

Lecture 16: QoS and Wireless

CS/ECE 438: Communication Networks

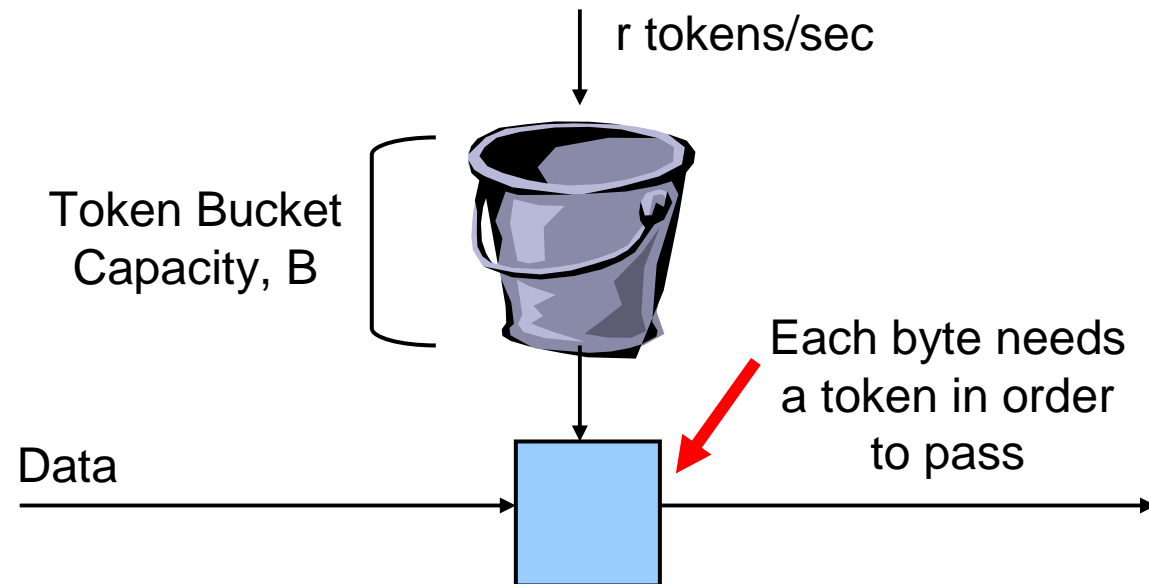
Prof. Matthew Caesar

May 5, 2010

Administrivia

- Watch Chris Popp's tutorial of content distribution:
 - <http://www.youtube.com/watch?v=gZz87tOLNGQ>
- Any questions on course content?

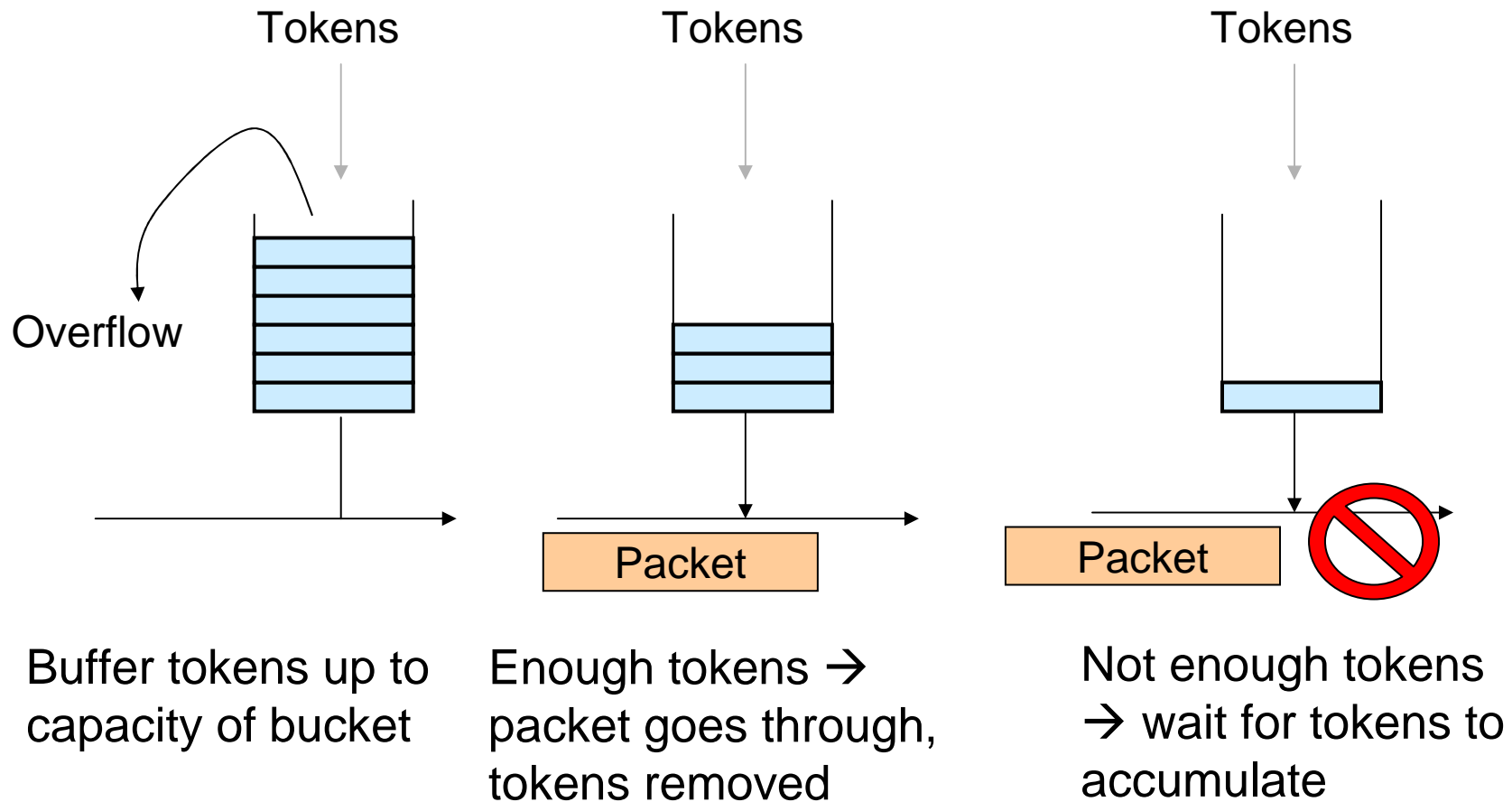
Token Bucket Filters



Dropping Filter: drops packets if token is not available

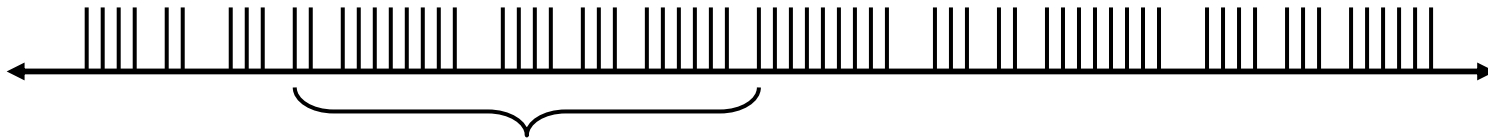
Buffered Filter: buffers data until tokens become available

Token Bucket Operation



Token Bucket Filters

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

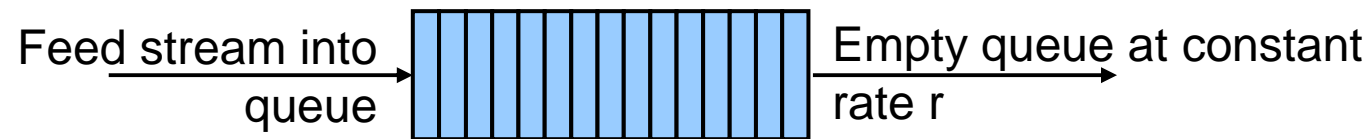


Not if during every time interval, the number of bytes is less than or equal to $B + rt$, where t is the length of the interval

- 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?

