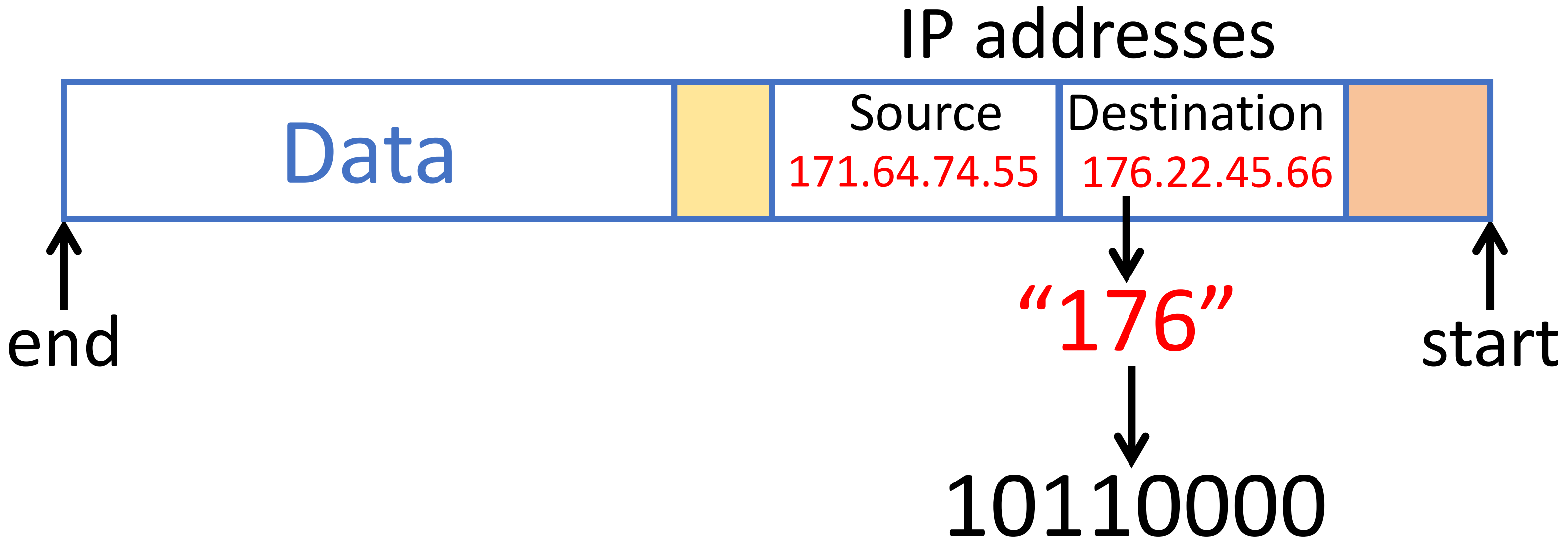
Links, clocks, optics and radios


LINKSYS
Secure Easy Setup
Power
DMZ
USB
Wireless-G
Ethernet
WLAN
1
2
3
4
Internet
Wireless-G Broadband Router With 4-Port Switch
Model WRT54GL
LINKSYS


Reset
Internet
1
2
3
4
Power



IP addresses

Data

Source

171.64.74.55

Destination

176.22.45.66

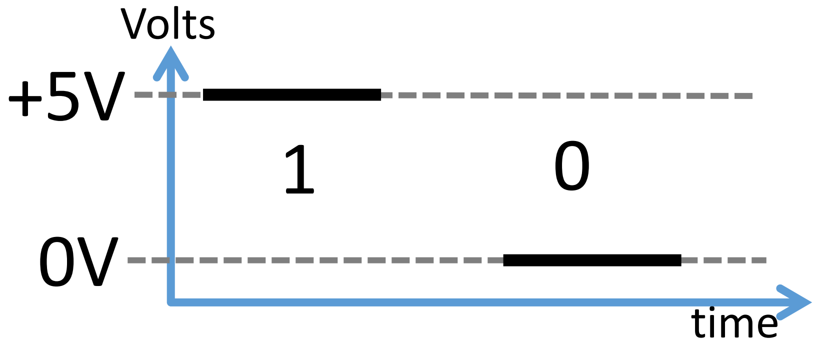
end

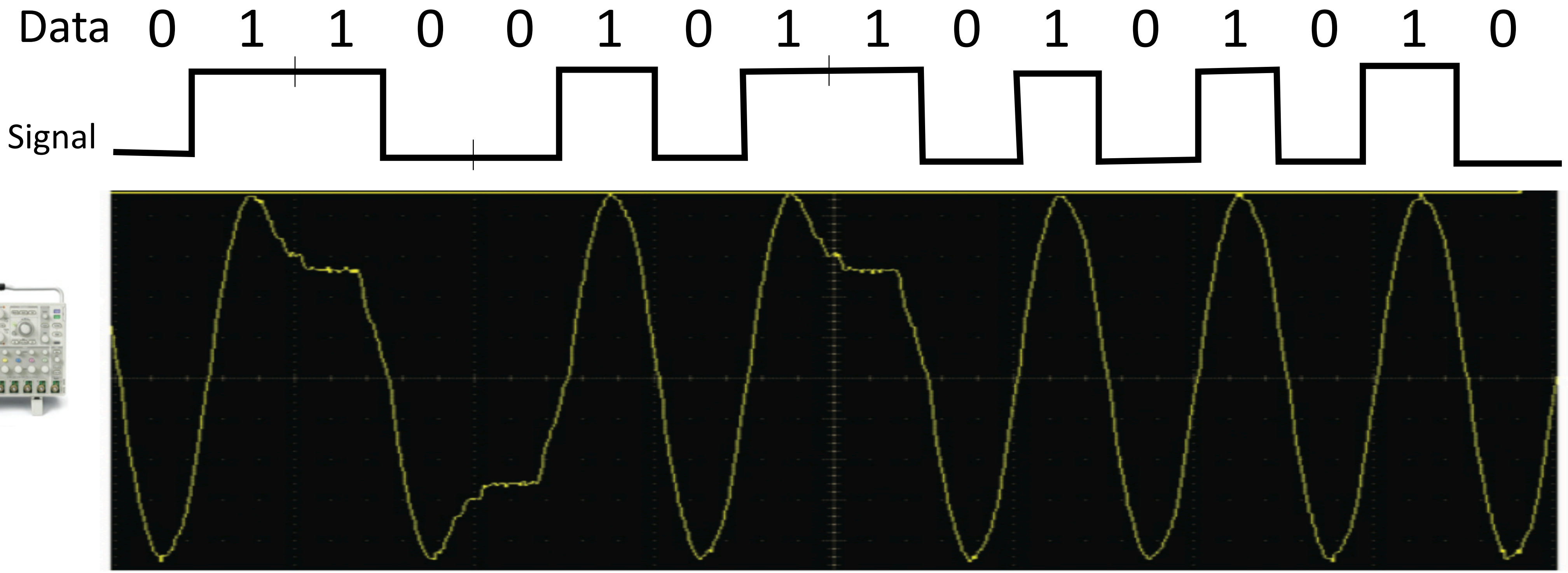
start

“176”

10110000

Example of “On-Off Keying”





