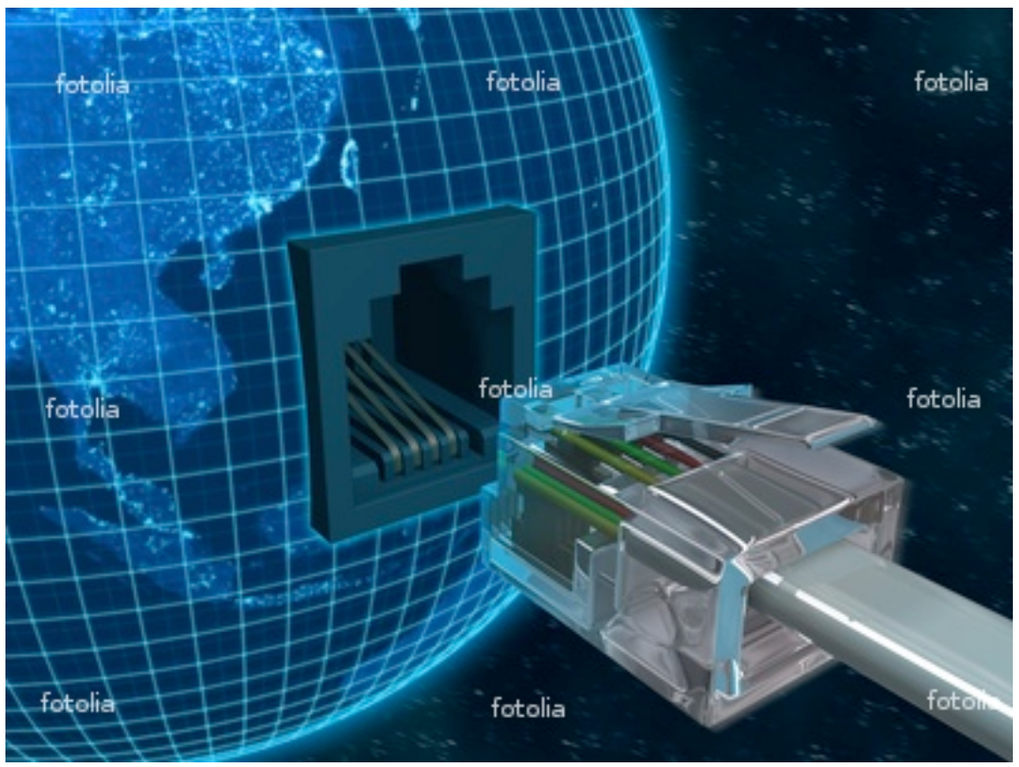
Direct Link Networks

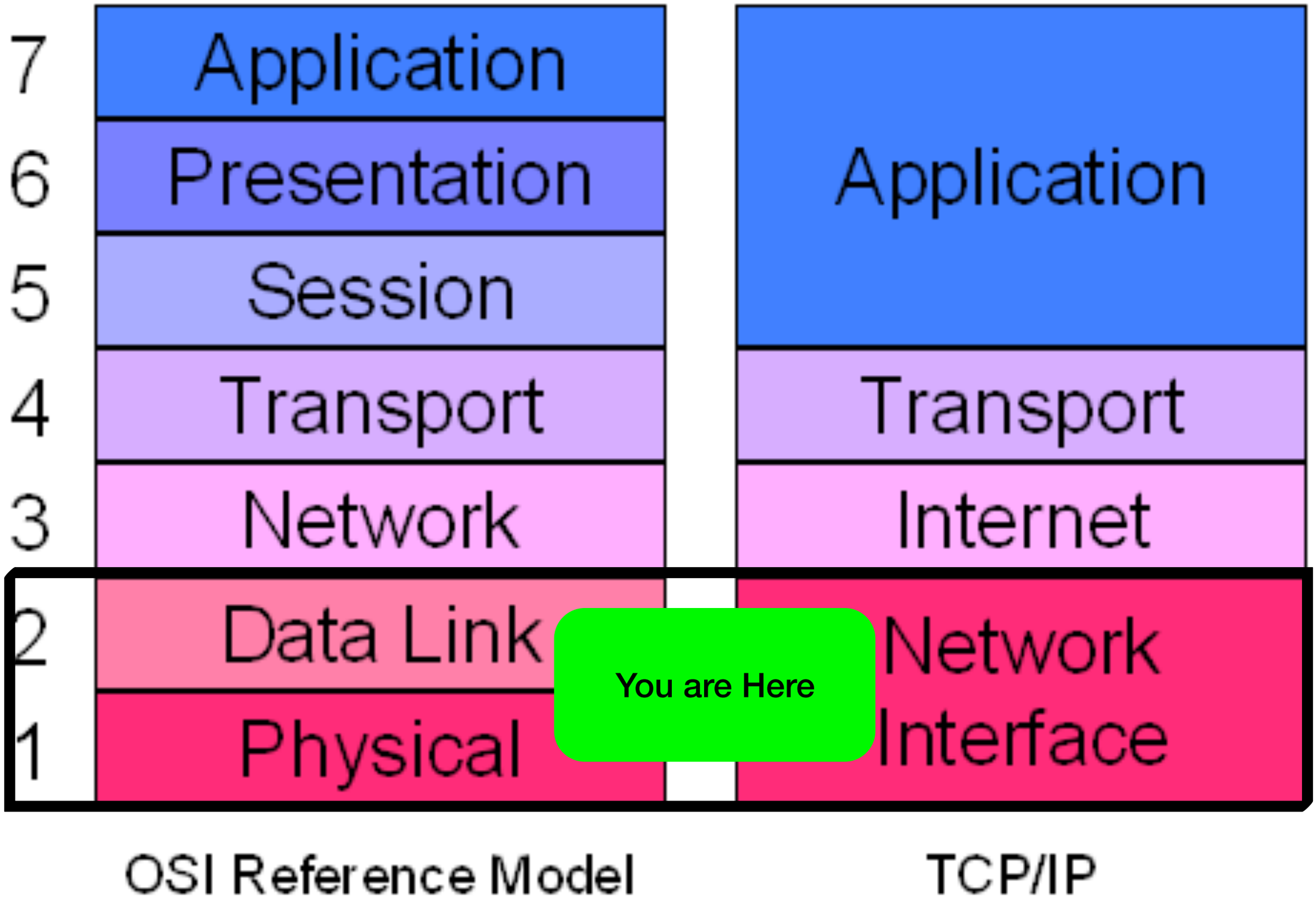
COS 460/540



How to physically connect hosts

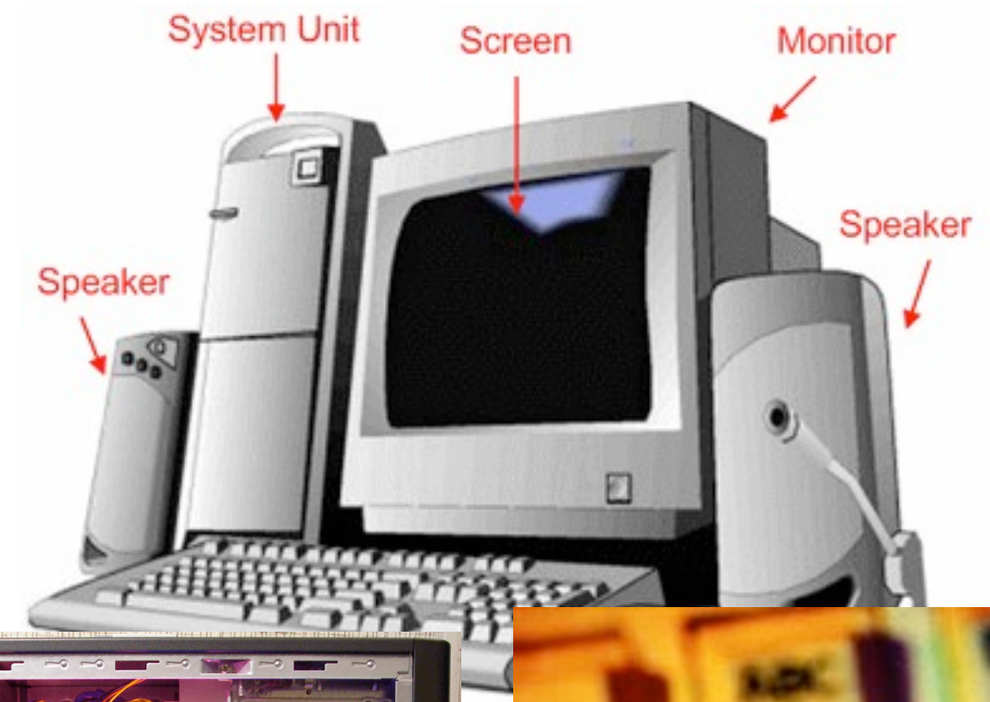
Direct Link Networks

- Hardware
- Encoding
- Framing & Error-Detection
- Reliable Transmission
- Examples (Ethernet & Wireless)

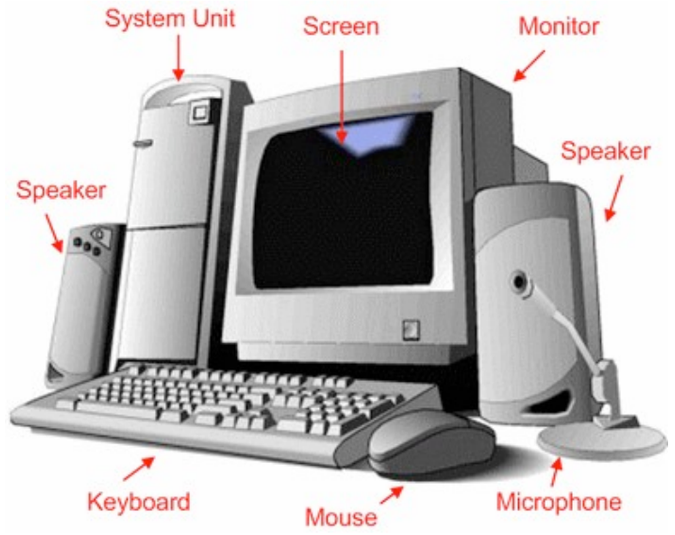

7
Application
6
Presentation
5
Session
4
Transport
3
Network
2
Data Link
1
Physical
Application
Transport
Internet
Network
Interface
You are Here
OSI Reference Model
TCP/IP

Hardware

- Nodes
- Links



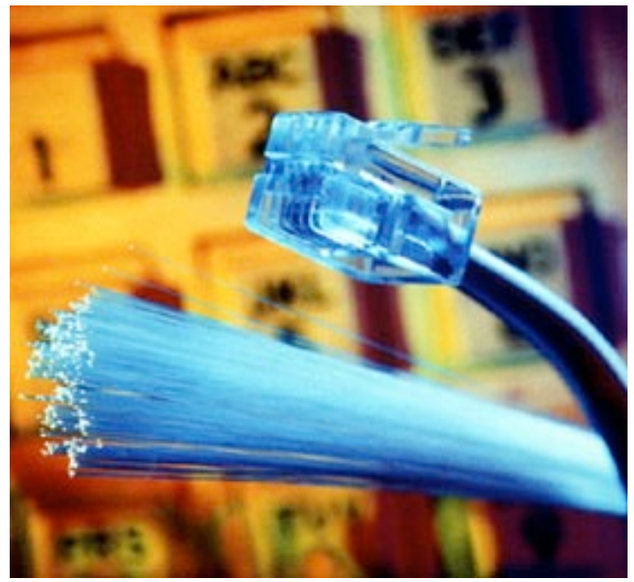
Nodes



- General Purpose Computer
  - Runs Application Software
  - Connects via Network Adapter
  - Limited Memory
  - Internal Bus = Internal Data Network

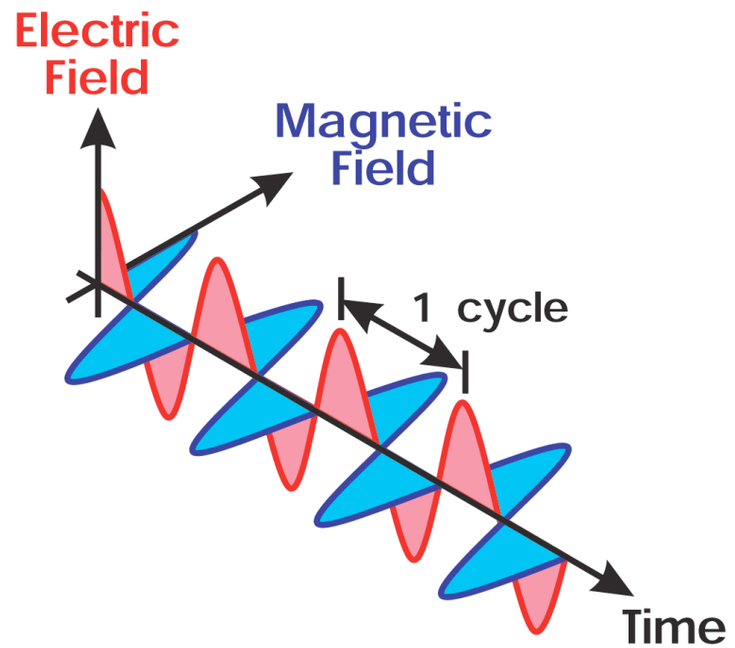
Links

- Physical Media
  - Copper
  - Coaxial Cable
  - Optical Fiber
  - Space



Physical Media

Carries
Electromagnetic Waves



- Frequency (Hz)
- Data is *encoded* in the signal - *modulation*
- One way or two way (half v full duplex)
- Signal degrades over distance

Cables

Distance and (max) Speed of different media

Media	Speed	Distance
Cat-5	100 Mbps	100 m
Coax	100 Mbps	200 m
Multimode Fiber	100 Mbps	2 km
Single-mode Fiber	10 Gbps	40 km

Last Mile Links

Technology	Speed Range
POTS	28.8 Kbps - 56 Kbps
xDSL	128 Kbps - 100 Mbps
4G/LTE	5 - 12 Mbps
Cable	1 - 40 Mbps (single channel)
FiOS	5 - 100 Mbps
WiMax	10 Mbps

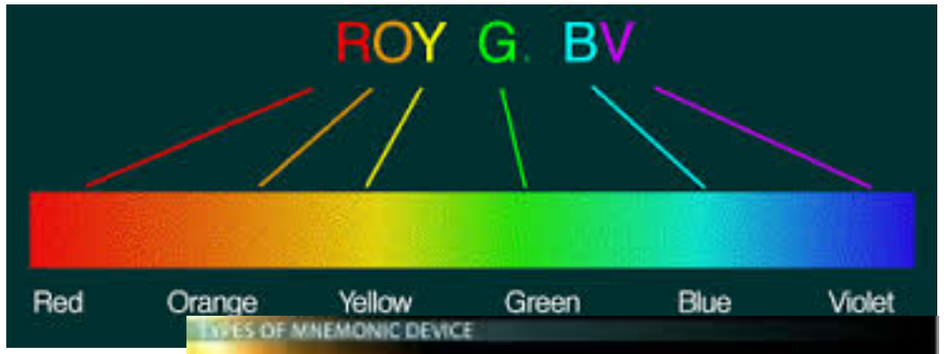
Direct Link Networks

✓Hardware

- Encoding
- Framing & Error-Detection
- Reliable Transmission
- Examples (Ethernet & Wireless)

