Lecture 16:
QoS and Wireless

CS/ECE 438: Communication Networks

Prof. Matthew Caesar

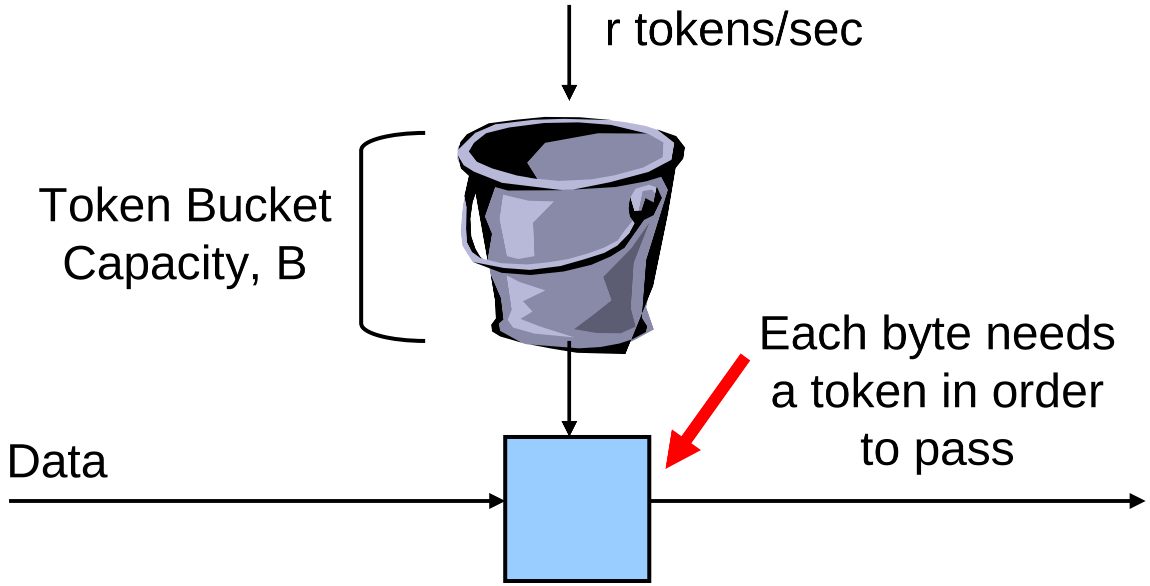
May 5, 2010

Administrivia

- Watch Chris Popp’s tutorial of content distribution:
  - http://www.youtube.com/watch?v=gZz87tOLNGQ

- Any questions on course content?

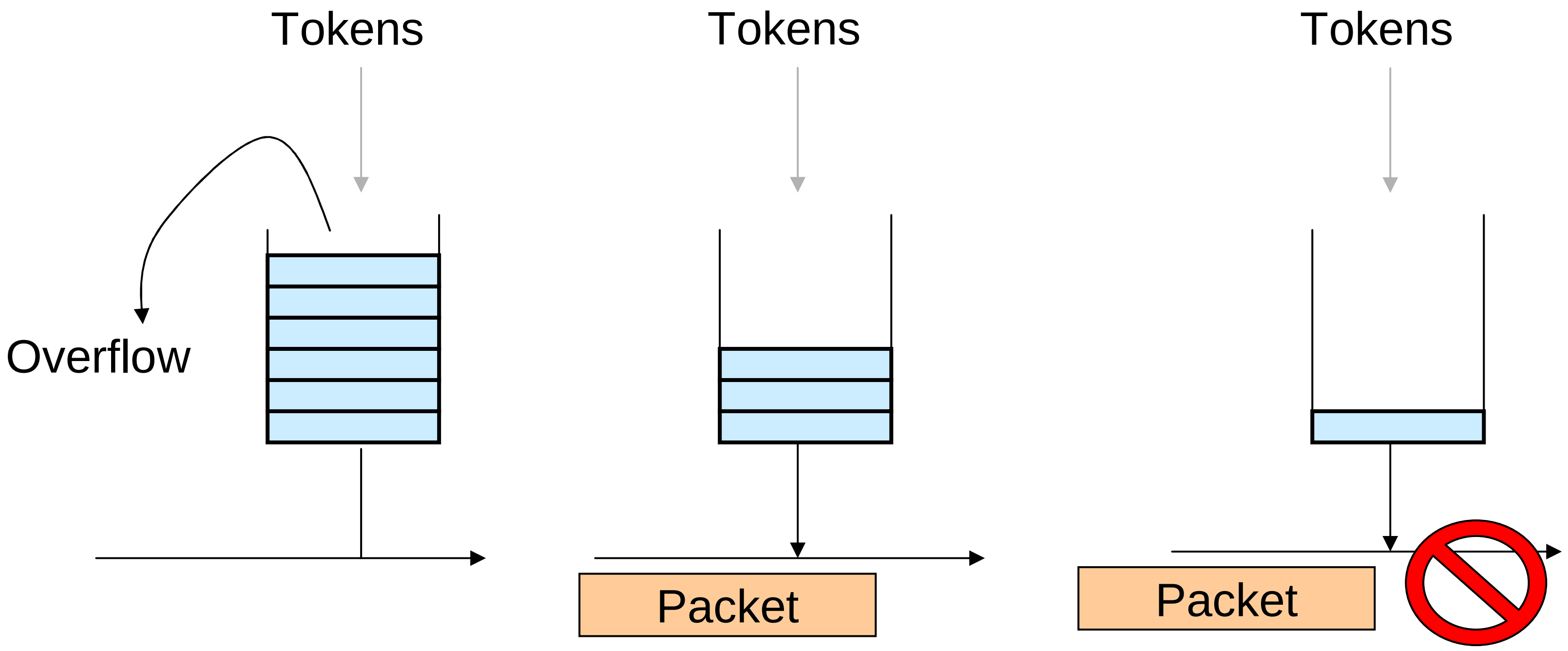
Token Bucket Filters



Dropping Filter: drops packets if token is not available

Buffered Filter: buffers data until tokens become available

Token Bucket Operation



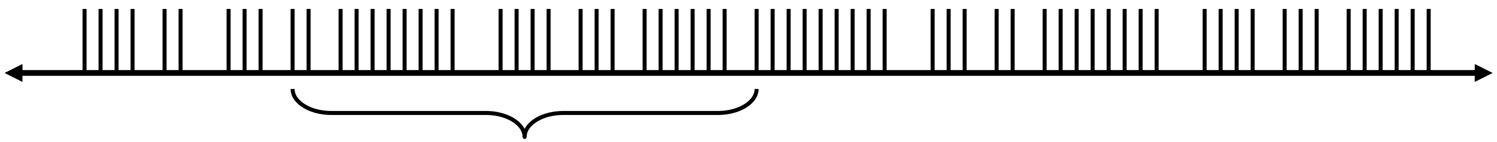
Buffer tokens up to capacity of bucket

Enough tokens → packet goes through, tokens removed

Not enough tokens → wait for tokens to accumulate

Token Bucket Filters

- Question
  - Given a finite length data stream, will it be affected by a token bucket filter?

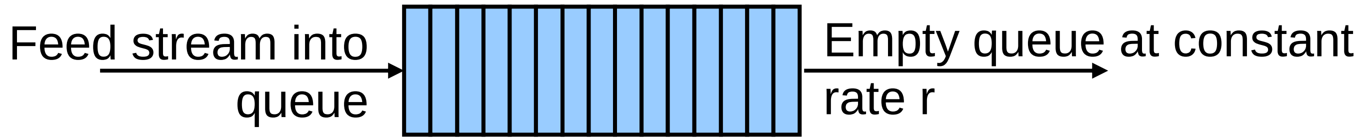


Not if during every time interval, the number of bytes is less than or equal to B + rt, where t is the length of the interval

- Given a token rate r and a finite data trace, how can the minimum token bucket size B be found such that there is no packet loss?

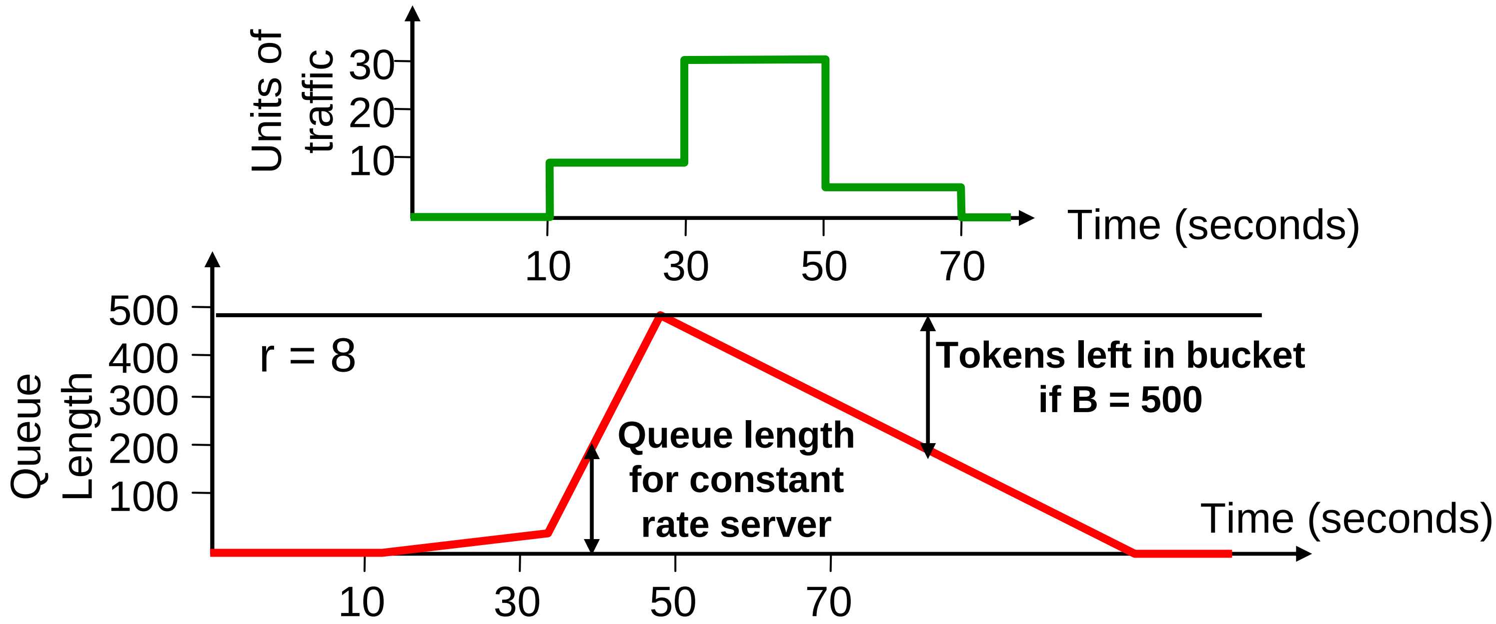
Token Bucket Filters

- Given a token rate r and a finite data trace, how can the minimum token bucket size B be found such that there is no packet loss?