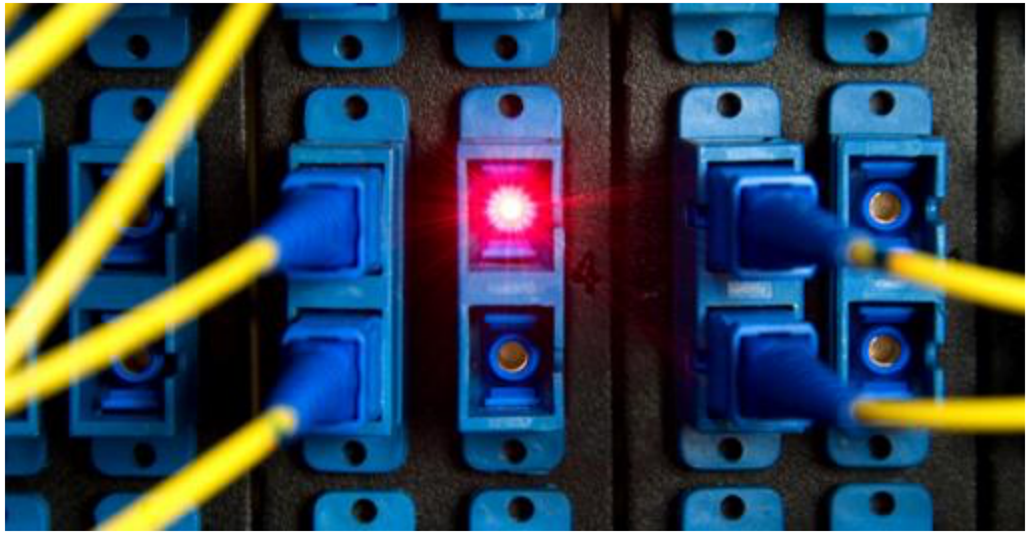
What determines the data rate?

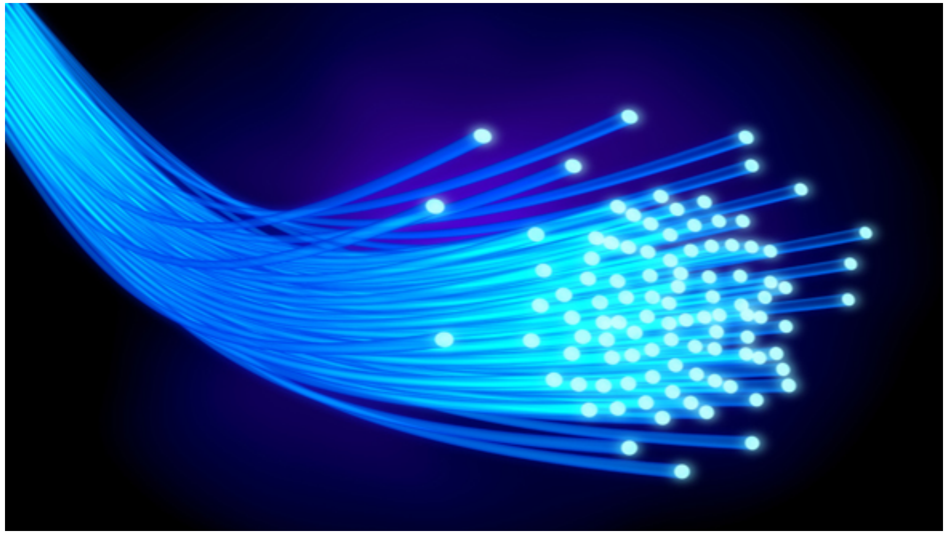
Q: What determines the steepness (i.e. rate) of this change?

Q: How does the rate of change affect the data rate?

Fiber-optic links

Packets are sent by turning a **laser** on and off very fast





Each fiber is smaller than a human hair

Used for very long, very fast communications (e.g. 100 Gb/s and 200km)

What determines the maximum data rate of a cable, fiber, wireless link, etc?

Q: What happens if we put the “bits” closer and closer together?

Q: If we can’t put them closer together, how can we increase the number bits of information transmitted per second?

Q: What other factors limit the number of bits per second we can transmit?

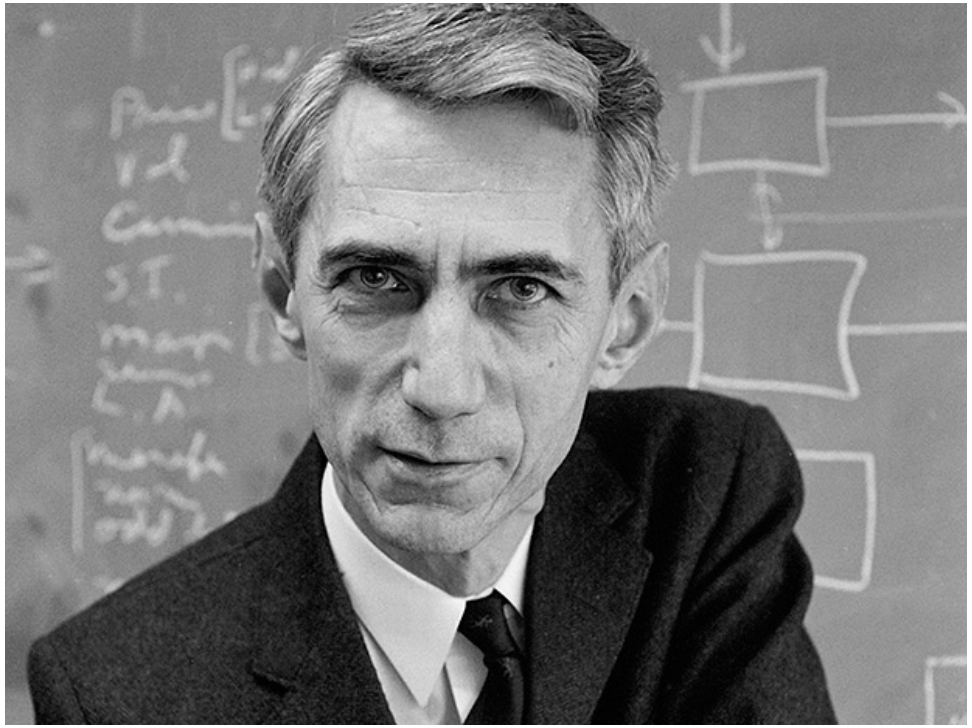
Q: Are there any other factors other than “Bandwidth” and “Noise” that determine the maximum data rate of a channel?

Claude Shannon

1937: MS Thesis proposed used Boolean algebra for digital circuit design.

1948: “A Mathematical Theory of Communication” led to the field of Information Theory and Shannon Capacity

(Juggling Machines!)



