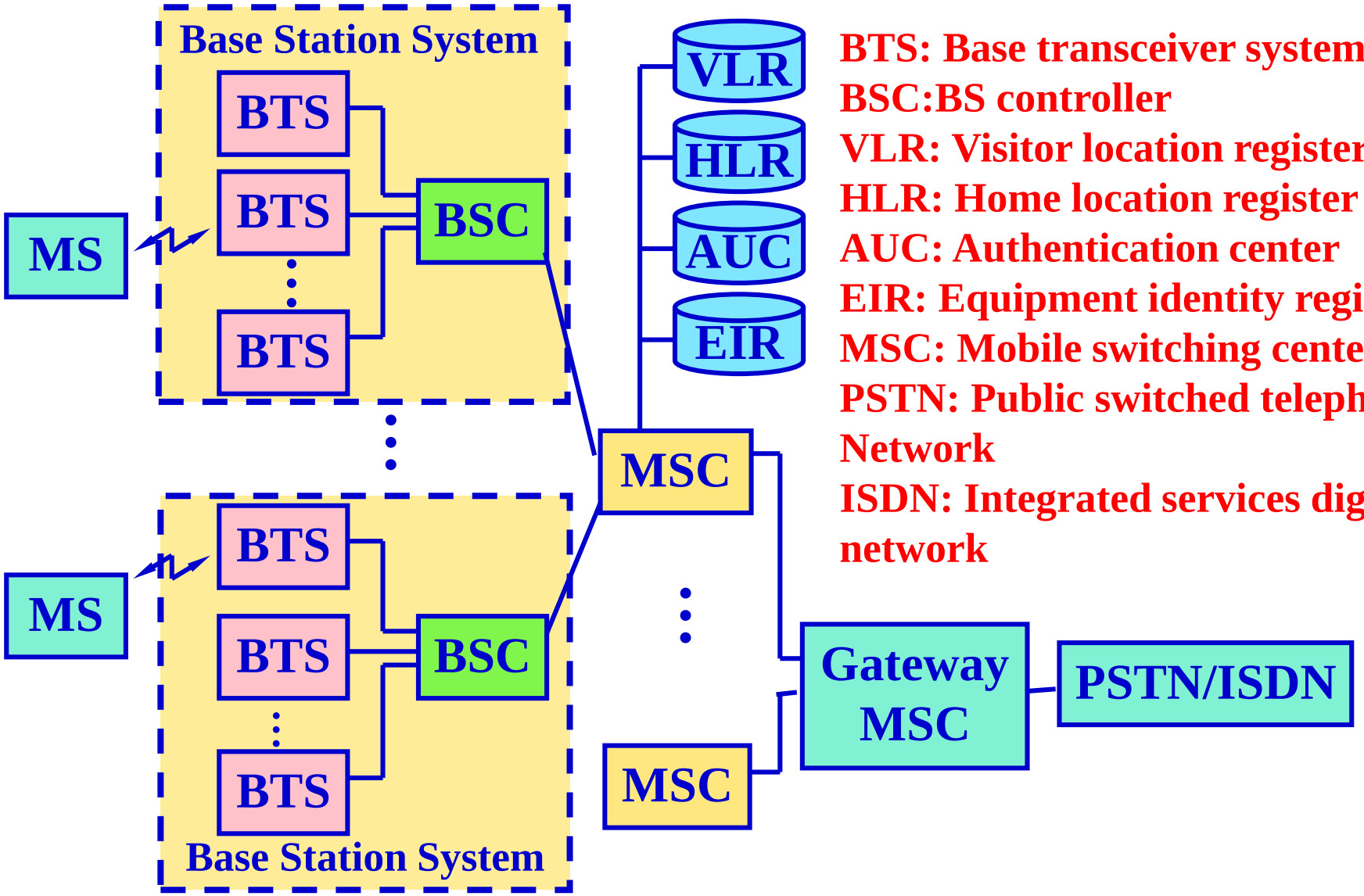
Chapter 9

Mobile Communication Systems

Outline

- Cellular System Infrastructure
- Registration
- Handoff Parameters and Underlying Support
- Roaming Support
- Ultra Wide Band
- Femto Cells

Cellular System Infrastructure

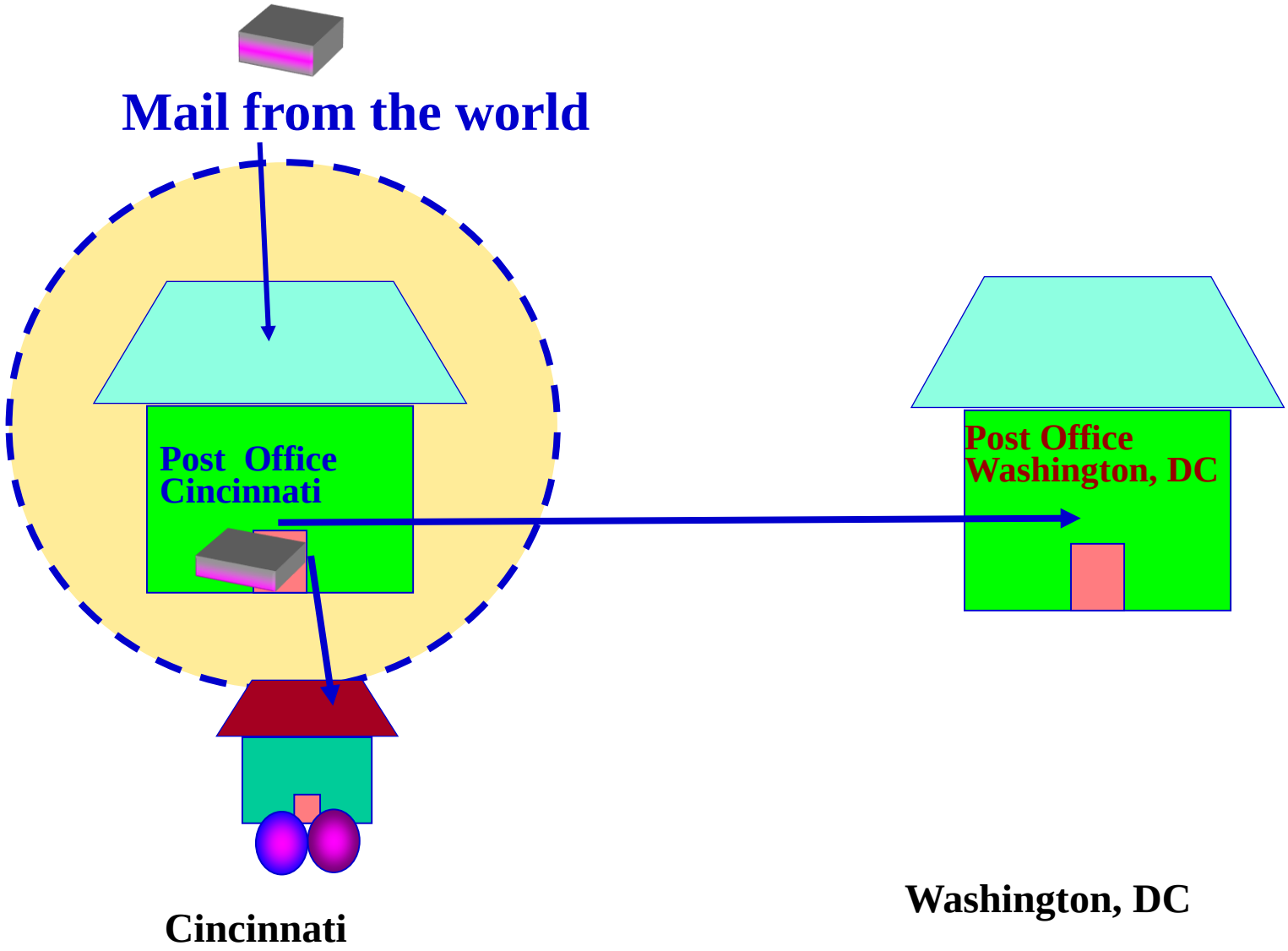


BTS: Base transceiver system
BSC:BS controller
VLR: Visitor location register
HLR: Home location register
AUC: Authentication center
EIR: Equipment identity register
MSC: Mobile switching center
PSTN: Public switched telephone Network
ISDN: Integrated services digital network

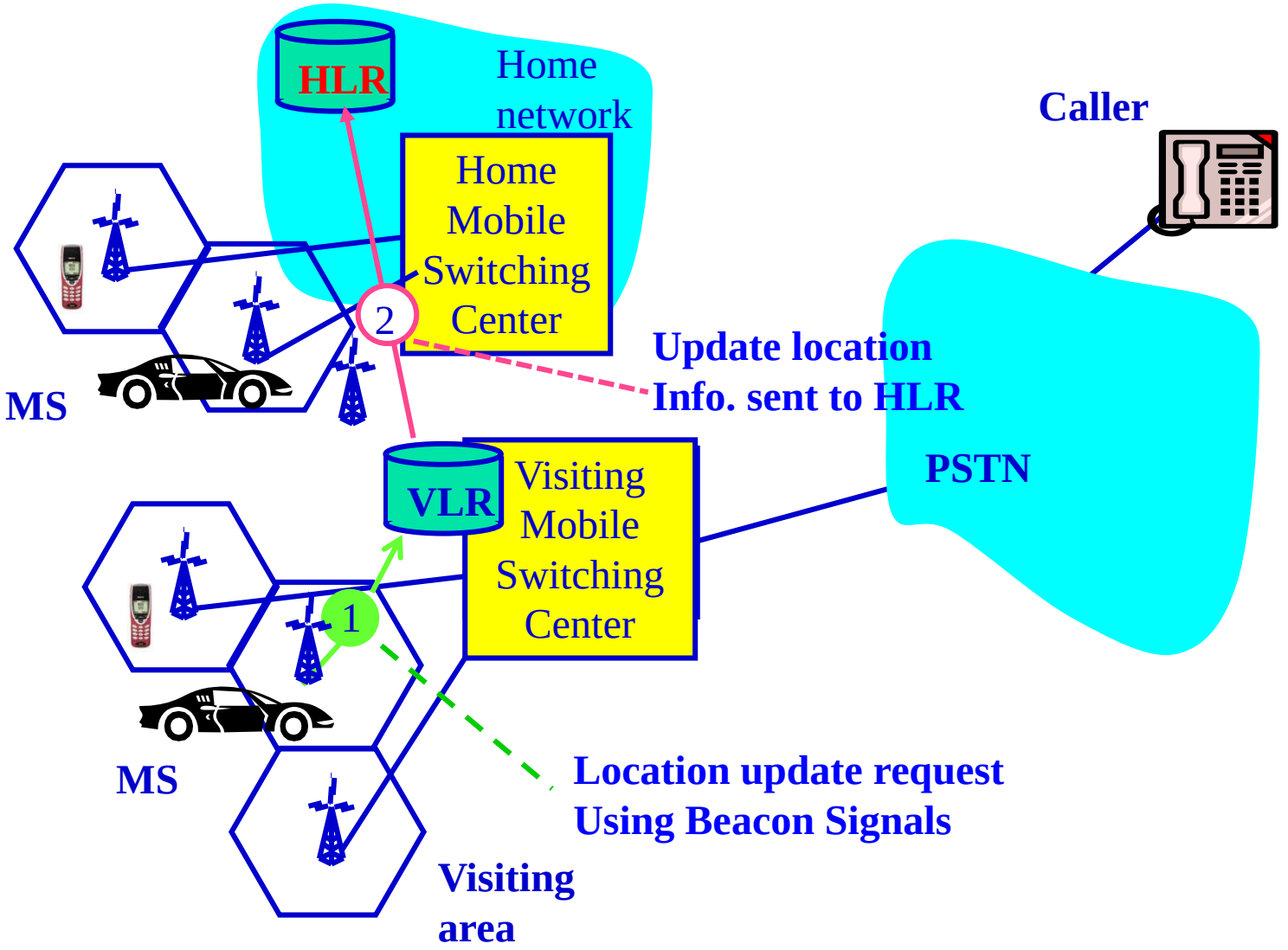
VLR/HLR/AUC/EIR

- VLR contains information about all visiting MSs in that particular area of MSC
- VLR has pointers to the HLR's of visiting MS
- VLR helps in billing and access permission to the visiting MS
- AUC provides authentication and encryption parameters
- EIR contains identity of equipment that prevents service to unauthorized MSs