- Simply observe the maximum buffer size
  - If the buffer is truncated to size B, then the number of empty buffer positions is equivalent to the number of tokens in an (r,B) token bucket filter

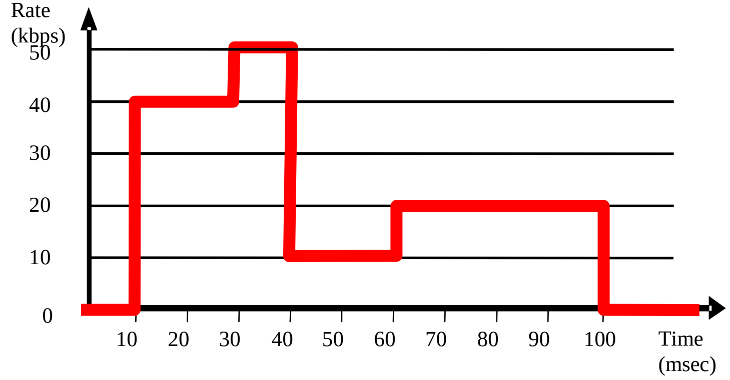
Token Bucket Filters



- The number of empty buffer positions for buffer size B and a constant rate server is equivalent to the number of tokens in an (r,B) token bucket filter

Token Bucket Filters

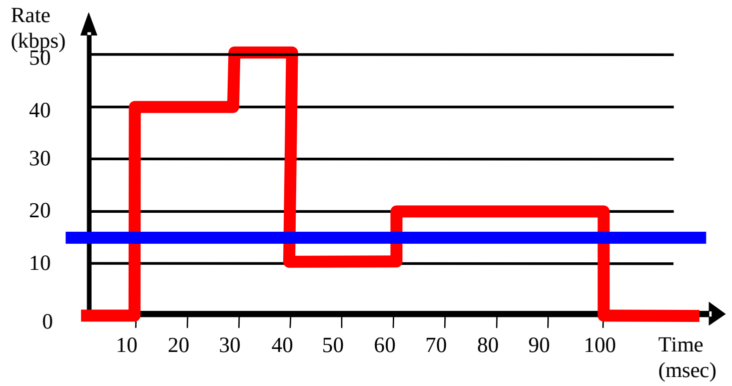
- r = 15 kbps



- What is the minimum size of B required so that the filter lets the stream pass with no loss or delay?

Token Bucket Filters

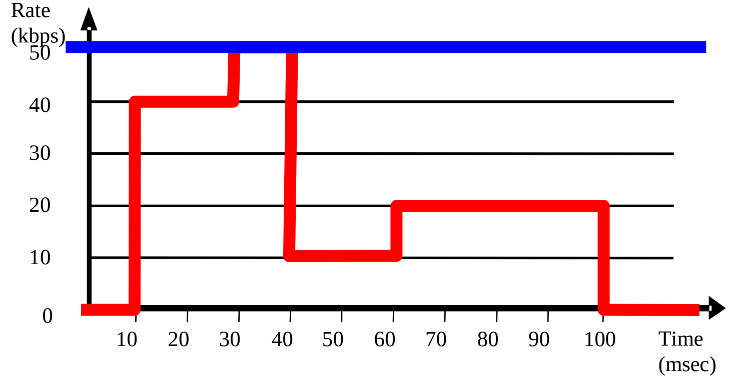
- r = 15 kbps



- Min B =
  (40 – 15) * 20 +
  (50 – 15) * 10 –
  (15 – 10) * 20 +
  (20 – 15) * 40
  = 950 bits

Token Bucket Filters

- What is the minimum *B* needed for arbitrary *r* > 0



- If r ≥ 50
  B = 0
- If 50 > r ≥ 40
  Min B = (50 – r) * 10
- If 40 > r ≥ 20
  Min B = (40 – r) * 20 + (50 – r) * 10
- If 20 > r ≥ 10
  Min B = (40 – r) * 20 + (50 – r) * 10 – (r – 10) * 20 + (20 – r) * 40
- If 10 > r ≥ 0
  Min B = (40 – r) * 20 + (50 – r) * 10 + (10 – r) * 20 + (20 – r) * 40

Wireless Networking

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Wired Communication

- Pros
  - Very reliable
    - For Ethernet, medium HAS TO PROVIDE a Bit Error Rate (BER) of 10^{-12} (one error for every trillion bits!)
      - Insulated wires; wires placed underground and in walls
      - Error Correction Techniques
  - Very high transfer rates
    - Up to 100-Gbit/s or more
  - Long distance
    - Up to 40km (~25 miles) in 10-Gbit/s Ethernet (cutting edge)
- Cons
  - Expensive to set up infrastructure
  - Infrastructure is fixed once set up
  - No physical mobility

Wireless Communication

- Pros
  - Allows mobility
  - Much cheaper and easier to deploy, change, and upgrade!
- Cons
  - Exposed (unshielded) medium
    - Susceptible to physical phenomena (interference)
    - Variable BER – Error correction may not suffice in all cases
  - Slower data rates for wider distances
  - OSI layered stack designed for wired medium
    - Difficult to “hide” underlying behavior
  - Security: anyone in range hears transmission

Goals for today’s lecture

- Characteristics of Wireless Media
- 802.11 Architecture and Media Access Control Protocol
- Collision Detection vs. Collision Avoidance
  - Hidden Terminal and Exposed Terminal Problem
  - Request To Send (RTS) / Clear To Send (CTS)
- Multihop Wireless Networks
  - Sensor Networks
  - TCP over Multihop Networks
- Wireless Security

Wireless Communication Standards (Alphabet Soup)

- Cellular
  - 2G: GSM (Global System for Mobile communication),
- CDMA (Code division multiple access)
  - 3G: CDMA2000
- IEEE 802.11
  - A: 5.0Ghz band, 54Mbps (25 Mbps operating rate)
  - B: 2.4Ghz band, 11Mbps (4.5 Mbps operating rate)
  - G: 2.4Ghz, 54Mbps (19 Mbps operating rate)
  - Other versions to come.
- IEEE 802.15 – lower power wireless
  - 802.15.1: 2.4Ghz, 2.1 Mbps (Bluetooth)
  - 802.15.4: 2.4Ghz, 250 Kbps (Sensor Networks)

Wireless Link Characteristics

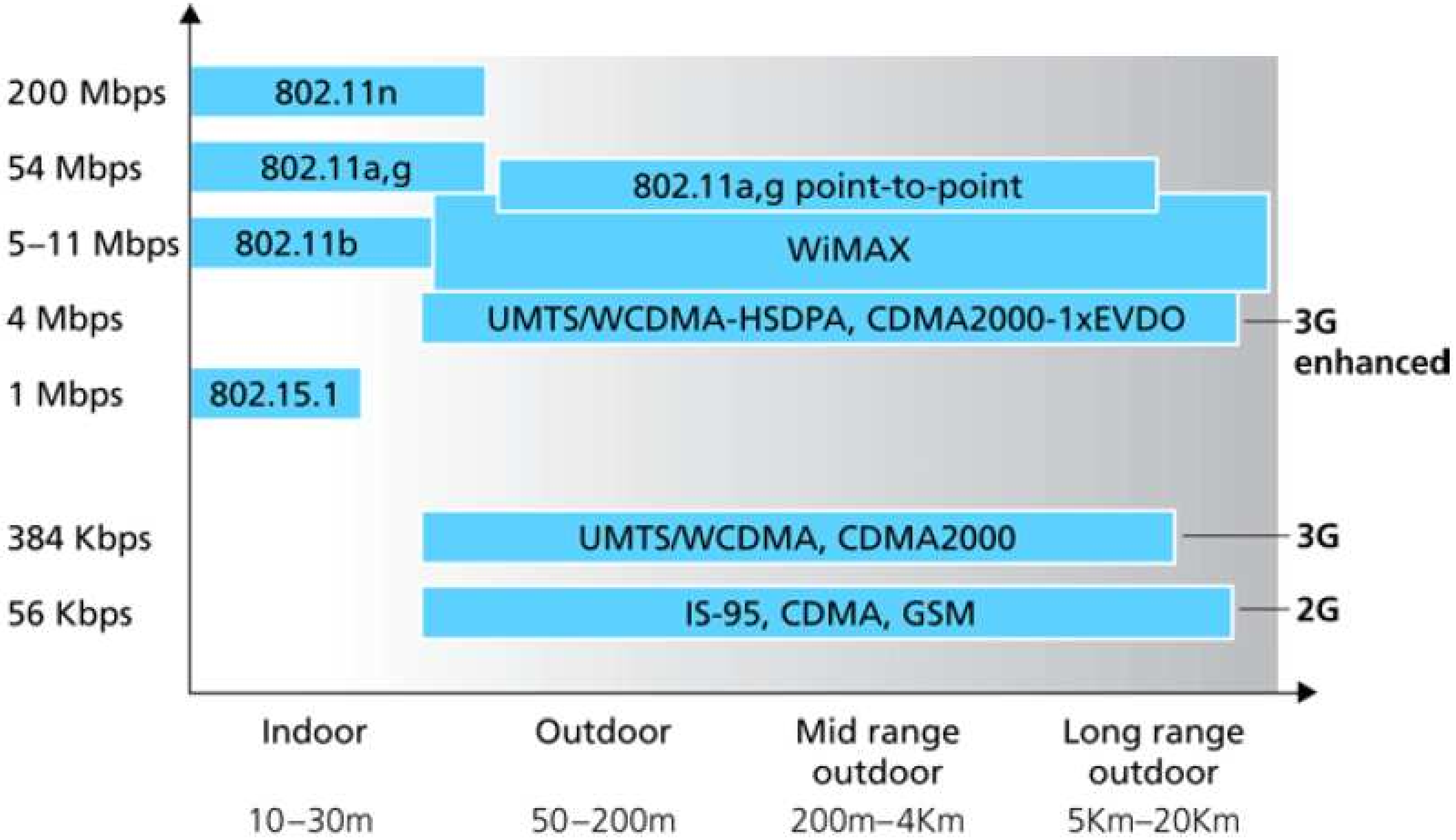


Figure 6.2 ♦ Link characteristics of selected wireless network standards

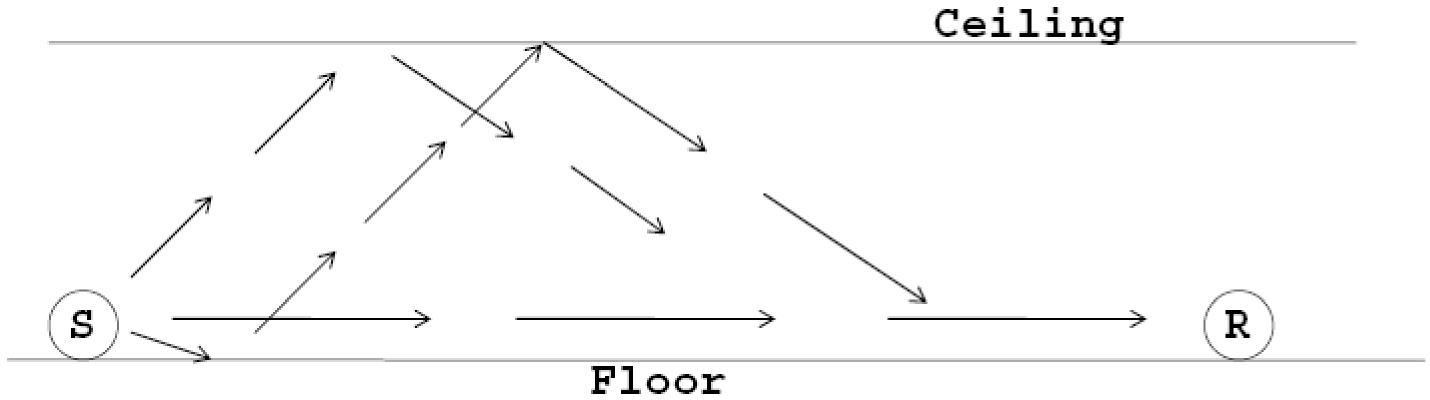
Other Wireless Link Characteristics

- Path loss
  - Signal attenuation as a function of distance
  - Signal-to-noise ratio (SNR—Signal Power/Noise Power) decreases, make signal unrecoverable
- Multipath Propagation
  - Signal reflects off surfaces, effectively causing selfinterference
- Interference from other sources
  - Internal Interference
    - Hosts within range of each other collide with one another's transmission (remember Aloha)
- External Interference
  - Microwave is turned on and blocks your signal

