無線網路概論
Intro. to Wireless Internet

Lecture 11 - Mobile IP

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YZU CSE

Lecture Material

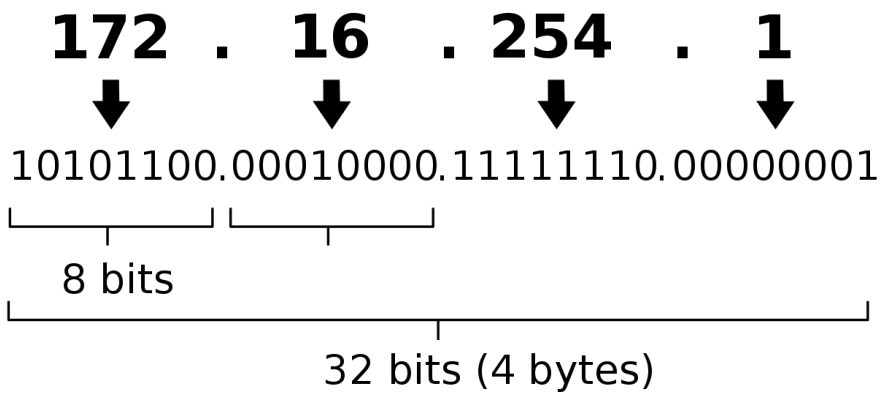
- "Wireless Communication Networks and Systems", Corry Beard and William Stallings, 2016.
  - Ch 15. Mobile applications and mobile IP
- Wireless Internet
  - Prof. You-Chiun Wang
  - National Sun Yat-sen University

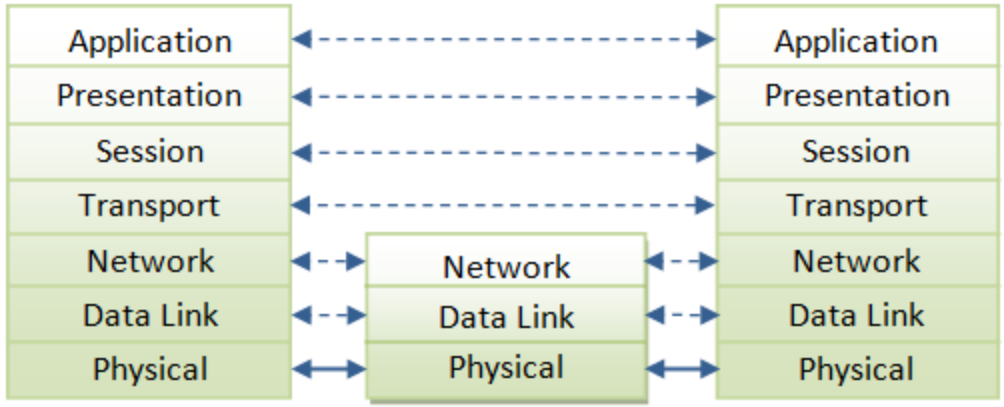
Outline

- Introduction
- Operations of mobile IPv4
- Agent discovery
- Registration
- Encapsulation

IPv4

IPv4 address in dotted-decimal notation





ISO OSI 7-layer network

Objectives of IP Address

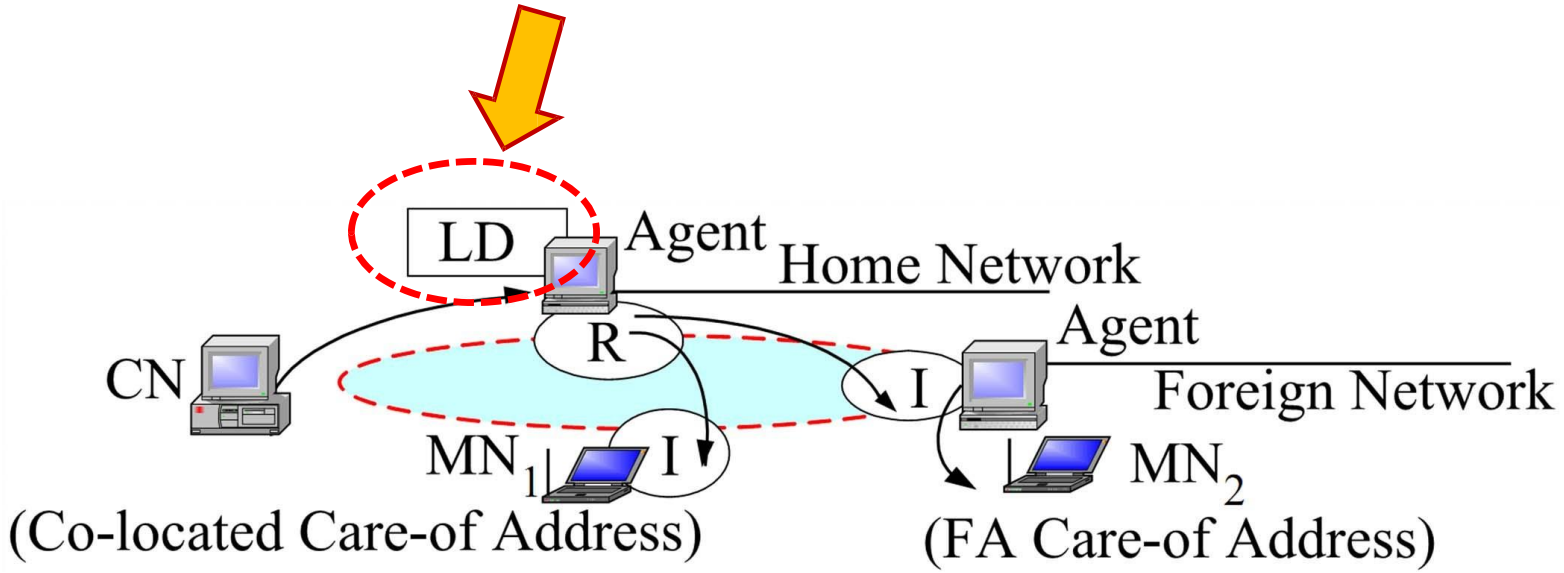
- IP address serves two purposes:
  - A routing directive:
    - A mobile node (MN) must be associated with a new IP when it moves.
  - An endpoint identifier from transport- and application- layer perspective:
    - Example: A TCP connection: (IP, port) ⇔ (IP, port)
    - IP address of an MN must be preserved regardless of the MN's point of attachment to the network.

Mobility of IP Address

- We can observe the dilemma of IP addressing in supporting mobility.
  - Solution: Mobile IP
- In mobile IP, each MN is given at least two IP addresses:
  - A permanent IP address (home address): Endpoint ID
  - A new IP address (care-of address): Point of attachment

Mobile IP Architecture

- Location directory (LD) is required to maintain the association of these two IP addresses for the MN.
  - Correspondent Node (CN) want to send data to the Mobile Node (MN)



Data Delivery in Mobile IP

- If the MN is located at its home network: Same as conventional IP routing.
- If the MN is not attached to its home network:
  - Readdressing: Home address => Care-of address
    - Redirect data to the MN's care-of address.
  - Inverse readdressing: Care-of address => Home address
    - Present original data to higher-level protocols.