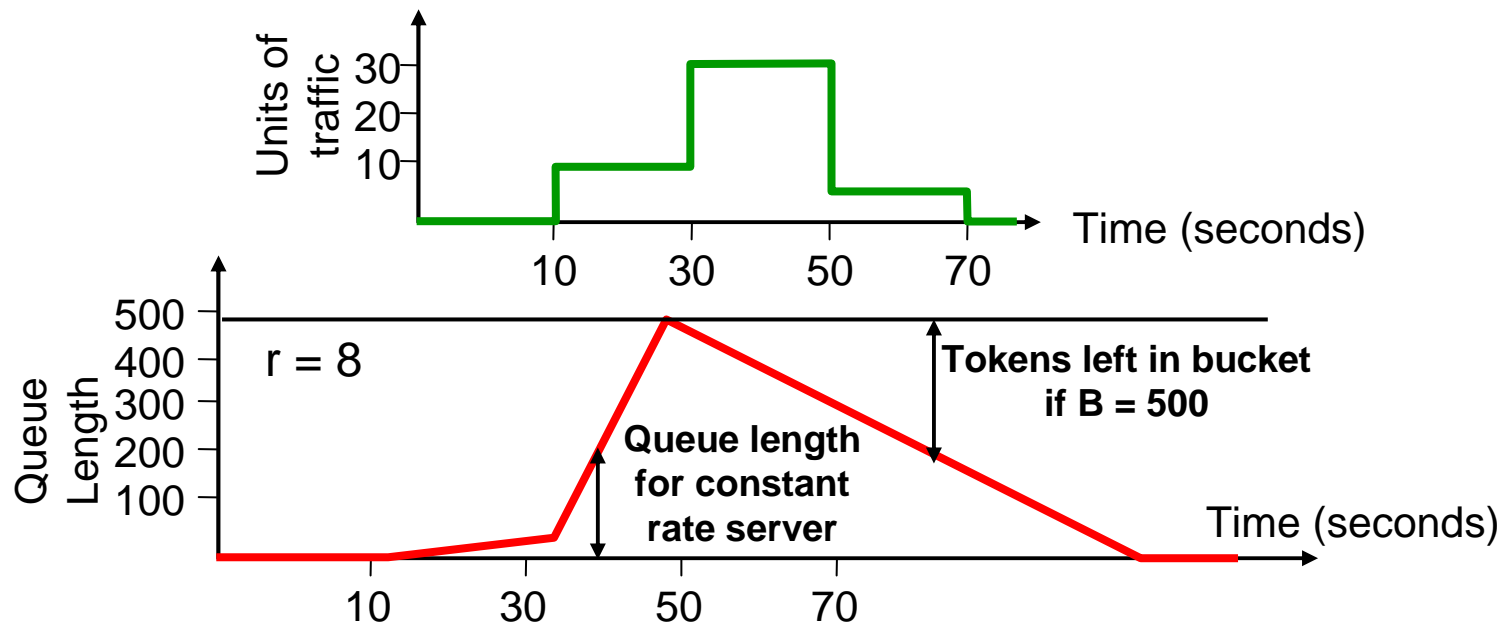
Token Bucket Filters

- 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

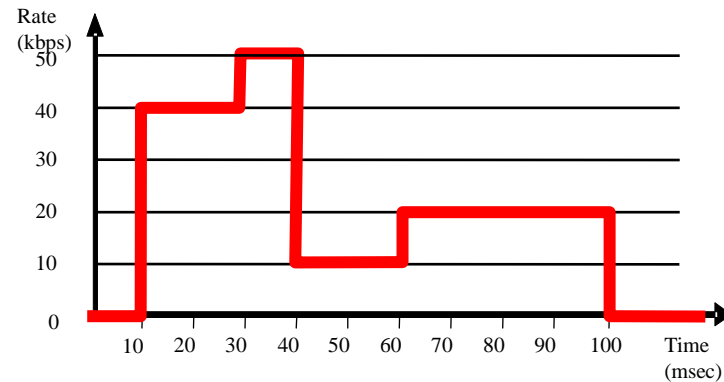
Token Bucket Filters



- 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

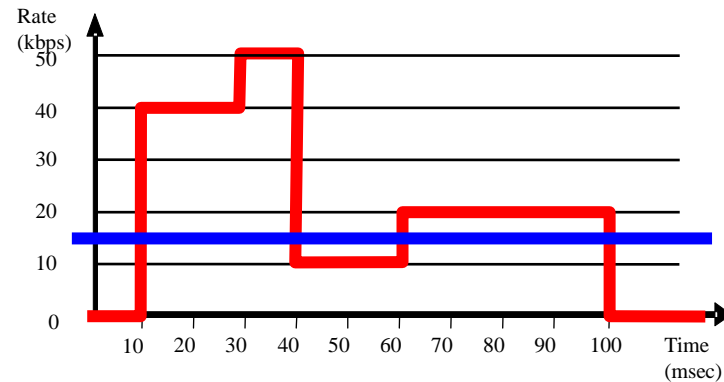
- $r = 15$ kbps



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

Token Bucket Filters

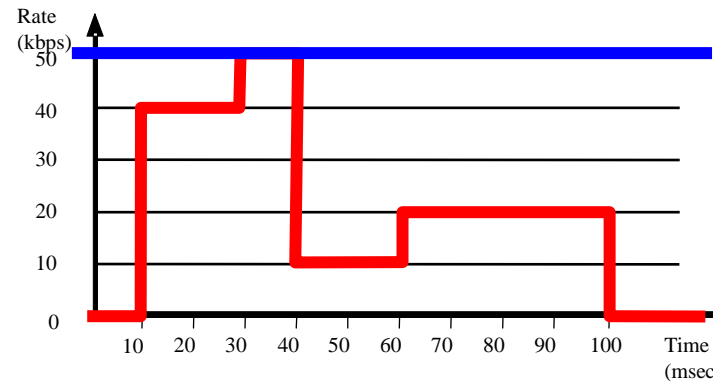
- $r = 15 \text{ kbps}$



- $\text{Min } B =$
 $(40 - 15) * 20 +$
 $(50 - 15) * 10 -$
 $(15 - 10) * 20 +$
 $(20 - 15) * 40$
 $= 950 \text{ bits}$

Token Bucket Filters

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



- If $r \geq 50$
 $B = 0$
- If $50 > r \geq 40$
 $\text{Min } B = (50 - r) * 10$
- If $40 > r \geq 20$
 $\text{Min } B = (40 - r) * 20 + (50 - r) * 10$
- If $20 > r \geq 10$
 $\text{Min } B = (40 - r) * 20 + (50 - r) * 10 - (r - 10) * 20 + (20 - r) * 40$
- If $10 > r \geq 0$
 $\text{Min } B = (40 - r) * 20 + (50 - r) * 10 + (10 - r) * 20 + (20 - r) * 40$

Wireless Networking

CS/ECE 438: Communication Networks

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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