Path Loss

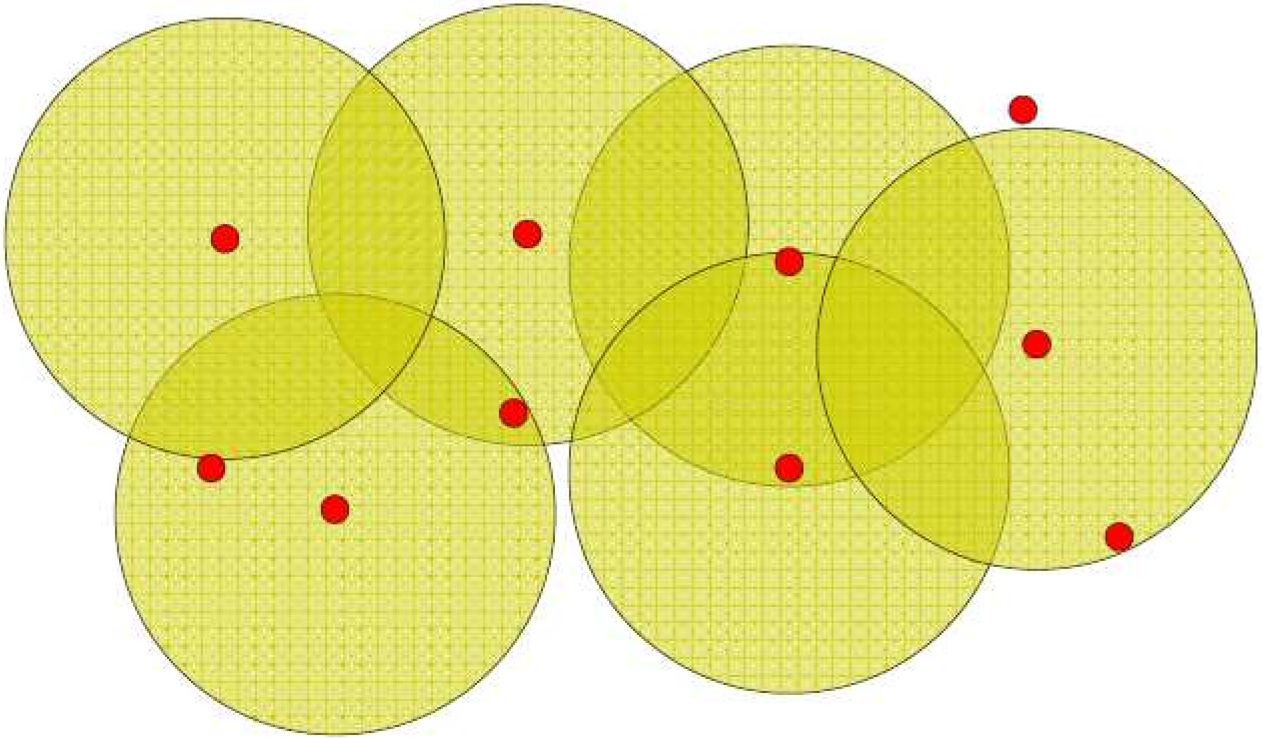
- Signal power attenuates by about ~r2 factor for omni-directional antennas in free space
  - Where r is the distance between the sender and the receiver
- The exponent in the factor is different depending on placement of antennas
  - Less than 2 for directional antennas
  - Faster Attenuation
    - Exponent greater than 2 when antennas are placed on the ground
    - Signal bounces off the ground and reduces the power of the signal

Multipath Effects



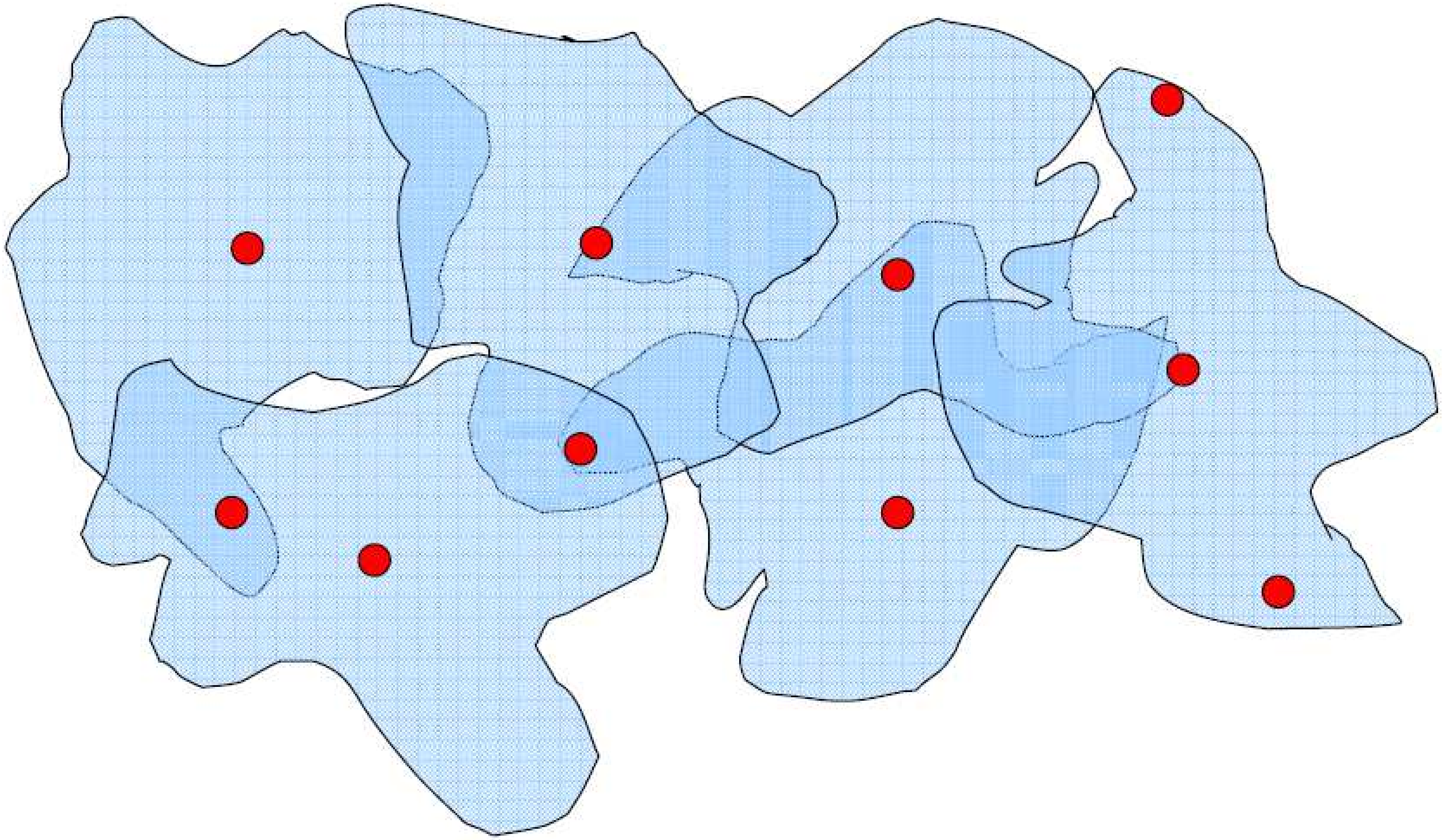
- Signals bounce off surface and interfere with one another
- What signals are out of phase?
  - Orthogonal signals cancel each other and nothing is received!

A Wireless Link?



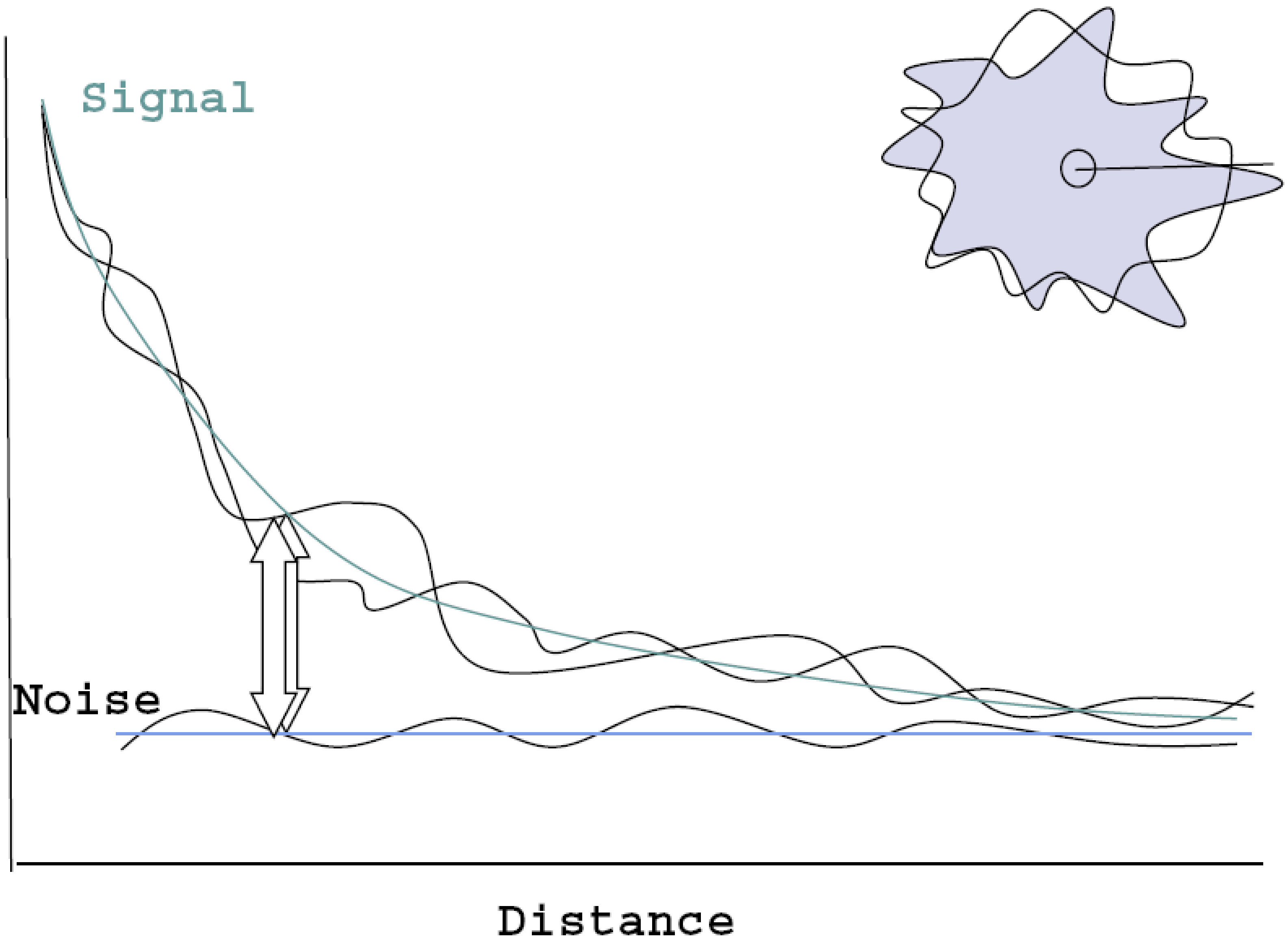
(courtesy of Gilman Tolle and Jonathan Hui, ArchRock)

A Wireless Link!