Claude Shannon (1916 – 2001)
Mathematician, Electrical Engineer

Shannon Capacity

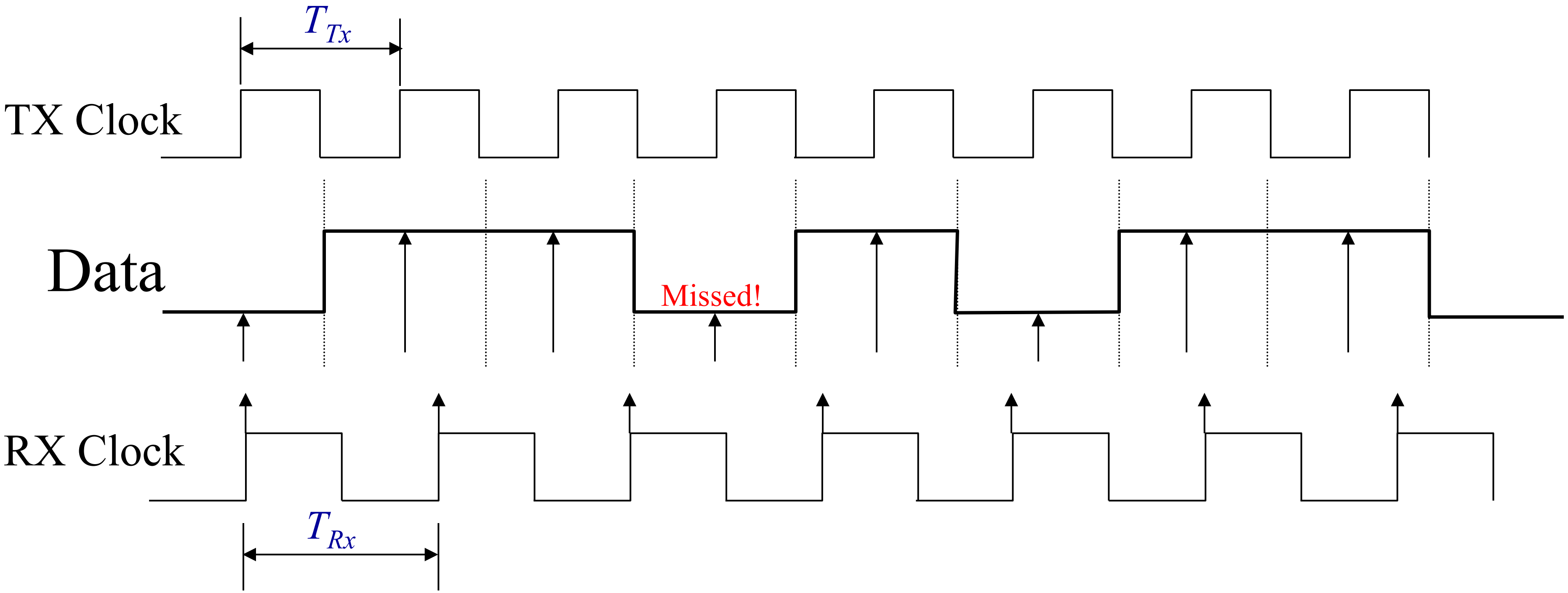
- Shannon capacity represents the maximum error-free rate we can transmit through a channel
- The maximum data rate.
- Under some mild assumptions:

$$\text{Shannon Capacity} = \text{B}\ log_2\left(1 + \frac{S}{N}\right)$$

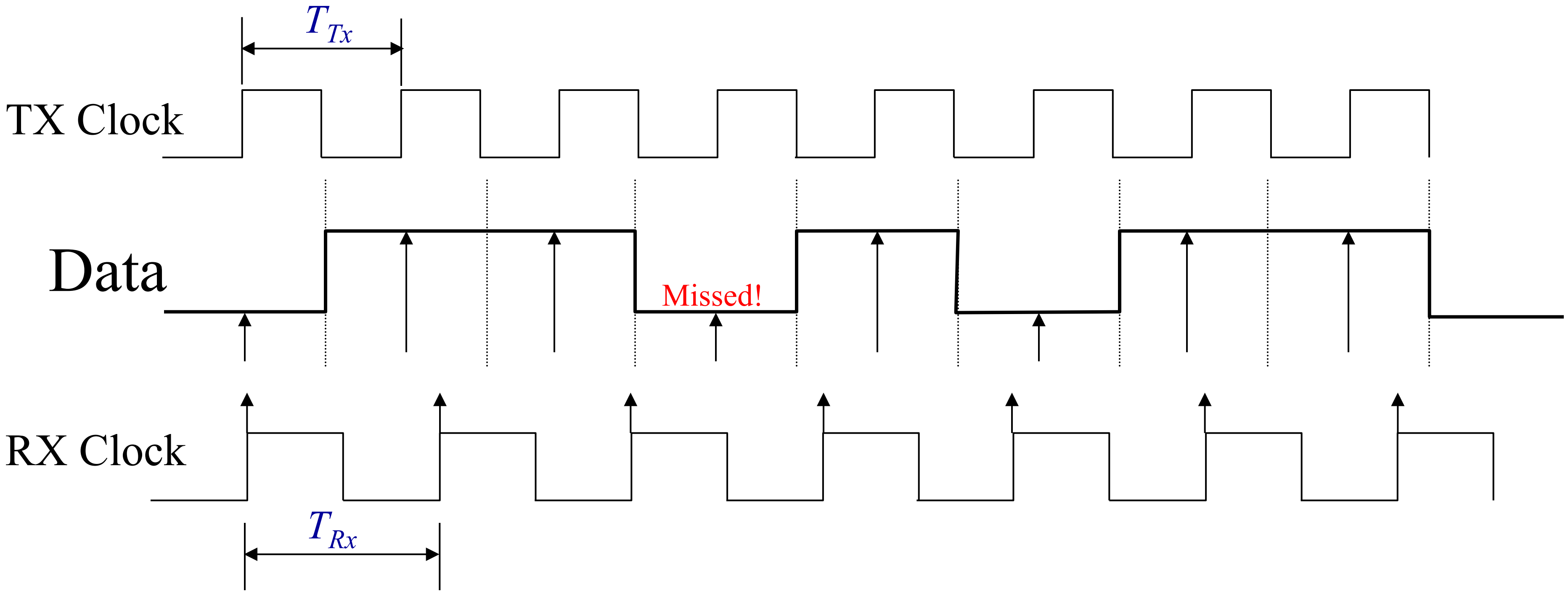
- In other words, it depends only on Bandwidth and Signal-to-Noise ratio!
- EE376A: Information Theory. Wow.

