Lecture 12: Wireless Physical and Link Layers

Static Routing is due today

Ethernet: 802.3

- **Dominant wired LAN technology**
  - 10BASE5 (vampire taps)
  - 10BASE-T, 100BASE-TX, 1000BASE-T
- **Frame format:**

Physical		Link			Layer 3	Link	
Preamble	SFD	Src	Dest	Type/ Len	Payload	CRC	Gap
7 x 10101010	10101011	6 bytes	6 bytes	2 bytes	46-1500 bytes	4 bytes	96 ns, 960 ns, 9600 ns

Physical Layer (Layer 1)

- **Responsible for specifying the physical medium**
  - Category 5 cable (Cat5): 8 wires, twisted pair, RJ45 jack
  - WiFi wireless: 2.4GHz
- **Responsible for specifying the signal**
  - 100BASE-T: 5-level pulse amplitude modulation (PAM-5)
  - 802.11b: Binary and quadrature phase shift keying (BPSK/QPSK)
- **Responsible for specifying the bits**
  - 100BASE-T: 4-to-6 bit-to-chip encoding, 3 chip symbols
  - 802.11b: Barker code (1-2Mbps), complementary code keying (5.5-11Mbps)

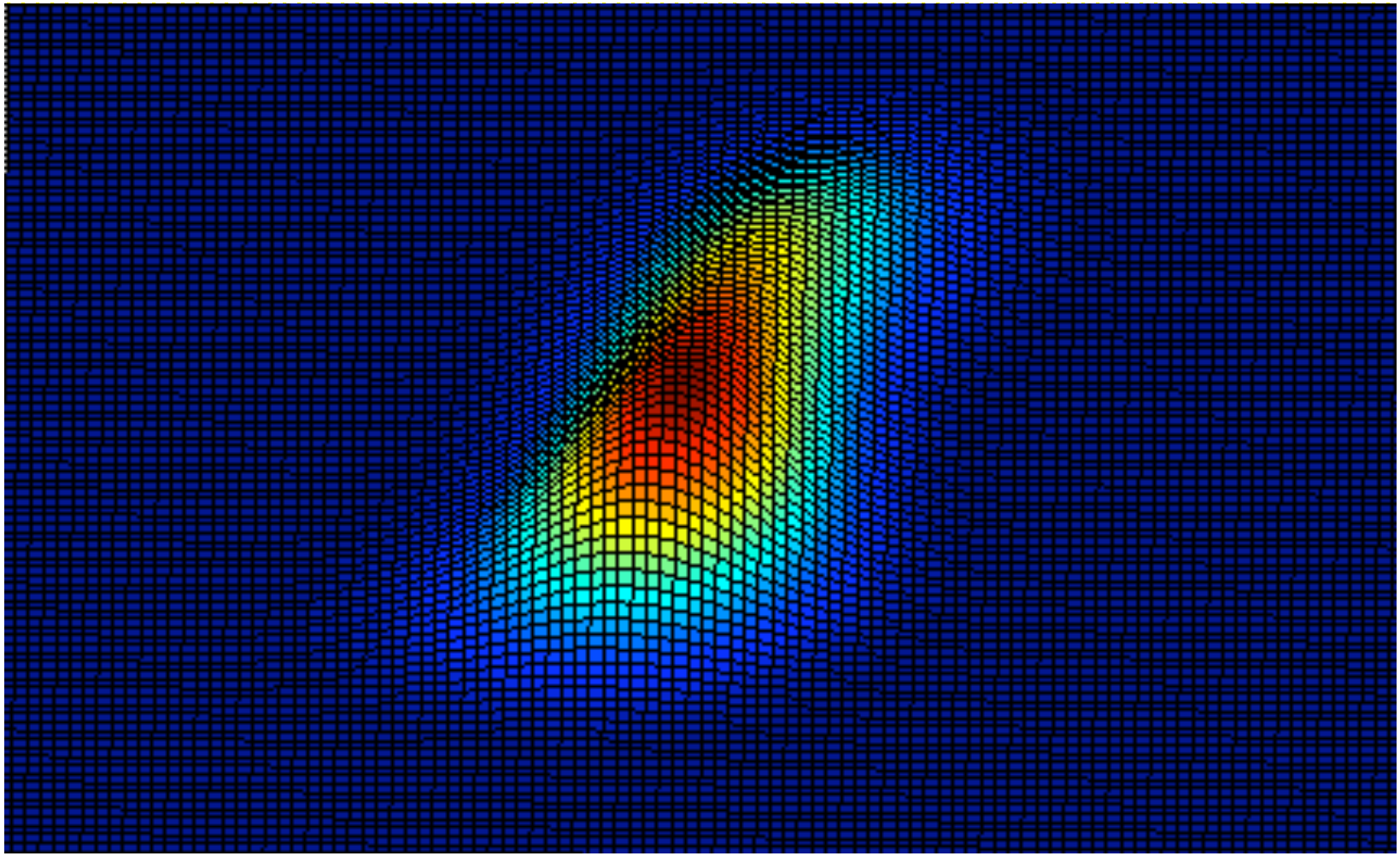
Wireless is Different

- **Variable: signal attenuates over space**
- **Interference: other RF sources can interfere with signal**
- **Multipath: signal can self-interfere**
- **Distributed: nodes cannot detect collisions**
- **To address these differences, wireless link layers use slightly different mechanisms**