(courtesy of Gilman Tolle and Jonathan Hui, ArchRock)

The Amoeboed "cell"



Wireless Bit Errors

- The lower the SNR (Signal/Noise) the higher the Bit Error Rate (BER)
- How can we deal with this?
  - Make the signal stronger
- Why is this not always a good idea?
  - Increased signal strength requires more power
  - Increases the interference range of the sender, so you interfere with more nodes around you
- Error Correction schemes can correct some problems

802.11 Architecture

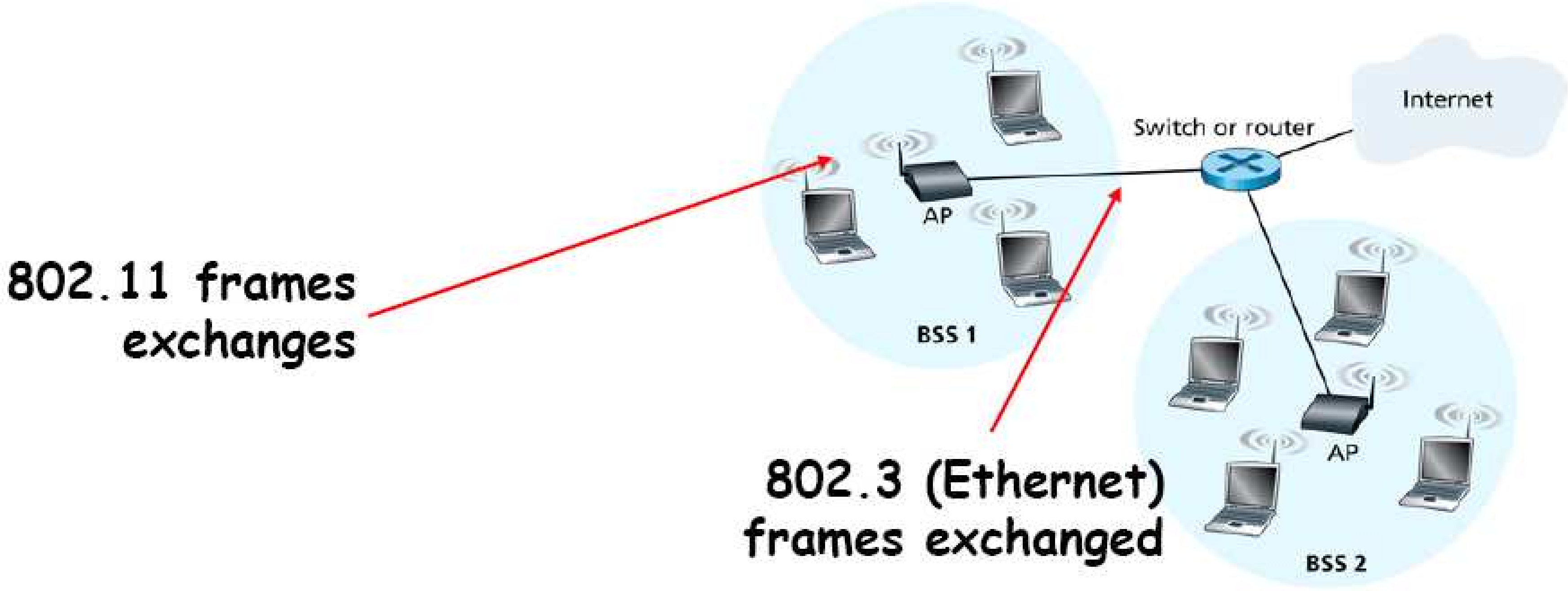


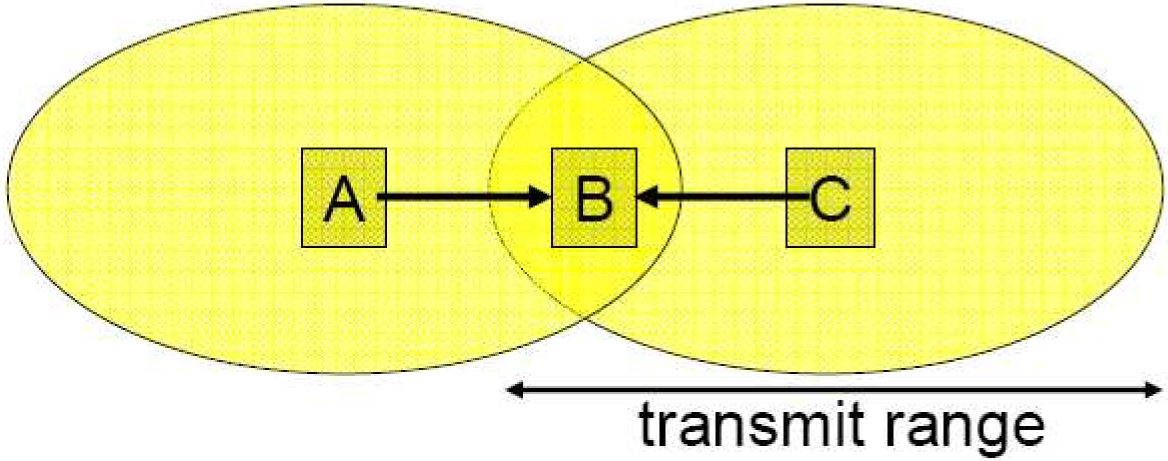
Figure 6.7 ♦ IEEE 802.11 LAN architecture

- Designed for limited geographical area
- APs (Access Points) are set to specific channel and broadcast beacon messages with SSID and MAC Address periodically
- Hosts scan all the channels to discover the APs
  - Host associates with AP (actively or passively)

Ethernet vs 802.11

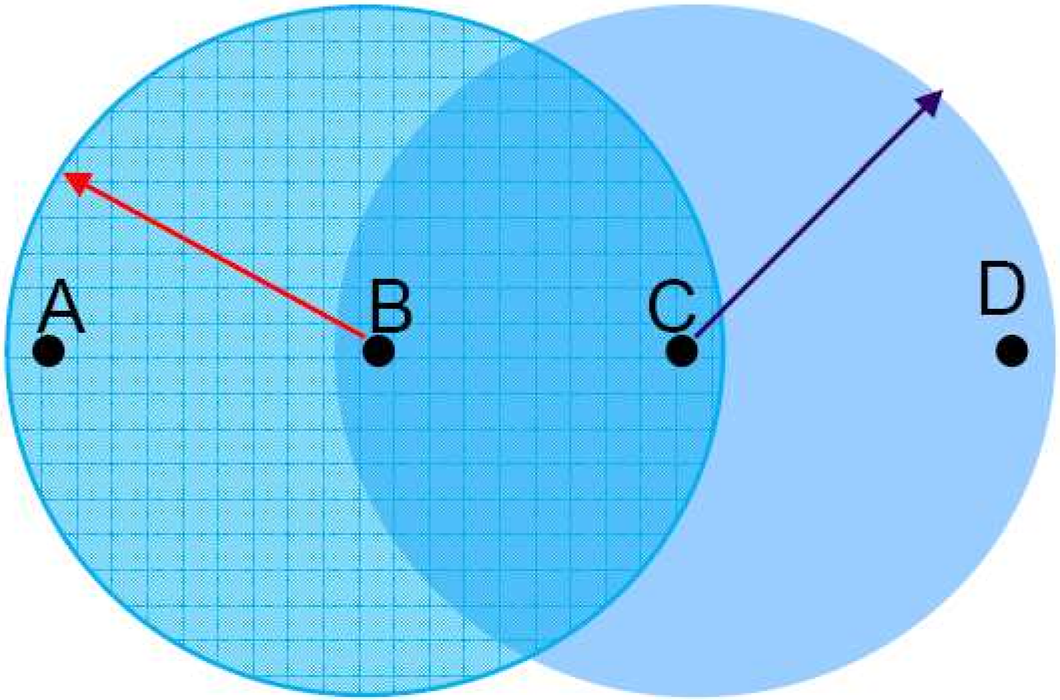
- Wireless MAC design
  - Why not just use Ethernet algorithms?
    - Ethernet: one shared "collision" domain
- It's technically difficult to detect collisions
  - Collisions are at receiver, not sender
- … even if we could, it wouldn't work
  - Different transmitters have different coverage areas
- In addition, wireless links are much more prone to loss than wired links
- Carrier Sense (CSMA) is OK; detection (CD) is not

Hidden Terminals



- A and C can both send to B, but can't hear each other
  - A is a hidden terminal for C and vice versa
- CSMA/CD will be ineffective – need to sense at *receiver*

Exposed Terminals

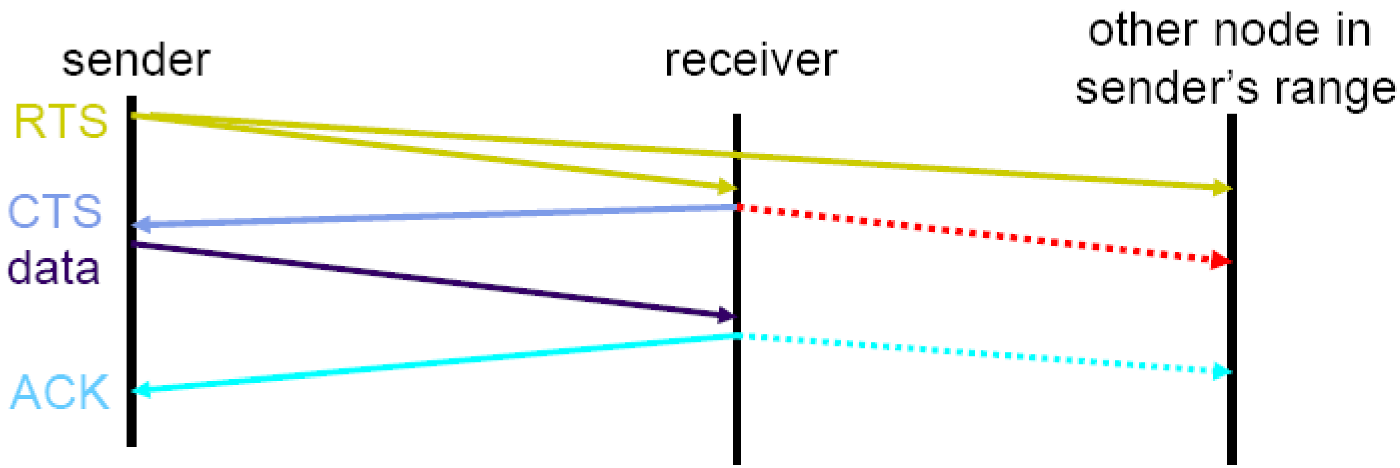


- Exposed node: B sends a packet to A; C hears this and decides not to send a packet to D (despite the fact that this will not cause interference!)

