Widespread Deployment

- Worldwide cellular subscribers
  - 1993: 34 million
  - 2005: more than 2 billion
  - 2009: more than 4 billion
- landline subscribers

- Wireless local area networks
  - Wireless adapters built into laptops, tablets, & phones
  - More than 220,000 known WiFi locations in 134 countries
  - Probably many, many more (e.g., home networks, corporate networks, ...)

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

Wireless Links: High Bit Error Rate

- Decreasing signal strength
  - Disperses as it travels greater distance
  - Attenuates as it passes through matter
**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

**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

**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 hosts 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 same as neighboring AP

- **Beacon frames from APs**
- **Associate request from host**
- **Association response from AP**
Mobility Within the Same Subnet

- H1 remains in same IP subnet
  - IP address of the host can remain same
  - Ongoing data transfers can continue uninterrupted
- H1 recognizes the need to change
  - H1 detects a weakening signal
  - Starts scanning for stronger one
- Changes APs with same SSID
  - H1 disassociates from one
  - And associates with other
- Switch learns new location
  - Self-learning mechanism

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

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

Exposed Terminal Problem

• B sending to A, C wants to send to D
• As C receives B’s 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

Bluetooth: 802.15.1
“personal-area-networks”
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

Ad-Hoc Networks
- Ad hoc mode
  - No base stations
  - Nodes can only transmit to other nodes within link coverage
  - Nodes self-organize and route among themselves
  - Can create multi-hop wireless networks, instead of a wired backend

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

Delay Tolerant Networking
- Nodes can both route and store
  - Next hop is available, forward
  - Otherwise, store packets
- Useful for data collection with no time limit
  - E.g., sensors in the field
- Analogous to email
  - Hold onto packets until another hop can take it from you
  - Eventually reach its destination

The Upside to Interference
- Some systems leverage interference
- If packets collide once, likely will again
  - Can use both collisions to construct original packets
  - Reduce effective error rate significantly
- If two hosts send to each other through an AP, and they collide, AP can broadcast collision to both
  - Both know what they sent, can “subtract” that from collision to get the other
  - Improves throughput of system!
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