15-744: Computer Networking

L-10 Ad Hoc Networks

Mobile Routing

- Mobile IP
- Ad-hoc network routing
- Assigned reading
  - Performance Comparison of Multi-Hop Wireless Ad Hoc Routing Protocols
  - A High Throughput Path Metric for MultiHop Wireless Routing

Overview

- Internet routing
- Ad hoc routing
- Ad hoc routing metrics

How to Handle Mobile Nodes?

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

Handling Mobile Nodes (Transport)

- 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

Handling Mobile Node

- Link layer mobility
  - Learning bridges can handle mobility → this is how it is handled at CMU
  - Encapsulated PPP (PPTP) → Have mobile host act like he is connected to original LAN
    - Works for IP AND other network protocols
- Multicast
  - Solves similar problem → how to route packets to different sets of hosts at different times
  - Can't we just reuse same solutions?
    - Don't really have solution for multicast either!

Handling Mobile Nodes (Routing)

- Allow mobile node to keep same address and name
- How do we deliver IP packets when the endpoint moves?
  - Why can't we just have nodes advertise route to their address?
- What about packets from the mobile host?
  - Routing not a problem
  - What source address on packet?
- 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

- 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

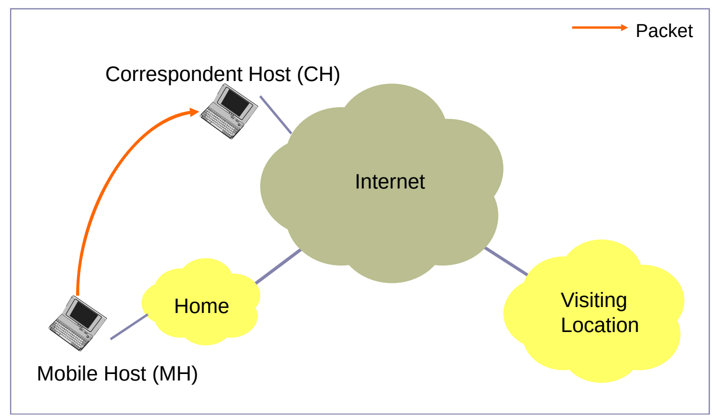
Delivery

- 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
- Network address translation (NAT)
  - What about packets from the mobile host?

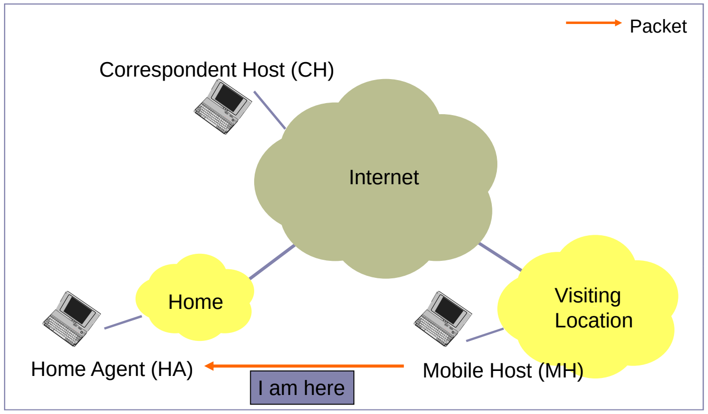
Mobile IP (RFC 2290)

- Interception
  - Typically home agent – hosts 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

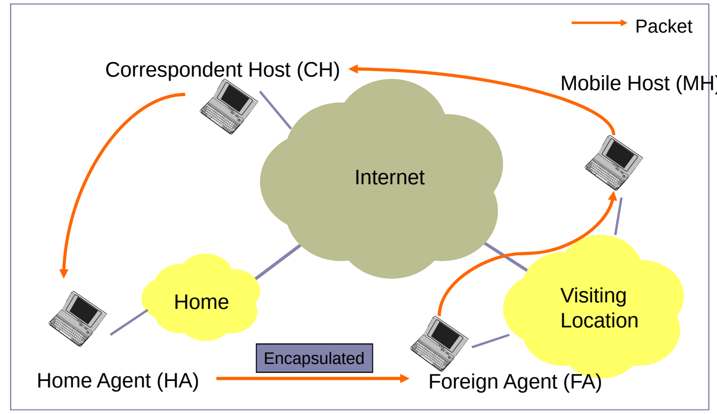
Mobile IP (MH at Home)