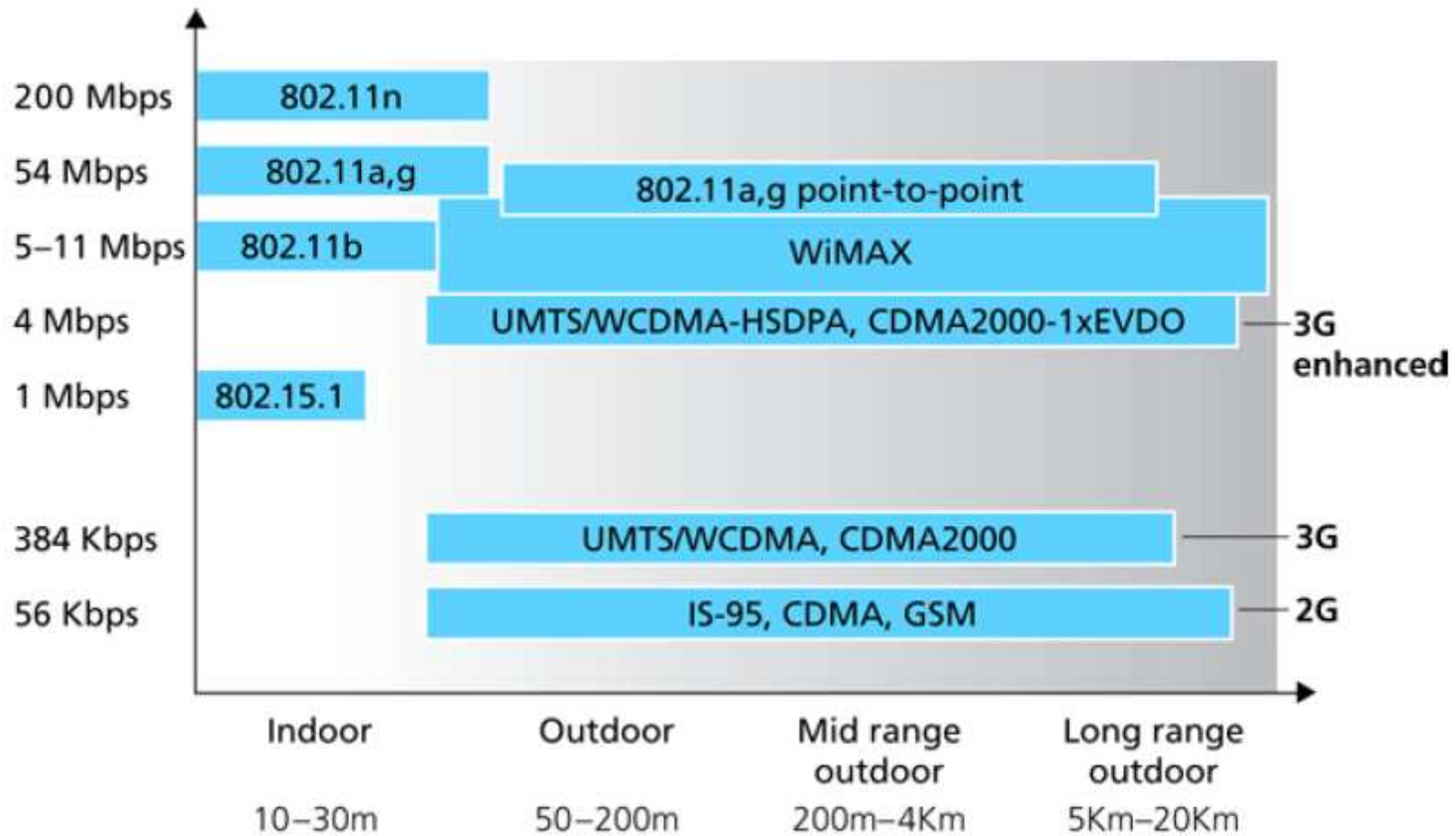


Figure 6.2 ♦ Link characteristics of selected wireless network standards

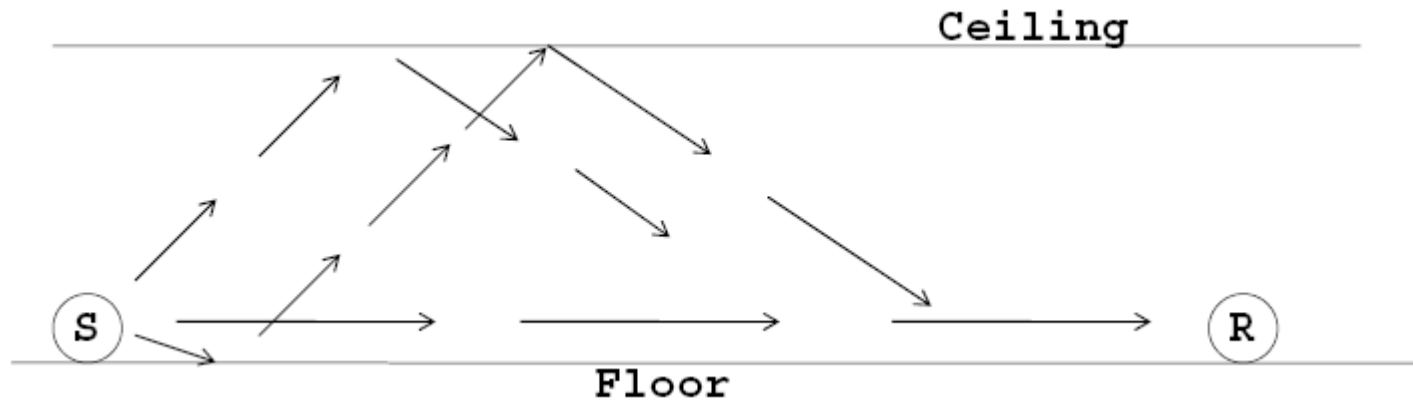
Other Wireless Link Characteristics

- 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

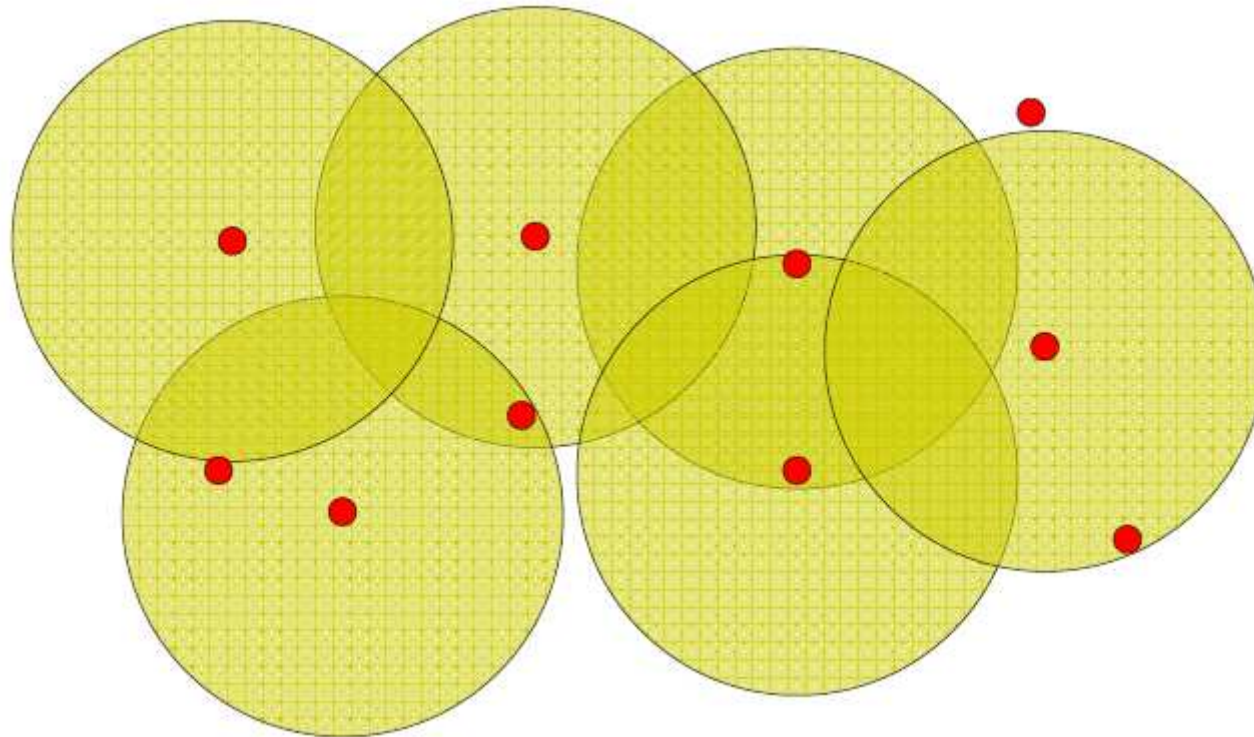
- Signal power attenuates by about $\sim r^2$ factor for omni-directional antennas in free space
 - Where r is the distance between the sender and the receiver
- The exponent in the factor is different depending on placement of antennas
 - Less than 2 for directional antennas
 - Faster Attenuation
 - 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



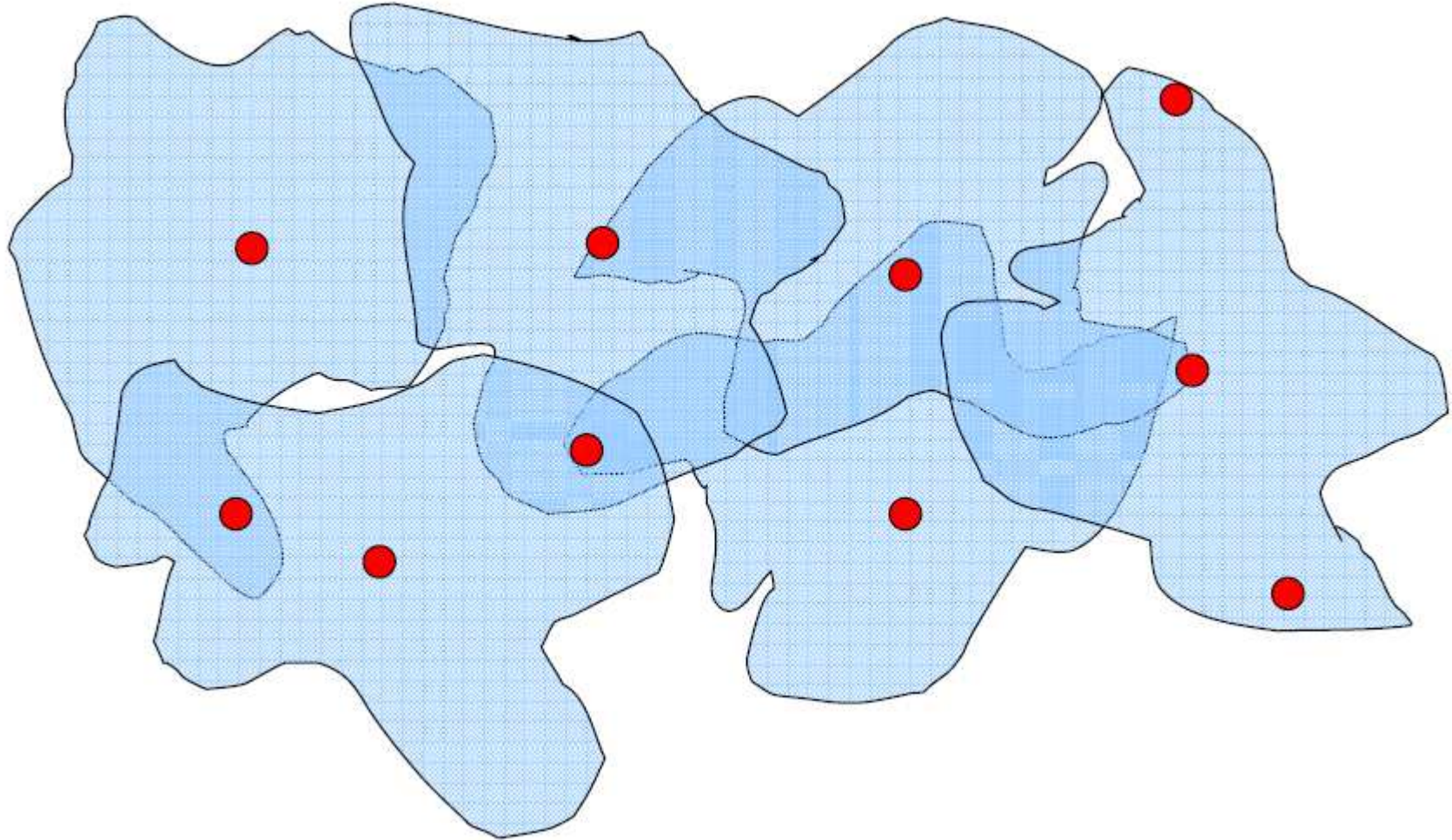
- Signals bounce off surface and interfere with one another
- What signals are out of phase?
 - Orthogonal signals cancel each other and nothing is received!

A Wireless Link?



