Network Layer; Location Management; Mobile IP

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Recap: Wireless Link Layer

• The basic services of the link layer
  – link access
    • interference, hidden terminal
    • quality of service (and fairness) control
  – framing, link reliability, etc

• Guided by network layer
  – transmit to which neighbor at what quality
Network Layer Services

- Transport packets from source to dest
- Network layer protocol in *every* host, router

**Basic functions:**
- **Control plane**
  - compute routing from sources to destinations
- **Data plane: forwarding**
  - move packets from input interface to appropriate output interface(s)
Network Layer: API

• API (provided to upper layer)
  – `transmit(info, src, dest, ...)``;

• A key decision in network layer design is how to represent destinations?
  – we refer to how applications specify destinations as the addressing scheme
  – the supported addressing scheme(s) can have profound impacts on usability, flexibility, and scalability
Discussion: How to Specify a Destination?
Two Basic Approaches for Identifying Destinations

• Locators
  – encode locations on network topology

• Identifiers (ID)
  – independent of network topology
Addressing Scheme: Sensornet Example

• Destination: message to a sensor (e.g., who detected fire)
  – <ID = D>
  – <Lat=37.3169; Long=-121.8740>
  – <temperature = highest>
Addressing Scheme: Telephone

- Very first scheme: connection by operators to business
  – ID or locator?

- The telephone numbering scheme:
  – invented in 1888 by Almon Strowger, an undertaker:
    “No longer will my competitor steal all my business just because his wife is a BELL operator.”
Telephone Addressing Scheme

• E.164: Maximum 15 digits
• Hierarchical addressing scheme: country code + national destination code (optional) + subscriber number
  – e.g., +1-203-432-6400

• Why hierarchical addressing scheme?
  – 203-432 uniquely determines the switch upon which the telephone is attached to

• Issues of such a scheme?
Addressing Scheme: Internet

• How to specify the destination which is the color printer on the 4th floor of AKW

  – Internet domain name: lw4c.cs.yale.edu
  – Internet protocol (IP) address: 128.36.231.8
  – [building = AKW; floor=4; entity = printer; quality = color]
Addressing Scheme: IP

- **IP address**: 32-bit identifier for an *interface*
- An IP address is associated with an interface

```bash
%sbin/ifconfig -a
```
IP Addressing

• Hierarchical scheme:
  – network part (high order bits)
  – host part (low order bits)

• What’s a network? (from IP address perspective)
  – device interfaces with same network part of IP address
  – link layer can reach each other
Why Hierarchy?

- The hierarchy is important for the scalability of Internet routing
- The routing system handles only the number of networks
  - 275,280 networks on Jan. 3 2009;
  - 625 mil hosts in Jan. 2009)

Routing in IP/Telephone Networks

• Represent network as a graph
• Determine a path to each destination on the graph
  – Q: what does a node in the graph represent?
Key Problems

• Location management
  – due to user mobility (roaming), hierarchical routing (address aggregation) may cause user devices to be not attached to their networks/switches
    • need forwarding/location management

• Dynamic routing
  – due to node mobility/wireless connectivity, link connectivity/quality can be highly dynamic
    • need to design routing protocols that are effective in handling dynamic topologies

• Broadcast wireless
  – there can be interference among links and paths (need good link performance metrics or scheduling)
Next

• Location management in cellular networks
Routing in Cellular Networks

• Cellular networks face the location management problem:
  – a phone may be out of its home switch

• How GSM handles out-of-switch phones:
  – a global home location register (HLR) database for each carrier
  – each base transceiver station (BTS) has a visitor location register (VLR)
GSM

Network & Switching Subsystem and Operation Subsystem

Radio Subsystem

MS (mobile station)
BSC (base station controller)
BTS (base transceiver station)
MSC (mobile switching center)
GMSC (gateway MSC)
Two Primitives for Cellular Location Management

• Mobile station: reports to the network of the cell it is in
  – called *update*
  – uses the uplink channel

• Network: queries different cells to locate a mobile station
  – called *paging*
  – uses the downlink channel
Performance of the Two Primitives

- A city with 3M users
- During busy hour (11 am - noon)
- Assume each paging message is 100 bits

- Update only
  - update messages: 25.84 millions
  - Q: why so many update messages?

- Paging only
  - paging traffic: 1433 calls/sec
  - Q: how many bits?
Location Management Through Location Areas (LA)

- A hybrid of paging and update
- Used in the current cellular networks such as GSM
- Partitions the cells into location areas (LA)
  - e.g., around 10 cells in diameter in current systems
- Each cell (BTS) periodically announces its LA id
- If a mobile station arrives at a new location area, it updates the base station about its presence
- When locating a MS, the network pages the cells in an LA
How to Decide the LAs: A Simple Model

• Assume the cells are given
• Cell \( i \) has on average \( N_i \) users in it during one unit time; each user receives \( c \) calls per unit time
• There are \( N_{ij} \) users move from cell \( i \) to cell \( j \) in a unit of time
How to Decide the LAs: A Simple Scenario

• Separate LAs for cells 1 and 2
  – update cost: $N_{12} + N_{21}$
  – paging cost: $c (N_1 + N_2)$

• Merge cells 1 and 2 into a single LA
  – update cost: 0
  – paging cost: $2c (N_1 + N_2)$

• When to merge and when to separate?
Discussions

• The LA design should consider
  – call pattern: when (how often) does a mobile station receive a call?
  – mobility model: how does a mobile station move?

