Widespread Deployment

- Worldwide cellular subscribers
  - 1993: 34 million
  - 2005: more than 2 billion
  - 2012: 6.8 billion
    (2.1B with mobile broadband)
  - >> 1.2B landline subscribers

- Wireless local area networks
  - Wireless adapters built into laptops, tablets, & phones
  - More ubiquitous than wired broadband? 700M in 2012

Wireless Properties

- Interference / bit errors
  - More sources of corruption compared to wired

- Multipath propagation
  - Signal does not travel in a straight line

- Broadcast medium
  - All traffic to everyone

- Power trade-offs
  - Important for power constrained devices
Wireless Links: High Bit Error Rate

• Decreasing signal strength
  – Disperses as it travels greater distance
  – Attenuates as it passes through matter

• Interference from other sources
  – Radio sources in same frequency band
  – E.g., 2.4 GHz wireless phone interferes with 802.11b wireless LAN
  – Electromagnetic noise (e.g., microwave oven)

Wireless Links: High Bit Error Rate

• Multi-path propagation
  – Electromagnetic waves reflect off objects
  – Taking many paths of different lengths
  – Causing blurring of signal at the receiver

Dealing With Bit Errors

• Wireless vs. wired links
  – Wired: most loss is due to congestion
  – Wireless: higher, time-varying bit-error rate

• Dealing with high bit-error rates
  – Sender could increase transmission power
    • Requires more energy (bad for battery-powered hosts)
    • Creates more interference with other senders
  – Stronger error detection and recovery
    • More powerful error detection/correction codes
    • Link-layer retransmission of corrupted frames
Wireless Links: Broadcast Limitations

- Wired broadcast links
  - E.g., Ethernet bridging, in wired LANs
  - All nodes receive transmissions from all other nodes
- Wireless broadcast: hidden terminal problem

  - A and B hear each other
  - B and C hear each other
  - But, A and C do not

  So, A and C are unaware of their interference at B

Wireless Links: Broadcast Limitations

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  - All nodes receive transmissions from all other nodes
- Wireless broadcast: fading over distance

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Example Wireless Link Technologies

- Data networks
  - 802.15.1 (Bluetooth): 2.1 Mbps – 10 m
  - 802.11b (WiFi): 5-11 Mbps – 100 m
  - 802.11a and g (WiFi): 54 Mbps – 100 m
  - 802.11n (WiFi): 200 Mbps – 100 m
  - 802.16 (WiMax): 70 Mbps – 10 km
- Cellular networks, outdoors
  - 2G: 56 Kbps
  - 3G: 384 Kbps
  - 3G enhanced (“4G“): 4 Mbps
  - LTE: 10-100 Mbps

Wireless Network: Wireless Link

- Typically used to connect mobile(s) to base station
- Also used as backbone link
- Multiple access protocol coordinates link access
Wireless Network: Wireless Hosts

- Wireless host
  - Laptop, smartphone
  - Run applications
  - May be stationary (non-mobile) or mobile

Wireless Network: Base Station

- Base station
  - Typically connected to wired network
  - Relay responsible for sending packets between wired network and wireless host(s) in its “area”
  - E.g., cell towers, 802.11 access points

Wireless Network: Infrastructure

- Network infrastructure
  - Larger network with which a wireless host wants to communicate
  - Typically a wired network
  - Provides traditional network services
  - May not always exist

Infrastructure Mode (APs)

- Infrastructure mode
  - Base station connects mobiles into wired network
  - Network provides services (addressing, routing, DNS)
  - Handoff: mobile changes base station providing connection to wired network
Channels and Association

- Multiple channels at different frequencies
  - Network administrator chooses frequency for AP
  - Interference if channel is the same as neighboring AP

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Channels and Association

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- Access points send periodic beacon frames
  - Containing AP’s name (SSID) and MAC address
  - Host scans channels, listening for beacon frames
  - Host selects an access point: association request/response protocol between host and AP

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Mobility Within the Same Subnet

- H1 remains in the same IP subnet
  - IP address of the host can remain the same
  - Ongoing data transfers can continue uninterrupted

- H1 recognizes the need to change
  - H1 detects a weakening signal
  - Starts scanning for a stronger one

- Changes APs with the same SSID
  - H1 disassociates from one
  - And associates with other

- Switch learns new location
  - Self-learning mechanism

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Questions

- Loss is primarily caused by bit errors
  - (Y) Ethernet (Wired)
  - (M) 802.11 (Wireless)
  - (C) Both
  - (A) Neither

- All hosts on the subnet see all communication
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WiFi: 802.11 Wireless LANs