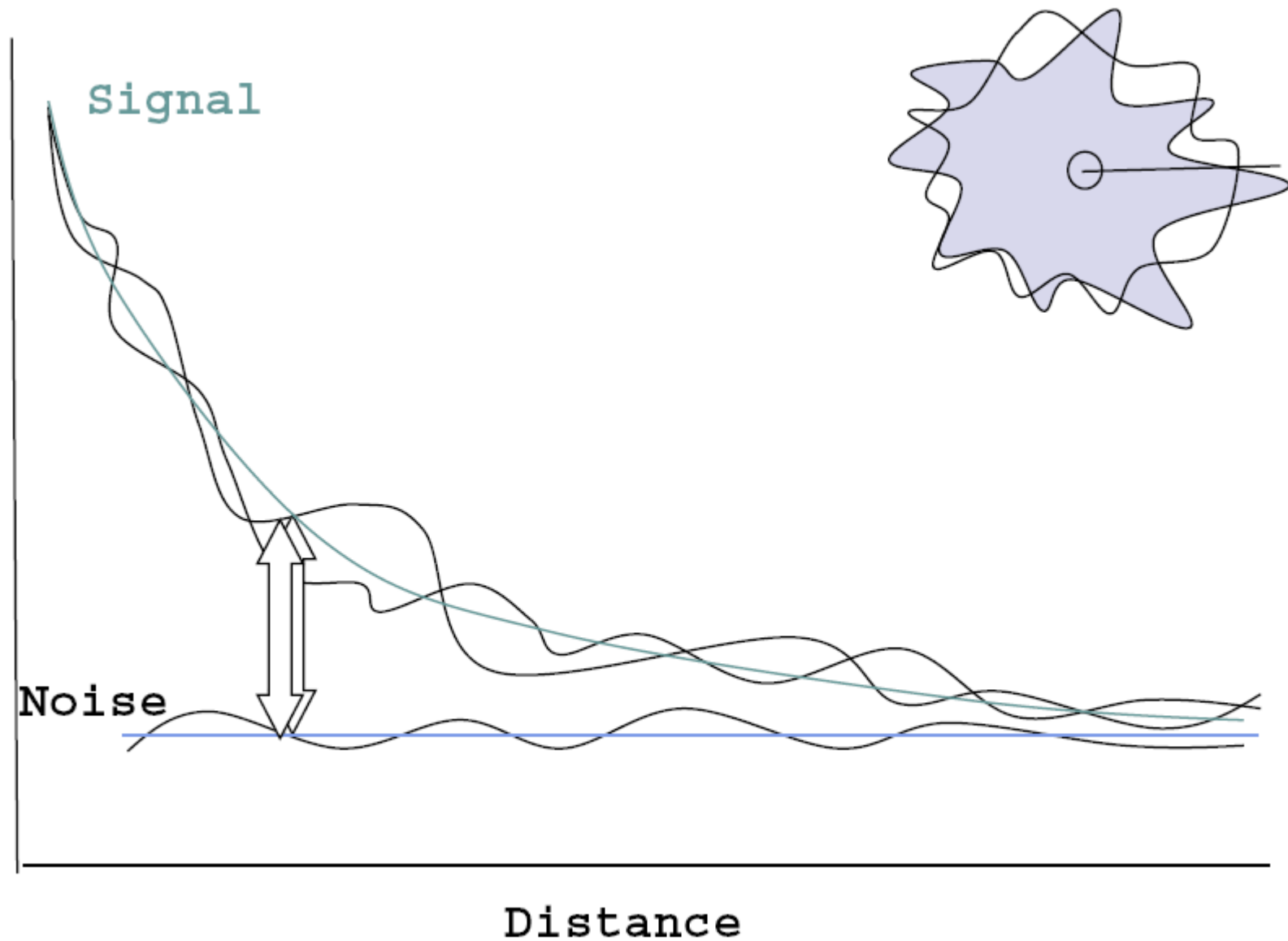
(courtesy of Gilman Tolle and Jonathan Hui, ArchRock)

A Wireless Link!



(courtesy of Gilman Tolle and Jonathan Hui, ArchRock)

The Amoeboid "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

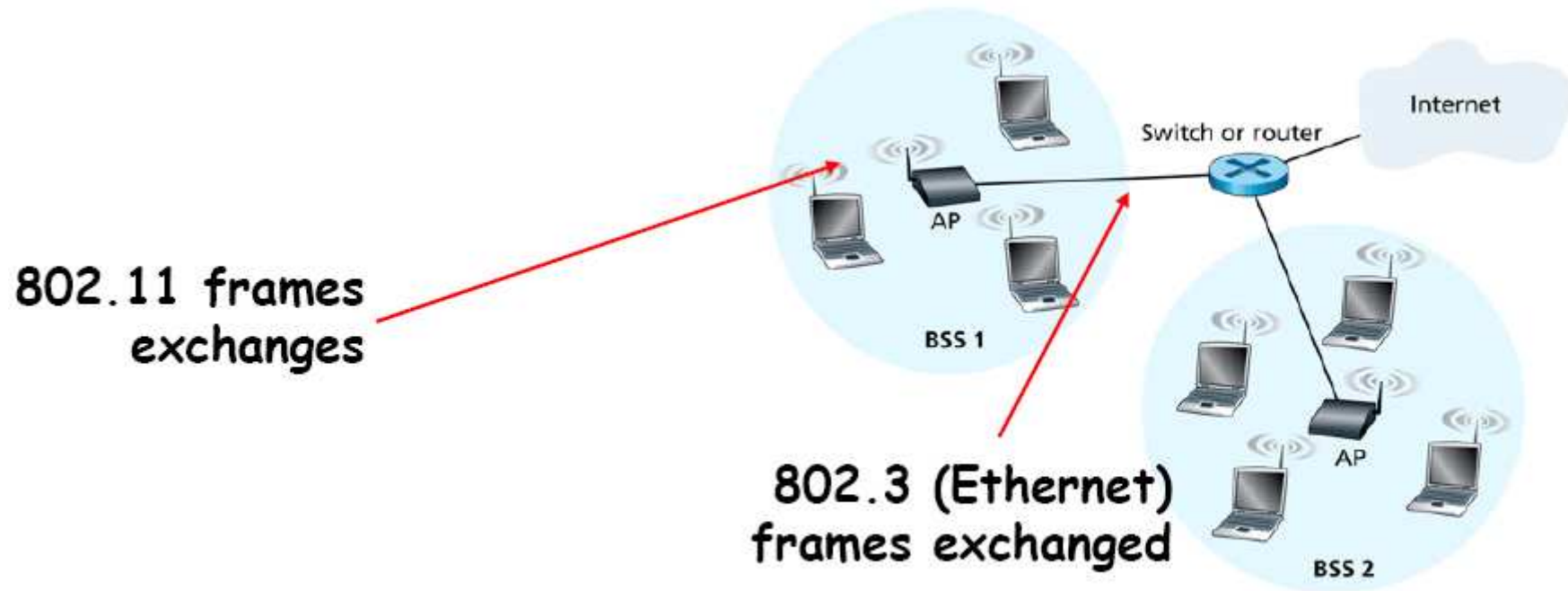


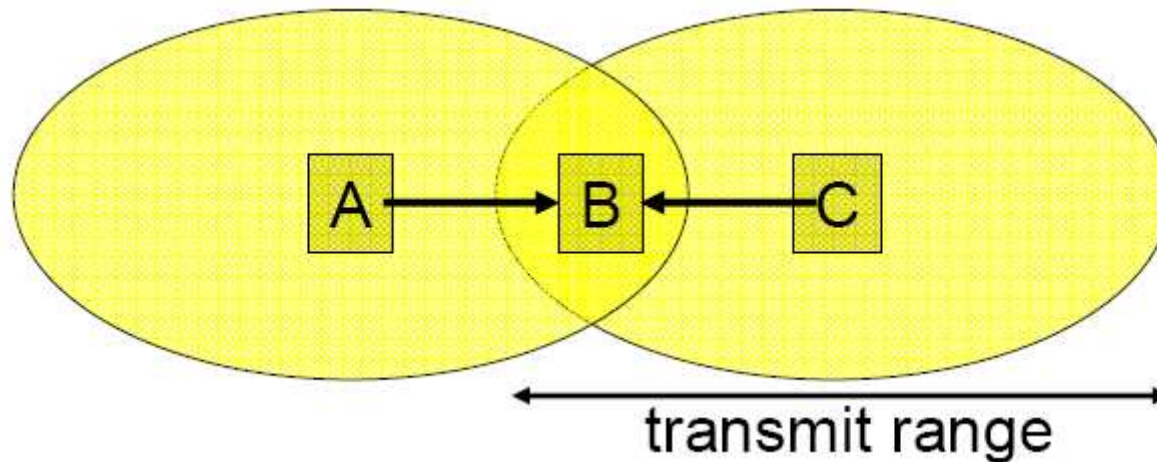
Figure 6.7 ♦ IEEE 802.11 LAN architecture

- 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

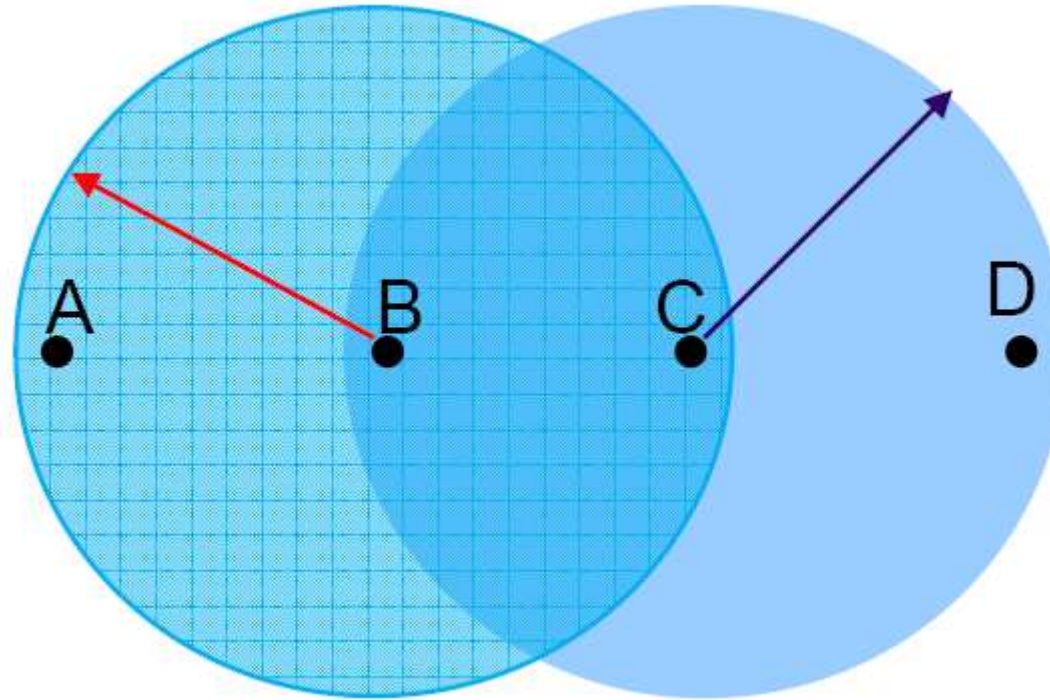
- Wireless MAC design
 - Why not just use Ethernet algorithms?
 - Ethernet: one shared “collision” domain
- It’s technically difficult to detect collisions
 - Collisions are at receiver, not sender
- ... even if we could, **it wouldn’t work**
 - Different transmitters have different coverage areas
- 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