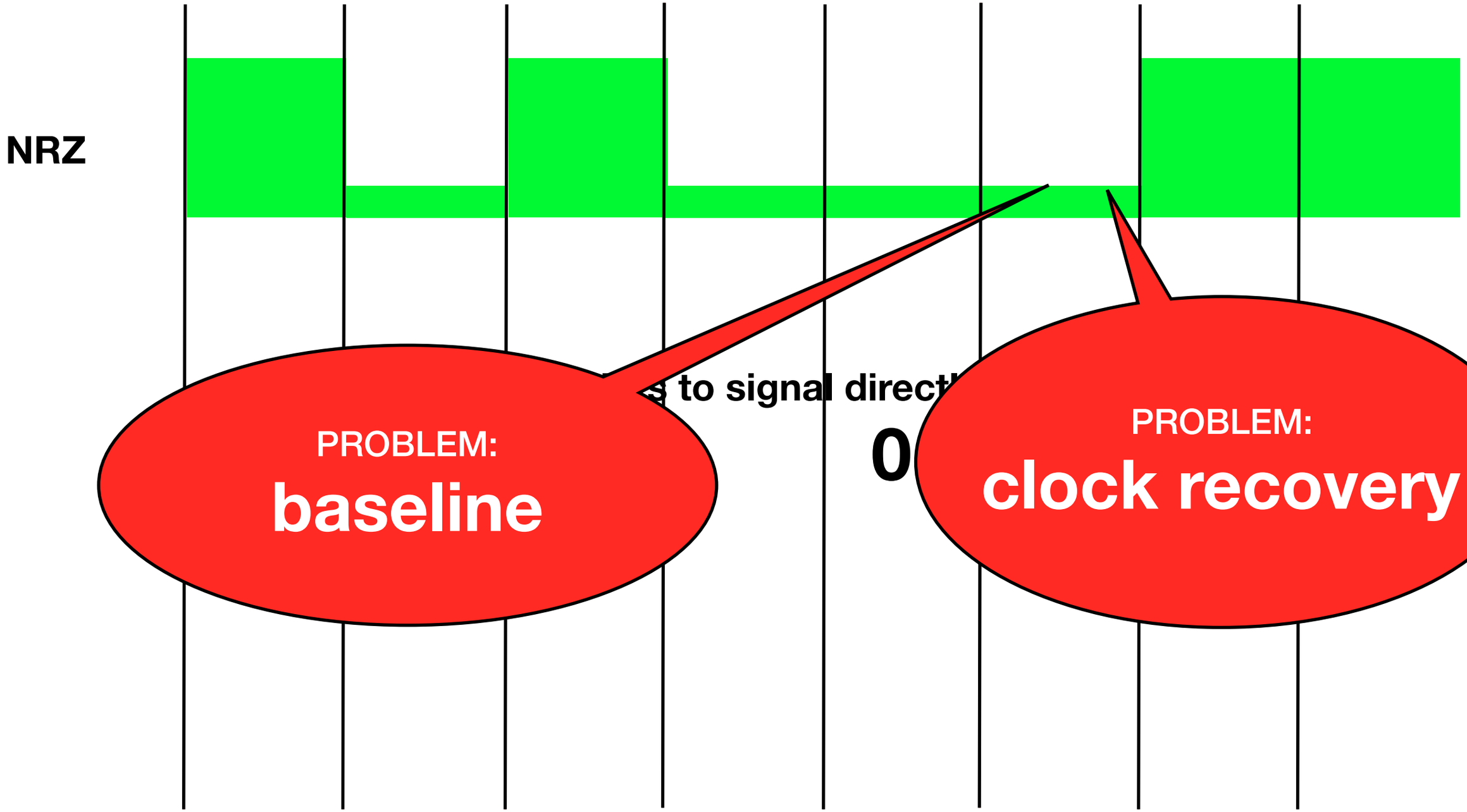
Encoding

- NRZ
- NRZI
- Manchester
- 4B/5B



NRZ

1 0 1 0 0 0 1 1

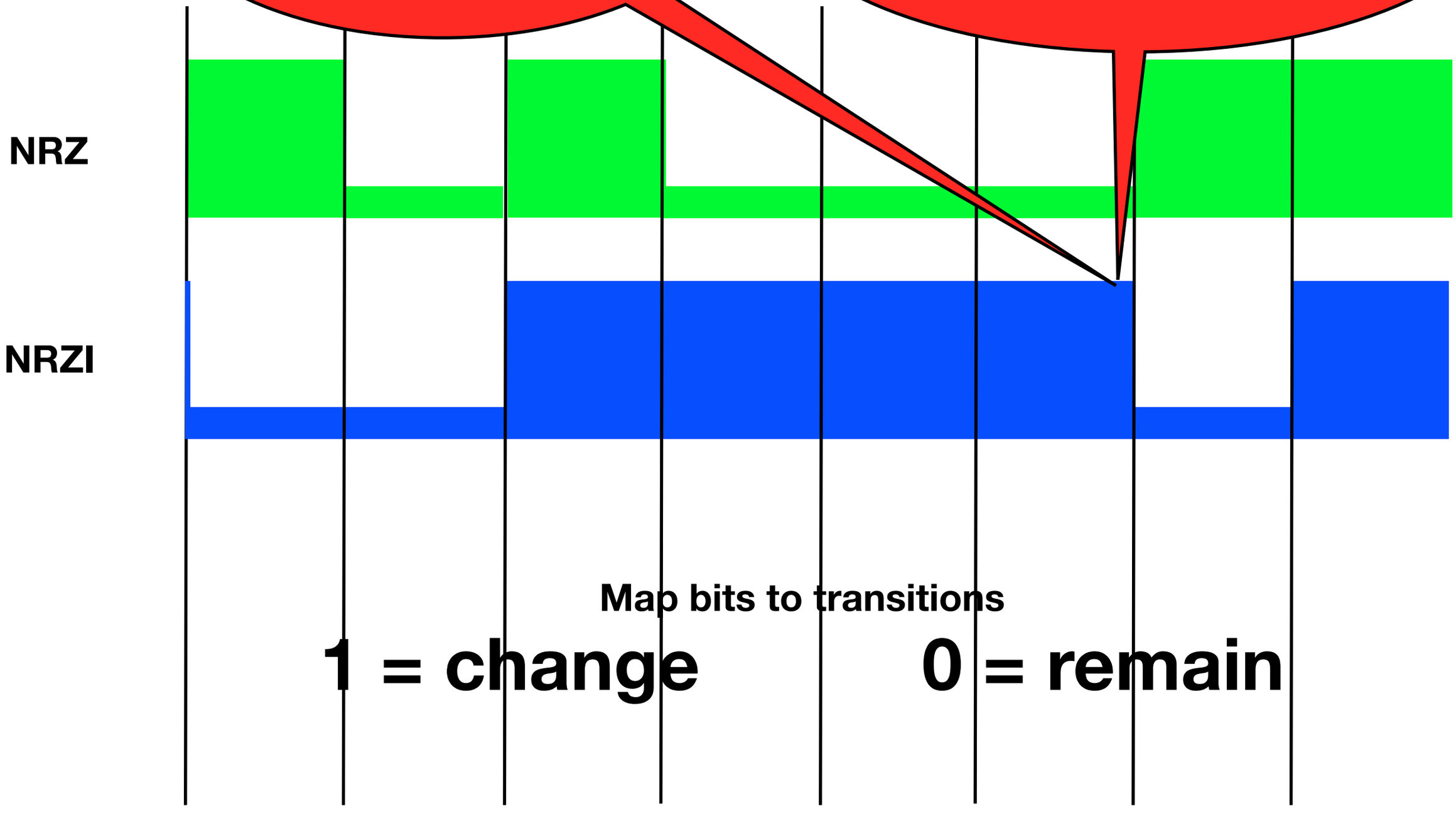


RZ

1

PROBLEM:
clock recovery

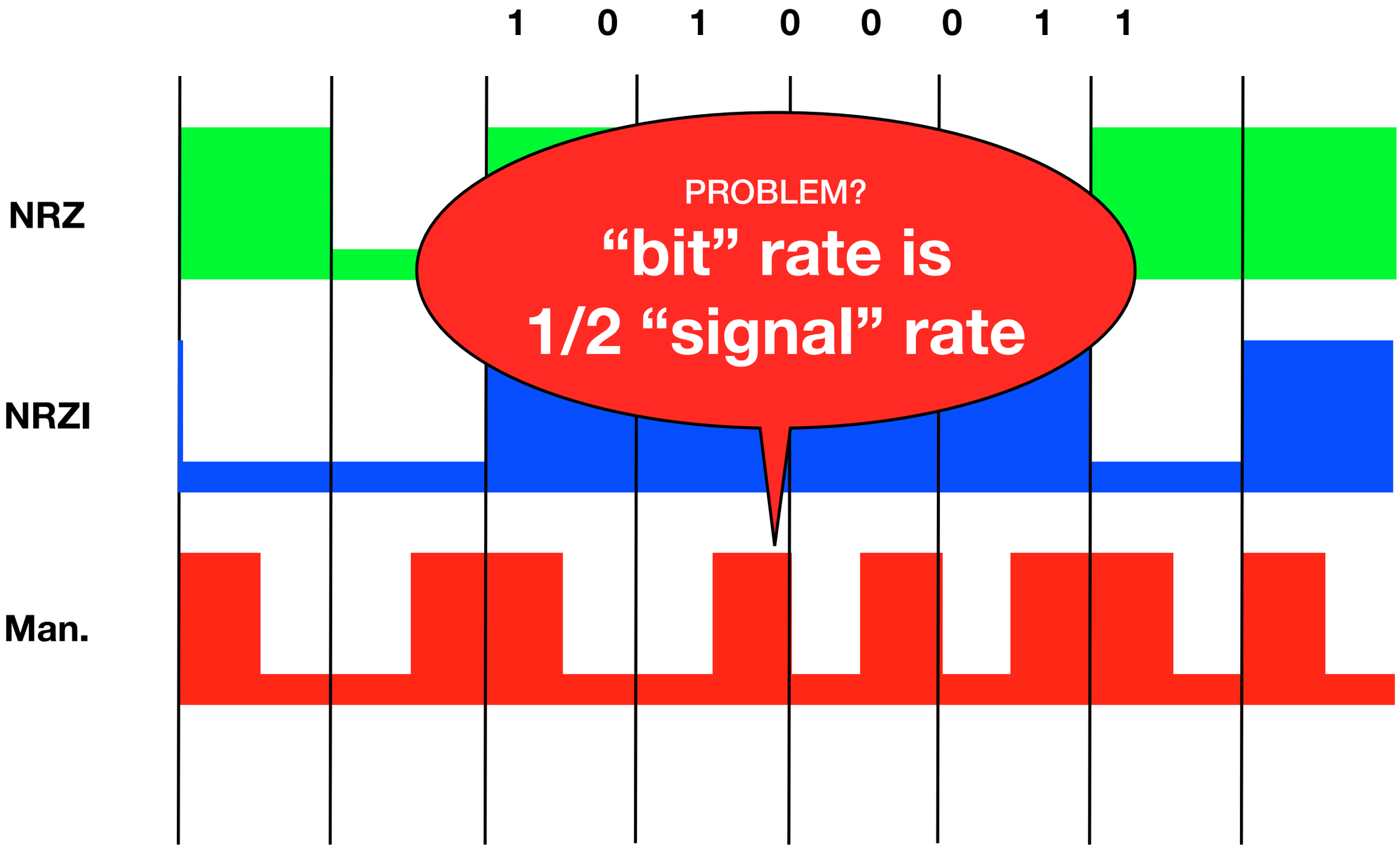
PROBLEM:
baseline wander
“1”s



Map bits to transitions

1 = change **0 = remain**

Manchester



4B/5B Encoding

- Solve NRZI problems
  - encode 5 bits for every 4
  - avoid repeated 0’s
  - ensure regular signal transitions

4B/5B Encoding

4B	5B	4B	5B
0000	11110	1000	10010
0001	01001	1001	10011
0010			10110
0011			10111
0100			11010
0101			11011
0110	01110		11100
0111	01111	1111	11101

PROBLEM:
“bit” rate is 7/8 “signal” rate

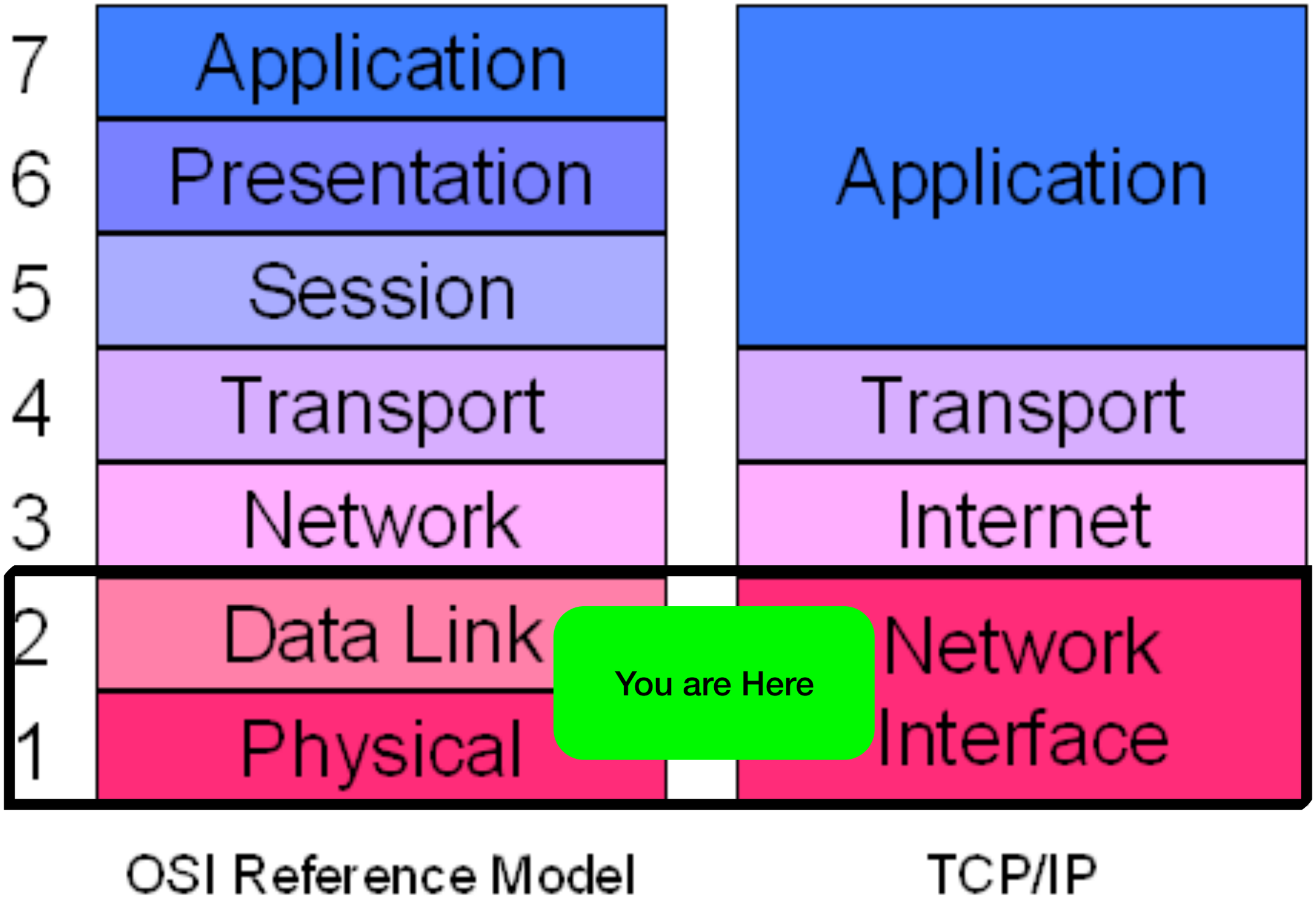
172 = 0xAC = 1010 1100 → 10110 11010

Direct Link Networks

✓Hardware

✓Encoding

- Framing & Error-Detection
- Reliable Transmission
- Examples (Ethernet & Wireless)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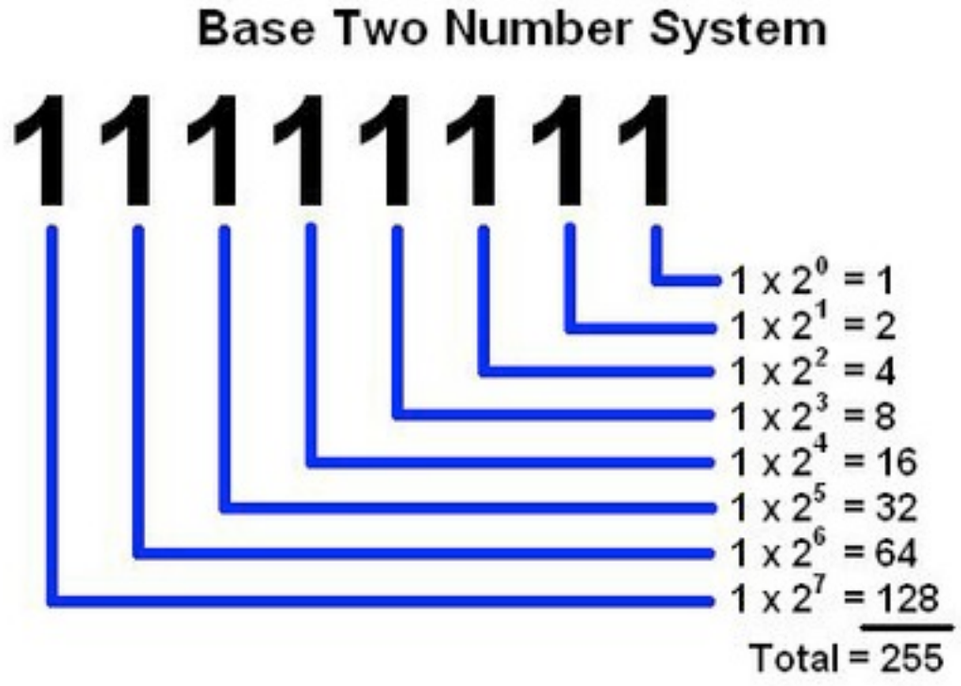
Framing

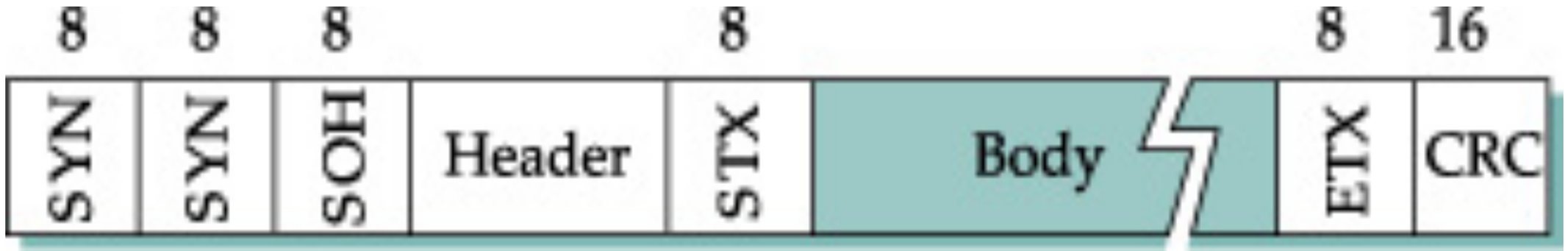
We can **transmit** and **receive** bits; but how do we recognize individual **messages**?

