Mobility in the Internet
Part I

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Motivation: the changing wireless environment

- Explosion in wireless services
  - Some connectivity everywhere
  - Overlapping, heterogeneous networks
- Small, portable devices
- A choice of network connectivity on one device
  - Sometimes built-in
  - Sometimes a portable “bridge” between choices

Opportunity for connectivity

- New environment gives us opportunity
  - Continuous connectivity for a mobile host
  - Seamless movement between networks
- Examples
  - Move from office to elsewhere in building
  - Move outside building, across campus, to cafe
- Why maintain connectivity?
  - Avoid restarting applications/networks
  - Avoid losing “distributed state”

Different approaches

- The traditional approach: support in the network
  - Intelligence (and expense) is in the network
  - End-points are cheap (handsets)
  - Allows for supporting infrastructure
  - Requires agreements/trust amongst multiple vendors
  - Examples:
    - A link/physical level (many wireless networks)
    - At routing level (Columbia, VIP)
  - Doesn't work when switching between technologies and often not between vendors
  - In Internet would require modifying lots of routers

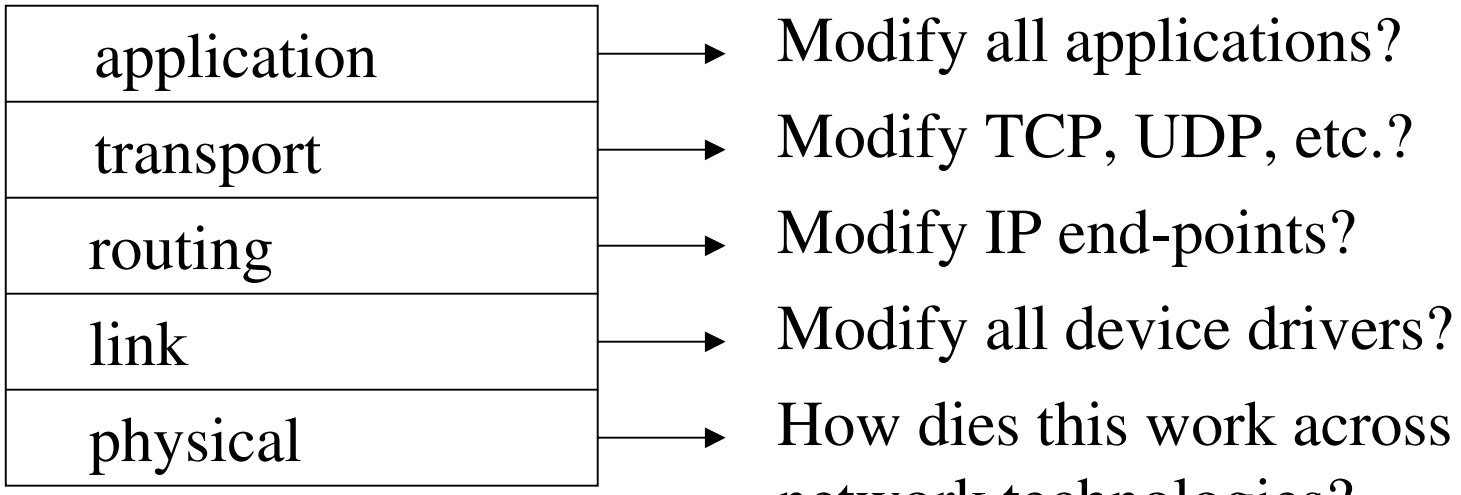
Different approaches, continued

- The Internet approach: end-to-end
  - Intelligence (and expense) is in the end-points
  - Network is cheap (relatively) and as fast as possible
  - Implies self-support for many activities
  - Less work/trust required amongst multiple vendors
- End-to-end support at transport/naming/application levels
  - May be ideal in future, but requires extensive changes
  - Not currently backwards compatible
  - TRIAD may be interesting approach

Different approaches, continued

- Use end-to-end support at routing level
  - Makes problem transparent at layers above and below
  - Current Internet standard: Mobile IP (RFC 2002)

TCP/IP network stack:



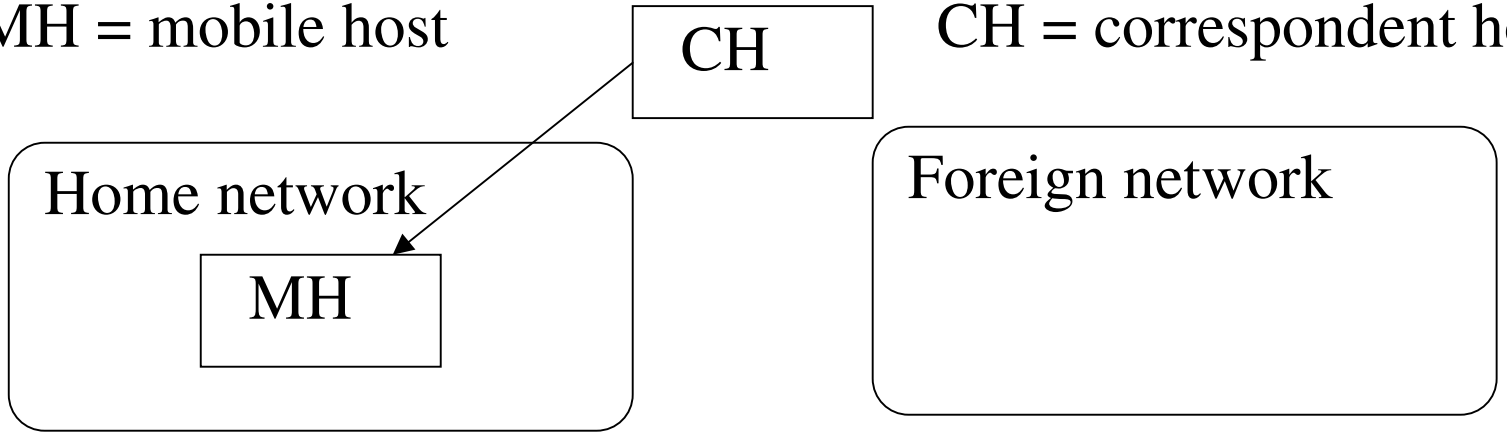
IP address problem

- Internet hosts/interfaces are identified by IP address
  - Domain name service translates host name to IP address
  - IP address identifies host/interface and locates its network
  - Mixes naming and location
- Moving to another network requires different network address
  - But this would change the host's identity
  - How can we still reach that host?