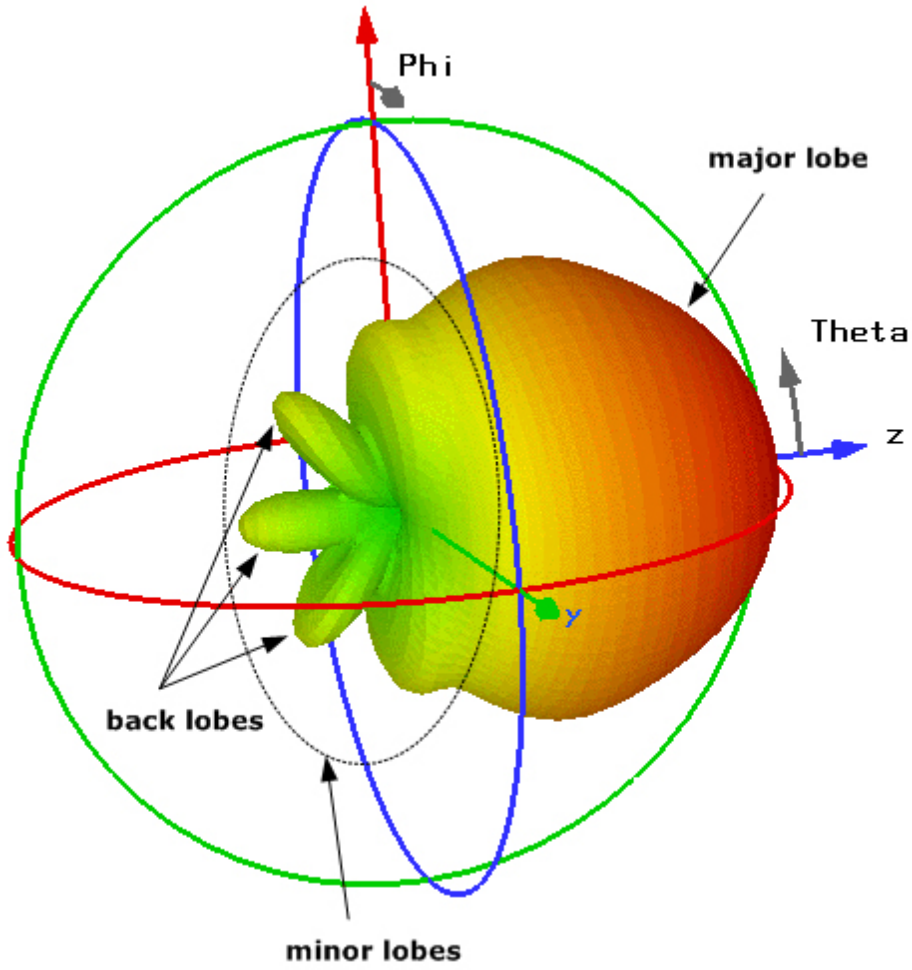
Attenuation Over Space

- Signal weakens as distance from transmitter increases
- Reflections, obstructions, etc. complicate the attenuation
- Depending on the antenna, not uniform in all directions
- Much more complex than the wired model