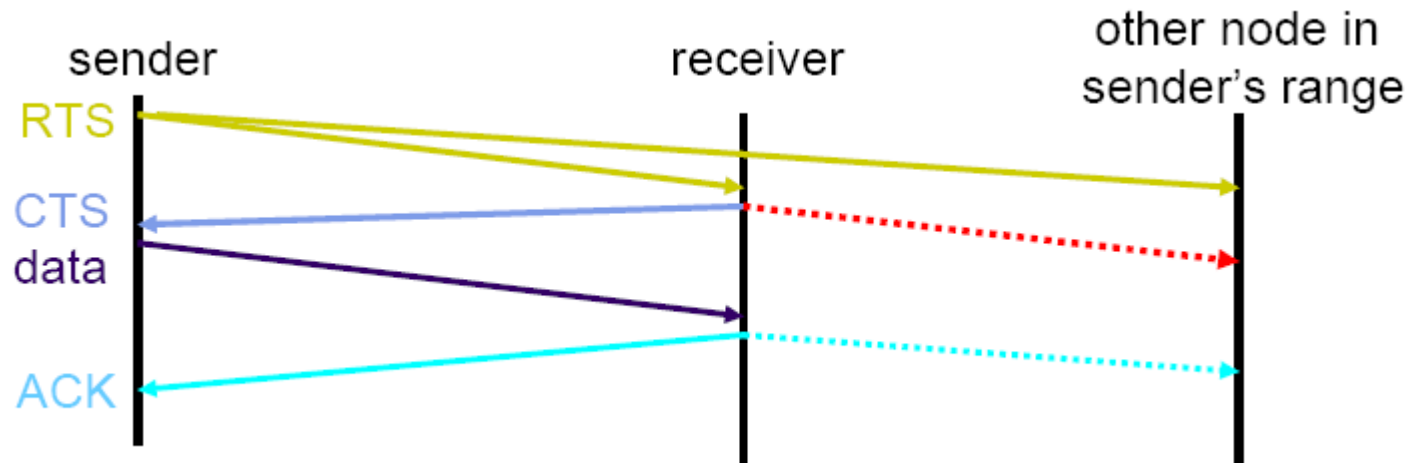


- **Exposed node:** B sends a packet to A; C hears this and decides not to send a packet to D (despite the fact that this will not cause interference!)

CSMA/CA: CSMA with *Collision Avoidance*

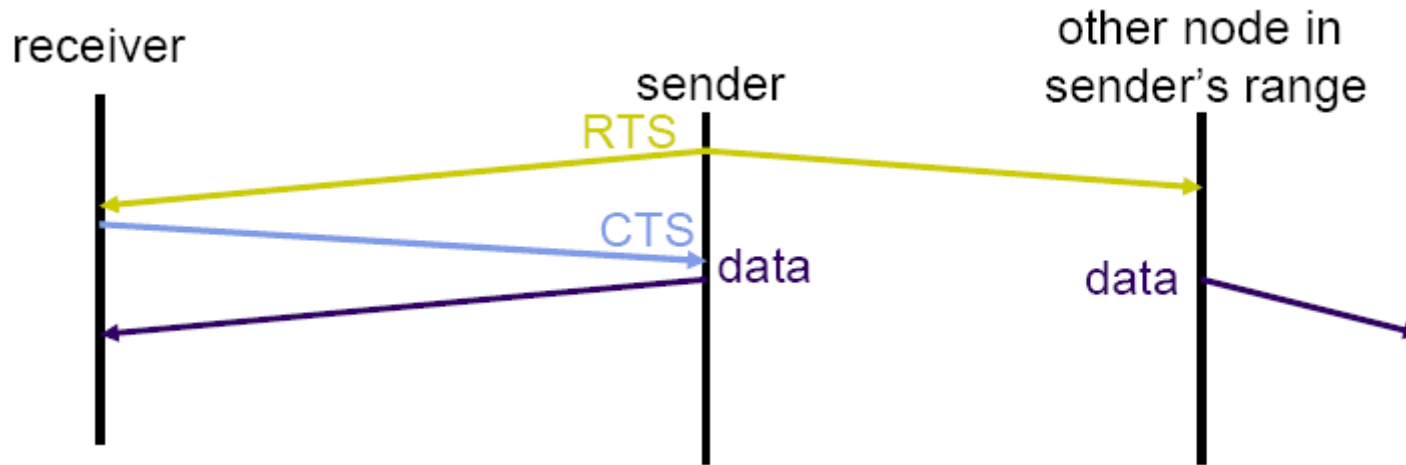
- Since we can't detect collisions, we try to **avoid** them
- When medium is busy, choose random interval (contention window)
 - Wait for that many idle timeslots to pass before sending
- When a collision is inferred, retransmit with binary exponential backoff (like Ethernet)
 - Use **ACK** from receiver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

Multiple Access with Collision Avoidance (MACA)



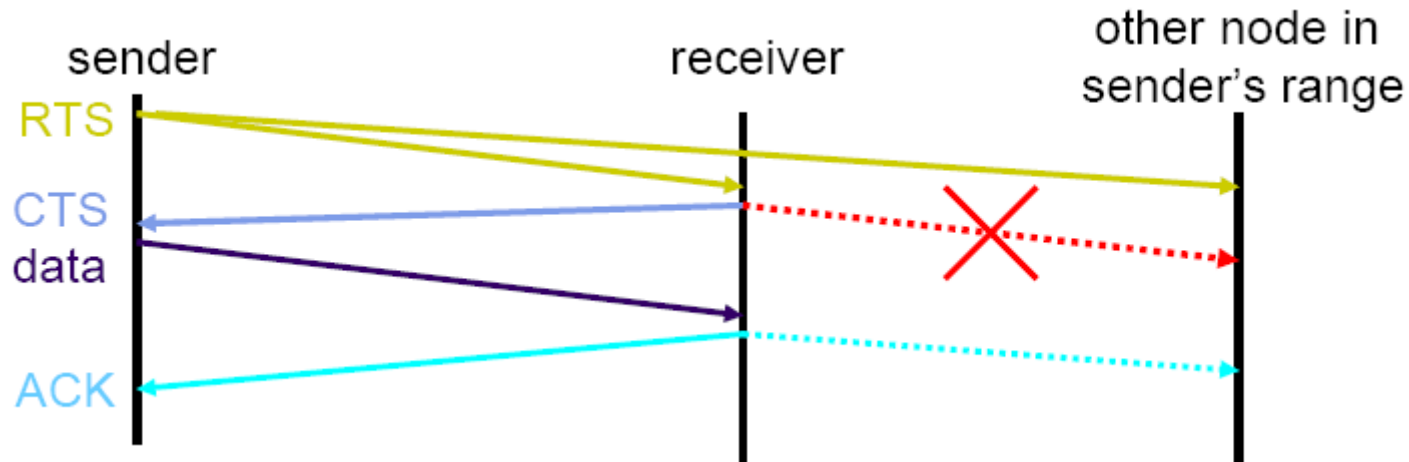
- Before every data transmission
 - Sender sends a Request to Send (RTS) frame containing the length of the transmission
 - Receiver responds with a Clear to Send (CTS) frame
 - Sender sends data
 - Receiver sends an ACK; now another sender can send data
- When sender doesn't get a CTS back, it assumes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

MACA, continued



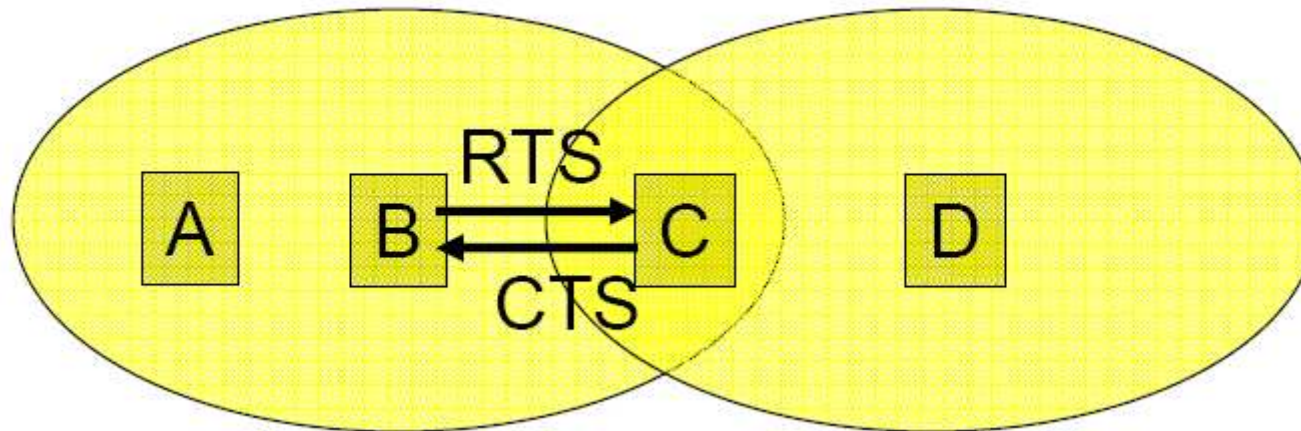
- If other nodes hear RTS, but not CTS: send
 - Presumably, destination for first sender is out of node's range...