Abstract Mobility Model

- Mobile IP requires the following abstract functions to support IP mobility:
  - Addresses binding and readdressing at home network
  - Delivering data to the MN's care-of address
  - Inverse readdressing at the care-of address

Two Agents

- Home agent:
  - Sometimes called readdressing node
  - Mobility agent which serves the MN on its home network
- Foreign agent:
  - Sometimes called inverse-readdressing node
  - Mobility agent which serves the MN on a foreign network

Two Care-of Addresses

- Foreign agent care-of address:
  - An IP address of the foreign agent
  - A single care-of address can be used to serve a number of MNs.
- Co-located care-of address:
  - A local IP address acquired by an MN through some external means (DHCP)
  - Each MN has a distinct address.
  - MN performs the inverse readdressing function by itself.

Mobile IP Requirements (1/2)

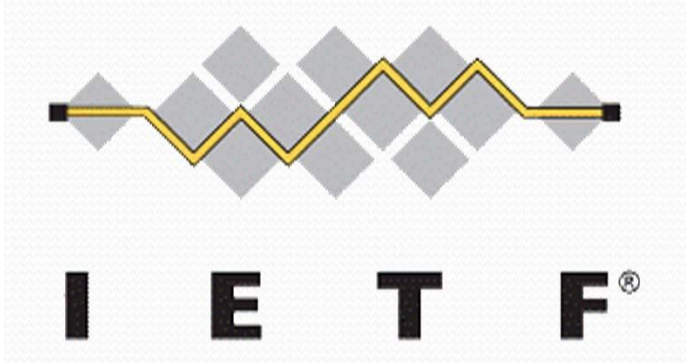
- MNs can communicate with other nodes even when moving without changing its IP address.
- MNs can communicate with other nodes which do not implement mobile IP.
- Messages regarding of MN's location must be authenticated.

Mobile IP Requirements (2/2)

- MNs are usually battery-powered.
  - We have to minimize power and bandwidth consumption.
  - We also have to minimize the total size of administrative messages sent by MNs.
- Mobile IP must place no additional constraints on the assignment of IP addresses (for any IP assignment strategy).

IETF RFCs for Mobile IP

- RFC 5944 - IP Mobility Support for IPv4, Revised
- RFC 4721 - Mobile IPv4 Challenge/Response Extensions
- RFC 6275 - Mobility support for IPv6



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Roles in Mobile IP

- Mobile node (MN): A host or a router
- Home agent (HA): An agent on an MN's home network
  - Maintain binding information and tunnels data.
- Foreign agent (FA): An agent on an MN's visited network
  - Provide routing services, detunnels, and delivers data.

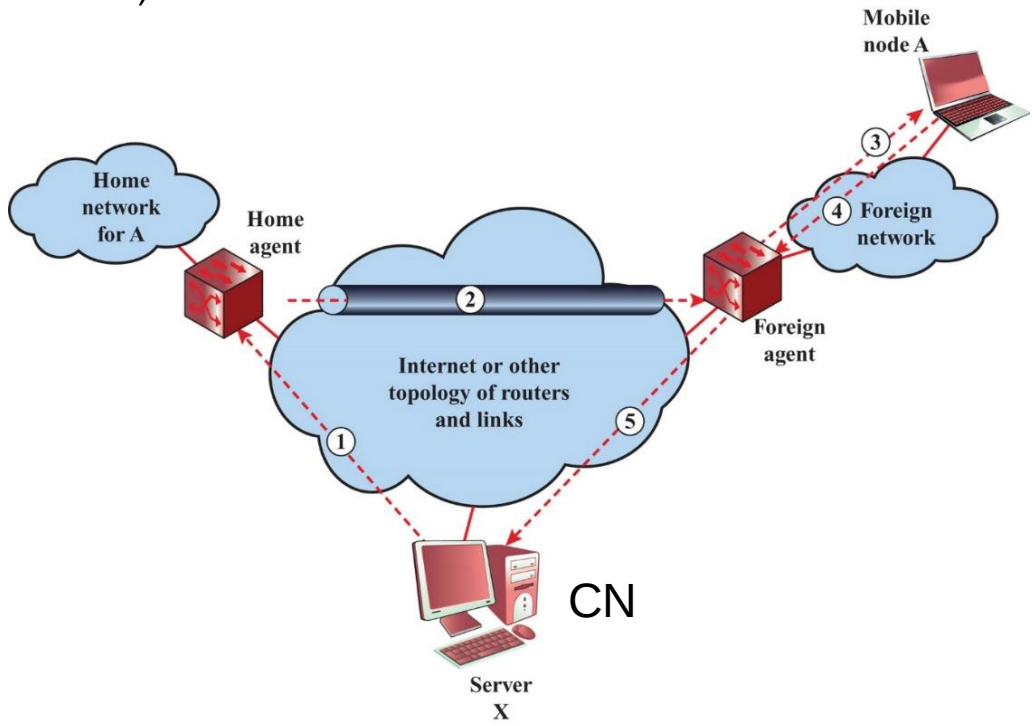


Table 15.1 Mobile IP Terminology (RFC 5944)

Mobile node	A host or router that changes its point of attachment from one network or subnetwork to another. A mobile node may change its location without changing its IP address; it may continue to communicate with other Internet nodes at any location using its (constant) IP address, assuming link-layer connectivity to a point of attachment is available.
Home address	An IP address that is assigned for an extended period of time to a mobile node. It remains unchanged regardless of where the node is attached to the Internet.
Home agent	A router on a mobile node's home network, which tunnels datagrams for delivery to the mobile node when it is away from home and maintains current location information for the mobile node.
Home network	A network, possibly virtual, having a network prefix matching that of a mobile node's home address. Note that standard IP routing mechanisms will deliver datagrams destined to a mobile node's home address to the mobile node's home network.
Foreign agent	A router on a mobile node's visited network which provides routing services to the mobile node while registered. The foreign agent detunnels and delivers datagrams to the mobile node that were tunneled by the mobile node's home agent. For datagrams sent by a mobile node, the foreign agent may serve as a default router for registered mobile nodes.