Signal Strength Over Space



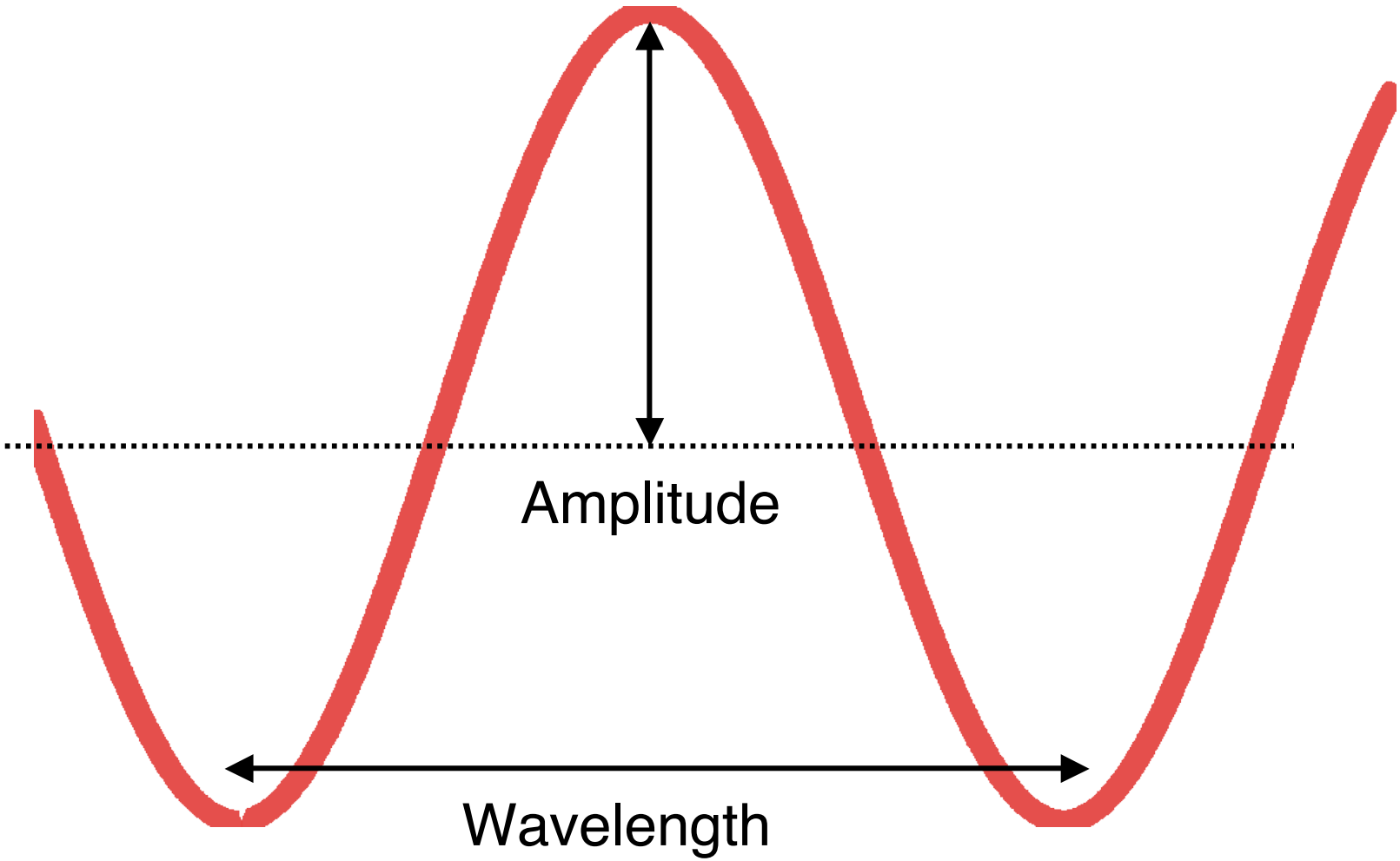
Directional Antennas



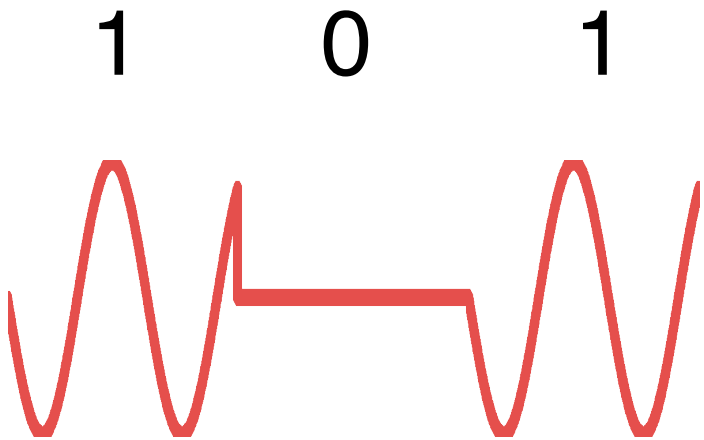
Interference

- **In unlicensed bands (e.g., 802.11), there are lots of transmitters**
  - 802.11 cards
  - 802.15.1 (Bluetooth)
  - 802.15.4 (ZigBee)
  - 2.4GHz phones
  - Microwave ovens
- **This interference can be stronger or weaker than the signal, and can prevent successful reception**

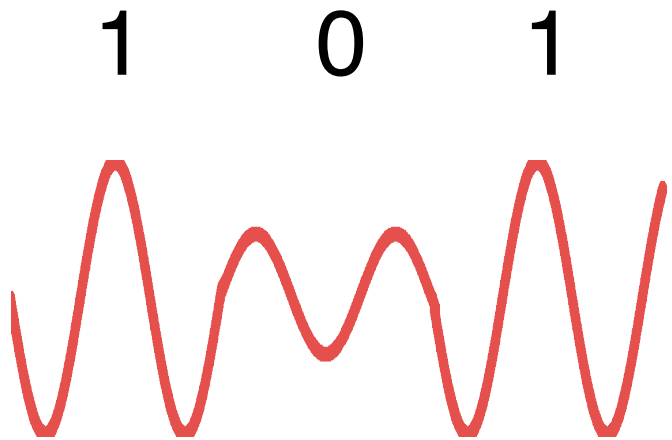
Analog Signals



Specifying the Signal: Modulation

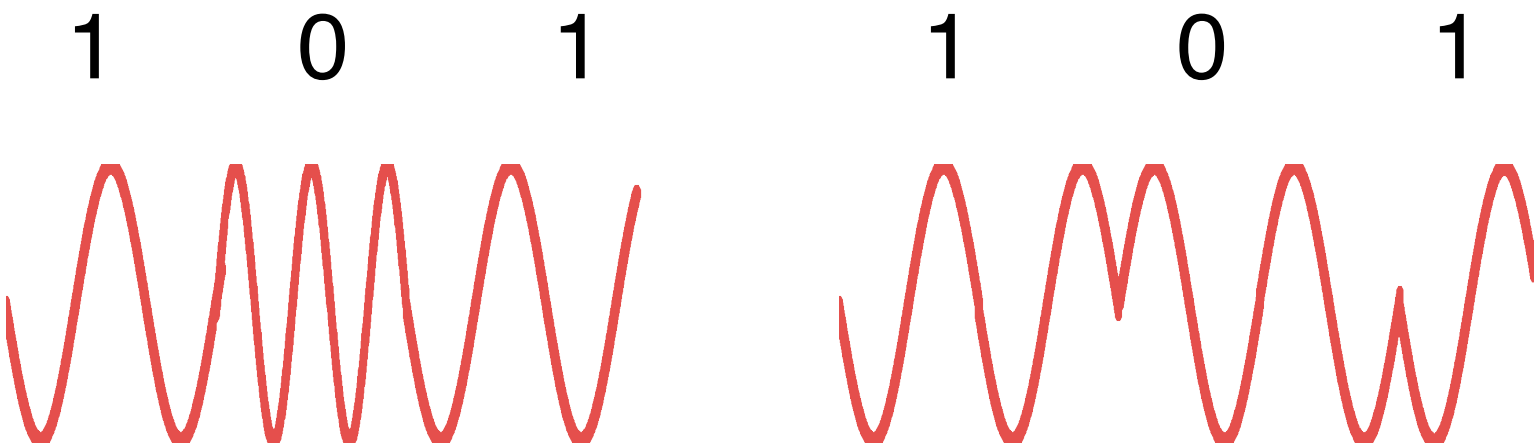


On-Off Keying (OOK)



Amplitude Shift Keying (ASK)

Modulation, Continued

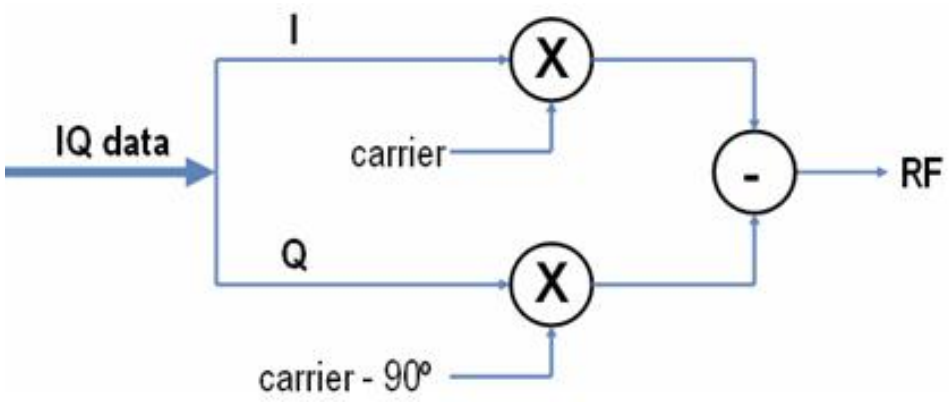


Frequency Shift Keying (FSK)

