# 15-441: 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



## Overview

- Internet mobility
- TCP over noisy links
- Link layer challenges
- Wireless deployments



## 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?

## 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?



## 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



## 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



## 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

## 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



## 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)



## 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

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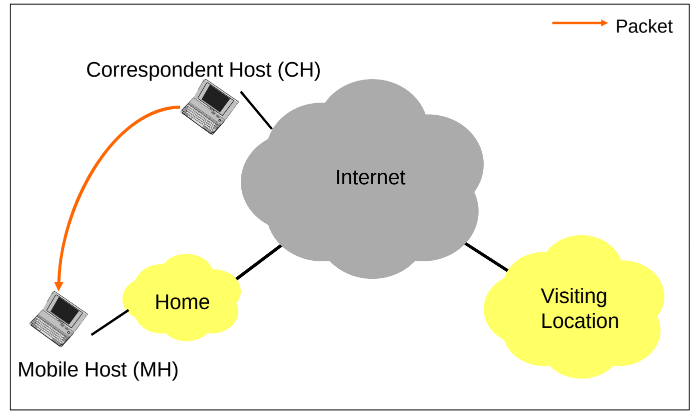
## Mobile IP (MH at Home)

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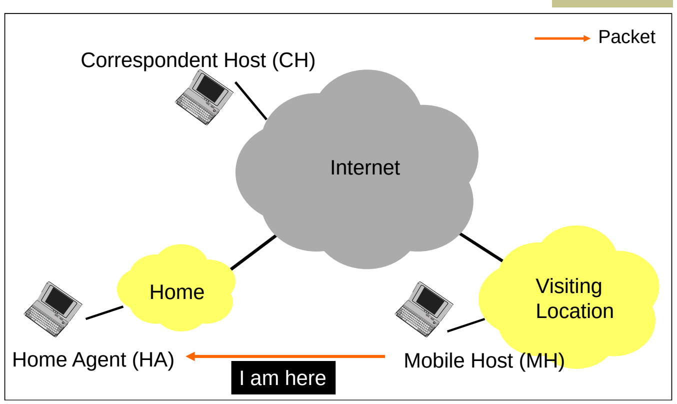
## Mobile IP (MH Moving)

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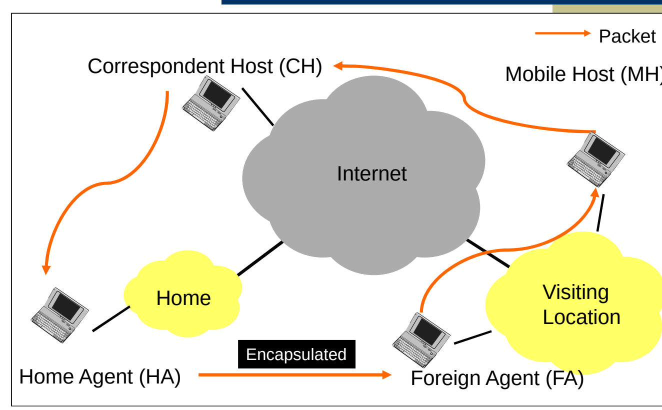
## Mobile IP (MH Away – FA)

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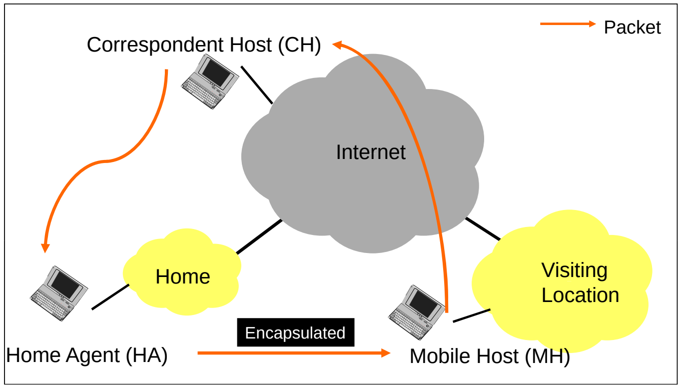
## Mobile IP (MH Away - Collocated)