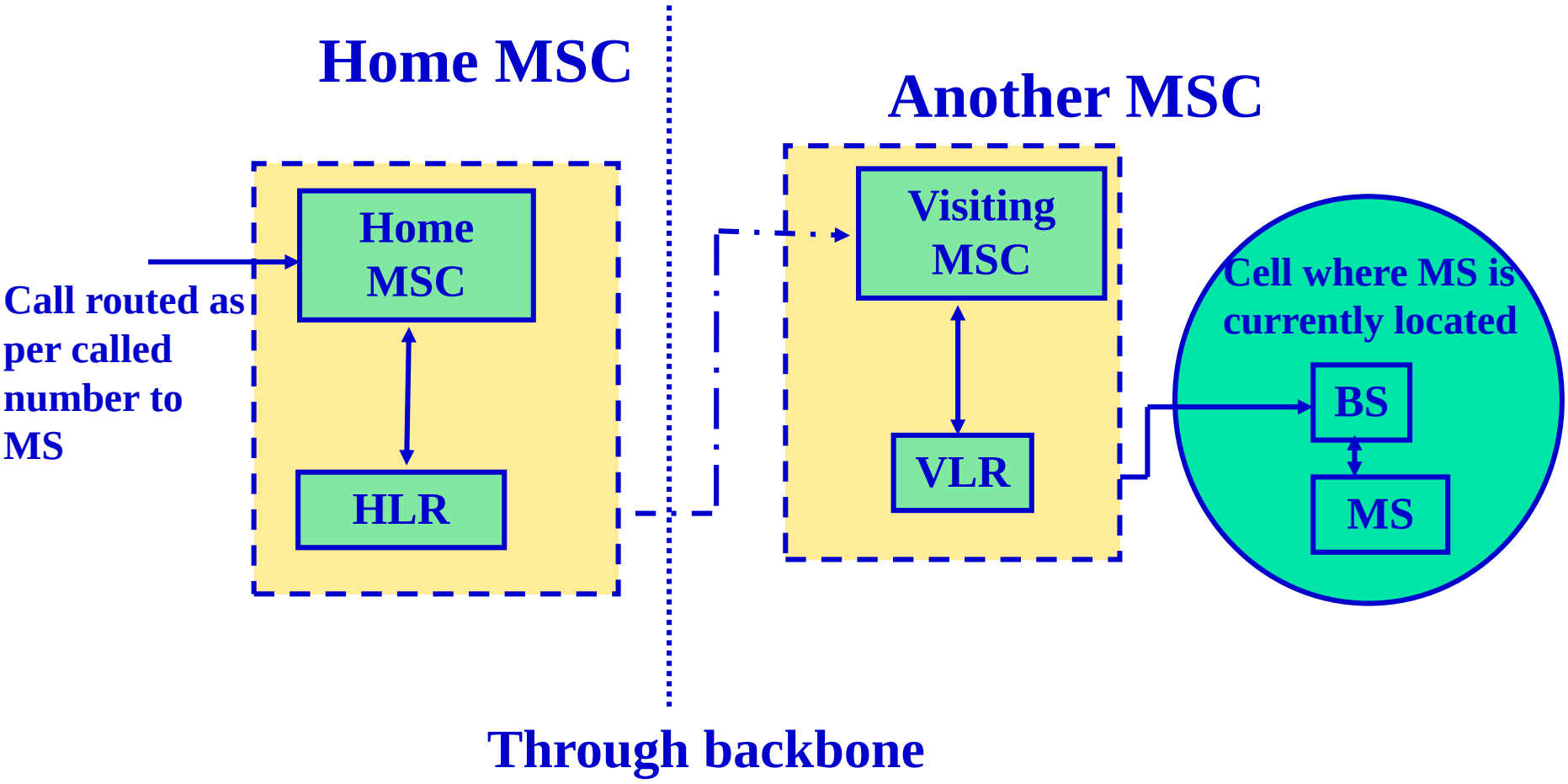
Classical Mail Forwarding Technique?



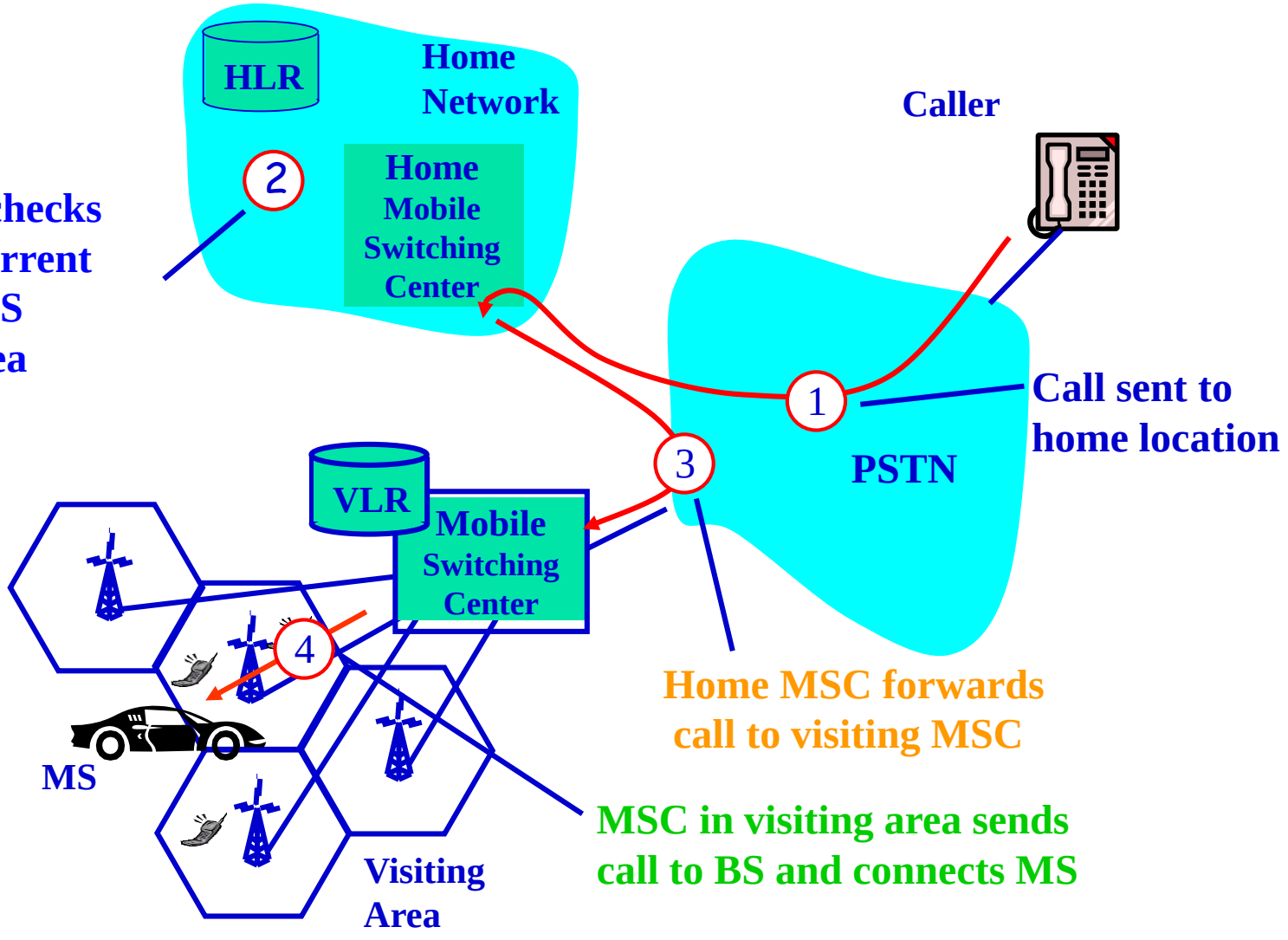
Automatic Location Update



Redirection of Call to MS at a Visiting Location



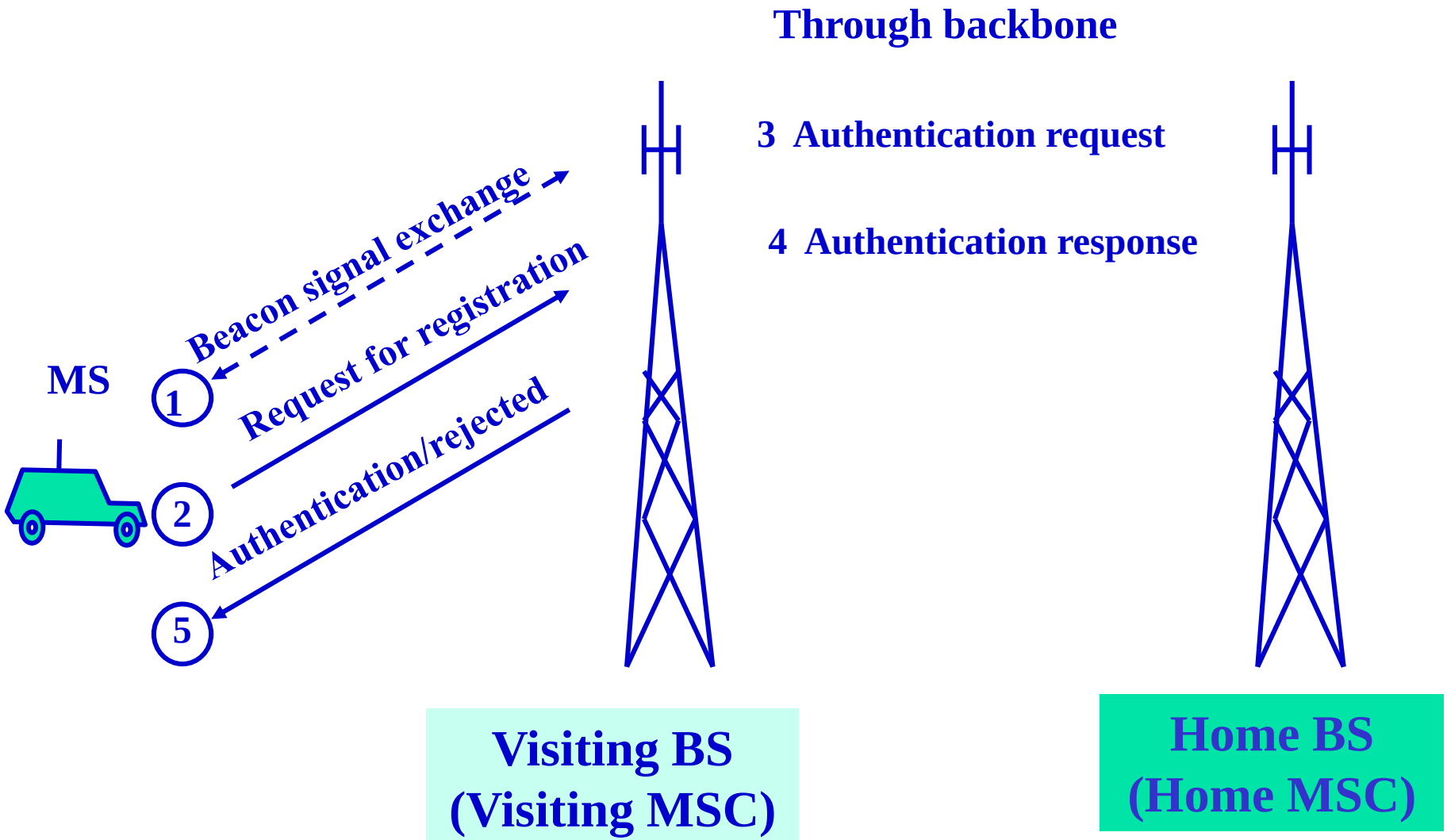
Automatic Call Forwarding using HLR-VLR



Registration

- Wireless system needs to know whether MS is currently located in its **home area** or some other area (routing of incoming calls)
- This is done by periodically exchanging signals between BS and MS known as ***Beacons***
- BS periodically broadcasts beacon signal (1 signal per second) to determine and test the MSs around
- Each MS listens to the beacon, if it has not heard it previously then it adds it to the ***active beacon kernel table***
- This information is used by the MS to locate the nearest BS
- Information carried by beacon signal: cellular network identifier, timestamp, gateway address, ID of the paging area, etc.

