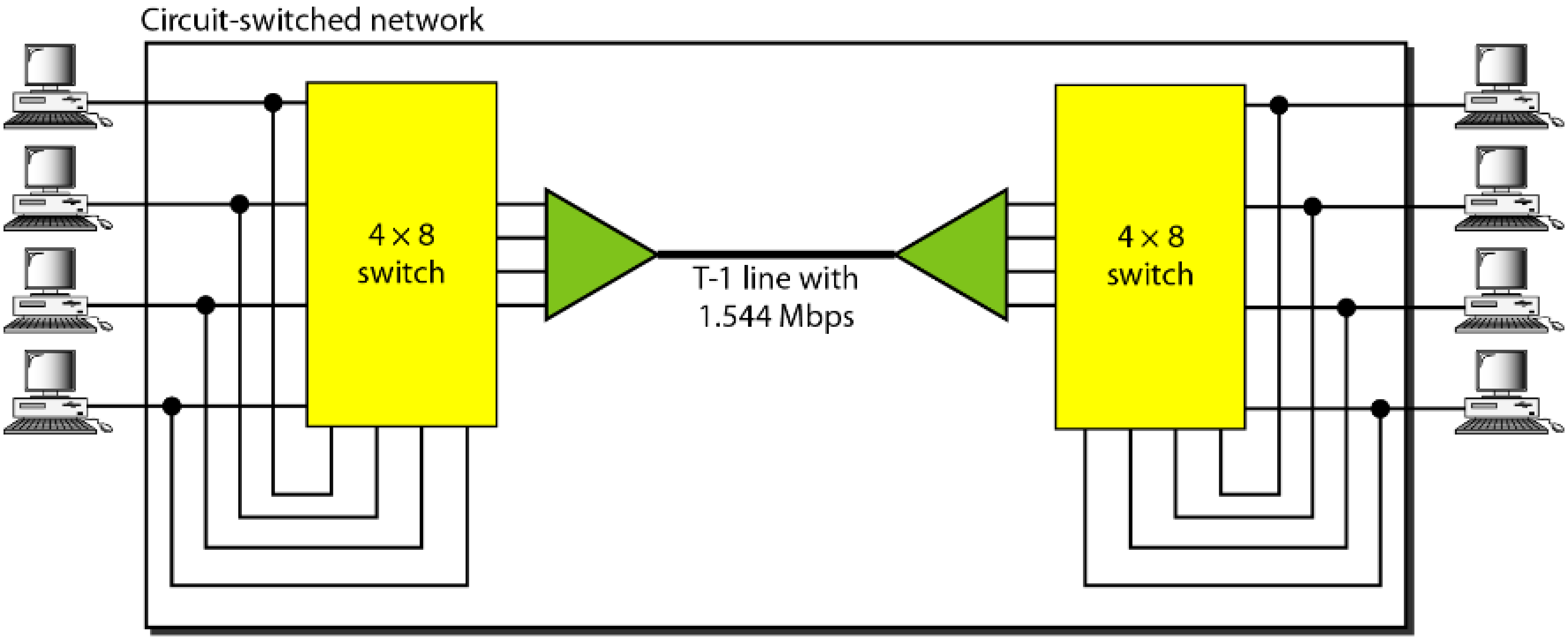
As a trivial example, let us use a circuit-switched network to connect eight telephones in a small area. Communication is through 4-kHz voice channels. We assume that each link uses FDM to connect a maximum of two voice channels. The bandwidth of each link is then 8 kHz.

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.

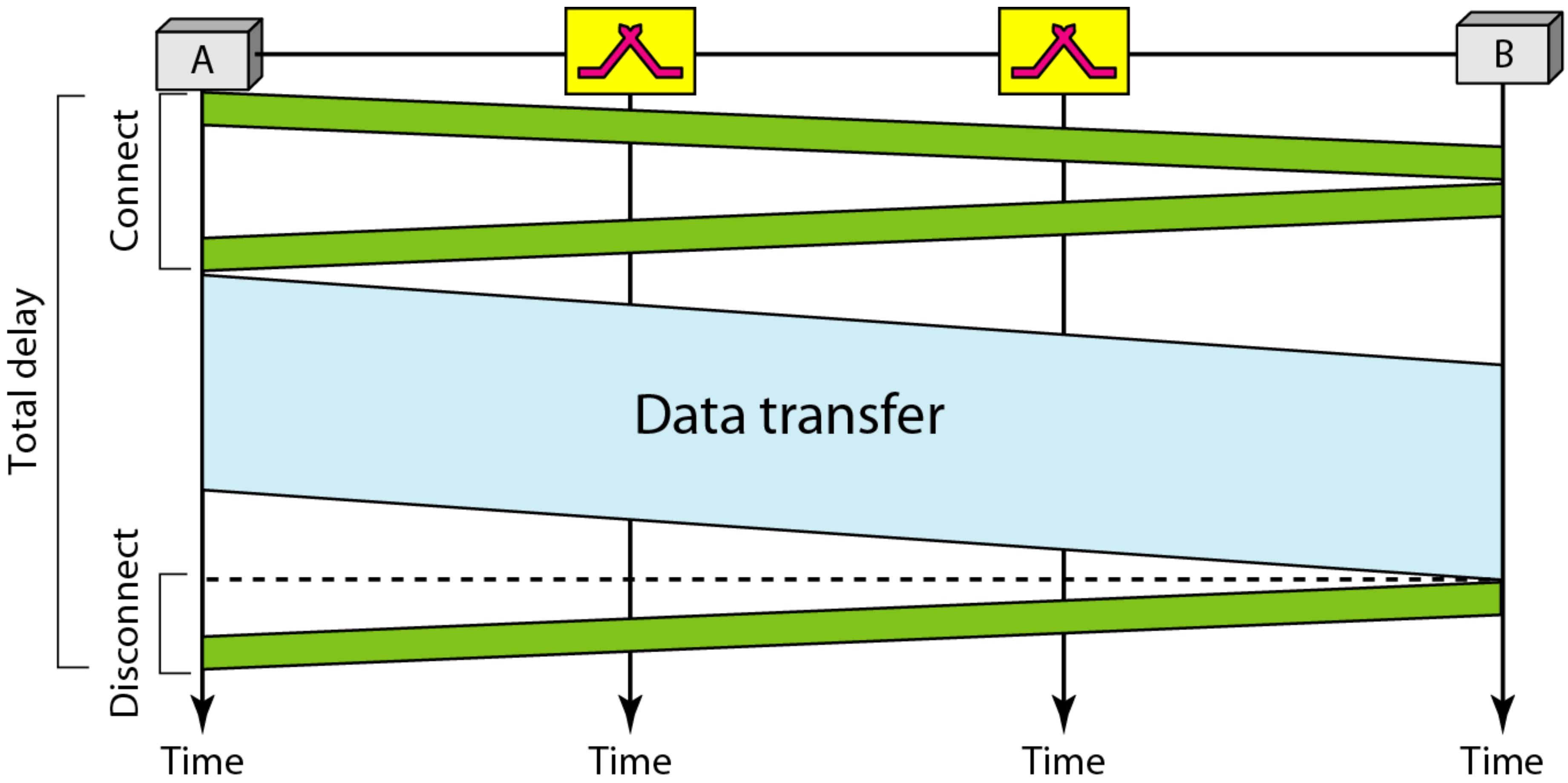
Circuit Switched Network 1



Circuit Switched Network 2



Delay in Circuit Switched Network



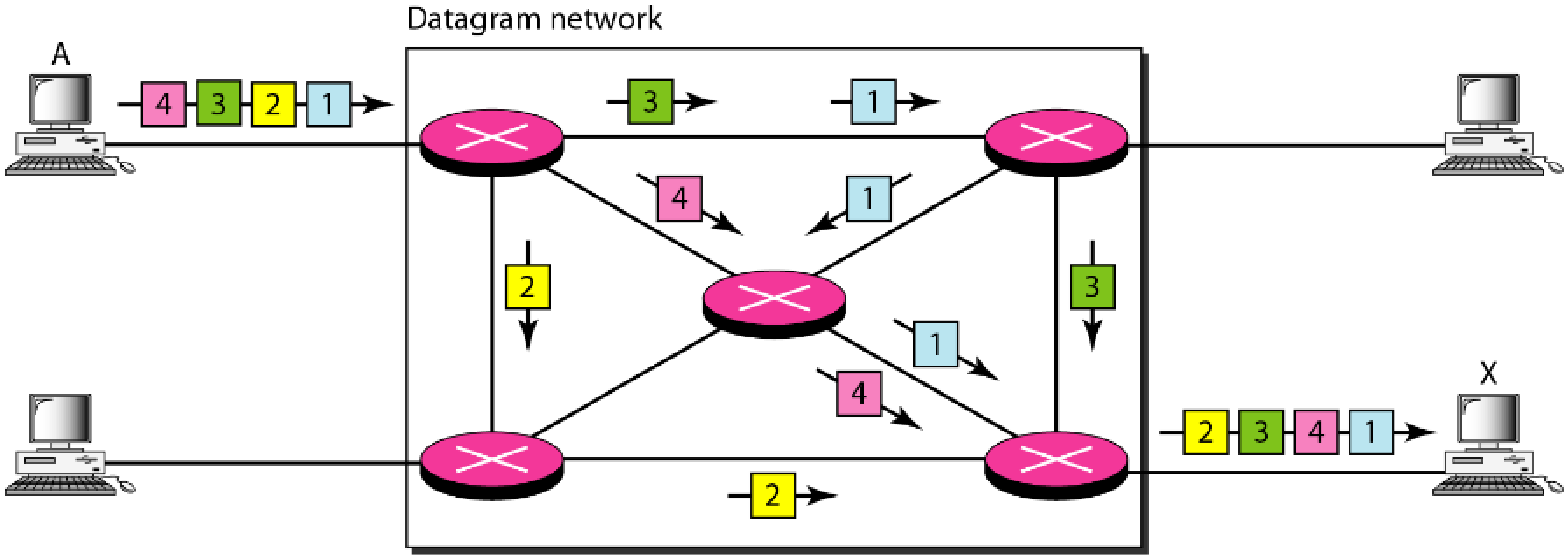
Datagram Networks

- ✓ 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.

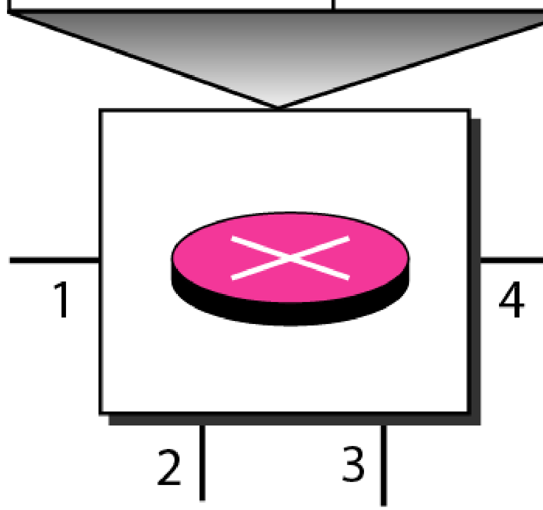
- ✓ The size of the packet is determined by the network and the governing protocol.

A Datagram Network with four switches (routers)



Routing table in a datagram Network

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

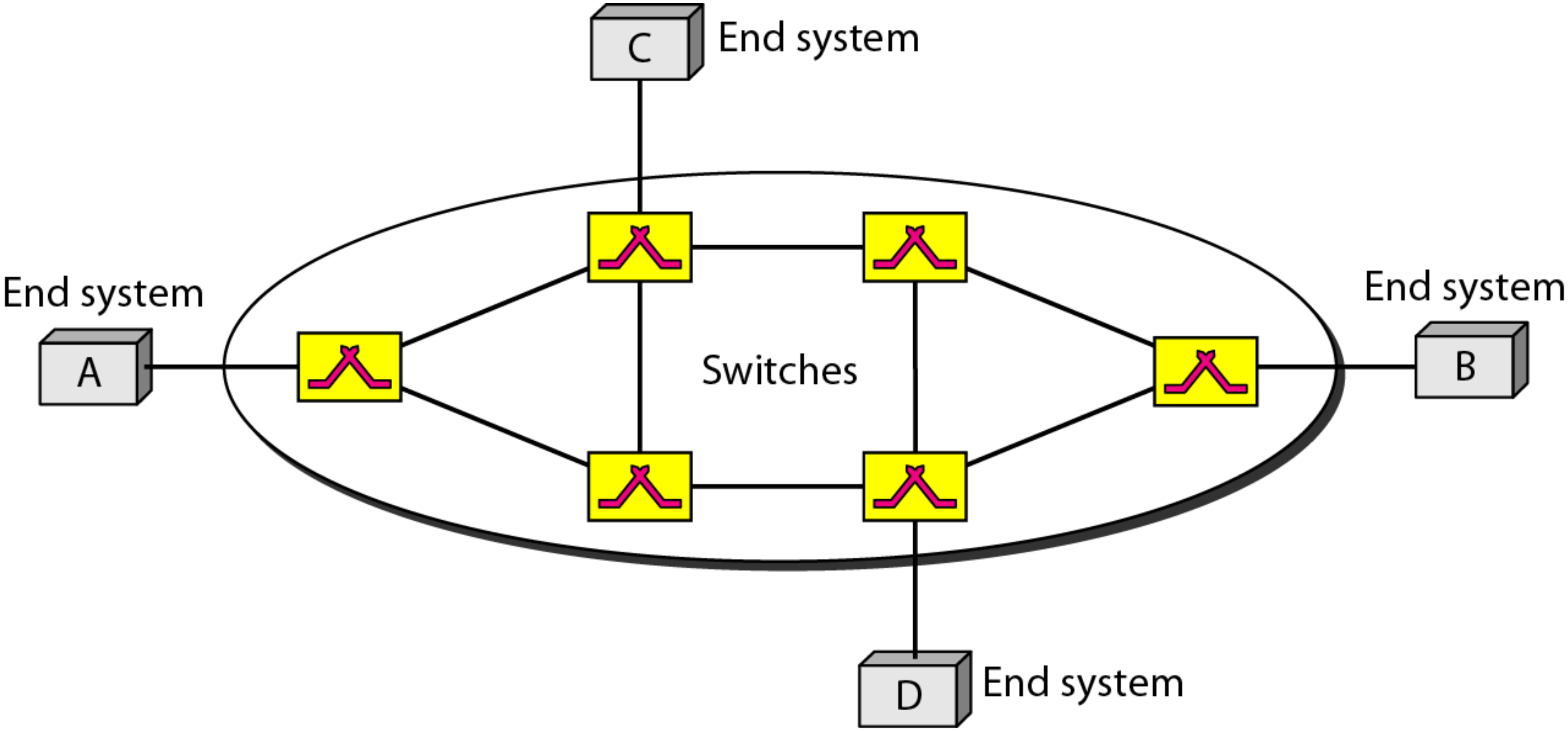


Virtual – Circuit Networks

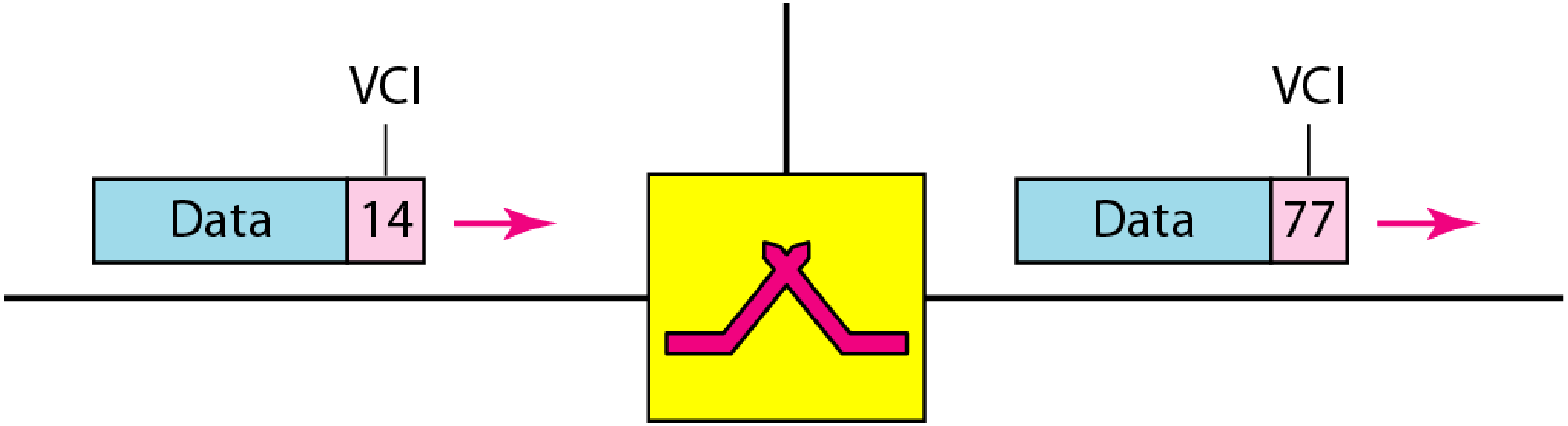
- ✓ A virtual-circuit network is a cross between a circuit-switched network and a datagram network.

- ✓ It has some characteristics of both.

