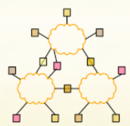
15-446 Distributed Systems Spring 2009



L-5 Wireless

Wireless Challenges

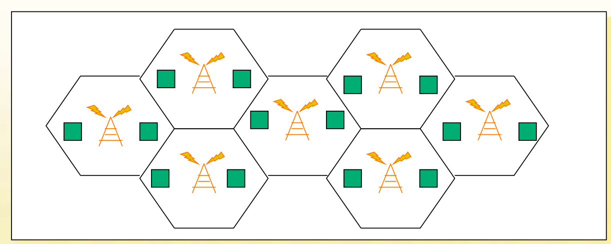
- Force us to rethink many assumptions
- Need to share airwaves rather than wire
  - Don't know what hosts are involved
  - Host may not be using same link technology
- Mobility
- Other characteristics of wireless
  - Noisy → lots of losses
  - Slow
  - Interaction of multiple transmitters at receiver
    - Collisions, capture, interference
  - Multipath interference

Overview

- Wireless Links
  - 802.11
  - Bluetooth
- Internet Mobility
- Performance Issues

Cellular Reuse

- Transmissions decay over distance
  - Spectrum can be reused in different areas
  - Different "LANs"
  - Decay is $1/R^2$ in free space, $1/R^4$ in some situations



IEEE 802.11 Wireless LAN

- 802.11b
  - 2.4-2.5 GHz unlicensed radio spectrum
  - up to 11 Mbps
  - direct sequence spread spectrum (DSSS) in physical layer
    - all hosts use same chipping code
  - widely deployed, using base stations
- 802.11a
  - 5-6 GHz range
  - up to 54 Mbps
- 802.11g
  - 2.4-2.5 GHz range
  - up to 54 Mbps
- All use CSMA/CA for multiple access
- All have base-station and ad-hoc network versions

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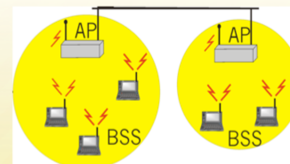
IEEE 802.11 Wireless LAN

- Wireless host communicates with a base station
  - Base station = access point (AP)
- **Basic Service Set (BSS) (a.k.a. "cell") contains:**
  - **Wireless hosts**
  - **Access point (AP): base station**
- **BSS's combined to form distribution system (DS)**



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Ad Hoc Networks

- Ad hoc network: IEEE 802.11 stations can dynamically form network *without* AP
- Applications:
  - Laptops meeting in conference room, car
  - Interconnection of "personal" devices

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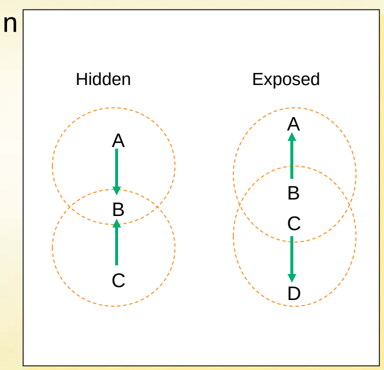
CSMA/CD Does Not Work

- Collision detection problems
  - Relevant contention at the receiver, not sender
    - Hidden terminal
    - Exposed terminal
  - Hard to build a radio that can transmit and receive at same time



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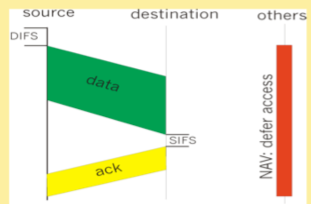
IEEE 802.11 MAC Protocol: CSMA/CA

802.11 CSMA: sender
- If sense channel idle for **DISF (Distributed Inter Frame Space)** then transmit entire frame (no collision detection)
- If sense channel busy then binary backoff

802.11 CSMA receiver:
- If received OK return ACK after **SIFS (Short IFS)** (ACK is needed due to lack of collision detection)



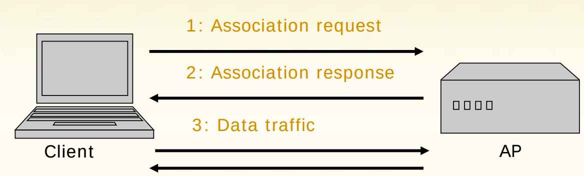
802.11 Management Operations

- Scanning
- Association/Reassociation
- Time synchronization
- Power management

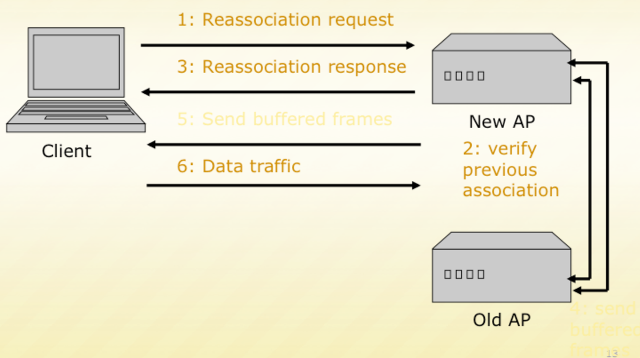
Scanning

- Goal: find networks in the area
- Passive scanning
  - No require transmission → saves power
  - Move to each channel, and listen for Beacon frames
- Active scanning
  - Requires transmission → saves time
  - Move to each channel, and send Probe Request frames to solicit Probe Responses from a network