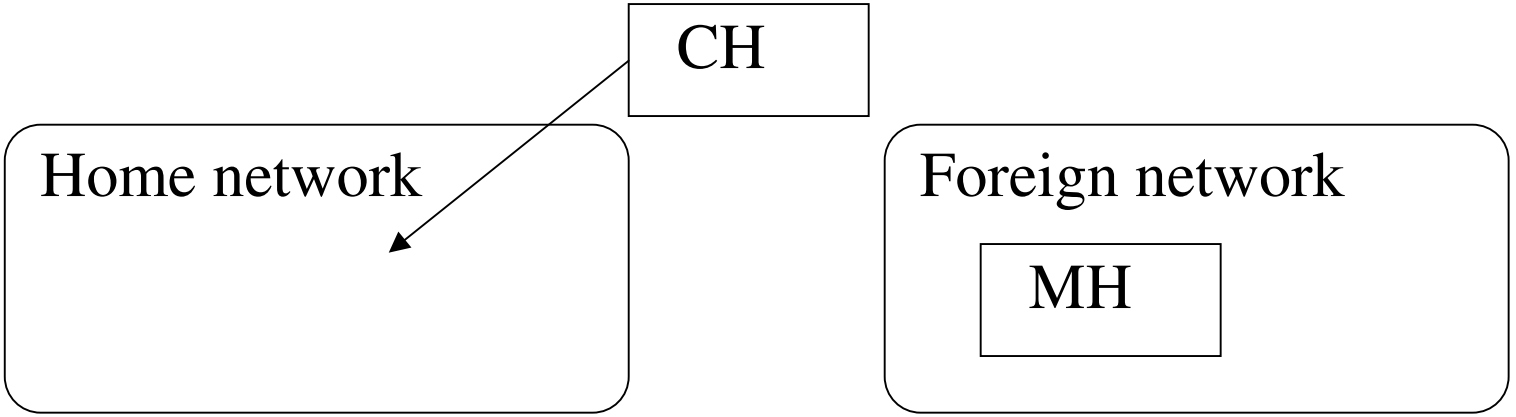
Routing for mobile hosts

MH = mobile host

CH = correspondent host

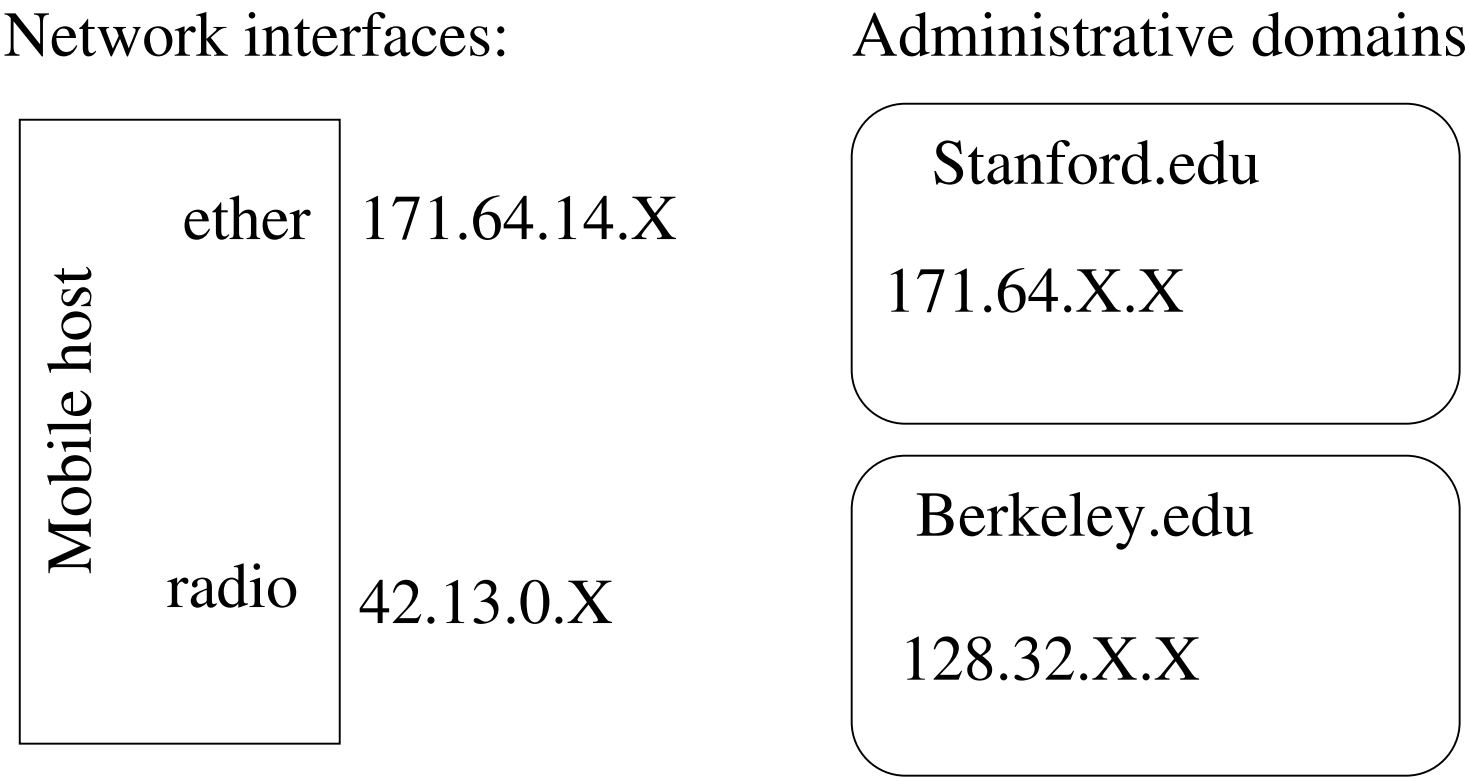


How to direct packets to moving hosts transparently?



Domains versus interfaces

- Switching domains & switching interfaces are the same problem at the routing level



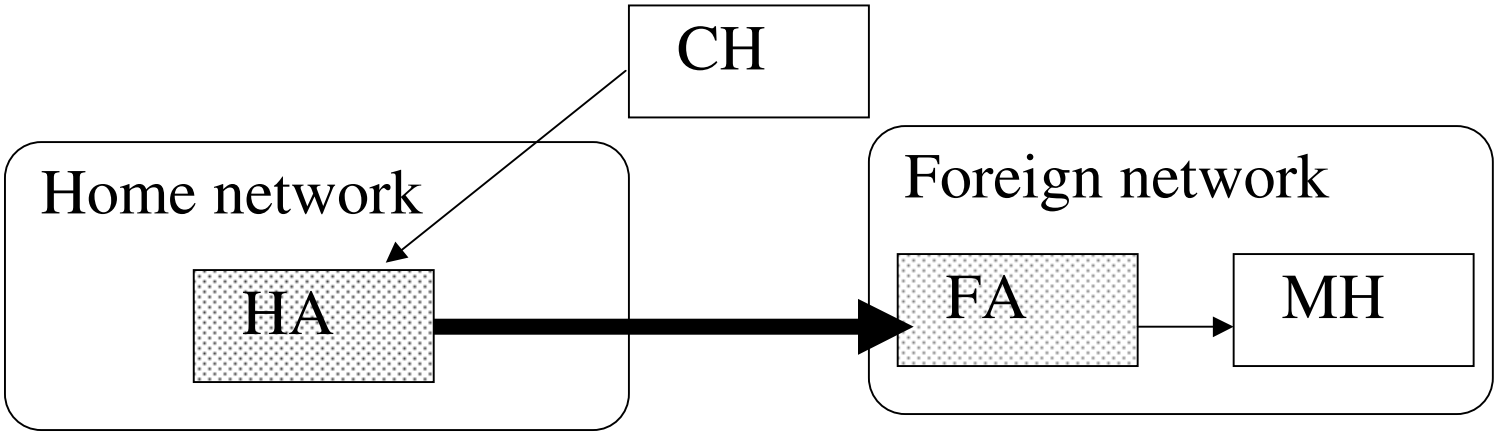
Mobile IP (RFC 2002)

- Leaves Internet routing fabric unchanged
- Does not assume “base stations” exist everywhere
- Simple
- Correspondent hosts don’t need to know about mobility
- Works both for changing domains and network interfaces

Basic Mobile IP – *to* mobile hosts

MH = mobile host
CH = correspondent host
HA = home agent
FA = foreign agent

(We'll see later that FA is not necessary or even desirable)



- MH registers new "care-of address" (FA) with HA
- HA tunnels packets to FA
- FA decapsulates packets and delivers them to MH