Clocks

If we don’t know the sender’s clock



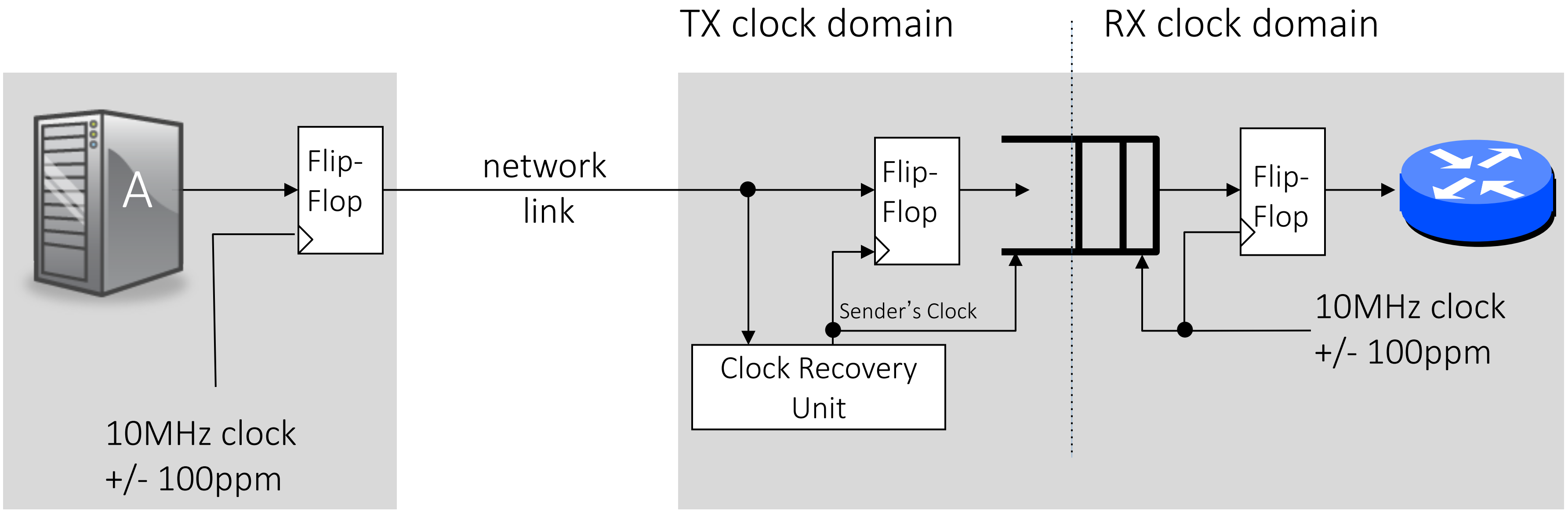
If we don’t know the sender’s clock



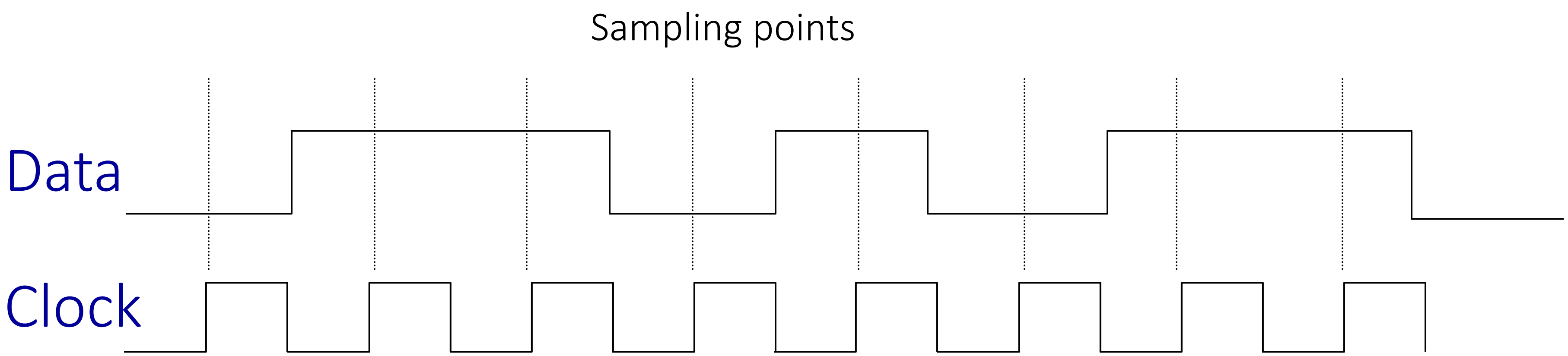
$$\textit{If the RX clock is p ppm } \underline{\textit{slower}} \textit{ than the TX clock, then: } T_{Rx} = T_{Tx}(1 + 10^{-6}p).$$

$$\textit{After } \frac{0.5}{10^{-6}p} \textit{ bit times, the RX clock will miss a bit.}$$

Synchronous communication on network links



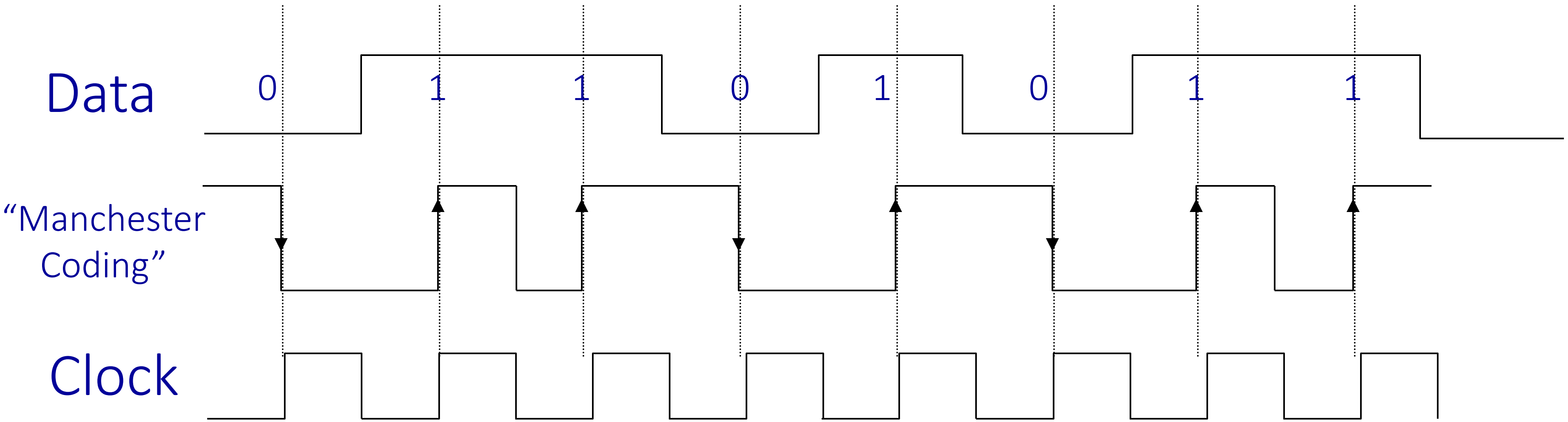
Encoding for clock recovery



If the clock is not sent separately, the data stream must have sufficient transitions so that the receiver can determine the clock.

Encoding for clock recovery

Example #1: 10Mb/s Ethernet



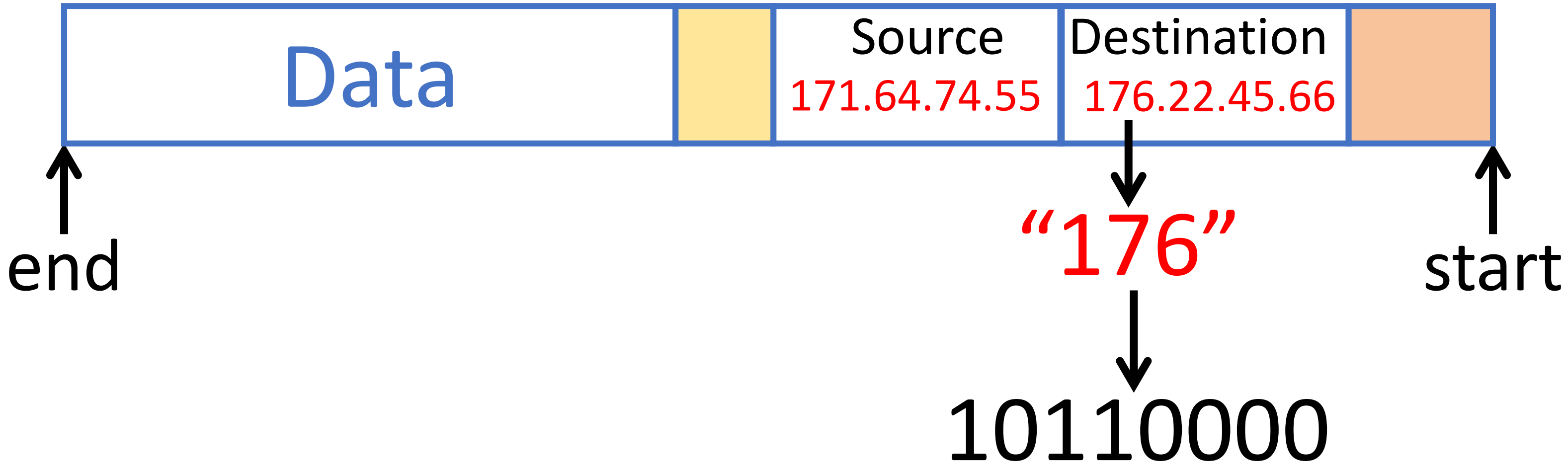
Advantages of Manchester encoding:

- Guarantees one transition per bit period.
- Ensures d.c. balance (i.e. equal numbers of hi and lo).