CSMA/CA: CSMA with *Collision Avoidance*

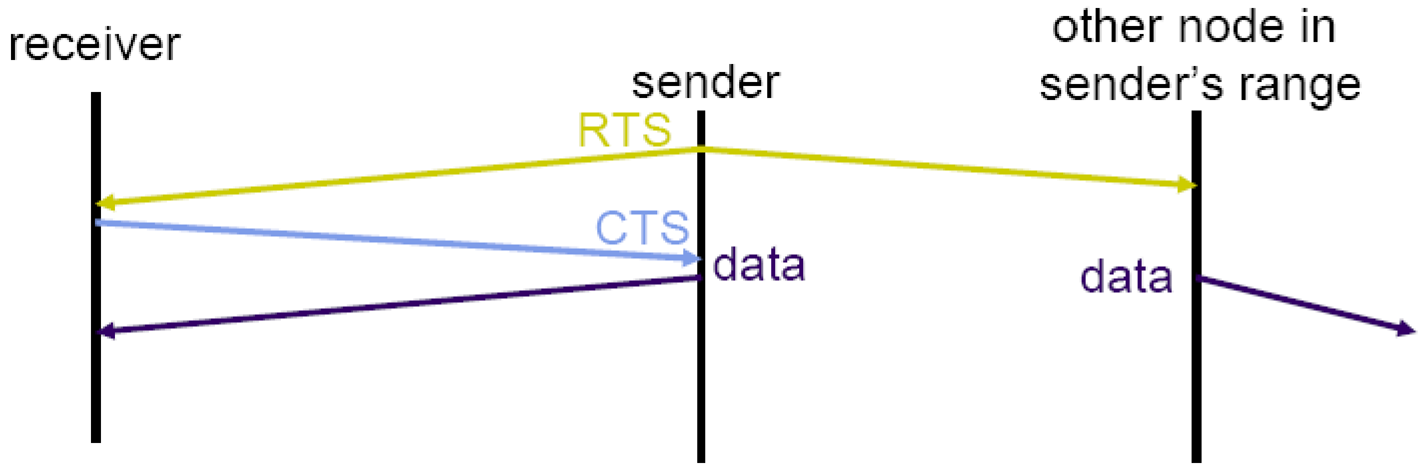
- Since we can't detect collisions, we try to avoid them
- When medium is busy, choose random interval (contention window)
  - Wait for that many idle timeslots to pass before sending
- When a collision is inferred, retransmit with binary exponential backoff (like Ethernet)
  - Use ACK from receiver to infer "no collision"
  - Use exponential backoff to adapt contention window

Multiple Access with Collision Avoidance (MACA)



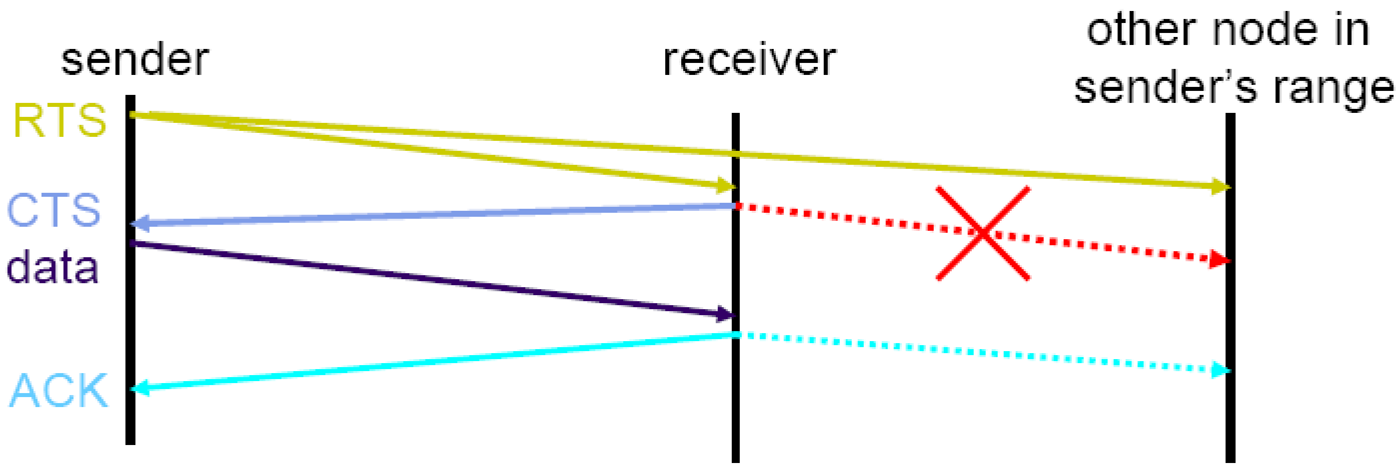
- Before every data transmission
  - Sender sends a Request to Send (RTS) frame containing the length of the transmission
  - Receiver responds with a Clear to Send (CTS) frame
  - Sender sends data
  - Receiver sends an ACK; now another sender can send data
- When sender doesn't get a CTS back, it assumes collision

MACA, continued



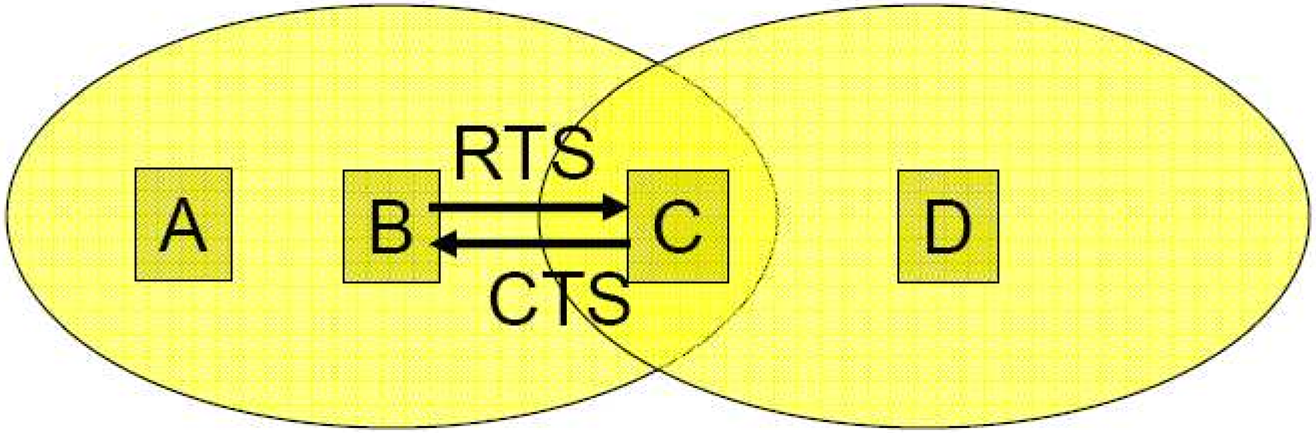
- If other nodes hear RTS, but not CTS: send
  - Presumably, destination for first sender is out of node's range…

MACA, continued



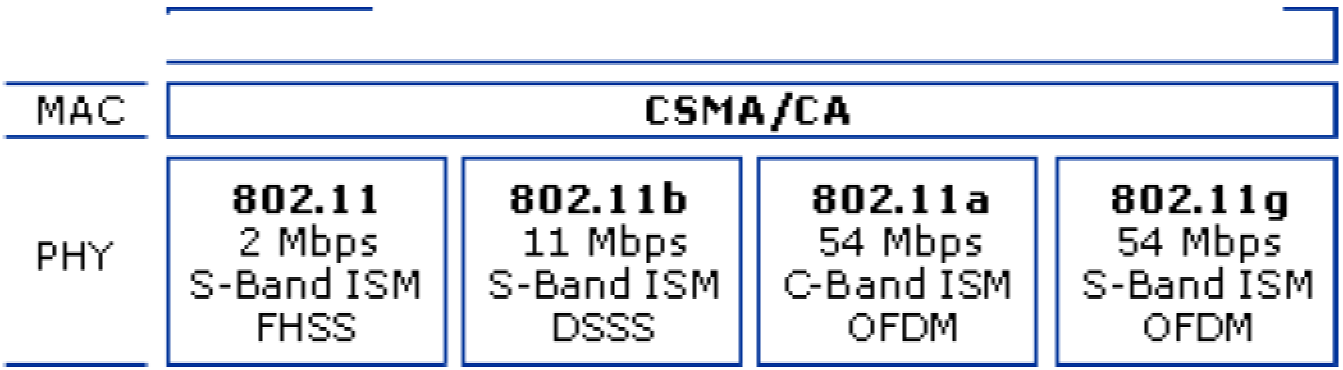
- If other nodes hear RTS, but not CTS: send
  - Presumably, destination for first sender is out of node's range…
  - … Can cause problems when a CTS is lost
- When you hear a CTS, you keep quiet until scheduled transmission is over (hear ACK)

RTS / CTS Protocols (MACA)



- MACA = Multiple Access with Collision Avoidance
- Overcome exposed/hidden terminal problems with contention-free protocol
  1. B stimulates C with Request To Send (RTS)
  2. A hears RTS and defers (to allow C to answer)
  3. C replies to B with Clear To Send (CTS)
  4. D hears CTS and defers to allow the data
  5. B sends to C

802.11 Stack View



- CSMA/CA runs over the 802.11 physical layer
- Link-level acknowledgements for every frame sent