Packet addressing

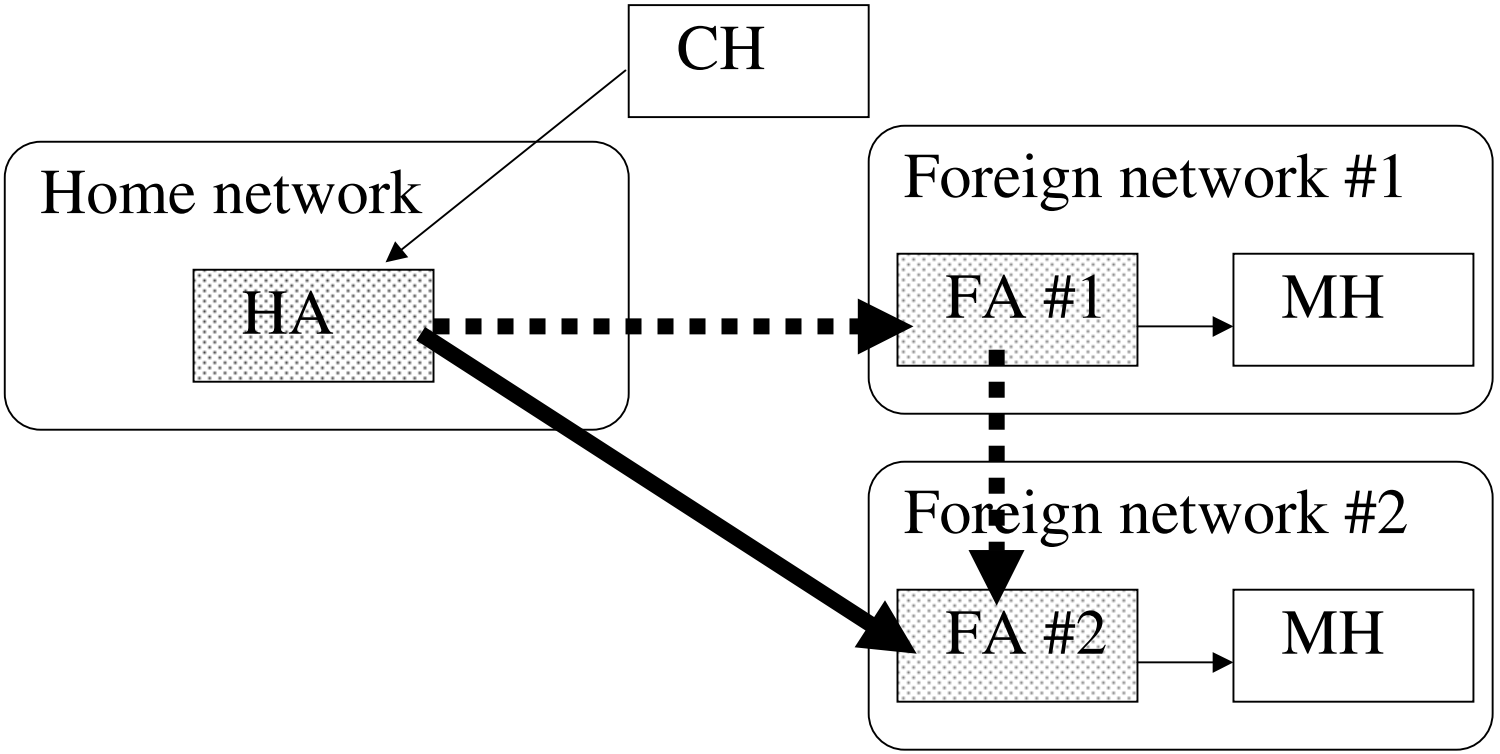
Packet from CH to MH

Source address = address of CH
Destination address = home IP address of MH
Payload

Home agent intercepts above packet and tunnels it

Source address = address of HA
Destination address = care-of address of MH
Source address = address of CH
Destination address = home IP address of MH
Original payload

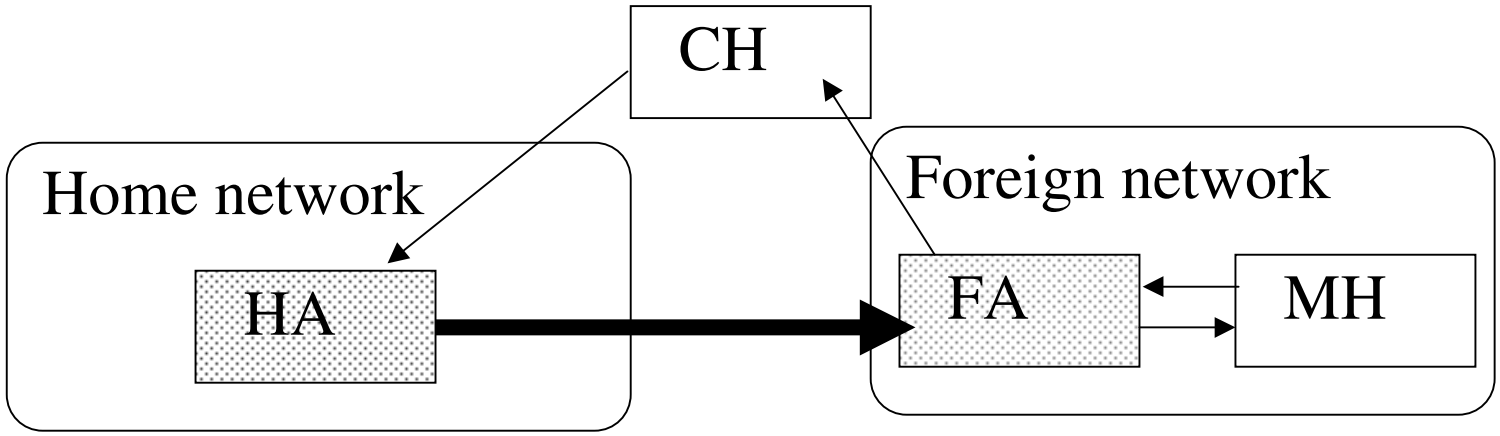
When mobile host moves again



- MH registers new address (FA #2) with HA & FA #1
- HA tunnels packets to FA #2, which delivers them to MH
- Packets in flight can be forwarded from FA #1 to FA #2