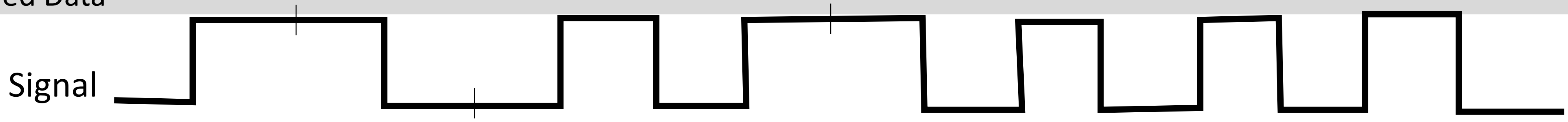
Disadvantages

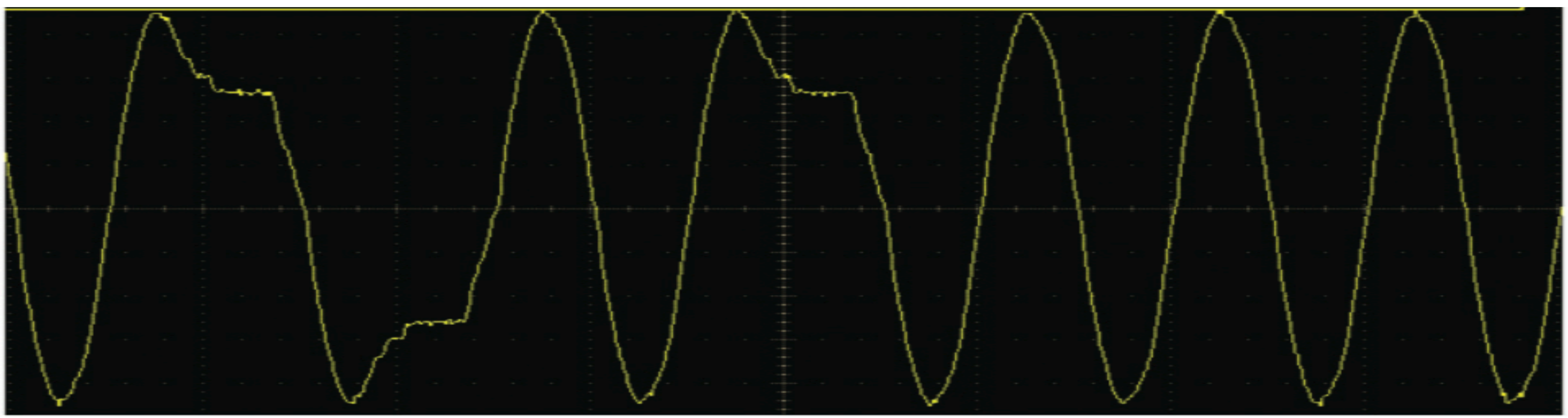
- Doubles bandwidth needed in the worst case.

IP addresses



Data		1		0		1		1		0		0		0		0
Manchester Encoded Data	0	1	1	0	0	1	0	1	1	0	1	0	1	0	1	0





Encoding for clock recovery

Example #2: 4b/5b encoding

4-bit data	**5-bit code**
0000	11110
0001	01001
0010	10100
…	…

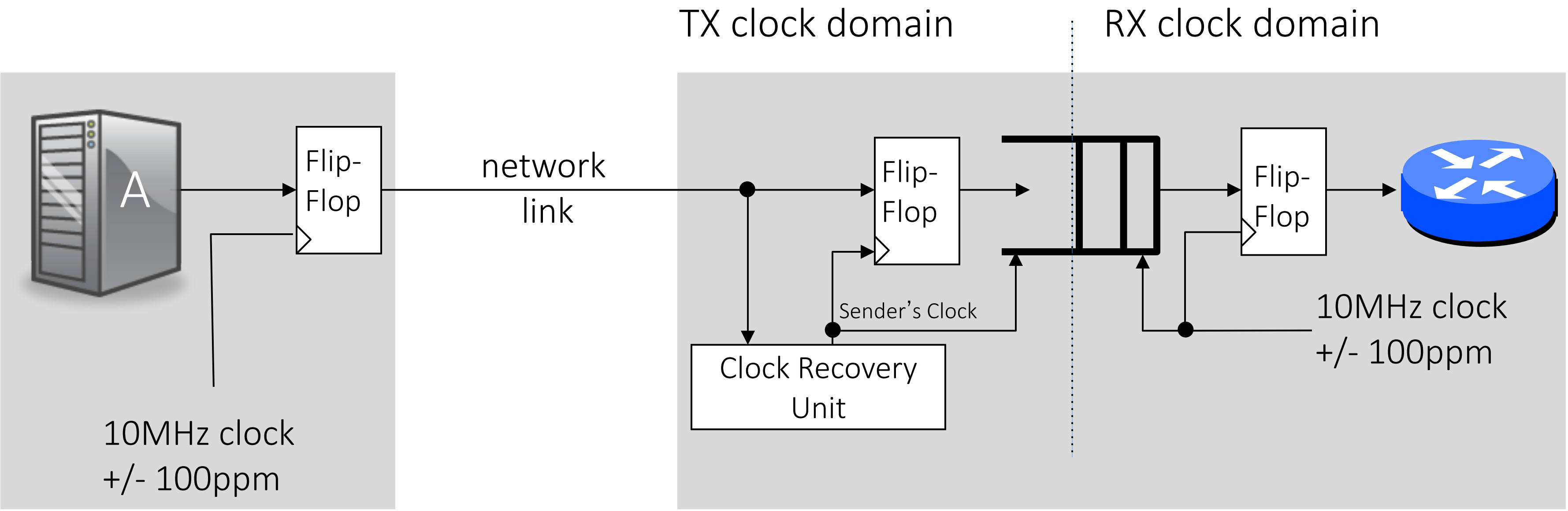
Advantages of 4b/5b encoding:

- More bandwidth efficient (only 25% overhead).
- Allows extra codes to be used for control information.

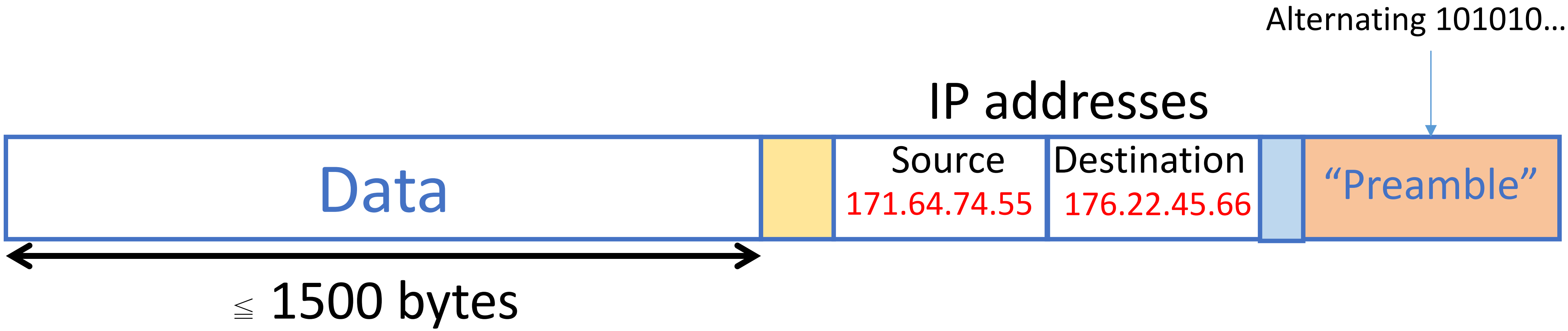
Disadvantages

- Fewer transitions makes clock recovery a little harder.

Summary of clock recovery on network links



How big can a packet be?



Q: How long does it take to send a 1500 byte packet at 1Gb/s?