802.11 LAN Architecture

- Access Point (AP)
  - Base station that communicates with the wireless hosts
- Basic Service Set (BSS)
  - Coverage of one AP
  - AP acts as the master
  - Identified by an "network name" known as an SSID

SSID: Service Set Identifier

CSMA: Carrier Sense, Multiple Access

- Multiple access: channel is shared medium
  - Station: wireless host or access point
  - Multiple stations may want to transmit at same time
- Carrier sense: sense channel before sending
  - Station doesn’t send when channel is busy
  - To prevent collisions with ongoing transfers
  - But, detecting ongoing transfers isn’t always possible
CA: Collision Avoidance, Not Detection

- Collision detection in wired Ethernet
  - Station listens while transmitting
  - Detects collision with other transmission
  - Aborts transmission and tries sending again
- Problem #1: cannot detect all collisions
  - Hidden terminal problem
  - Fading

Problem #2: listening while sending
- Strength of received signal is much smaller
- Expensive to build hardware that detects collisions

So, 802.11 does collision avoidance, not detection

Hidden Terminal Problem

- A and C can’t see each other, both send to B
- Occurs b/c 802.11 relies on physical carrier sensing, which is susceptible to hidden terminal problem

Virtual carrier sensing

- First exchange control frames before transmitting data
  - Sender issues “Request to Send” (RTS), incl. length of data
  - Receiver responds with “Clear to Send” (CTS)
- If sender sees CTS, transmits data (of specified length)
- If other node sees CTS, will idle for specified period
- If other node sees RTS but not CTS, free to send
Hidden Terminal Problem

- A and C can’t see each other, both send to B
- RTS/CTS can help
  - Both A and C would send RTS that B would see first
  - B only responds with one CTS (say, echoing A’s RTS)
  - C detects that CTS doesn’t match and won’t send

Exposed Terminal Problem

- B sending to A, C wants to send to D
- As C receives packets, carrier sense would prevent it from sending to D, even though wouldn’t interfere
- RTS/CTS can help
  - C hears RTS from B, but not CTS from A
  - C knows it’s transmission will not interfere with A
  - C is safe to transmit to D

Impact on Higher-Layer Protocols

- Wireless and mobility change path properties
  - Wireless: higher packet loss, not from congestion
  - Mobility: transient disruptions, and changes in RTT
- Logically, impact should be minimal ...
  - Best-effort service model remains unchanged
  - TCP and UDP can (and do) run over wireless, mobile
- But, performance definitely is affected
  - TCP treats packet loss as a sign of congestion
  - TCP tries to estimate the RTT to drive retransmissions
  - TCP does not perform well under out-of-order packets
- Internet not designed with these issues in mind

Questions

- RTS/CTS more like:
  (Y) Statistical multiplexing
  (M) Time-division multiplexing
  (C) Frequency-division multiplexing
- Which of following is NOT true?
  (Y) Collisions are minimized when RTS/CTS used.
  (M) Sender can always detect a collision without feedback from receiver.
  (C) TCP congestion control works poorly in wireless without link-layer retransmission.
  (A) Wireless generally has higher loss rates than wired.
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Bluetooth piconets

• Up to 7 “slave devices and 225 “parked” devices
• Operates on unlicensed wireless spectrum
  – How to prevent interference?

PHY: Spread Spectrum – Frequency Hopping

• Nodes rapidly jump between frequencies
• Sender and receiver coordinated in jumps
  – How coordinate? Pseudorandom number generator, with shared input known to sender/receiver
• If randomly collide with other transmitted, only for short period before jump again

• Bluetooth
  – 79 frequencies, on each frequency for 625 microseconds
  – Each channel also uses TDMA, with each frame taking 1/3/5 consecutive slots.
  – Only master can start in odd slot, slave only in response
Infrastructure vs. Ad Hoc

- **Infrastructure mode**
  - Wireless hosts are associated with a base station
  - Traditional services provided by the connected network
    - E.g., address assignment, routing, and DNS resolution

- **Ad hoc networks**
  - Wireless hosts have no infrastructure to connect to
  - Hosts themselves must provide network services

- **Similar in spirit to the difference between**
  - Client-server communication
  - Peer-to-peer communication

Conclusions

- **Wireless**
  - Already a major way people connect to the Internet
  - Gradually becoming more than just an access network

- **Mobility (not discussed)**
  - Today’s users tolerate disruptions as they move
  - ... and applications try to hide the effects
  - Tomorrow’s users expect seamless mobility

- **Challenges the design of network protocols**
  - Wireless breaks the abstraction of a link, and the assumption that packet loss implies congestion
  - Mobility breaks association of address and location
  - Higher-layer protocols don’t perform as well