Using a Mobile Phone Outside the Subscription Area



Steps for Registration

- MS listens to a new beacon, if it's a new one, MS adds it to the active beacon kernel table
- MS locates the nearest BS via user level processing
- The visiting BS performs user level processing and decides:
  - Who the user is?
  - What are its access permissions?
  - Keeping track of billing
- Home site sends appropriate authentication response to the current serving BS
- The BS approves/disapproves the user access

Applications and Characteristics of Beacon Signals

Application	Frequency band	Information carried
Cellular networks	824-849 MHz (AMPS/CDPD), 1,850-1,910 MHz (GSM)	Cellular IP network identifier, Gateway IP address, Paging area ID, Timestamp
Wireless LANs (discussed in Chapter 15)	902-928 MHz (industrial, scientific, and medical band for analog and mixed signals) 2.4-2.5GHz (ISM band for digital signals)	Traffic indication map
Ad hoc networks (discussed in Chapter 14)	902-928 MHz (ISM band for analog and mixed signals) 2.4-2.5 GHz (ISM band for digital signals)	Network node identify
GPS (discussed in Chapter 12)	1575.42 MHz	Timestamped orbital map and astronomical information
Search and rescue	406 and 121.5 MHz	Registration country and ID of vessel or aircraft in distress
Mobile robotics	100 KHz - 1 MHz	Position of pallet or payload
Location tracking	300 GHz - 810 THz (infrared)	Digitally encoded signal to identify user's location
Aid to the impaired	176 MHz	Digitally coded signal uniquely identifying physical locations

Handoff Parameters and Underlying Support

- Change of radio resources from one cell to another adjacent one
- Handoff depends on cell size, boundary length, signal strength, fading, reflection, etc.
- Handoff can be initiated by MS or BS and could be due to
  - Radio link
  - Network management (load balance)
  - Service issues (QoS)

Handoff Parameters (Cont'd)

- Radio link handoff is due to mobility of MS
- It depends on:
  - Number of MSs in the cell
  - Number of MSs that have left the cell
  - Number of calls generated in the cell
  - Number of calls transferred from the neighboring cells
  - Number and duration of calls terminated in the cell
  - Number of calls that were handoff to neighboring cells
  - Cell dwell time

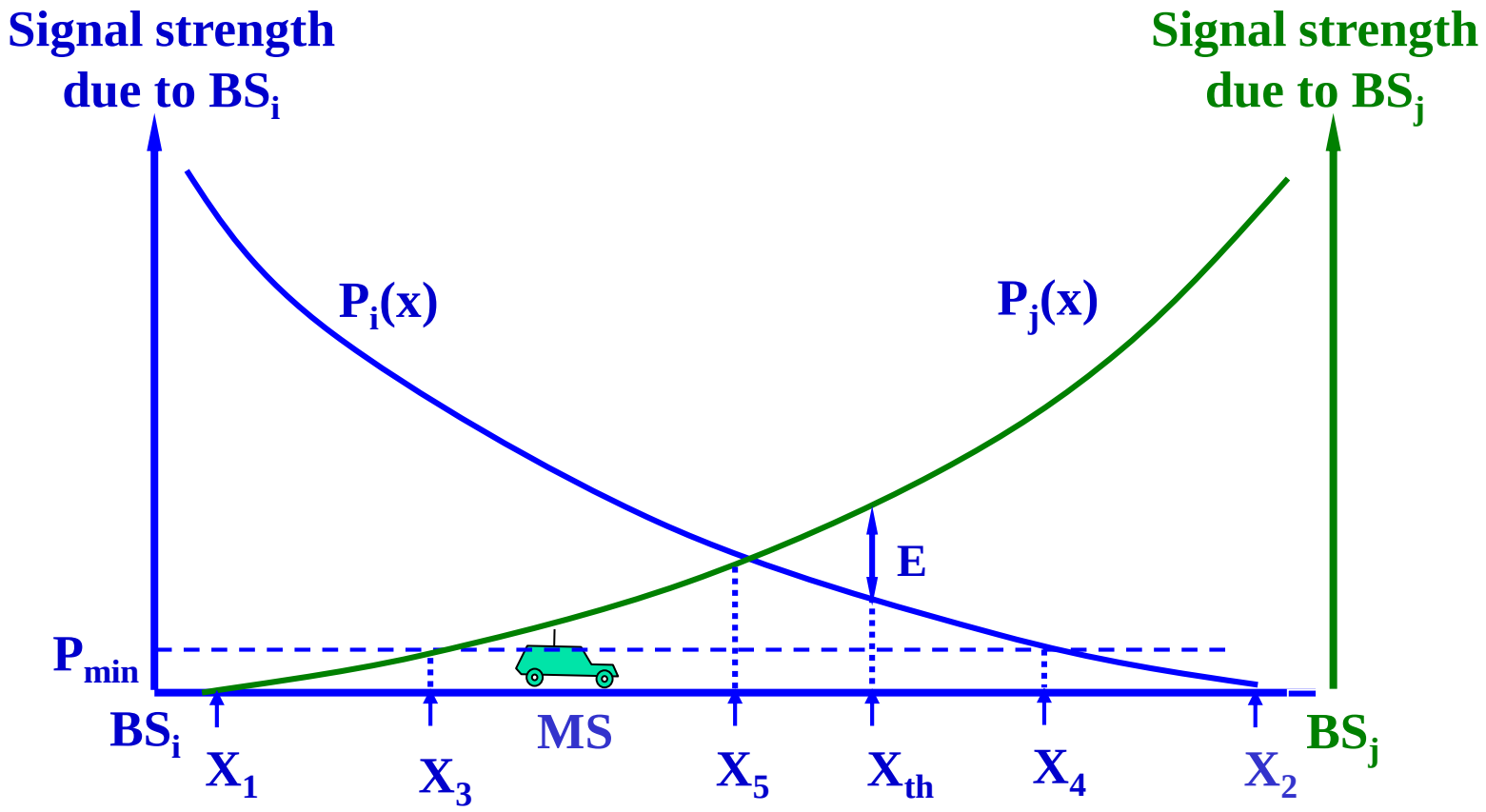
Handoff Parameters (Cont'd)

- Network management may cause handoff if there is drastic imbalance of traffic in adjacent cells and optimal balance of resources is required
- Service related handoff is due to the degradation of QoS (quality of service)

Time for Handoff

- **Need for Handoff is determined by:**
  - **Signal strength**
  - **CIR (carrier to interference ratio)**
- **Factors deciding right time for handoff:**
  - **Signal strength**
  - **Bit error rate (BER)**
  - **Distance**

Handoff Region



By looking at the variation of signal strength from either base station it is possible to decide on the optimum area where handoff can take place

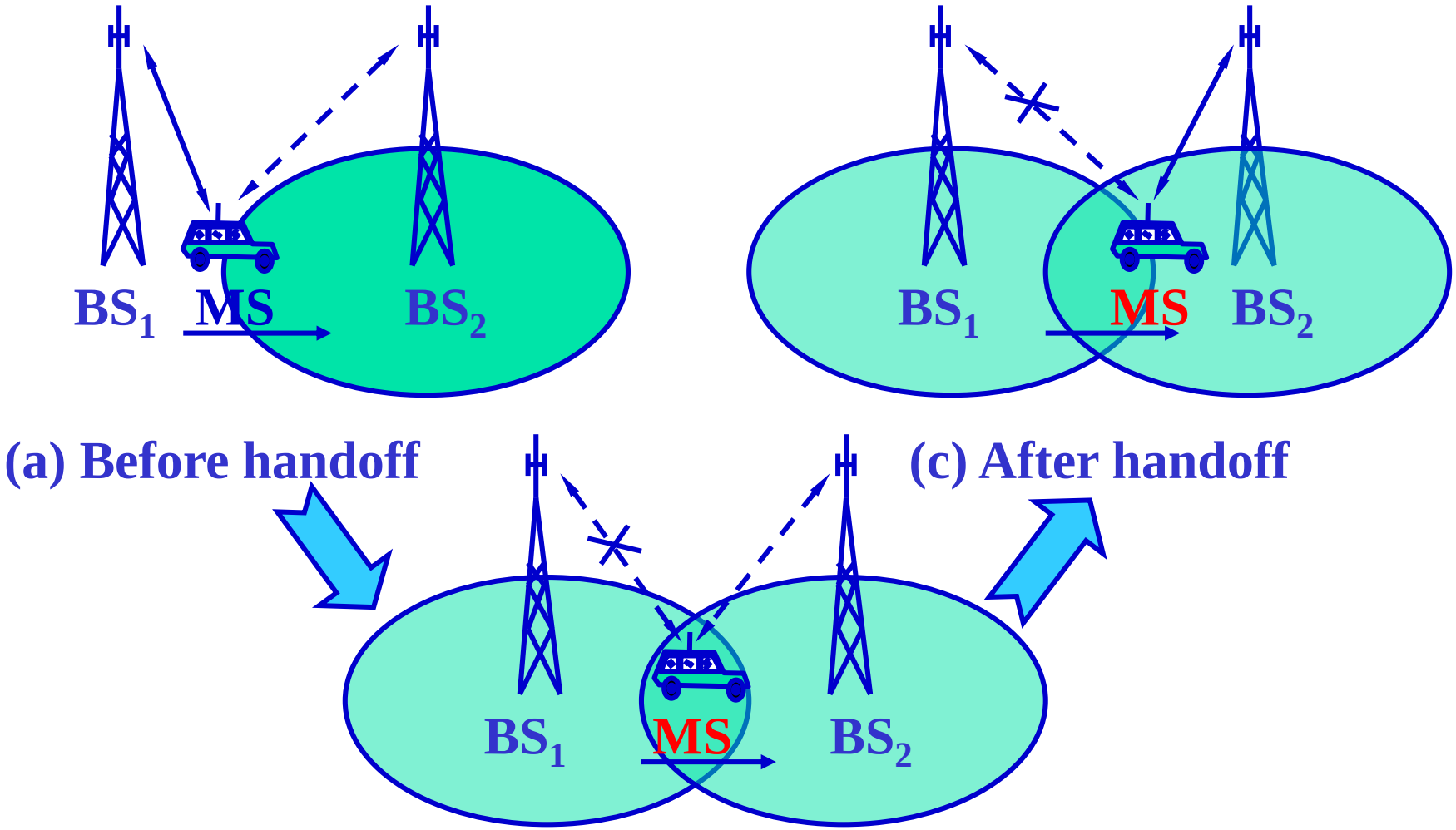
Handoff Initiation (Cont'd)

- Region X_3-X_4 indicates the handoff area, where depending on other factors, the handoff needs to be performed
- One option is to do handoff at X_5 where the two signal strengths are equal
- If MS moves back and forth around X_5, it will result in too frequent handoffs (*ping-pong effect*)
- Therefore MS is allowed to continue with the existing BS till the signal strength decreases by a threshold value E
- Different cellular systems follow different handoff procedure