(1Gb/s = 10^9 bits per second)

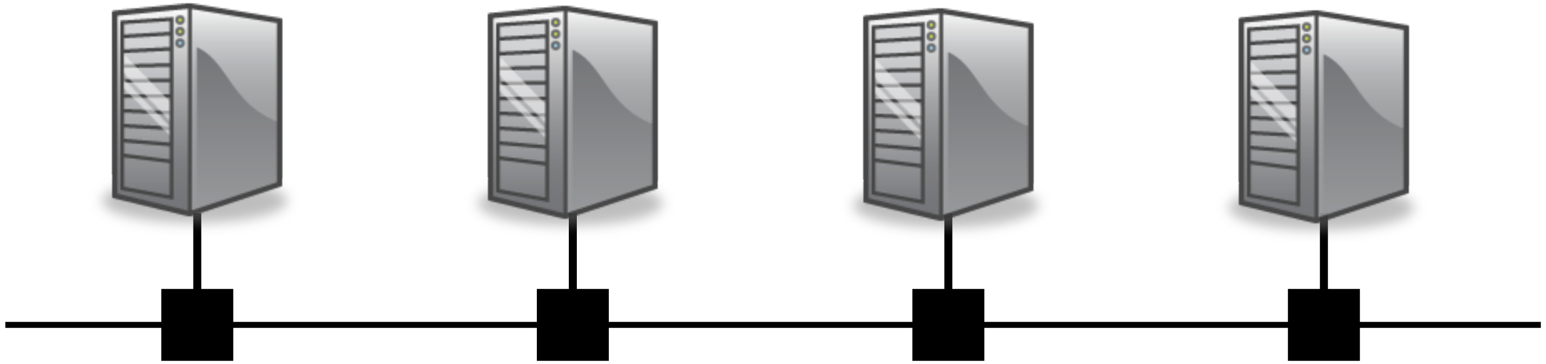
At 1Gb/s it takes (8bits/byte x 1500 bytes)/10^9 bits/second

= 12µs to send a 1500 byte packet.

(The packet is 4km long!)

Ethernet and CSMA/CD

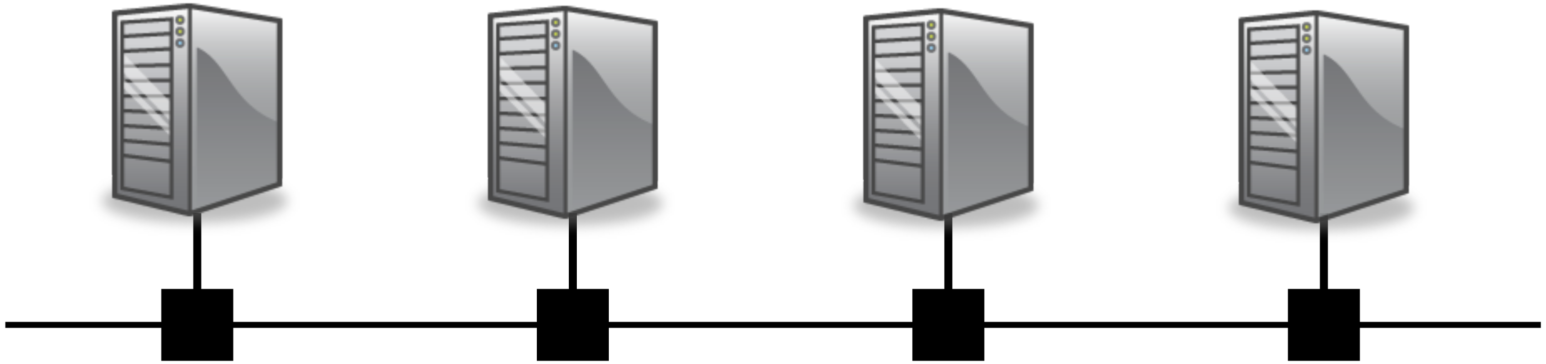
The origins of Ethernet



Sharing a “medium”

- Ethernet is (or at least was originally) an example of multiple hosts sharing a common cable (“medium”).
- To share the medium, we need to decide who gets to send, and when.
- There is a general class of “Medium Access Control Protocols”, or MAC Protocols.

CSMA/CD Protocol



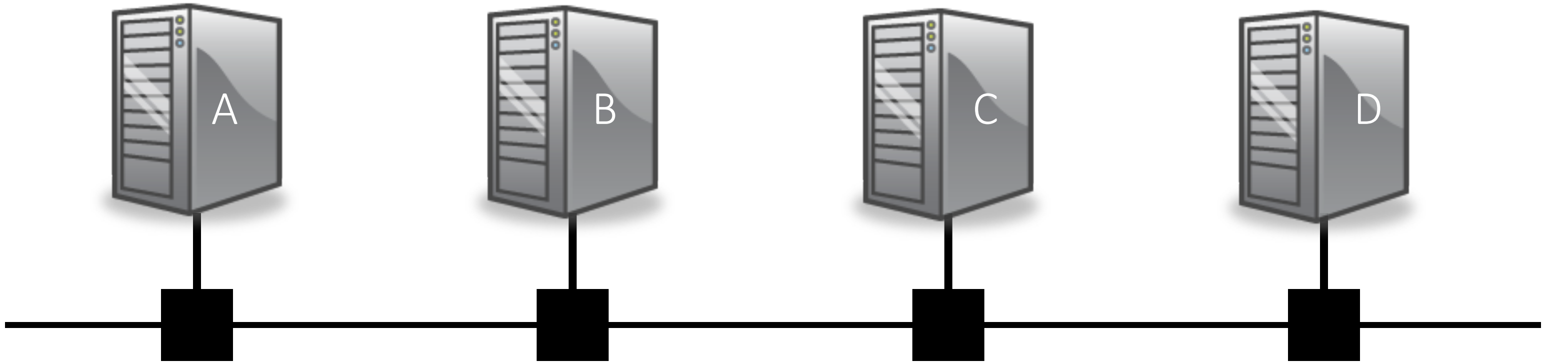
All hosts transmit & receive on one channel
Packets are of variable size.

When a host has a packet to transmit:

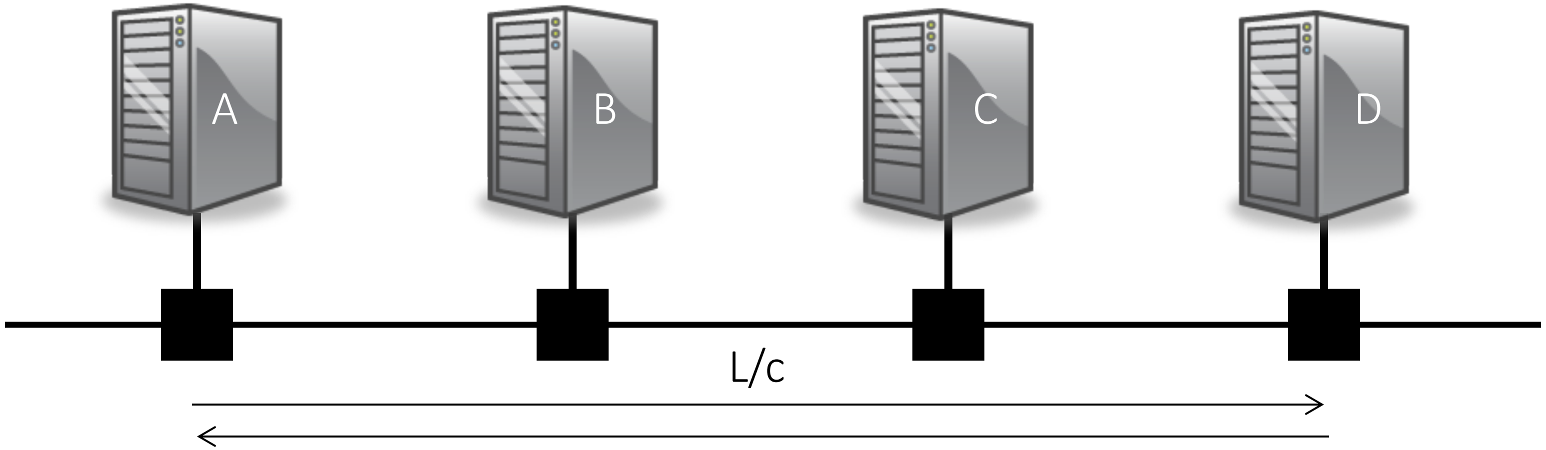
1. Carrier Sense: Check the line is quiet before transmitting.
2. Collision Detection: Detect collision as soon as possible. If a collision is detected, stop transmitting; wait a random time, then return to step 1.