Basic Mobile IP - *from* mobile hosts

Mobile hosts also send packets



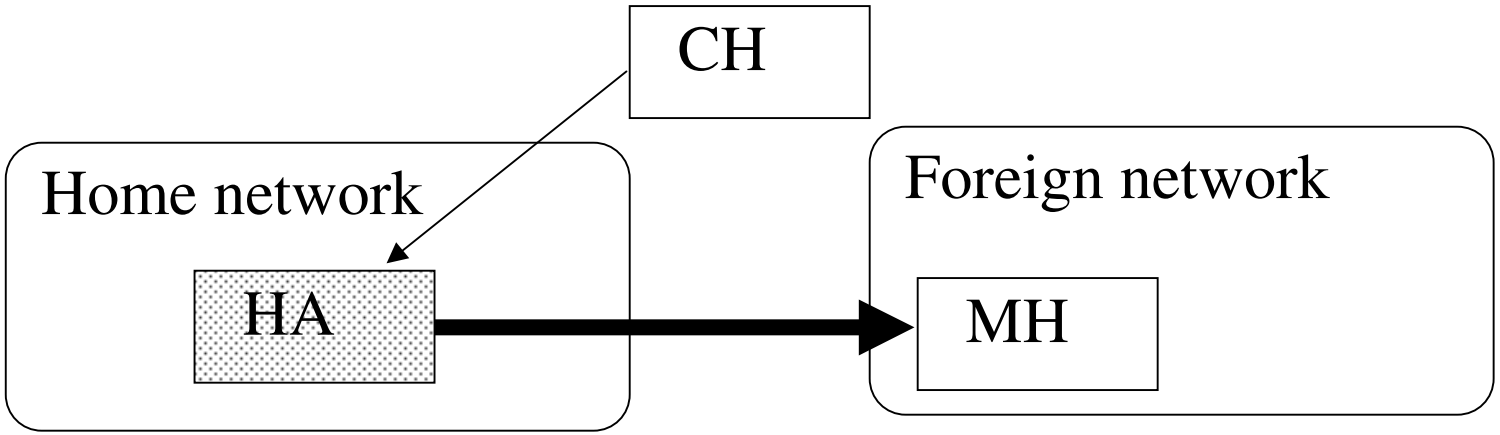
- Mobile host uses its home IP address as source address
  - -Lower latency
  - -Still transparent to correspondent host
  - -No obvious need to encapsulate packet to CH
- This is called a “triangle route”

Problems with Foreign Agents

- Assumption of support from foreign networks
  - A foreign agent exists in all networks you visit?
  - The foreign agent is robust and up and running?
  - The foreign agent is trustworthy?
- Correctness in security-conscious networks
  - We'll see that "triangle route" has problems
  - MH under its own control can eliminate this problem
- Other undesirable features
  - Some performance improvements are harder with FAs
- We want end-to-end solution that allows flexibility

Solution

- Mobile host is responsible for itself
  - -(With help from infrastructure in its home network)
  - -Mobile host decapsulates packets
  - -Mobile host sends its own packets
  - -"Co-located" FA on MH



⇒MH must acquire its own IP address in foreign network

This address is its new "care-of" address

Mobile IP spec allows for this option

Obtaining a foreign IP address

- Can we expect to obtain an IP address?
  - DHCP becoming more common
  - Dynamic IP address binding like some dial-up services
  - Your friend can reserve an IP address for you
  - Various other tricks
  - More support for dynamic IP address binding in IPv6
- This assumes less than getting others to run a FA
- For more information about provisioning networks for visitors, we'll look at SPINACH later

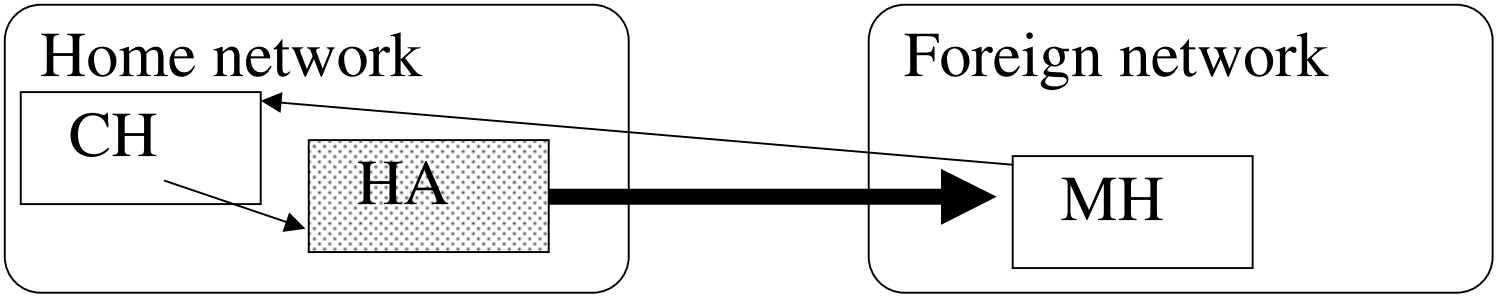
Design implications

- New issues: the mobile host now has two roles:
  - Home role
  - Local role

- More complex mobile host
- Loss of in-flight packets? (This can happen anyway.)