Virtual – Circuit Networks

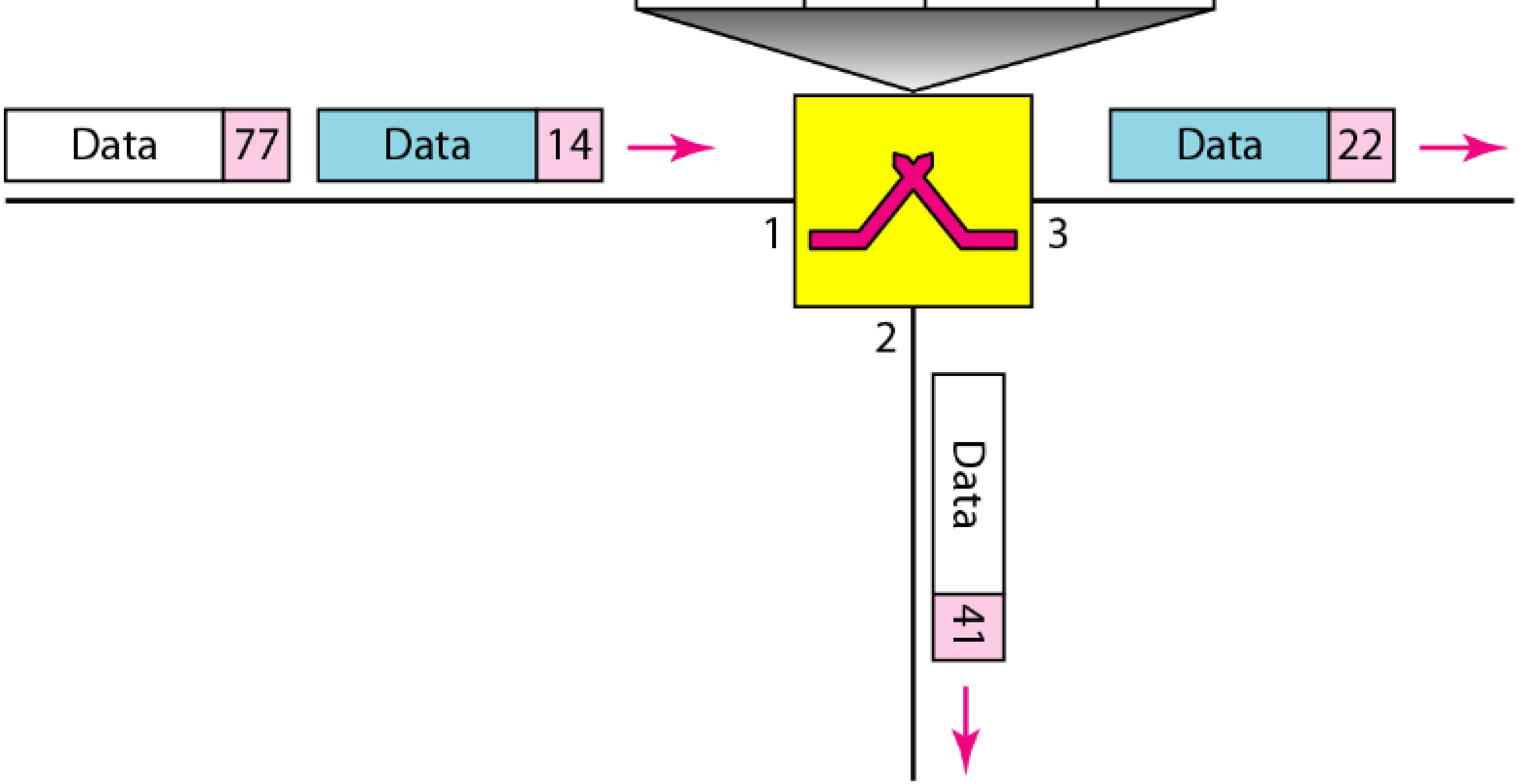


Virtual – Circuit Identifier

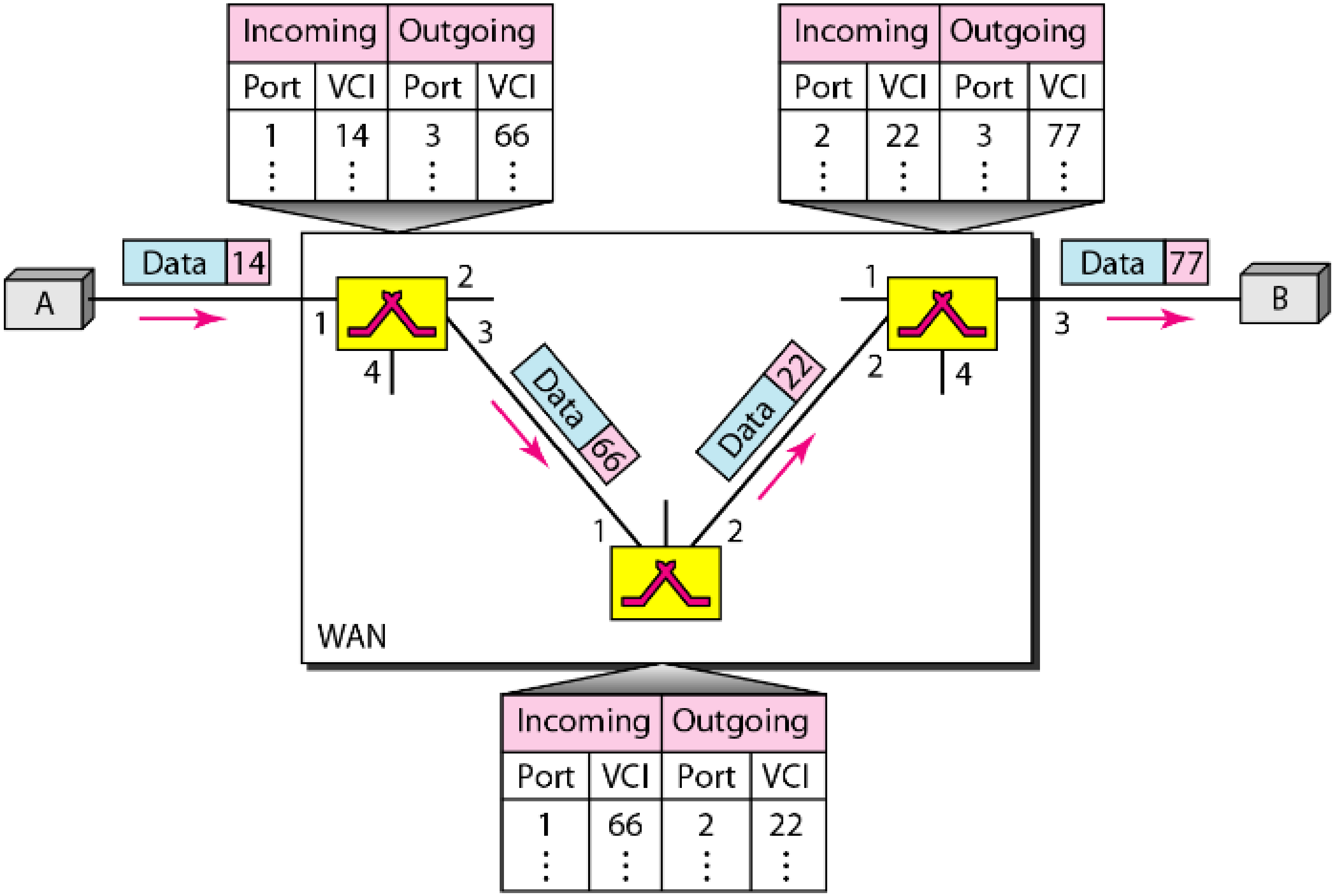


Switch and tables in a virtual-circuit network

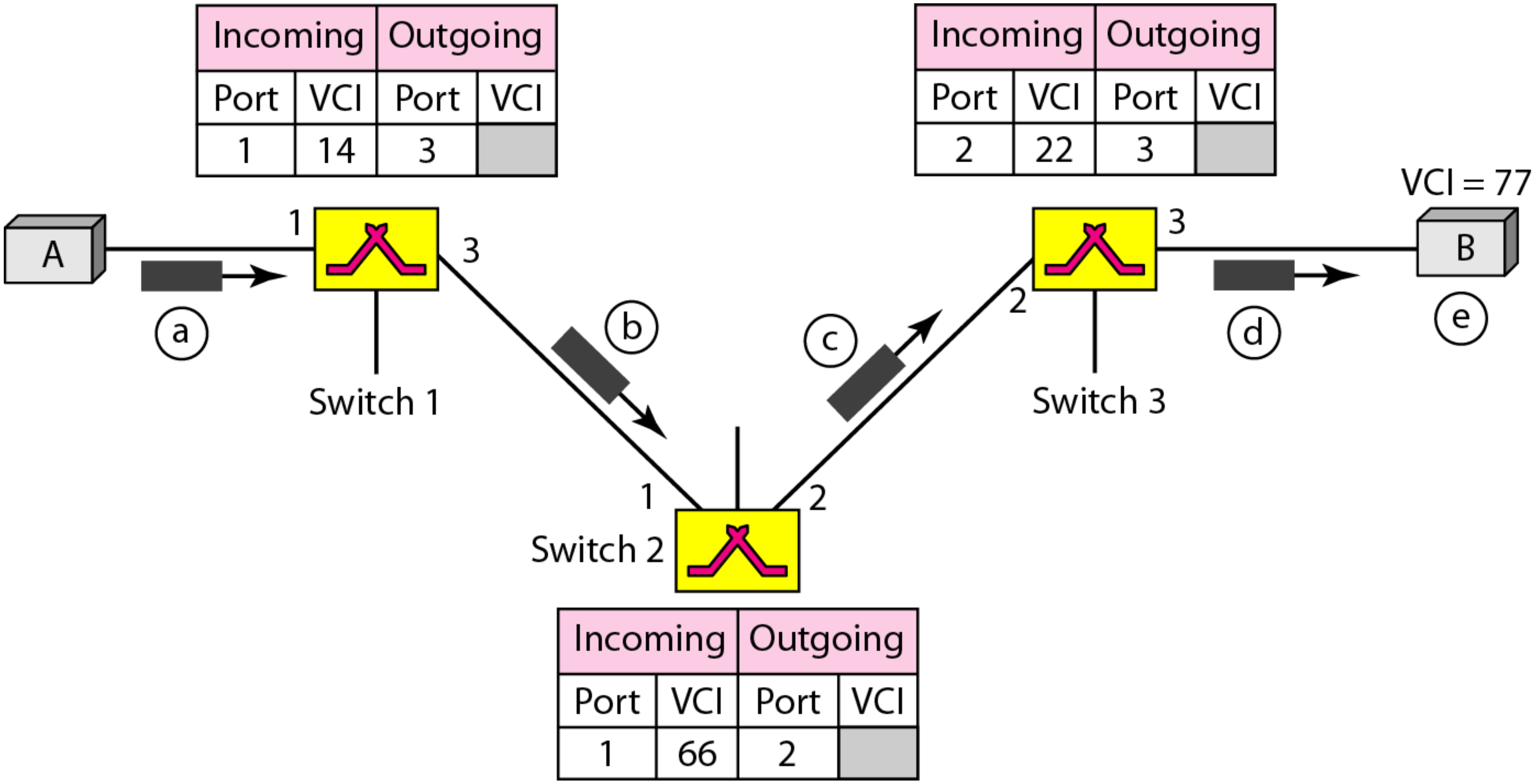
Incoming		Outgoing	
Port	VCI	Port	VCI
1	14	3	22
1	77	2	41



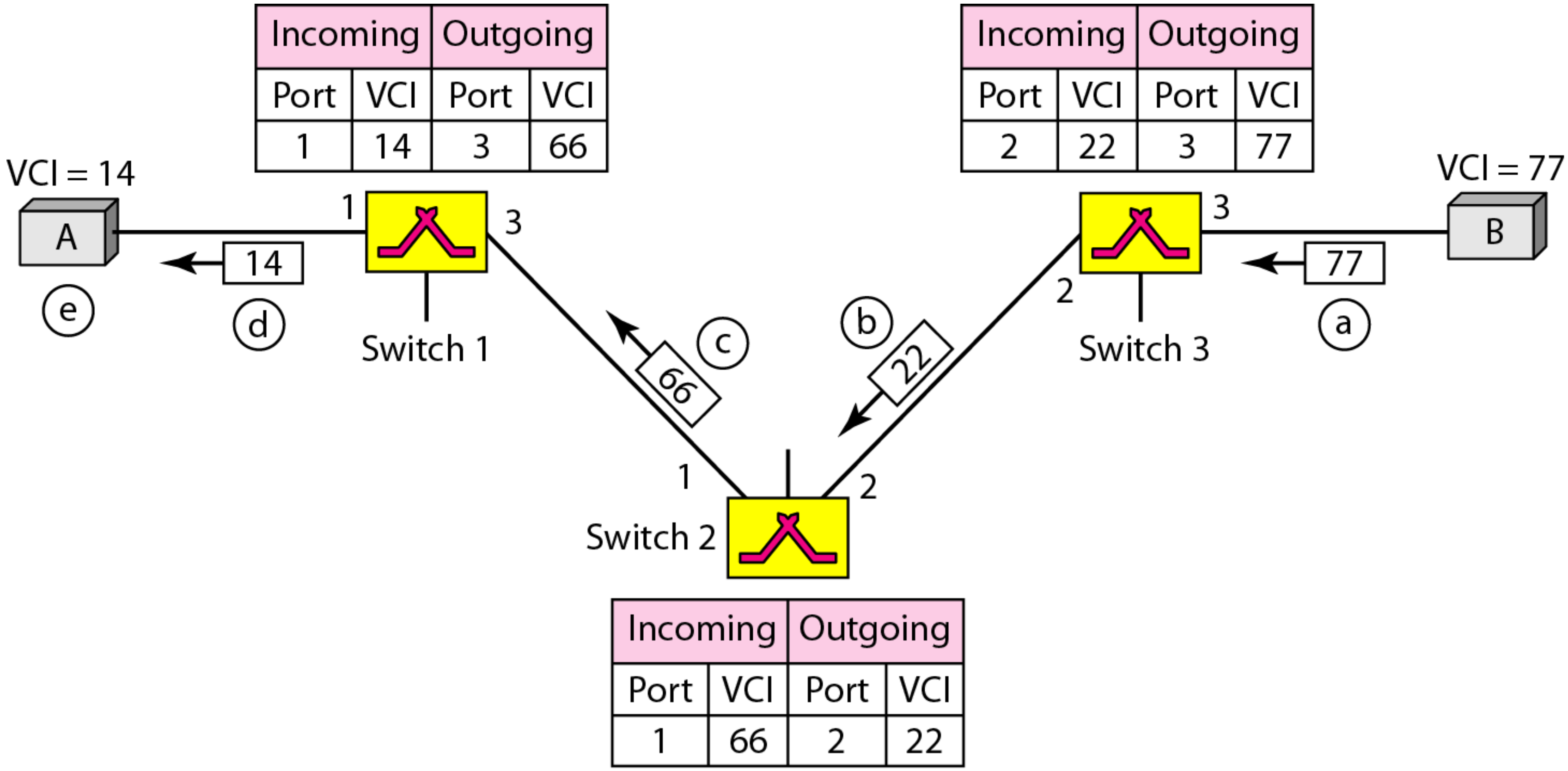
Source-to-destination data transfer in a virtual-circuit network



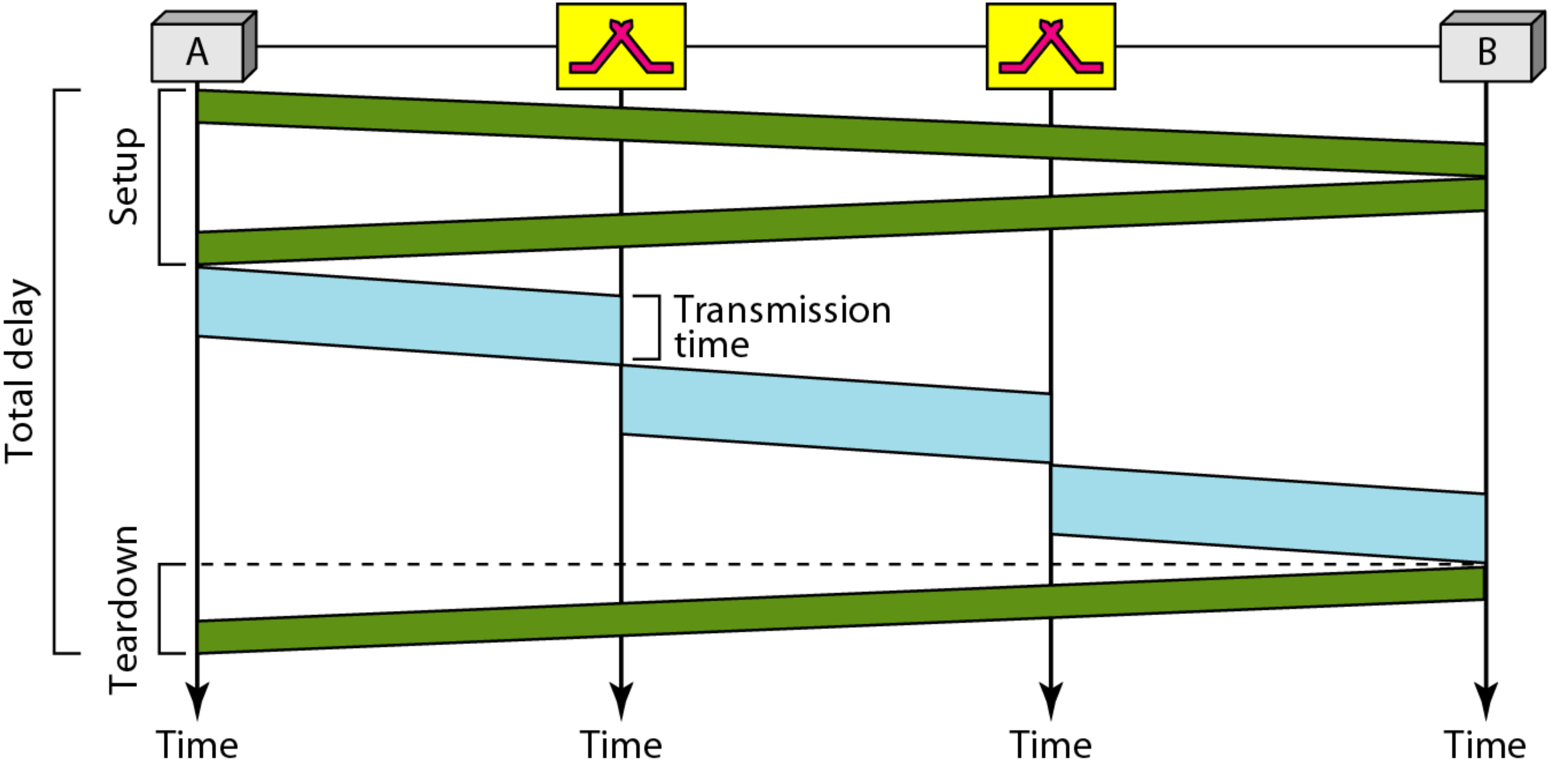
Setup Request in a virtual-circuit network



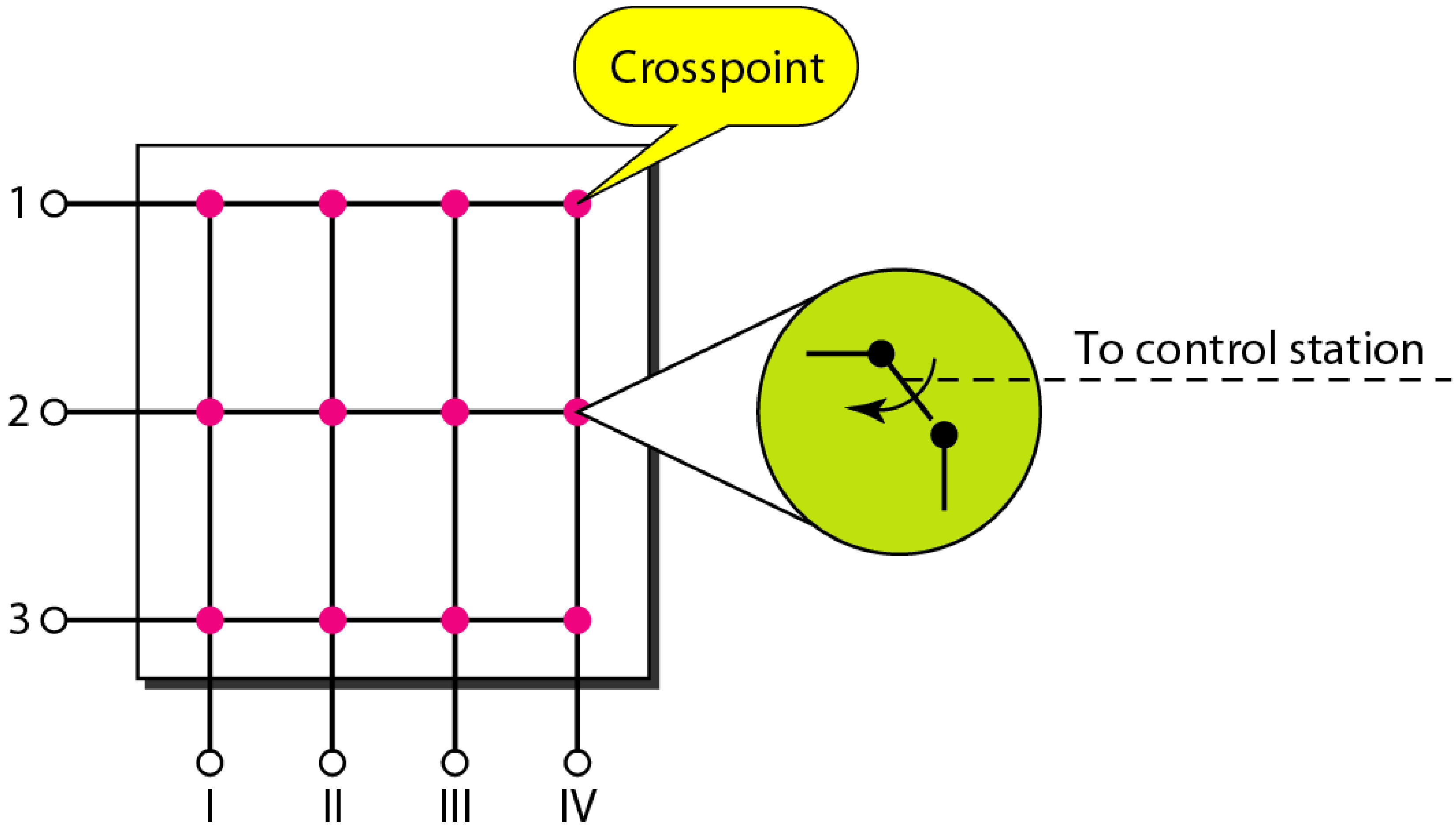
Set up acknowledgement in a virtual-circuit network



