15-441 15-641 Computer Networking

Lecture 24: Mobile and Wireless

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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
  - Often slow compared with wired (but not always)
  - Interaction of multiple transmitters at receiver
    - Collisions, capture, interference
  - Communication is broadcast based

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Overview

- Internet mobility
- TCP over noisy links
- Link layer challenges and WiFi
- Cellular

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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 Addressing for Mobile Nodes?

- Simple existing solution: Dynamic Host Configuration (DHCP)
- Host gets new IP address in new locations
  - No impact on Internet routing
- Problems for the mobile host
  - Host does not have constant name/address → how do others contact host?
  - What happens to active transport connections when the host moves?

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We Can Fix the Naming Problem

- Use DNS and update name-address mapping whenever host changes address
  - An awkward solution, at best
  - Increases “write” load on DNS
  - Also raises security issues
- Fixes contact problem but the broken transport connection problem remains

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How to Handle Transport Connections for Mobile Nodes?

- TCP currently uses 4 tuple to describe connection
  - <Src Addr, Src port, Dst addr, Dst port>
- Modify TCP to allow peer's address to be changed during connection
- Security issues
  - Can someone easily hijack connection?
- Difficult deployment → both ends must support mobility

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How about Link Layer Mobility?

- Link layer mobility is easier
- Learning bridges can handle mobility → this is how it is handled at CMU
- Wireless LAN (802.11) also provide some help to reduce impact of handoff
  - Reduce latency, packet loss
- Problem is with inter-network mobility, i.e. Changing IP addresses
  - Need to make it look as if we stay in the same network

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Mobile IP: Supporting Host Mobility in the Internet

- 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

- When a host sends a packet to the mobile host, it is intercepted so the packet can be forwarded to the mobile host's real location
- Interception must happen somewhere along normal forwarding path
  - At source
  - Any router along path
  - Router to home network
  - Machine on home network (masquerading as mobile host)