+ Can visit networks without a foreign agent
+ Can join local multicast groups, etc.
+ More control over packet routing = more flexibility

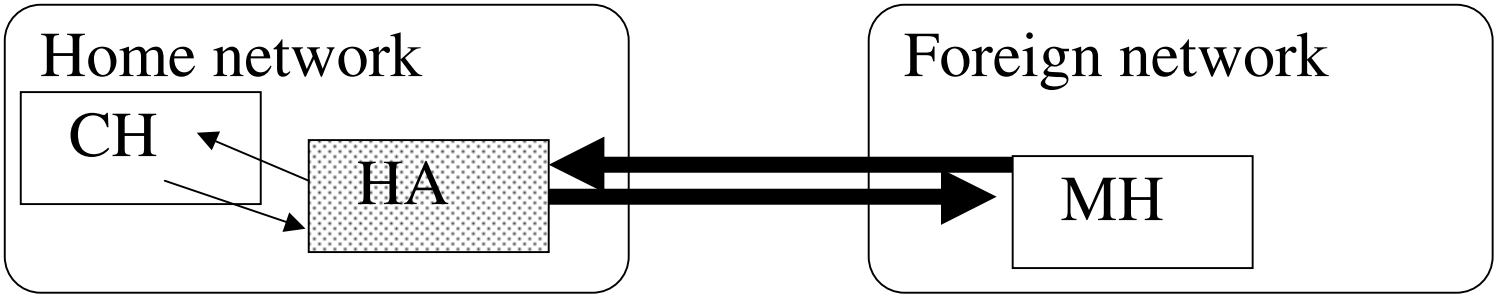
Problems with ingress filtering



- Mobile host uses its home IP address as source address
- Security-conscious boundary routers will drop this packet

Solution: bi-directional tunnel

•Provide choice of “safe” route through home agent both ways



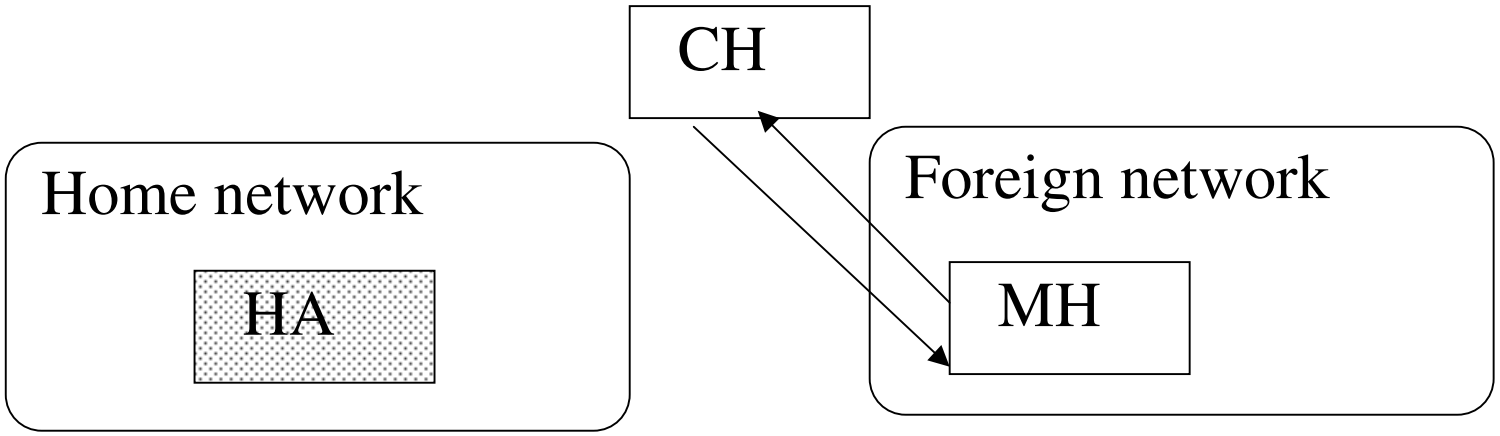
•This is the slowest but most conservative option

At the other extreme…

Problem: performance

- Example: short-lived communication
  - When accessing a web server, why pay for mobility?
  - Do without location-transparency
  - Unlikely to move during transfer; can reload page
  - Works when CH keeps no state about MH

Solution: yet more flexibility



- Use current care-of address and send packet directly
  - This is regular IP!

- More generally:
  - MH should have flexibility to adapt to circumstances
  - A range of options: from slow-but-safe to regular IP
  - Should be an end-to-end packet delivery decision (no FA)