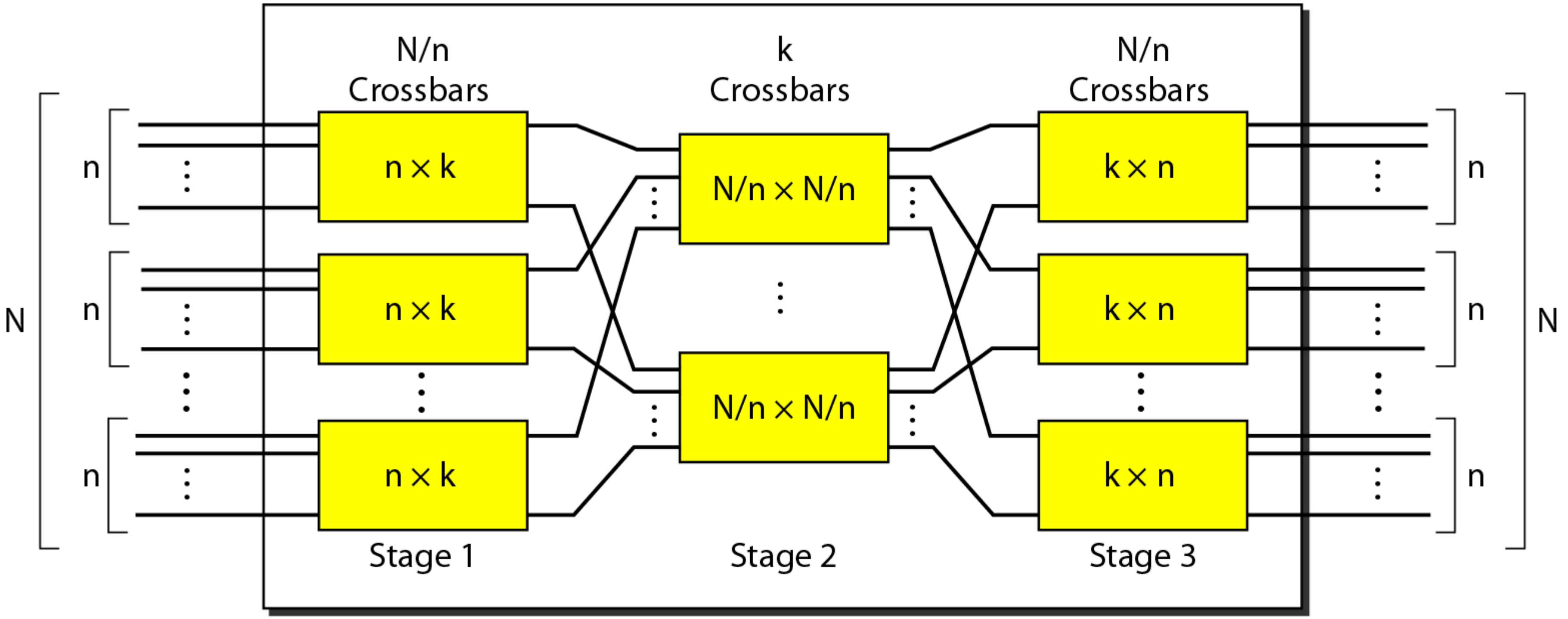
Delay in a virtual-circuit network



Structure of a Switch



Multistage Switch



Formulation in a multistage switch

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

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

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

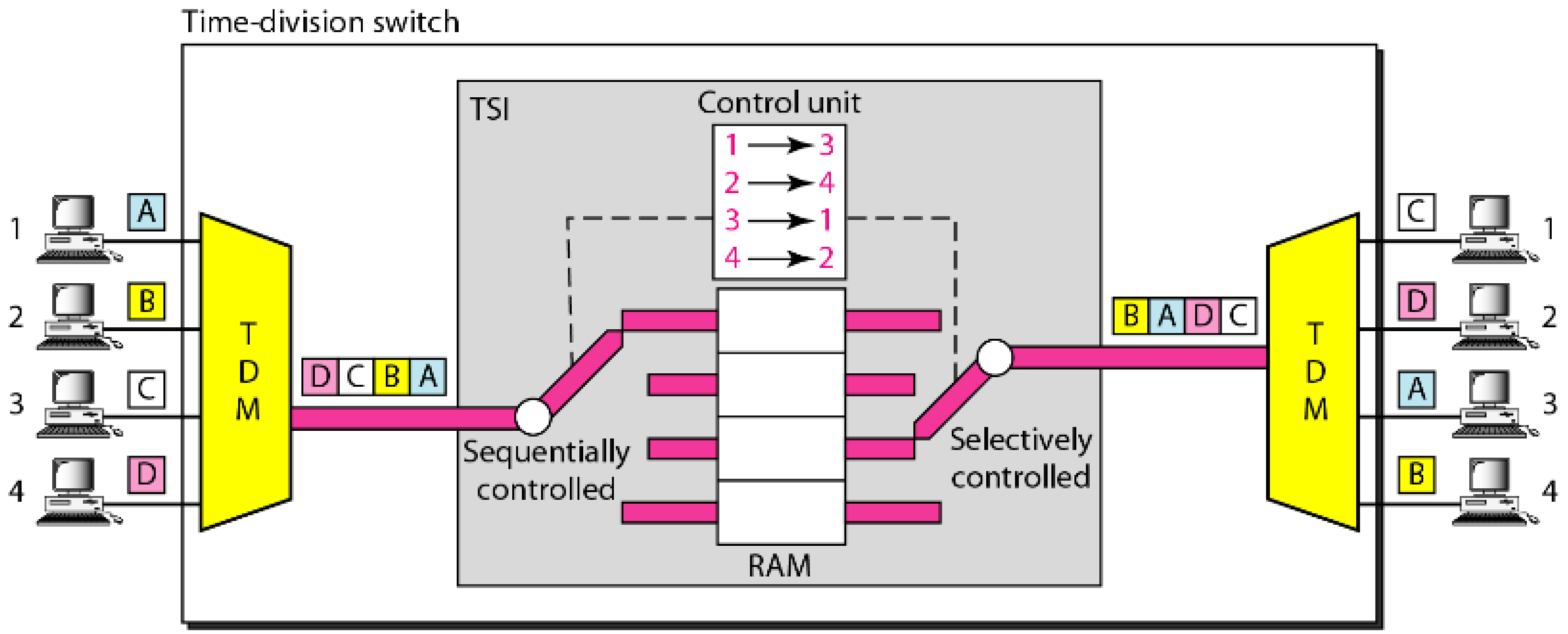
Example

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

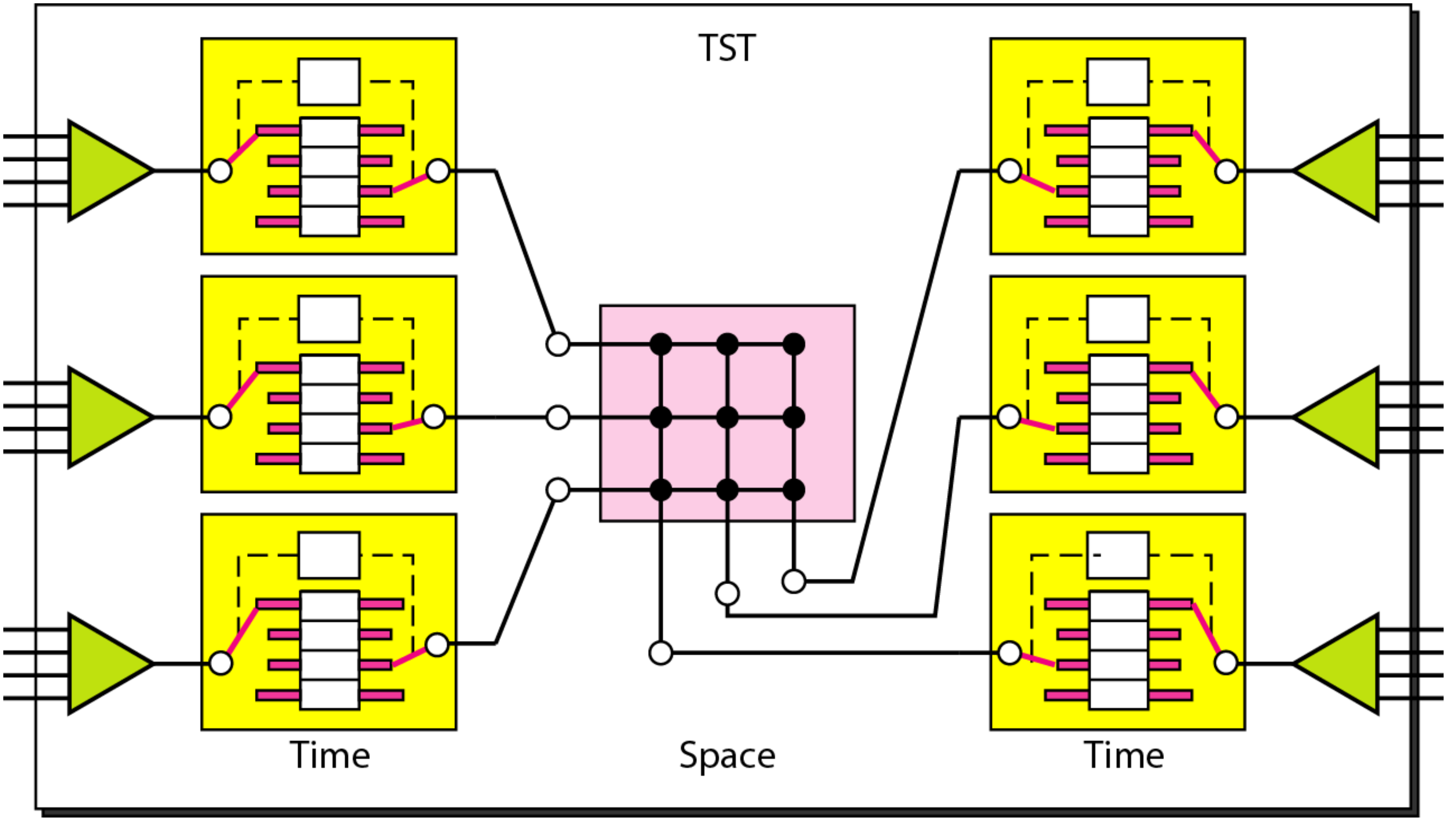
Solution

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).*

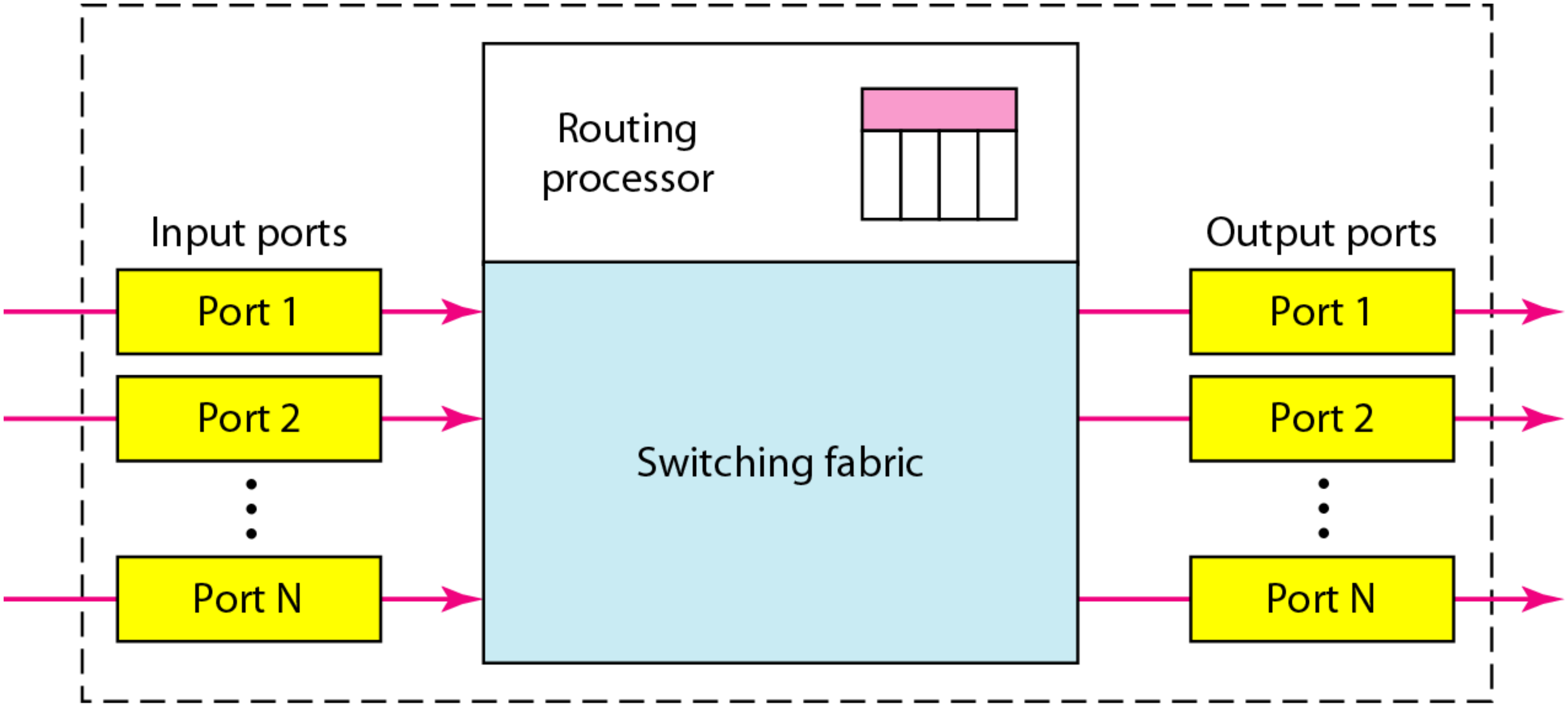
Time-Slot Interchange



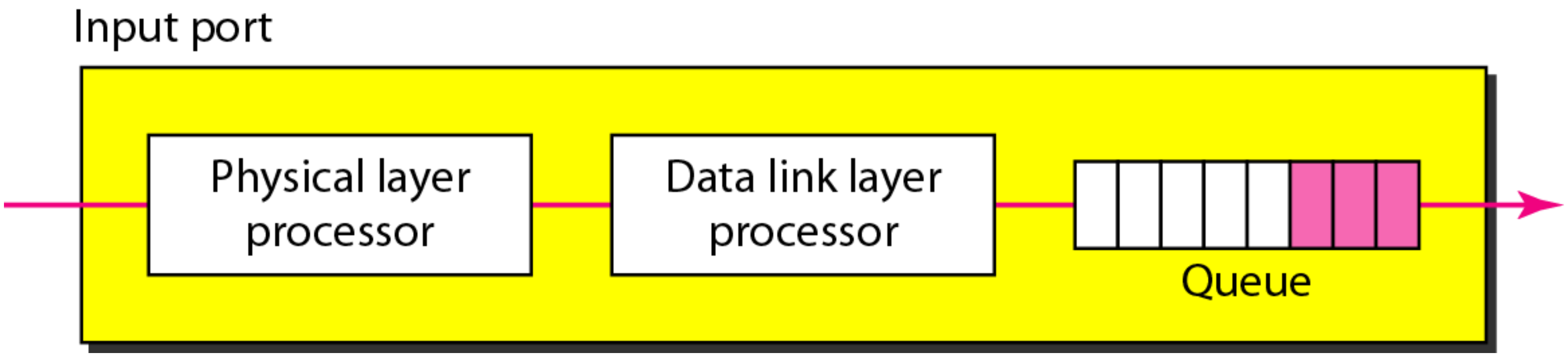
Time-space-time switch



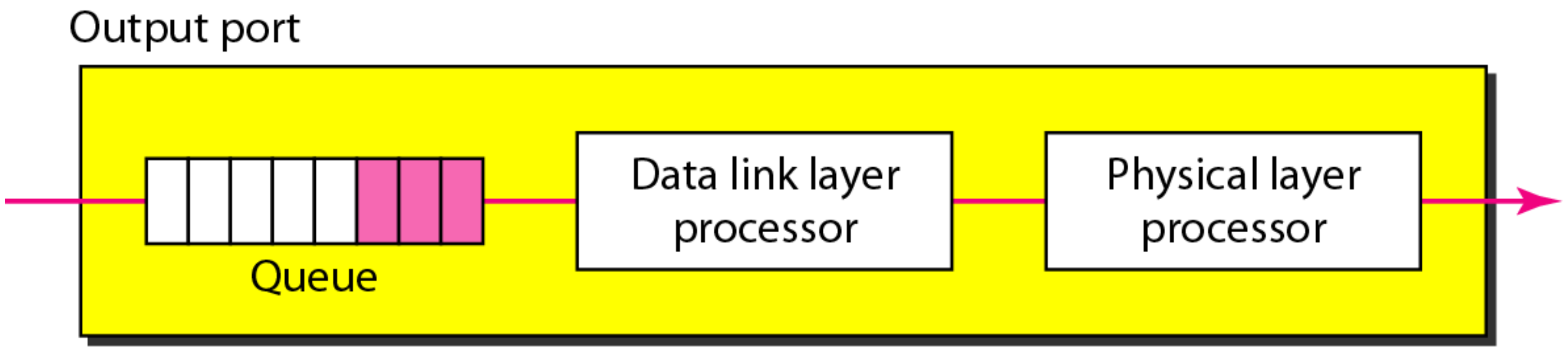
Packet Switch Components



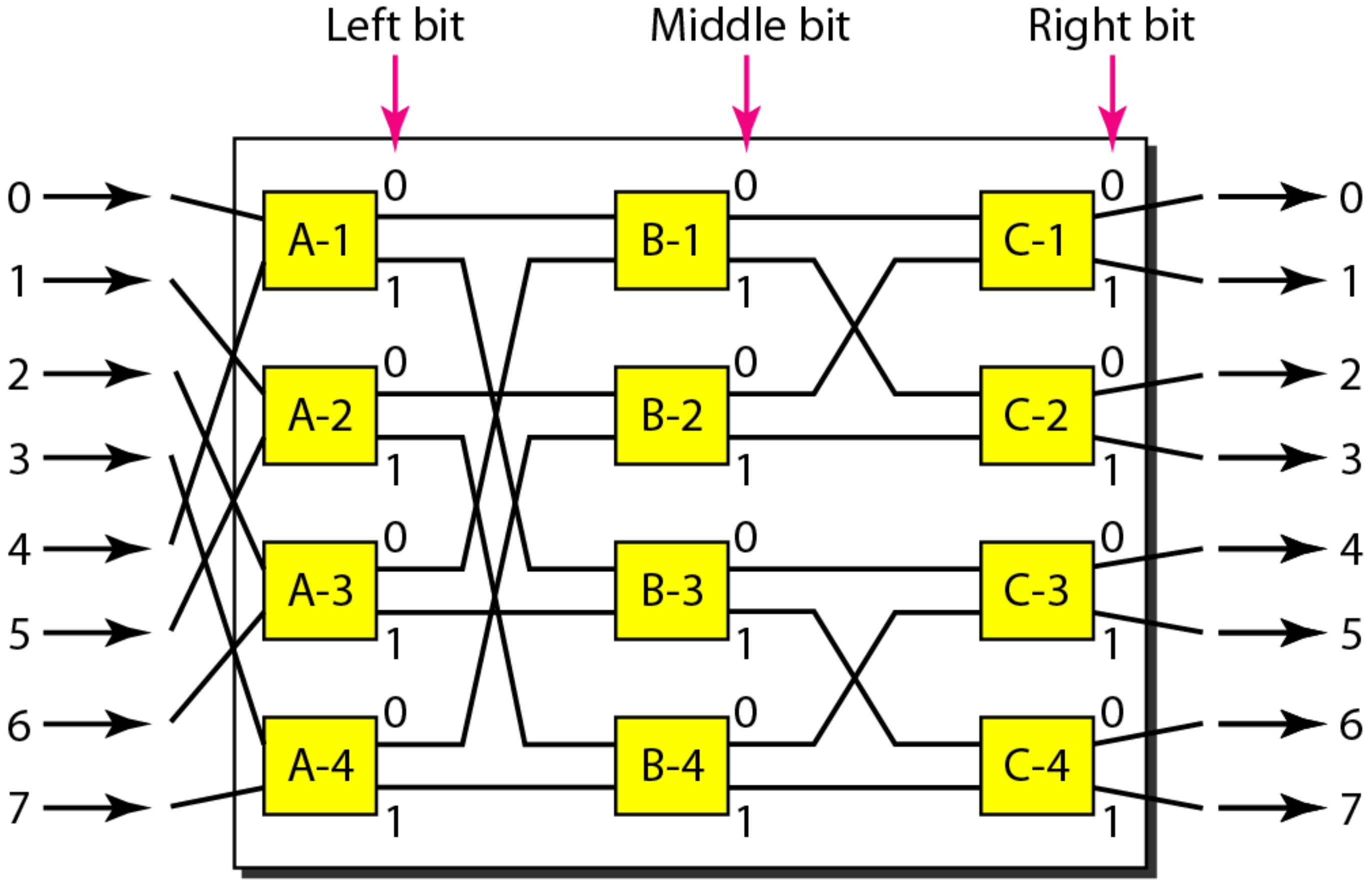
Input Port


Input port
Physical layer processor
Data link layer processor
Queue

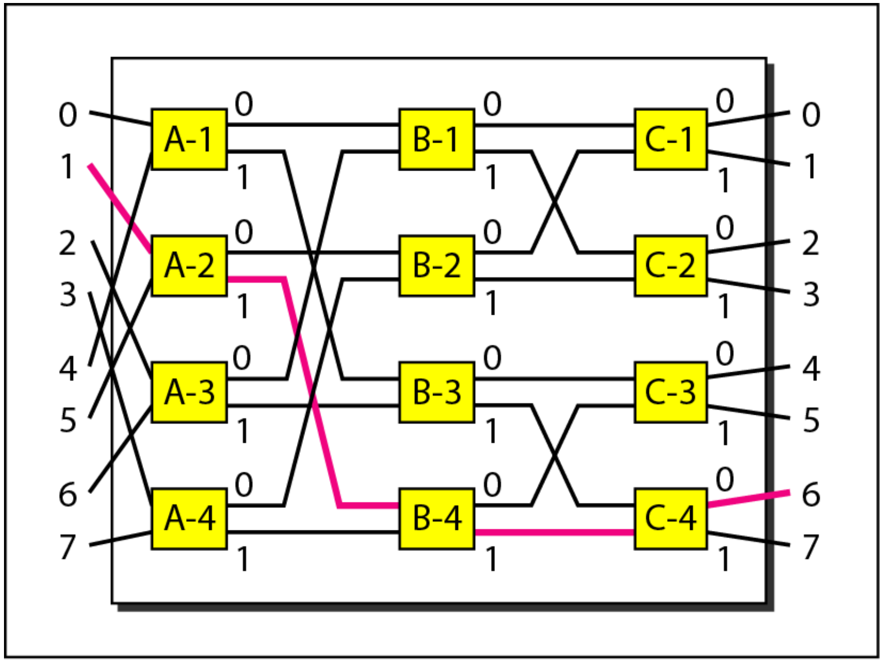
Output Port


Output port
Data link layer processor
Physical layer processor
Queue

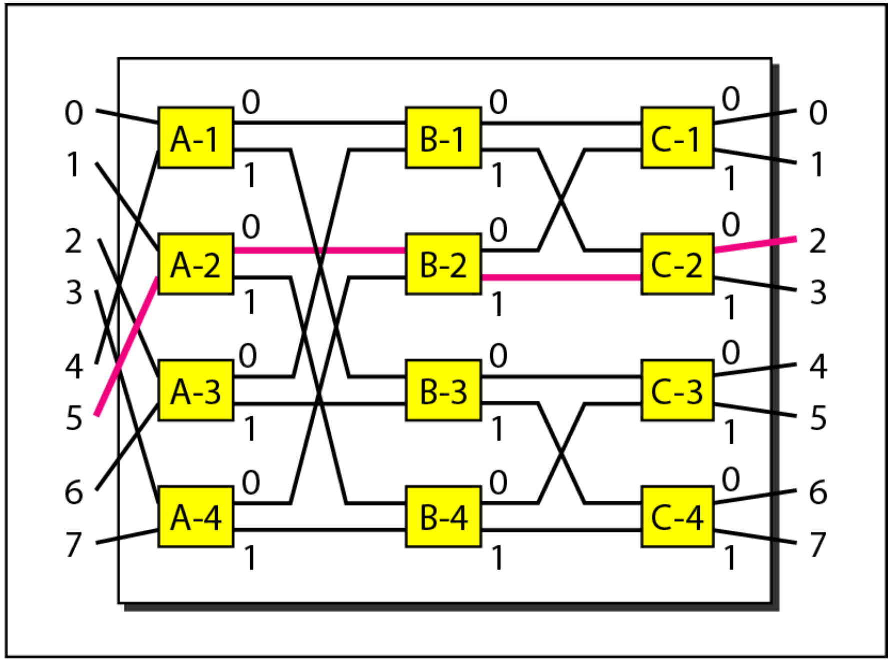
A Banyan Switch



Examples of routing in a banyan switch



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

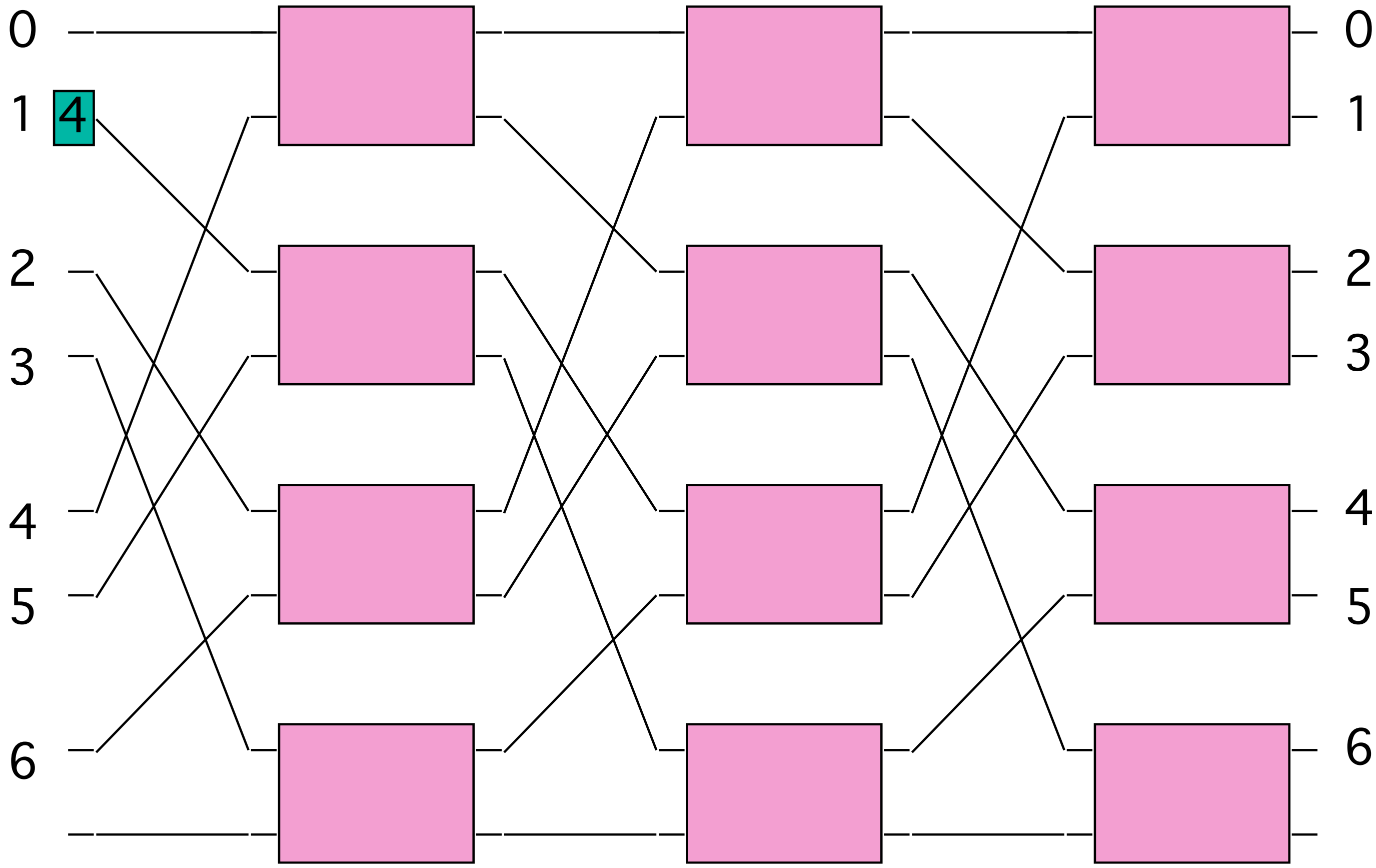


b. Input 5 sending a cell to output 2 (010)

