CPET 565/CPET 499
Mobile Computing Systems
Lecture on
Mobility Management

Based on the Text used in the course: Fundamentals of Mobile & Pervasive Computing, 2005, by Frank Adelstein, et. al, from McGraw-Hill

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Mobility Management

- Mobile IP
- Mobility Management
  - **Cellular network (base station)/Wireless network location (Access Point-AP) management related tasks and routing**
    - Location management
    - Handoff management
- Location Management Principles & techniques
  - **Location Registrars (databases)**
  - **Operations**
    - Search operation
    - Update operation
- Location Management Case Studies
- Summary

Mobile IP Protocol

- Introduction to Mobile IP, http://www.cisco.com/c/en/us/td/docs/ios/solutions_docs/mobile_ip/mobil_ip.html
  - Mobile IP is an open standard, defined by the Internet Engineering Task Force (IETF) RFC 2002, that allows users to keep the same IP address, stay connected, and maintain ongoing applications while roaming between IP networks. Mobile IP is scalable for the Internet because it is based on IP—any media that can support IP can support Mobile IP.

Mobile IP Protocol

- Allows location-independent routing of IP datagrams on the Internet
- Each mobile node is identified by its
  - Permanent IP address (home)
  - Home agents
- Away from home (foreign network)
  - Care-of IP address
  - Foreign agents
- IP tunnel
  - The home agent redirect data packet toward the remote address using care-of IP

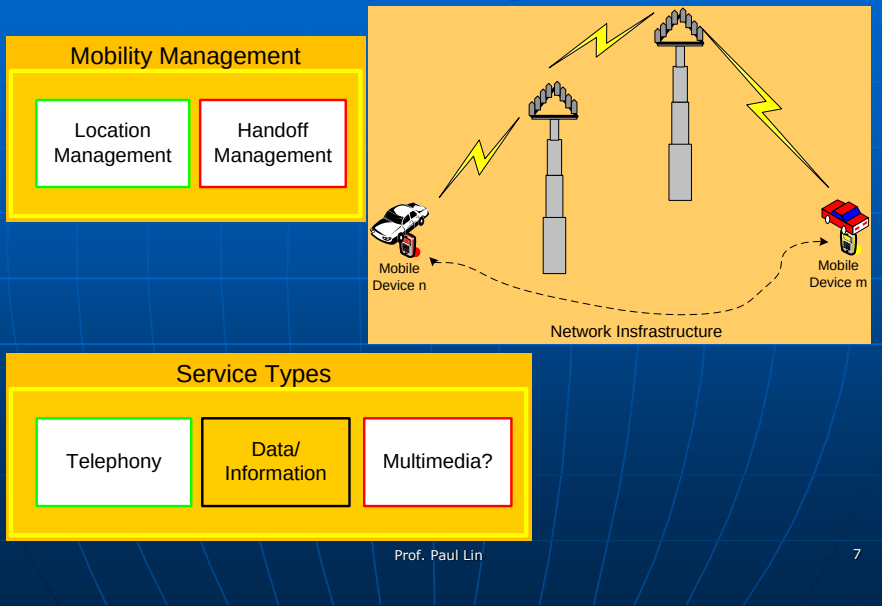
Mobile IP References

- Cisco
  - Introduction to Mobile IP (RFC 2002), Cisco, 2001, http://www.cisco.com/c/en/us/td/docs/ios/solutions_docs/mobile_ip/mobil_ip.html
  - Cisco Mobile Workforce Architecture Mobile IP Implementation Guide, http://www.cisco.com/en/US/solutions/collateral/ns170/ns896/guide_c07-677831.html
  - Mobile IP, Cisco, http://www.cisco.com/en/US/docs/ios/12_0t/12_0t1/feature/guide/MobileIP.html
- Oracle
  - How Mobile IP Works, Mobile IP Administration Guide, http://docs.oracle.com/cd/E19455-01/806-7600/6jgfbep13/