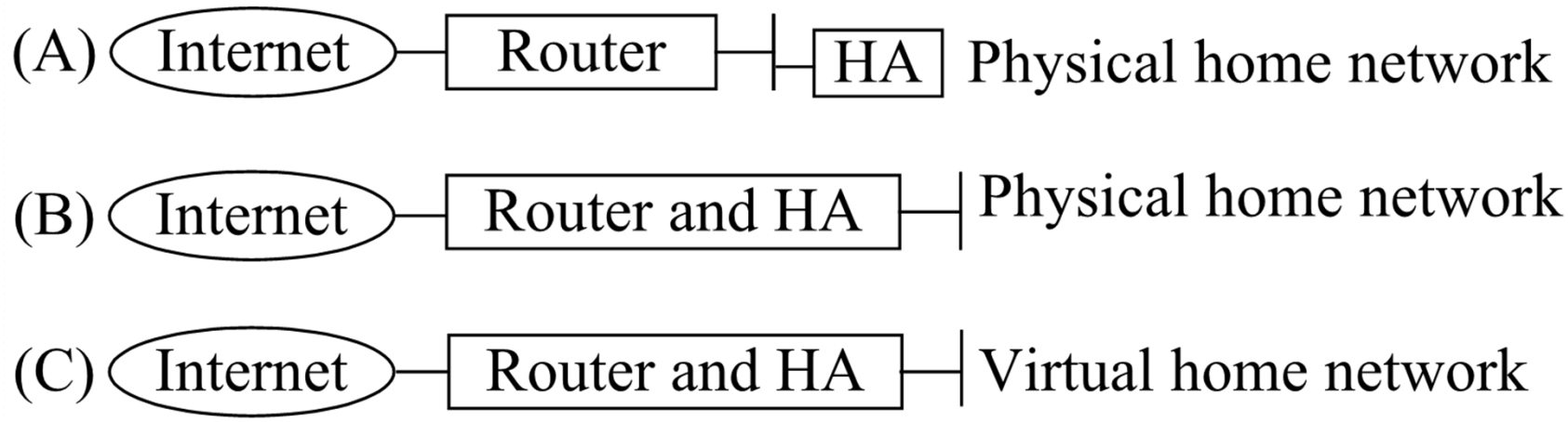
Table 15.1 Mobile IP Terminology (RFC 5944)

Foreign network	Any network other than the mobile node's home network
Care-of address	The termination point of a tunnel toward a mobile node, for datagrams forwarded to the mobile node while it is away from home. The protocol can use two different types of care-of address: a "foreign agent care-of address" is an address of a foreign agent with which the mobile node is registered, and a "co-located care-of address" is an externally obtained local address which the mobile node has associated with one of its own network interfaces.
Correspondent node	A peer with which a mobile node is communicating. A correspondent node may be either mobile or stationary.
Link	A facility or medium over which nodes can communicate at the link layer. A link underlies the network layer.
Node	A host or a router.
Tunnel	The path followed by a datagram while it is encapsulated. While it is encapsulated, a datagram is routed to a knowledgeable decapsulating agent, which decapsulates the datagram and then correctly delivers it to its ultimate destination.

Configuration of Mobility Agents

- Two alternative attachments:

- Ways to put a home agent on a home network:

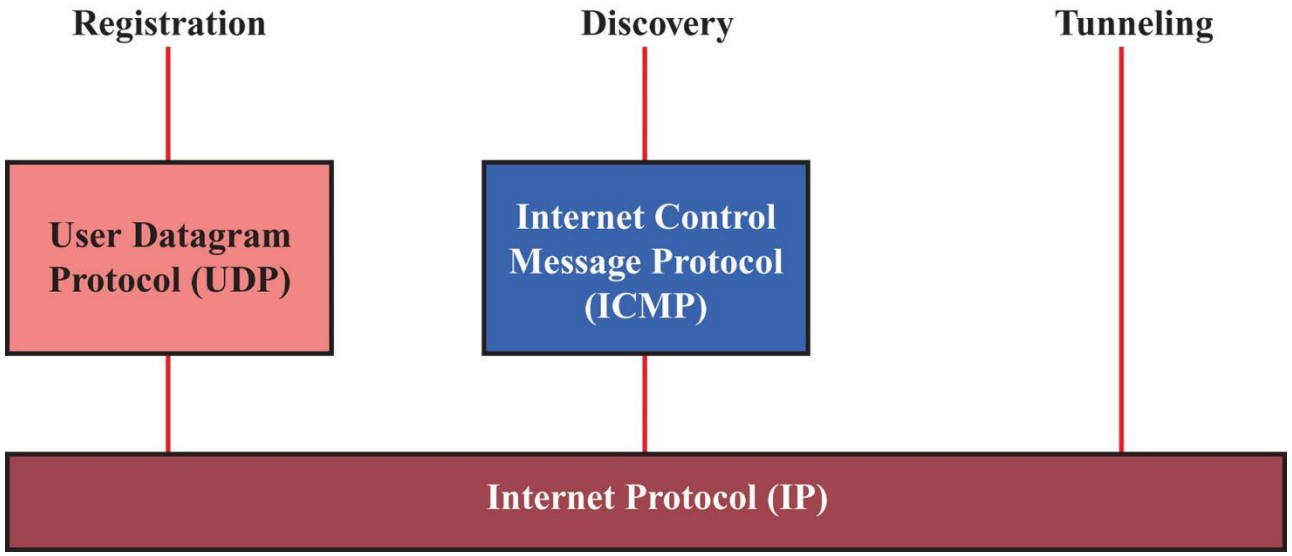


Functions of Mobile IPv4 (1/2)

- Location tracking:
  - FA informs the MN's HA of the location change.
  - HA keeps track of the location of each MN that it serves.
- Agent discovery:
  - MN must be able to detect its movement.
- Registration:
  - MN should inform its HA of its movement (can be through or not through FA).

Functions of Mobile IPv4 (2/2)

- Tunneling:
  - HA must redirect data to the care-of address of the MN.
- Mobile-originated data routing:
  - MN uses its home address as the source addresses of all IP data packets (with exception during registration).



Mobile IP Messages

- Mobile IP defines two sets of administrative messages:
- Registration:
  - A set of control messages, sent with UDP using well-known port number 434.
  - Registration request and registration reply
- Agent discovery:
  - Extend ICMP router discovery messages as its primary mechanism
    - ICMP: Internet control message protocol
  - Agent advertisement and agent solicitation

Protocol Extensibility

- Extension mechanism for carrying optional information:
  - It follows the type-length-value format (TLV) format.

  - Two separately sets defined for extension types (skippable: 0~127, not skippable: 128~255)
  - Allow variable amounts of information to be carried.
  - End of the list of extensions is indicated by the total length of IP datagram.

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Agent Discovery (1/2)

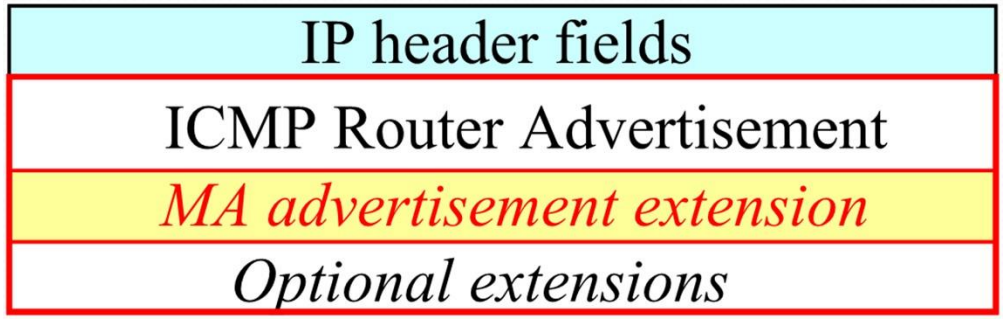
- MNs use agent discovery messages to detect their points of attachment.
  - At home network?
  - Entering a new network? => Determine the FA care-of address.
- Agent discovery messages are extended from ICMP router discovery protocol:
  - Agent advertisement is extended from ICMP router advertisement.
  - Agent solicitation is extended from ICMP router solicitation.