Framing

- **Byte-Oriented**
- Bit-Oriented
- Clock-Based



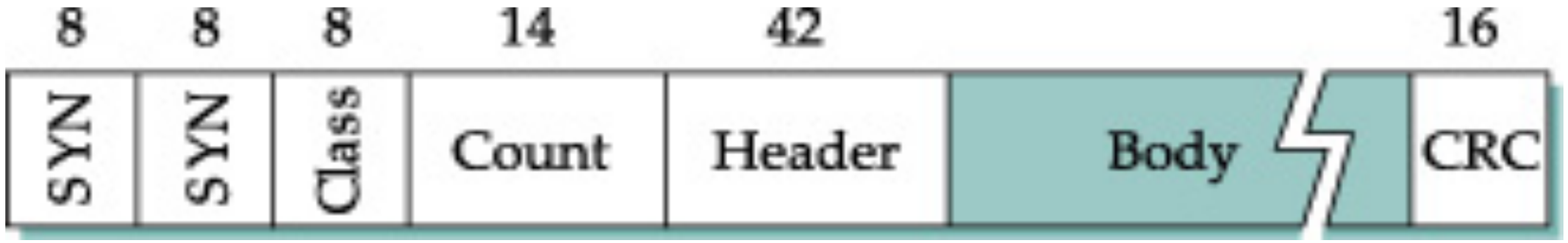
Sentinel Based



Use **special** characters, wrap message

- SYN, SOH, STX, ETX, DLE, ...
- Indicate where things begin… and end
- Problems: corrupt ETX

Byte Counting



Include count of bytes in message

Problems: corrupt count field

Bit-Oriented

- Frame is a collection of bits
- STX is distinguished bit sequence
  - 01111110 (six 1’s)
  - used when link is idle as well
  - bit-stuffing
    (after 5 1’s stuff in a 0 & ignore)

Clock Based

- Works well on optical networks
- fixed frame sizes; 9 rows x 90 bytes
- rigid (and large) definition
- “special” bit pattern
  - at start of frame
  - every 810 bytes

Error **DETECTION**

- Parity
- 2D Parity
- Checksum
- Cyclic Redundancy Check (CRC)

Parity

1010101p **Even = 0**
Odd = 1

- Simple method to detect bit errors
- 1 bit parity for each 7 bits of data
- 7/8 of data rate (87%)
- only odd # of errors (bad)

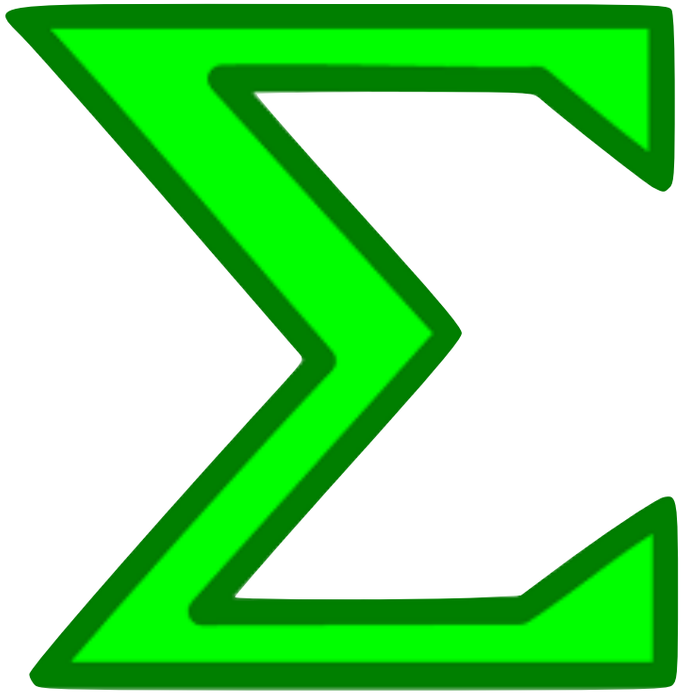
2D Parity

- Compute across 7 rows as well as 7 columns
- 7/8 of 7/8 data rate (76%)
- catches multi-bit errors (good)

1010101p
1110001p
1011010p
....
pppppppp

Internet CheckSUM

- Add up all the words and transmit the sum
- Truncate to 16 bit word
- Much better on “bandwidth”
- Misses 1/65k errors



CRC

- message = 10101010
- $M(x) = 1x^7 + 0x^6 + 1x^5 + 0x^4 \ldots = x^7 + x^5 \ldots$
- P(x) = message bits + CRC bits such that

  $P(x)/C(x) = 0$

- C(x) chosen based on common errors

Direct Link Networks

✓Hardware

✓Encoding

✓Framing & Error-Detection

- Reliable Transmission

- Examples (Ethernet & Wireless)

Reliable Transmission

- Stop and Wait
- Sliding Window
- Concurrent Logical Channels

ARQ

Automatic Repeat Request

Tools:

- acknowledgement (ACK)
- timeout

Card Tricks #1

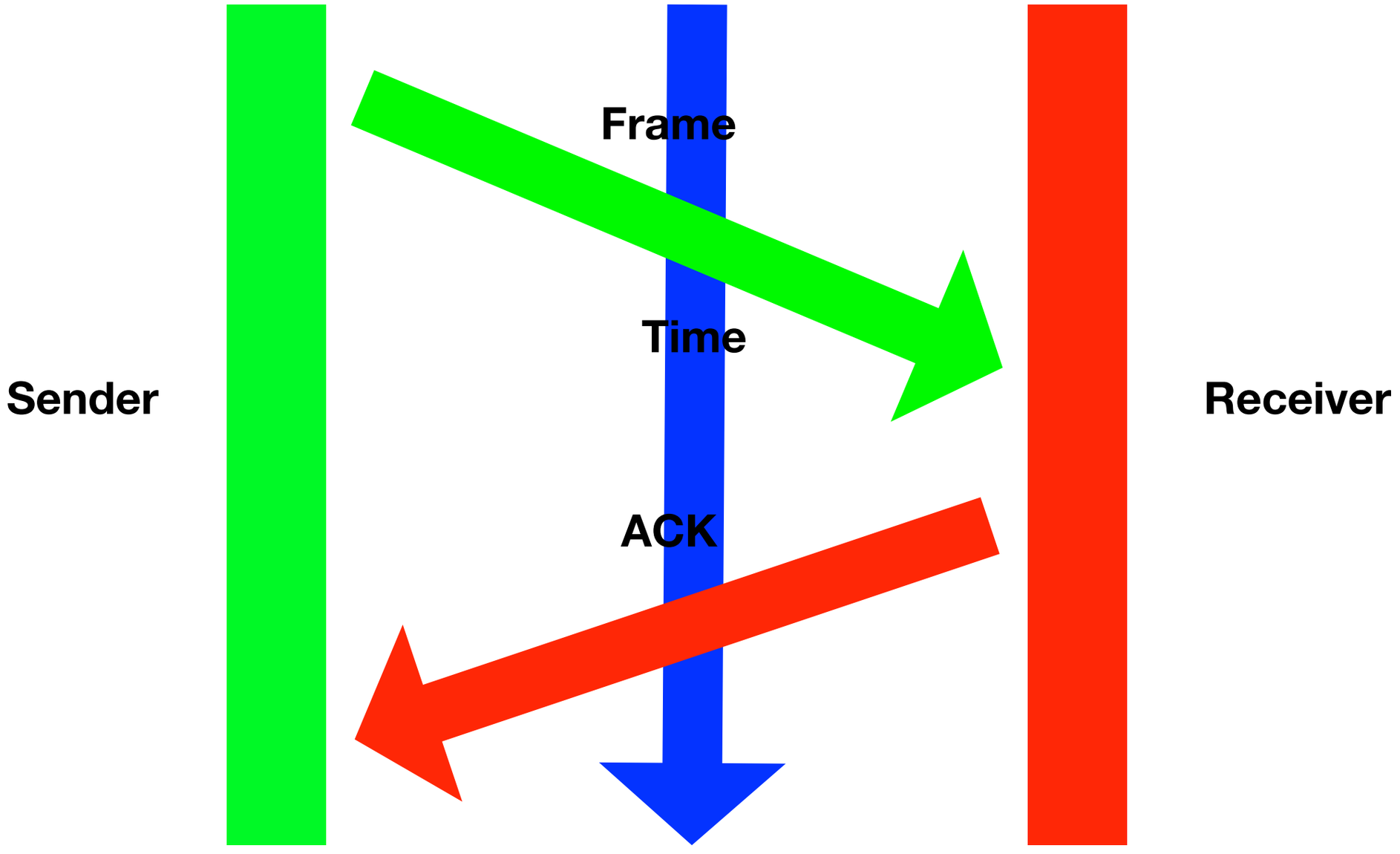
Sender

- Order the cards in your hand
- pass them one at a time to your partner
- Wait for an acknowledgement (matching card) before passing the next card

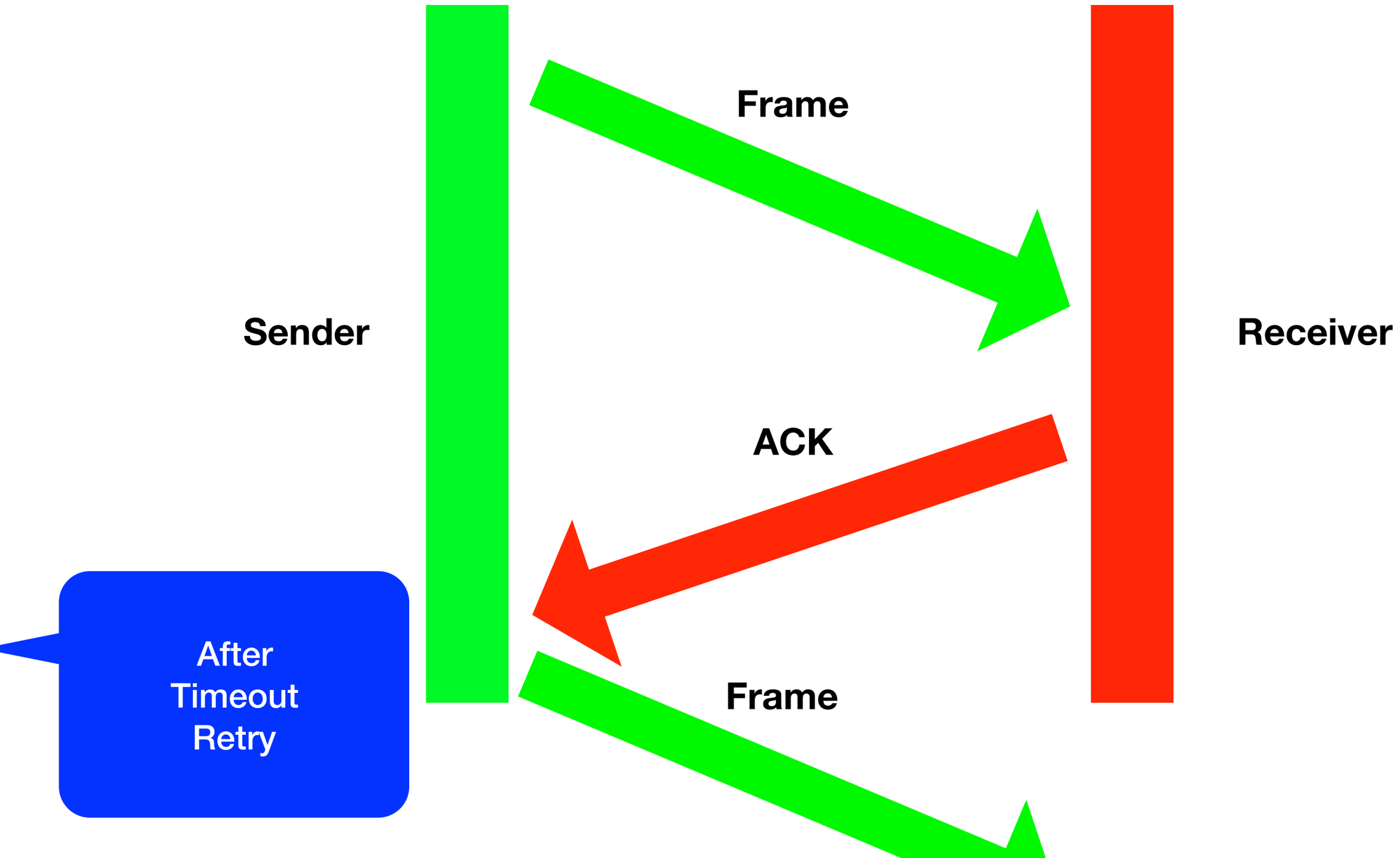
Receiver

- Order the cards in your hand
- Take the sender cards one at a time into your hand
- Keep/assemble them in order
- Return an acknowledgment for the received card