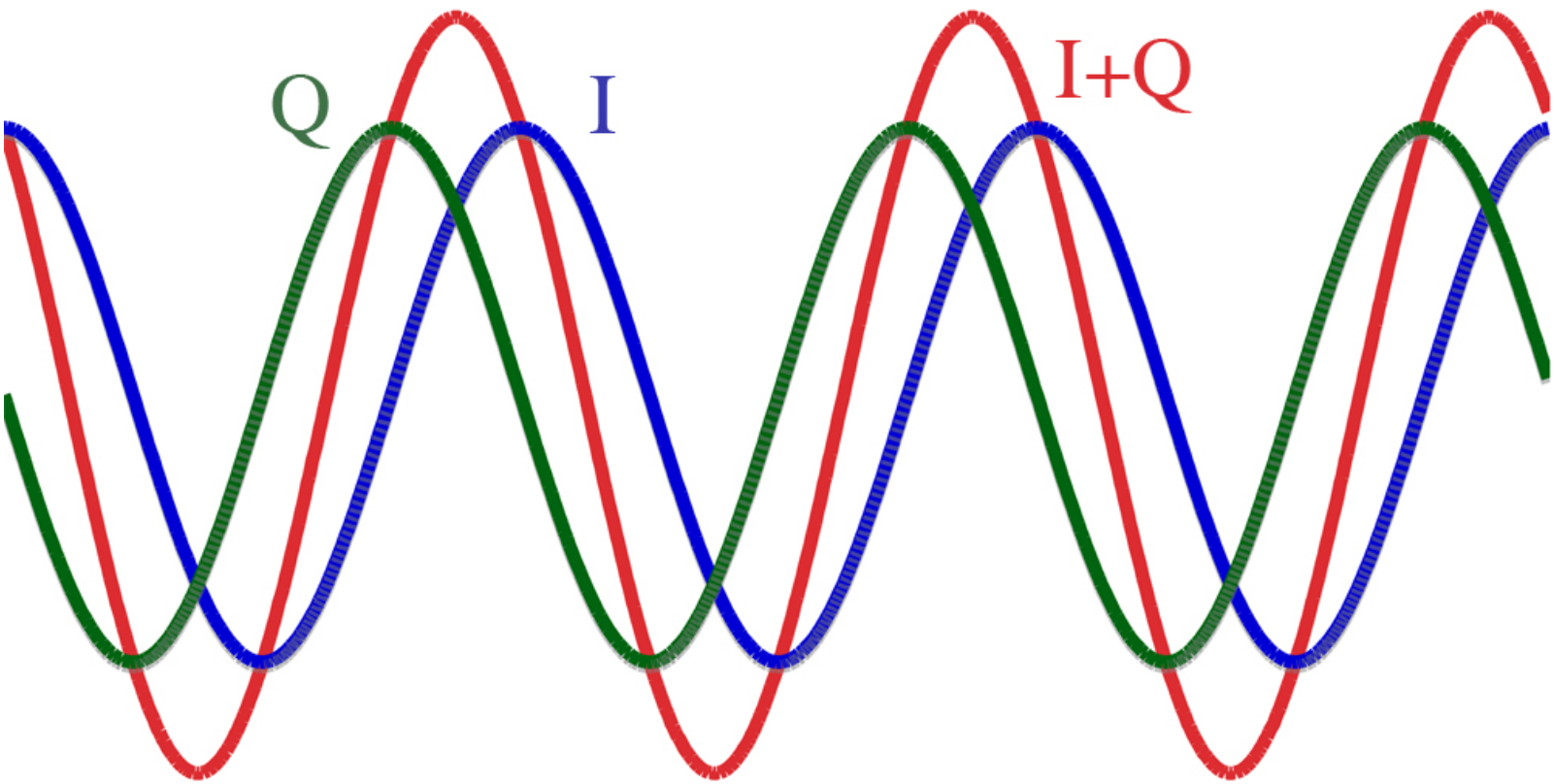
Phase Shift Keying (PSK)

I/Q Modulation

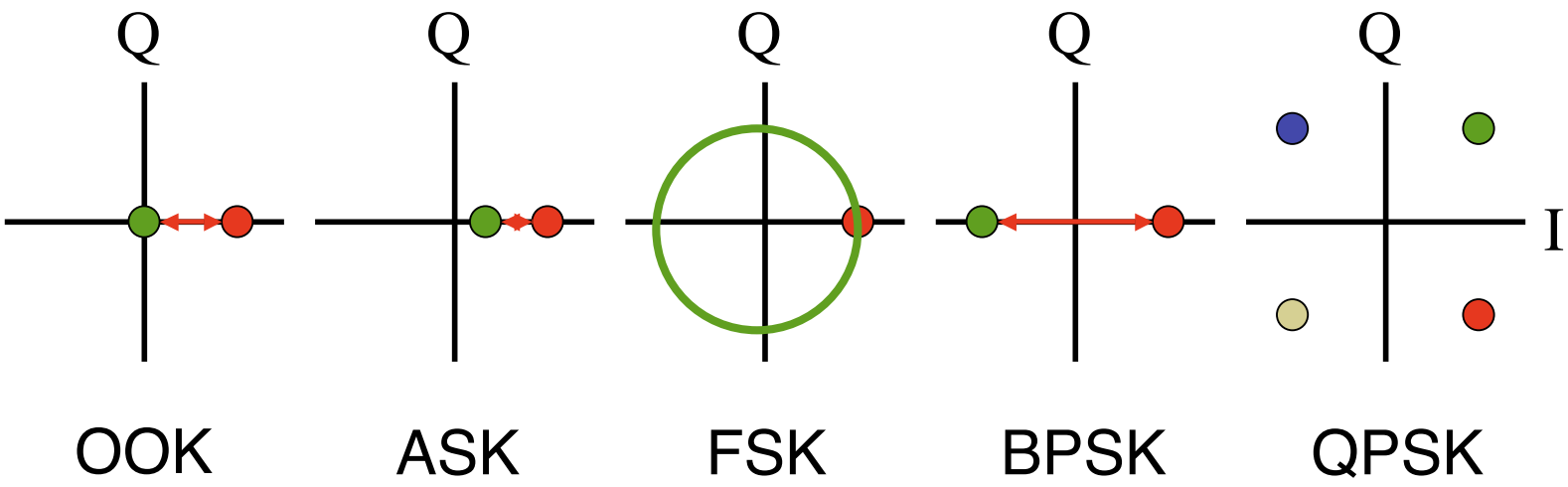
- I: in-phase, Q: quadrature
- Sum of two sines is a sine
- Show what the carrier looks like compared to a simple, unmodulated signal
- Use I/Q because this is how it's actually done in hardware