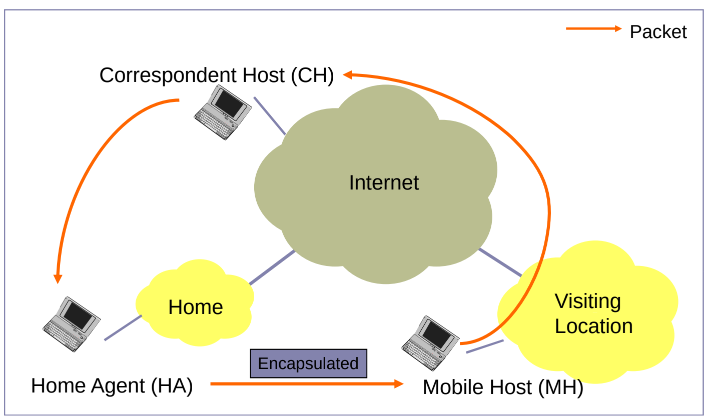
Mobile IP (MH Moving)



Mobile IP (MH Away – Foreign Agent)



Mobile IP (MH Away - Collocated)



Other Mobile IP Issues

- Route optimality
  - Triangle routing
  - 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
  - Reverse path check for security
  - Do we really need it…

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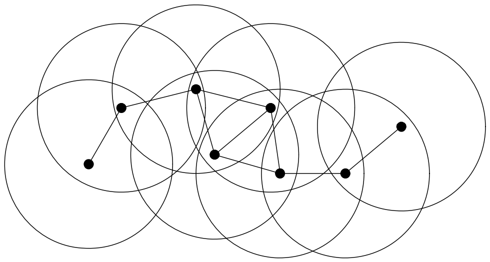
Ad Hoc Routing

- Goal: Communication between wireless nodes
  - No external setup (self-configuring)
  - Often need multiple hops to reach dst



Ad Hoc Routing

- Create multi-hop connectivity among set of wireless, possibly moving, nodes
- Mobile, wireless hosts act as forwarding nodes as well as end systems
- Need routing protocol to find multi-hop paths
  - Needs to be dynamic to adapt to new routes, movement
  - Interesting challenges related to interference and power limitations
  - Low consumption of memory, bandwidth, power
  - Scalable with numbers of nodes
  - Localized effects of link failure

Challenges and Variants

- Poorly-defined "links"
  - Probabilistic delivery, etc. Kind of n^2 links
- Time-varying link characteristics
- No oracle for configuration (no ground truth configuration file of connectivity)
- Low bandwidth (relative to wired)
- Possibly mobile
- Possibly power-constrained

Problems Using DV or LS

- DV protocols may form loops
  - Very wasteful in wireless: bandwidth, power
  - Loop avoidance sometimes complex
- LS protocols: high storage and communication overhead
- More links in wireless (e.g., clusters) - may be redundant → higher protocol overhead

Problems Using DV or LS

- Periodic updates waste power
  - Tx sends portion of battery power into air
  - Reception requires less power, but periodic updates prevent mobile from "sleeping"
- Convergence may be slower in conventional networks but must be fast in ad-hoc networks and be done without frequent updates

Proposed Protocols

- Destination-Sequenced Distance Vector (DSDV)
  - DV protocol, destinations advertise sequence number to avoid loops, not on demand
- Temporally-Ordered Routing Algorithm (TORA)
  - On demand creation of hbh routes based on link-reversal
- Dynamic Source Routing (DSR)
  - On demand source route discovery
- Ad Hoc On-Demand Distance Vector (AODV)
  - Combination of DSR and DSDV: on demand route discovery with hbh routing

