Acknowledgments: Lecture slides are from Computer networks course thought by Jennifer Rexford at Princeton University. When slides are obtained from other sources, a reference will be noted on the bottom of that slide. A full list of references is provided on the last slide.
Goals of Today’s Lecture

• **Wireless links**: unique channel characteristics
  – High, time-varying bit-error rate
  – Broadcast where some nodes can’t hear each other

• **Mobile hosts**: addressing and routing challenges
  – Keeping track of the host’s changing attachment point
  – Maintaining a data transfer as the host moves

• **Some specific examples**
  – Wireless: 802.11 wireless LAN (aka “WiFi”)
  – Mobility: Boeing Connexion and Mobile IP

Many slides adapted from Jim Kurose’s lectures at UMass-Amherst
Widespread Deployment

- **Worldwide cellular subscribers**
  - 1993: 34 million
  - 2005: more than 2 billion
  - Now more than landline subscribers

- **Wireless local area networks**
  - Wireless adapters built in to most laptops, and even PDAs
  - More than 220,000 known WiFi locations in 134 countries
  - Probably many, many more (e.g., home networks, corporate networks, …)
Wireless Links and Wireless Networks
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

- 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 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

• Wired broadcast links
  – E.g., Ethernet bridging, in wired LANs
  – All nodes receive transmissions from all other nodes

• Wireless broadcast: fading over distance

A's signal strength

space

C's signal strength

• 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**
  - Indoor (10-90 meters)
    - 802.11a and g: 54 Mbps
    - 802.11b: 5-11 Mbps
  - Outdoor (300 meters to 20 kmeters)
    - 802.11 n: 600 Mbps
    - WiMax: 144/35 (D/U) Mbps

- **Cellular networks, outdoors**
  - 3G enhanced: 4 Mbps
  - 3G: 384 Kbps
  - 2G: 56 Kbps
Wireless Network: Wireless Link

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

- [Image of network infrastructure with wireless links]
Wireless Network: Wireless Hosts

Wireless host
- Laptop, PDA, IP phone
- Run applications
- May be stationary (non-mobile) or mobile

Network infrastructure

Wireless hosts
- 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
Network infrastructure

- Larger network with which a wireless host wants to communicate
- Typically a wired network
- Provides traditional network services
- May not always exist
Scenario #1: Infrastructure Mode

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
Scenario #2: 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
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
Different Types of Wireless Networks

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<thead>
<tr>
<th></th>
<th>Infrastructure-based</th>
<th>Infrastructure-less</th>
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<tr>
<td><strong>Single hop</strong></td>
<td>Base station connected to larger wired network (e.g., WiFi wireless LAN, and cellular telephony networks)</td>
<td>No wired network; one node coordinates the transmissions of the others (e.g., Bluetooth, and ad hoc 802.11)</td>
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<tr>
<td><strong>Multi-hop</strong></td>
<td>Base station exists, but some nodes must relay through other nodes (e.g., wireless sensor networks, and wireless mesh networks)</td>
<td>No base station exists, and some nodes must relay through others (e.g., mobile ad hoc networks, like vehicular ad hoc networks)</td>
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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 a “network name” known as an SSID

SSID: Service Set Identifier
Channels and Association

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

• 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 to associate with

• 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
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 *not* do collision detection
Medium Access Control in 802.11

• Collision avoidance, not detection
  – Once a station starts transmitting, send in its entirety
  – More aggressive collision-avoidance techniques
  – E.g., waiting a little after sensing an idle channel
  – To reduce likelihood two stations transmit at once

• Link-layer acknowledgment and retransmission
  – CRC to detect errors
  – Receiving station sends an acknowledgment
  – Sending station retransmits if no ACK is received
  – Giving up after a few failed transmissions
Host Mobility
Varying Degrees of User Mobility

- Moves only within same access network
  - Single access point: mobility is irrelevant
  - Multiple access points: only link-link layer changes
  - Either way, users is not mobile at the network layer

- Shuts down between changes access networks
  - Host gets new IP address at the new access network
  - No need to support any ongoing transfers
  - Applications have become good at supporting this

- Maintains connections while changing networks
  - Surfing the ‘net while driving in a car or flying a plane
  - Need to ensure traffic continues to reach the host
Maintaining Ongoing Transfers

• Seamless transmission to a mobile host
E.g., Keep Track of Friends on the Move

- Sending a letter to a friend who moves often
  - How do you know where to reach him?