↑ binary exponential backoff

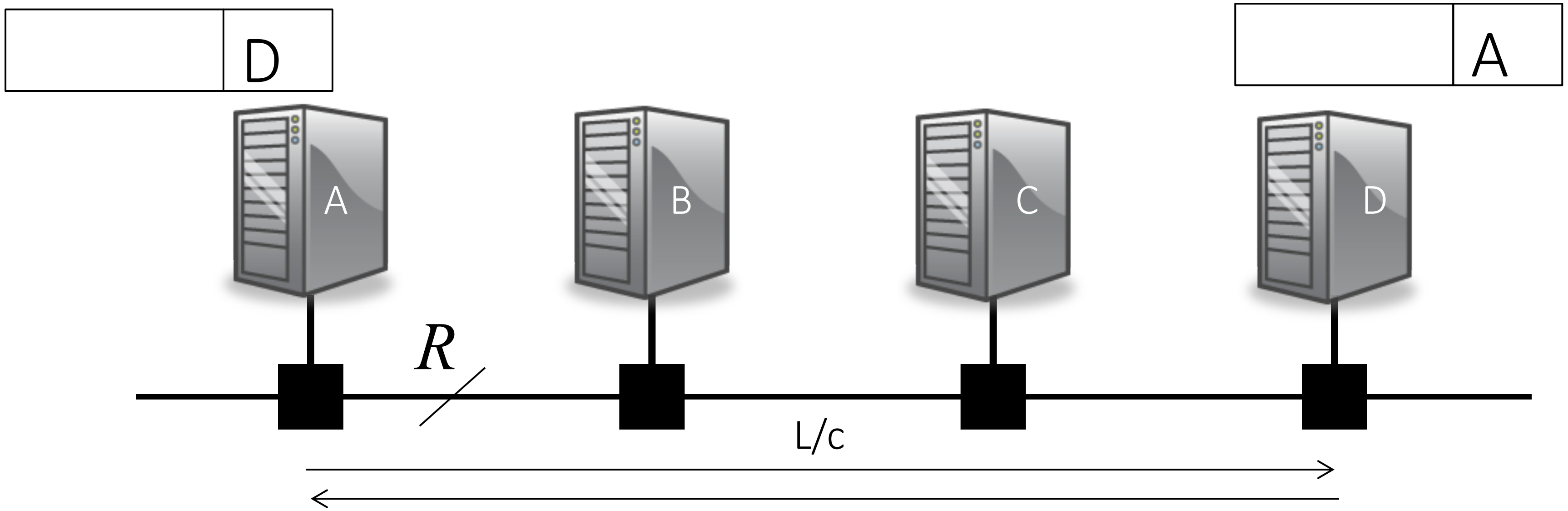
CSMA/CD operation



CSMA/CD Packet size requirement



CSMA/CD Packet size requirement



For an end host to detect a collision before it finishes transmitting a packet, we require:

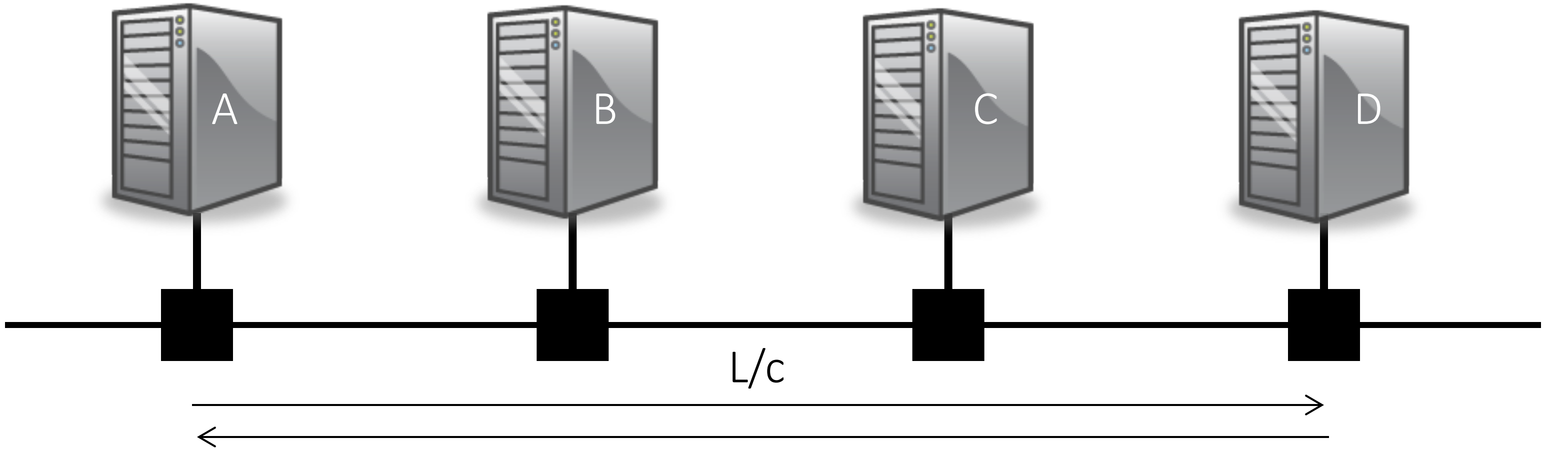
$$\frac{P}{R} \geq \frac{2L}{c}$$

where P is the size of a packet.

CSMA/CD Packet size requirement

Example:

R = 10Mb/s, L = 10,000m, c = 2 x 10^8 m/s.



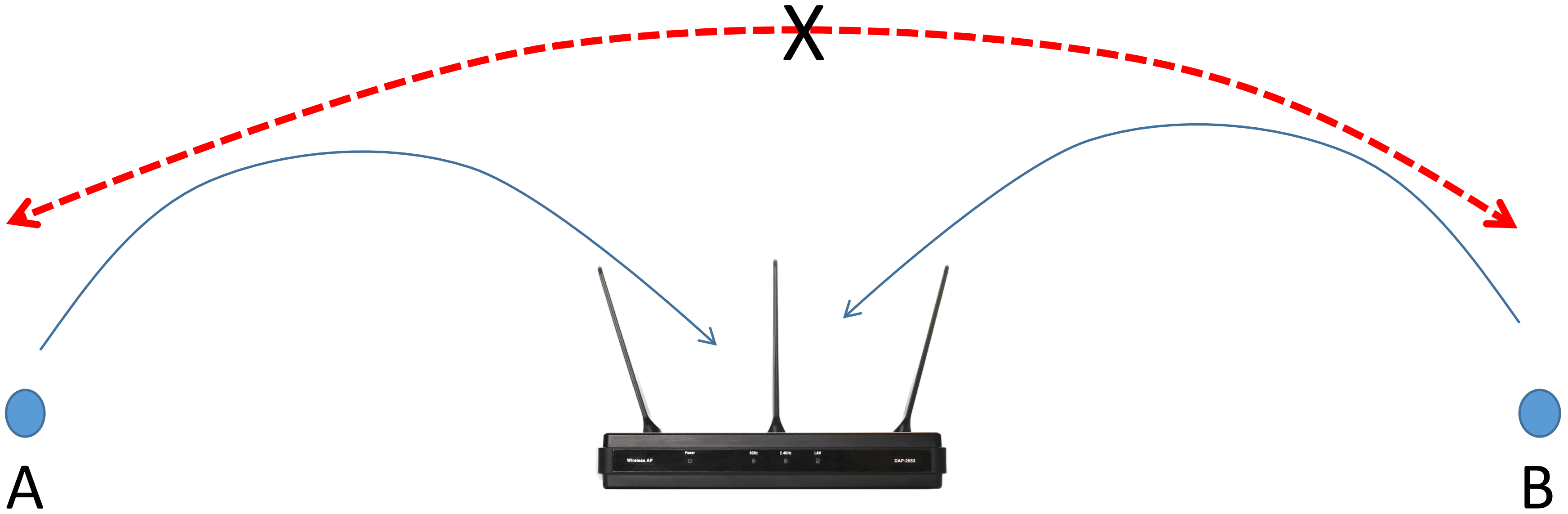
$$\frac{P}{R} \geq \frac{2L}{c}$$

$$\therefore P_{\min} = \frac{2LR}{c} = \frac{2\times 10^{11}}{2\times 10^{8}} = 1{,}000\ bits.$$

Why wireless is different

Q: Why might CSMA/CD not work in a wireless network?