Mobile IP References

- Mobile IP, Charles E. Perkins, Sun Microsystems, http://www.cs.jhu.edu/~cs647/class-papers/Routing/mobile_ip.pdf
- IP Mobility Support for IPv4, RFC 3320, Jan. 2002, http://www.ietf.org/rfc/rfc3220.txt
- IP Routing for Wireless/Mobile Host Working Group, 2003, http://datatracker.ietf.org/wg/mobileip/charter/
- An Implementation of Mobile IP under Linux, 1997, http://www.hpl.hp.com/personal/Jean_Tourrilhes/MobileIP/index.html
- Mip4 Working Group Status Pages, Jan. 2004, http://www.mip4.org/2004/implementations/

Mobility Management

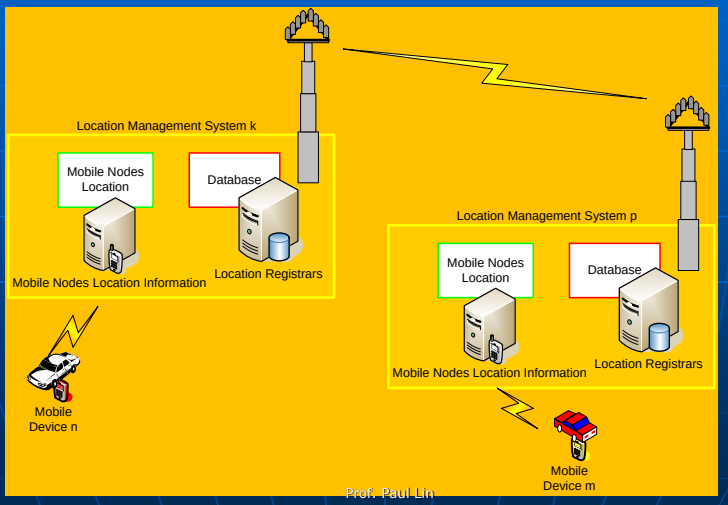


Mobility Management Tasks (cont.)

- **Mobile device m ↔ Mobile device n**
- **Task 1. Determine Device m's Location and Establish a Route**
  - Its access point (AP) in the wireless network
  - Base stations in cellular networks
- **Task 2. Handoff - when m device move out of the range of current AP, it established a connection with another AP**
- **Task 3. The connection/data packets are routed correctly to new AP**

Mobility Management Tasks (cont.)

- Task 1: Location Management System & Operations



Mobility Management Tasks (cont.)

- Task 1: Location Management System & Operations
  - **Location Registrars – databases**
  - **Two Operations**
    - Search
      - Mobile Node m – Invoke the search operation
      - Mobile Node n – Current Location Unknown
      - Cost of Search: Finest Granularity, Coarser Granularity
    - Update (Registration)
      - Mobile Node n – Informs the system of its current location
      - Frequency of update (never performed?, too frequent?)

Mobility Management Tasks (cont.)

- Task 1: Location Management System & Operations
- Cost of Search Operations
  - The granularity and currency of location information
    - **Finest granularity**
      - Maintained in a Cell
      - Requires a mobile node to update its location whenever it move from one cell to another
    - **Coarser granularity**
      - In an area consisting of certain number of contiguous cells
      - Search cost ↑, because a large number of cells need to be paged to obtain the exact location (cell) of the mobile node each time a call needs to be established

Mobility Management Tasks (cont.)

- Task 2 Handoff
  - Ensure the mobile node remains connected while moving from one cell to another
  - Or In-transit packets can be routed correctly
- Subtasks
  1. Deciding when to handoff to a new AP
  2. Selecting a new AP from several APs in the vicinity
  3. Acquiring resources: channels
  4. Informing Old AP to reroute data packets; and send state information

Mobility Management Tasks (cont.)

- Handoff Management Subtasks

1. Deciding when to handoff (switch) to a new AP

Handoff Decision can be initiated/controlled:

- Mobile-controlled Handoff
- Network-controlled Handoff

Decision Factors:

- Signal quality or quality of wireless communication (Signal-to-Noise ratio)
- The Load of current AP is high → Switch to a lightly loaded AP

Smooth Operation:

- Code Division Multiple Access – permit smooth handoffs
- Multiple base stations can be in communication before selecting a base station

Mobility Management Tasks (cont.)