Link-Layer Acknowledgements

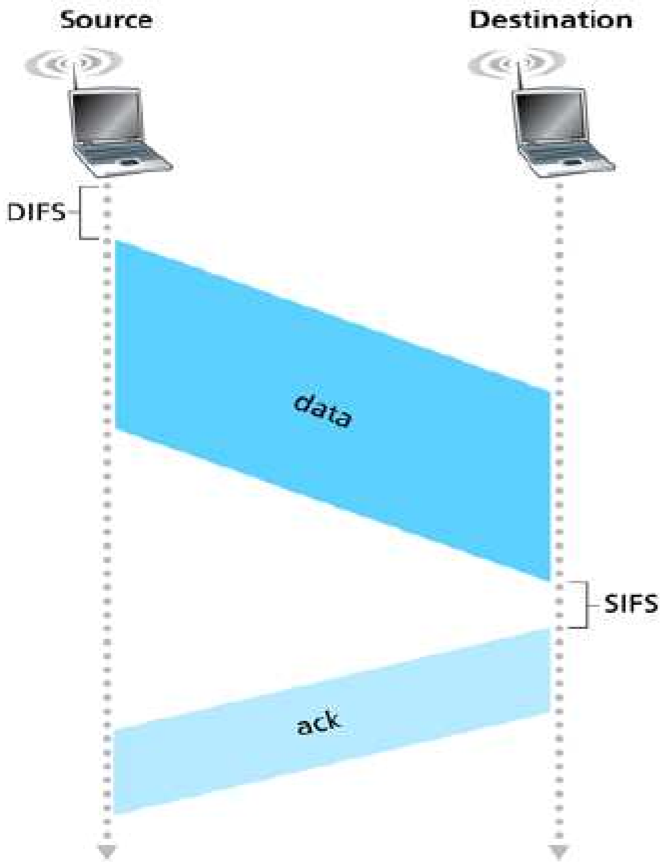
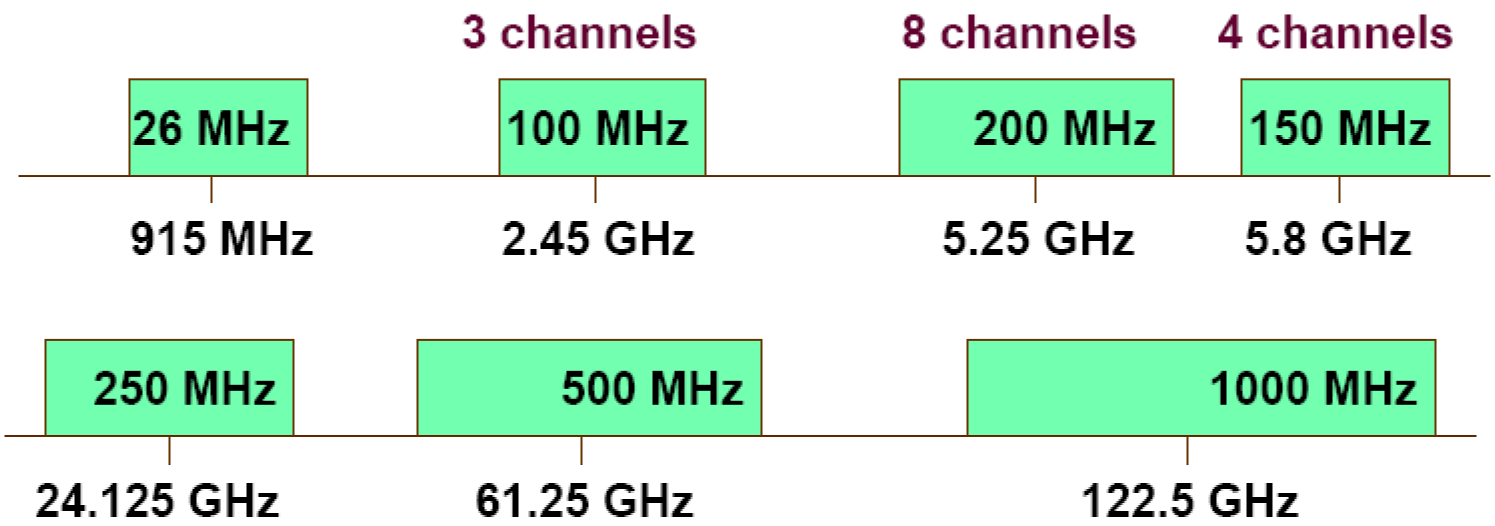


Figure 6.10 ♦ 802.11 uses link-layer acknowledgments.

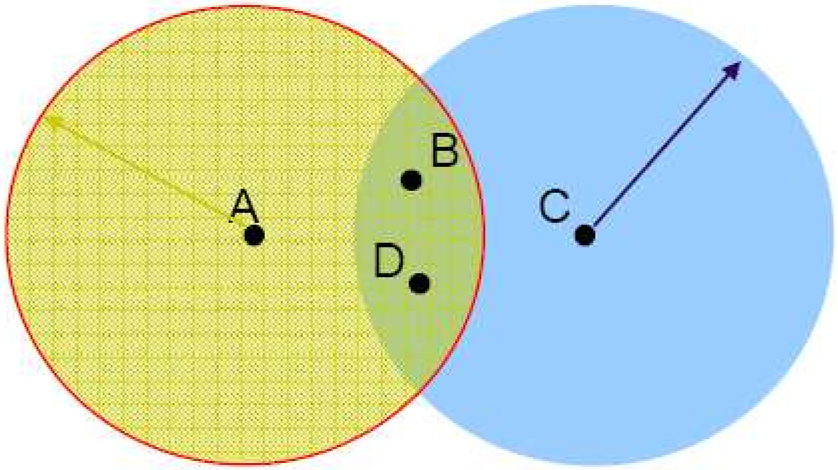
- Receiver acks every data packet
- If ACK is lost, source tries again until a maximum retransmission number is reached

Channelization of spectrum

- Typically, available frequency spectrum is split into multiple channels
- Some channels may overlap



Preventing Collisions Altogether



- Frequency Spectrum partitioned into several channels
  - Nodes within interference range can use separate channels
  - Now A can send to B while C sends to D without any interference!
  - Aggregate Network throughput doubles

Using Multiple Channels

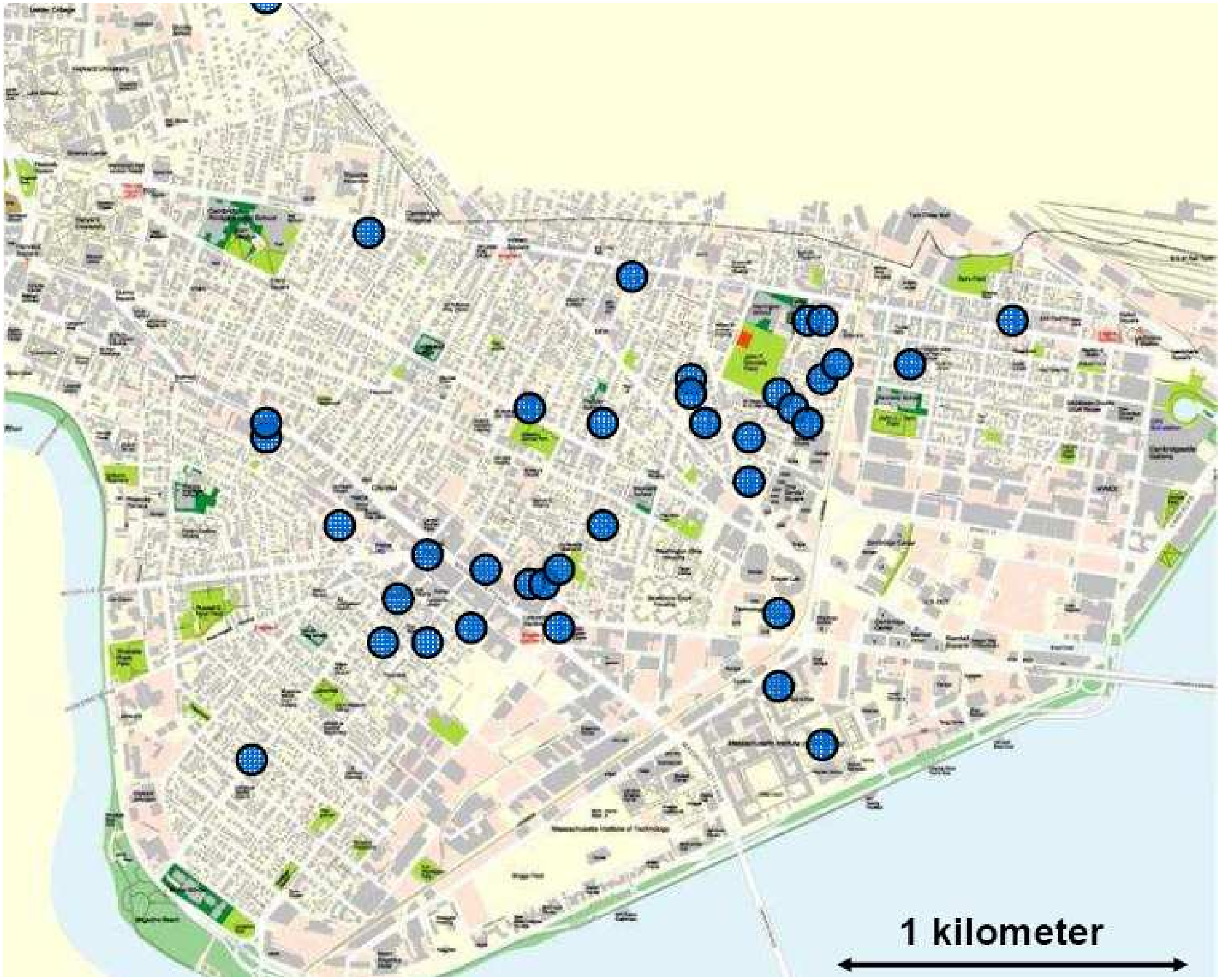
- 802.11: AP’s on different channels
  - Usually manually configured by administrator
  - Automatic Configuration may cause problems
- Most cards have only 1 transceiver
  - Not Full Duplex: Cannot send and receive at the same time
- Multichannel MAC Protocols
  - Automatically have nodes negotiate channels
    - Channel coordination amongst nodes is necessary
    - Introduces negotiation and channel-switching latency that reduce throughput

Wireless Multihop Networks

- Vehicular Networks
  - Delay Tolerant (batch) sending over several hops carry data to a base station
- Common in Sensor Network for periodically transmitting data
  - Infrastructure Monitoring
    - E.g., structural health monitoring of the Golden Gate Bridge
- Multihop networking for Internet connection sharing
  - Routing traffic over several hops to base station connected to Internet
  - E.g., Meraki Networks