- Option #1: have him update you
  - Friend contacts you on each move
  - So you can mail him directly
  - E.g., Boeing Connexion service

- Option #2: ask his parents when needed
  - Parents serve as “permanent address”
  - So they can forward your letter to him
  - E.g., Mobile IP
Option #1: Let Routing Protocol Handle It

- Mobile node has a single, persistent address
- Address injected into routing protocol (e.g., OSPF)

Mobile host with IP address 12.34.45.7
Example: Boeing Connexion Service

- **Boeing Connexion service**
  - Mobile Internet access provider
  - WiFi “hot spot” at 35,000 feet moving 600 mph
  - Went out of business in December 2006… 😞

- **Communication technology**
  - Antenna on the plane to leased satellite transponders
  - Ground stations serve as Internet gateways

- **Using BGP for mobility**
  - IP address block per airplane
  - Ground station advertises into BGP
Example: Boeing Connexion Service

12.78.3.0/24

Internet
Summary: Letting Routing Handle It

• Advantages
  – No changes to the end host
  – Traffic follows an efficient path to new location

• Disadvantages
  – Does not scale to large number of mobile hosts
    • Large number of routing-protocol messages
    • Larger routing tables to store smaller address blocks

• Alternative
  – Mobile IP
Option #2: Home Network and Home Agent

Home network: permanent “home” of mobile (e.g., 128.119.40/24)

Home agent: entity that will perform mobility functions on behalf of mobile when mobile is remote

Permanent address: address in home network, can always be used to reach mobile e.g., 128.119.40.186

Correspondent: wants to communicate with mobile
Visited Network and Care-of Address

Permanent address: remains constant (e.g., 128.119.40.186)

Care-of-address: address in visited network. (e.g., 79.129.13.2)

Visited network: network in which mobile currently resides (e.g., 79.129.13/24)

Foreign agent: entity in visited network that performs mobility functions on behalf of mobile

Correspondent: wants to communicate with mobile
Mobility: Registration

- Foreign agent knows about mobile
- Home agent knows location of mobile
Mobility via Indirect Routing

1. Correspondent addresses packets using home address of mobile
2. Home agent intercepts packets, forwards to foreign agent
3. Foreign agent receives packets, forwards to mobile
4. Mobile replies directly to correspondent

Home network
Wide area network
Visited network
Indirect Routing: Efficiency Issues

• Mobile uses two addresses
  – Permanent address: used by correspondent (making mobile’s location is transparent to correspondent)
  – Care-of-address: used by the home agent to forward datagrams to the mobile

• Mobile may perform the foreign agent functions

• Triangle routing is inefficient
  – E.g., correspondent and mobile in the same network
Mobility via Direct Routing

1. Correspondent requests, receives foreign address of mobile
2. Correspondent forwards to foreign agent
3. Foreign agent receives packets, forwards to mobile
4. Mobile replies directly to correspondent

No longer transparent to the correspondent
Mobility Today

• Limited support for mobility
  – E.g., among base stations on a campus

• Applications increasingly robust under mobility
  – Robust to changes in IP address, and disconnections
  – E.g., e-mail client contacting the e-mail server
  – … and allowing reading/writing while disconnected

• Increasing demand for seamless IP mobility
  – E.g., continue a VoIP call while on the train

• Increasing integration of WiFi and cellular
  – E.g., dual-mode cell phones that can use both networks
  – Called Unlicensed Mobile Access (UMA)
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
Conclusions

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

• Mobility
  – 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