Association in 802.11



Reassociation in 802.11



Time Synchronization in 802.11

- Timing synchronization function (TSF)
  - AP controls timing in infrastructure networks
  - All stations maintain a local timer
  - TSF keeps timer from all stations in sync
- Periodic Beacons convey timing
  - Beacons are sent at well known intervals
  - Timestamp from Beacons used to calibrate local clocks
  - Local TSF timer mitigates loss of Beacons

Power Management in 802.11

- A station is in one of the three states
  - Transmitter on
  - Receiver on
  - Both transmitter and receiver off (dozing)
- AP buffers packets for dozing stations
- AP announces which stations have frames buffered in its Beacon frames
- Dozing stations wake up to listen to the beacons
- If there is data buffered for it, it sends a poll frame to get the buffered data

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Bluetooth Basics

- Short-range, high-data-rate wireless link for personal devices
  - Originally intended to replace cables in a range of applications
  - e.g., Phone headsets, PC/PDA synchronization, remote controls
- Operates in 2.4 GHz ISM band
  - Same as 802.11
  - Frequency Hopping Spread Spectrum across ~ 80 channels

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Usage Models

- Wireless audio
  - e.g., Wireless headset associated with a cell phone
  - Requires guaranteed bandwidth between headset and base
  - No need for packet retransmission in case of loss
- Cable replacement
  - Replace physical serial cables with Bluetooth links
  - Requires mapping of RS232 control signals to Bluetooth messages
- LAN access
  - Allow wireless device to access a LAN through a Bluetooth connection
  - Requires use of higher-level protocols on top of serial port (e.g., PPP)
- File transfer
  - Transfer calendar information to/from PDA or cell phone
  - Requires understanding of object format, naming scheme, etc.

Lots of competing demands for one radio spec!

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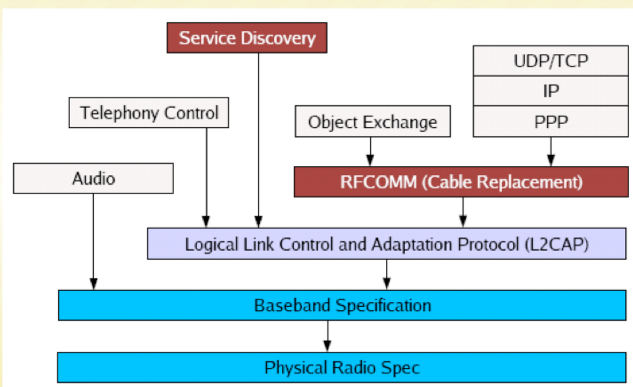
Protocol Architecture



Piconet Architecture

- One master and up to 7 slave devices in each *Piconet*
- Master controls transmission schedule of all devices in the Piconet
  - Time Division Multiple Access (*TDMA*): Only one device transmits at a time
- Frequency hopping used to avoid collisions with other Piconets
  - 79 physical channels of 1 MHz each, hop between channels 1600 times a sec

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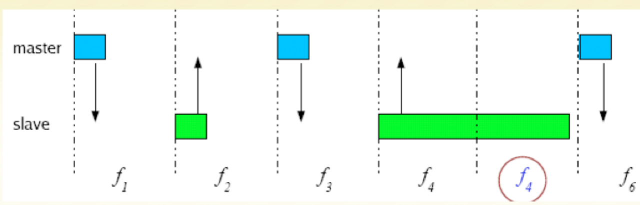
Bluetooth Physical Layer

- Maximum data rate of up to 720 Kbps
  - *But, requires large packets (> 300 bytes)*
- Class 1: Up to 100mW (20 dBm) transmit power, ~100m range
  - *Class 1 requires that devices adjust transmit power dynamically to avoid interference with other devices*
- Class 2: Up to 2.4 mW (4 dBm) transmit power
- Class 3: Up to 1 mW (0 dBm) transmit power