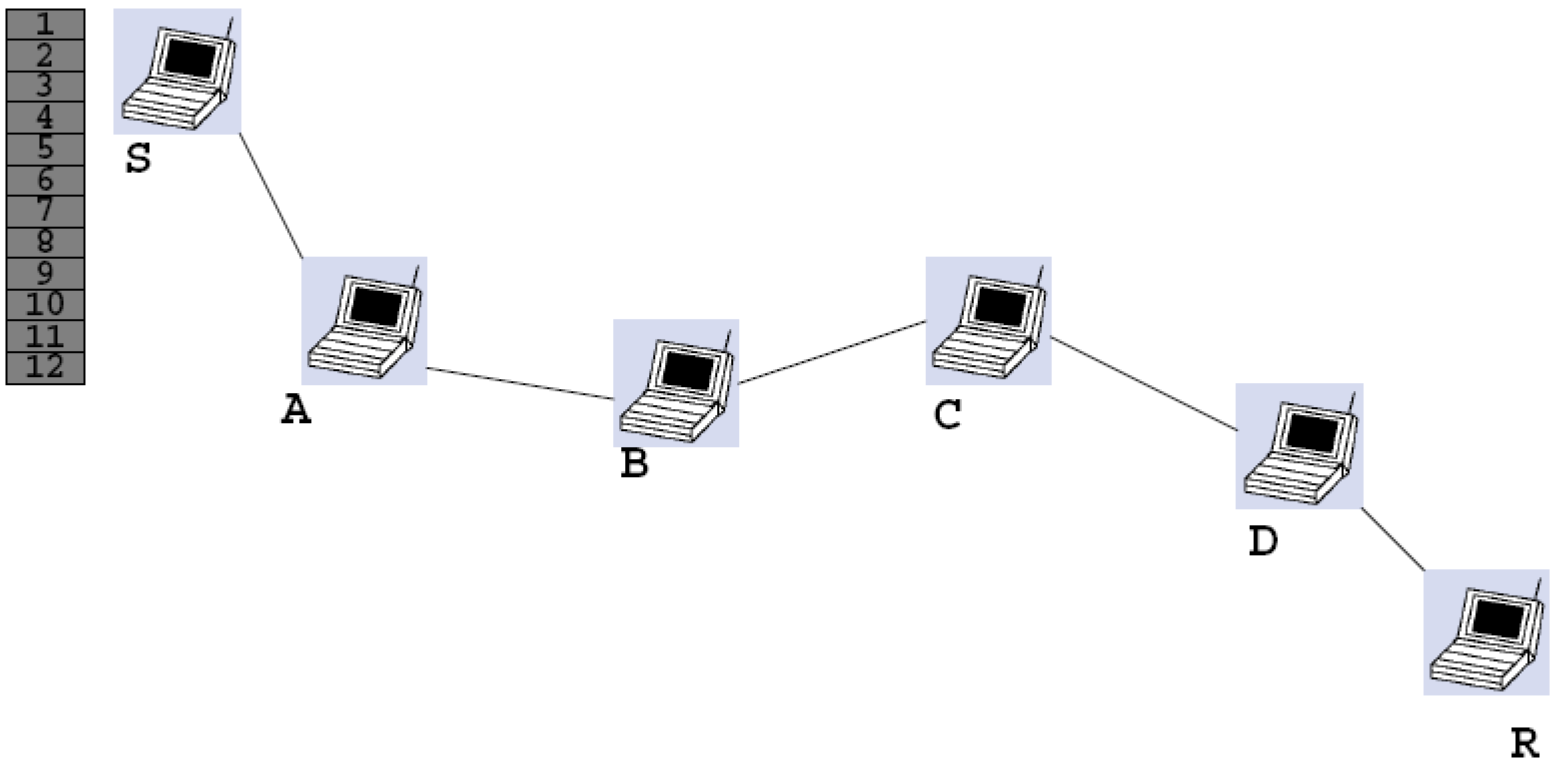
Large Multihop Network

(courtesy of Sanjit Biswas, MIT)

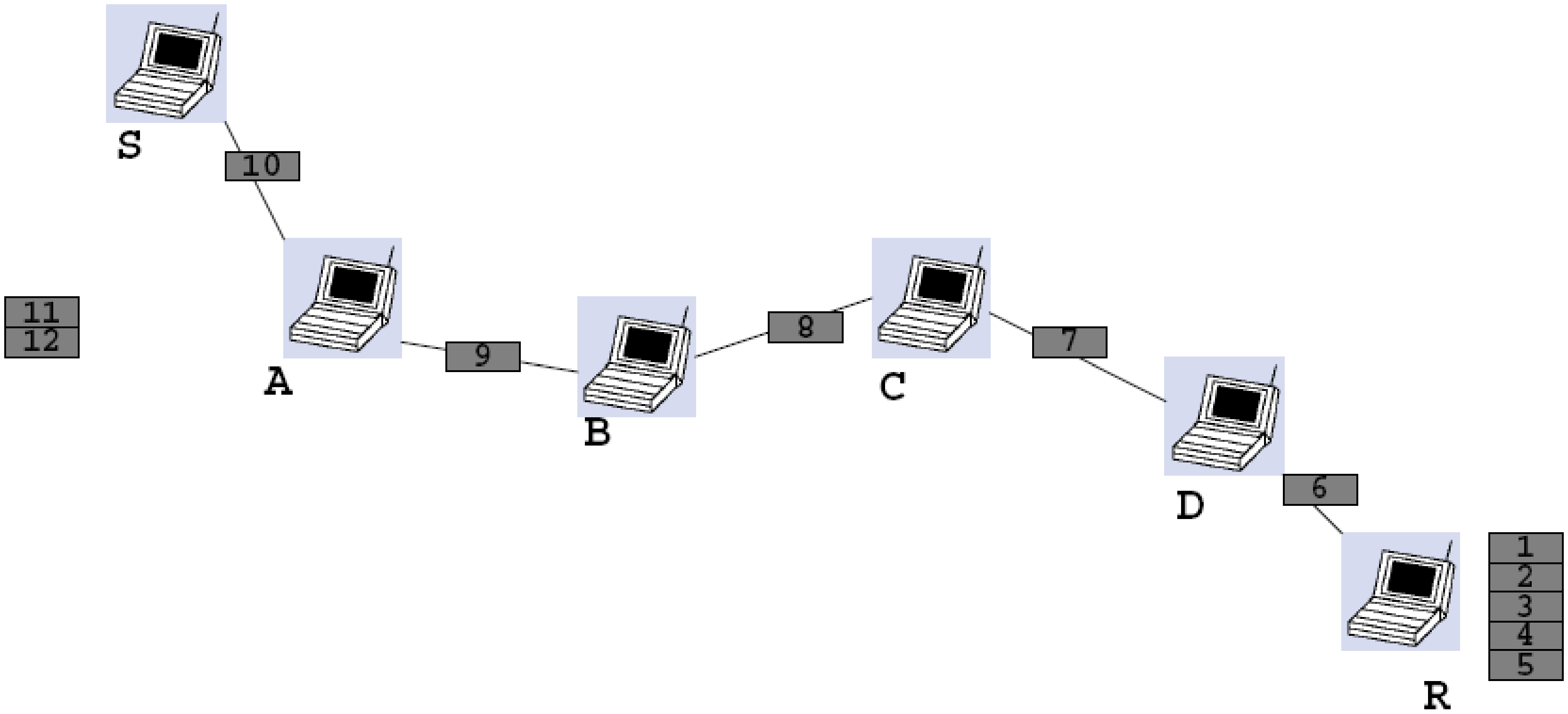


Multi-Hop Wireless Ad Hoc Networks

(Assume ideal world…)