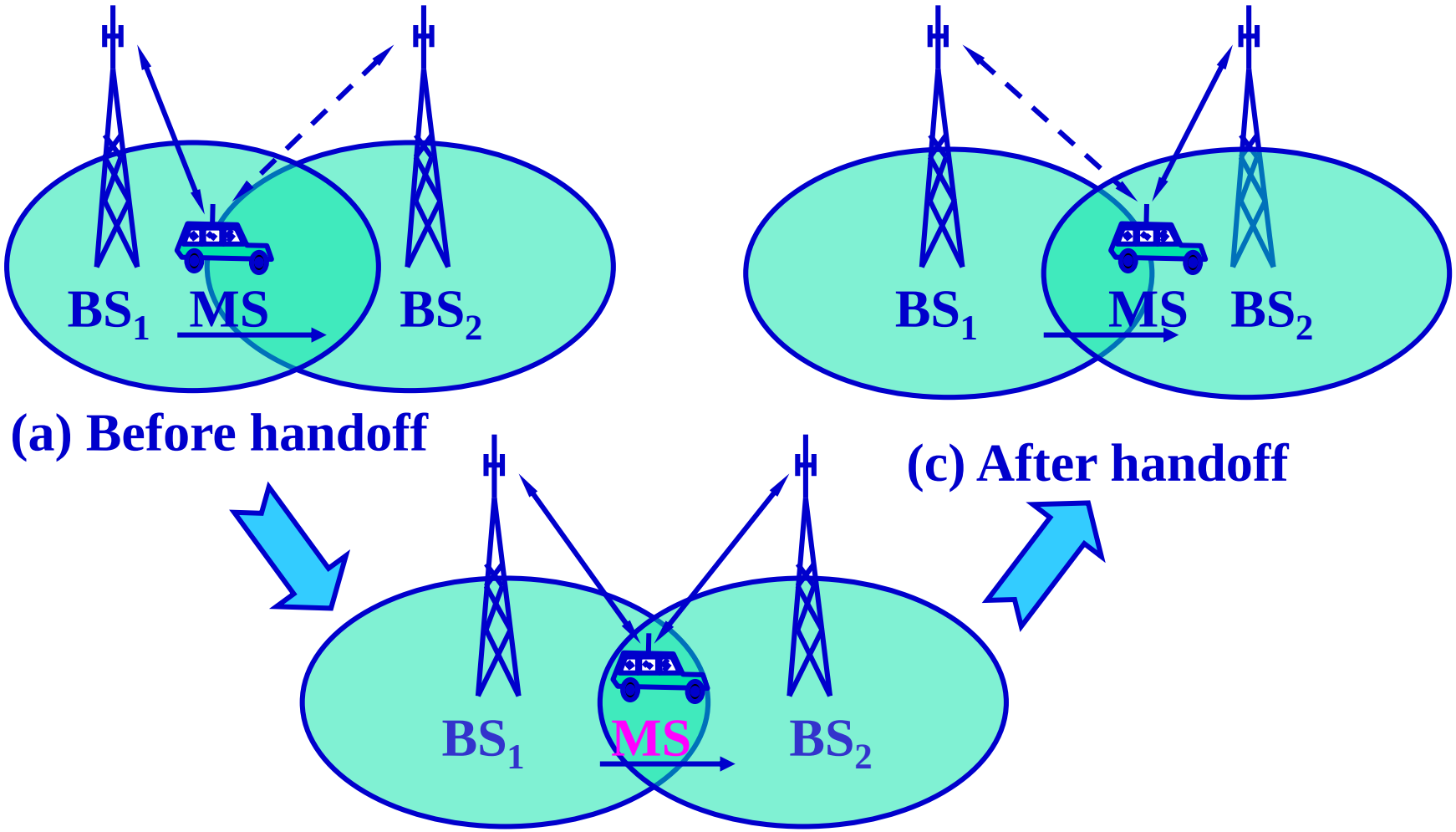
Types of Handoff

- **Hard Handoff (*break before make*)**
  - ✓ **Releasing current resources from the prior BS before acquiring resources from the next BS**
  - ✓ **FDMA, TDMA follow this type of handoff**
- **Soft Handoff (*make before break*)**
  - ✓ **In CDMA, since the same channel is used, we can use the same if orthogonal to the codes in the next BS**
  - ✓ **Therefore, it is possible for the MS to communicate simultaneously with the prior BS as well as the new BS**

Hard Handoff



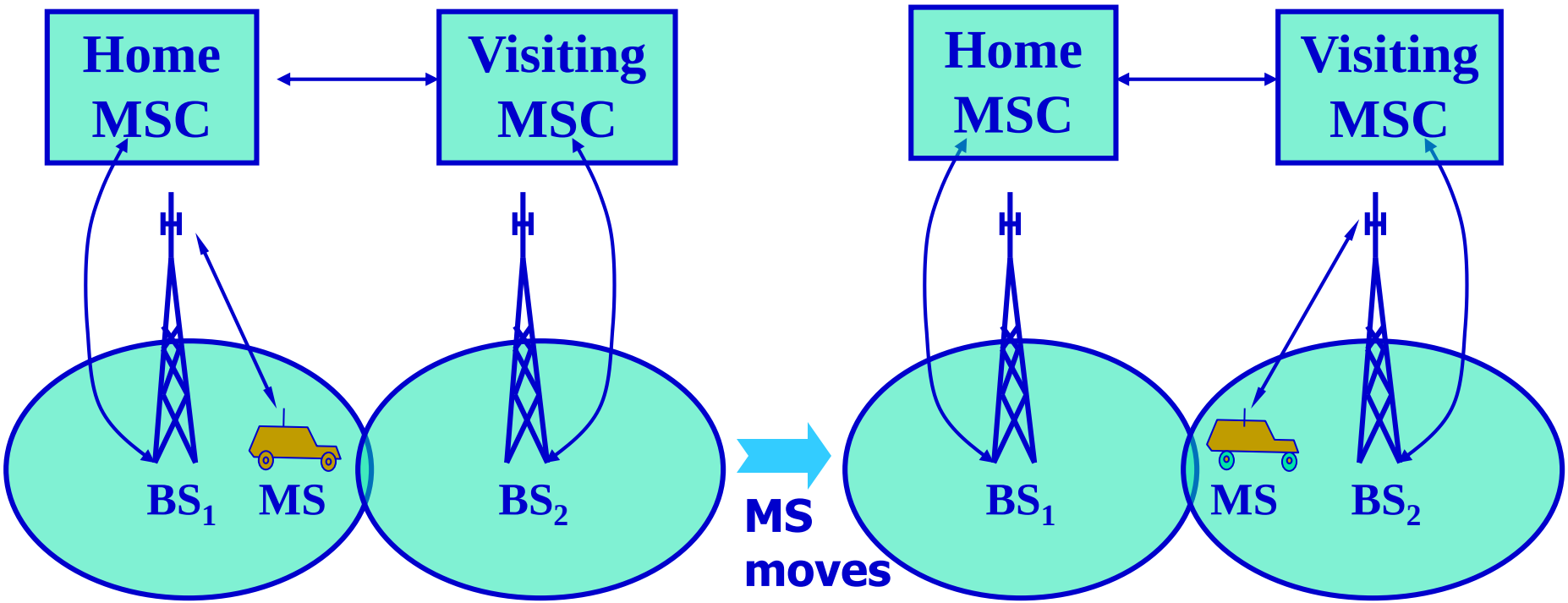
Soft Handoff (CDMA only)



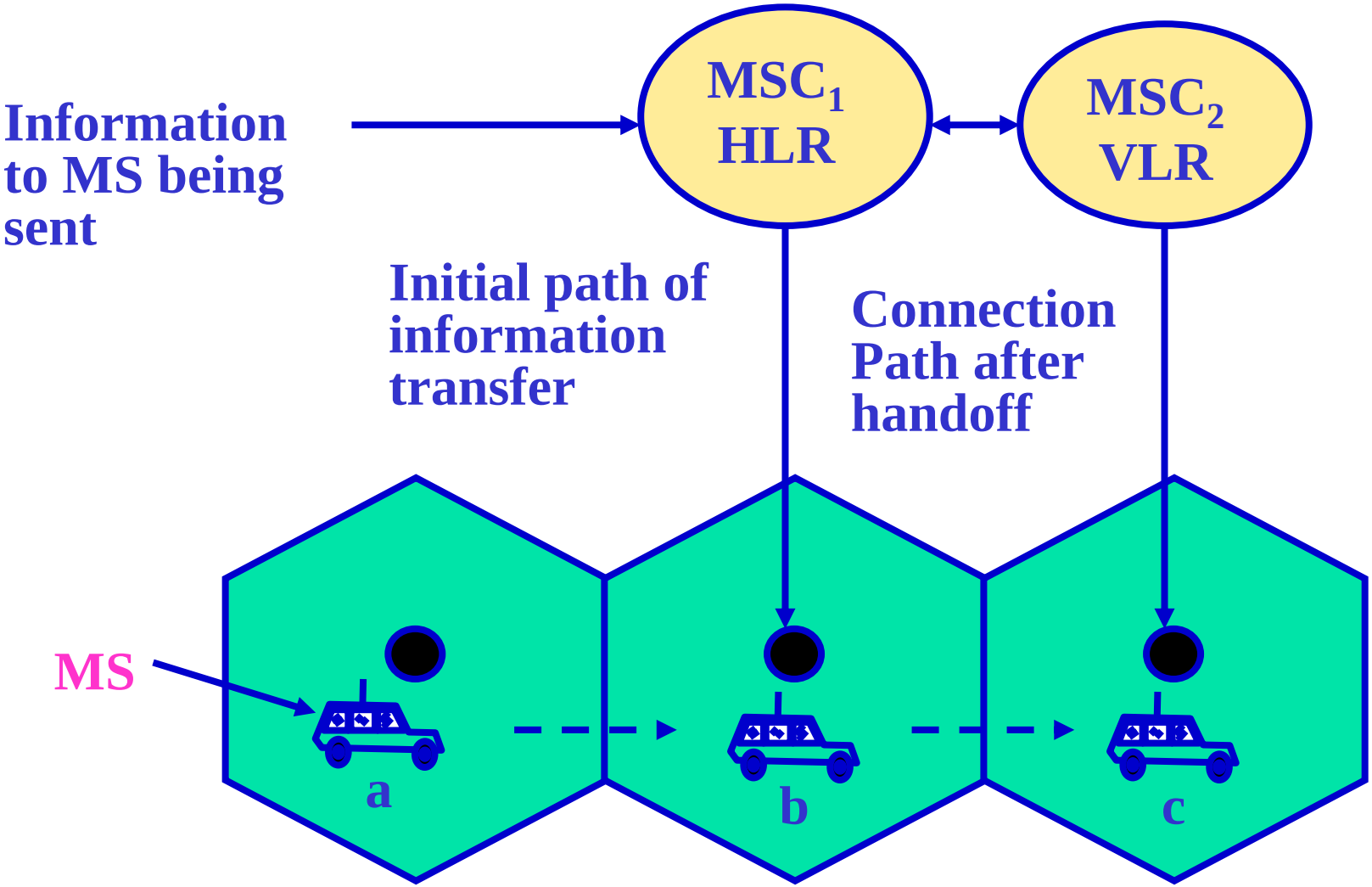
Roaming Support

- To move from a cell controlled by one MSC area to a cell connected to another MSC
- Beacon signals and the use of HLR-VLR allow the MS to roam anywhere provided the same service provider using that particular frequency band, is there in that region