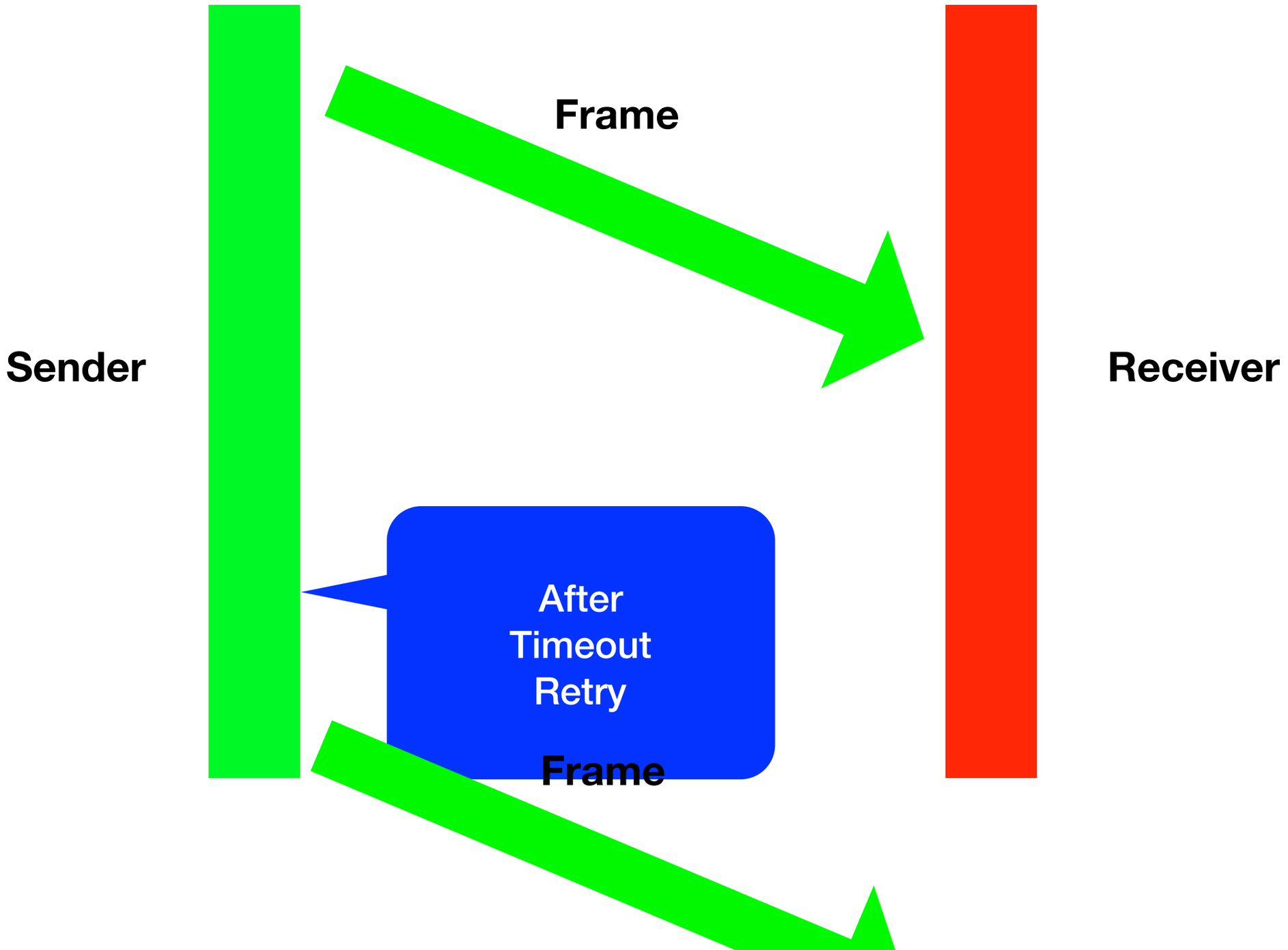
Stop and Wait



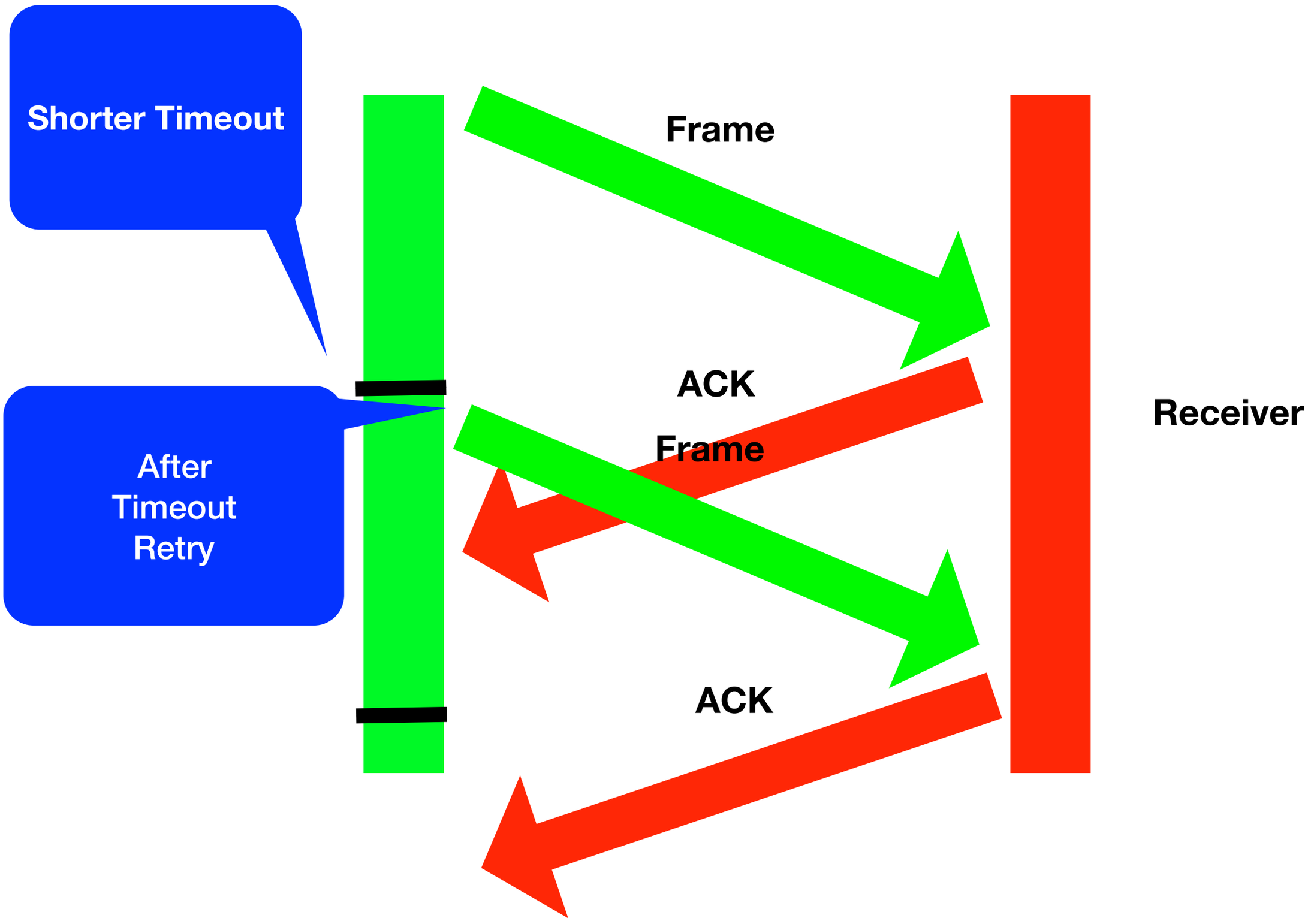
Stop and Wait



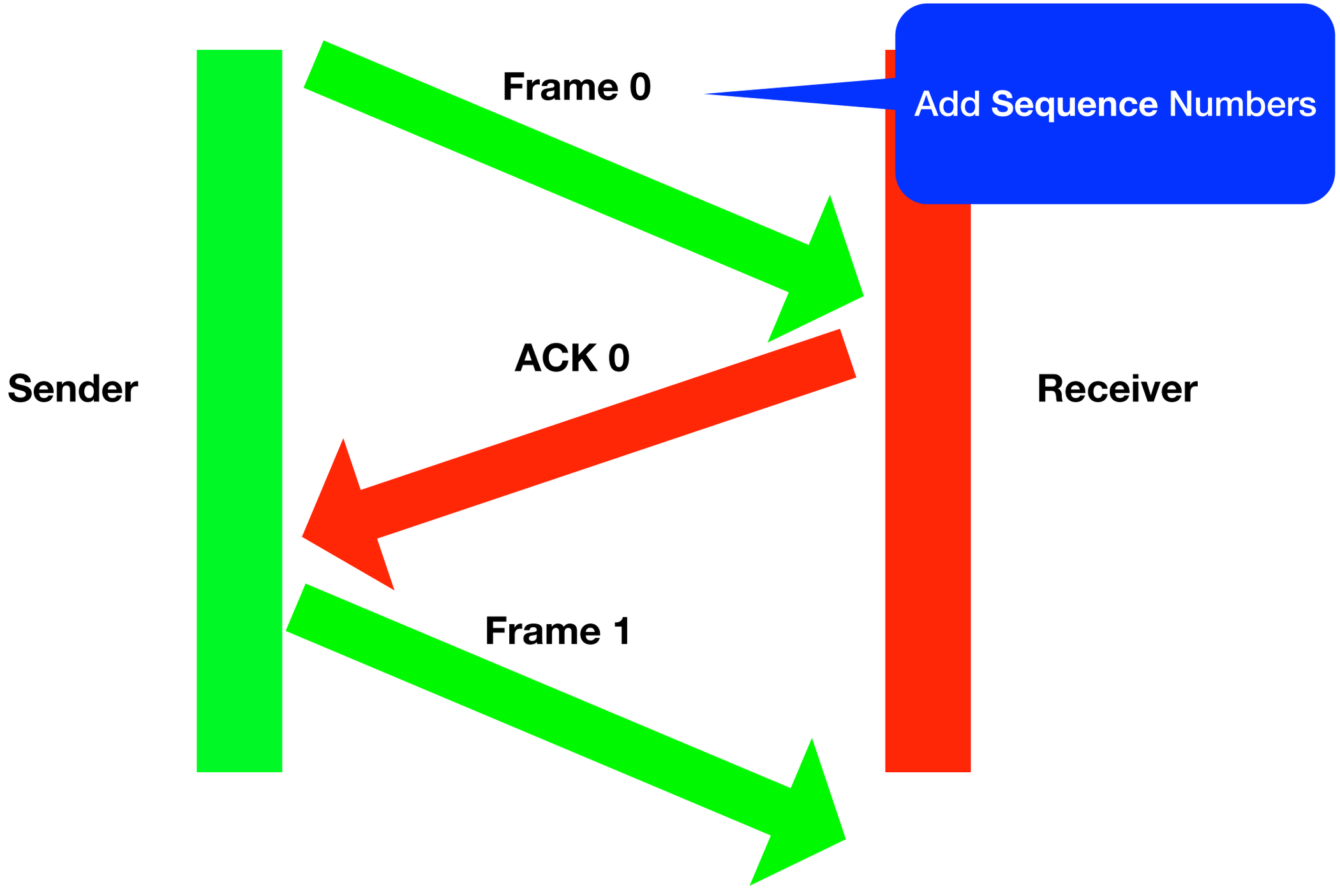
Stop and Wait



Stop and Wait



Stop and Wait



Stop and Wait

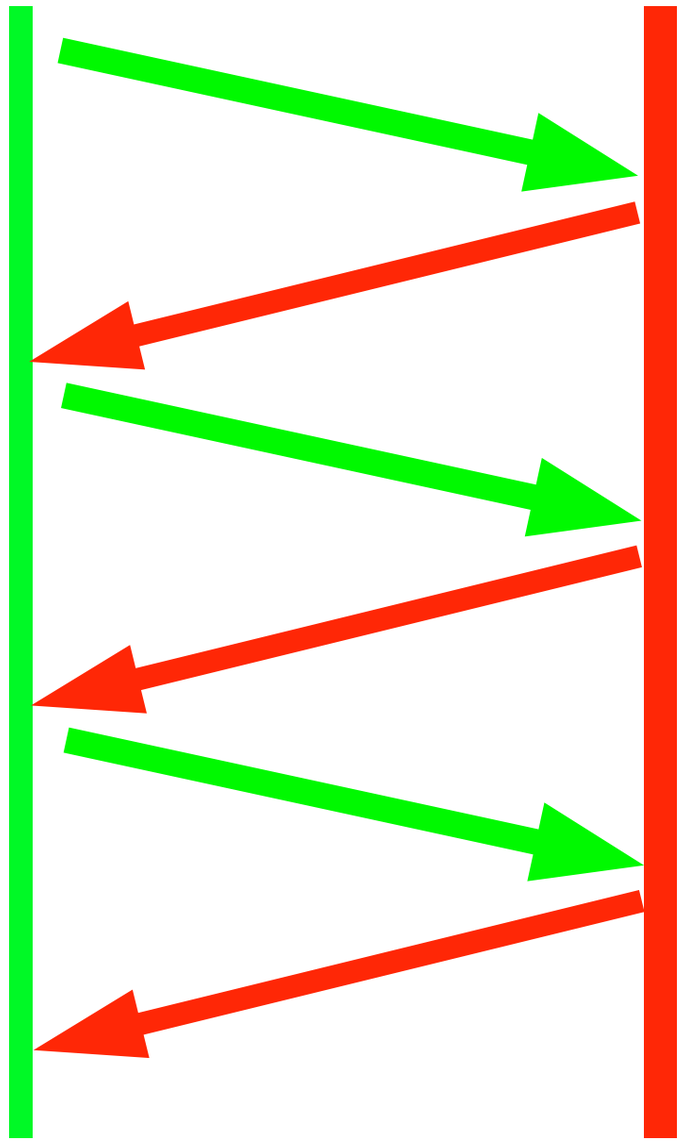
An Example:

1.5Mbps link

45ms RTT

1KB frames

Send 8KB of data...



Stop and Wait

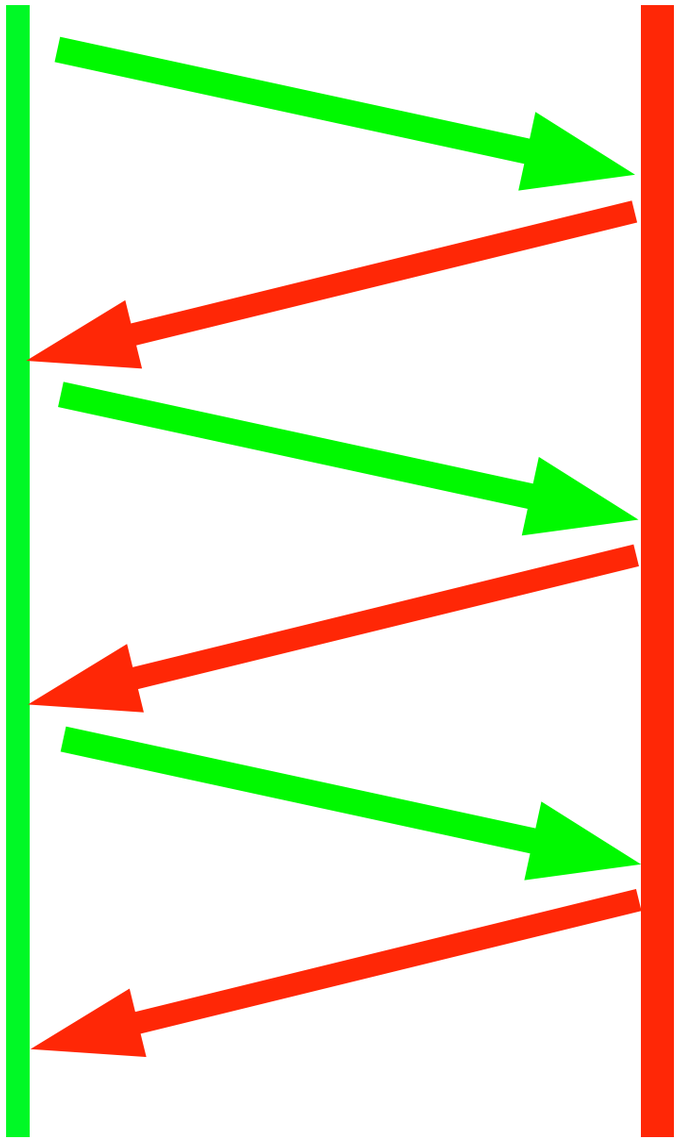
Sending Rate

1KB every 45ms

(1024 x 8) / 0.045

182 Kbps

on a 1.5Mbps link!