MACA, continued



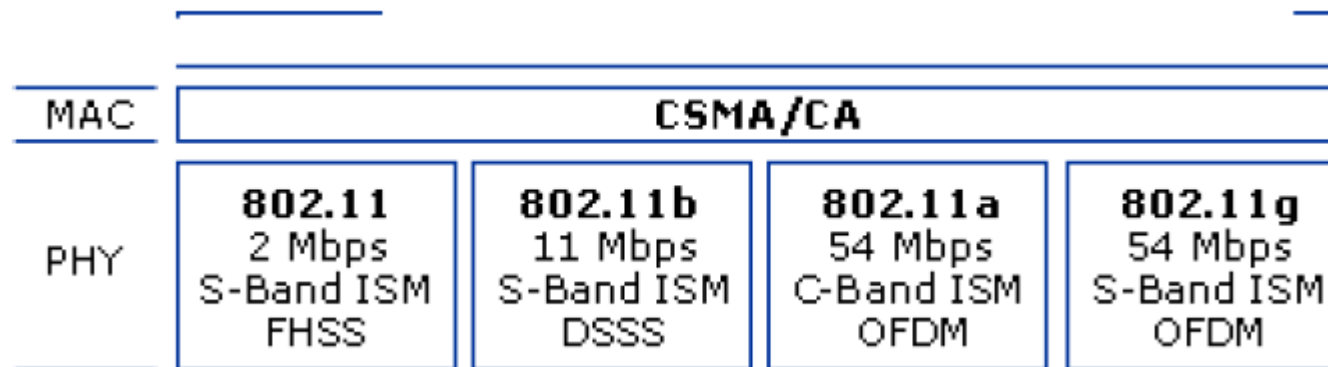
- If other nodes hear RTS, but not CTS: send
 - Presumably, destination for first sender is out of node's range...
 - ... Can cause problems when a CTS is **lost**
- When you hear a CTS, you keep quiet until scheduled transmission is over (hear ACK)

RTS / CTS Protocols (MACA)



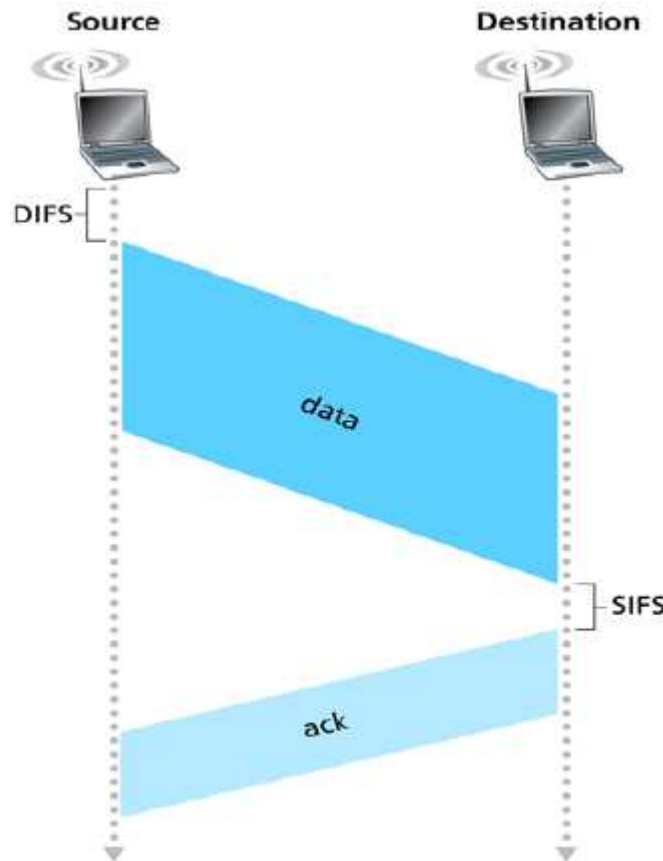
- MACA = Multiple Access with Collision Avoidance
- Overcome exposed/hidden terminal problems with contention-free protocol
 1. B stimulates C with Request To Send (RTS)
 2. A hears RTS and defers (to allow C to answer)
 3. C replies to B with Clear To Send (CTS)
 4. D hears CTS and defers to allow the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

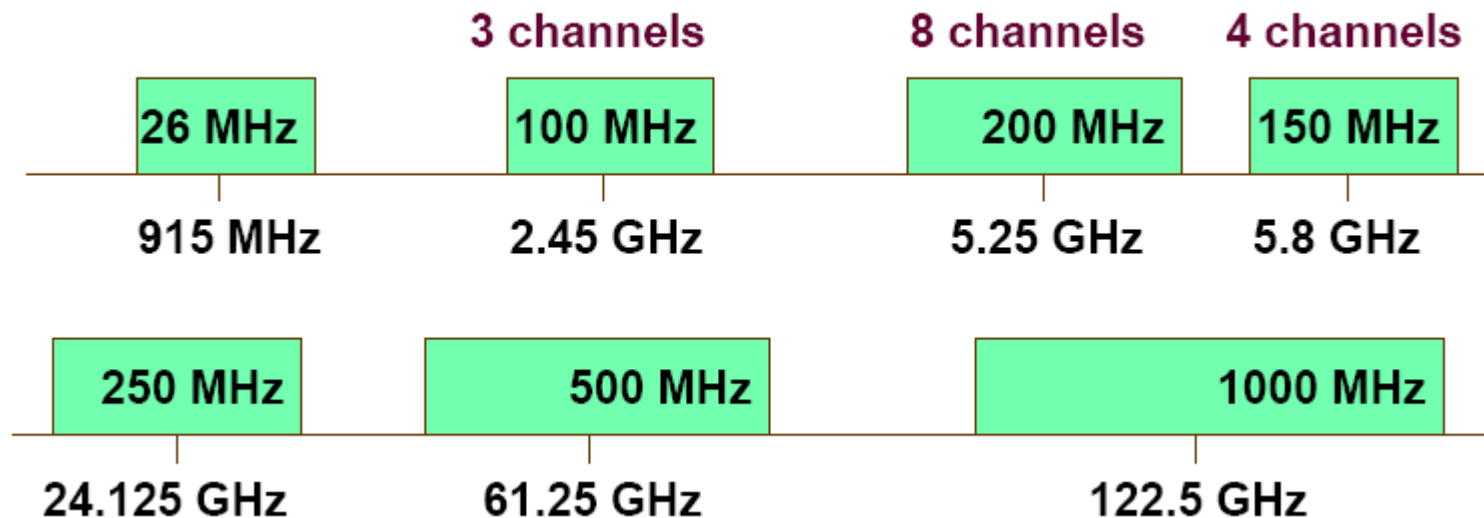


- Receiver acks every data packet
- If ACK is lost, source tries again until a maximum retransmission number is reached

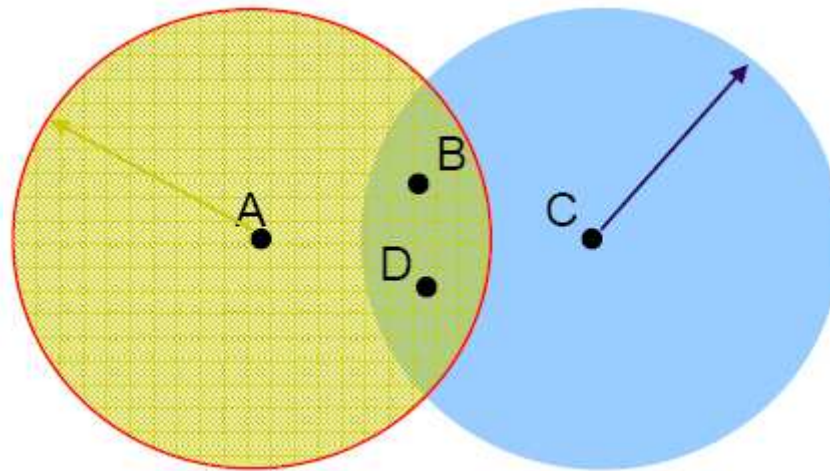
Figure 6.10 ♦ 802.11 uses link-layer acknowledgments.