Bluetooth Physical Layer

- 79 1-MHz channels defined in the 2.4 GHz ISM band
  - Gaussian FSK used as modulation, 115 kHz frequency deviation
- Frequency Hopping Spread Spectrum
  - Each Piconet has its own FH schedule, defined by the master
  - 1600 hops/sec, slot time 0.625 ms
- Time Division Duplexing
  - Master transmits to slave in one time slot, slave to master in the next
- TDMA used to share channel across multiple slave devices
  - Master determines which time slots each slave can occupy
  - Allows slave devices to sleep during inactive slots

Time slots



- Each time slot on a different frequency
  - According to FH schedule
- Packets may contain ACK bit to indicate successful reception in the *previous* time slot
  - Depending on type of connection…
  - e.g., Voice connections do not use ACK and retransmit
- Packets may span multiple slots – stay on same frequency

Discussion

- Nice points
  - A number of interesting low power modes
  - Device discovery
    - Must synchronize FH schemes
    - Burden on the searcher
- Some odd decisions
  - Addressing
  - Somewhat bulky application interfaces
    - Not just simple byte-stream data transmission
    - Rather, complete protocol stack to support voice, data, video, file transfer, etc.
      - *Bluetooth operates at a higher level than 802.11 and 802.15.4*

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Routing to Mobile Nodes

- Obvious solution: have mobile nodes advertise route to mobile address/32
  - Should work!!!
- Why is this bad?
  - Consider forwarding tables on backbone routers
    - Would have an entry for each mobile host
    - Not very scalable
- What are some possible solutions?

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How to Handle Mobile Nodes? (Addressing)

- Dynamic Host Configuration (DHCP)
  - Host gets new IP address in new locations
  - Problems
    - Host does not have constant name/address → how do others contact host
    - What happens to active transport connections?

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How to Handle Mobile Nodes? (Naming)

- Naming
  - Use DHCP and update name-address mapping whenever host changes address
  - Fixes contact problem but not broken transport connections

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How to Handle Mobile Nodes? (Routing)

- Allow mobile node to keep same address and name
- How do we deliver IP packets when the endpoint moves?
  - Can't just have nodes advertise route to their address
- What about packets from the mobile host?
  - Routing not a problem
  - What source address on packet? → this can cause problems
- Key design considerations
  - Scale
  - Incremental deployment

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Basic Solution to Mobile Routing

- Same as other problems in computer science
  - Add a level of indirection
- Keep some part of the network informed about current location
  - Need technique to route packets through this location (interception)
- Need to forward packets from this location to mobile host (delivery)

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Interception

- Somewhere along normal forwarding path
  - At source
  - Any router along path
  - Router to home network
  - Machine on home network (masquerading as mobile host)
- Clever tricks to force packet to particular destination
  - "Mobile subnet" – assign mobiles a special address range and have special node advertise route

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Delivery

- Need to get packet to mobile's current location
- Tunnels
  - Tunnel endpoint = current location
  - Tunnel contents = original packets
- Source routing
  - Loose source route through mobile current location

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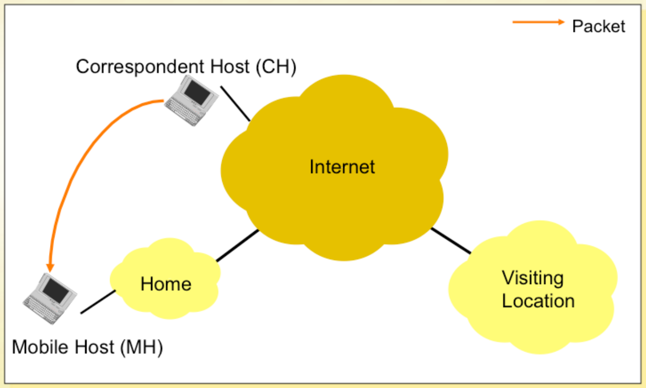
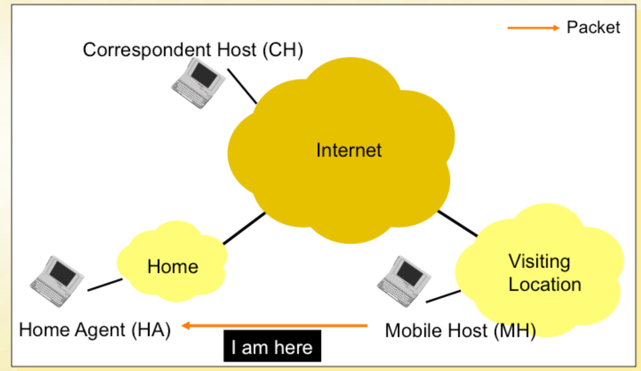
Mobile IP (MH at Home)



Mobile IP (MH Moving)