Agent Discovery (2/2)

- Agent advertisement message:
  - It is formed by including a mobility agent advertisement extension in an ICMP router advertisement message.
- Agent solicitation message:
  - It is identical to an ICMP router solicitation, except that its IP TTL (time-to-live) must be set to 1.
- Agent advertisement and agent solicitation may not be necessary.
- No authentication is required for agent advertisement and agent solicitation messages.

Agent Advertisement (1/4)

- Each agent periodically broadcasts agent advertisement:



- IP header of agent advertisement:
  - TTL = 1: This advertisement can pass only one router.
  - Destination address:

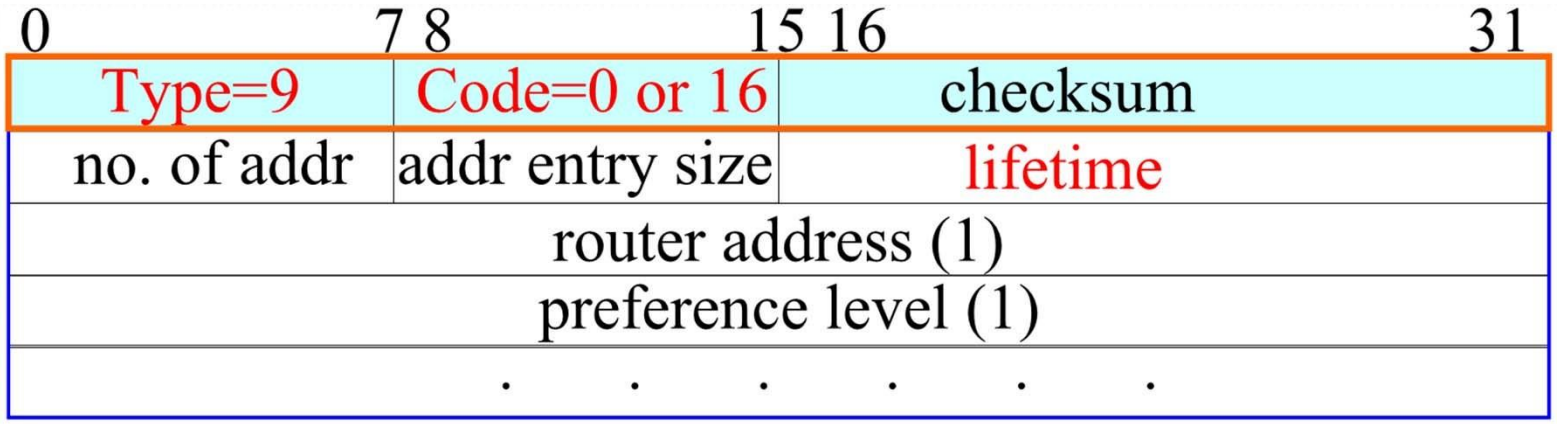
224.0.0.1: “all-system on this link” multicast address

255.255.255.255: “ limited-broadcast” address

  - When the agent advertisement is unicasted to an MN, the IP home address of the MN should be used.

Agent Advertisement (2/4)

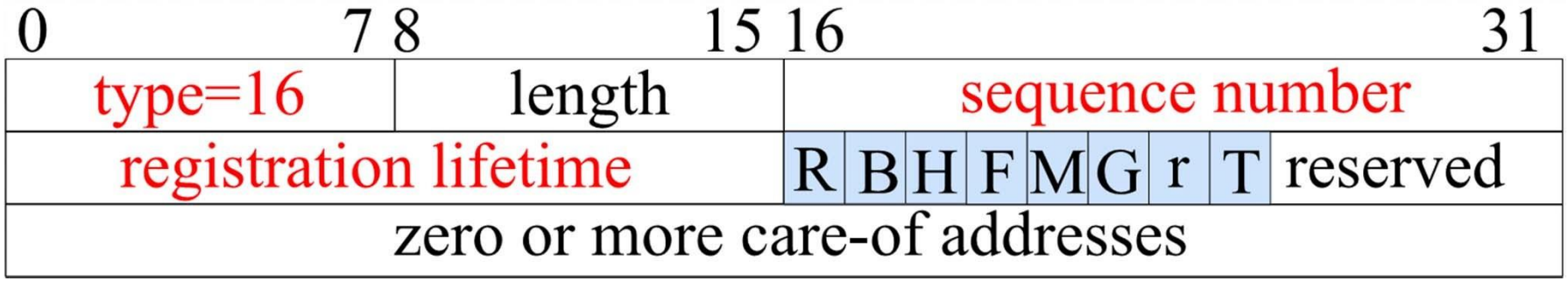
- ICMP router advertisement:



  - Code = 0: MA handles normal traffics.
  - Lifetime: Maximum length of time in seconds that the advertised addresses can be considered “valid”

Agent Advertisement (3/4)

- MA advertisement extension to the ICMP router advertisement:



  - Sequence number: Count of agent advertisement messages sent since the agent was initialized
  - Registration lifetime: Longest time (in second) that the agent is willing to accept any registration request (65535: infinity)

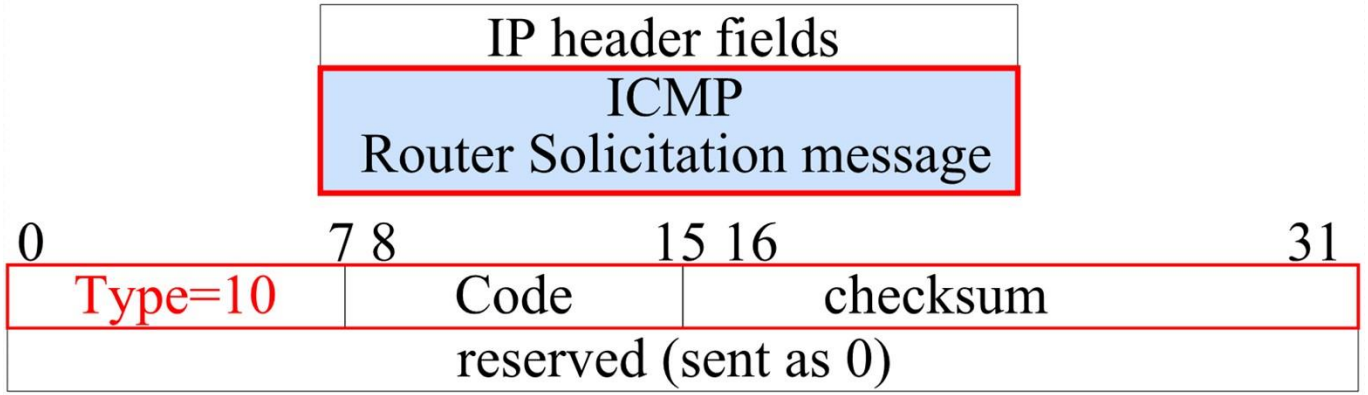
Agent Advertisement (4/4)

- Flags of MA advertisement extension:

Flag	Name	Meaning
R	Registration required	Registration with this FA (or another FA on this link) is required *even when using a co-located care-of address*.
B	Busy	FA will *not accept registrations* from additional MNs.
H	Home agent	This agent *offers service as an HA* on the link on which the agent advertisement message is sent.
F	Foreign agent	This agent *offers service as a FA*.
M	Minimal encapsulation	
G	Generic record encapsulation	
r	Sent as zero; *ignored on reception*	
T	FA supports *reverse tunneling*.	