Hidden node problem
(*aka* Hidden terminal problem)



X

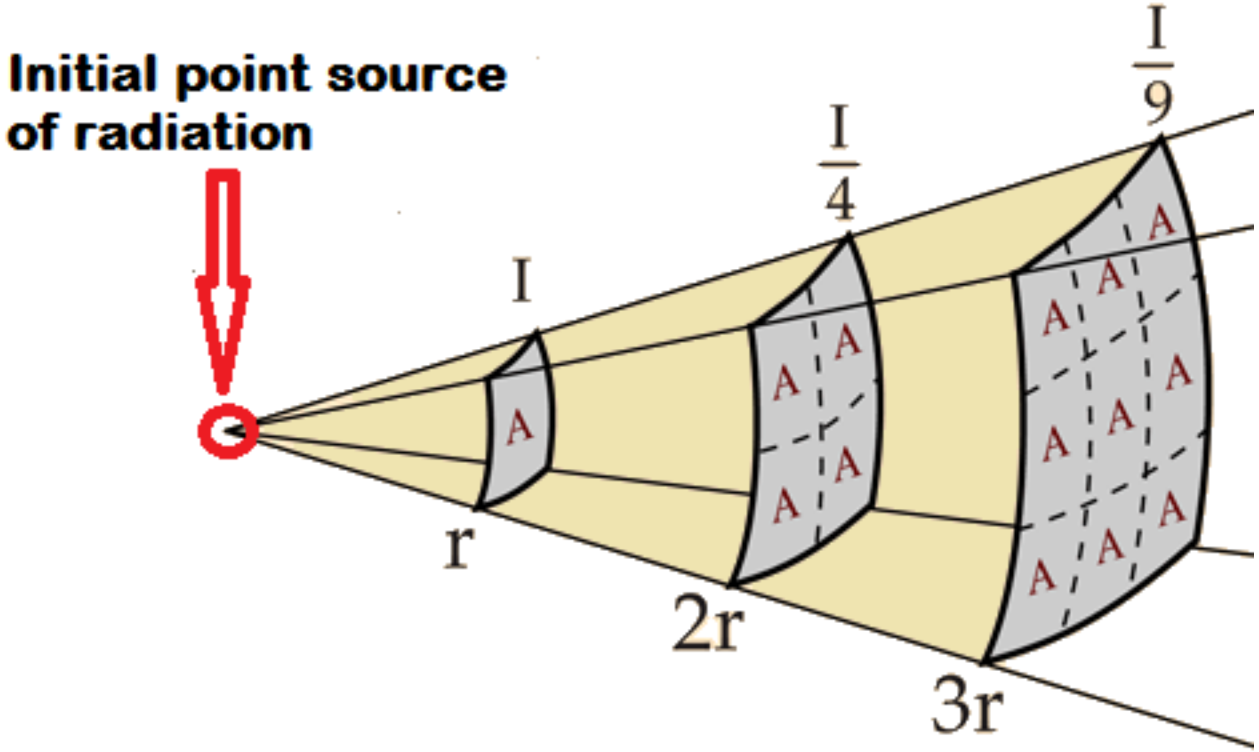
A

B

WiFi AP

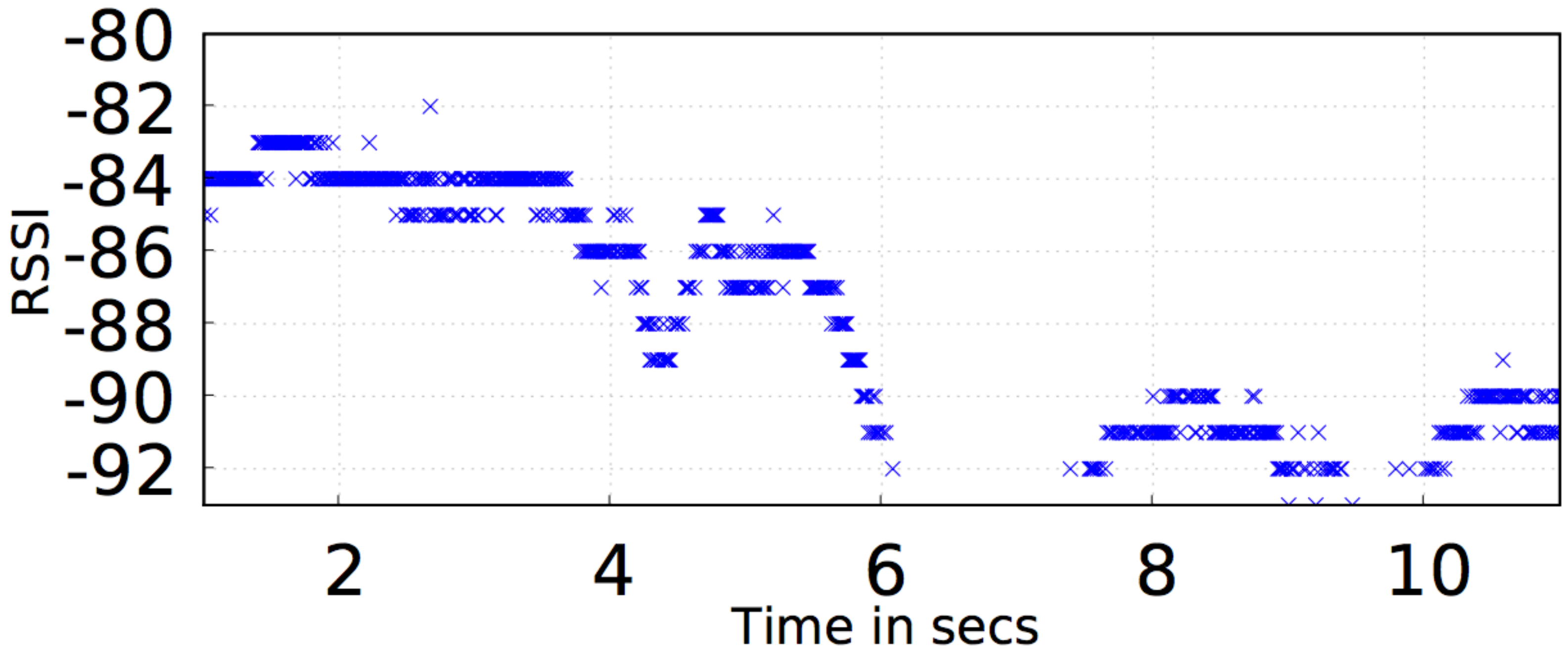
Signal loss

Signal degrades approximately $1/r^2$



Signal variation over time

Received Signal Strength Indicator



Signal interference

From other transmitters

- Close-by transmitters on same frequency
- Leakage from adjacent channels and frequencies

From myself

- Multipath signals (“echoes” in a canyon)