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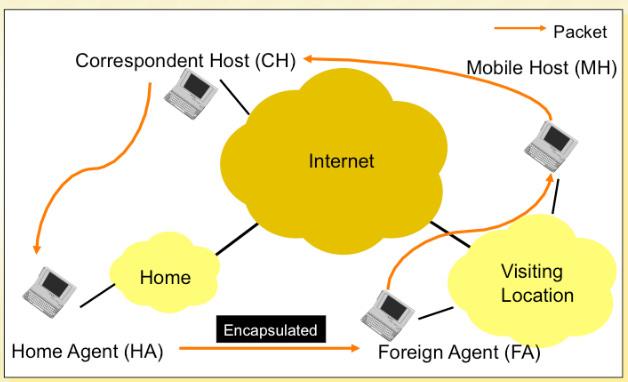
Mobile IP (MH Away – FA)



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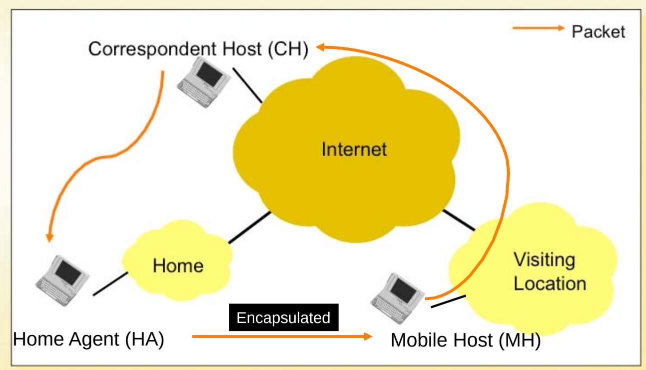
Mobile IP (MH Away - Collocated)



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Other Mobile IP Issues

- Route optimality
  - Resulting paths can be sub-optimal
  - Can be improved with route optimization
    - Unsolicited binding cache update to sender
- Authentication
  - Registration messages
  - Binding cache updates
- Must send updates across network
  - Handoffs can be slow
- Problems with basic solution
  - Triangle routing
  - Reverse path check for security

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Adapting Applications

- Applications make key assumptions
  - Hardware variation
    - E.g. how big is screen?
  - Software variation
    - E.g. is there a postscript decoder?
  - Network variation
    - E.g. how fast is the network?
- Basic idea – distillation
  - Transcode object to meet needs of mobile host

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Transcoding Example

- Generate reduced quality variant of Web page at proxy
  - Must predict how much size reduction will result from transcoding
  - How long to transcode?
- Send appropriate reduced-size variant
  - Target response time?

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Source Adaptation

- Can also just have source provide different versions
  - Common solution today
  - No waiting for transcoding
  - Full version not sent across network
  - Can't handle fine grain adaptation

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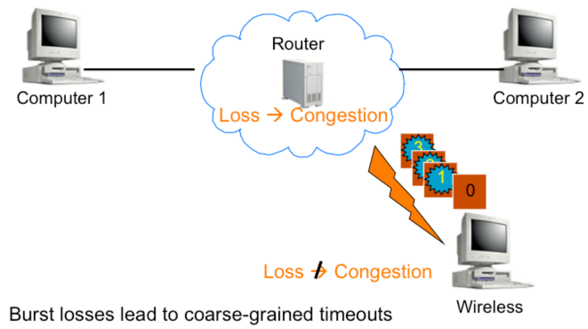
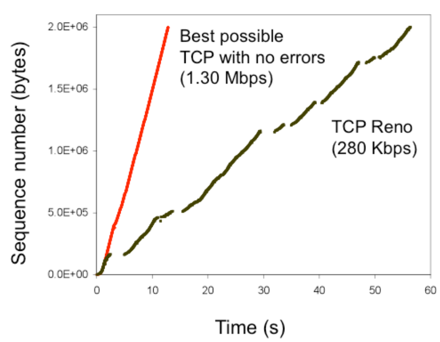
Wireless Bit-Errors



Burst losses lead to coarse-grained timeouts
Result: Low throughput

Performance Degradation



2 MB wide-area TCP transfer over 2 Mbps Lucent WaveLAN

Important Lessons

- Many assumptions built into Internet design
  - Wireless forces reconsideration of issues
- Link-layer
  - Spatial reuse (cellular) vs wires
  - Hidden/exposed terminal
  - CSMA/CA (why CA?) and RTS/CTS
- Network
  - Mobile endpoints – how to route with fixed identifier?
  - Link layer, naming, addressing and routing solutions
    - What are the +/- of each?
- Transport
  - Losses can occur due to corruption as well as congestion
    - Impact on TCP?
  - How to fix this → hide it from TCP or change TCP

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