I+Q



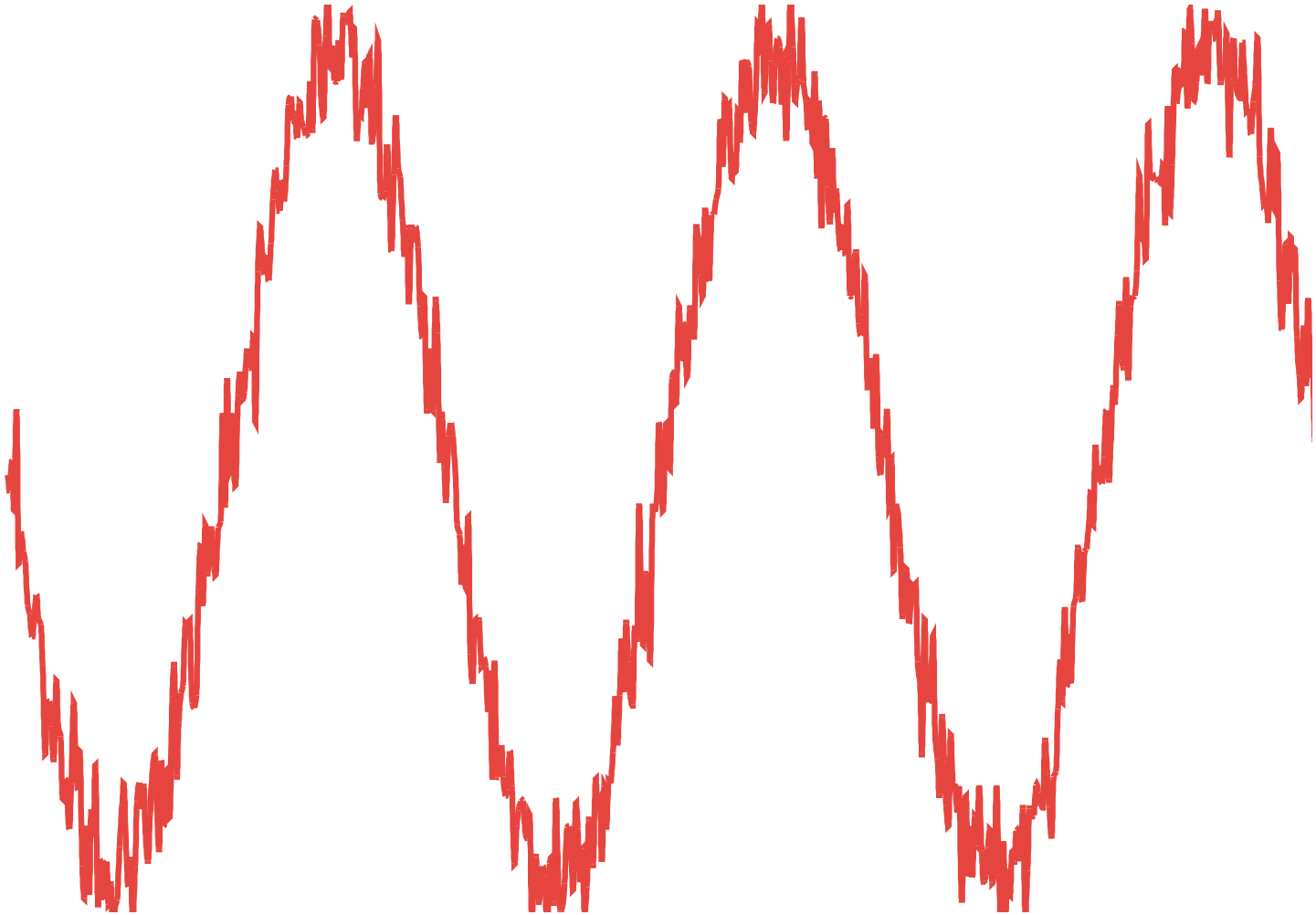
Modulation in I/Q Plots



Signal, Noise, and Interference

- **Signal: energy of desired transmission**
- **Noise/Noise floor: energy of hardware thermal effects**
- **Interference: energy of other transmitters**
- **Usually measured in dBm/dBW: 0dBm = 1mW, 0dBW = 30dBm = 1W**
  - Note dB is a logarithmic scale: 10dBm = 10mW, 20dBm = 100mW

Signal Plus Noise

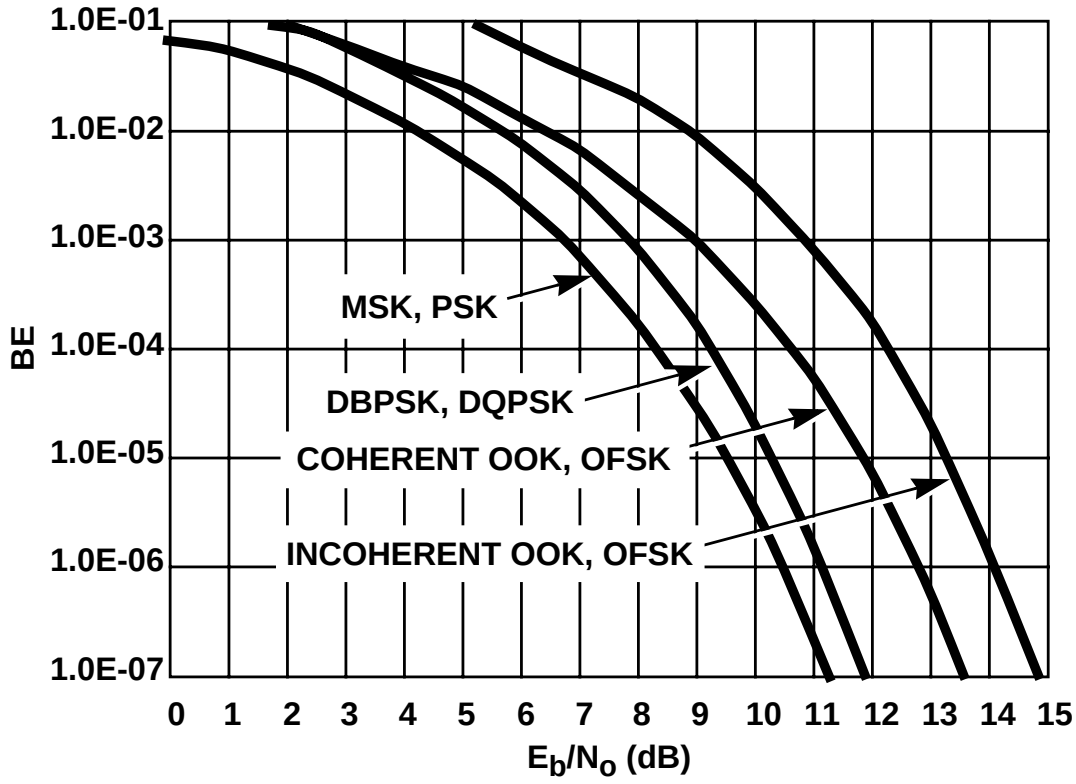


SINR

- **Signal to Interference-and-Noise Ratio**
- **Measured in dB:** $\frac{|S|}{|N+I|}$
  - S = -50dBm, N+I = -95dBm, SINR = 35dB
  - S = -89dBm, N+I = -93dBm, SINR = 4dB