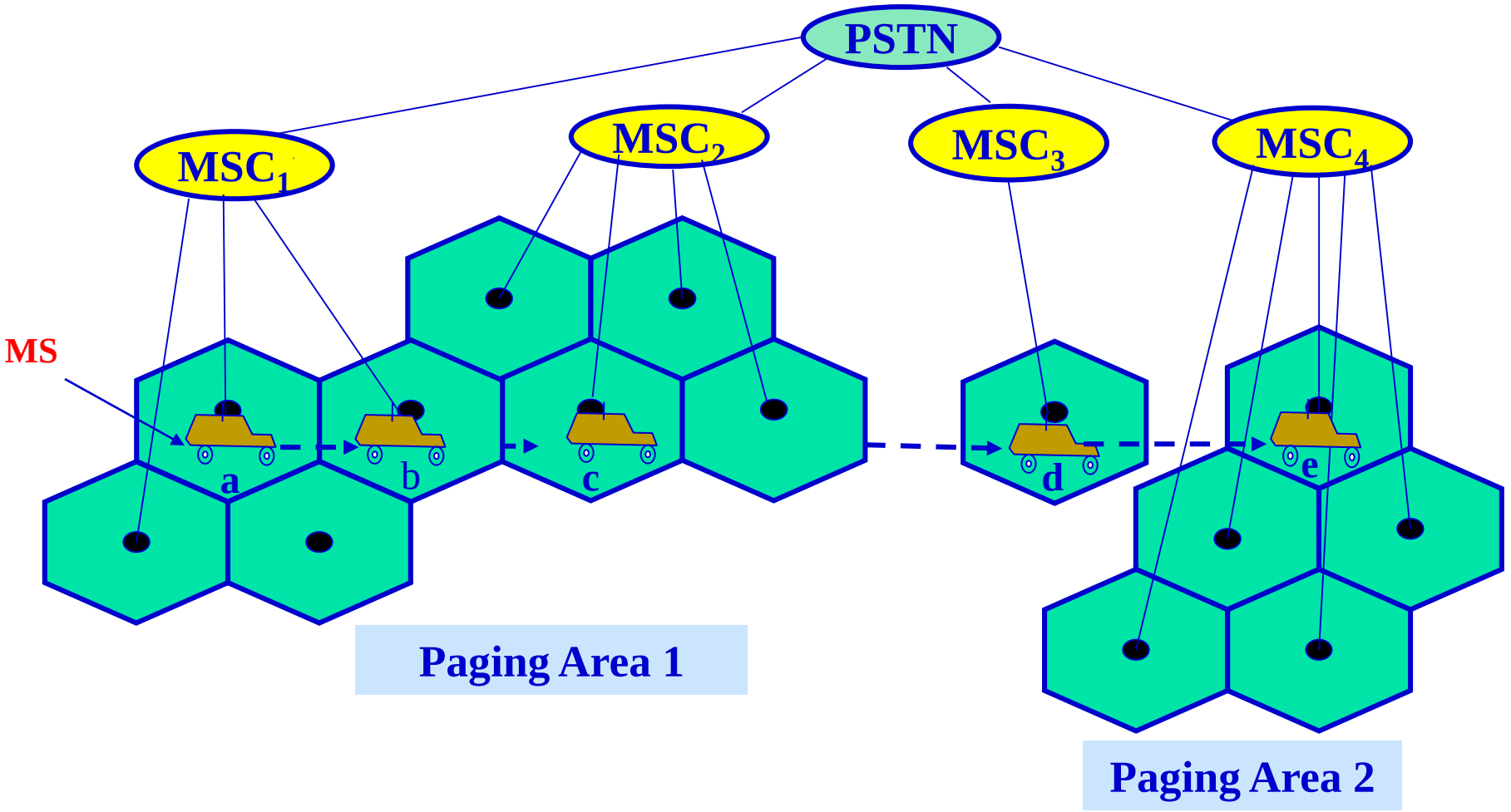
Roaming Support



Information Transmission Path when MS Hands Off from "b" to "c"



Handoff Scenarios with Different Degree of Mobility



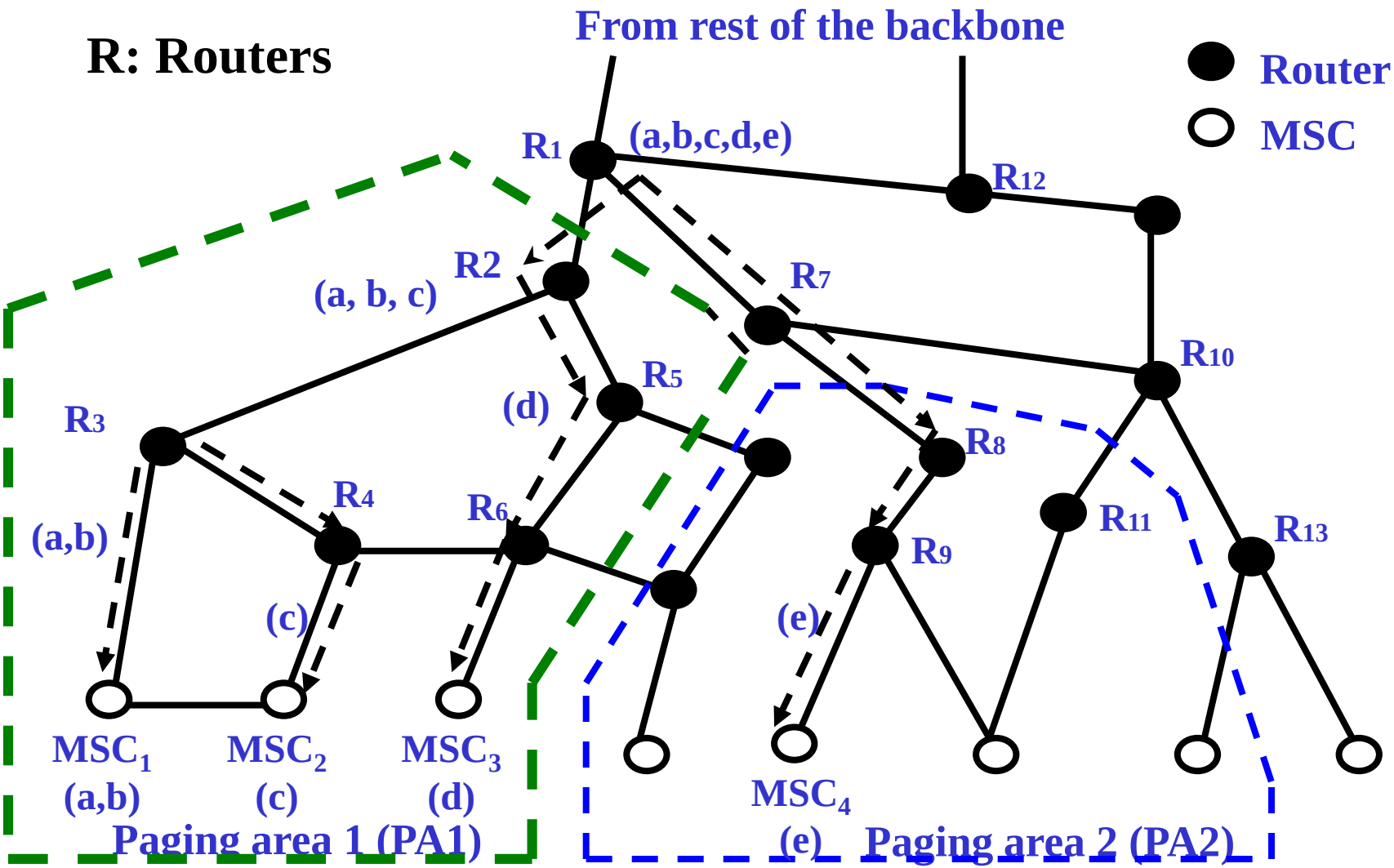
Possible Handoff Situations

- Assume MSC_1 to be the home of the MS for registration, billing, authentication, etc.
- When handoff is from position “a” to “b”, the routing can be done by MSC_1 itself
- When handoff is from position “b” to “c” , then bi-directional pointers are set up to link the HLR of MSC_1 to VLR of MSC_2
- When handoff occurs at “d” or “e”, routing of information using HLR-VLR may not be adequate (“d” is in a different *paging area*)
- Concept of Backbone network

Backbone Network

- Routing done according to the topology and connectivity of the backbone network
- The dotted lines show the possible paths for a call headed for different MS locations
- One option is to let all the messages reach MSC_1 and forward the message from there to the MS
- Another option is to find a router along the original path, from where a new path needs to start to reach the **destination** MSC along the shortest path

Illustration of MSC Connections to Backbone Network and Routing/Rerouting



Home Agents (HA), Foreign Agents (FA) and Mobile IP

- Two important software modules are associated with routers, home agent (HA) and foreign agent (FA)
- MS is registered with a router, mostly a router closest to the home MSC can be used to maintain its HA
- A router other than closest one could also serve as an HA
- Once a MS moves from the home network, a software module in the new network FA assists MS by forwarding packets for the MS
- This functionality is somewhat similar to HLR-VLR

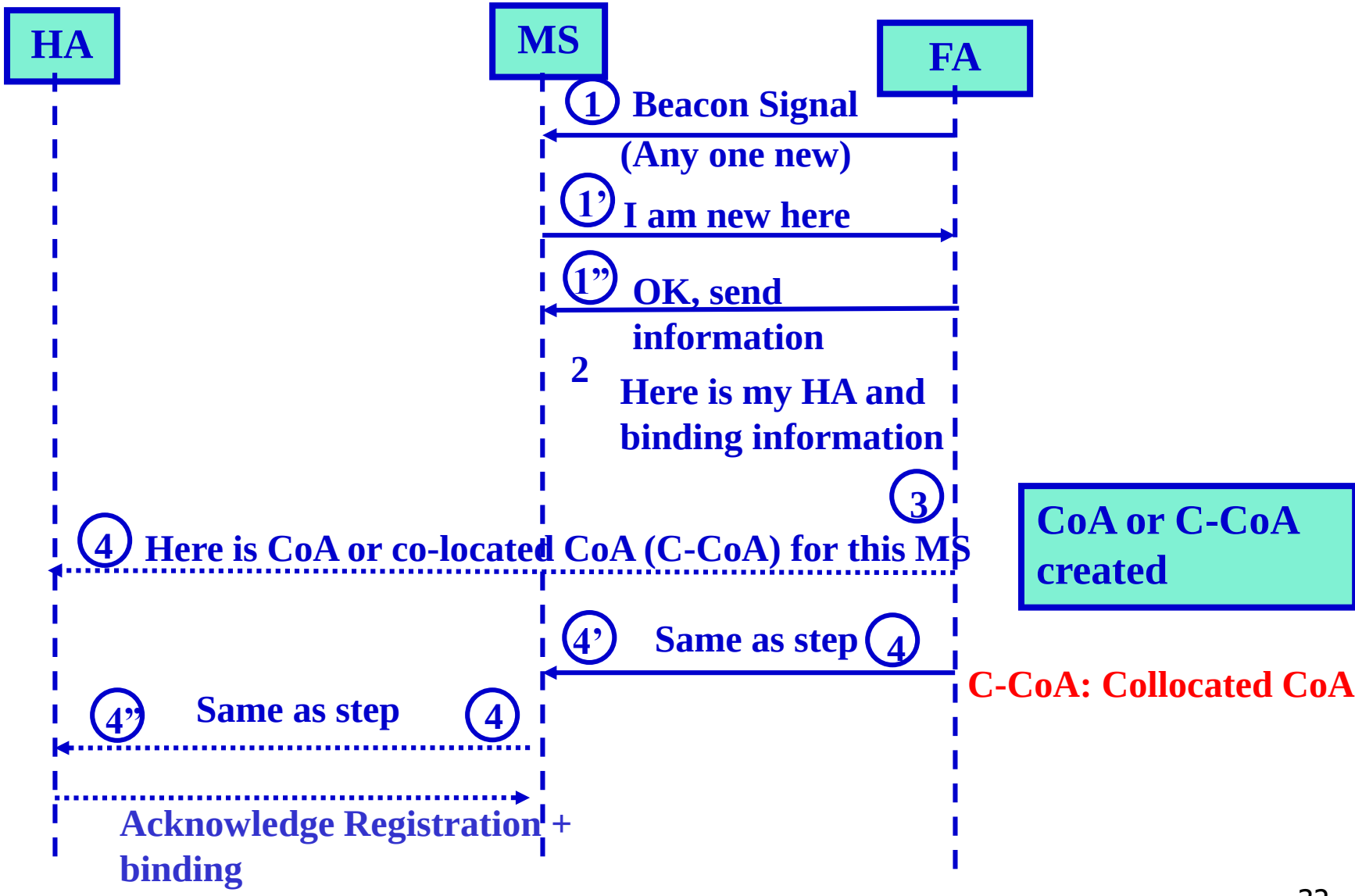
Home MSC and Home Agent (HA) for the Previous Network