Routing options

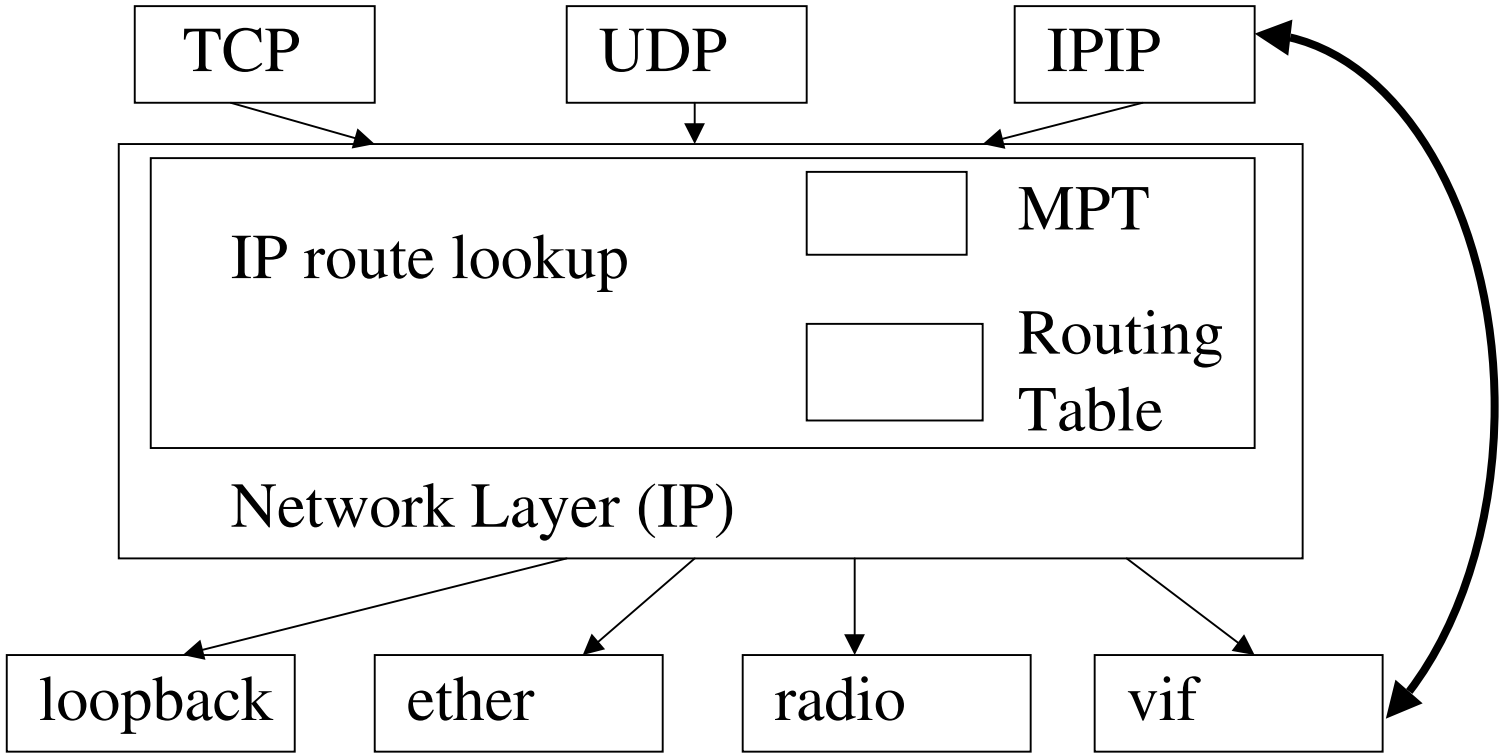
- Allow MH to choose from among all routing options
- Options:
  - Encapsulate packet or not?
  - Use home address or care-of address as source address?
  - Tunnel packet through home agent or send directly?
- Choice determined by:
  - Performance
  - Desire for transparent mobility
  - Mobile-awareness of correspondent host
  - Security concerns of networks traversed
- Equivalent choices for CH sending packets to MH

Mobility 4x4

	Outgoing Indirect, Encapsulated	Outgoing Direct, Encapsulated	Outgoing Direct, Home Address	Outgoing Direct, Temp. Address
Incoming Indirect, Encapsulated	Most reliable, least efficient	Requires decapsulation on CH	No security-conscious routers on path	
Incoming Direct, Encapsulated		Requires fully mobile-aware CH	No security-conscious routers on path	
Incoming Direct, Home Address			Requires both hosts to be on same net. seg.	
Incoming Direct, Temp. Address				Most efficient, no mobility support

Implementation

- Virtual interface (vif): illusion of MH still on home network
- We hijack the route table lookup
- Consult Mobile Policy Table in conjunction with route table



Implementation, continued

- Traffic back to home net handles boundary routers
- All web traffic uses regular IP
- Other traffic uses regular “triangle route”
- Handles multicast addresses too (bi-directional or regular IP)

Destination	Netmask	Port Number	Transparent Mobility?	Bi-directional tunneling?
a.b.0.0	255.255.0.0	0	Yes	Yes
0.0.0.0	0.0.0.0	80	No	N/A
0.0.0.0	0.0.0.0	0	Yes	No

Figuring out which to use

- With bidirectional tunneling
  - Probe destination using triangle route
  - If it works, switch to that option
- With triangle route
  - If packets aren't getting through after some number of tries

Is it fast enough to be seamless?

		Interval between packets	Packet loss (common case)	Packet loss (worst case)	Time in transition
Cold switch	Ether => ether	10 ms	0	1	< 10 ms
	Ether => radio	250 ms	1	4	< 1.25 s
	Radio => ether				
Hot switch	Ether => radio	250 ms	0	1	< 0.5 s
	Radio => ether				

Mobile IP issues on local network

- Host visiting local network with foreign agent
  - No real presence on local network
- Host visiting local network with its own IP address
  - Has a role on local network
  - Reverse name lookups through special name?
  - Or do you change the DNS entry?
  - Its IP address / HW address gets into local hosts' ARP caches
  - Which IP address should go into cache?
  - How do you update caches if host moves again?