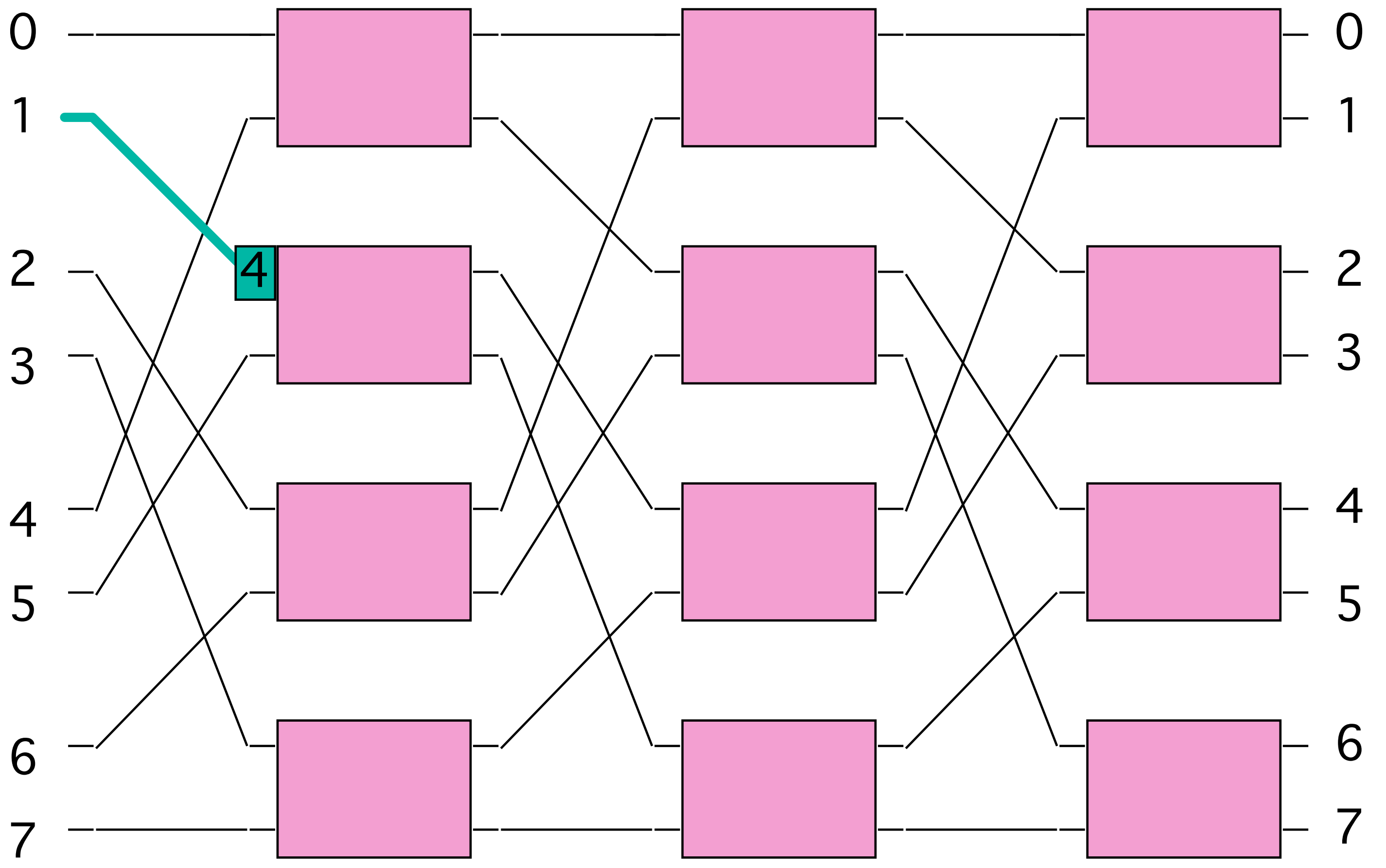
Self-Routing

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

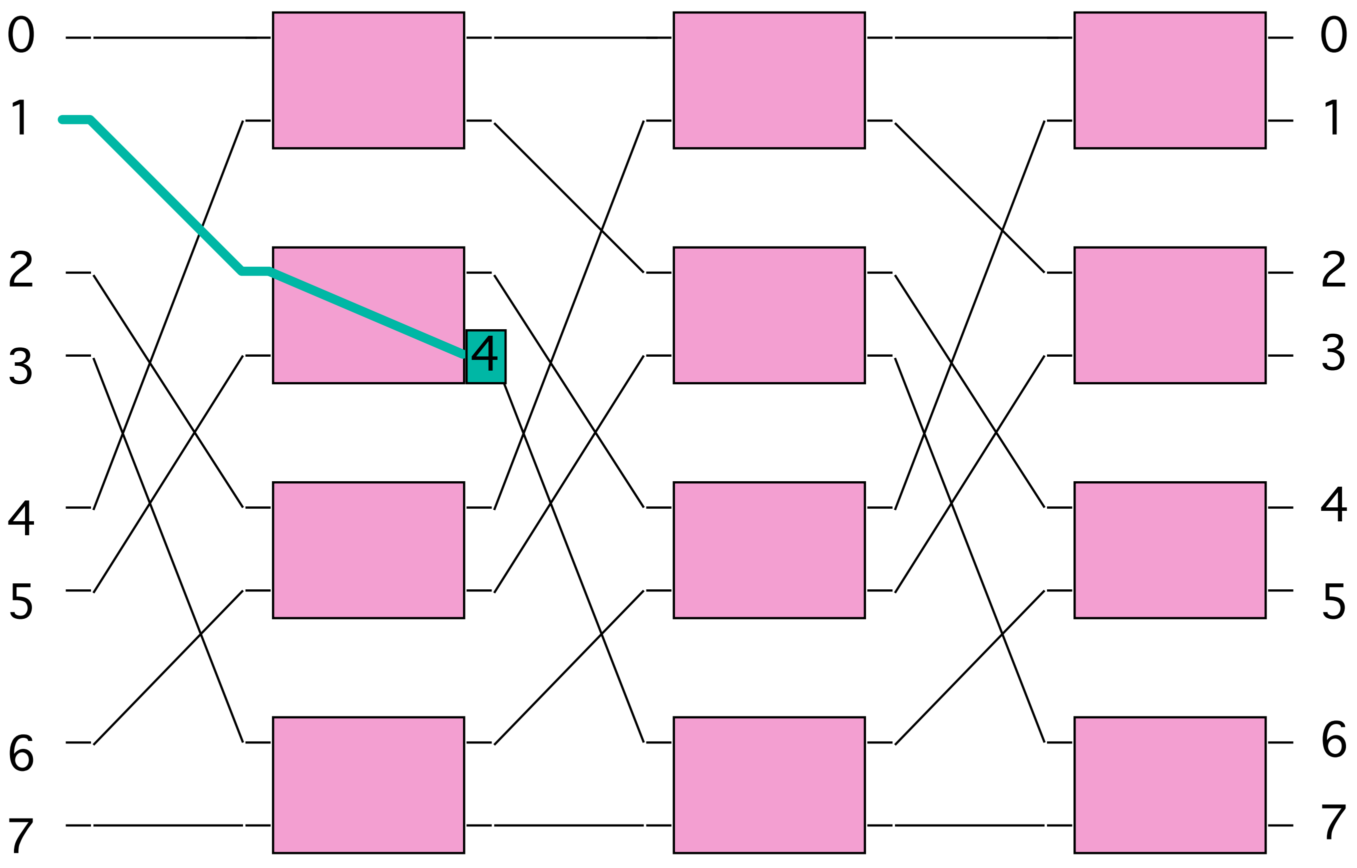
Example of Self-Routing
(Cell destined for output port 4 (= 100_2))



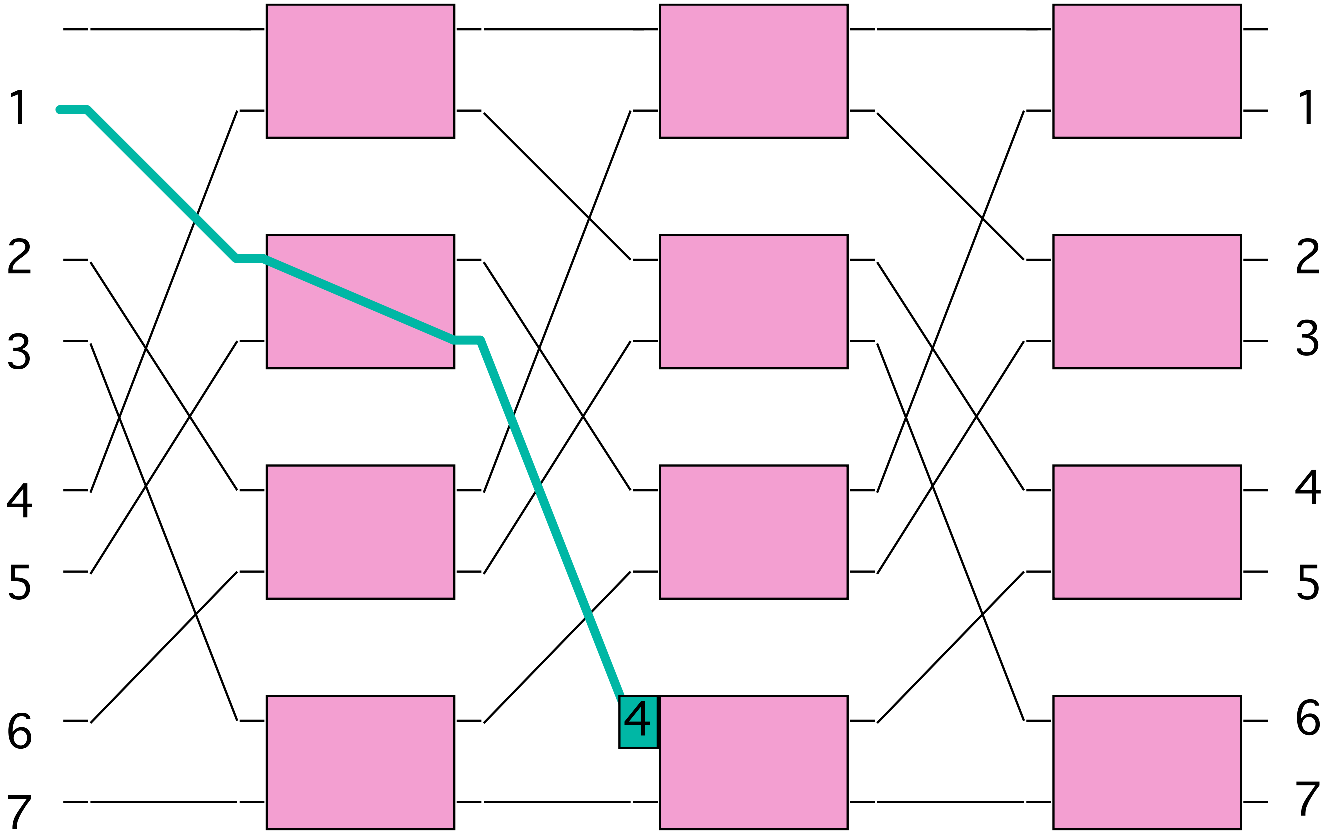
Example of Self-Routing
(Cell destined for output port 4 (= 100_2))



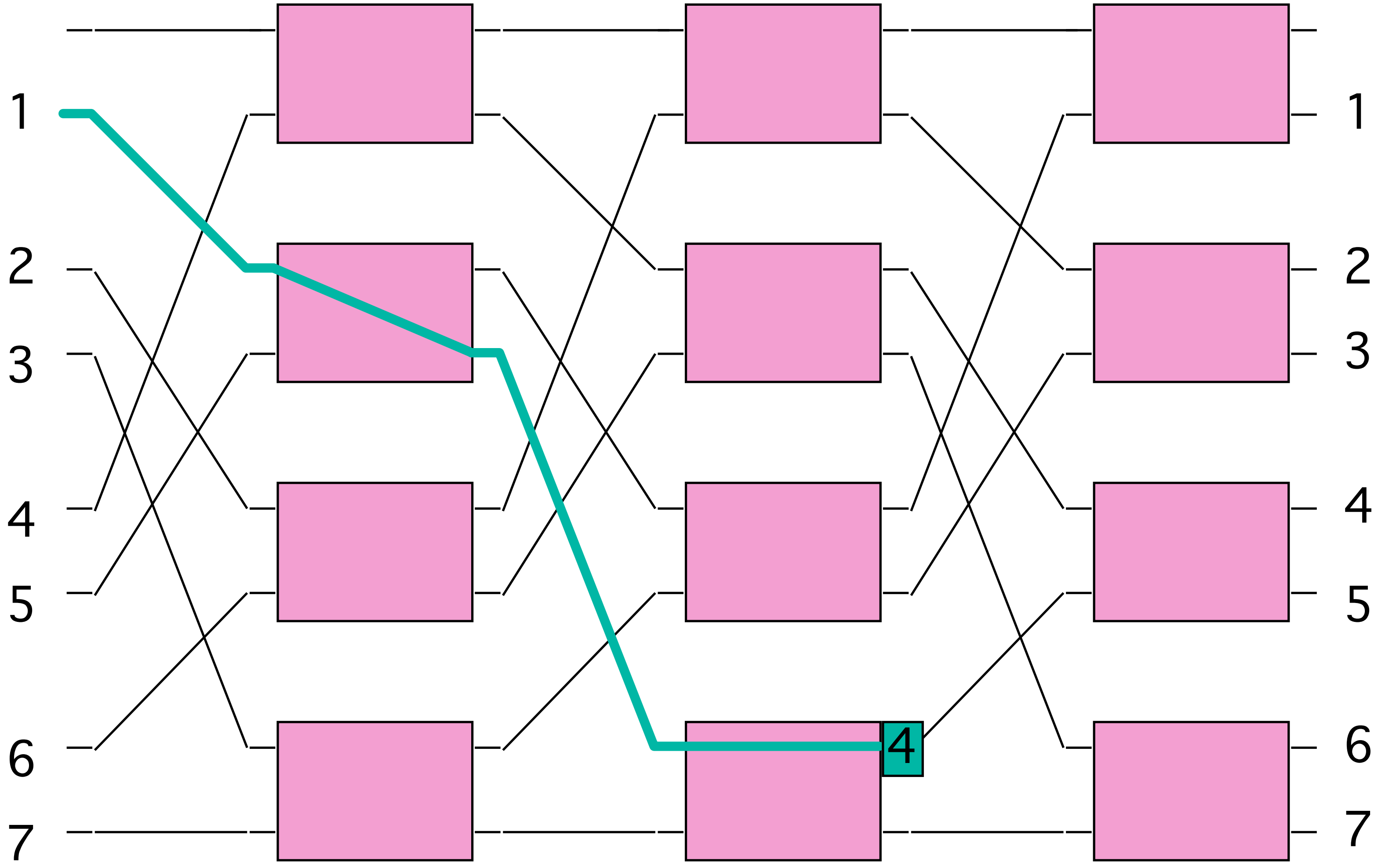
Example of Self-Routing
(Cell destined for output port 4 (= 100_2))



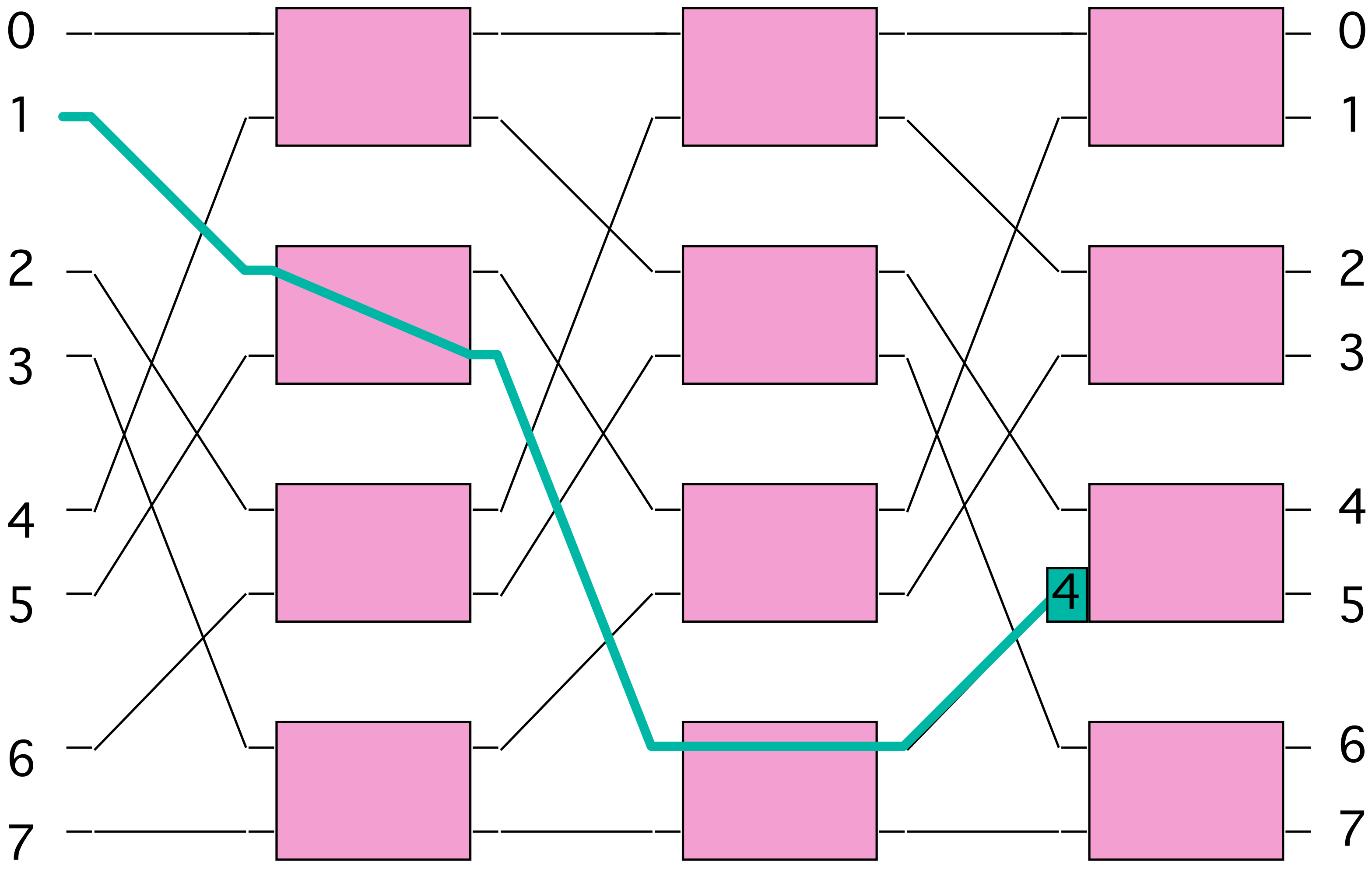
Example of Self-Routing
(Cell destined for output port 4 (= 100_2))



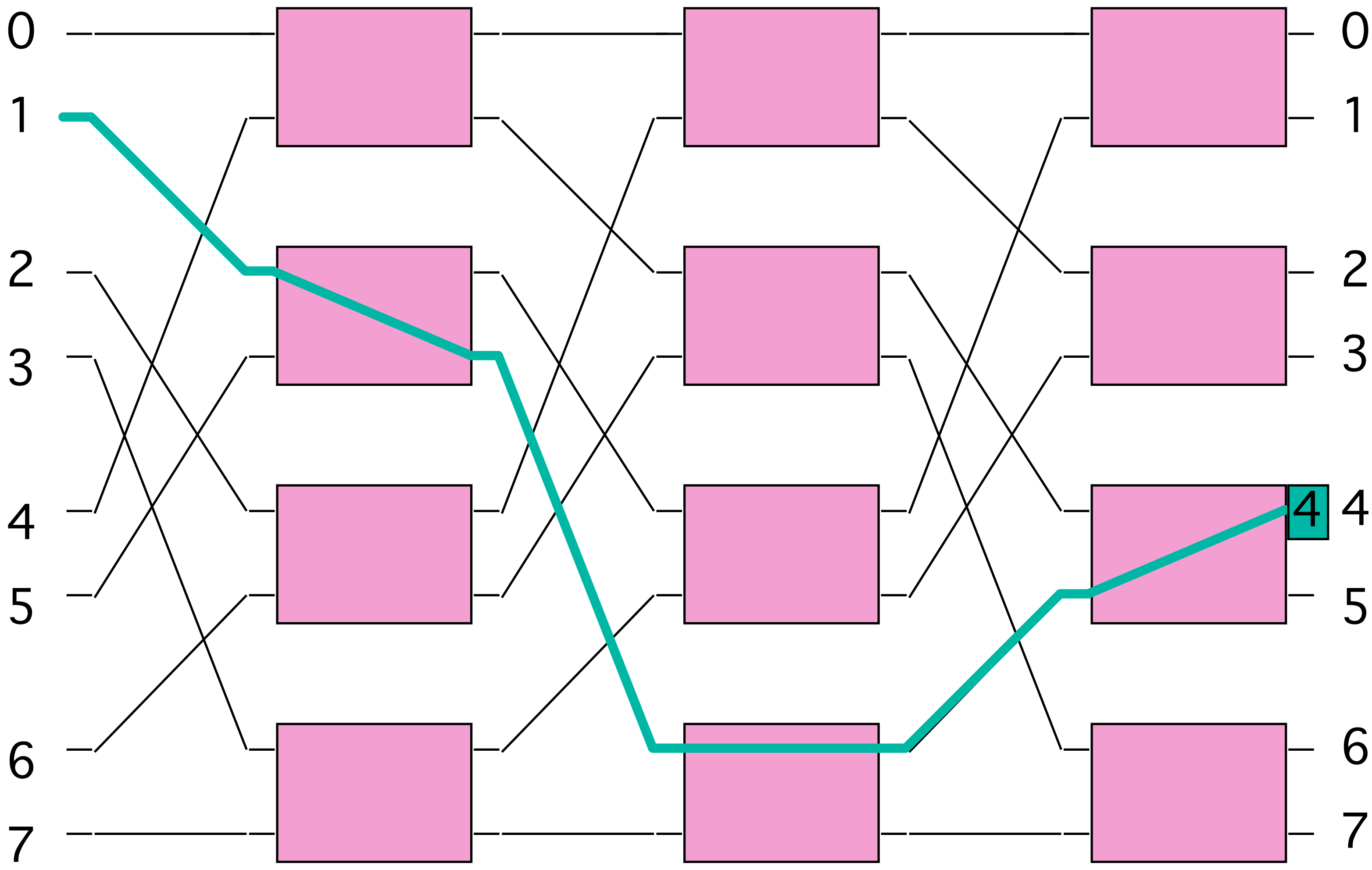
Example of Self-Routing
(Cell destined for output port 4 (= 100_2))