DSR Concepts

- Source routing
  - No need to maintain up-to-date info at intermediate nodes
- On-demand route discovery
  - No need for periodic route advertisements

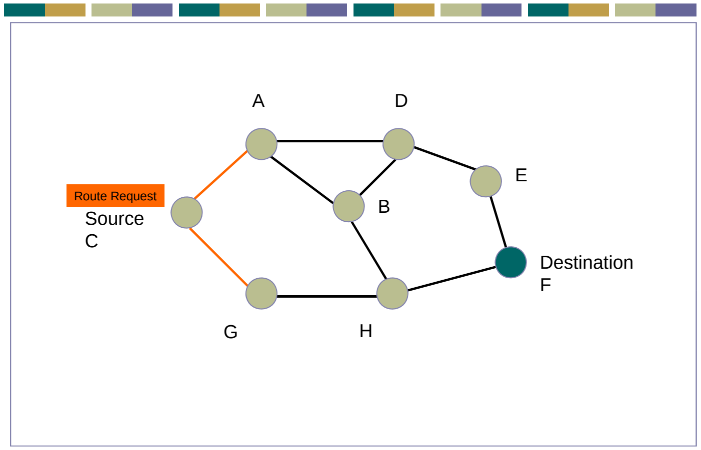
DSR Components

- Route discovery
  - The mechanism by which a sending node obtains a route to destination
- Route maintenance
  - The mechanism by which a sending node detects that the network topology has changed and its route to destination is no longer valid

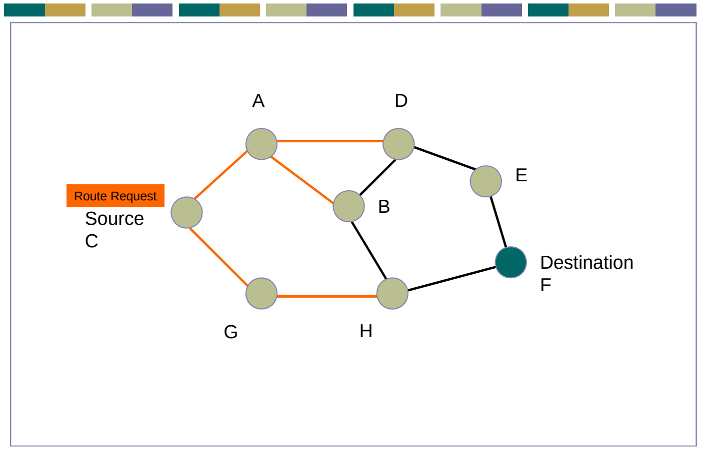
DSR Route Discovery

- Route discovery - basic idea
  - **Source** broadcasts route-request to **Destination**
  - Each node forwards request by adding own address and re-broadcasting
  - Requests propagate outward until:
    - Target is found, or
    - A node that has a route to Destination is found

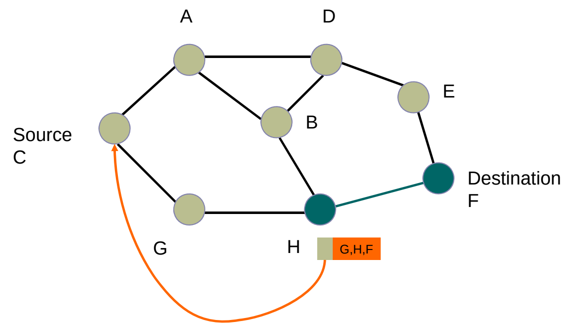
C Broadcasts Route Request to F



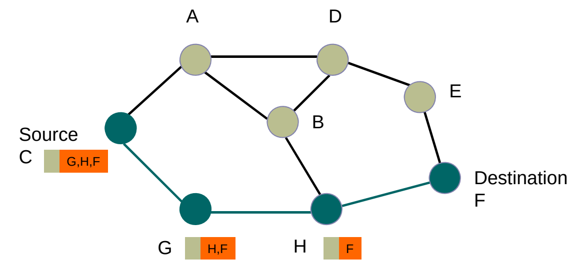
C Broadcasts Route Request to F



H Responds to Route Request



C Transmits a Packet to F



Forwarding Route Requests

- A request is forwarded if:
  - Node is not the destination
  - Node not already listed in recorded source route
  - Node has not seen request with same sequence number
  - IP TTL field may be used to limit scope
- Destination copies route into a Route-reply packet and sends it back to **Source**