Mobility Agent Solicitation

- Mobility agent solicitation (= ICMP router solicitation):



- TTL = 1: This advertisement can pass only one router.
- Destination address:
  - 224.0.0.2: "all-routers on this link" multicast address
  - 255.255.255.255: " limited-broadcast" address
  - 224.0.0.11: "all mobility agents" multicast address

Move Detection

- Mobile node may move from one network to another due to some handoff mechanism without IP level being aware
  - Agent discovery process is intended to enable the agent to detect such a move.
- Algorithms to detect move:
  - Use of lifetime field – mobile node uses lifetime field as a timer for agent advertisements
  - Use of network prefix – mobile node checks if any newly received agent advertisement messages are on the same network as the node's current care-of address

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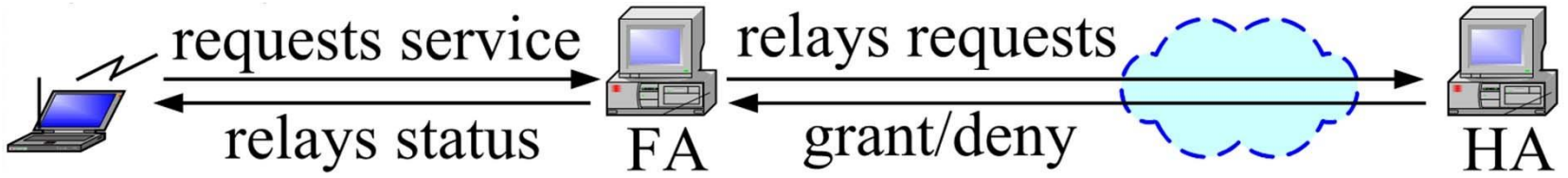
Registration Process

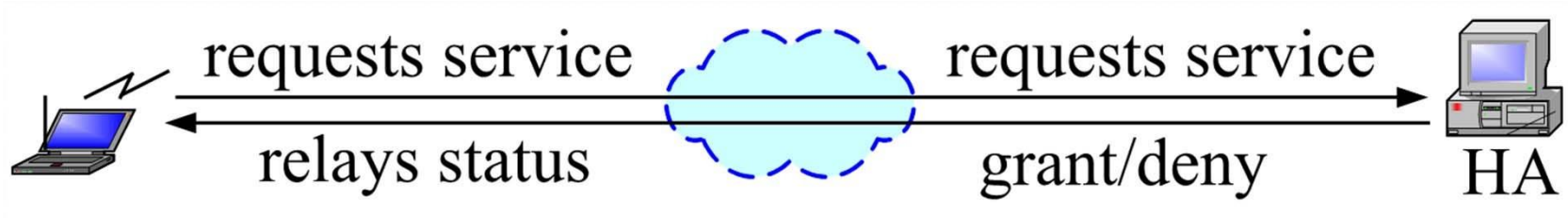
- MN requests the forwarding service by sending a registration request to the FA.
- FA relays the request to MN's HA.
- HA sends a registration reply to the FA
  - Accept or deny
- FA relays the reply to MN.

Registration Procedures

- Registering via an FA:



- Registering directly with the HA:



Registration Request (1/2)

- Format of the request message:
  - IP fields: (typically)
    - Source address: Interface address from which the message is sent
    - Destination address: Interface address of FA or HA
  - UDP fields:
    - Source port: Variable
    - Destination port: 434
  - Mobile IP fields: (see the next page)

type=1	S	B	D	M	G	r	T	x	lifetime
home address									
home agent (IP of the home agent)									
care-of address									
identification									
extensions									

Registration Request (2/2)

- Mobile IP fields

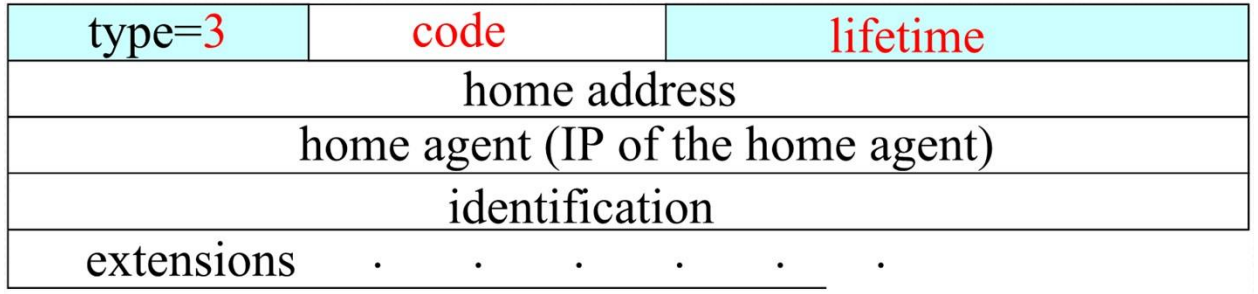
Field	Name	Meaning
S	Simultaneous bindings	1: Retain prior mobility binding
B	Broadcast data	1: Forward broadcast data
D	Decapsulation	1: MN is using a co-located care-of address
M/G/r	Refer to page 30	
T	Reverse tunneling requested	
x	Sent as zero; *ignored on reception*	
Lifetime	Registration lifetime	Number of seconds remaining before the *registration is considered expired*.
ID	For *matching requests with replies* and *protecting against replay attacks* of registration messages (64-bit number constructed by the MN)	

Registration Reply

- Purposes of registration reply:
  - 1. Inform an MN of the status of its request.
  - 2. Indicate the lifetime granted by HA.
- Lifetime granted by HA may be smaller than that in the original request.
  - If lifetime in registration reply < lifetime in registration request, then MN uses the lifetime in registration reply.
- Lifetime is covered by mobile-home authentication extension.
  - FA is not allowed to modify the lifetime in a request/reply.
  - FA may reject the request with lifetime greater than limitation.