Example of Self-Routing
(Cell destined for output port 4 (= 100_2))



Example of Self-Routing
(Cell destined for output port 4 (= 100_2))



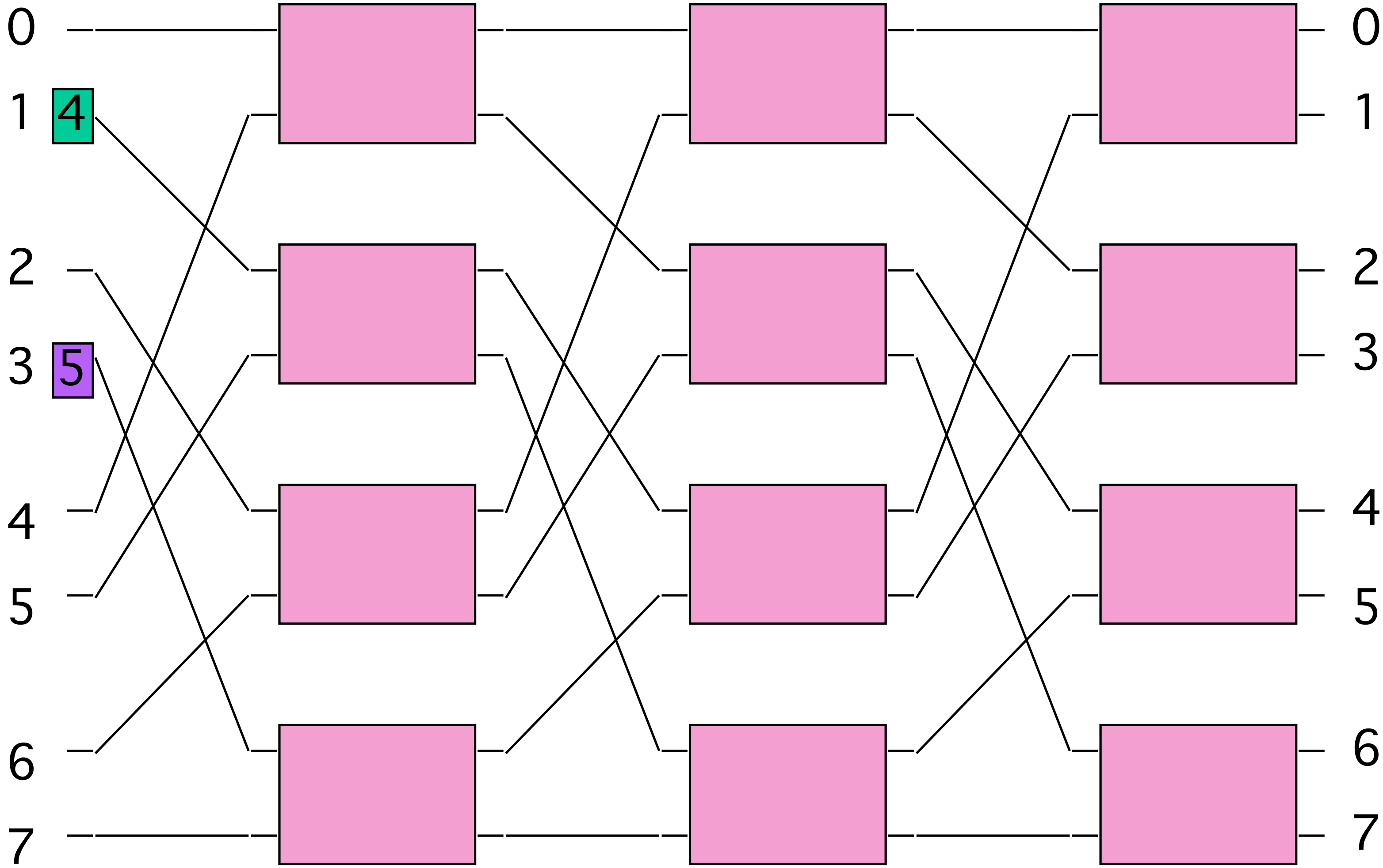
Path Contention

- ✓ The omega network has the problems as the delta network with output port contention and path contention

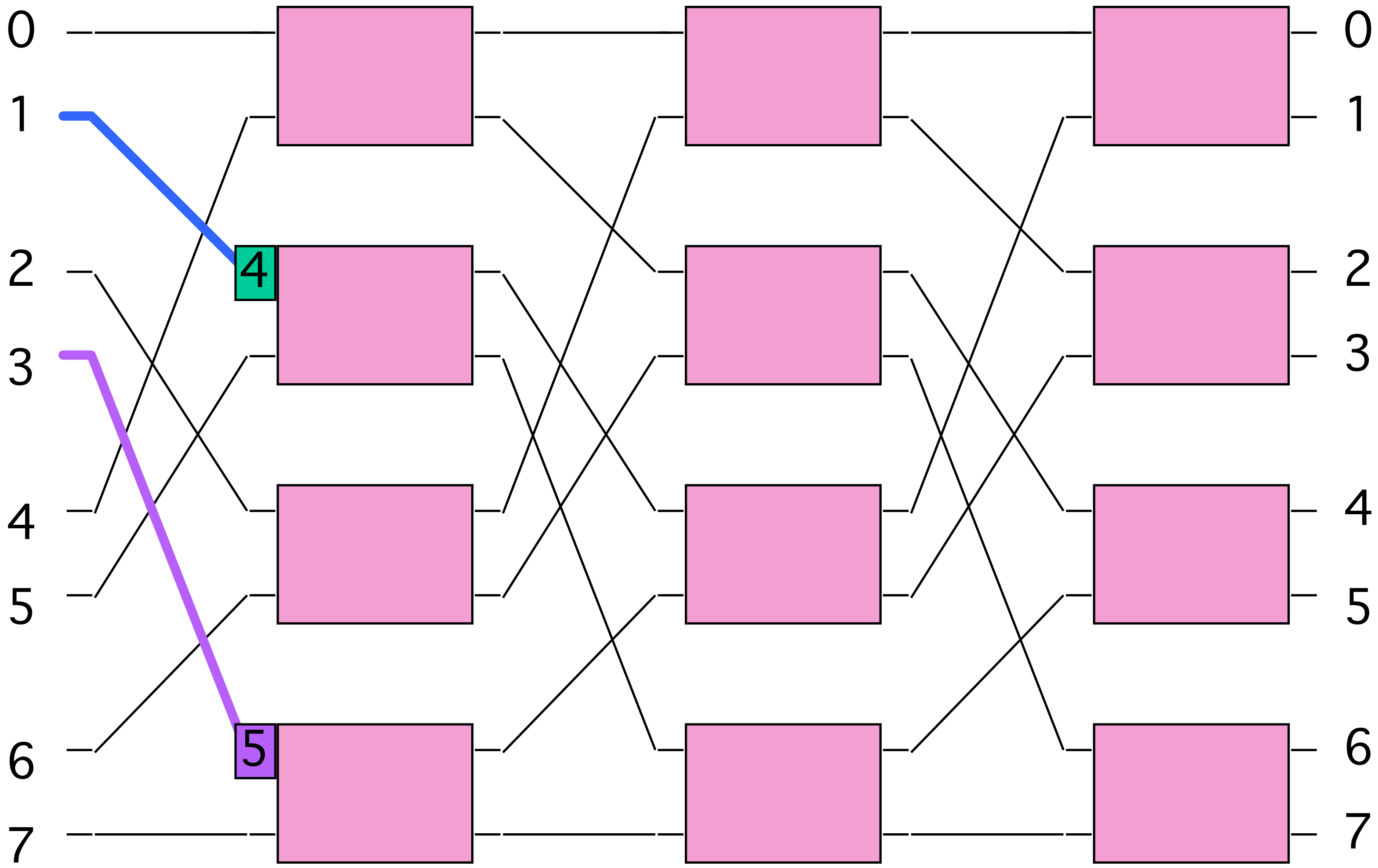
- ✓ Again, the result in a bufferless switch fabric is <u>cell loss</u> (one cell wins, one loses)

- ✓ Path contention and output port contention <u>can seriously degrade the achievable throughput of the switch</u>