- Handoff Management Subtasks

2. Selecting a new AP from several APs in the vicinity

Deciding Factors

- The SNR of the beacon signals from these APs
- The anticipated region, the mobile node is expected to move to
- The availability of resource at the AP:
  - Uplink & downlink channels of connection-oriented circuit-switched network
  - Address (such as IP) in a packet switched network

Mobility Management Tasks (cont.)

- Handoff Management Subtasks

3. Acquiring resources: channels
   - Channel Allocation Schemes

4. Informing old AP to reroute data packets; and send state information
   - Route several in-transit packets:
   - Connection-less traffic (UDP/IP data grams): the IP address of the new AP as the destination address
   - Connection-oriented traffic
     - TCP/IP on the Internet: Quad-tuple(source IP address, source port, destination IP address, destination port)
     - Asynchronous Transfer Mode (ATM)
     - Public Switched Telephone Networks (PSTN)

Mobility Management (cont.)

- Mobile Location Code
  - Mobile Country Code
  - Mobile Network Code
  - Local Area Code
  - Routing Area Code
  - Cell Identity
- Location Update Procedure
  - A mobile device inform a cellular network whenever it moves from one location area to another
  - Mobiles are responsible for detecting location area code

Mobility Management (cont.)

- Periodic Location Update
  - Each mobile is require to regularly report its location at a set time interval
- Radom Location Update
  - When a mobile moves from one location area to the next while not on a call
  - A stationary mobile that selects coverage from a cell in a different location area because of signal fading
- Roaming
  - A Mobility management procedure of all cellular networks

Mobility Management (cont.)

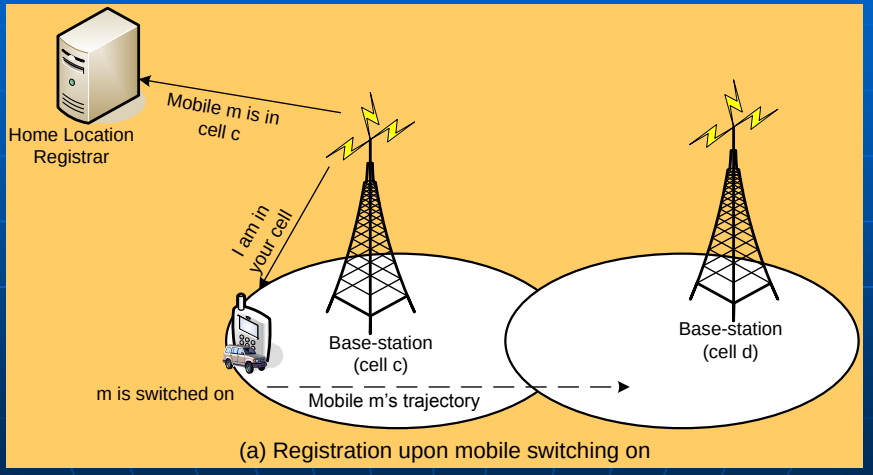
- TMSI (Temporary Mobile Subscriber Identity)
  - Given to the mobile, the moment it is switched on
  - Local to location area
  - Has to be updated, each time the mobile moves to a new geographical area
- IMSI (International Mobile Subscriber Identify)
  - A unique number associated with GSM and UMTS network mobile phone users
  - The number is stored in SIM (Subscriber Identity Module) card

Mobility Management (cont.)

- Location Management Principles & Techniques
  - Location Registrars (databases)
  - Location Area
    - A set of base stations (10s or even 100s)
    - Grouped for optimized signaling
  - Search Operation
  - Update operation
    - Static Update Schemes
    - Dynamic Update Schemes

Simple Location Management Scheme (cont.)