Stop and Wait

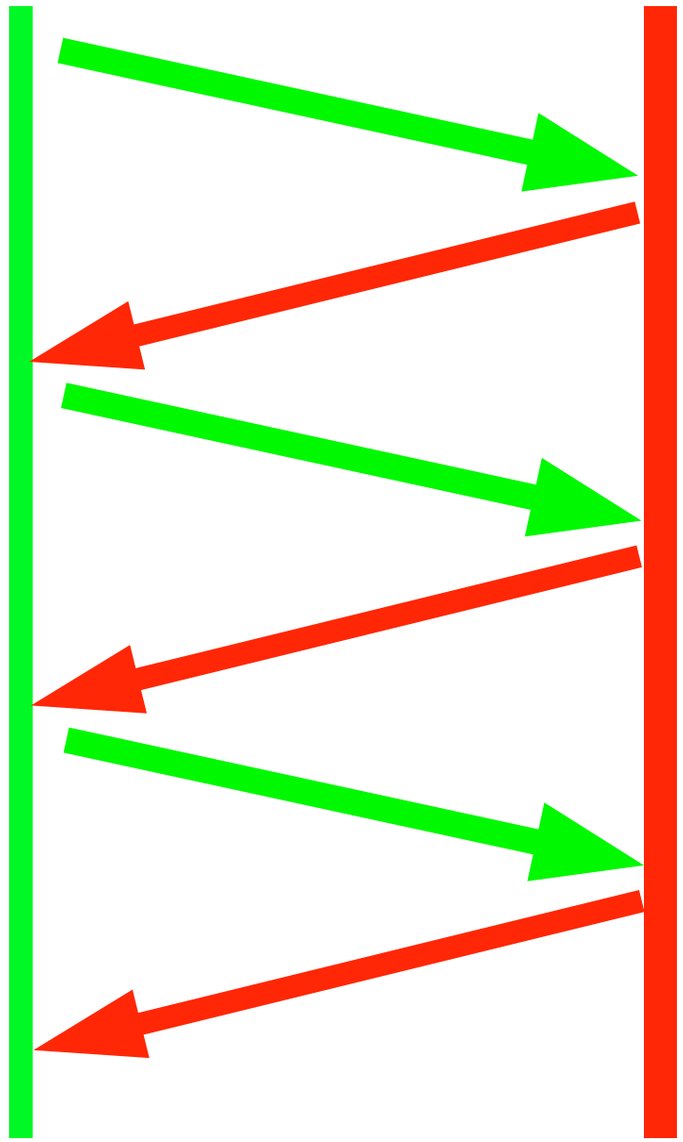
The “pipe” is not full

we could have…

delay x bandwidth

67.5Kb

on the wire



Card Tricks #2

Sender

- Shuffle the cards in your hand
- pass them two at a time to your partner (not necessarily in order)

Receiver

- Take the cards one at a time into your hand
- Reorder them as you get them
- Pass an acknowledgement card for the highest in-sequence card you have

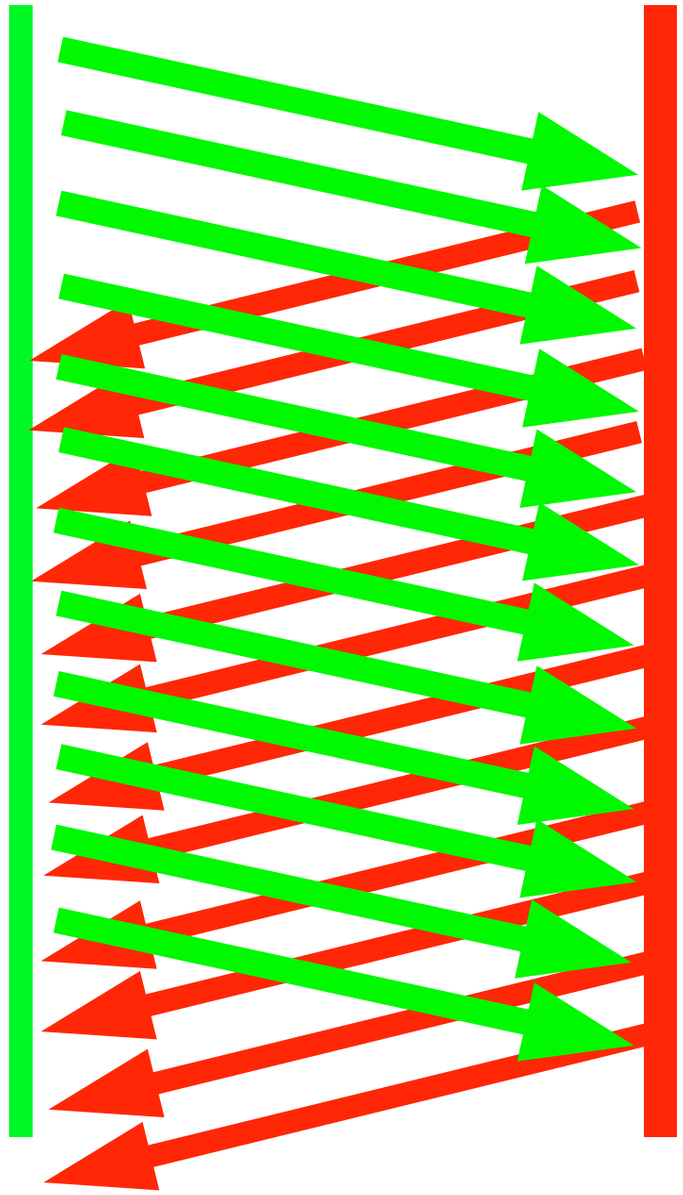
What do you acknowledge? How “big” can your hand be?

Sliding Window

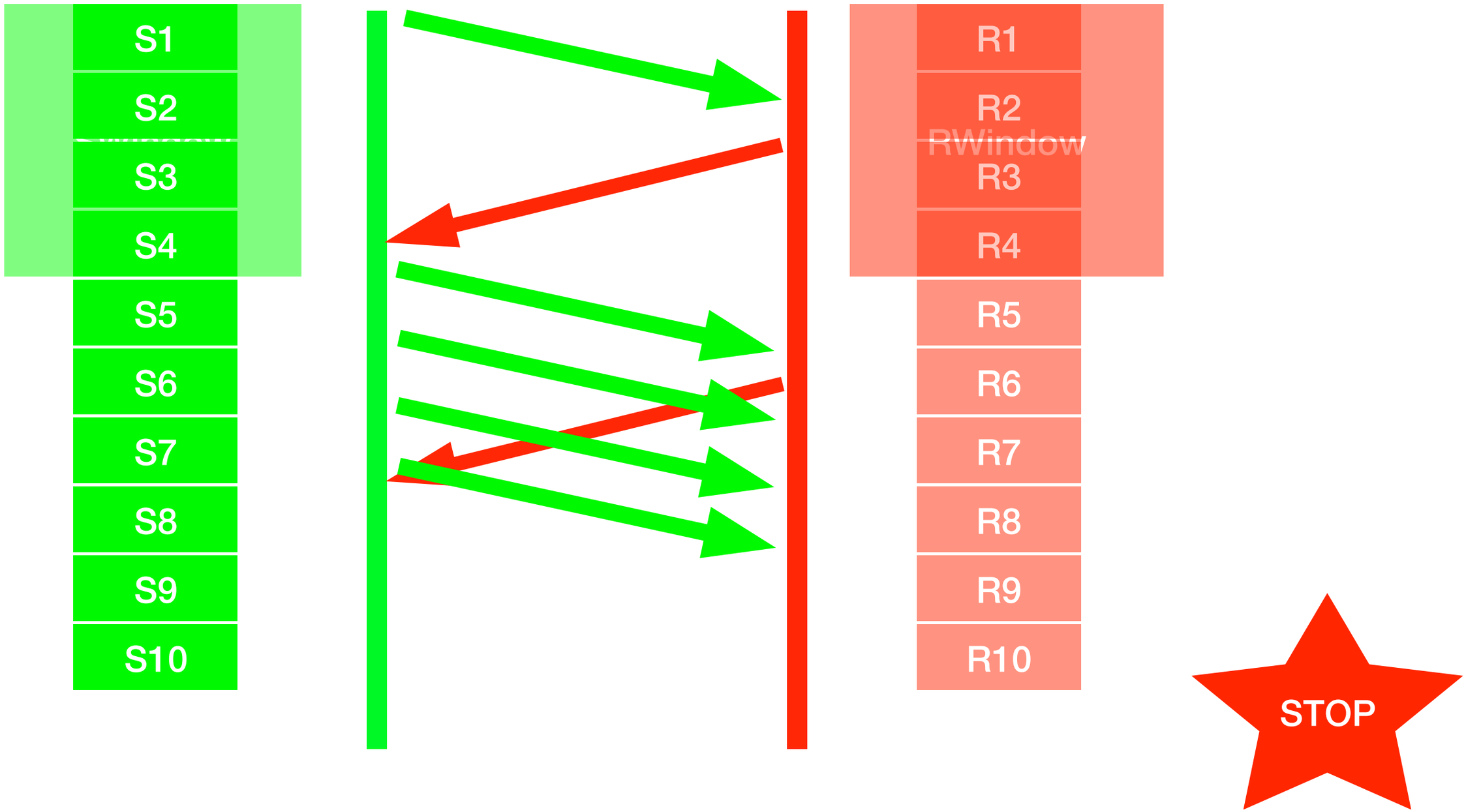
Keep the “pipe” full

Overlap **sending** data and **acknowledgements**

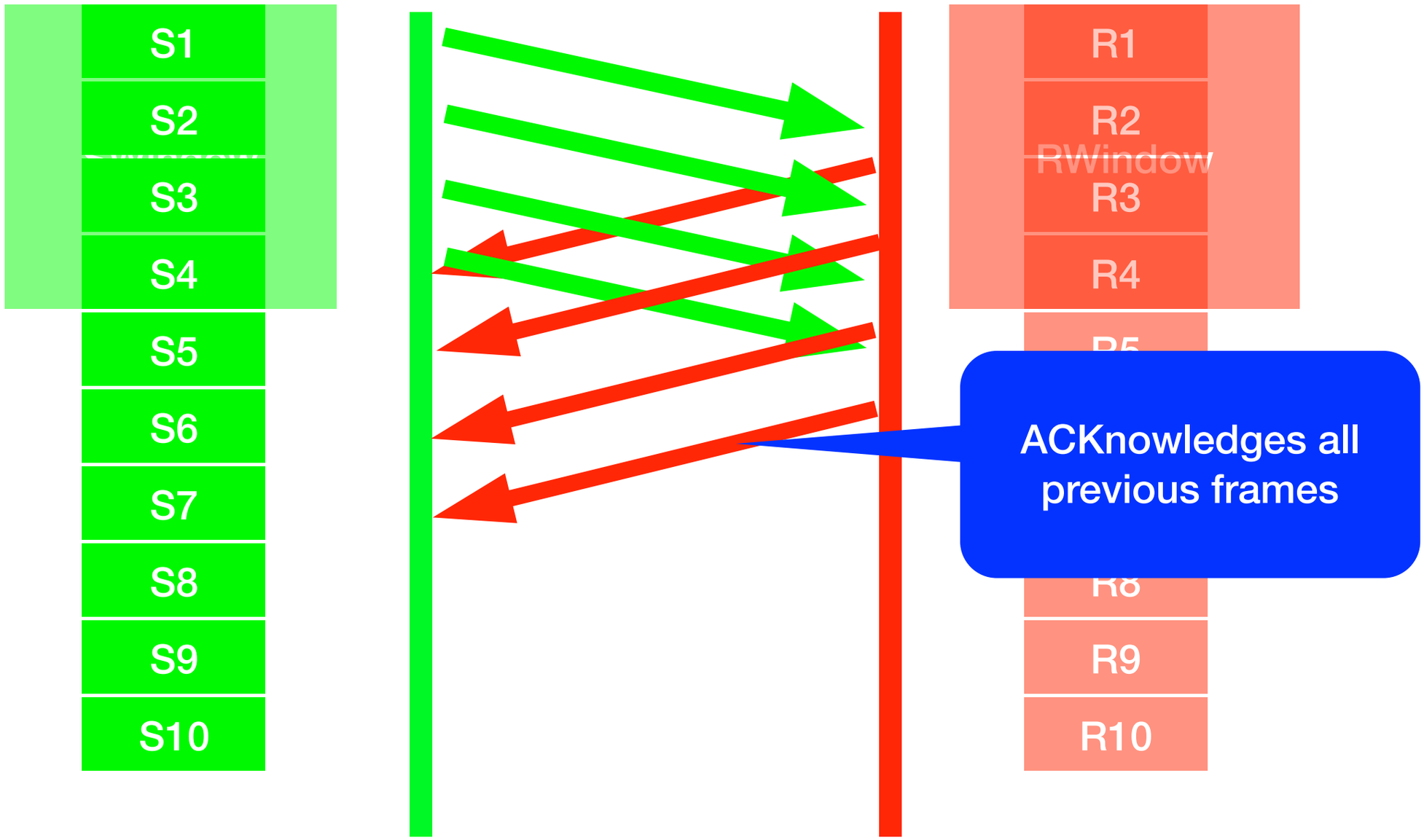
with “buffers” on each end



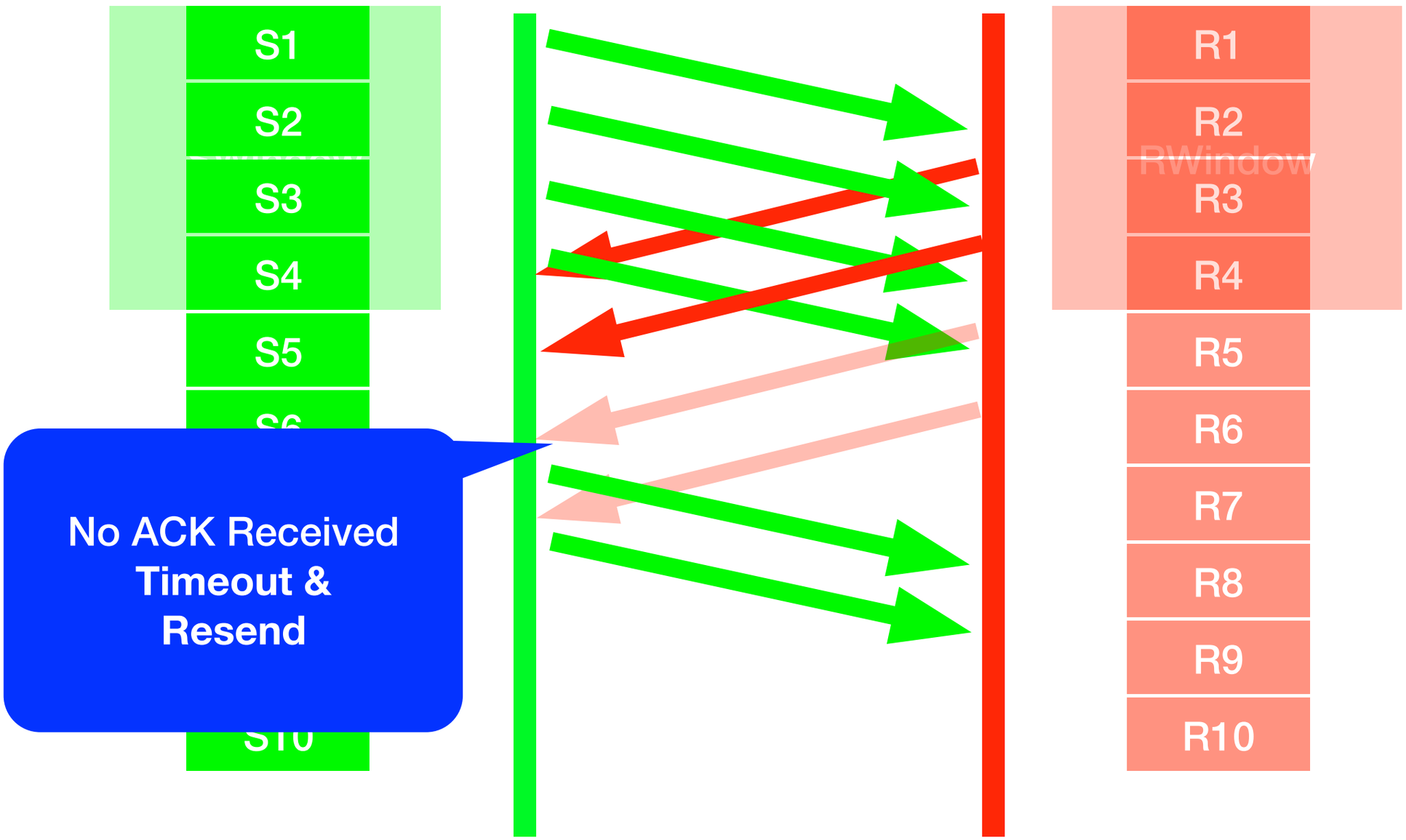
Sliding Window



Sliding Window

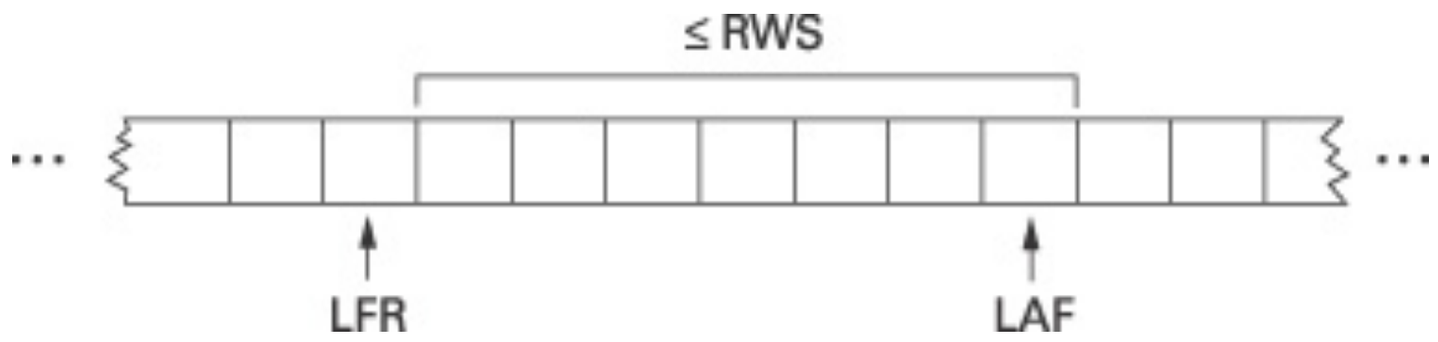


Sliding Window



Sliding Window

LFS - LAR <= SWS



LAF - LFR <= RWS

Reliable Transmission

- Using;
    - Error Detection
    - Timeout & Acknowledgements
- Stop and Wait
- Sliding Window