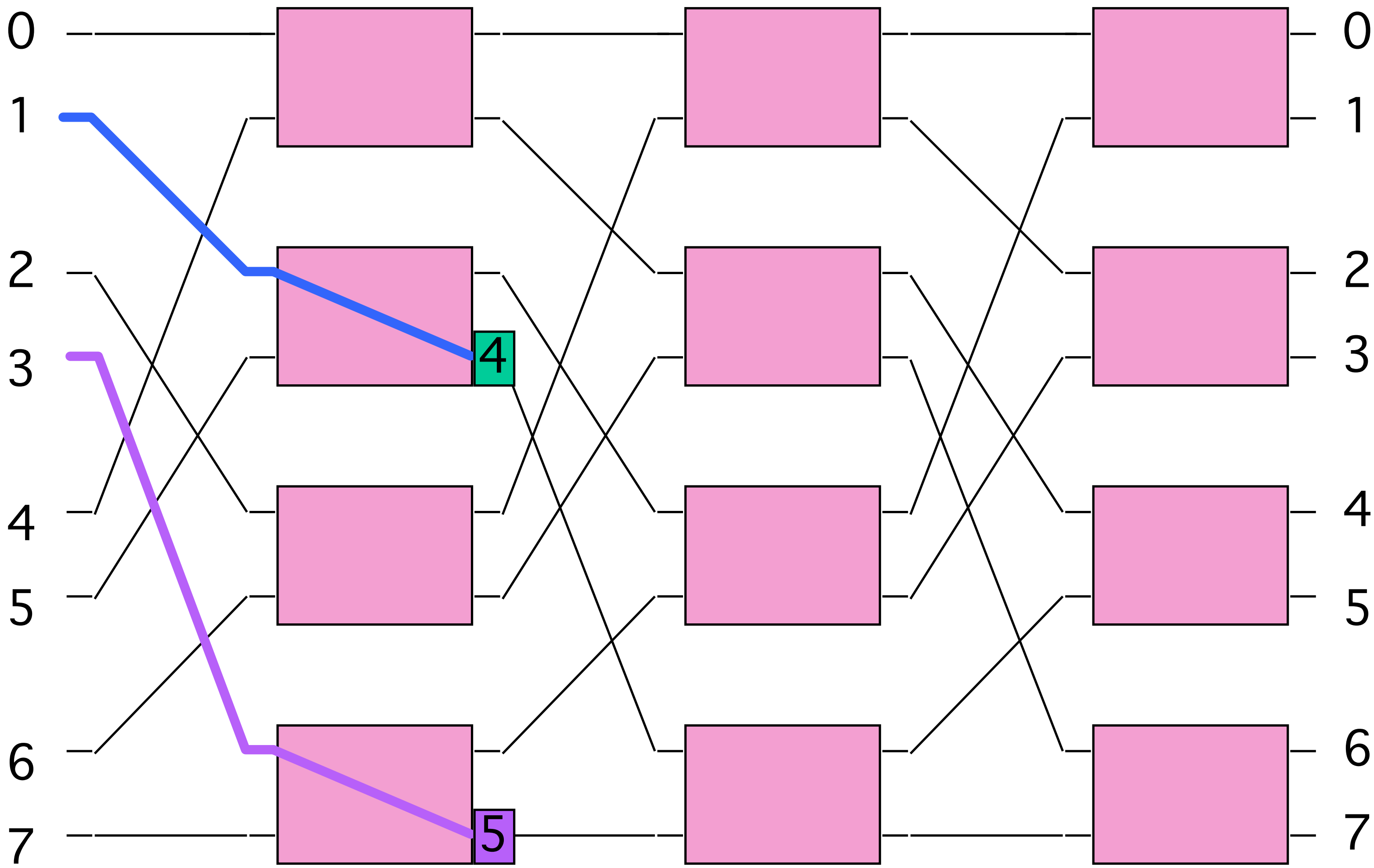
Path Contention



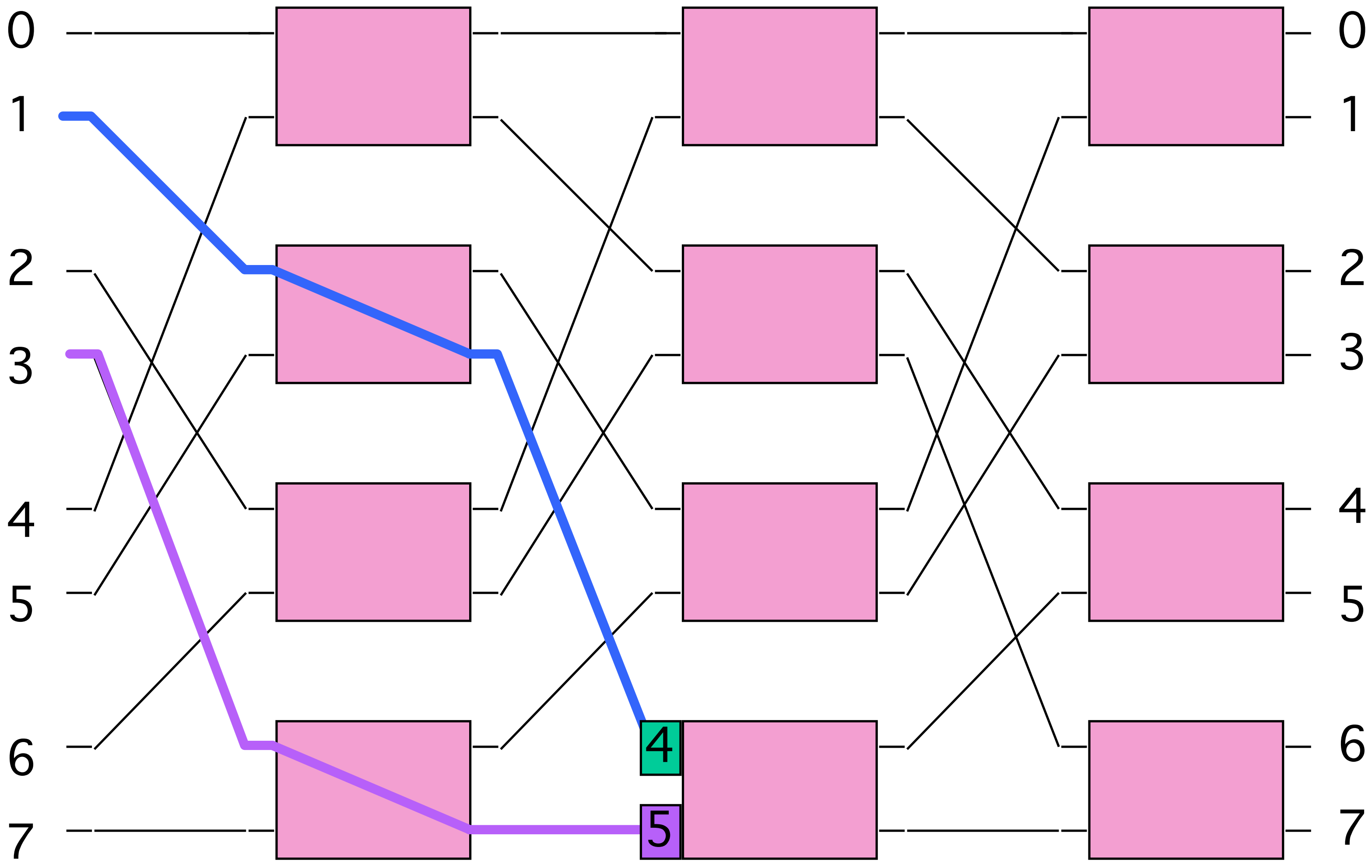
Path Contention



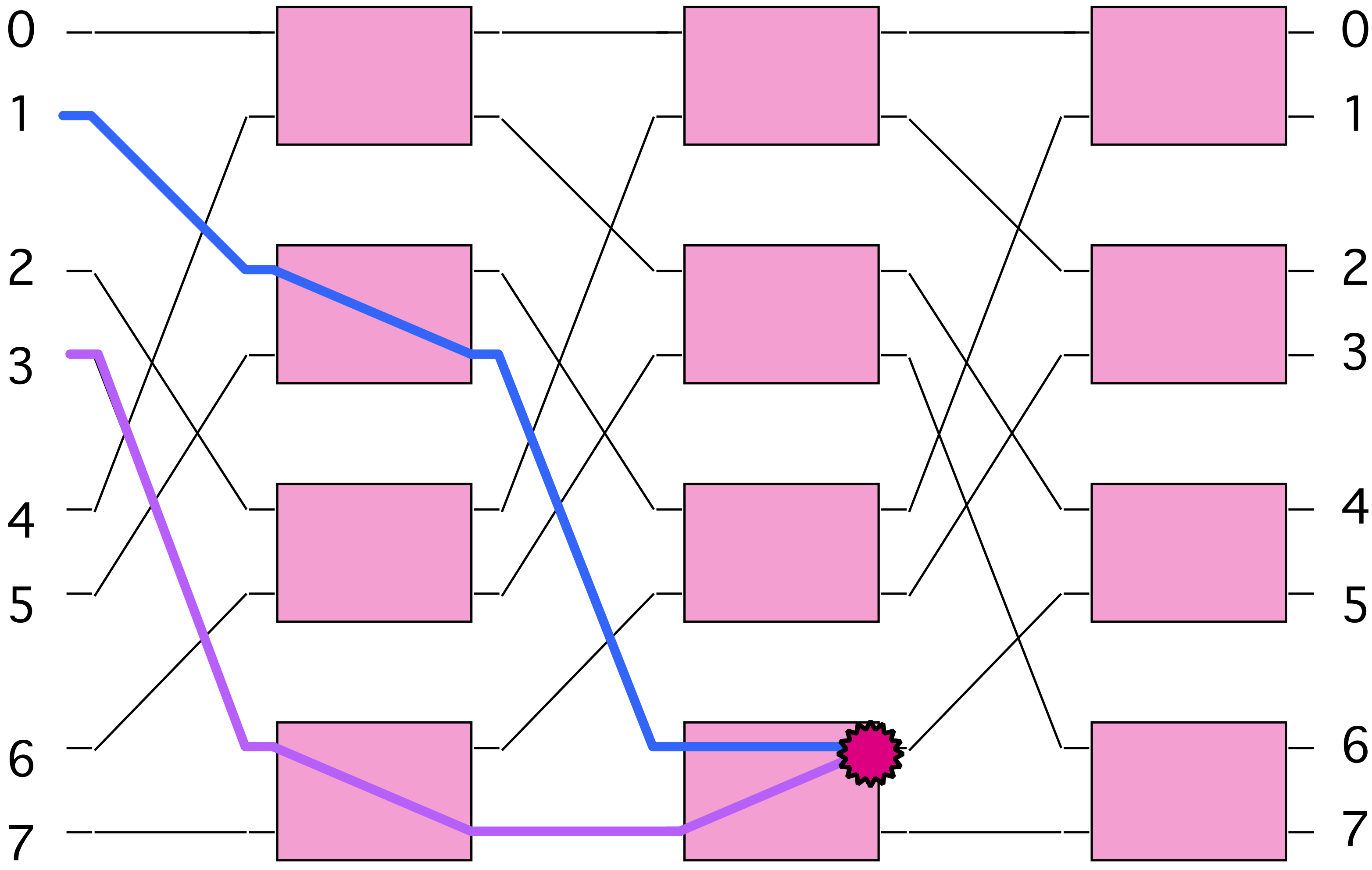
Path Contention



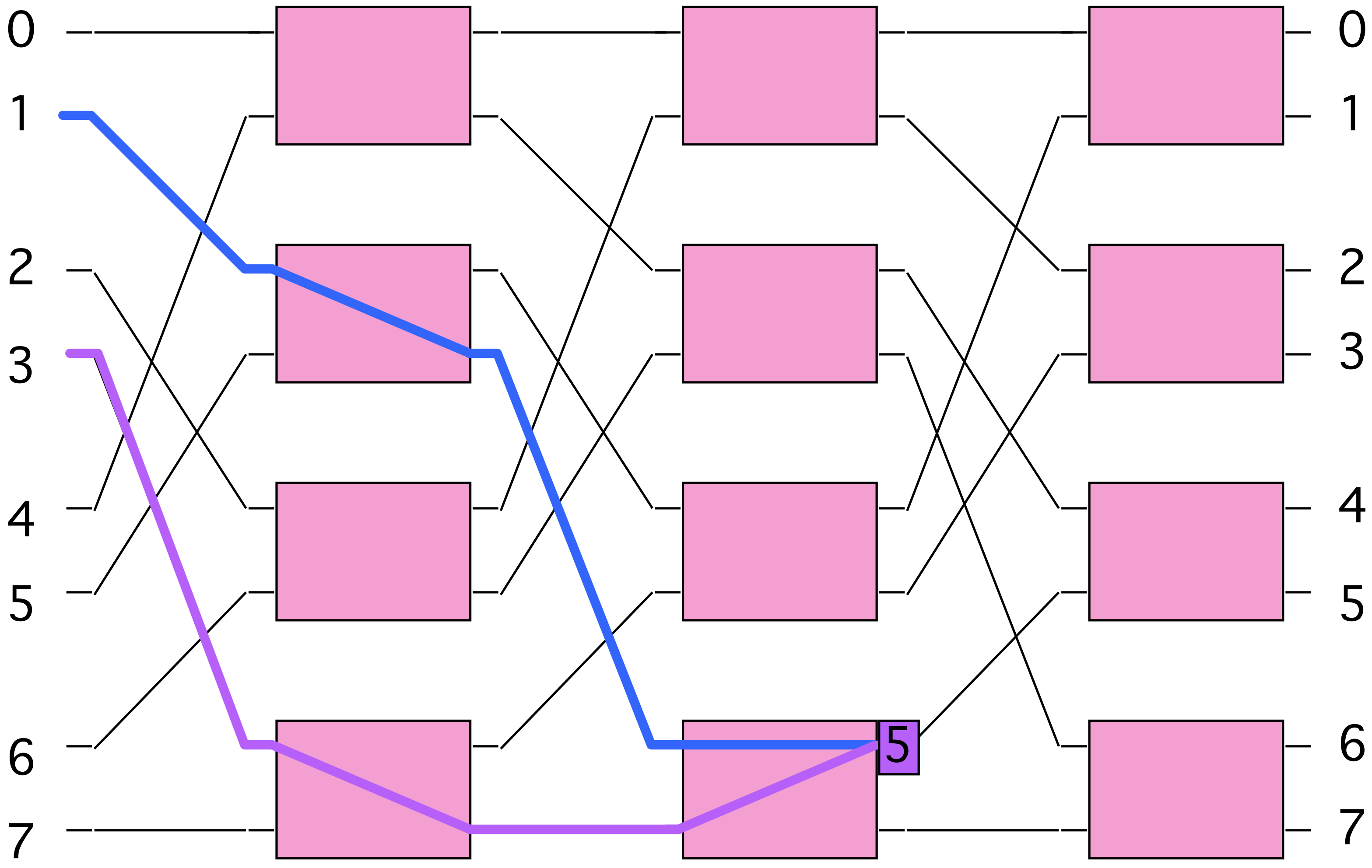
Path Contention



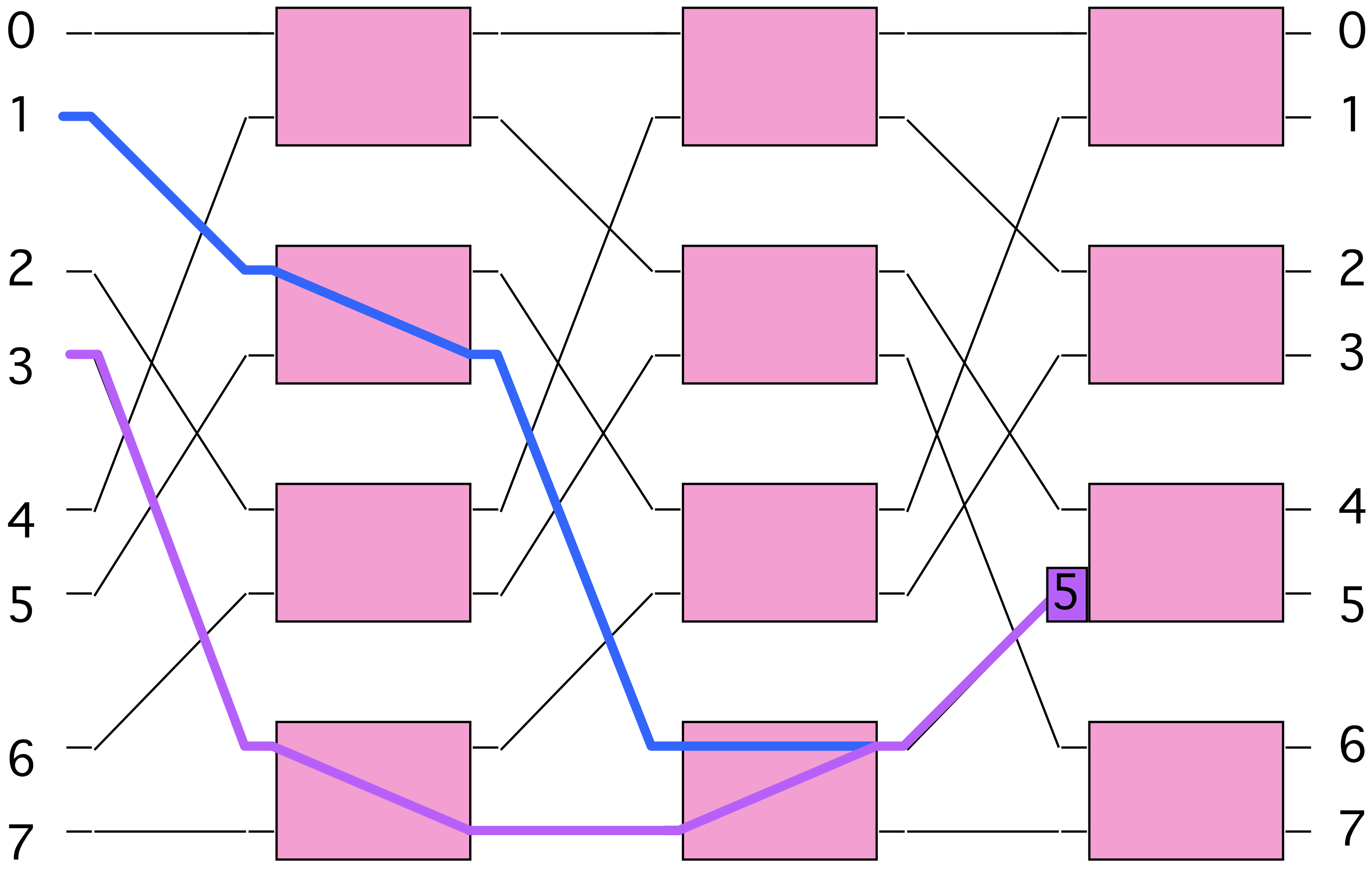
Path Contention



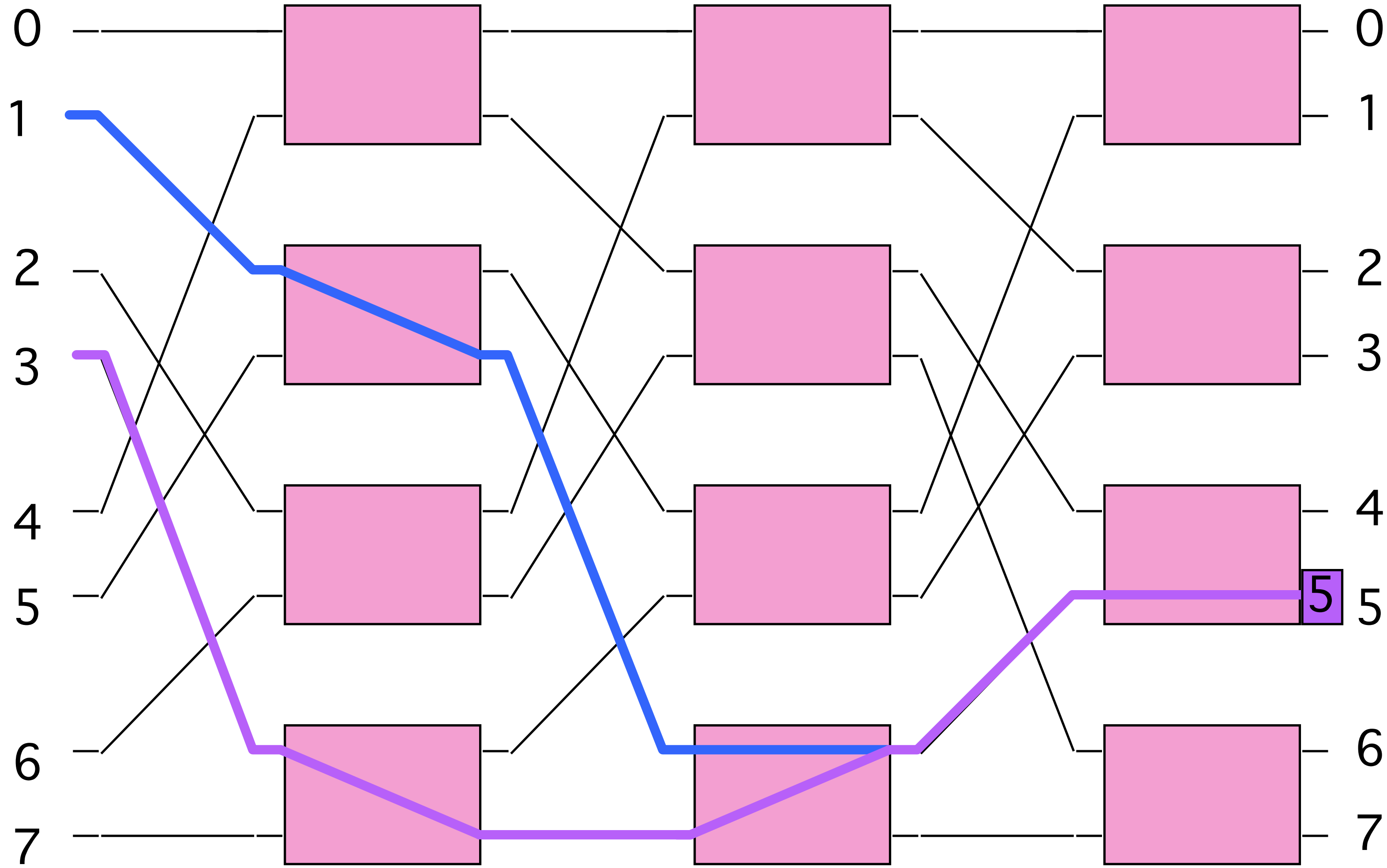
Path Contention



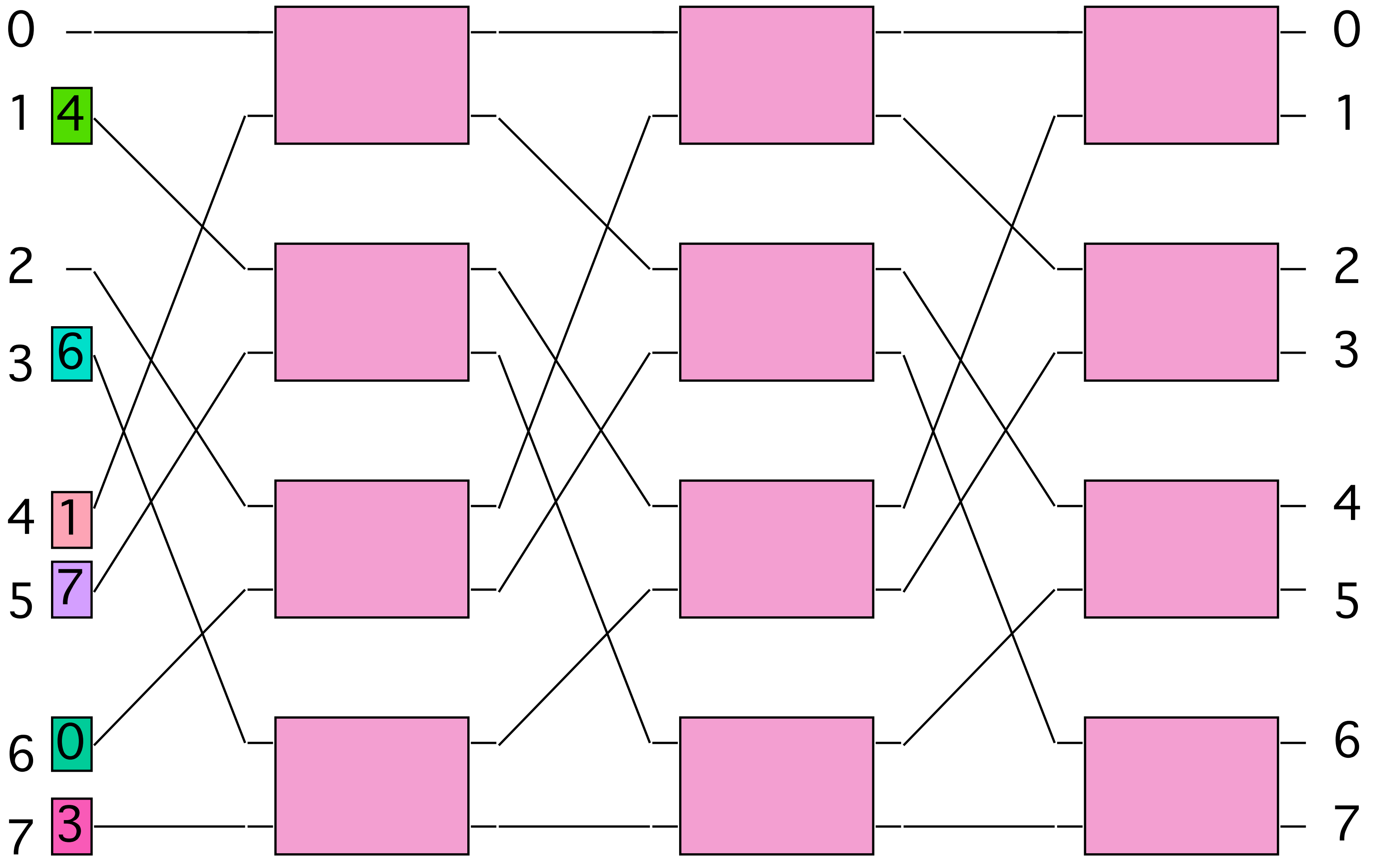
Path Contention



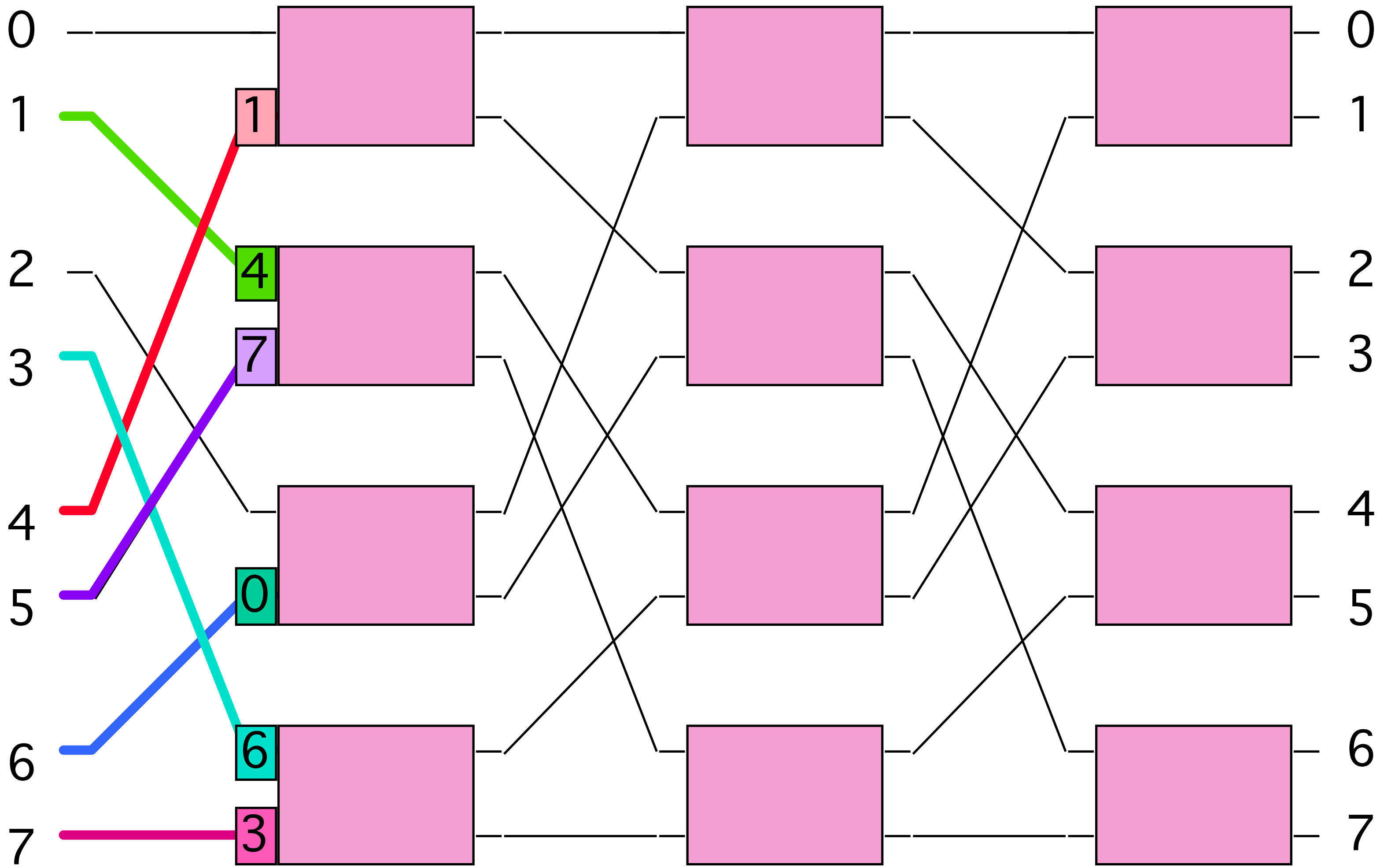
Path Contention



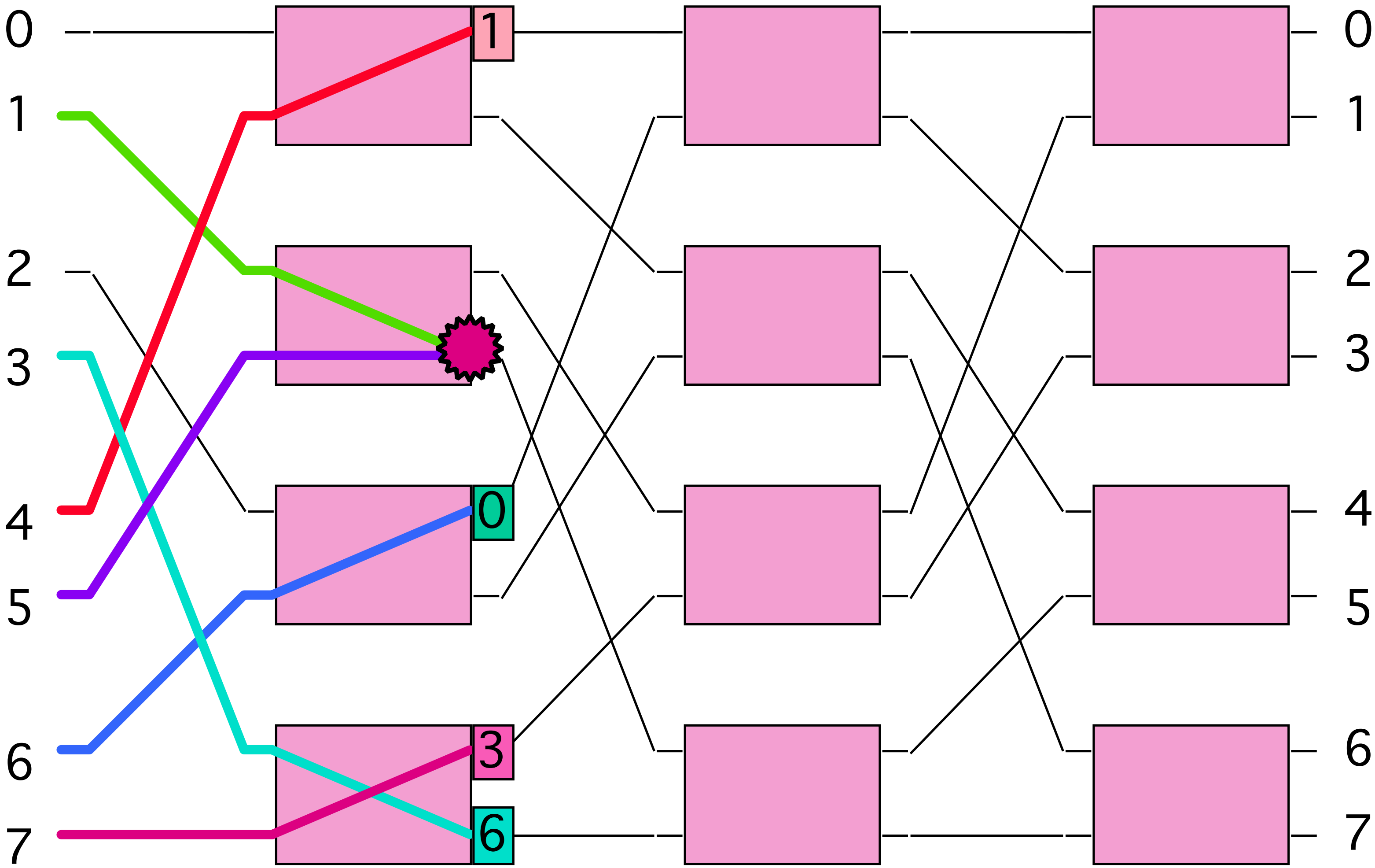
Performance Degradation



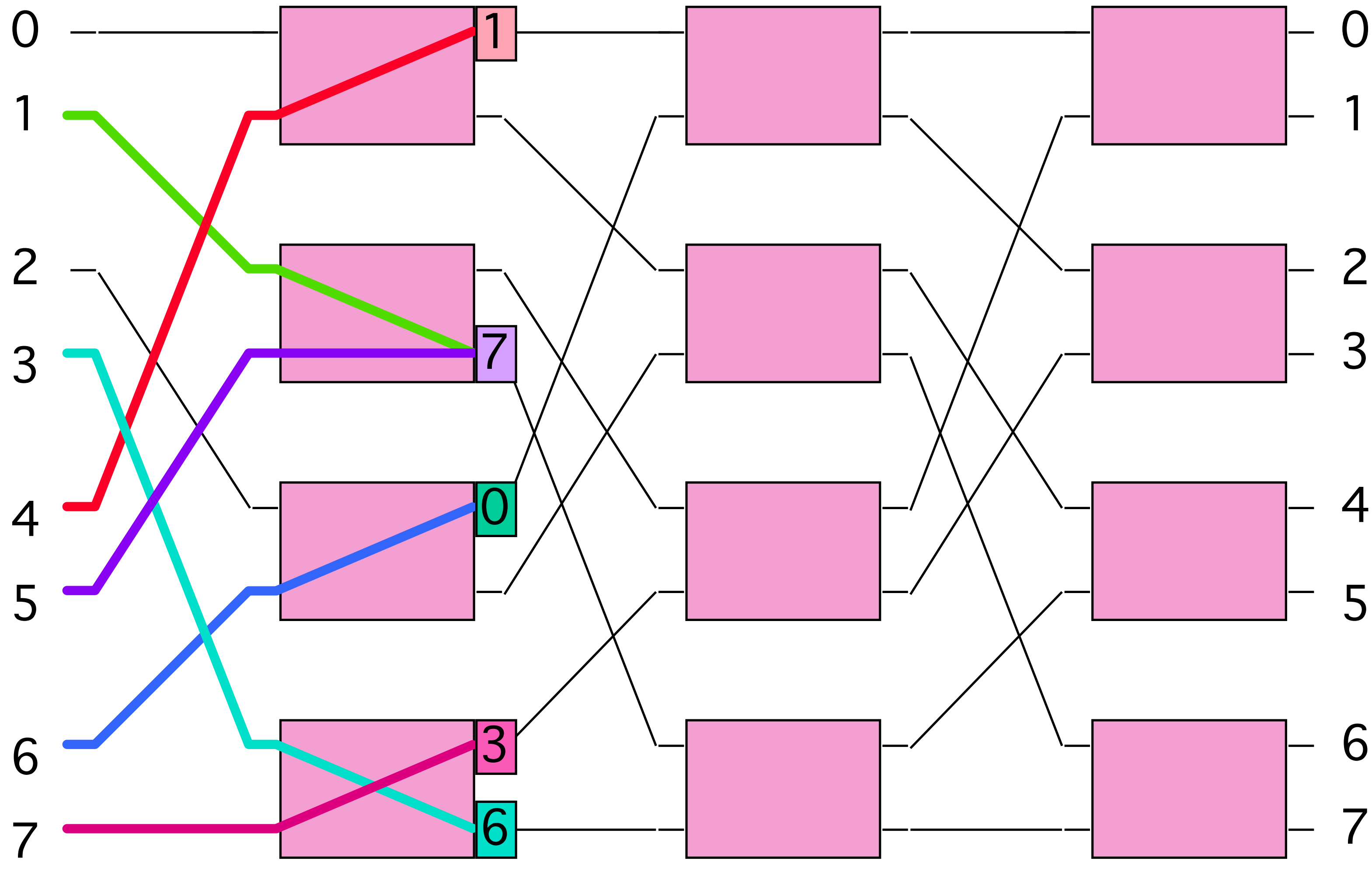
Performance Degradation