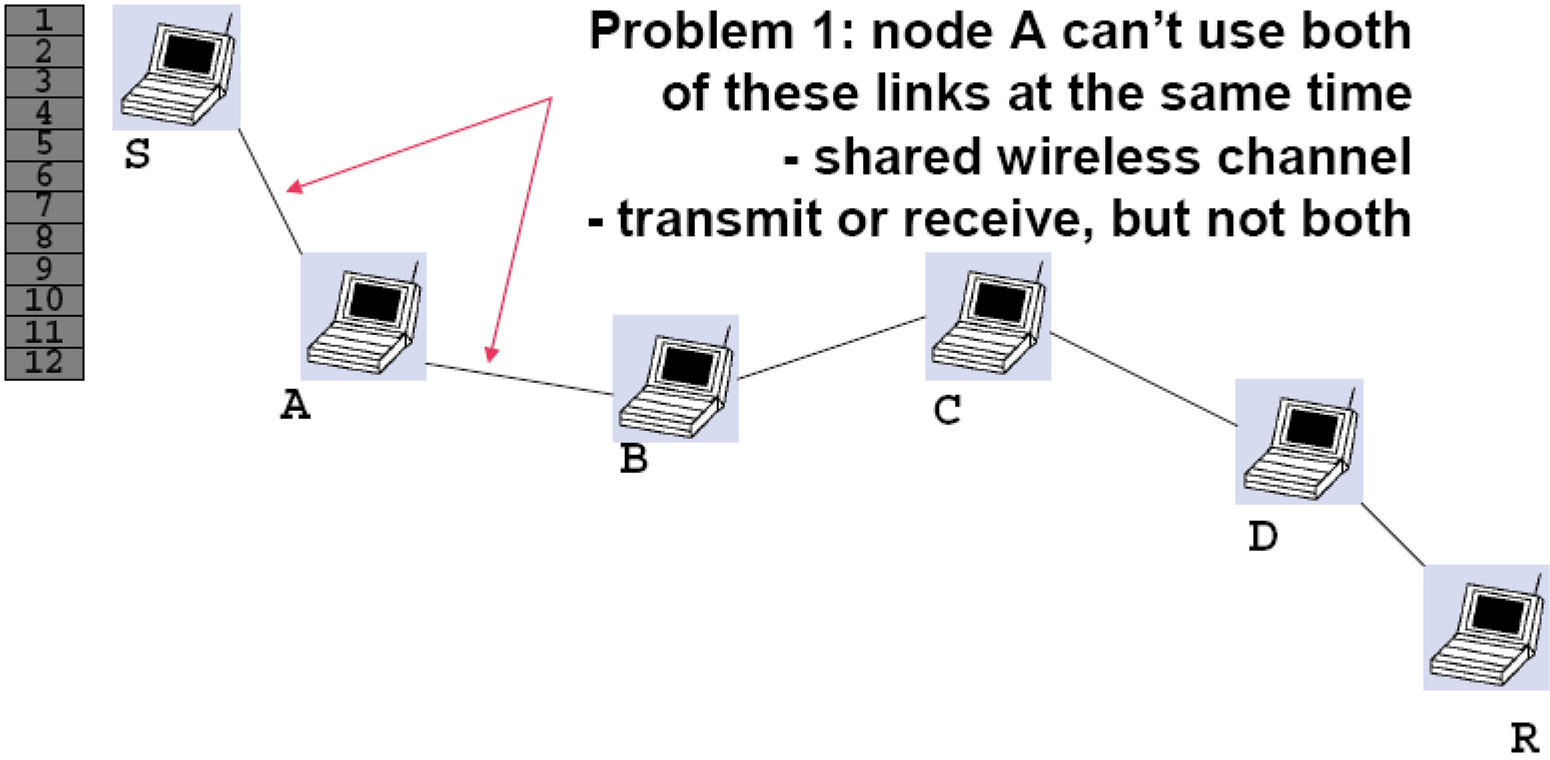


Multi-Hop Wireless Ad Hoc Networks



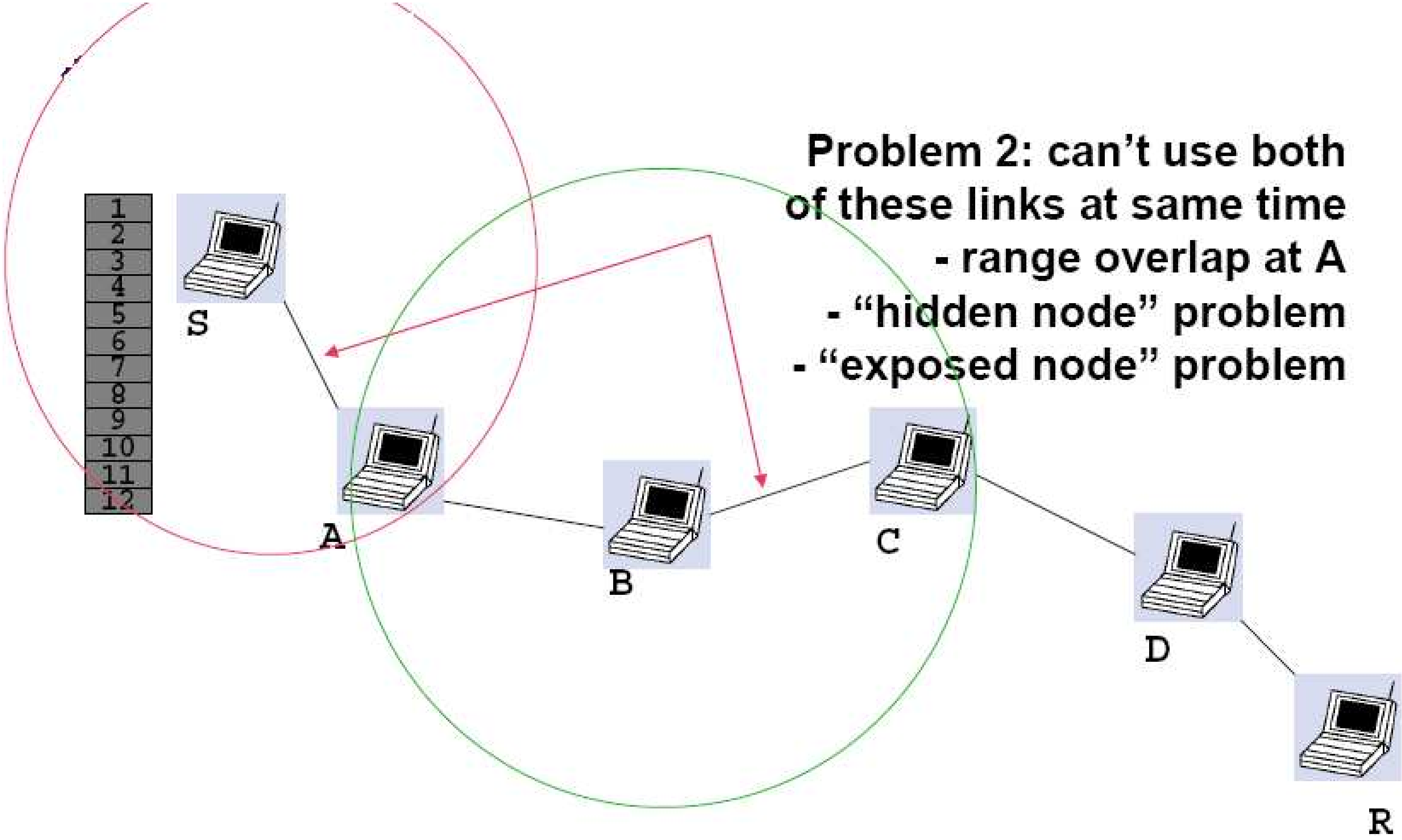
Multi-Hop Wireless Ad Hoc Networks

(Reality check…)



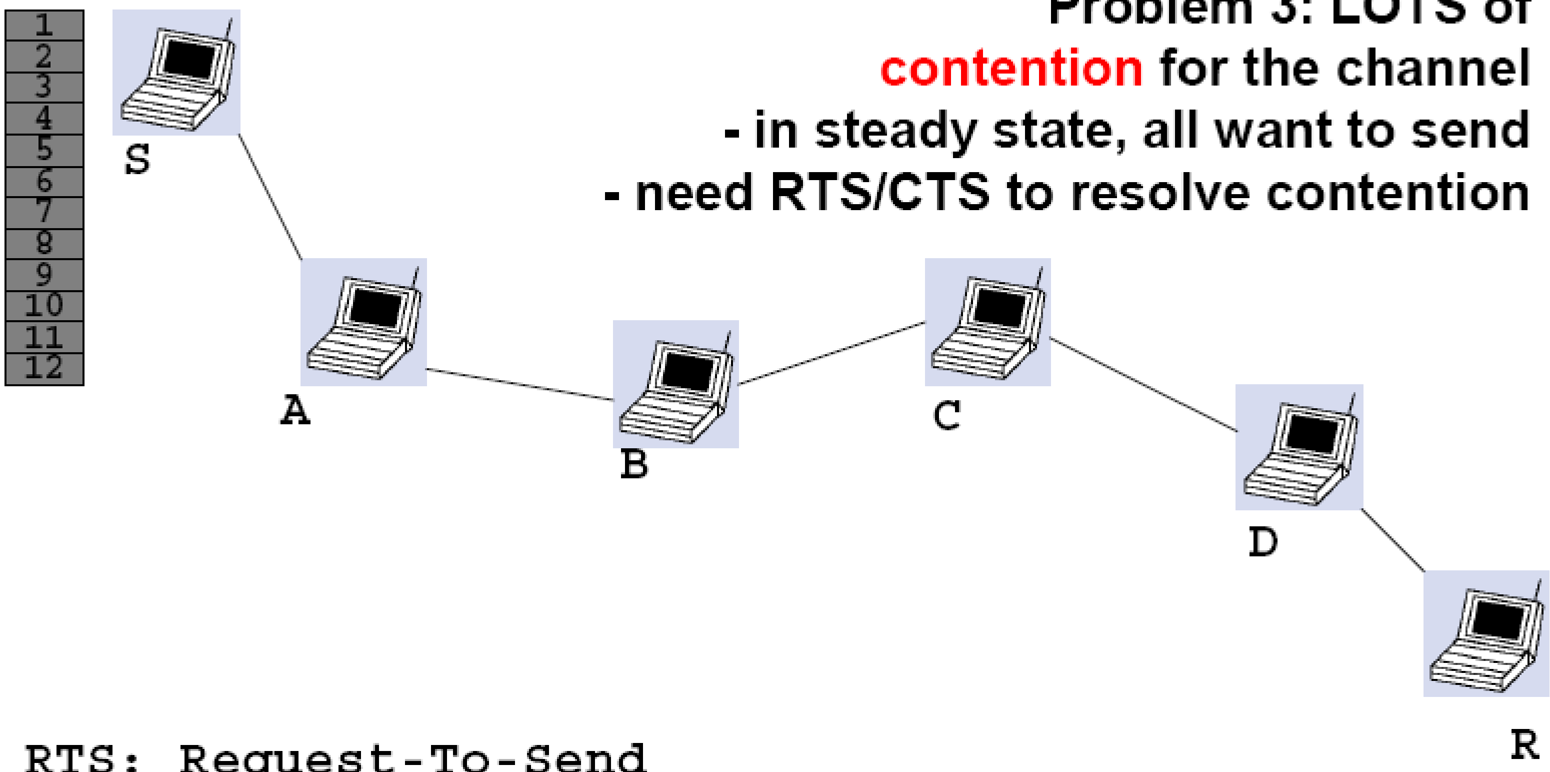
Multi-Hop Wireless Ad Hoc Networks

Problem 2: can't use both of these links at same time
- range overlap at A
- "hidden node" problem
- "exposed node" problem



Multi-Hop Wireless Ad Hoc Networks

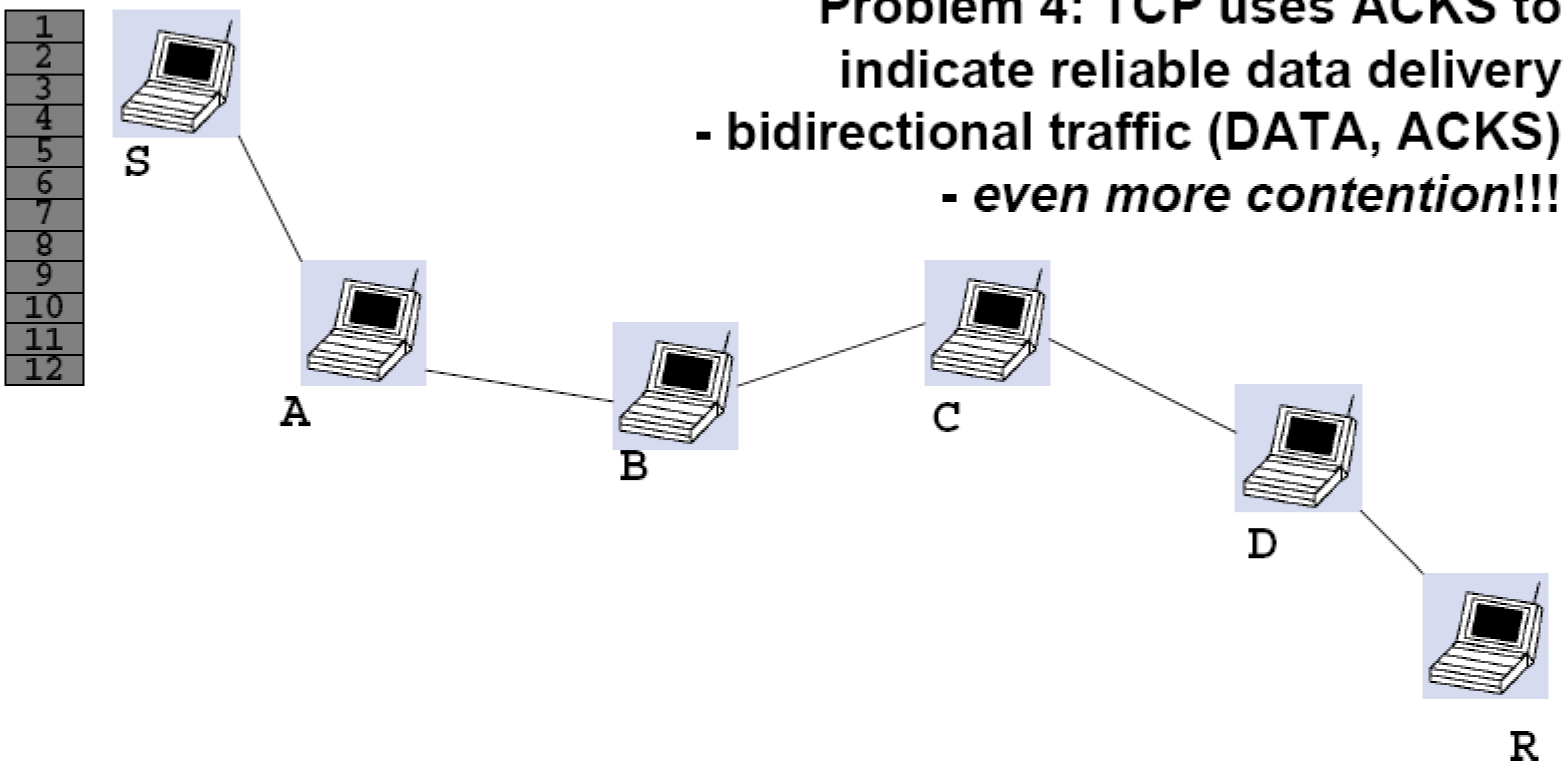
Problem 3: LOTS of contention for the channel
- in steady state, all want to send
- need RTS/CTS to resolve contention



RTS: Request-To-Send
CTS: Clear-To-Send

Multi-Hop Wireless Ad Hoc Networks

Problem 4: TCP uses ACKS to indicate reliable data delivery
- bidirectional traffic (DATA, ACKS)
- *even more contention*!!!



Summary

- Wireless connectivity provides a very different set of tradeoffs from wired
  - Much greater ease of deployment
  - Mobility
  - But: unprotected physical signaling
  - Complications due to interference, attenuated range
  - Leading to much more frequent loss
- Hidden terminal and Exposed terminal problems motivate need for a different style of Media Access Control: CSMA/CA
- Multihop provides applications to sensornets, citynets
  - But additional complications of routing, contention
- Wireless devices bring new security risks

Final Words

What Remains

- Final Exam
  - May 10, 7-10pm, rooms 1105 and 1111 SC
- Homework 7
  - Due at final exam

Where to go from here?

- CS 425: Distributed systems
  - Focus on applications, distributed algorithms
- CS 538 (listed as CS 598: Advanced Networking)
  - Graduate version of this class
- Undergraduate research
  - Hands-on experience, show you can complete a major project
  - Create your own innovations!

Where to go from here?

- CS 461/463
  - Computer security (including network security)
- Chat with me anytime