Direct Link Networks

✓Hardware

✓Encoding

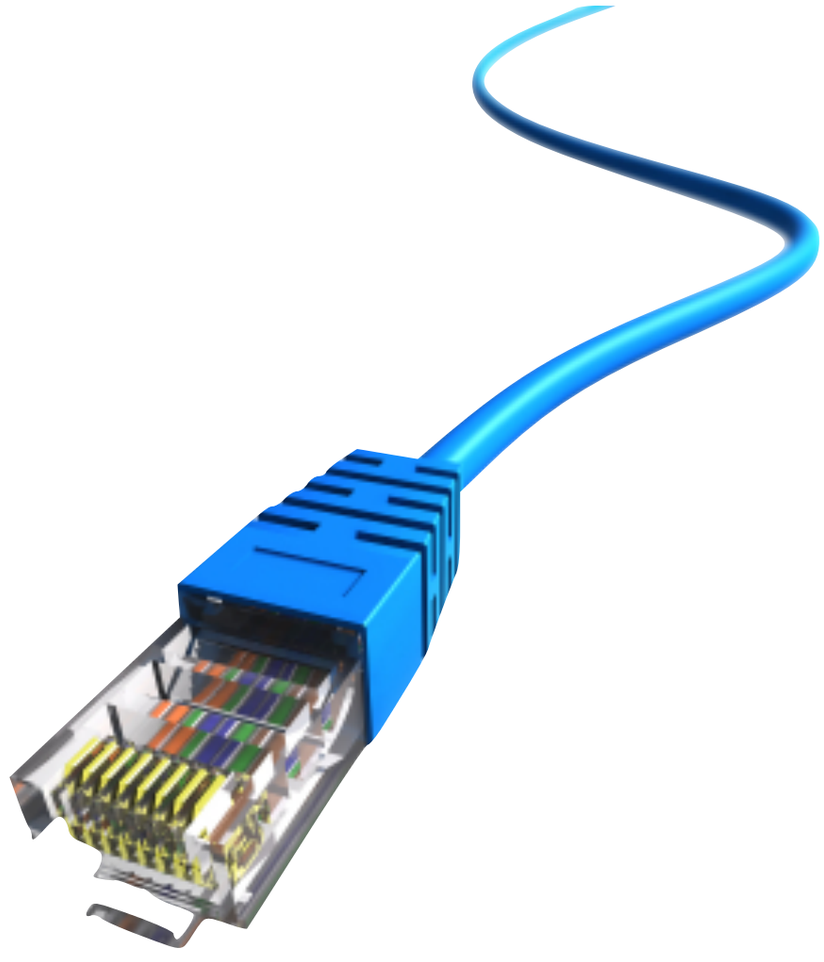
✓Framing & Error-Detection

✓Reliable Transmission

- Examples (Ethernet, Token Ring, & Wireless)

Ethernet (802.3)

- Physical Properties
- Access Protocol
- Experience



Ethernet

- Most popular & successful Local Area Network (LAN)
- Carrier Sense Multiple Access with Collision Detection (CSMA/CD)
- Updated with larger bandwidth

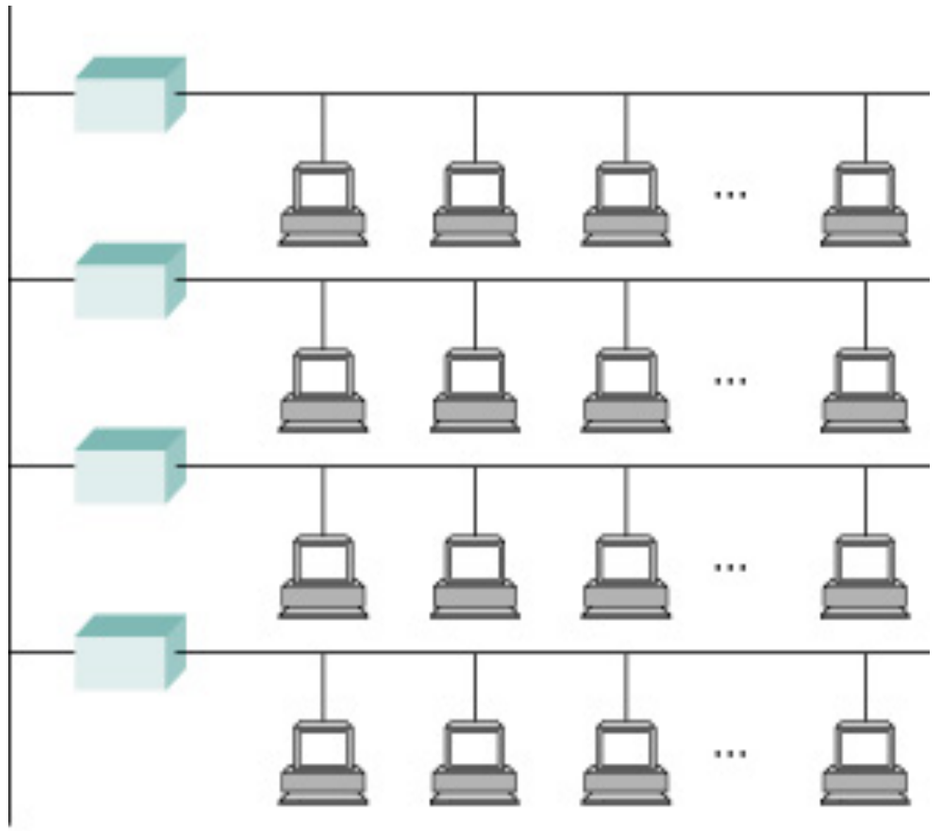
Physical Properties

- Coaxial Cable <= 500m
- Same cable shared among all nodes
- Literally “tap” into cable to get on Ethernet
- ~255 hosts per “link”

Joining Ethernets

- Multiple segments joined by “repeaters”
- Much like an amplifier
- <= 4 repeaters between nodes (total 2500m reach)
- terminators at ends
- broadcast over entire network

Typical Ethernet

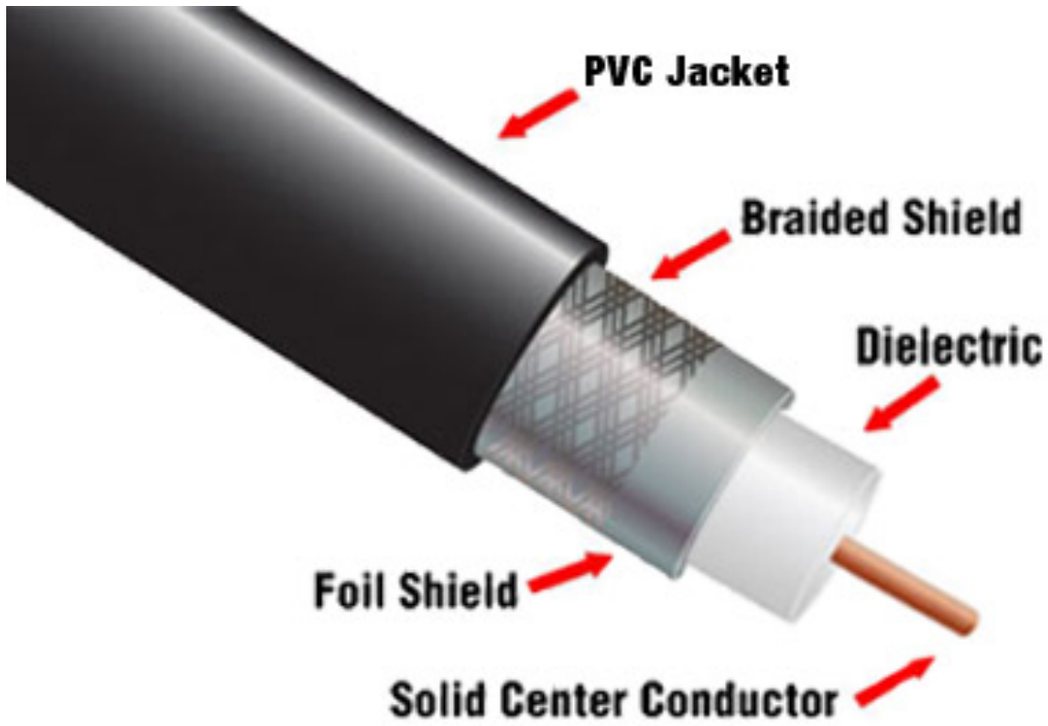


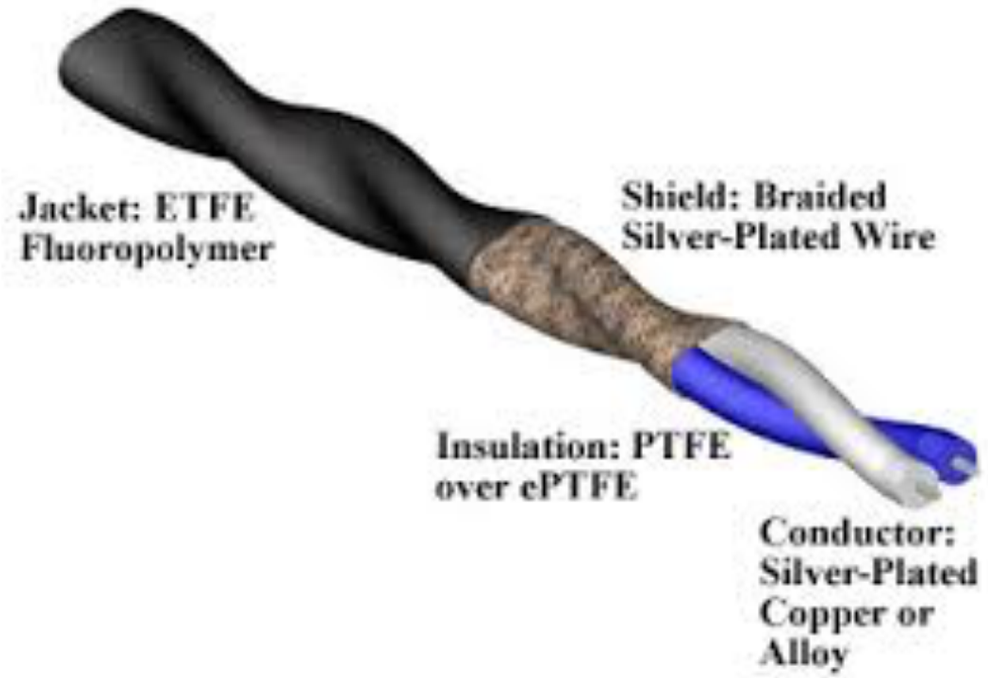
Ethernet Encoding

- Manchester encoding

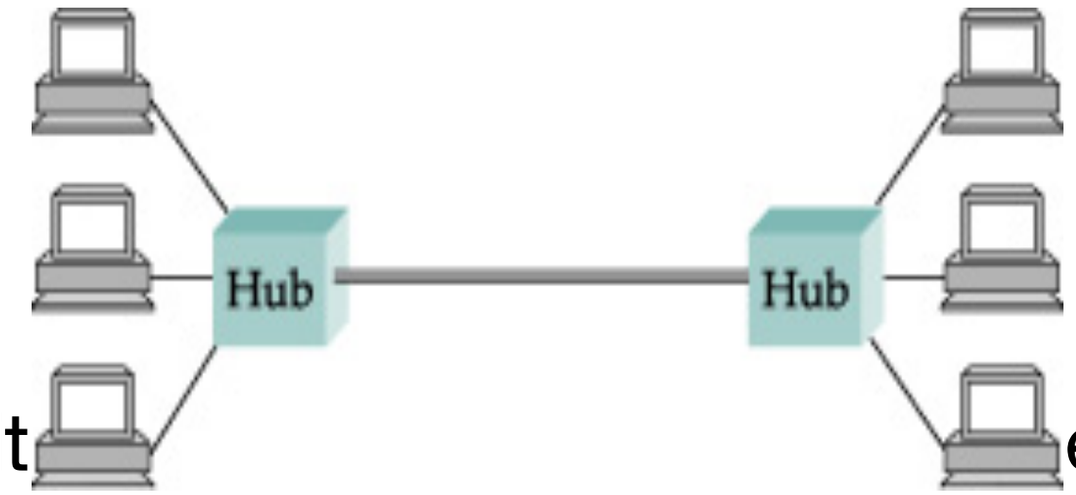
Alternate Media

- Coax - 10Base2 (thin - 10Mbps, 200m)
- Coax - 10Base5 (thick - 10Mbps, 500m)
- Twisted Pair - 10BaseT (10Mbps, 100m)
    - 100BaseT... etc..


PVC Jacket
Braided Shield
Dielectric
Foil Shield
Solid Center Conductor


Jacket: ETFE
Fluoropolymer
Shield: Braided
Silver-Plated Wire
Insulation: PTFE
over ePTFE
Conductor:
Silver-Plated
Copper or
Alloy

Ethernet Switches



- Ethernet Switches provide dedicated access to the same media
- Optimizations are made to make better use of bandwidth and buffers

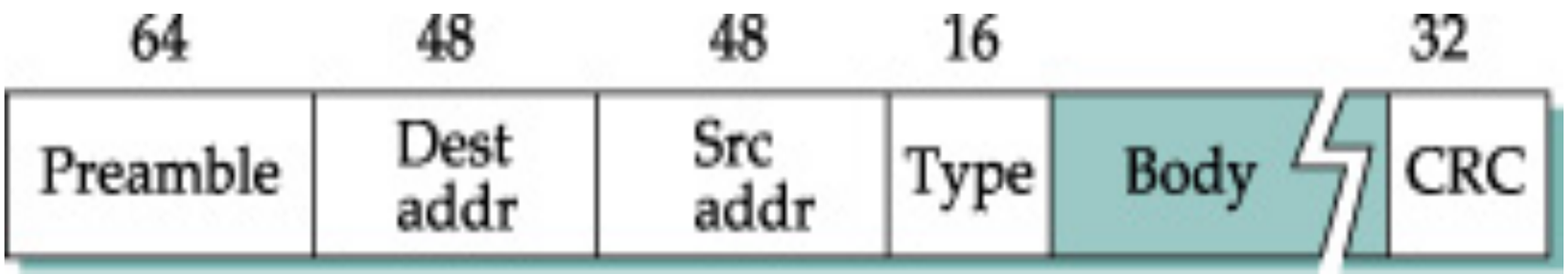
Physical Properties

- Shared link between all nodes
  - Good: easy to transmit/rcv. traffic
  - Bad: same “collision domain”
- Connected by repeaters
- ~2,500m max length

Access Protocol

- Frame Format
    - Addresses
- Receiver Algorithm
- Transmitter Algorithm

Frame Format



- Preamble = 01010101010....
- Addresses (MAC Address)
- Type (or length) <= 1,500
- Body = Data >= 46 bytes
- CRC = Cyclic Redundancy Check

Addresses

- MAC = Media Access Control
- Every host has unique address (on LAN)
- 48 bits
  - 24 bits assigned to manufacturer
  - 24 bits assigned by manufacturer

Receiver Algorithm

- Pass to host if destination address...
  - is *my* address?
  - is the *broadcast* address?
  - is a subscribed *multicast* address
- Or if adapter is in *promiscuous* mode

Transmitter Algorithm

- If the link is idle, transmit frame immediately
- If the link is not idle, wait for idle and transmit immediately
- Look for a *collision*

Collision

When two or more nodes begin transmitting at (or near) the same time the frames are said to **collide**.