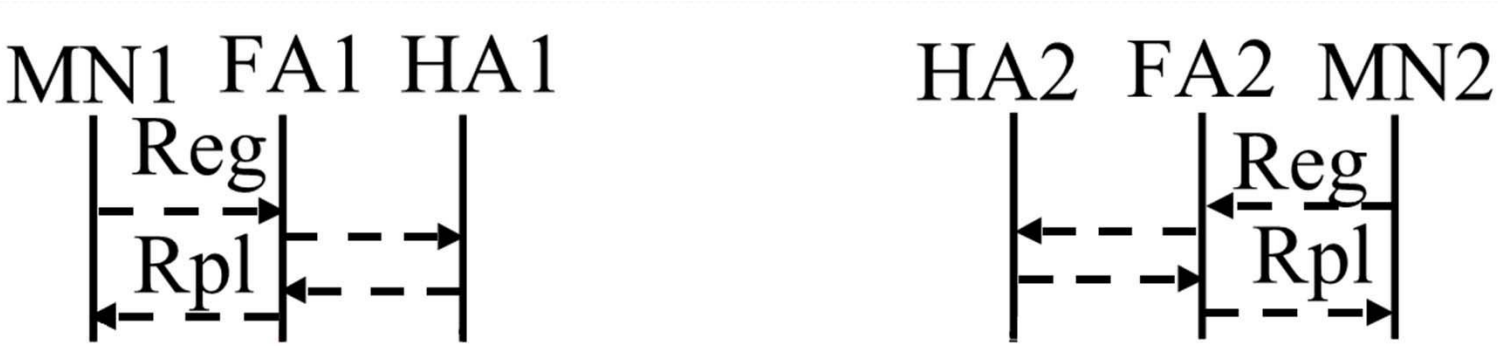
Format of Registration Reply

- IP fields:
  - Source address: Destination address of the registration request
  - Destination address: Source address of the registration request
- UDP fields:
  - Source port: Variable
  - Destination port: Source port of the registration request
- Mobile IP fields:
  - Code: Result of the registration request
  - Lifetime: Registration lifetime (duration which a binding is valid)



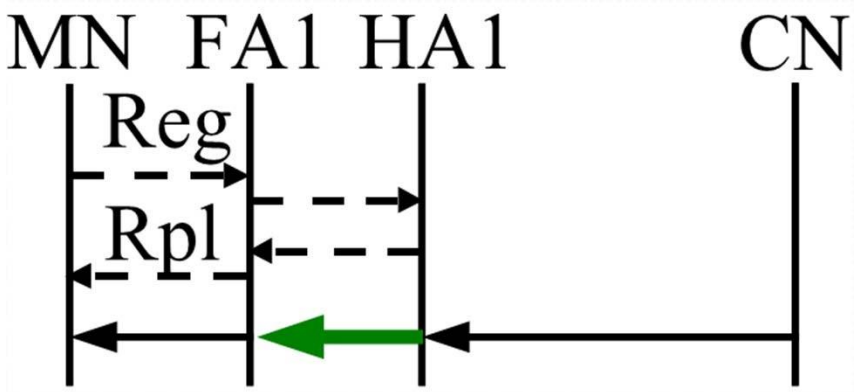
Location Tracking (1/2)

- Registration:
  - Each agent broadcasts advertisement periodically.
  - MN initiates a registration process if the MN detects that it is moving into the coverage area of a new agent.



Location Tracking (2/2)

- Delivering data to an MN in a foreign network:



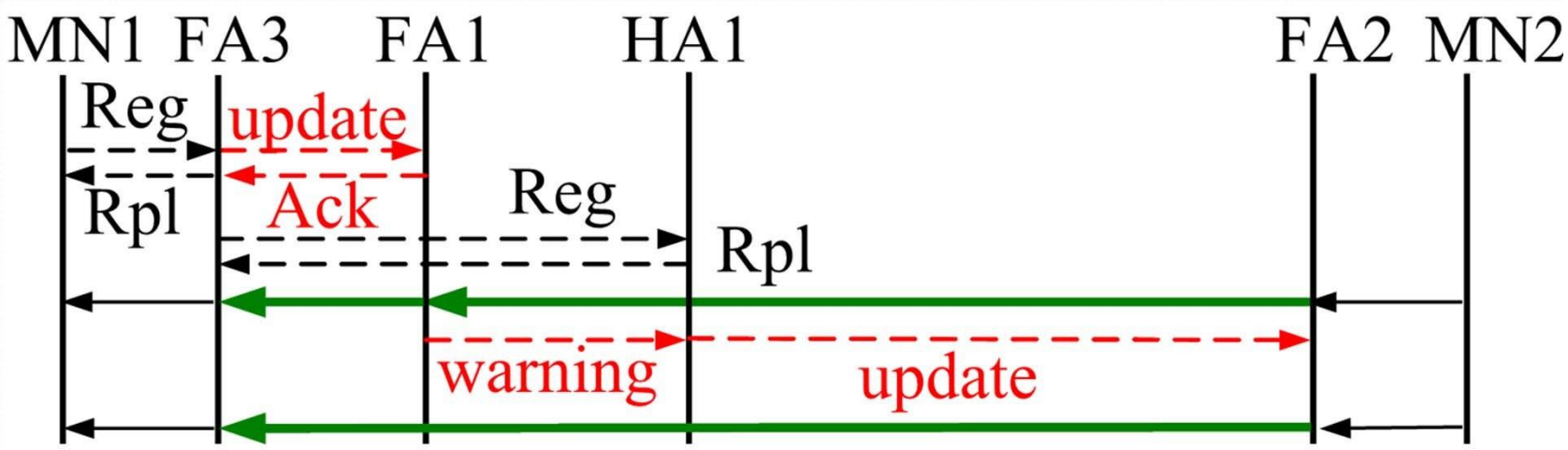
- Backward compatible:
  - Triangular routing => Route optimization

Route Optimization (1/2)

- Agents can learn and cache the current addresses of MNs.
- Case 1: MN to MN

Route Optimization (2/2)

- Case 2: MN to MN with movement
  - FA1 creates a forwarding point to forward the data in flight or sent by a mobile agent with stale binding entry.