Home MSC	MSC_1	MSC_2	MSC_3	MSC_4
Selected router for maintaining its home agent	R_3	R_4	R_6	R_9

Call Establishment using HA-FA

- Whenever a MS moves to a new network, it still retains its initial HA
- The MS detects the FA of the new network, by sensing the periodic beacon signals which FA transmits
- MS can also itself send *agent solicitation messages* to which FA responds
- When FA detects a new MS, it allocates a CoA (care of address) to the MS, using dynamic host configuration protocol (DHCP)
- Once MS receives CoA, it registers its CoA with its HA and the time limit binding for its validity
- Such registration is initiated either directly by MS to the HA of the home router or indirectly through FA

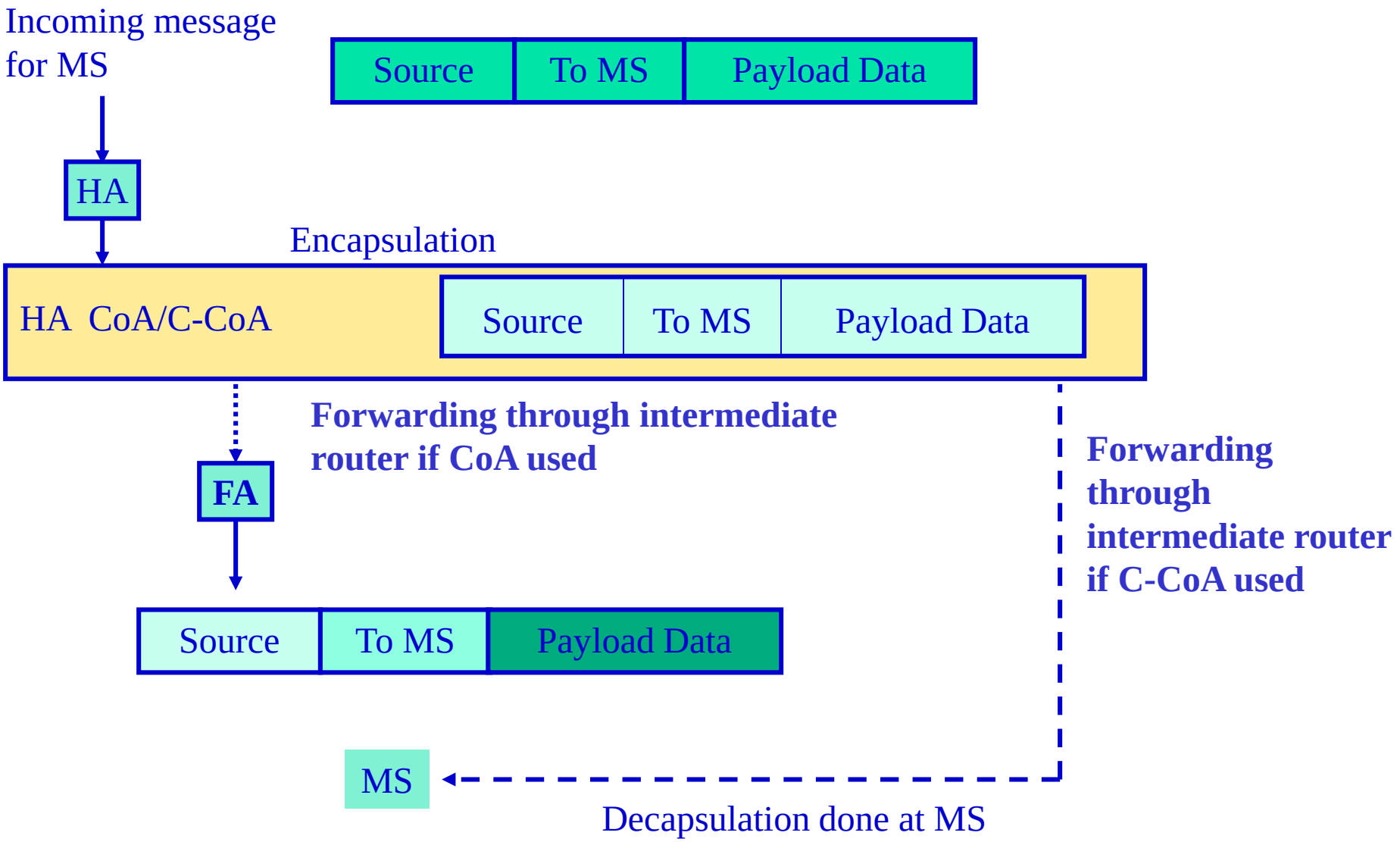
Registration Process Between FA, MS, and HA When the MS Moves to a Paging area



Call Establishment (Cont'd)

- HA confirms its binding through a reply to the MS
- A message sent from an arbitrary source to the MS at the home address is received by the HA
- Binding is checked, the CoA of the MS is encapsulated in the packet and forwarded to the network
- If CoA of the FA is used, then packet reaches FA, it decapsulates packet and passes to MS at the link layer
- In an internet environment, it is called ***Mobile IP***
- After binding time, if MS still wants to have packets forwarded through HA, it needs to renew its registration
- When MS returns to its home network, it informs its HA

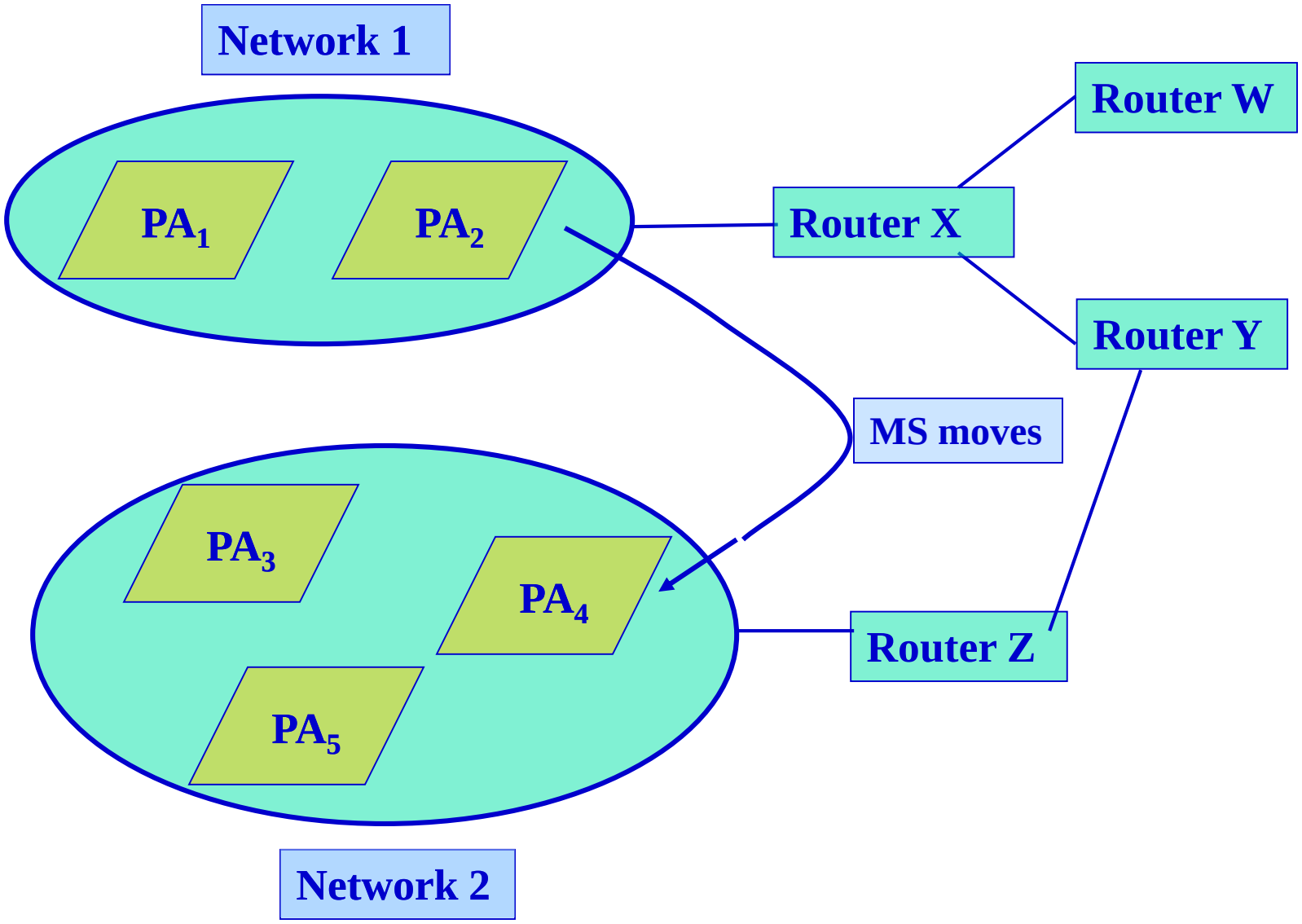
Message Forwarding using HA-FA Pair



Routing in Backbone Routers

- How FA finds HA of the MS?
- One approach is to have a global table at each router of each MSC so that the route from FA to HA for that MS can be determined
- Disadvantages: Information too large, one network might not like to give out information about all its routers to any external network (only gateways information is provided)
- Use of ***Distributed Routing Scheme***

Illustration of Paging Areas (PAs) and Backbone Router Interconnect



Distributed Routing Table and Location PAs

Table at router W		Table at router X		Table at router Y		Table at router Z	
Route to PA	Next hop	Route to PA	Next hop	Route to PA	Next hop	Route to PA	Next hop
1	X	1	-	1	X	1	Y
2	X	2	-	2	X	2	Y
3	X	3	Y	3	Z	3	-
4	X	4	Y	4	Z	4	-
5	X	5	Y	5	Z	5	-

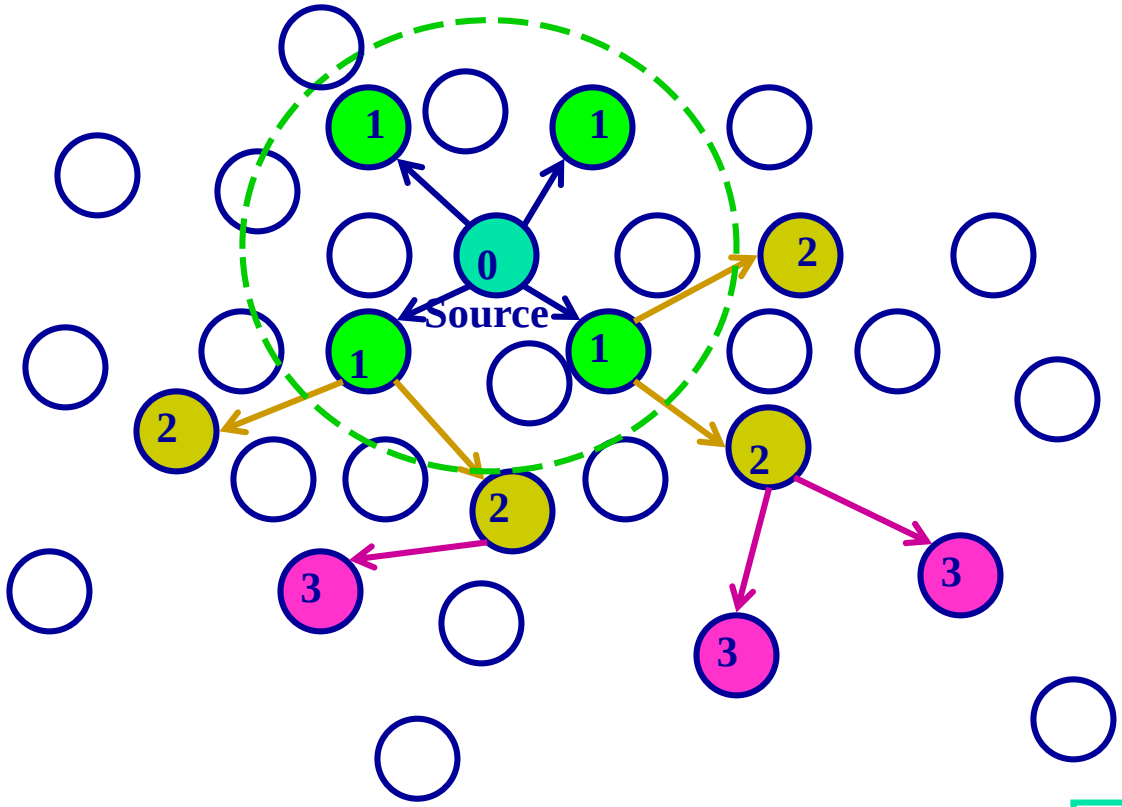
Multicasting

- Process of transmitting messages from a source to multiple recipients by using a *group address* for all hosts that wish to be the members of the group
- Reduces number of messages to be transmitted as compared to multiple unicasting
- Useful in video/audio conferencing, multi-party games