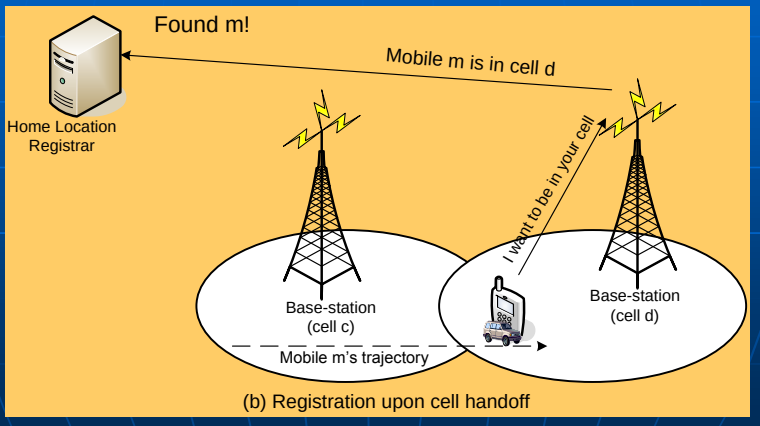
- Search and Update Operations (mobile node m is switched on) – Static Update



(a) Registration upon mobile switching on

Simple Location Management Scheme (cont.)

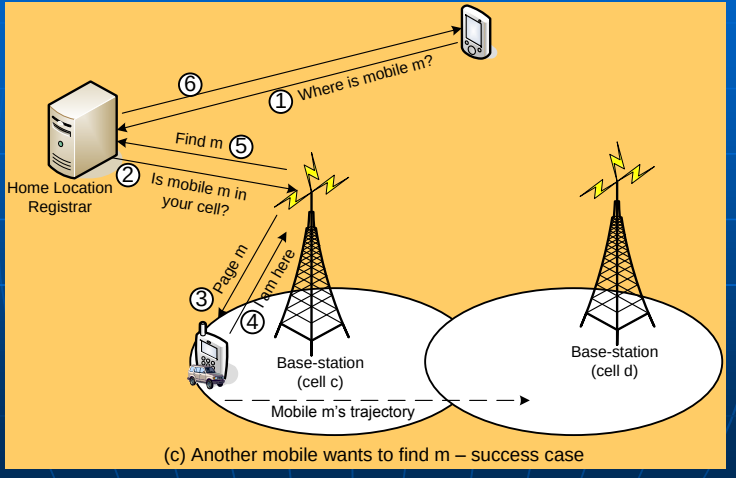
- Search and Update Operations (mobile node moves from cell c to cell d)



(b) Registration upon cell handoff

Simple Location Management Scheme (cont.)

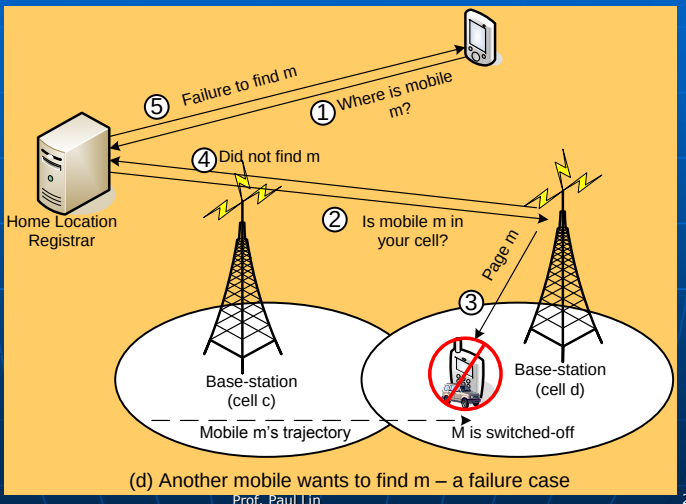
- Search and Update Operations (m in cell c & ON)



(c) Another mobile wants to find m – success case

Simple Location Management Scheme (cont.)

- Search and Update Operations (find m location; m is OFF)



(d) Another mobile wants to find m – a failure case

Mobility Binding of a Mobile Node

- How to reduce the probability of failure (1 – max, 0 – min)?
- Enhancement 1 – reduce search cost through the # of updates performed at HLR (Home Location Registrar - <mobile,cell> bindings) per mobile node
  - t_U – the time when the binding was last updated
  - ttL – the time to live (how long the binding is valid)
  - t_P – periodically update time < ttL

Mobility Binding of a Mobile Node (cont.)