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

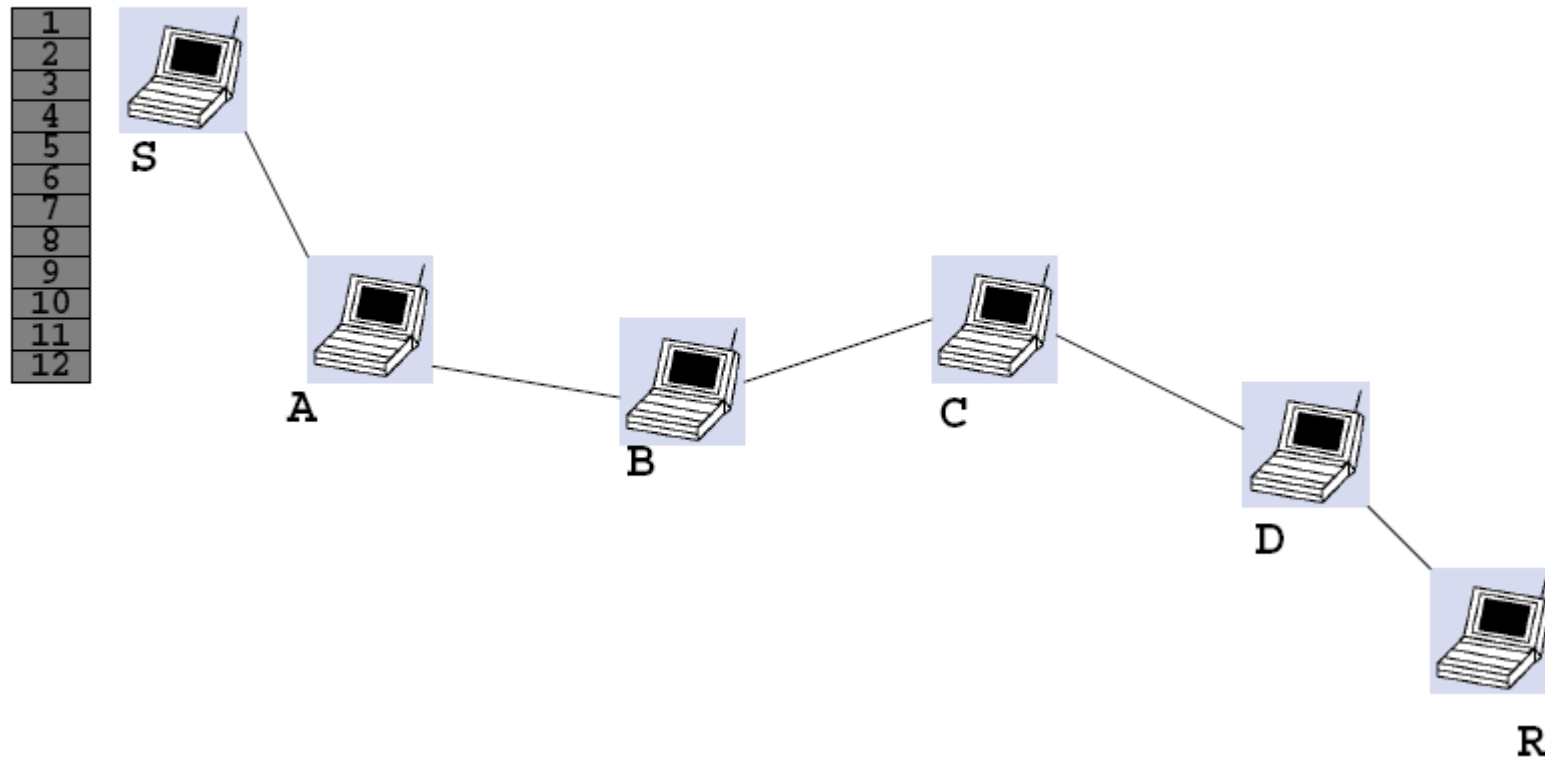
Large Multihop Network

(courtesy of Sanjit Biswas, MIT)

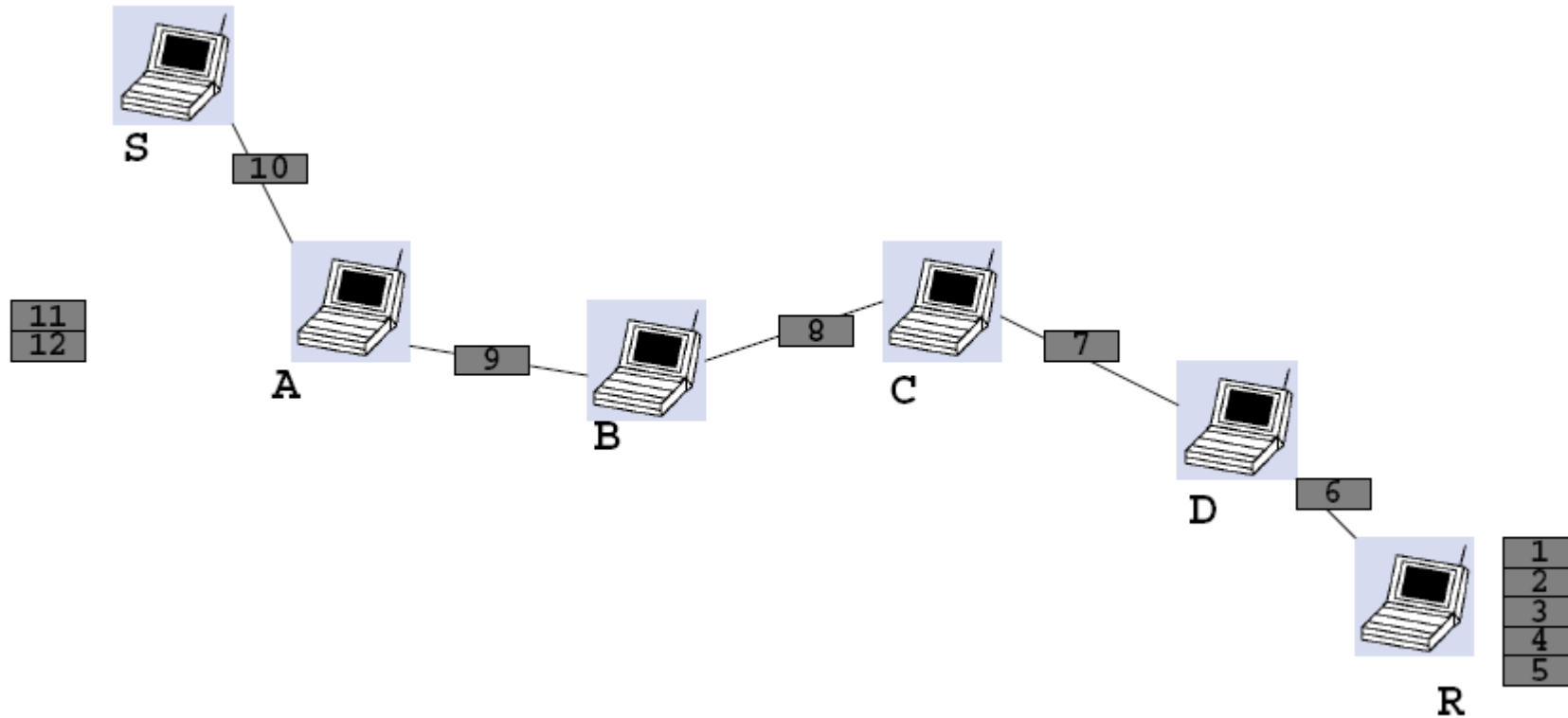


Multi-Hop Wireless Ad Hoc Networks

(Assume ideal world..)