Multicasting

- Multicasting can be performed either by building a *source based tree* or *core based tree*
- In *source based tree*, for each source of the group a shortest path is maintained, encompassing all the members of the group, with the source being the root of the tree
- In *core based tree*, a particular router is chosen as a core and a tree is maintained with the core being the root
  - Every source forwards the packet to a core router, which then forwards it on the tree to reach all members of the multicast group

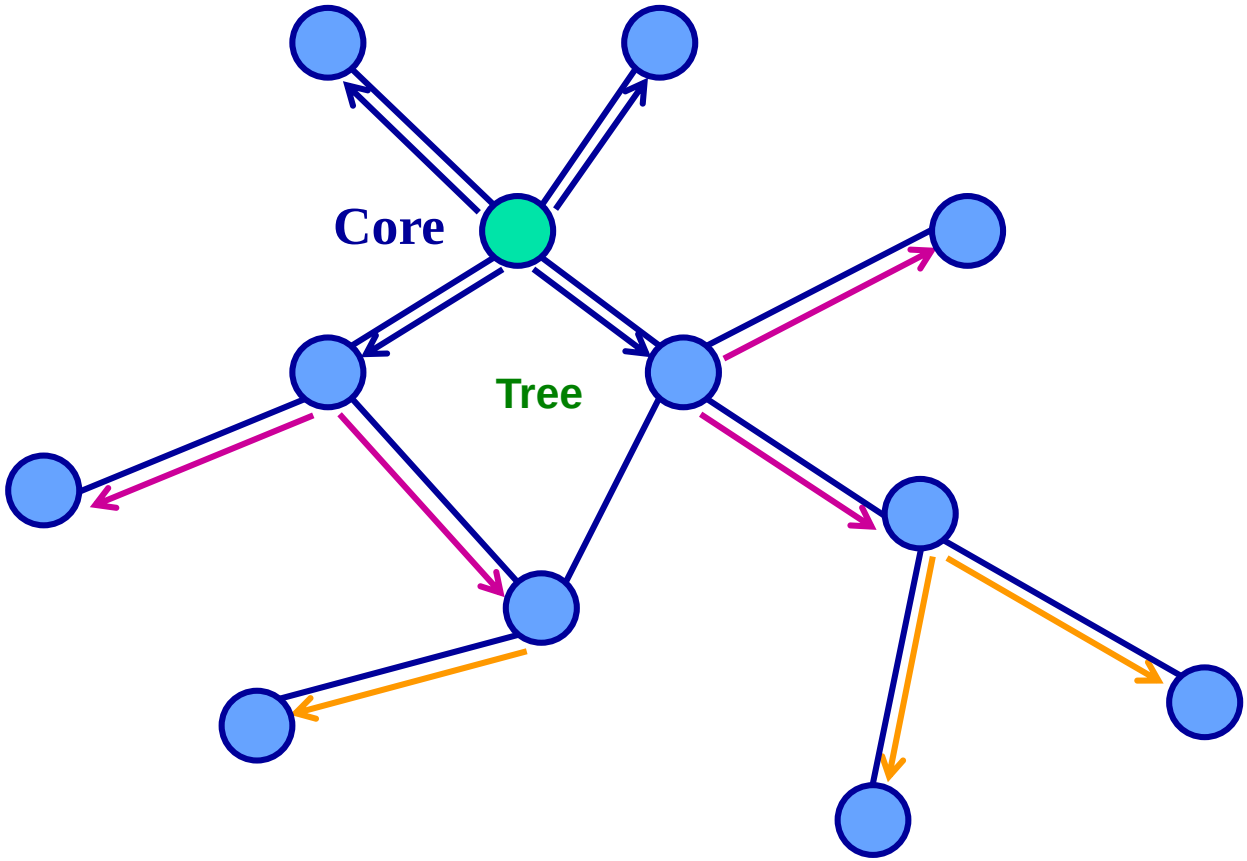
Tree-based Multicasting



Nodes not a part of Multicast group

Core-based Multicasting

- ✓ **Every source forwards the packet to a core router, which then forwards it on the tree to reach all members of the multicast group**



Multicasting

- ***Bi-directional Tunneling*** **(BT) and** ***Remote Subscription*** **approaches have been proposed by IETF (Internet Engineeing Task Force) for providing multicast over Mobile IP**
- **In BT approach, whenever a MS moves to a foreign network, HA is responsible for forwarding the multicast packets to the MS via FA**
- **In Remote Subscription protocol, whenever a MS moves to a foreign network, the FA (if not already a member of multicast group) sends a tree join request**

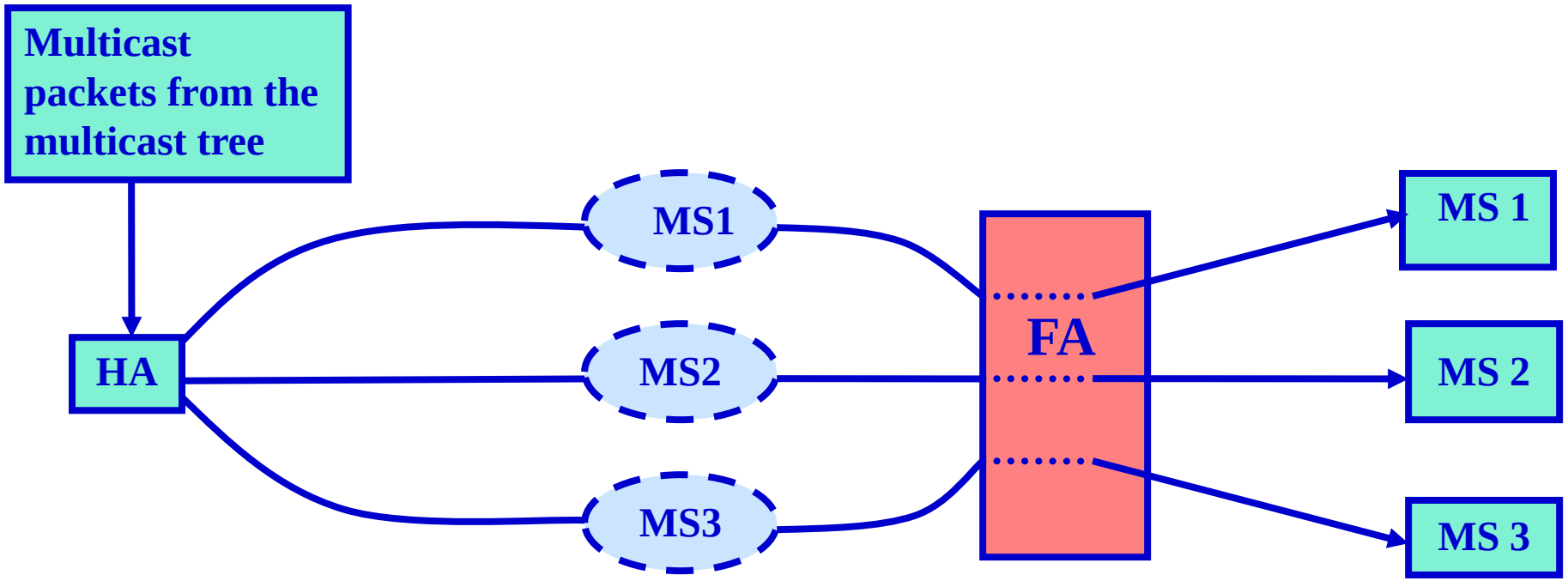
Multicasting

- **Remote Subscription based approach is simple and prevents packet duplication and non optimal path delivery**
- **It can cause data interruption till the FA is connected to the tree**
- **It results in a number of tree join and tree leave requests when MS are in continuous motion**
- **In contrast, in the BT approach, the HA creates a bi-directional tunnel to FA and encapsulates the packets for MS**
- **FA then forwards the packets to the MS**

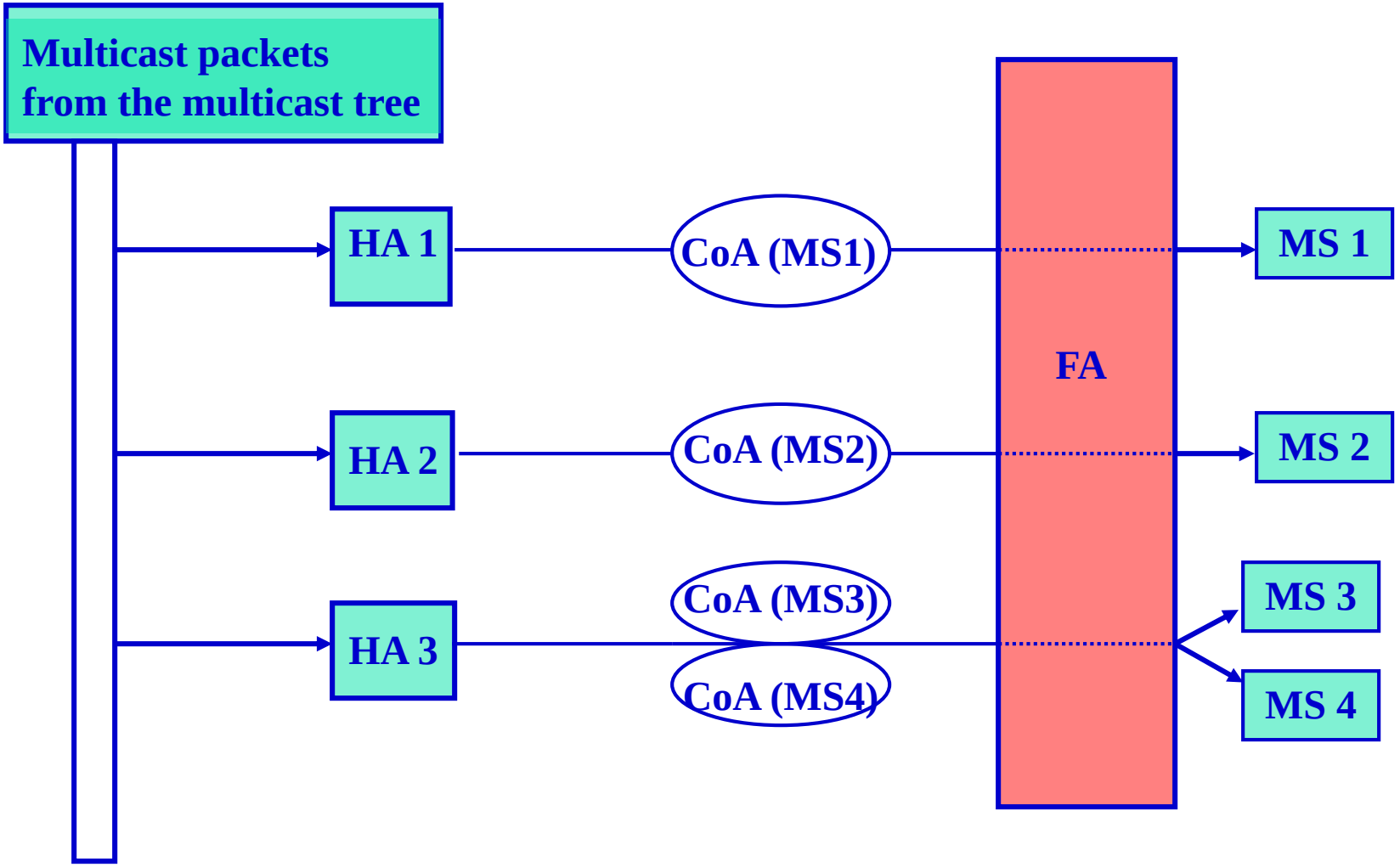
Multicasting

- BT approach prevents data disruption due to the movement of MS
- But causes packet duplication if several MSs of the same HA, that have subscribed to the same multicast group move to same FA
- Also causes *Tunnel Convergence Problem*, where one FA may have several MSs subscribed to the same group, belonging to different HAs and each HA may forward a packet for its MSs to the same FA