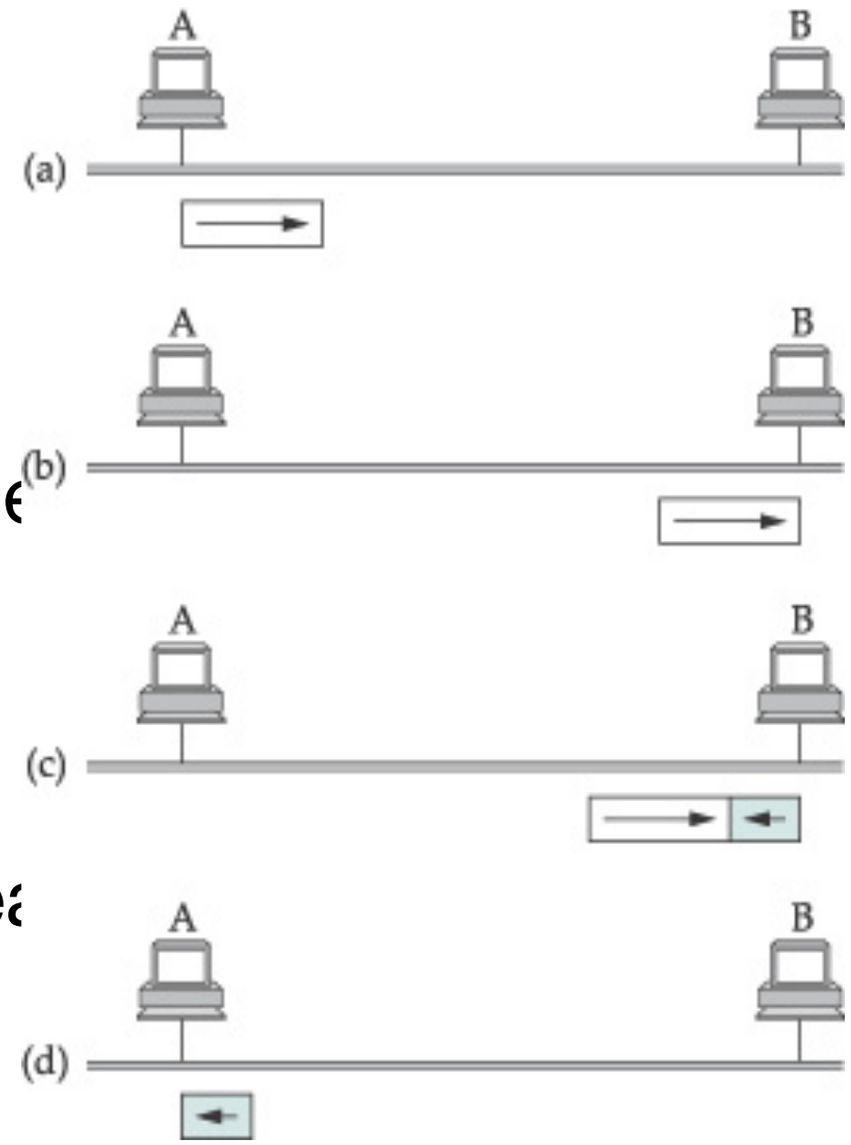
Collision Detection

- Adapter “listens” to wire when transmitting

- If what it “hears” is not what was sent... we have a collision

Collision Detection

- A sends to B.
- B starts to send just before A's frame
- B senses and sends jam
- If the link is "too long" A will not "hea



Collision Detection

- Max length = 2,500m
- 10 Mbps
- RTT = 51.2 μs
- 512 bits, hence minimum frame size

Exponential Backoff

When a host recognizes a collision it does not immediately retry

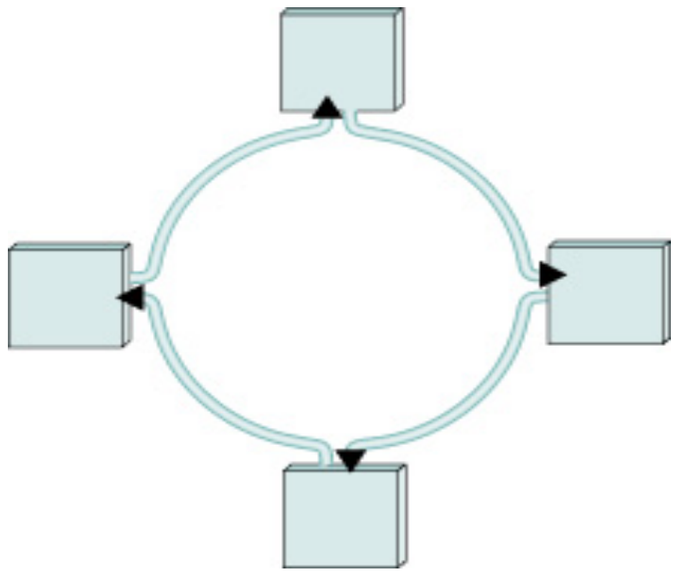
- Wait either 0 or 51.2 μs
- If collide again, wait either
  0, 51.2, 102.4, or 153.6 μs
- if we collide again, double the max....

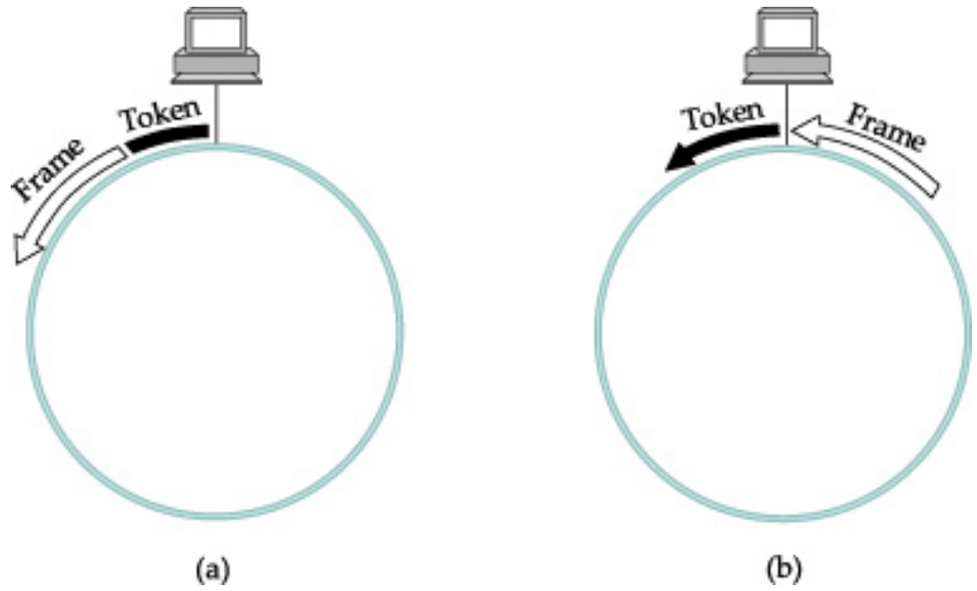
Ethernet Experience

- Simple to deploy and administer
- Works best under light load; <30%
- Most are conservative deployments
- Inexpensive to implement

Token Ring

- Multiple access
- Receive and forward
- “token” circulates around the ring
- Deterministic access

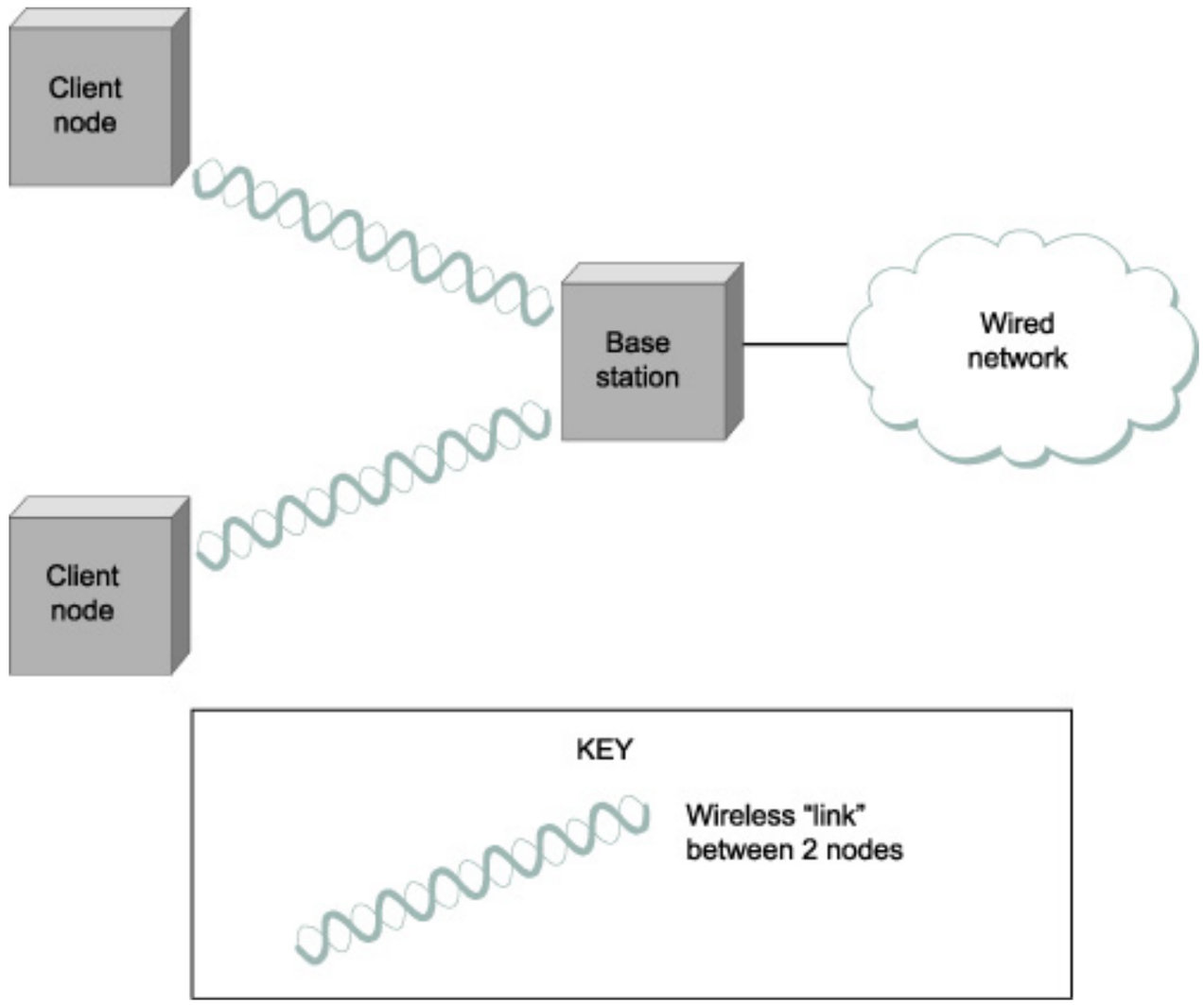




Wireless

- Bluetooth (802.15.1)
- Wi-Fi (802.11)
- WiMax (802.16)
- Cell Phones

Wireless Technology



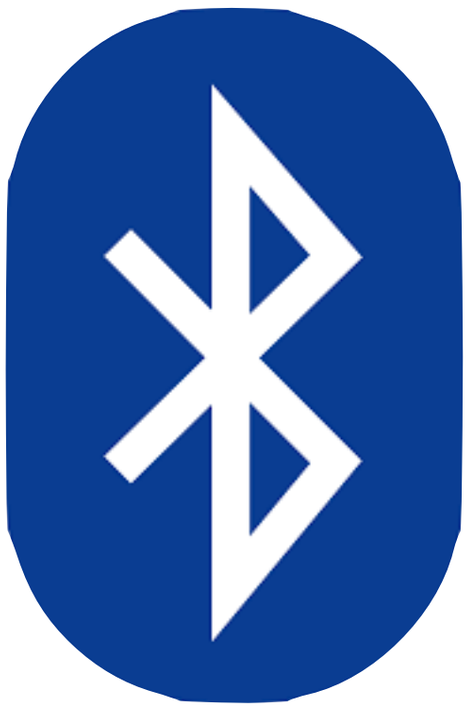
Wireless Technology

- Bandwidth capabilities
- Frequency range - license required?
- Power requirements
- Symmetric vs Asymmetric (base vs host)

Wireless Technology

	Bluetooth	Wi-Fi	WiMAX	3G
Length	10m	100m	10km	10’s km
Bandwidth	2.1Mbps	54Mbps	70Mbps	384Kbps
Use	Devices	Notebook	Building	Phone
Compare	USB	Ethernet	Coaxial	DSL

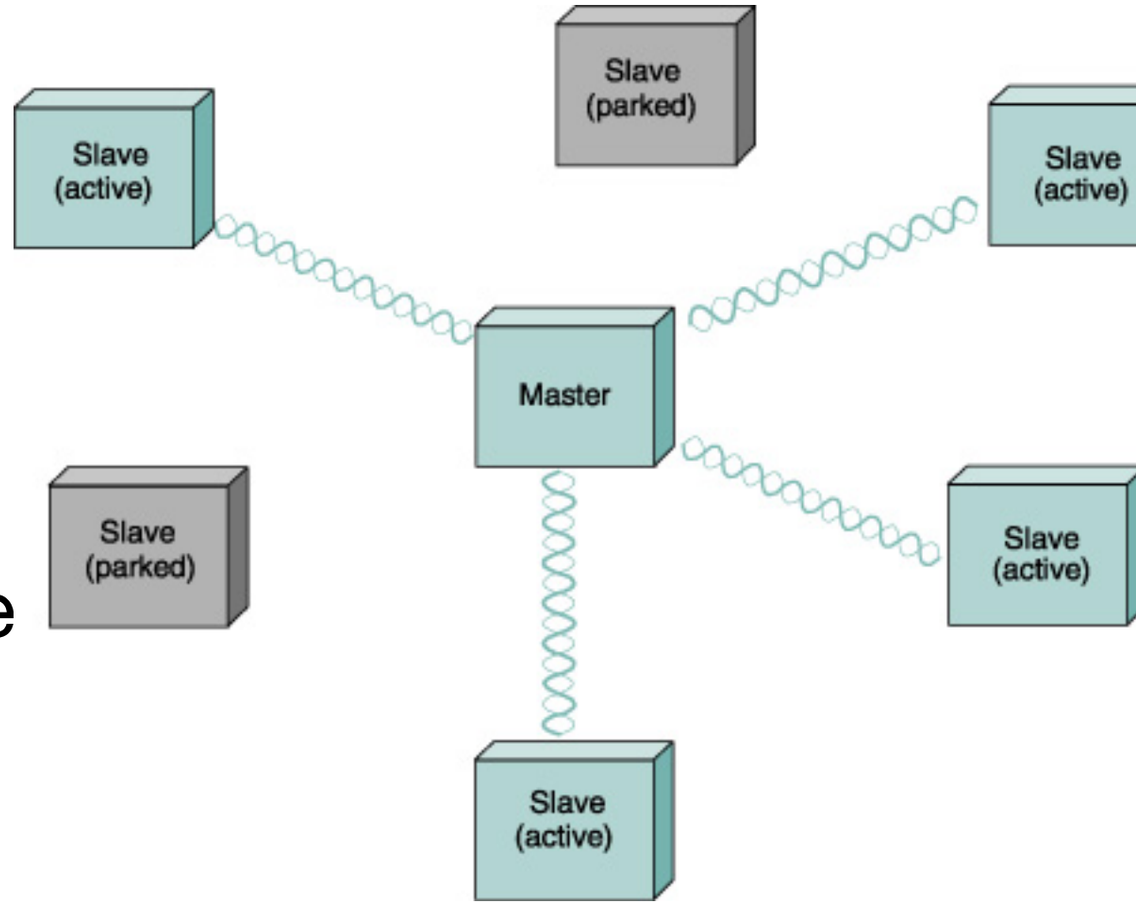
Bluetooth (802.15.1)