## 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



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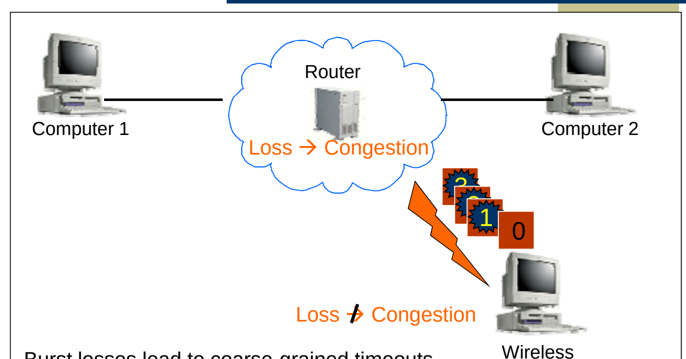
## Wireless Bit-Errors




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

## 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

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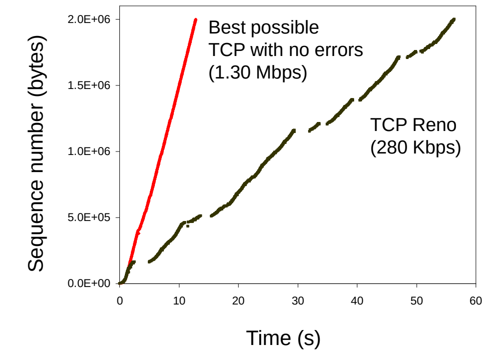
## Performance Degradation




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

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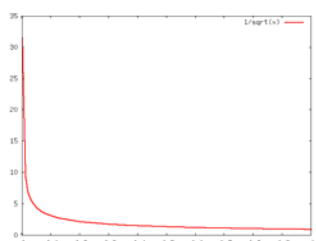
## Performance Degradation 2

- 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

- Incremental deployment
  - Solution should not require modifications to fixed hosts
  - If possible, avoid modifying mobile hosts
- End-to-end protocols
  - Selective ACKs, Explicit loss notification
- Split-connection protocols
  - Separate connections for wired path and wireless hop
- Reliable link-layer protocols
  - Error-correcting codes
  - Local retransmission

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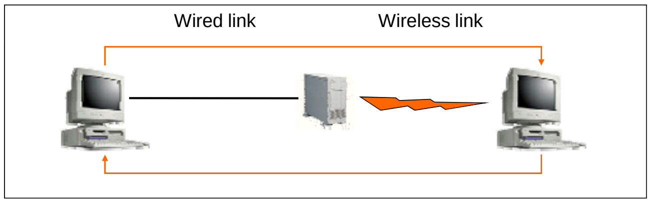
## Approach Styles (End-to-End)

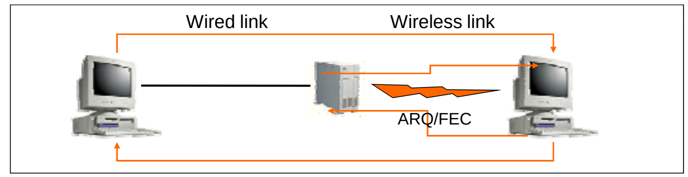
- Improve TCP implementations
  - Not incrementally deployable
  - Improve loss recovery (SACK, NewReno)
  - Help it identify congestion (ELN, ECN)
    - E.g. ACKs include flag indicating wireless loss
  - Trick TCP into doing right thing → E.g. send extra dupacks if wireless host suspects errors (e.g. mobility)






## Approach Styles (Link Layer)

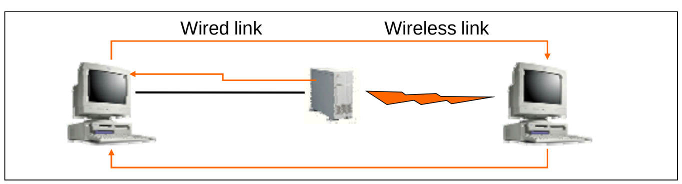
- More aggressive local rexmit than TCP
  - Approach used in 802.11
  - Bandwidth not wasted on wired links + fast recovery
- Possible adverse interactions with transport layer
  - Interactions with TCP retransmission
  - Large end-to-end RTT variation (but RTO considers variance?)
- FEC used in some wireless networks (802.11a)
  - But does not work well with burst losses