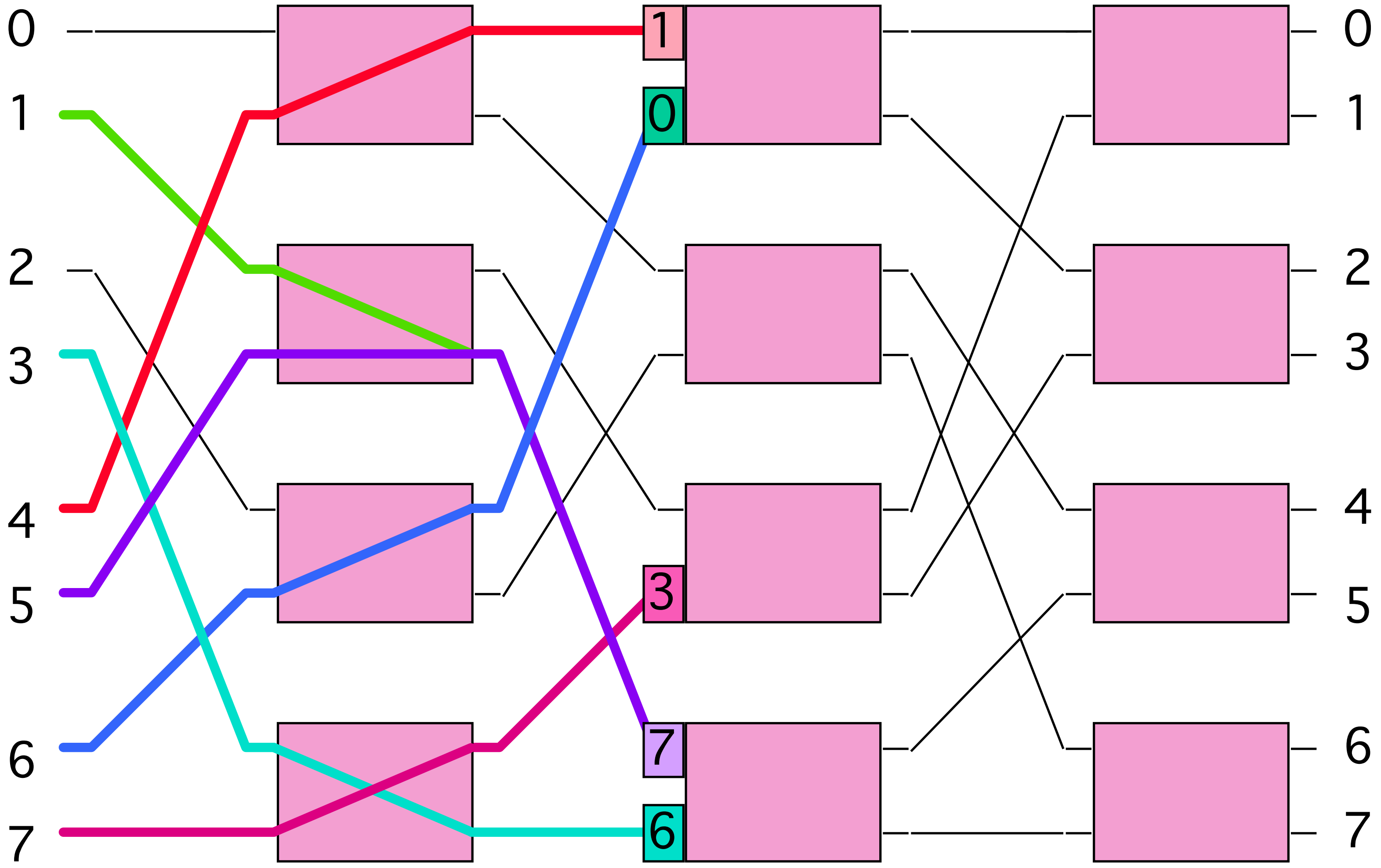
Performance Degradation



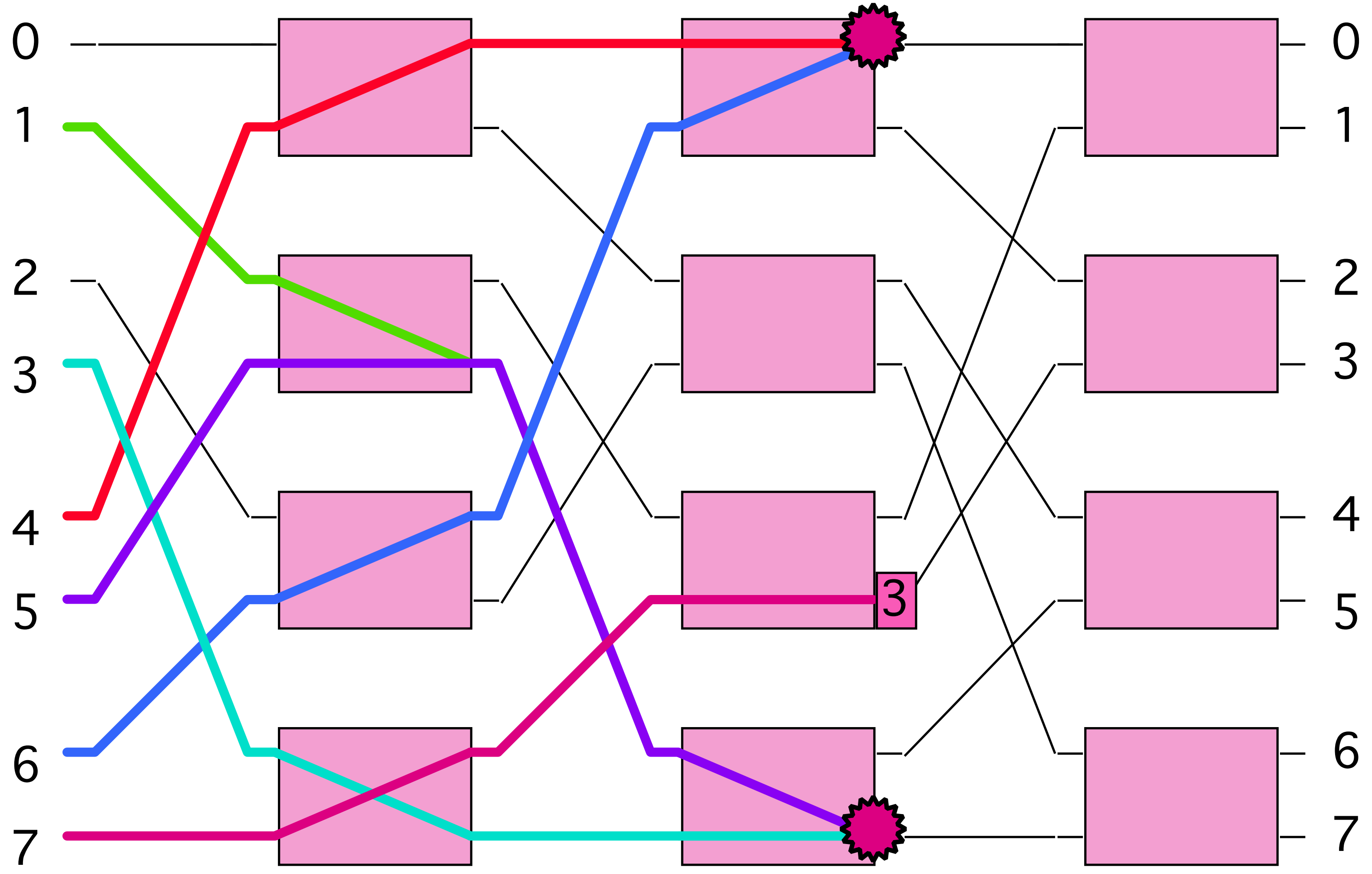
Performance Degradation



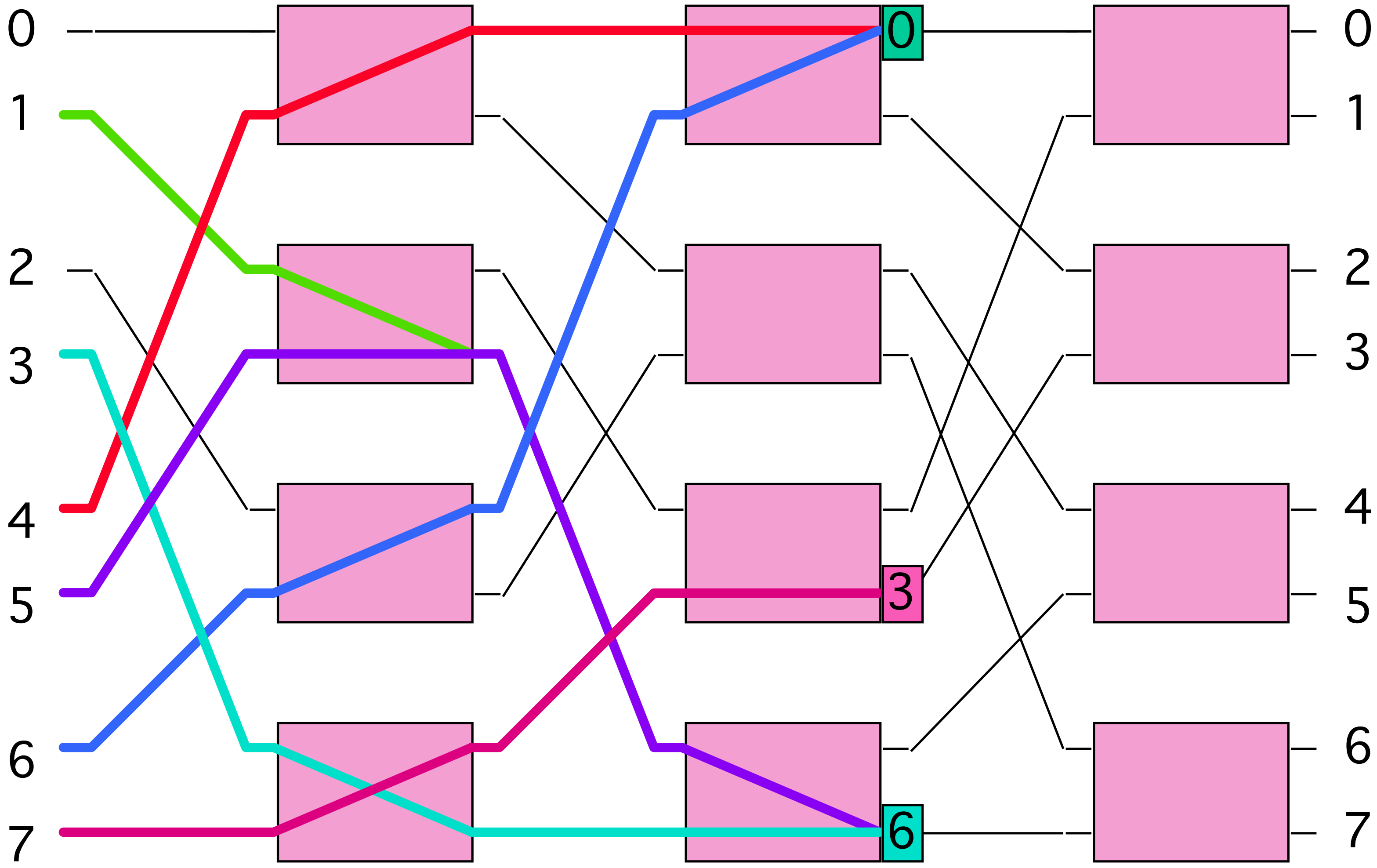
Performance Degradation



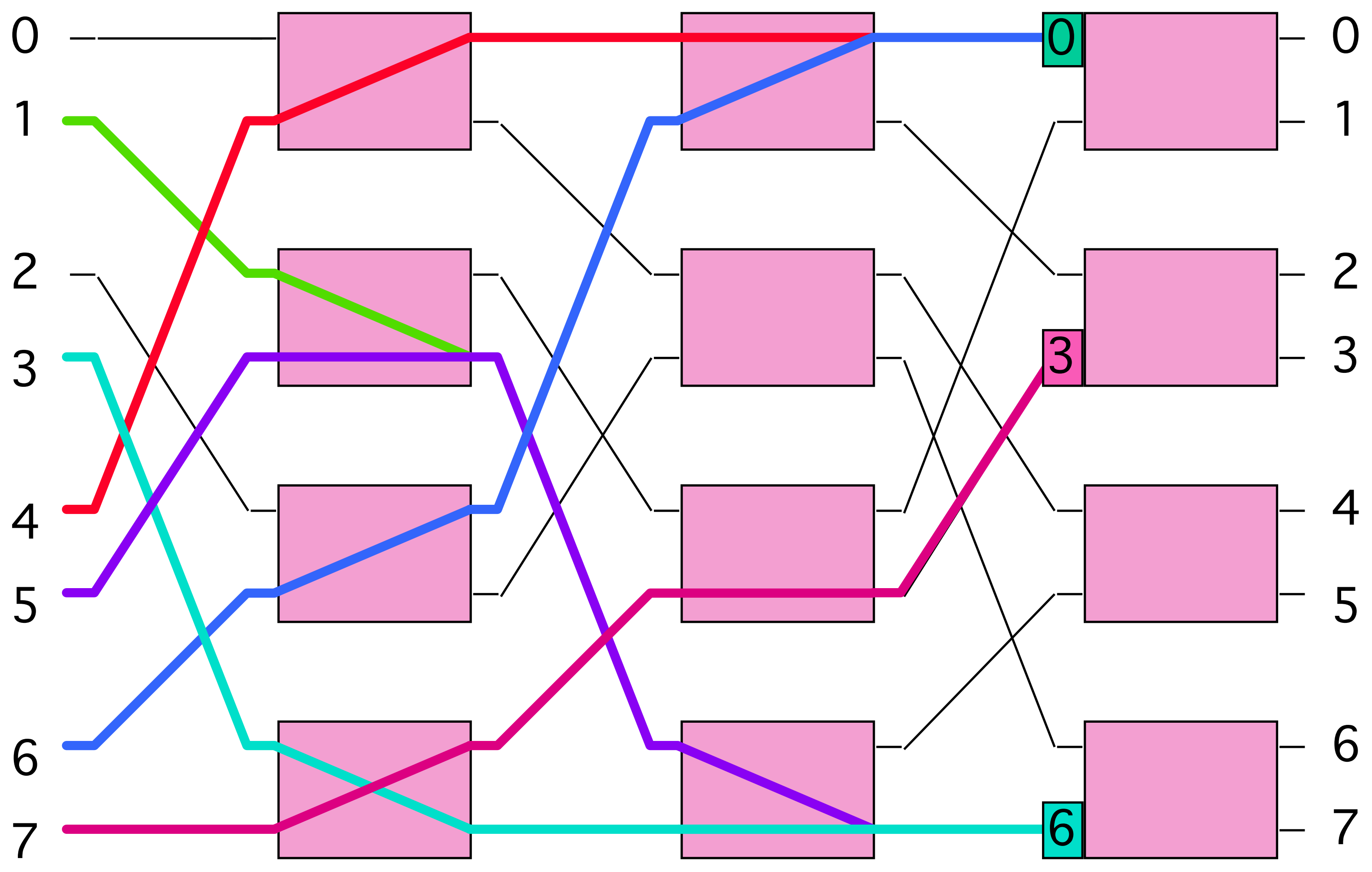
Performance Degradation



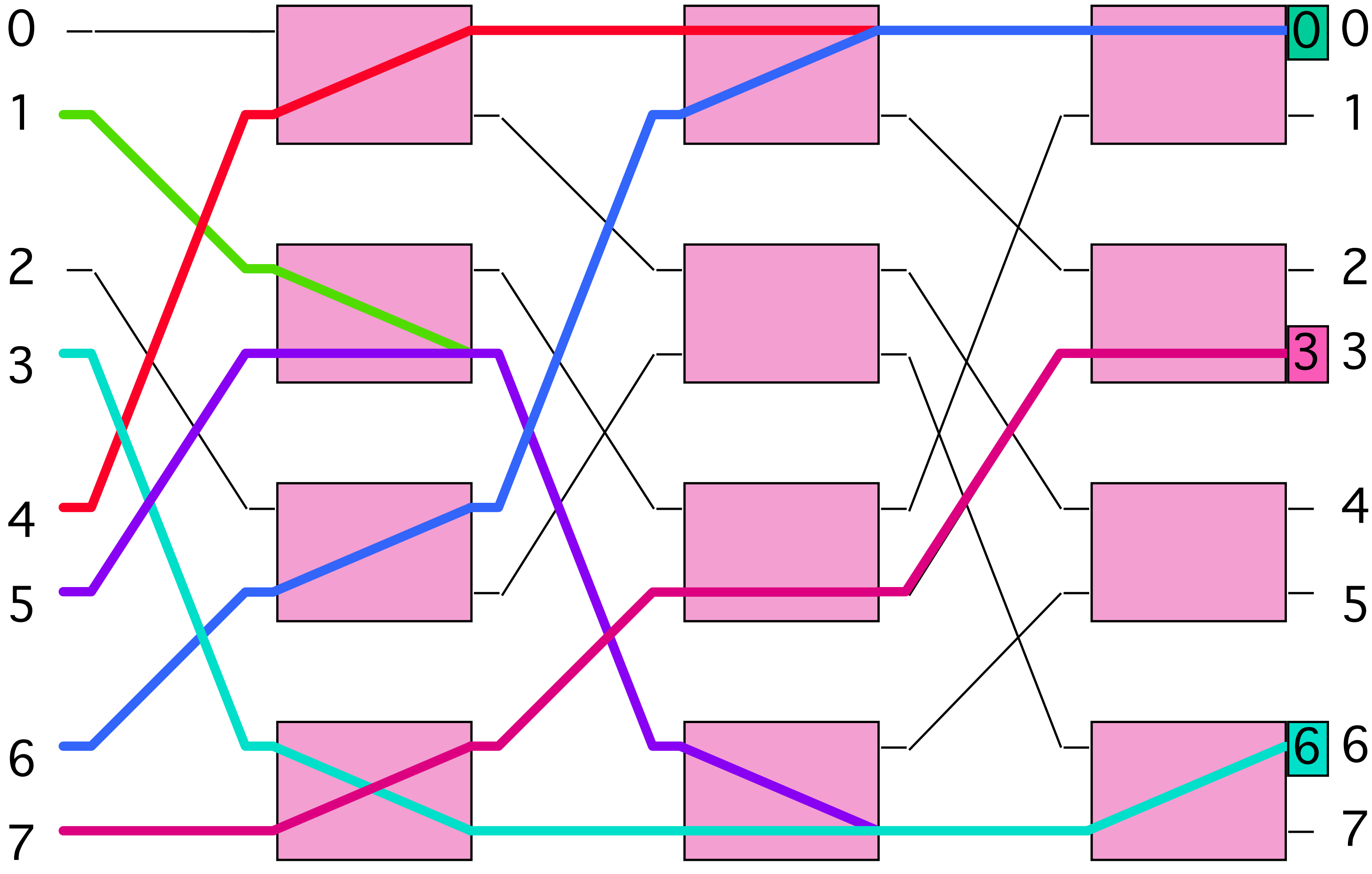
Performance Degradation



Performance Degradation



Performance Degradation



A Solution : Batcher Sorter

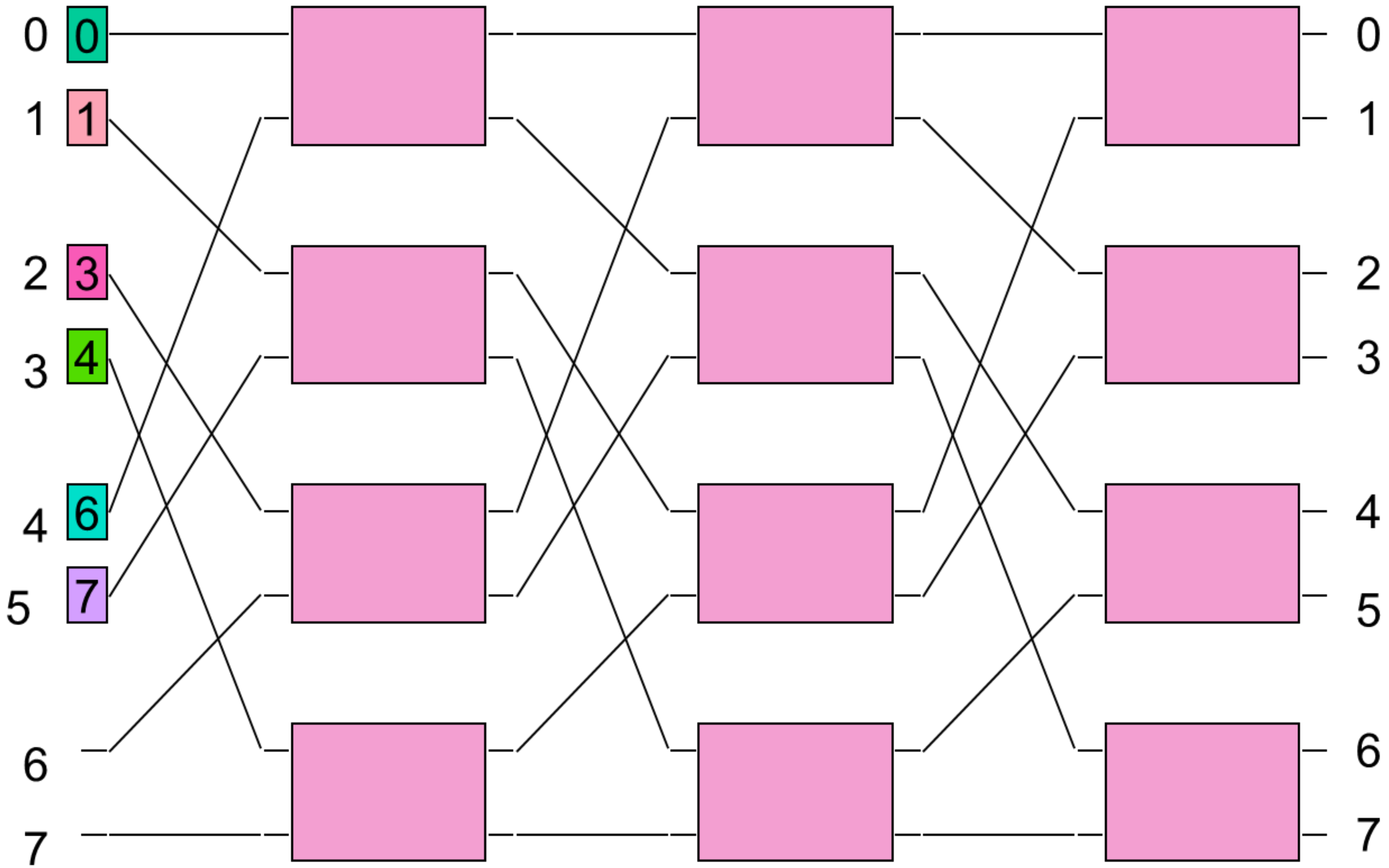
- ✓ One solution to the contention problem is to sort the cells into monotonically increasing order based on desired destination port