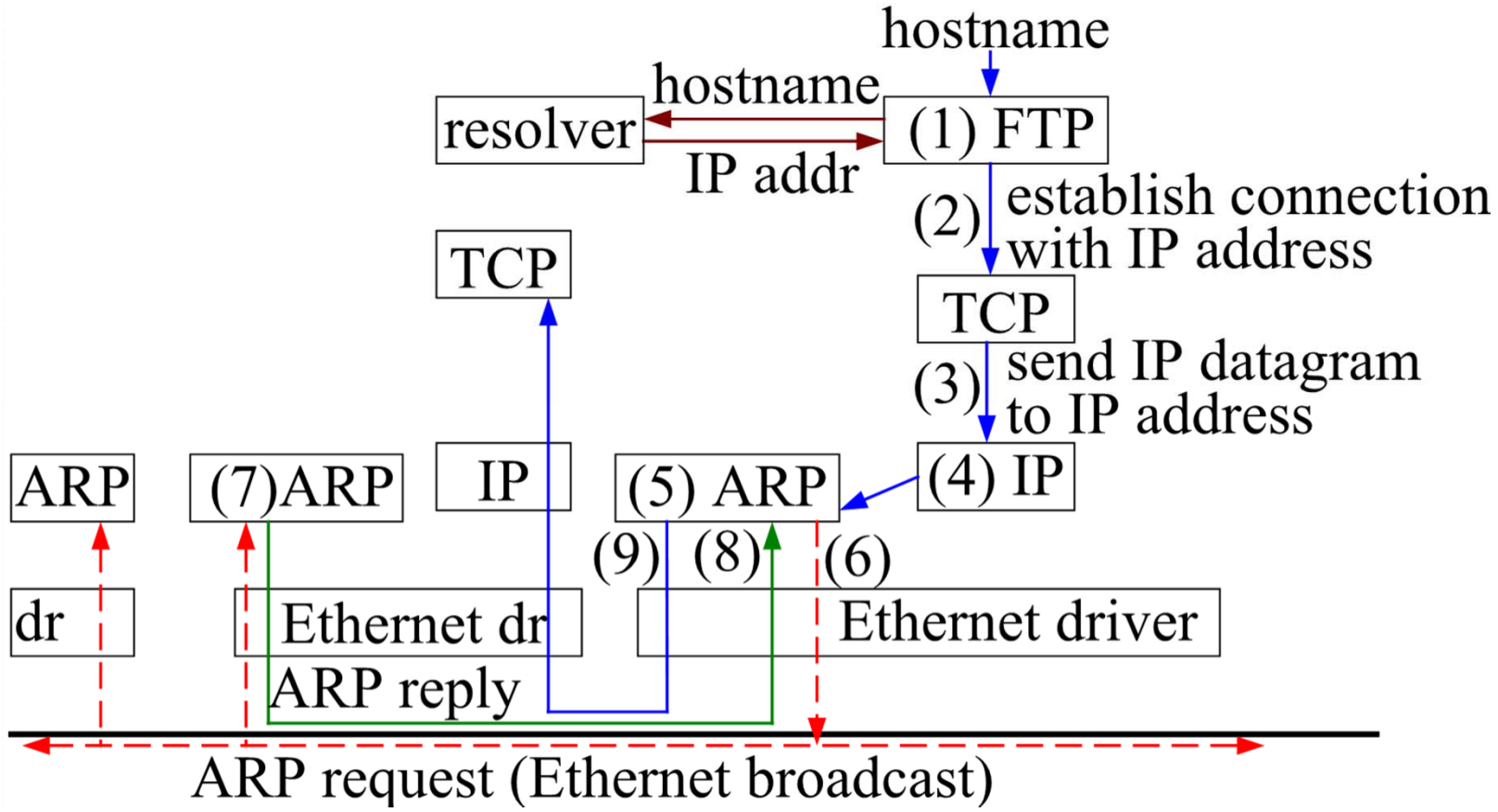


ARP (1/4)

- Two machines on a physical network communicate using their physical addresses (i.e., MAC address).
- Address resolution protocol (ARP):
  - Map Internet (IP) addresses to physical (MAC) addresses.
  - Determine physical addresses when sending a packet.
  - Answer physical address requests from other machines.

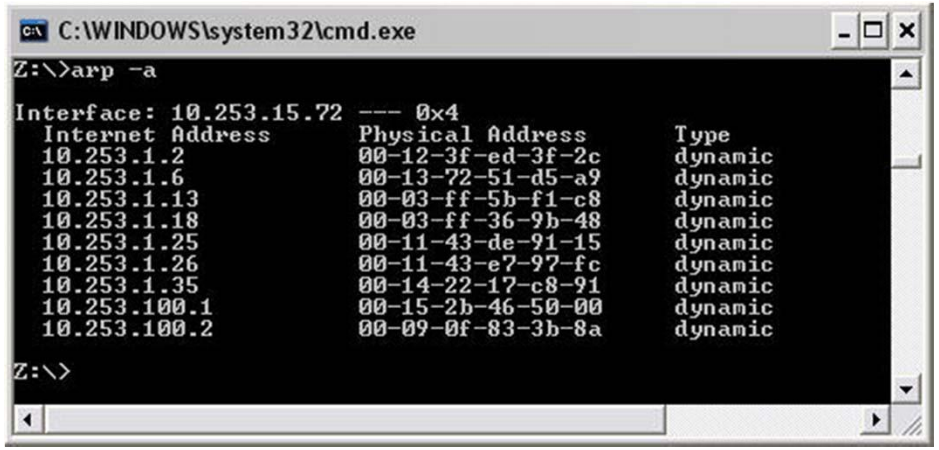
ARP (2/4)

- Operation of ARP when user types "ftp hostname":



ARP (3/4)

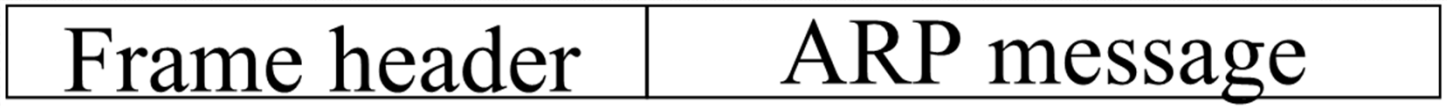
- Address resolution cache:
  - Recently acquired IP-to-physical address bindings can be cached.



- ARP refinement:
  - This is to avoid the request from an anticipated source.
  - Sender includes its IP-to-physical address binding in ARP request.
  - Receivers update the cached IP-to-physical bindings.

ARP (4/4)

- ARP encapsulation:
  - On the Ethernet, frame type is 0806_{16} for ARP messages.



- Reverse address resolution protocol (RARP):
  - Used to obtain the IP of a machine from a server
- Proxy ARP:
  - Reply ARP requests on behalf of other nodes.
- Gratuitous ARP:
  - Spontaneously cause other nodes to update an entry in their ARP cache.

ARP in Mobile IP (1/2)

- Case 1: MN registering with an FA
  - MN disables its broadcast ARPs before sending registration request.
    - This must use unicast reply for a unicast request (by FA).
  - HA performs a gratuitous ARP on behalf of the MN.
  - HA uses proxy ARP to reply ARP requests for the MN.
  - MN should reply to the ARP request in which the target address is its co-located care-of address.

ARP in Mobile IP (2/2)

- Case 2: MN returning home
  - MN enables its ARPs before sending registration request.
  - MN performs a gratuitous ARP for itself.
  - HA stops using proxy ARP for the MN.
  - HA performs a gratuitous ARP on behalf of the MN.