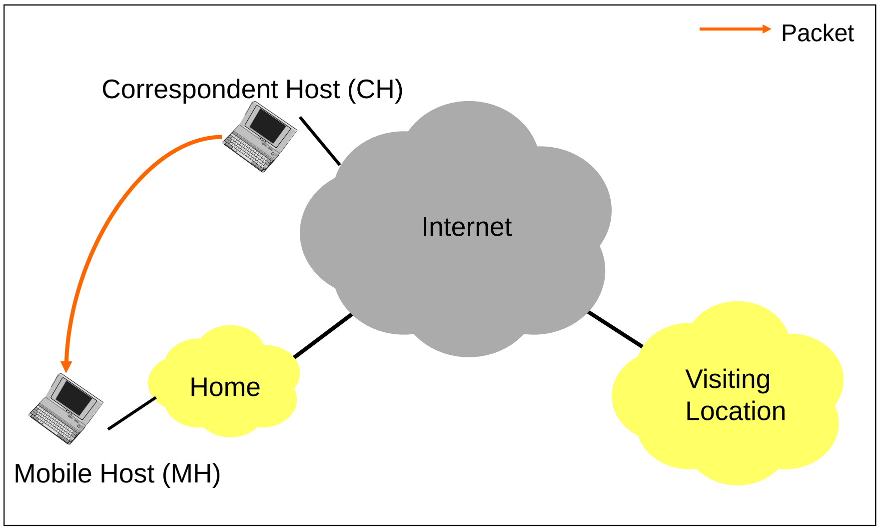
Delivery

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

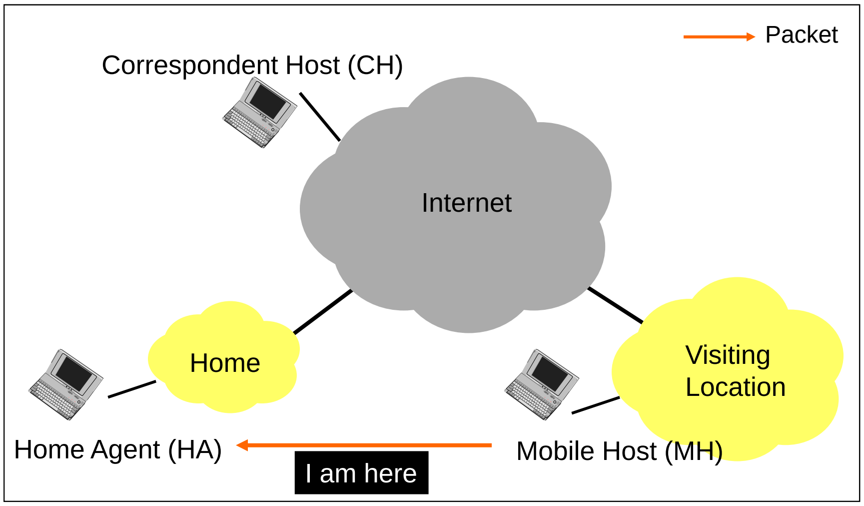
Mobile IP (RFC 2290)

- Interception
  - Typically home agent – a host on home network
- Delivery
  - Typically IP-in-IP tunneling
  - Endpoint – either temporary mobile address or foreign agent
- Terminology
  - Mobile host (MH), correspondent host (CH), home agent (HA), foreign agent (FA)
  - Care-of-address, home address

Mobile IP (MH at Home)



Mobile IP (MH Moving)



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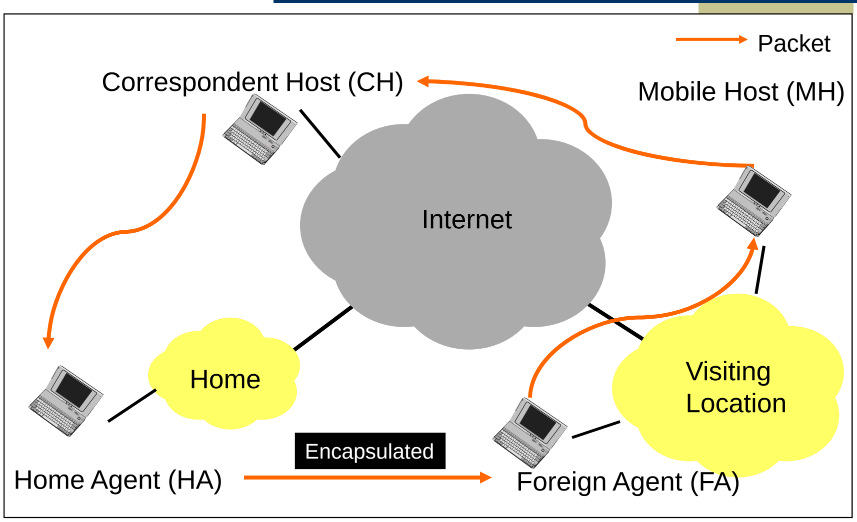
Mobile IP (MH Away – FA)



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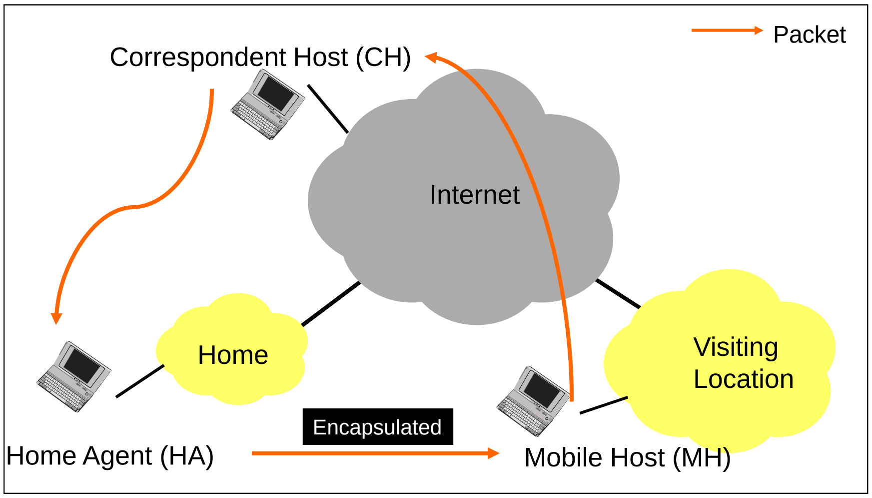
Mobile IP (MH Away - Collocated)