- ✓ Done using a bitonic sorter called a Batcher

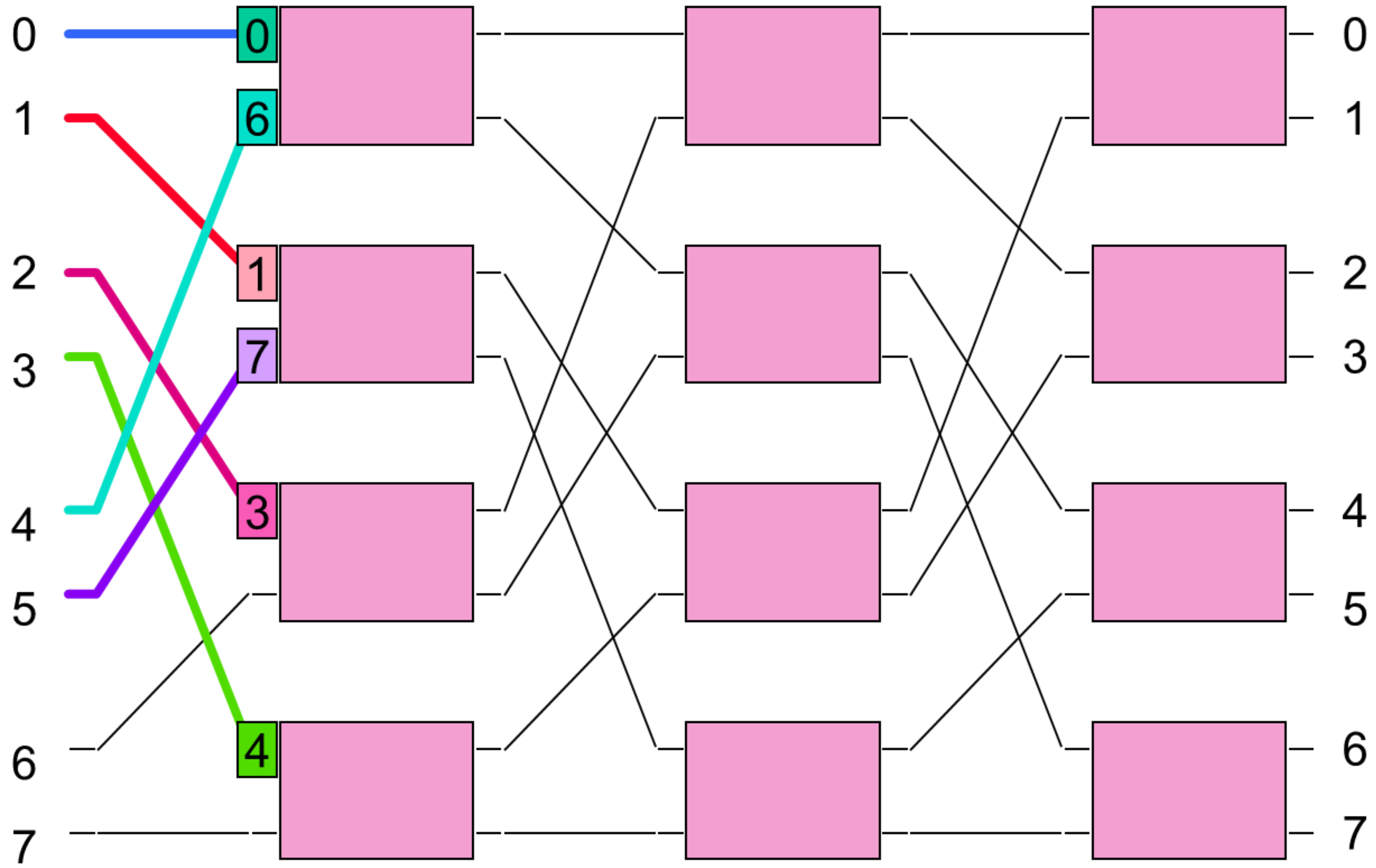
- ✓ Places the M cells into gap-free increasing sequence on the first M input ports

- ✓ Eliminates duplicate destinations

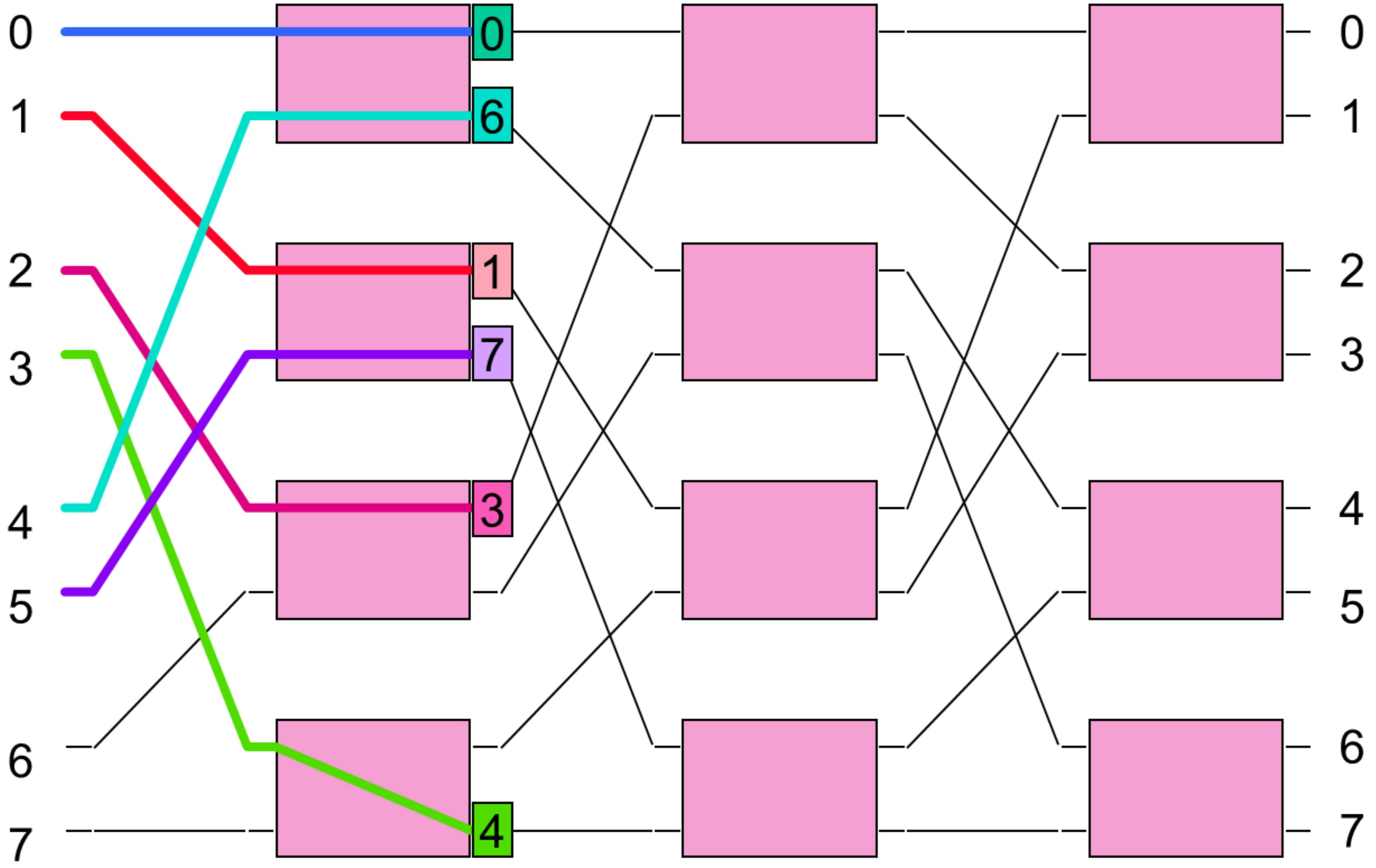
Batcher-Banyan Example



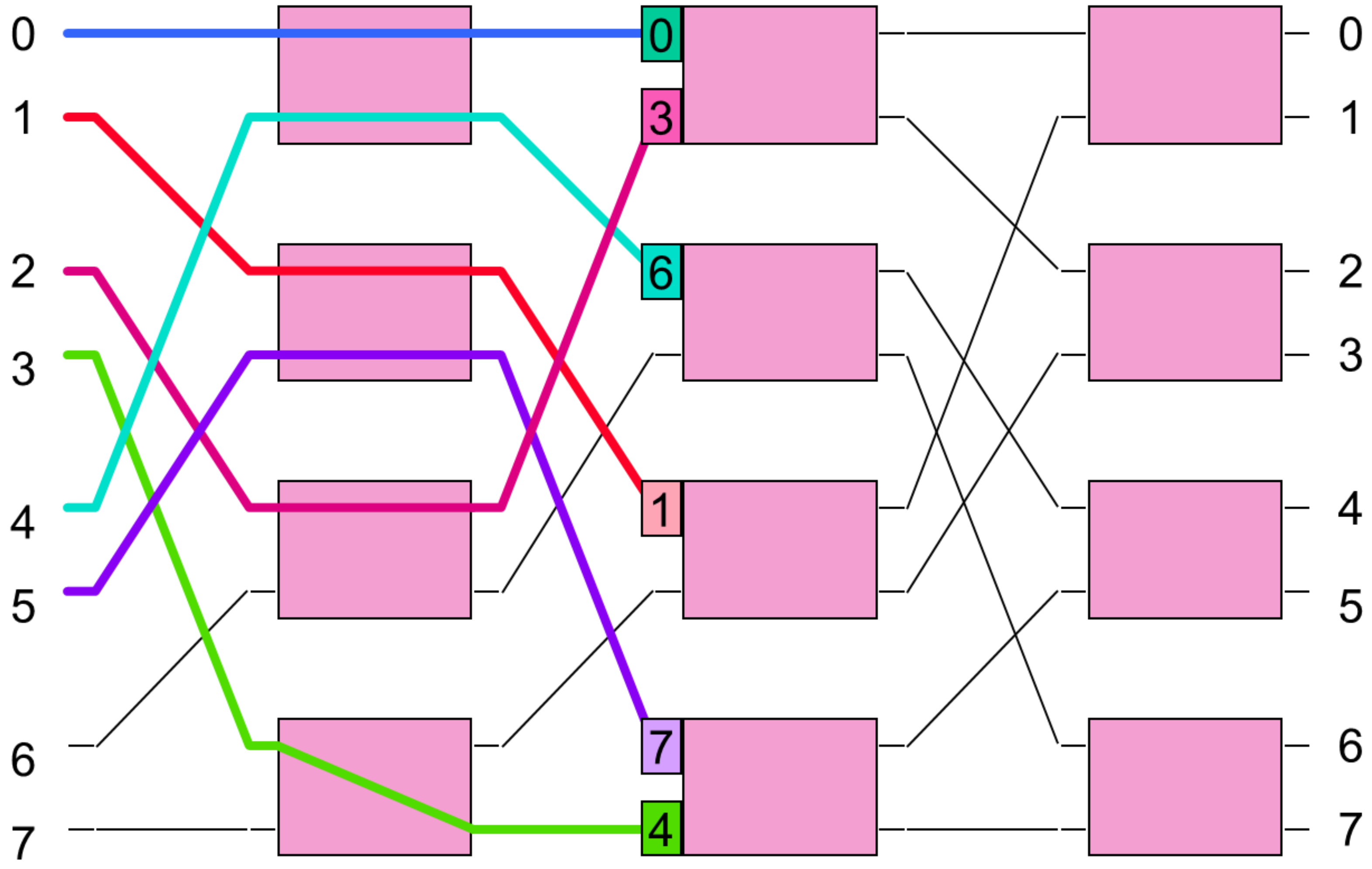
Batcher-Banyan Example



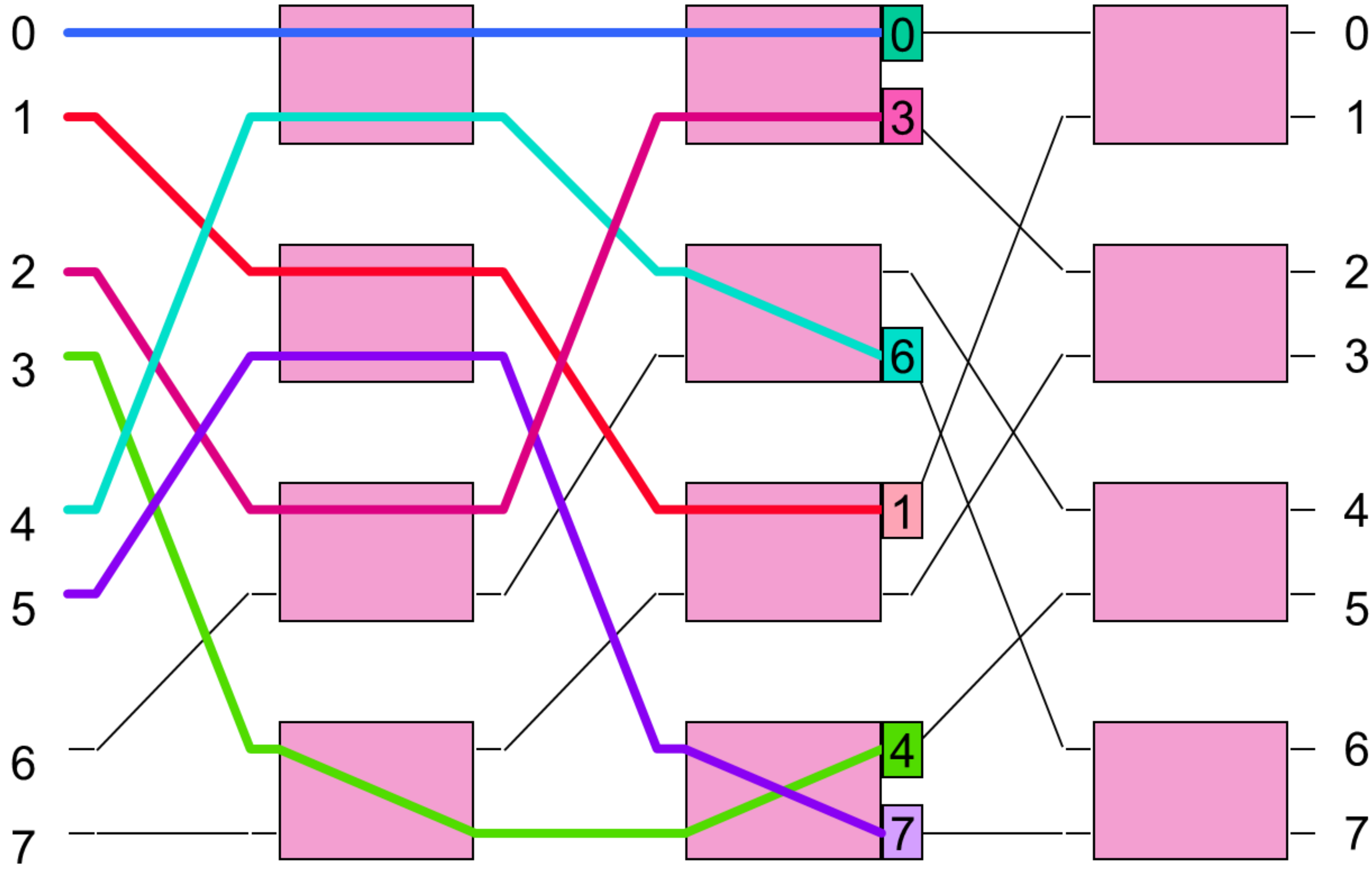
Batcher-Banyan Example



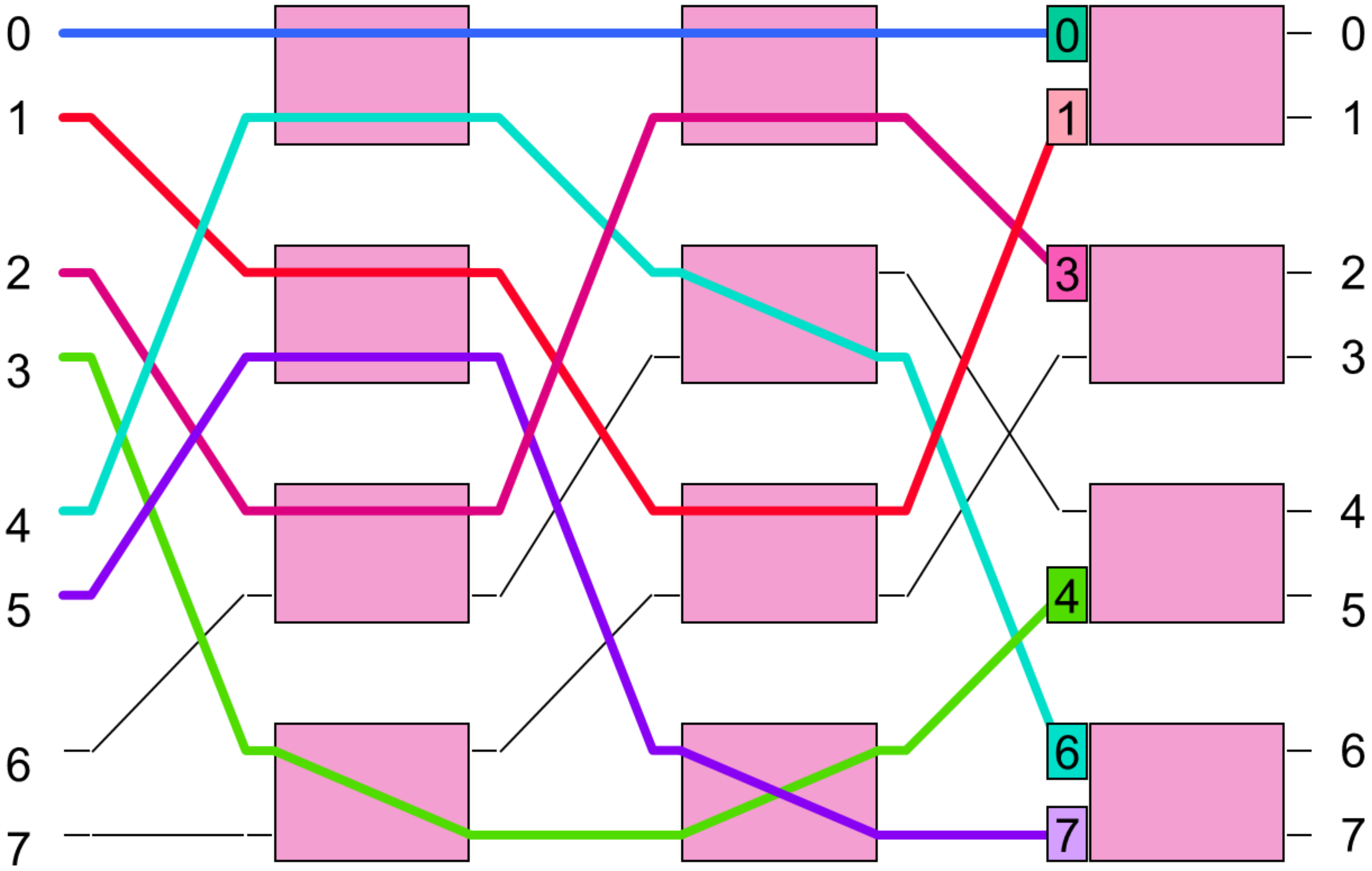
Batcher-Banyan Example



Batcher-Banyan Example



Batcher-Banyan Example



Batcher-Banyan Example