• Any problems with LA-based scheme?
Dynamic/Distributed Location Management Schemes

• In dynamic/distributed location management schemes, each user makes independent decision about when to update
Dynamic/Distributed Location Management Schemes

• Timer based
  • A MS sends an update after some given time T

• Movement based
  • A MS sends an update after it has visited N different cells

• Distance based
  • A MS sends an update after it has moved away for D distance (need ability to measure distance)

• Profile based
  • A MS predicts its mobility model and updates the network when necessary
Timer-based Location Management

• A MS sends an update after some given timer $T$
• The network pages the MS upon a call request at all cells which the MS can potentially arrive during $T$
  – cells reachable from last update cell, e.g., within distance $v_{\text{max}} \times T$, where $v_{\text{max}}$ is the maximum speed

• Question: how to determine $T$?
Timer-based Location Management

- Assume time between call arrivals is $T$.
- Cell radius is $d_{\text{cell}}$.
- Total bandwidth cost:

$$
T_{\text{call}} \frac{b_{\text{update}}}{T} \left( \frac{v_{\text{max}}}{d_{\text{cell}}} \right)^2 b_{\text{paging}}
$$

Take derivative and set it to 0 to derive the optimal value:

$$
T = \frac{3}{2} \frac{d_{\text{cell}}^2 T_{\text{call}}}{v_{\text{max}}^2} \frac{b_{\text{update}}}{b_{\text{paging}}}
$$
Summary: Location Management

- Two primitives of location management in cellular networks
  - update (a proactive approach)
  - paging (a reactive approach)
- The location area (LA) approach
  - a hybrid approach
- Distributed approaches
  - timer based
  - movement based
  - distance based
  - profile based
Mobile IP
Mobile IP: Architecture

- Assume the current Internet addressing and routing architecture
- Design extensions to handle out of network devices
Mobile IP: Terminology

- **Mobile Node (MN)**
  - the node under consideration

- **Home Agent (HA)**
  - a stationary network node (e.g., a router) at the home network

- **Foreign Agent (FA)**
  - a network node (e.g. a router) in the foreign network

- **Care-of Address (COA)**
  - the address in the foreign network

- **Correspondent Node (CN)**
  - communication partner
Illustration

HA

router

home network

(physical home network for the MN)

Internet

router

mobile node

FA foreign network

(CN end-system)

MN

router

(CN end-system)

(CN end-system)

(CN end-system)
Mobile IP Operations

- Basic idea of Mobile IP:
  - a MN acquires a COA in a foreign network from a foreign agent
  - registers to the home agent
  - all messages sent to its home address is forwarded by its home agent to its COA
Discovering the Agents and Care-of Address

- Mobile IP discovery process
  - (home or foreign) agent broadcasts advertisements at regular intervals
    - announce the network
    - list one or more available care-of addresses
  - mobile node takes a care-of address
  - mobile node can also send solicitation to start the process
Registering the Care-of Address

- Mobile node sends an update (called registration request) to its home agent with the care-of address information
- Home agent approves/disapproves the request
- Home agent adds the necessary information to its routing table
- Home agent sends a registration reply back to the mobile node
Registration Operations in Mobile IP

- MH = Mobile Host
- FA = Foreign Agent
- HA = Home Agent
Data Transfer from the Mobile Node

1. Sender sends to the IP address of the receiver as usual, FA works as default router.
Data Transfer to the Mobile Node

1. Sender sends to the IP address of MN, HA intercepts packet
2. HA tunnels packet to COA, here FA, by encapsulation
3. FA forwards the packet to the MN
Tunneling Operations in Mobile IP

Correspondent Node X

Diagram showing the flow of packets in Mobile IP, including Home agent, Foreign agent, and mobile mode.
Discussion

• Any problems of the Mobile IP approach?
Triangular Routing

- Triangular Routing
  - CN sends all packets via HA to MN
  - higher latency and network load

- “Solution”
  - CN learns the current location of MN
  - direct tunneling to this location
  - HA or MN informs a CN about the location of MN

- Problem of the solution?
Handoff

• Change of FA (COA)
  – packets on-the-fly during the change can be lost

• “Solution”
  – new FA informs old FA to avoid packet loss, old FA buffers and then forwards remaining packets to new FA
  – this information also enables the old FA to release resources for the MN
Summary: Mobile IP

• An out-of-network mobile node (MN) registers its current reachable address (COA) with its home agent

• Home agent forwards packets to the MN

• Several optimization techniques to improve efficiency and reduce packet losses during mobility