Other Mobile IP Issues

- Route optimality
  - Resulting paths can be sub-optimal
  - Can be improved with route optimization
- 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

Mobility with GSM

- Interception
  - Network
  - G-MSC “Gateway Mobile Switching Center”
- Delivery
  - Varied
- Terminology
  - Mobile Station (MS)
  - Cell
  - Location Area
  - Home MSC
  - Target MSC

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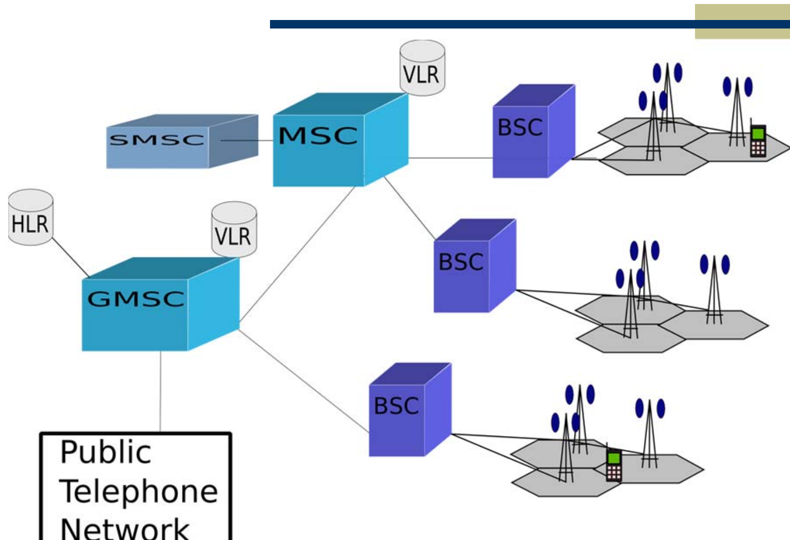
GSM Core Architecture



Modified from http://commons.wikimedia.org/wiki/File:GSM_network_architecture_01-pl.svg by Farmer Jan

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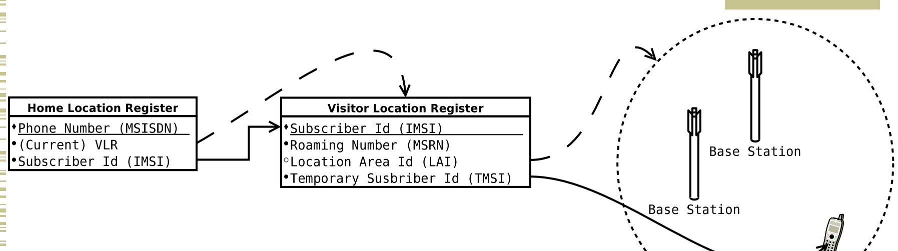
GSM Addressing Hierarchy

- Device
  - IMEI (International Mobile Equipment Identifier)
- User
  - IMSI (International Mobile Subscriber Identifier)
  - MSISDN (Mobile Subscriber IDSN Number)
    - “Real phone number”
  - MSRN (Mobile Station Roaming Number)
  - TMSI (Temporary Mobile Subscriber Identity
  - LMSI (Local Mobile Subscriber Identity)
- Other
  - LAI (Location Area Identity)
  - CI (Cell Identity)

GSM Address Lookup (“registers”)



- Hard state: Current MSC/VLR, LAI
  - (Necessary to page phone, updated whenever mobile moves)
- Soft-ish state:
  - MSRN, cell ID, TMSI

Note: Grossly simplified for your safety and sanity!