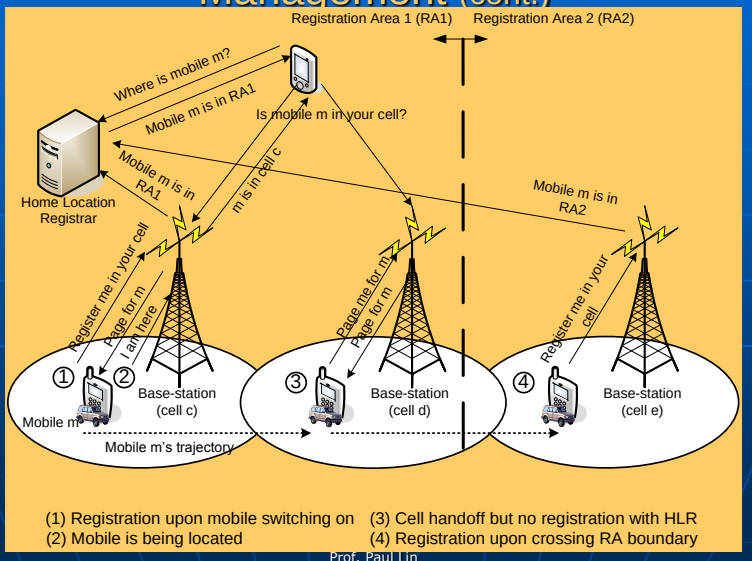
- How to reduce the probability of failure (1 – max, 0 – min)?
- Enhancement 2 – page neighbor cells
  - Increasing areas/cells for a maximum of k rings
  - If the speed of mobile node m is a maximum of v_m cells per second, then k (rings) can be set to

    $k = v_m \times t_p$, where t_p – periodical update time

Registration Area-based Location Management

- Used by Personal Communication Service – GSM (Global System for Mobile Communication)
- Service areas of PCs – the set of all cells (the union of coverage area of all the cells)
  - Partitioned into several Registration Areas (RAs) or Location Areas
  - Each RA consists of several contiguous communication cells

Registration Area-based Location Management (cont.)



Registration Area-based Location Management (cont.)

- Cell c & d – in RA1 (registration area 1)
- Cell e – in RA2
- Node m moves from cell c to d
  - Average update cost is reduced, because the HLR is not informed when handoff involves cells belonging to same RAs
  - Search cost is increased, because all the cells in the RA have to be contacted for the exact location of the mobile node

Registration Area-based Location Management (cont.)

- 2-Level Hierarchy of Location Registrars
  - Local Location Registrars
  - Remote Location Registrars
- Used in GSM to avoid contacting all the cells in the RA to locate a mobile node
  - One Location Registrar ↔ 1 RA
  - One Location Registrar ↔ several RAs (in practice)
  - N Registration Areas (RA1, RA2, …, RAn)
  - N Local Location Registrars (LR1, LR2, …, LRn)
  - LRi is the Local Location Registrars of RAi
  - All others location registrars as Remote Location Registrars

Location Management

- Home Location Registrars
- Visitor Location Registers
- Forwarding Pointers
- Per-user Caching

Actual Address vs. Forwarding Pointer

- Alice – a resident of New York
  - Temporary move to Texas, in & moves quite often (every week) – Texas: Dallas → El Paso → Austin → Houston
  - Maintaining a forwarding location pointer: reduce the burden of Local Updating cost for Alice
- Bob – a resident of Arizona
  - Wants to contact Alice
  - Increasing the Remote Search Cost
  - Contact NY Registrar first, then contact Texas Registrar
- Which Method is better?
  - Actual Address at Home Location Registrar
  - Forwarding Pointer (Location pointer)

Actual Address vs. Forwarding Pointer (cont.)

Alice:
If Never Change address in TX
***Maintain the Actual addr at Home LR: NY Is better!**

Bob:

→ NY LR

Figure 2.3 (1) Maintaining actual address at HLR (courtesy: http://www.infoplease.com/atlas/unitedstates.html)

Actual Address vs. Forwarding Pointer (cont.)