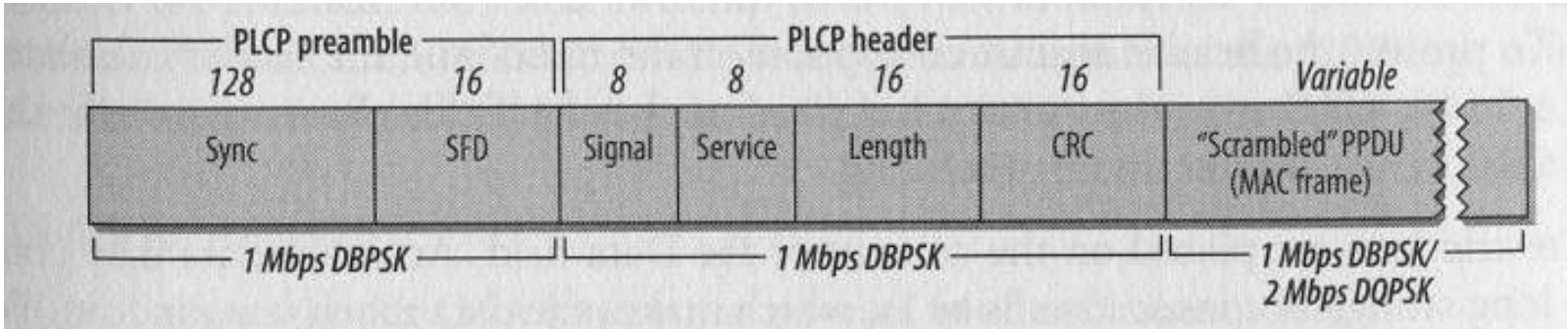
Bit Error Rates

- **There is a theoretical limit on how much information a channel can carry**
- **Bit error rate depends on the SINR and the modulation**
- **This is why wireless link layers use more complex chip/bit encoding**


1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
BE
MSK, PSK
DBPSK, DQPSK
COHERENT OOK, OFSK
INCOHERENT OOK, OFSK
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Eb/No (dB)

Example: 802.11b

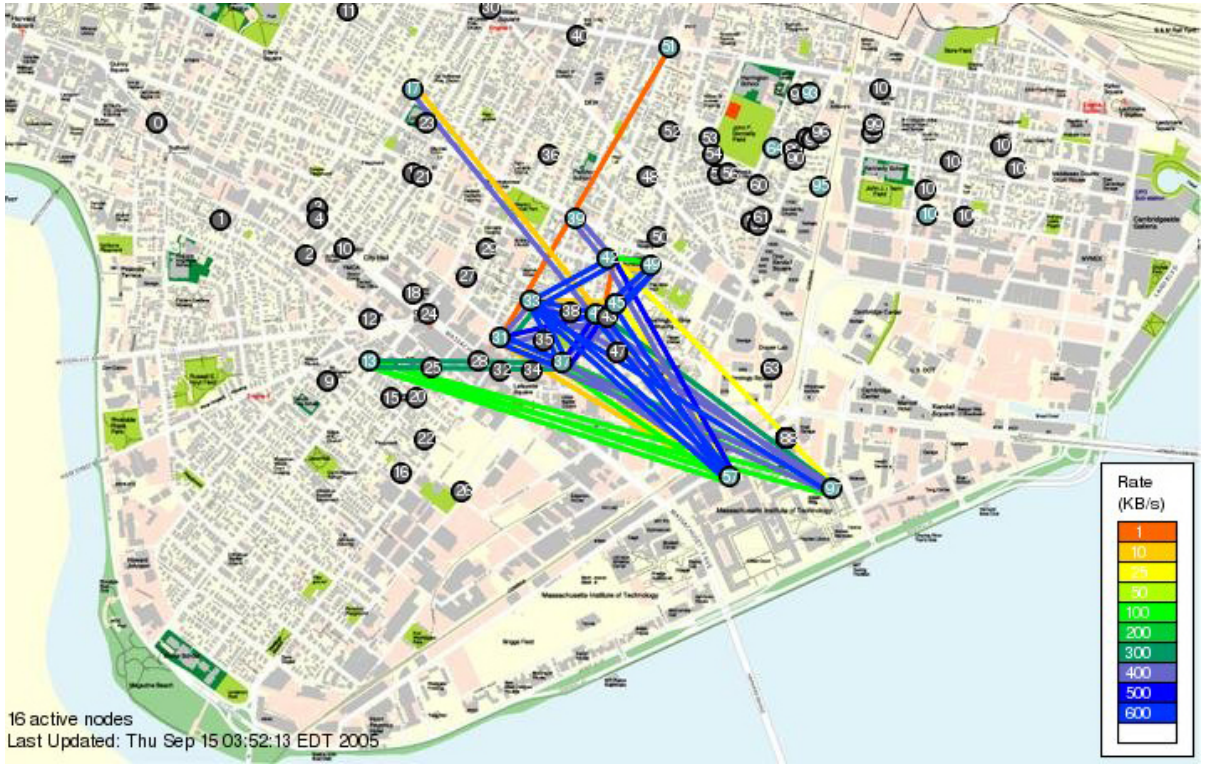
- 11-chip Barker sequence: 10110111000
- Binary Phase Shift Keying (BPSK)
- SYNC, SFD, signal, service, length, CRC, data
- Service field reserved, length is in us