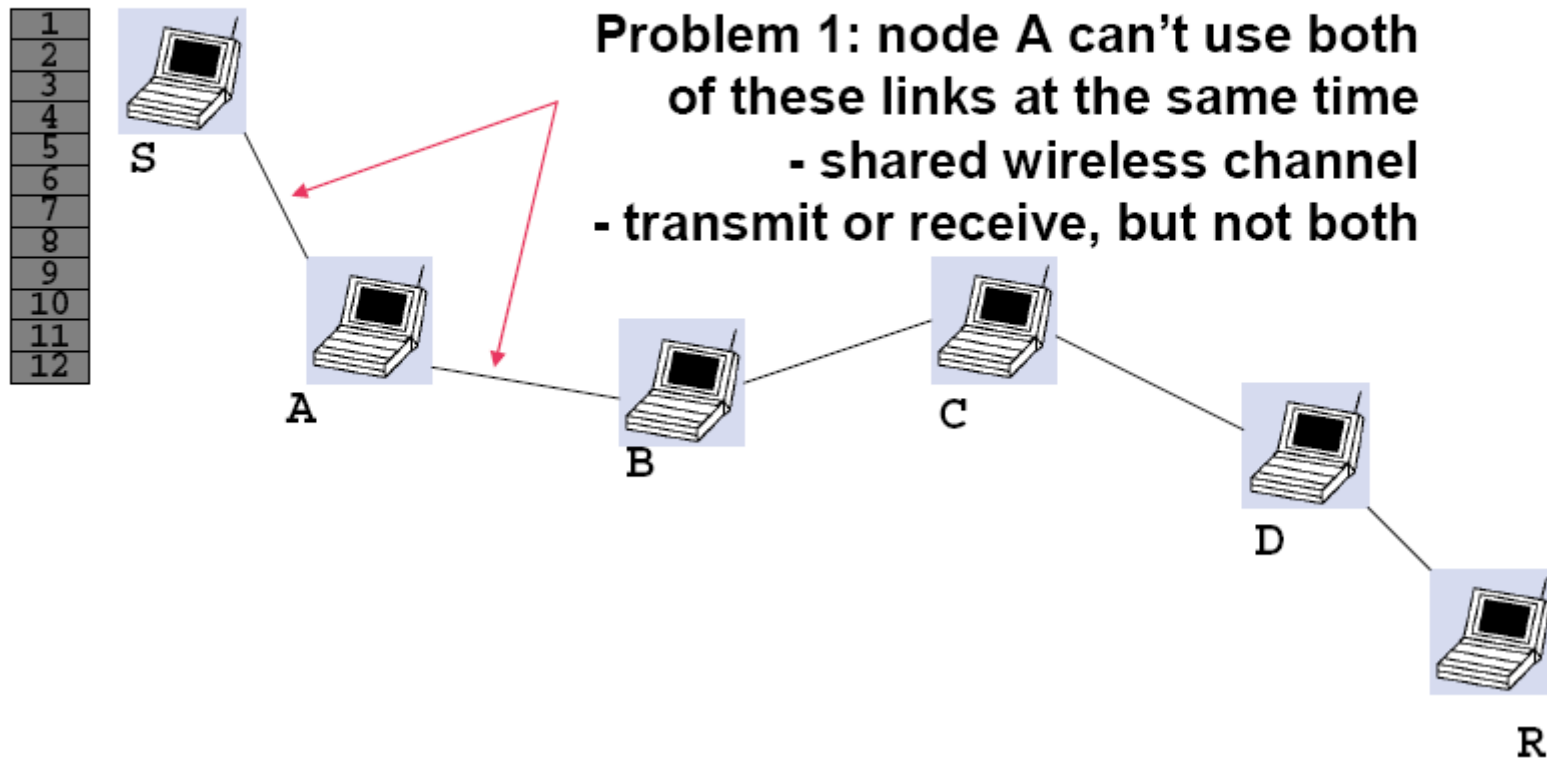


Multi-Hop Wireless Ad Hoc Networks

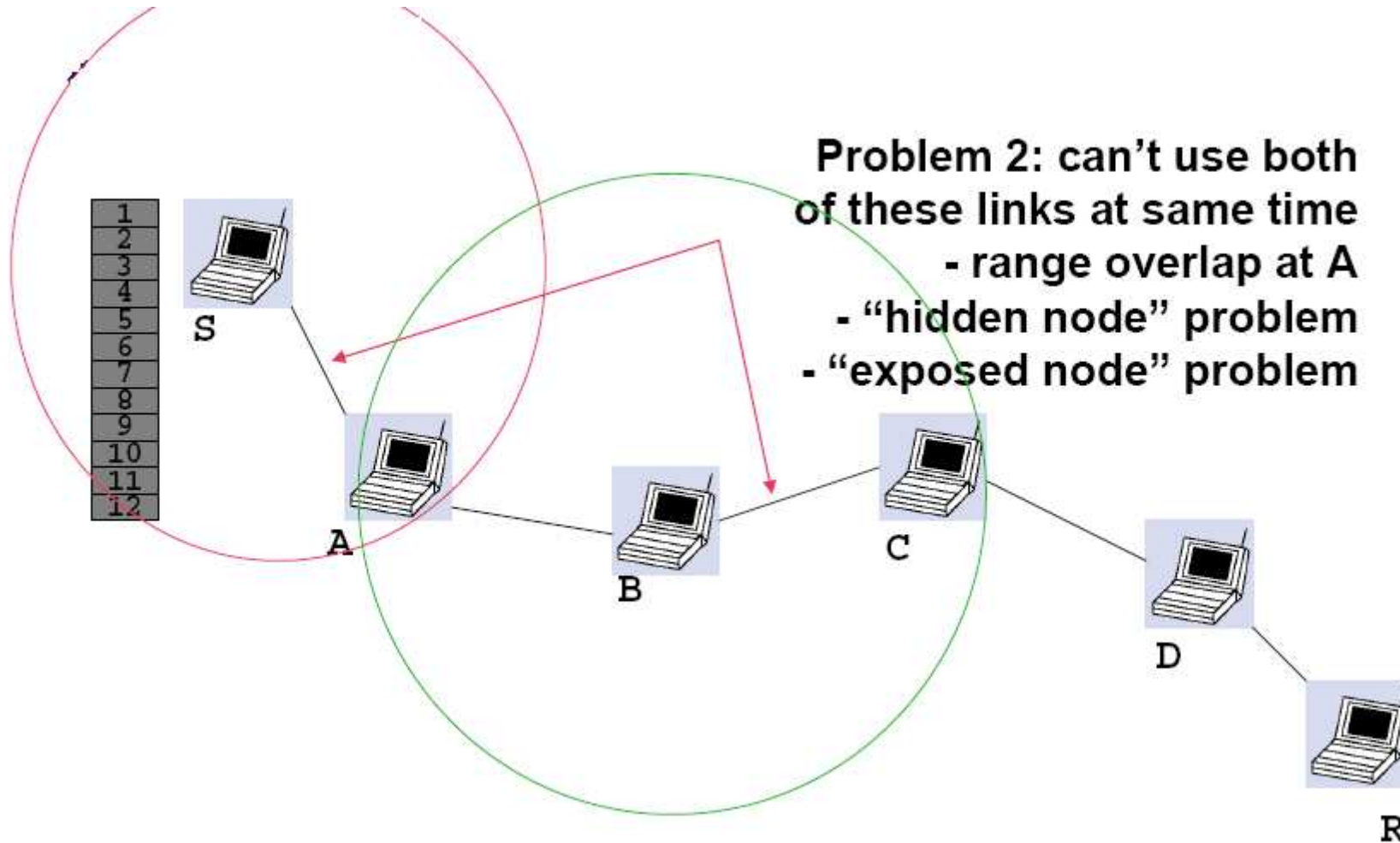


Multi-Hop Wireless Ad Hoc Networks

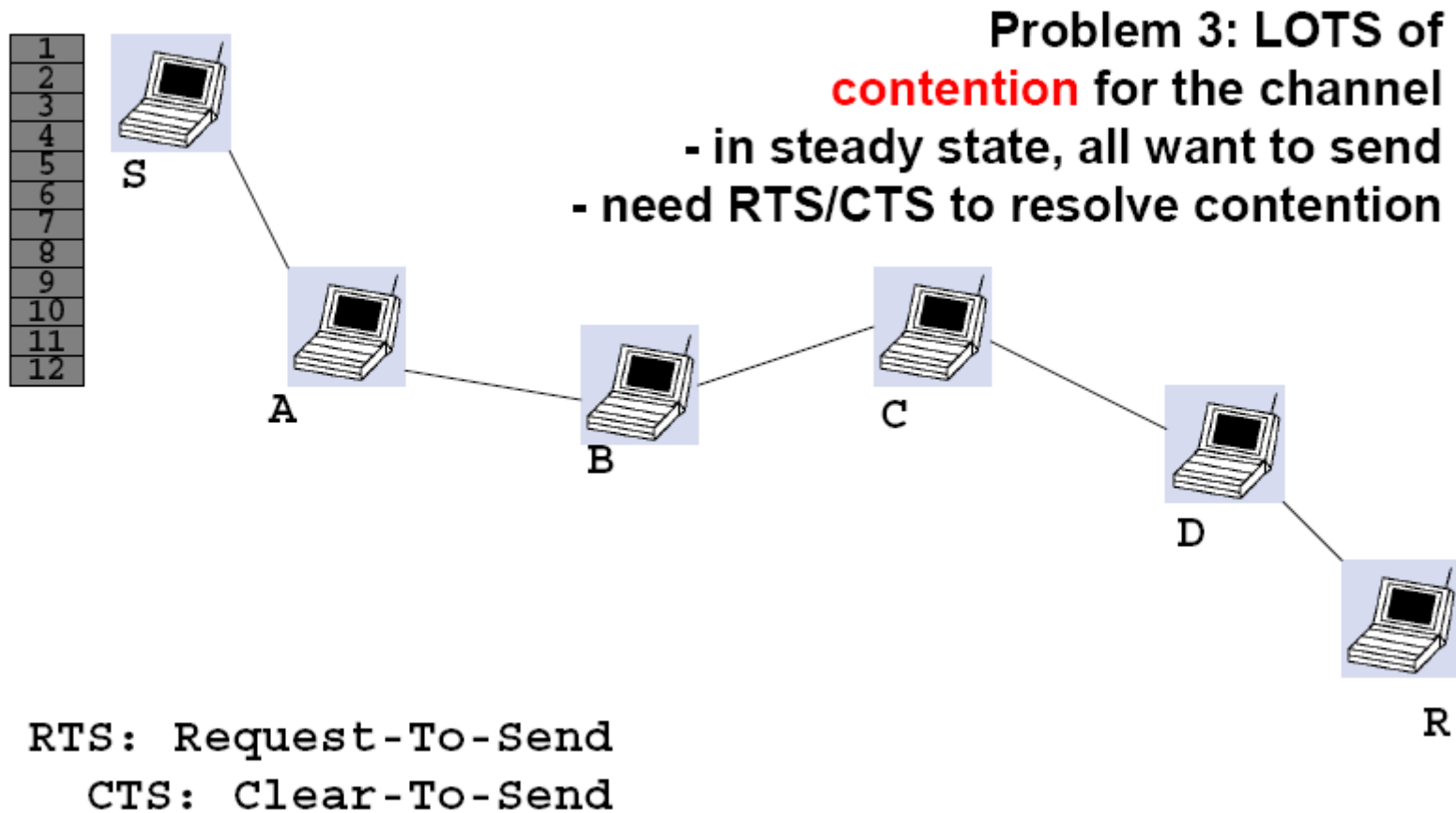
(Reality check...)



Multi-Hop Wireless Ad Hoc Networks



Multi-Hop Wireless Ad Hoc Networks



Multi-Hop Wireless Ad Hoc Networks

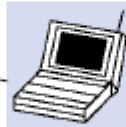
| |
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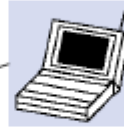
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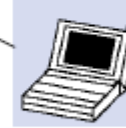
A



B



C



D



R

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