Alice moves often: Dallas, El Paso, Austin, Houston

*** Maintain a location pointer at NY**

Bob: contact Tx-LR for subsequent loc. info

Figure 2.3 (2) Maintaining forwarding pointer at Home Location Registrar (HLR)
(courtesy: http://www.infoplease.com/atlas/unitedstates.html)

A Chain of Forwarding Pointers

- Alice
  - Maintaining Forwarding Pointers of length 3
  - New York → Texas → Alaska → Alabama
- Bob
  - Trying to locate Alice
  - Start with New York registrar then follow the forwarding pointers
  - For 4 location registrars New York → Texas → Alaska → Alabama

A Chain of Forwarding Pointers (cont.)

Figure 2.4 Location management using a chain of forwarding pointer (courtesy: http://www.infoplease.com/atlas/unitedstates.html)

Static vs Dynamic Update Schemes

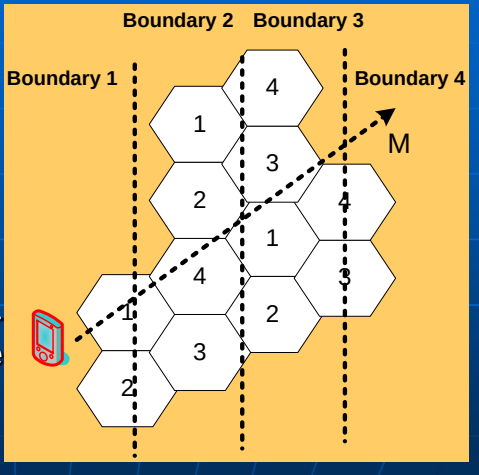
- Static Update Scheme
  - RA-based Location Update
  - Ignore dynamic behavior of mobile nodes
  - Boundaries of RAs are predetermined (static)
  - Cost: a lot of location update due to mobile nodes moving between two adjacent RAs in quick succession
- Dynamic Update Schemes
  - Time-based (periodic) Updates
  - Movement-based Updates
  - Distance-based Updates

Dynamic Update Schemes

- Time-based (periodic) Updates
  - Update Control Timer
  - The simplest method to implement

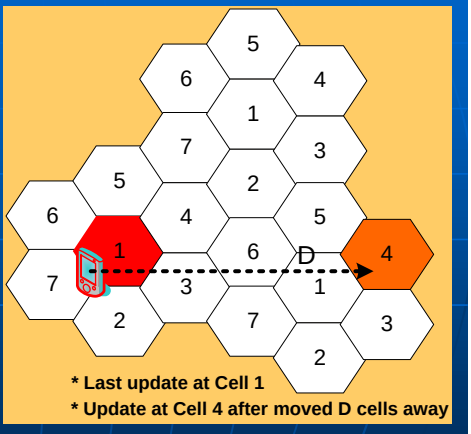
Dynamic Update Schemes

- Movement-based Updates
  - A mobile node update its location
  - When?
    - It crosses a certain number of cell boundaries M since it last registered
  - Mechanism
    - Counting the number of Handoffs since the last update
  - Suitable for stationary users



Dynamic Update Schemes

- Distance-based Updates
  - A mobile node updates its location
  - When?
    - It moves a certain number of cells D away from the last cell at which it last updated its location
  - Need to know the topology of cellular network
  - Difficult to implement
  - Suitable for mobile user who moves within a locality



Dynamic Update Schemes (cont.)

- Per-User Location Caching (on the mobile)
  - Used to avoid accessing a roaming mobile's location frequently
  - CMR (Call-to-Mobility Ratio) =
    (Avg rate at which a user received calls) / (Avg rate at which the user moves)
  - LCMR (Local CMR) =
    (Avg rate at which a user receives calls from a given Registration Area) / (Avg rate at which the user moves)
  - RCMR (Regional CMR) =
    Same definition as that of the LCMR

Replicating Location Information (cont.)

- Location info stored at one of the n Location Registrars
- Load balancing of Registrars
- Replicating info & methods
  - Redundancy – failed registrars (for example, hit by the storm)
  - How many replicas?
    - Full replication – increase the cost of updates
    - Partial replication – preferable
  - Methods of replication
    - Flat Organization
    - Hierarchical Organization

Replicating Location Information (cont.)