Route Cache

- All source routes learned by a node are kept in Route Cache
  - Reduces cost of route discovery
- If intermediate node receives RR for destination and has entry for destination in route cache, it responds to RR and does not propagate RR further
- Nodes overhearing RR/RP may insert routes in cache

Sending Data

- Check cache for route to destination
- If route exists then
  - If reachable in one hop
    - Send packet
  - Else insert routing header to destination and send
- If route does not exist, buffer packet and initiate route discovery

Discussion

- Source routing is good for on demand routes instead of a priori distribution
- Route discovery protocol used to obtain routes on demand
  - Caching used to minimize use of discovery
- Periodic messages avoided
- But need to buffer packets

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ETX measurement results

- Delivery *is* probabilistic
  - A 1/r^2 model wouldn't really predict this!
  - Sharp cutoff (by spec) of "good" vs "no" reception. Intermediate loss range band is just a few dB wide!
- Why?
  - Biggest factor: Multi-path interference
    - 802.11 receivers can suppress reflections < 250ns
    - Outdoor reflections delay often > 1 \mu sec
    - Delay offsets == symbol time look like valid symbols (large interferece)
    - Offsets != symbol time look like random noise
    - Small changes in delay == big changes in loss rate

Deciding Between Links

- Most early protocols: Hop Count
  - Link-layer retransmission can mask some loss
  - But: a 50% loss rate means your link is only 50% as fast!
- Threshold?
  - Can sacrifice connectivity. ☹
  - Isn't a 90% path better than an 80% path?
- Real life goal: Find highest throughput paths

Is there a better metric?

- Cut-off threshold
  - Disconnected network
- Product of link delivery ratio along path
  - Does not account for inter-hop interference
- Bottleneck link (highest-loss-ratio link)
  - Same as above
- End-to-end delay
  - Depends on interface queue lengths

ETX Metric Design Goals

- Find high throughput paths
- Account for lossy links
- Account for asymmetric links
- Account for inter-link interference
- Independent of network load (don't incorporate congestion)

Forwarding Packets is Expensive

- Throughput of 802.11b =~ 11Mbits/s
  - In reality, you can get about 5.
- What is throughput of a chain?
  - A → B → C ?
  - A → B → C → D ?
  - Assume minimum power for radios.
- Routing metric should take this into account! Affects throughput

ETX

- Measure each link's delivery probability with broadcast probes (& measure reverse)
- P(delivery) = (d_f * d_r) (ACK must be delivered too…)
- Link ETX = 1 / P(delivery)
- Route ETX = Σ link ETX
  - Assumes all hops interfere - not true, but seems to work okay so far

ETX: Sanity Checks

- ETX of perfect 1-hop path: 1
- ETX of 50% delivery 1-hop path: 2
- ETX of perfect 3-hop path: 3
- (So, e.g., a 50% loss path is better than a perfect 3-hop path! A threshold would probably fail here…)

Rate Adaptation

- What if links @ different rates?
- ETT – expected *transmission time*
  - ETX / Link rate
  - = 1 / (P(delivery) * Rate)
- What is best rate for link?
  - The one that maximizes ETT for the link!
  - SampleRate is a technique to adaptively figure this out.

Discussion

- Value of implementation & measurement
  - Simulators did not "do" multipath
    - Routing protocols dealt with the simulation environment just fine
    - Real world behaved differently and really broke a lot of the proposed protocols that worked so well in simulation!
- Rehash: Wireless differs from wired…
- Metrics: Optimize what matters; hop count often a very bad proxy in wireless
- What we didn't look at: routing protocol overhead
  - One cool area: Geographic routing