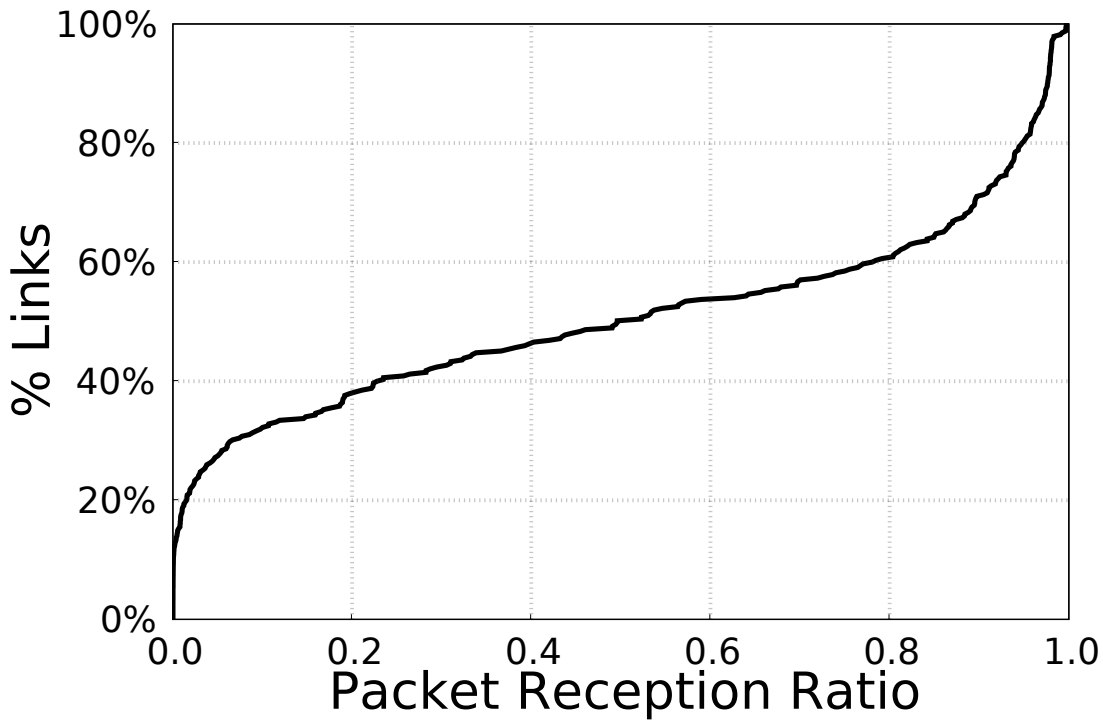
Variable Bit Rates

- **802.11b supports 1, 2, 5.5, and 11Mbps**
- **2, 5.5Mbps and 11Mbps are QPSK**
- **To support this, the signal field says what the data rate is**
  - 00001010: 1Mbps (11 chips/bit, barker code)
  - 00010100: 2Mbps (11 chips/bit, barker code)
  - 00110111: 5.5Mbps (2 chips/bit, CCK)
  - 01101110: 11Mbps (1 chip/bit, CCK)
- **So the header is still at 1Mbps, even if the data is at 11Mbps**
- **CCK is rather complex: don't worry about it**

802.11 Packet Loss Rates



802.11 Packet Loss Rates (at 11Mbps)



- **How does this affect TCP?**

Wireless PHY Summary

- Can't control or limit the channel
- Need to deal with weak signals, interference, etc.
- Many different kinds of modulation: amplitude, frequency, phase
- Use robust encodings when needed, use fast speeds when possible
- Lots of intermediate packet delivery ratios

2 minute break

MAC Layer Responsibilities

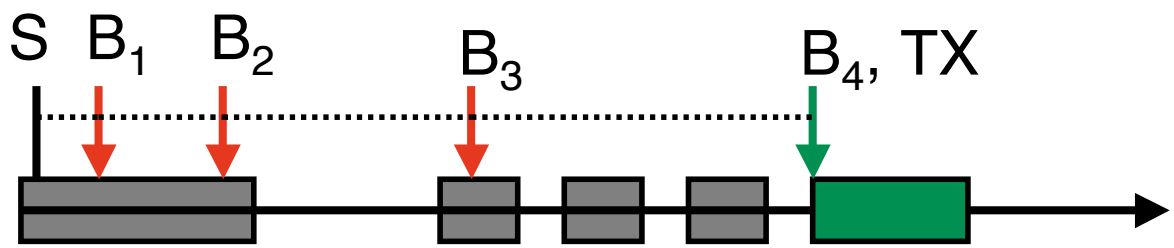
- Arbitrate control of the channel
- One node should be able to use 100%
- Multiple nodes should get a fair share
- Want high utilization under contention

CA versus CD

- **Collision detect (CD) is hard in wireless**
- **Local signal is much stronger than anything received**
- **Protocols use collision avoidance (CA) by sensing the channel**

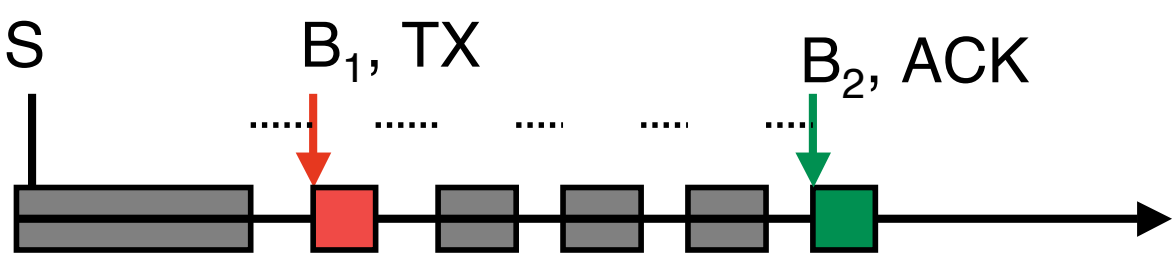
Simple MAC: CSMA/CA

- 1) Wait a small random period, check the channel
- 2) If the channel is busy, go to 1 (maybe longer wait)
- 3) Transmit packet



802.11b MAC: CSMA/CA

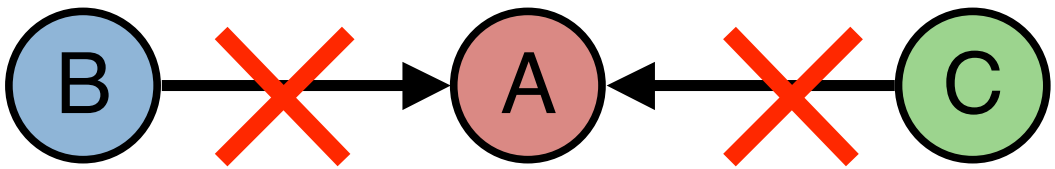
- **Maintain a waiting counter c**
- **For each time step channel is idle, $c--$**
- **When $c = 0$, transmit**
- **If packet is not acknowledged (layer 2), pick a new, larger c**
  - Use lack of layer 2 ack as collision detect