- Flat Organization
  - Given n Location Registrars
  - If a mobile node info can be stored at any LR, without any penalty in terms of access cost
  - An Example:
    - **n = 16 LRs**
    - **k Replication Factor = 4 (k ≤ n)**
    - **Update starts at the randomly selected LR6 → LR10 → LR14 → LR2**
    - **Search for the same mobile node starts at randomly selected location registrar, sequentially, LR12 → LR13 →LR14 (found it)**

Replicating Location Information (cont.)

- Flat Organization

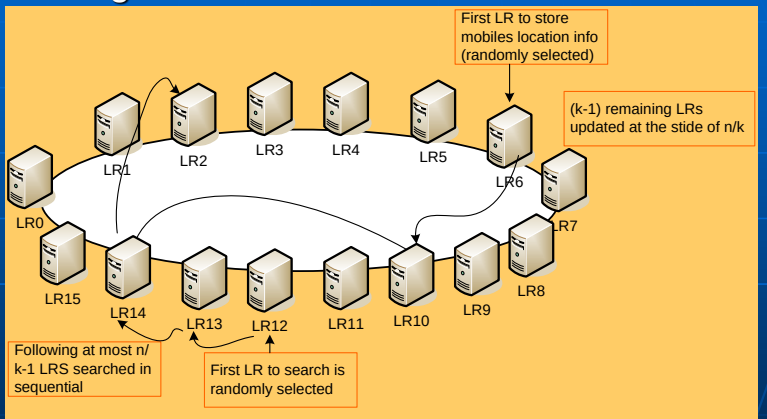


Figure 2.6 Search and update in a location management system with flat organization.

Replicating Location Information (cont.)

- Hierarchical Organization
  - Multi-level (tree) of LRs
  - Leaf LR: has info on all the mobile nodes in the RA(s) associated with it
  - Root LR: stores info on all the mobile nodes in the system
- An Example
  - 15 LRs: LR0 … LR15 formed a balanced tree
  - 8 RAs (RA0, RA1, …, RA7)
  - Caller – LR4
  - Callee – LR1 (before move), LR2 (after move)
  - Location Info maintained at LR1, LR6, LR12, and LR14

Replicating Location Information (cont.)

- Hierarchical Organization

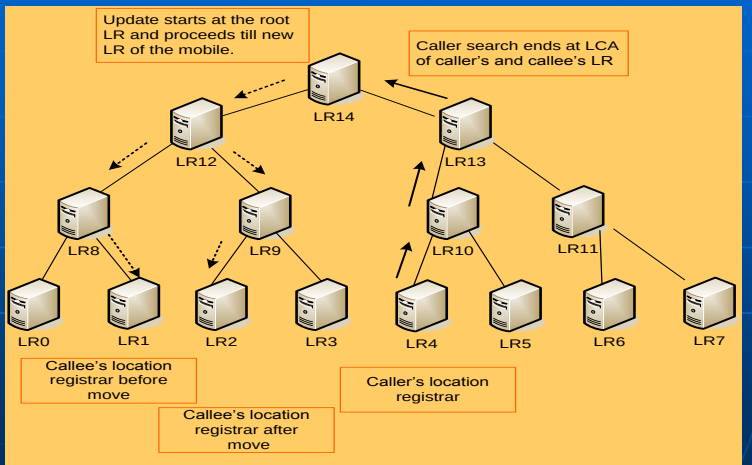


Figure 2.7 Update and search in a hierarchical (Tree) location management system.

Replicating Location Information (cont.)

- The Search Scenario (in Fig. 2.7)
  - Caller – LR4 in RA4
  - Callee mobile node – in RA1
  - Search operation
    - In the order: LR4, LR10, LR13, and LR14 (root)
    - Callee moves from RA1 to RA2
    - The Location info needs to be updated in: LR14, LR12;
    - Added to LR7 and LR2
    - Deleted from LR6 and LR1

Summary

Q&A?