- Short range
- Replace (augment) device connections
- License exempt 2.45GHz frequency band
- Range of 10m
- Personal Area Network (PAN)

Bluetooth

- Master-Slave Network
- Devices only talk to master
- Spread spectrum technique (see



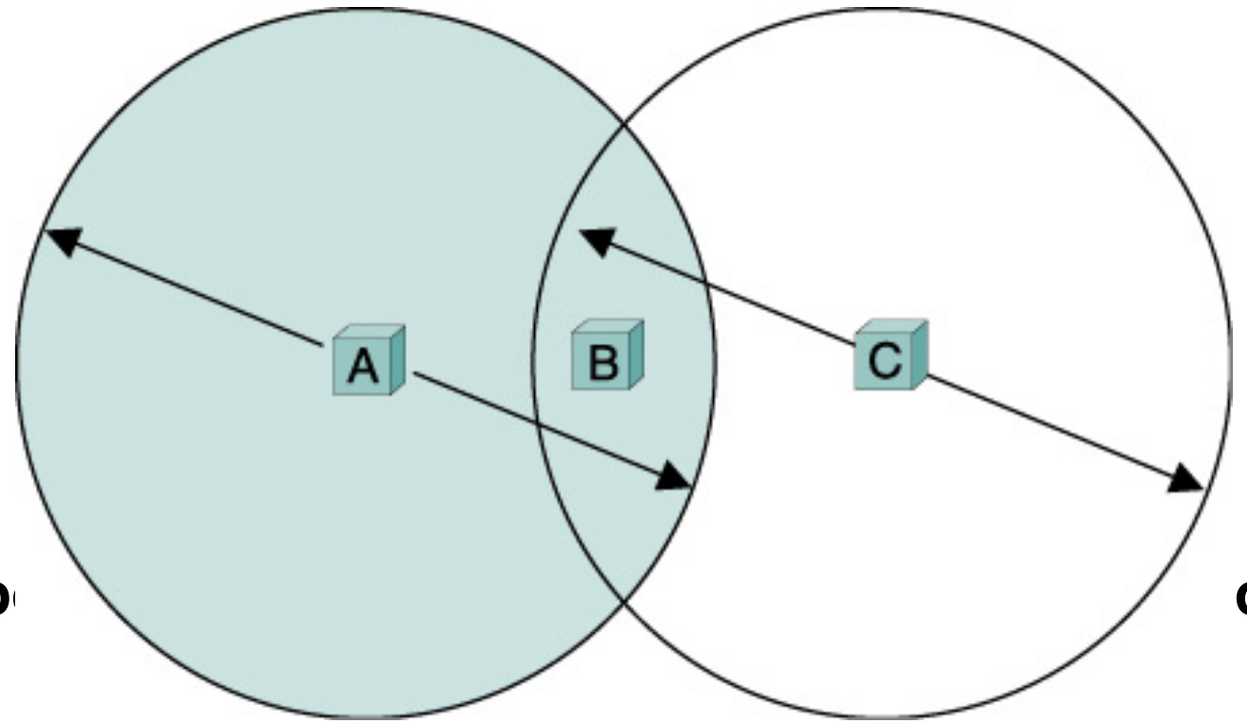
Wi-Fi (802.11)

- Physical Properties
- Collision Avoidance
- Distribution System
- Frame Format

Wi-Fi Physical

- 6 different physical layers (a, b, g, n...)
- various spread spectrum techniques
- 2.4GHz & 5GHz license free bands
- Range 10+m
- Chooses highest bandwidth available

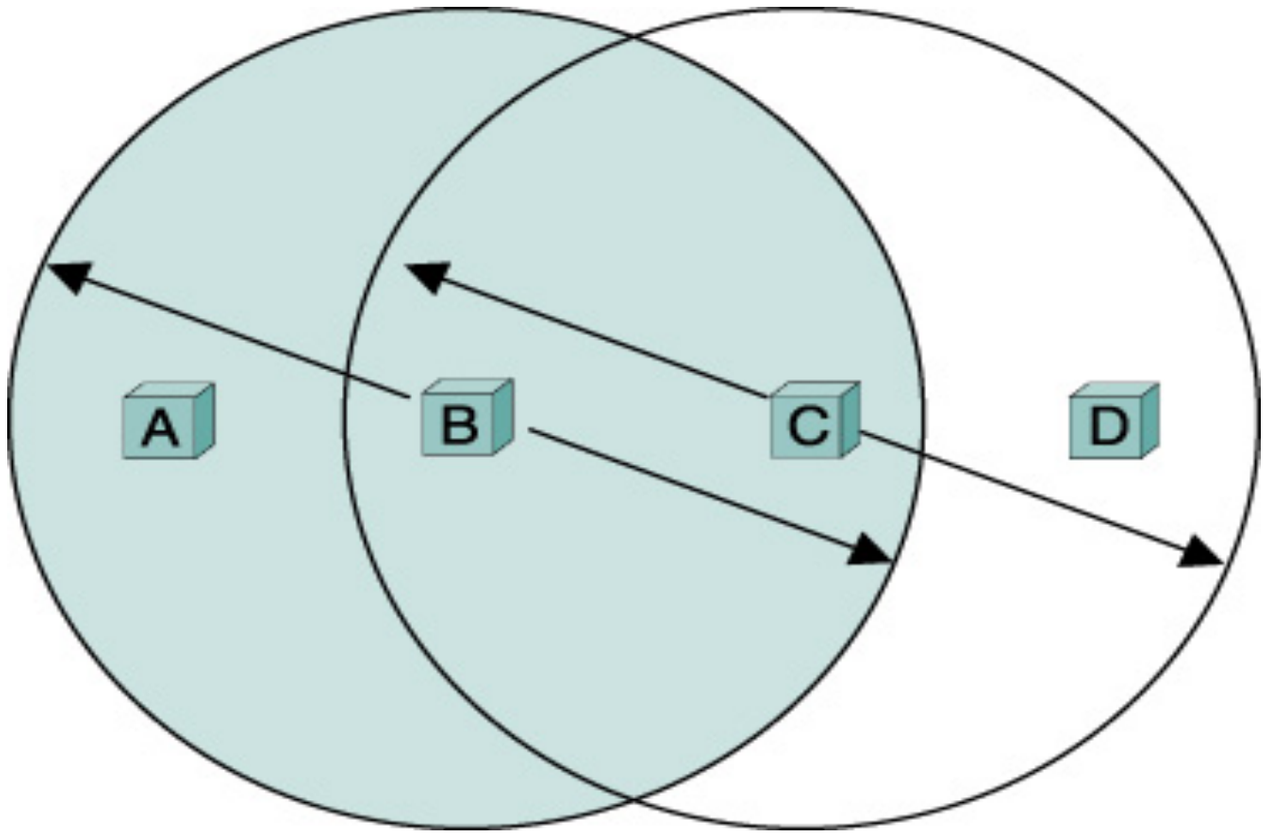
Collision Avoidance



Cannot b

den nodes”

Collision Avoidance



Collision Avoidance

Multiple Access with Collision Avoidance

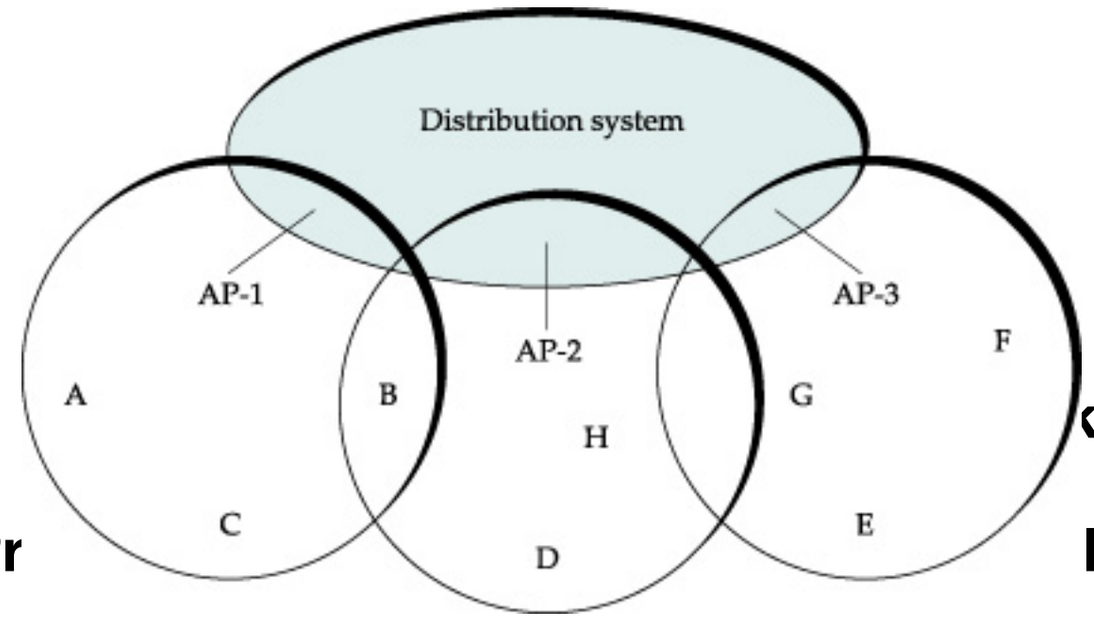
- Send Request to Send (RTS) w/length
    - Reply with Clear to Send (CTS) w/length

Now all nodes in range know the length

Collision Avoidance

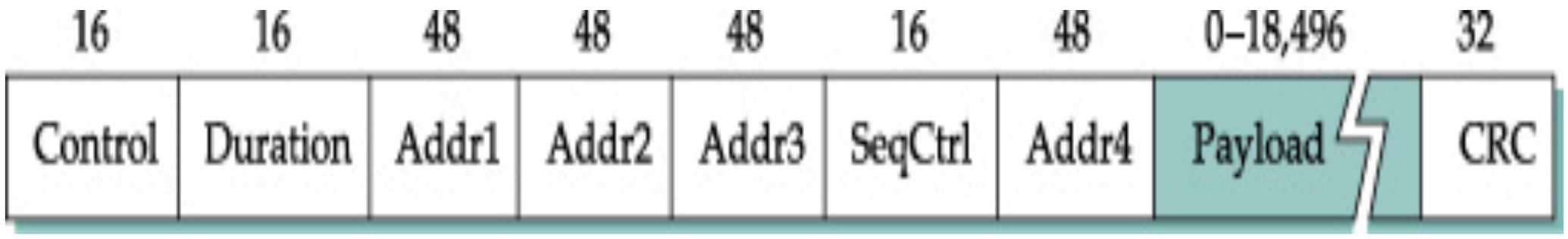
- If a node sees RTS but not CTS?
  - free to communicate (hidden)
- Receiver also sends ACK after frame
  - everyone waits for ACK
- Simultaneous RTS?
  - Corruption at receivers and no CTS

Distribution & Association



Pr **best**

Frame Format



- Similar to Ethernet?
- Control = CTS, RTS, etc.
- 4 addresses; used for proxy frames through distribution system

WiMAX (802.16)

- “Last Mile” Technology
- Range 6 - 30 miles
- No “mobility”
- 10 - 60GHz frequency bands
- Asynchronous upstream & downstream using time division multiplexing

Cellular (1&2G)

- Licensed spectrum, wired base stations
- 1G = analog
- 2G = digital optimized for voice
    - TDM, FDM, and CDMA (code division)
- 2.5G = “data oriented” 2G
    - TDM with dynamic time slots

Cellular 3G

- Planned to be international standard
- Higher data bandwidth
- Incompatible implementations
- CDMA based (UTMS)
- 1.92 Mbps
- Satellite Phones

Wireless

✓Bluetooth (802.15.1)

✓Wi-Fi (802.11)

✓WiMax (802.16)

✓Cell Phones

Direct Link Networks

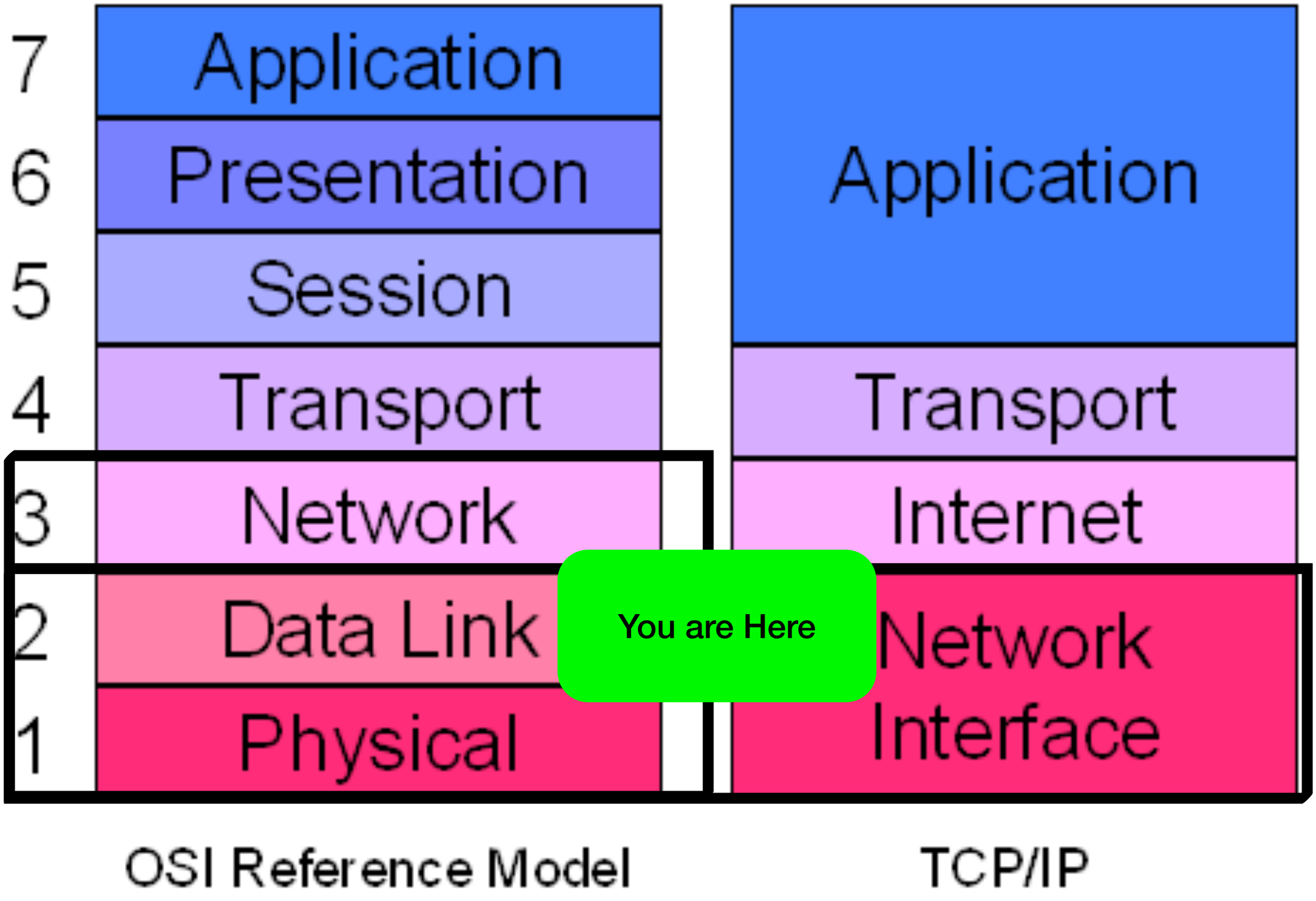
✓Hardware

✓Encoding

✓Framing & Error-Detection

✓Reliable Transmission

✓Examples (Ethernet, Token Ring, & Wireless)


7
Application
6
Presentation
5
Session
4
Transport
3
Network
2
Data Link
1
Physical
You are Here
Application
Transport
Internet
Network
Interface
OSI Reference Model
TCP/IP

fin

Direct Link Networks