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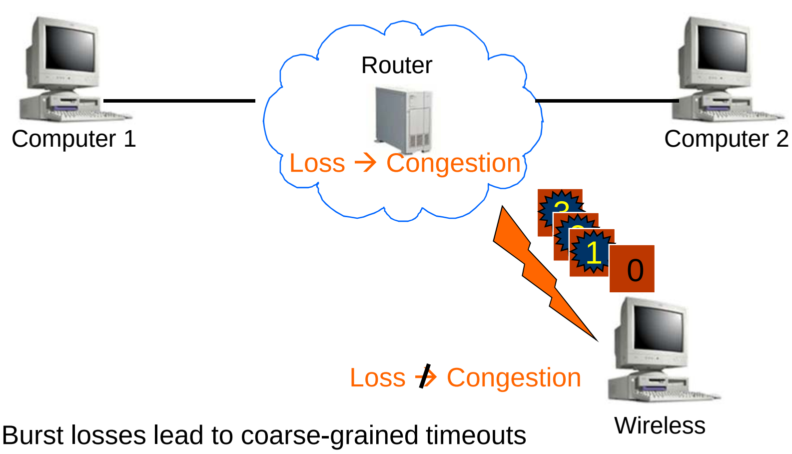
Wireless Bit-Errors



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

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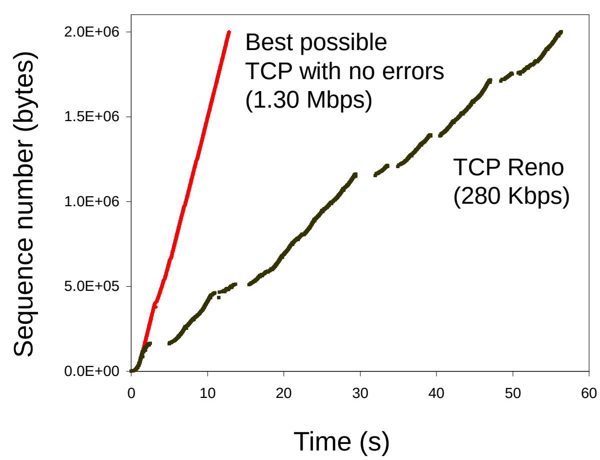
TCP Problems Over Noisy Links

- Wireless links are inherently error-prone
  - Fades, interference, attenuation
  - Errors often happen in bursts
- TCP cannot distinguish between corruption and congestion
  - TCP unnecessarily reduces window, resulting in low throughput and high latency
- Burst losses often result in timeouts
- Sender retransmission is the only option
  - Inefficient use of bandwidth

Performance Degradation



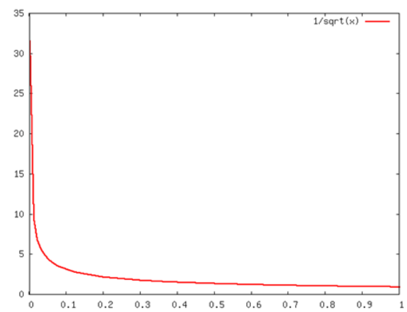
2 MB wide-area TCP transfer over 2 Mbps Lucent WaveLAN

Performance Degradation 2

- Recall TCP throughput / loss / RTT rel:
  - BW = MSS / (rtt * sqrt(2p/3))
  - = proportional to 1 / rtt * sqrt(p)
  - == ouch!