Packet Duplication in BT Tunnel Approach



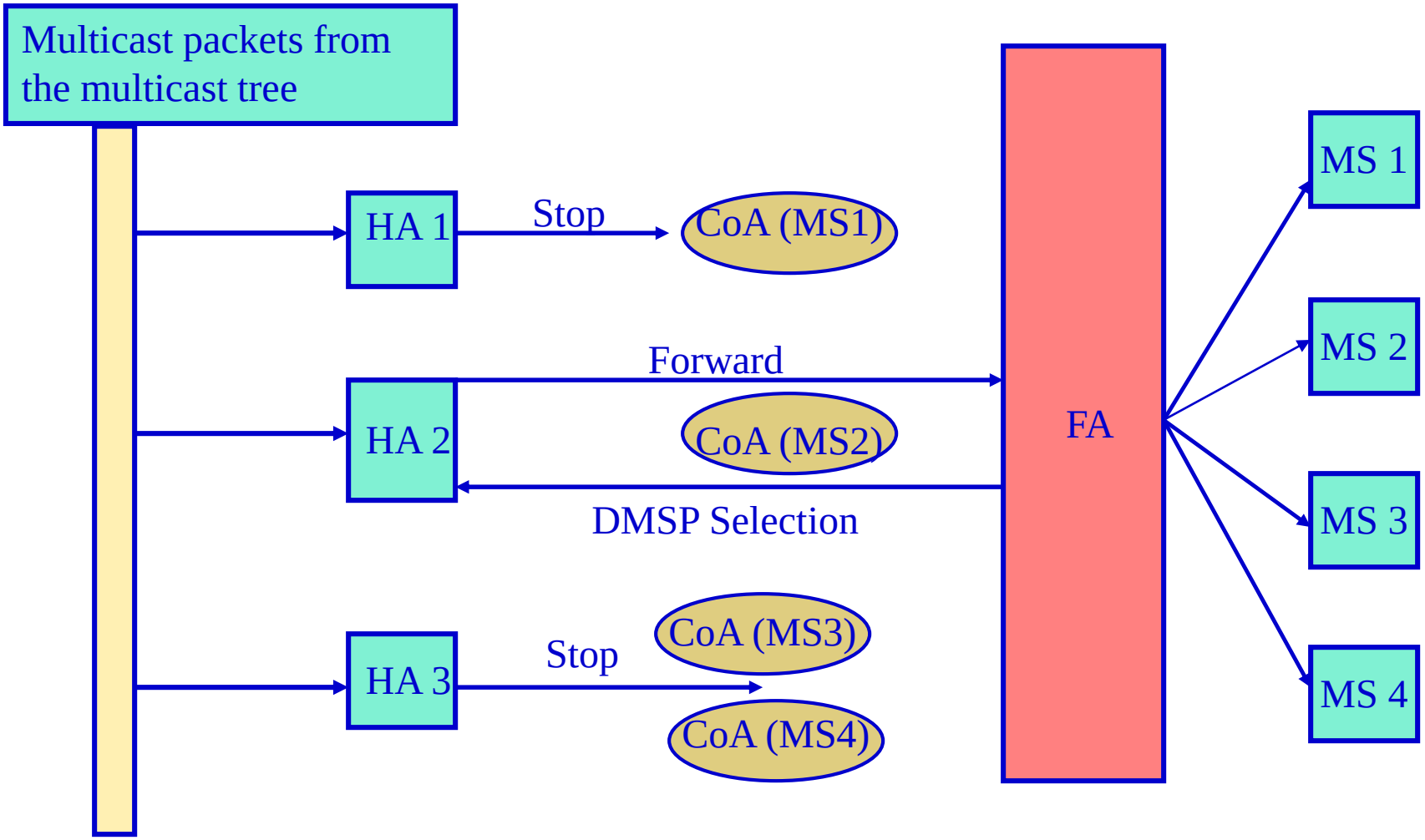
Tunnel Convergence Problem



Multicasting

- To overcome Tunnel Convergence Problem, mobile multicast (MoM) protocol is proposed wherein the FA selects one of the HAs for each group, called the Designated Multicast Service Provider (DMSP), from the HA List for a particular group
- The remaining HAs do not forward packets to FA

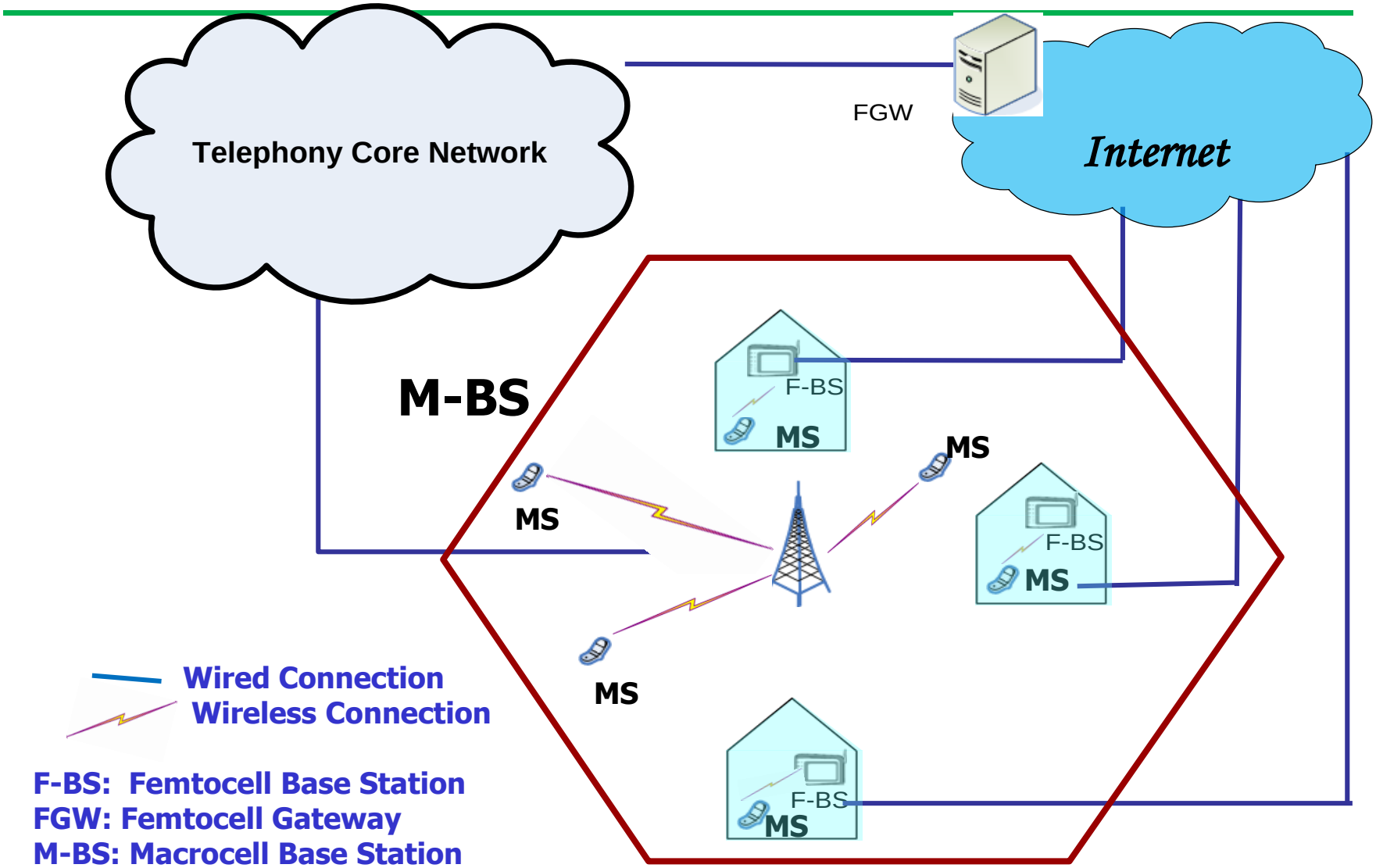
Illustration of MoM Protocol



Need for Femtocell

- Advanced cellular standards such as 3GPP's UMTS and LTE; 3GPP2's CDMA2000, 1x, EVDO and WiMAX
- High data rate and seamless coverage important objective
- Signal strength is weak inside buildings More than 50% voice call and more than 70% data traffic start from an indoor environment
- Easier solution is to deploy some indoor devices serving only the indoor users
- Femtocell Network is an effective way to remedy coverage holes

Femtocell


Telephony Core Network
FGW
Internet
M-BS
F-BS
MS
MS
MS
F-BS
MS
MS
F-BS
MS
Wired Connection
Wireless Connection
F-BS: Femtocell Base Station
FGW: Femtocell Gateway
M-BS: Macrocell Base Station
MS: User Mobile Station

Femtocell Characteristics

- **Femtocell Base Station (F-BS)**
  - Wireless Interface
  - Internet Interface
- **Internet Link**
- **Femtocell Gateway (FGW)**
- **Benefits of Femtocell Network**
  - Better and seamless coverage
  - Enhanced capacity
  - Lower transmit power
  - Prolong handset battery life
  - Higher signal-to-interference-noise ratio (SINR)
- **Hand off, Synchronization, Self-Configuration, Self-Operation and Location Tracking, Security Issues**

Femtocell Characteristics

Characteristics	Femtocell	Macrocell
Air interface	Telecommunication standard	Telecommunication standard
Backhaul	Broadband Internet	Telephony network
Cost	$200/year	$60,000/year
UE	Power consumption low	high
Radio Range	10-50 meters	300-2000 meters

Comparing F-BS with AP

Characteristics	F-BS	AP
Spectrum	Licensed	Unlicensed
Wireless MAC	Connection-based	Contention-based
Backhaul	Broadband Internet	Broadband Internet
Power	100mW	~1.5 W
Air interface	Telecommunication standard	802.11a/b/g/n
Range	10-50m	35-70m
Service	Primarily voice	Primarily data
Current cost	$200-$250	$50-$100

Handoff

- **Three hand off categories:**
  - ✓ **Hand-Out: user handset handoff from a Femtocell to a macrocell**
  - ✓ **Hand-In: user handset handoff from a macrocell to a Femtocell**
  - ✓ **Hand off: user handset handoff from a Femtocell to close-by another Femtocell**

Homework

- 9.2, 9.6, 9.9, 9.10