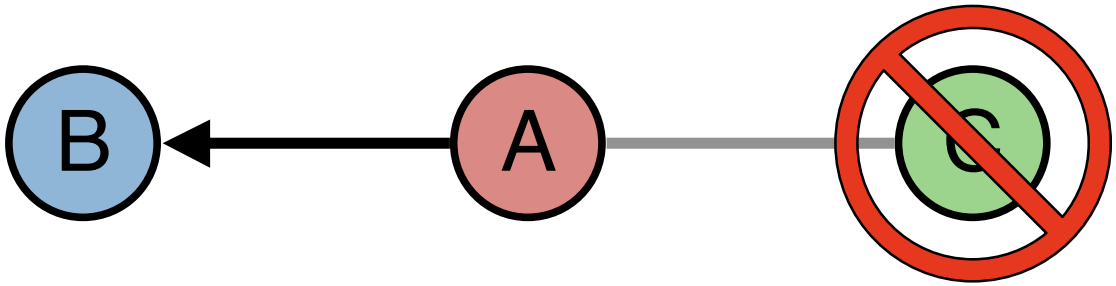
Problems with CSMA/CA

- **Want to know state of channel at receiver, not transmitter**
- **But wireless is not transitive!**
  - A hears B
  - A hears C
  - B and C may not hear each other
  - B and C can only sense their channel, but need to know if A's channel is clear

Hidden Terminal Problem



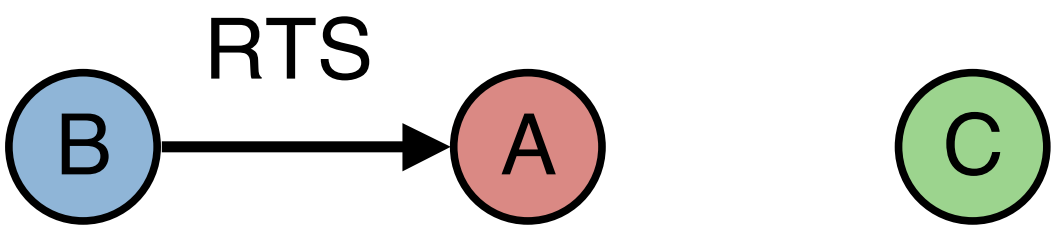
Exposed Terminal Problem



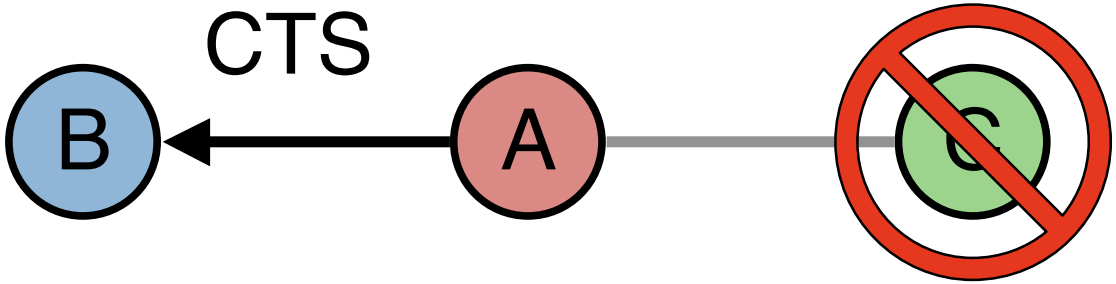
RTS/CTS

- Request-to-send, Clear-to-send (RTS/CTS)
- Allows transmitter to check availability of channel at receiver
- Transmitter sends an RTS
- If it hears a CTS, sends data
- If not, retries RTS some time later
- If you hear a CTS for someone else, don’t transmit

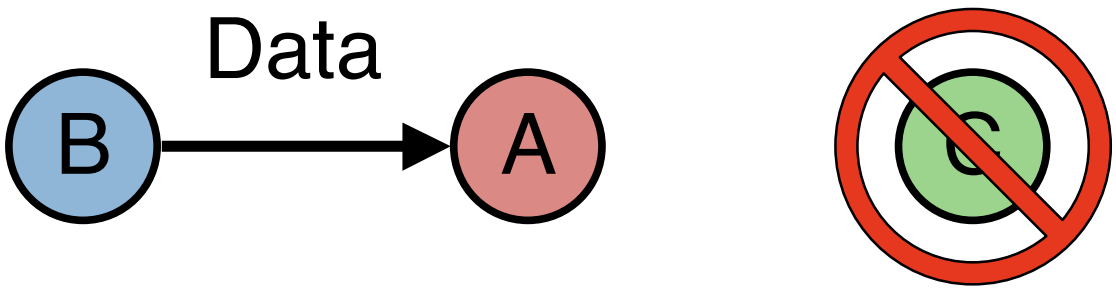
RTS



CTS



Data

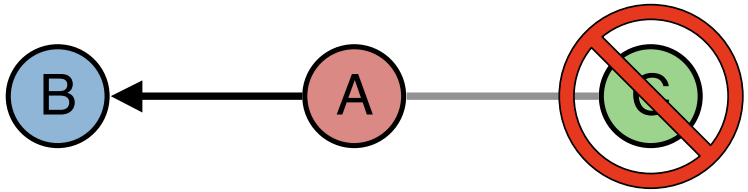


Network Allocation Vector (NAV)

- **802.11b supports RTS/CTS**
- **NAV is data structure node uses to know when channel may be clear**
- **NAV is in terms of *time*: variable bit rates, RTS, etc.**

RTS/CTS Benefits

- Solves the hidden terminal problem (assuming CTS not corrupted)
- Improves packet delivery ratio
- Does it solve the exposed terminal problem? What about ACKs?



RTS/CTS Drawbacks

- 3 packets per packet: RTS/CTS/DATA
- RTS still go through CSMA: they can be lost
- CTS losses cause lengthy retries
- 33% of IP packets are TCP ACKs: is it worth it?
- In practice, WiFi doesn't use RTS/CTS