  - Normal TCP operating range: < 2% loss

  Internet loss usually < 1%



Proposed Solutions

- Error recovery by link-layer protocols
  - Solution used by today's wireless standards
  - Uses aggressive local retransmissions, possible combined with error-correcting codes
- End-to-end protocols
  - Selective ACKs and explicit loss notification can reduce impact of losses, but often not sufficient
- Split-connection protocols
  - Separate transport connections for wired path and wireless hop + fast recovery solution for wireless hop
  - Not common in practice

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IEEE 802.11 Wireless LAN

- 802.11b
  - 2.4-2.5 GHz unlicensed radio spectrum
  - 20 MHz channel
  - up to 11 Mbps
- 802.11a
  - 5-6 GHz range
  - 20 MHz channel
  - up to 54 Mbps
  - OFDM in physical layer
- 802.11g
  - 2.4-2.5 GHz range
  - Otherwise like a
- 802.11n
  - 20 or 40 MHz channel
  - (up to) 4x4 MIMO
  - Up to 600 Mbps
- 802.11ac
  - 80 or 160 MHz channel
  - (up to) 8x8 MIMO
  - Up to 6 Gbps
- All use CSMA/CA for multiple access
- All have base-station and ad-hoc network versions

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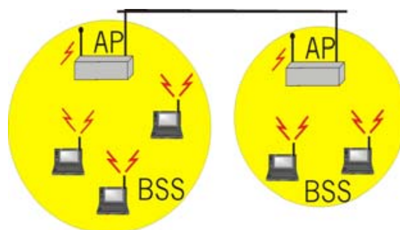
IEEE 802.11 Wireless LAN

- 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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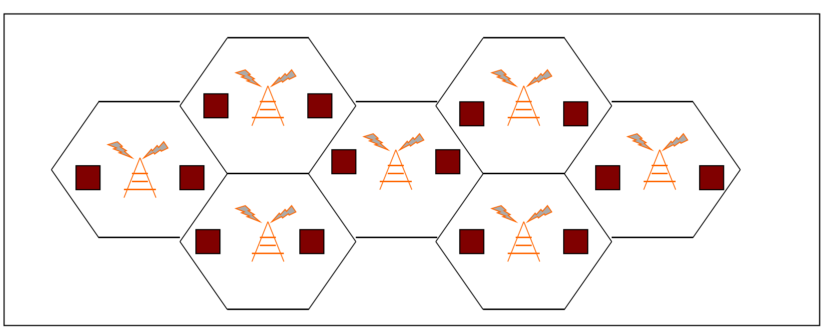
Cellular Reuse

- 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



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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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But We Need a MAC

- How do we get a bunch of nodes that can all hear each other to talk nicely?
- Sounds familiar?

- Ethernet or CSMA/CD: carrier-sense multiple access with collision detection
  - Listen before you talk
  - When node senses a collision, it aborts and retries the transmission

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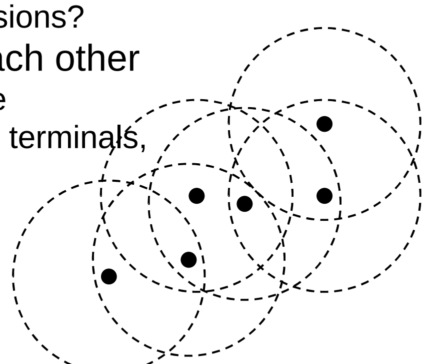
Wireless Ethernet is a Good Idea, but …