Local ARP cache problem

- ARP caches store (IP address, HW address) pairs
- MH host visits foreign network
- Wants to talk directly back and forth to local hosts
  - If it wants to maintain connectivity with them after moving
    - Use home IP address
    - Other hosts address MH by HW address on local link
    - But if MH moves again, ARP cache entries are wrong
  - If it doesn't care
    - Use local IP address
    - If MH moves, ARP cache is wrong, but nobody cares

Multiple Network Interfaces – Why?

- Want to probe hosts through all active interfaces
  - Example: register with HA through new interface before switching to it
  - Helps with smooth handoff between types of networks
- Want transparent mobility for more than one interface
- Example:
  - One application users cheap/slow interface while another uses expensive/fast interface
  - Move to new network(s) or lose contact with one network
  - Don’t want to restart either application

Why is this hard?

- System support missing in at least two areas
- Need “next hop” info for more than one interface
  - Need to be able to send packets beyond local subnet for more than one interface
  - Current support only uses gateway info for one interface
- Mobile IP doesn’t separate traffic flows to different interfaces
  - (This isn’t the Mobile IP “simultaneous binding” feature)
  - Current HA won’t keep different bindings for more than one interface per host based on traffic flow

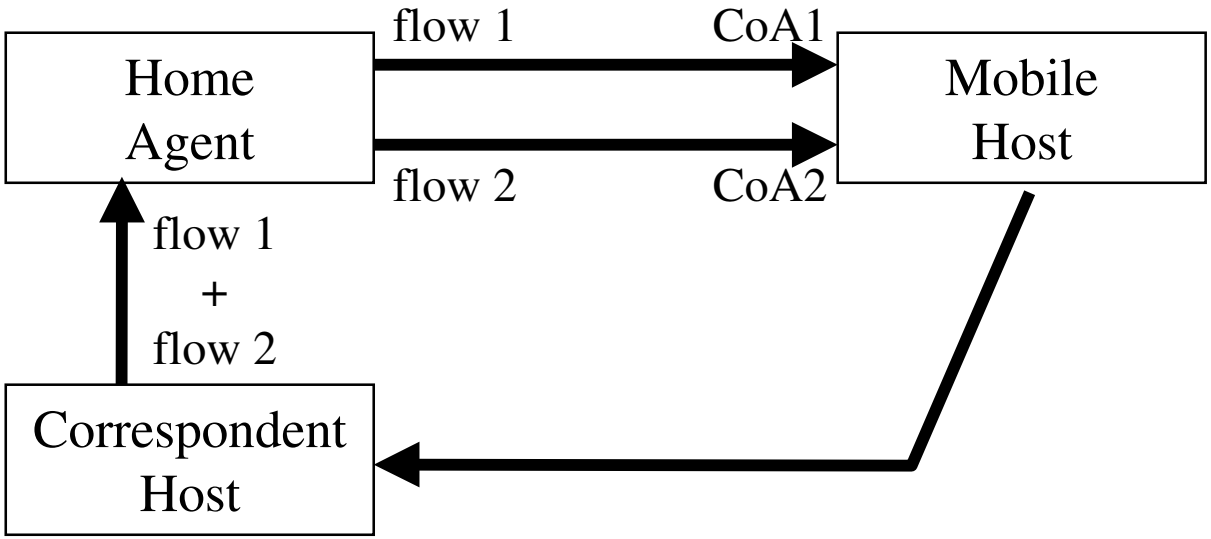
Solution for next hop

- Backwards-compatible extension to routing table
  - Add “next-hop” info for more than one interface
  - Take advantage of “metric” field for priority of interface
  - This maintains backwards compatible default route

Destination	Gateway	Netmask	Flags	Metric	Iface
a.b.0.0	0.0.0.0	255.255.0.0	U	0	eth0
c.d.0.0	0.0.0.0	255.255.0.0	U	0	st0
127.0.0.0	0.0.0.0	255.0.0.0	U	0	lo
0.0.0.0	a.b.0.1	0.0.0.0	UG	1	eth0
0.0.0.0	c.d.0.1	0.0.0.0	UG	100	st0

Solution for Mobile IP

- Extend home agent
- Mobile host registers flow-to-interface bindings



Performance overhead

- Flow binding demultiplexing cost

Flow Bindings	Demultiplexing Time (µs)	Cost (µs)	Per flow (µs)
0	2.1 (0.30 std. dev.)	N/A	N/A
1	2.3 (0.45 std. dev.)	0.2	0.20
2	2.7 (0.30 std. dev.)	0.6	0.30
10	3.9 (0.30 std. dev.)	1.8	0.18
20	4.7 (0.46 std. dev.)	2.6	0.13
30	5.3 (0.46 std. dev.)	3.2	0.11
40	6.7 (0.64 std. dev.)	4.6	0.12
60	9.2 (0.40 std. dev.)	7.1	0.12

Flexible connectivity management

- Need to manage this extra flexibility through adaptivity
  - Monitor availability of various interfaces
  - System detects & configures interfaces automatically
  - Applications can express interest in types of service
  - System (or application) can choose best interface
  - System feedback necessary: system notifies application of changes as conditions warrant

Connectivity management, continued

- Must address protocol interaction when connecting
  - Is DHCP available?
  - Is this a frequently visited network? (probe for gateways)
    - If so, can use pre-determined address
  - Must the host use a foreign agent here?
- If it's broken, how do we find what's wrong & fix it?
  - Cable loose?
  - Battery in radio dead?
  - Home agent dead?
- Strong need for "no-futz" computing on mobile hosts