## Split Connection Approach

- Gateway splits connection in two segments
  - Separates congestion, error, and flow control
- Gateway tries to keep the server happy
  - Insert additional acks, change timing of acks, etc.
- Very difficult to do without modifying TCP on server
  - Especially considering the diversity of TCP implementations
  - Some proposals modify semantics, e.g. local acks



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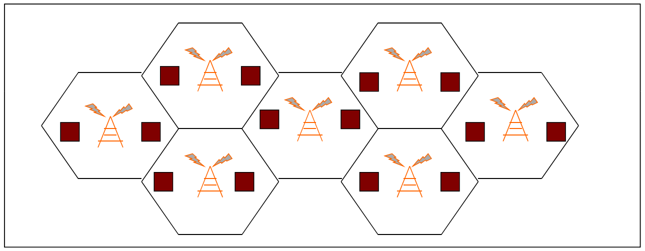
## Cellular Reuse

- 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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## 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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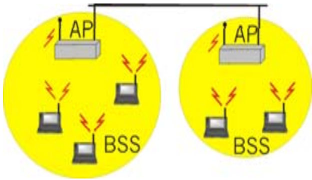
## IEEE 802.11 Wireless LAN

- 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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## 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

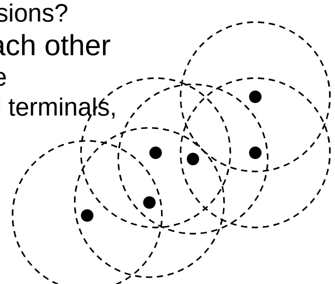


## Wireless Ethernet is a Good Idea, but …

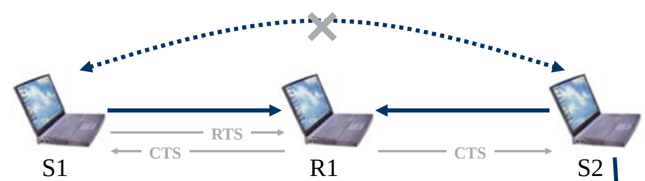
- Attenuation varies with media
  - Also depends strongly on distance, frequency
- Wired media has exponential dependence
  - Received power at d meters proportional to $10^{-kd}$
  - Attenuation in dB = *k d*, where *k* is dB/meter
- Wireless media has logarithmic dependence
  - Received power at d 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!

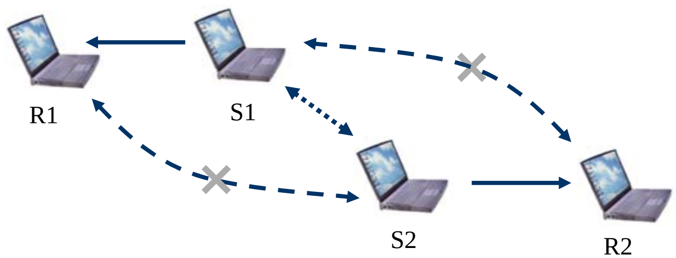


## Hidden Terminal Problem



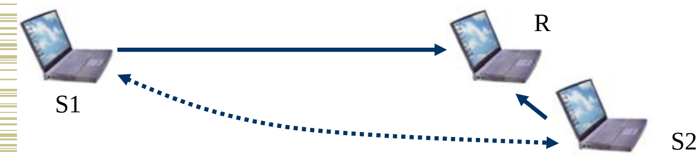

- Lack signal between S1 and S2 and cause collision at R1
- Severity of the problem depends on the sensitivity of the carrier sense mechanism
  - Clear Channel Assessment (CCA) threshold

## Exposed Terminal Problem



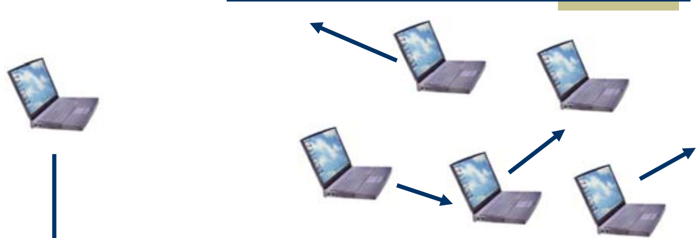

- Carrier sense prevents two senders from sending simultaneously although they do not reach each other's receiver
- Severity again depends on CCA threshold

## 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