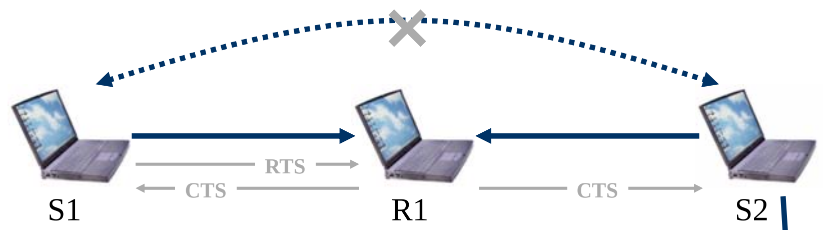
- Attenuation varies with media
  - Also depends strongly on distance, frequency
- Wired media has exponential dependence
  - Received power at d meters proportional to 10^{-kd}
  - Attenuation in dB = $k\ d$, where k is dB/meter
- Wireless media has logarithmic dependence
  - Received power at d meters proportional to d^{-n}
  - Attenuation in dB = $n \log d$, where n is path loss exponent; $n=2$ in free space
  - Signal level maintained for much longer distances?
- But we are ignoring the constants!
  - Wireless attenuation at 2.4 GHz: 60-100 dB
  - In practice numbers can be much lower for wired

Implications for Wireless Ethernet

- Collision detection is not practical
  - Ratio of transmitted signal power to received power is too high at the transmitter
  - Transmitter cannot detect competing transmitters (is deaf while transmitting)
  - So how do you detect collisions?
- Not all nodes can hear each other
  - A problem for carrier sense
  - Hidden terminals, exposed terminals,
  - Capture effects
- Made worse by fading
  - Changes over time!

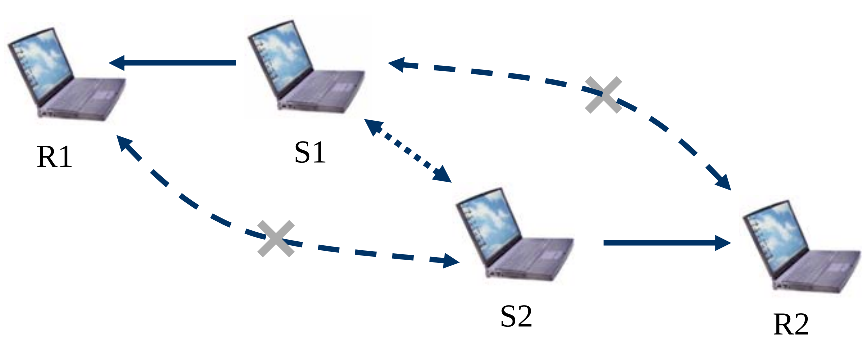


Hidden Terminal Problem



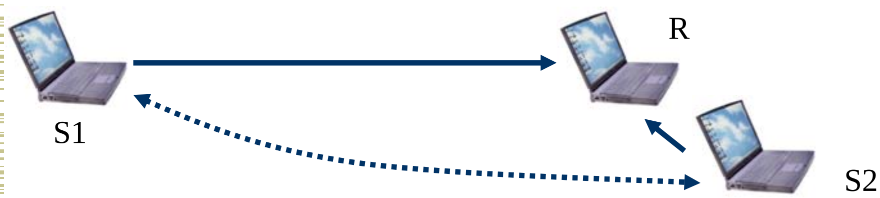
- Lack signal between S1 and S2 and cause collision at R1
- Severity of the problem depends on the sensitivity of the carrier sense mechanism
  - Clear Channel Assessment (CCA) threshold

Exposed Terminal Problem



- Carrier sense prevents two senders from sending simultaneously although they do not reach each other's receiver
- Severity again depends on CCA threshold

Capture Effect



- Sender S2 will almost always “win” if there is a collision at receiver R.
- Can lead to extreme unfairness and even starvation.
- Solution is power control
  - Very difficult to manage in a non-provisioned environment!

Wireless Packet Networking Problems

- Some nodes suffer from more interference than others
  - Node density
  - Traffic volume sent by neighboring nodes
- Leads to unequal throughput
- Similar to wired network: some flows traverse tight bottleneck while others do not

Important Lessons

- Many assumptions built into Internet design
  - Wireless forces reconsideration of issues
- 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
- Link-layer
  - Spatial reuse (cellular) vs wires
  - Hidden/exposed terminal
  - No collision detection