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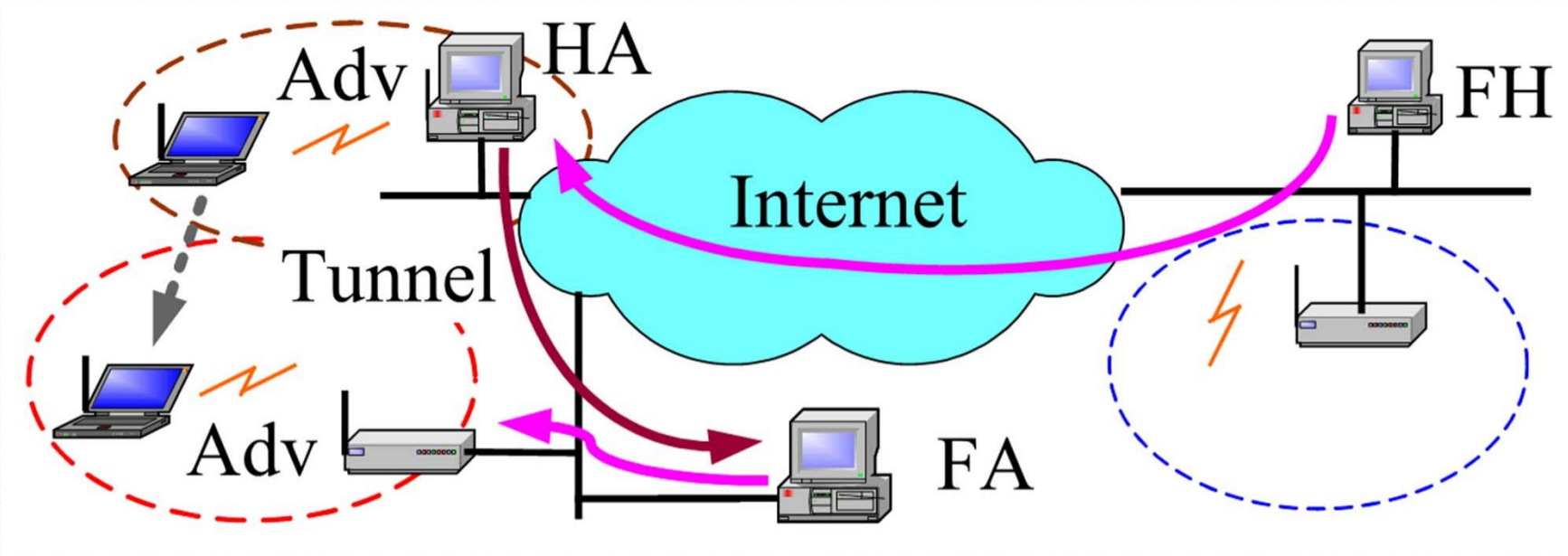
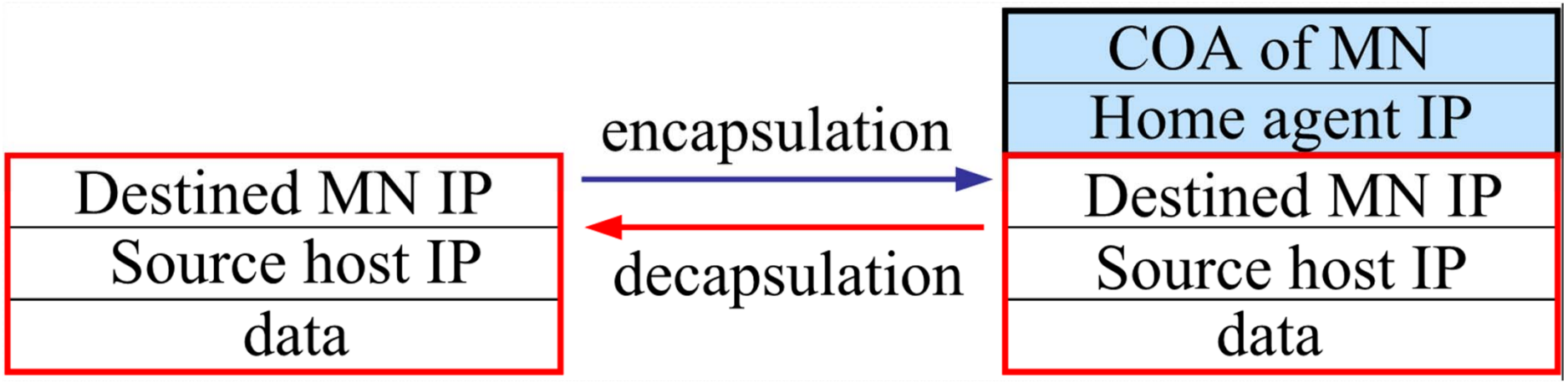
Tunneling

- Packets destined to an MN are routed to its HA using its permanent IP address.
- HA then tunnels packets to the MN using IP-in-IP encapsulation.

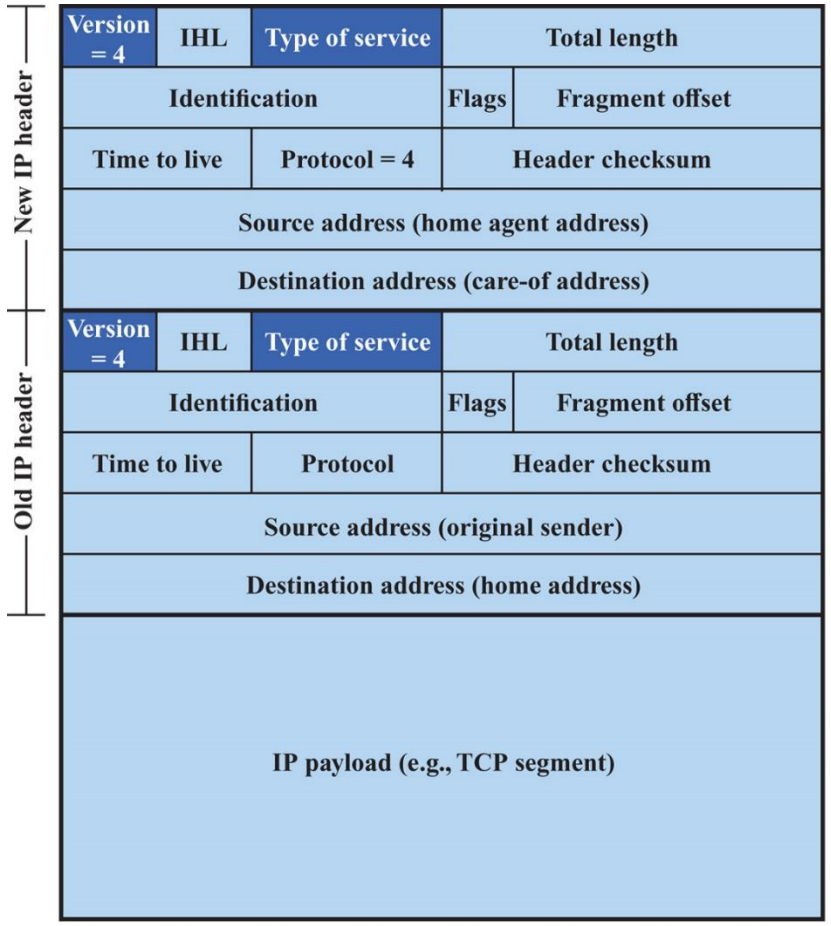


Encapsulation & Decapsulation



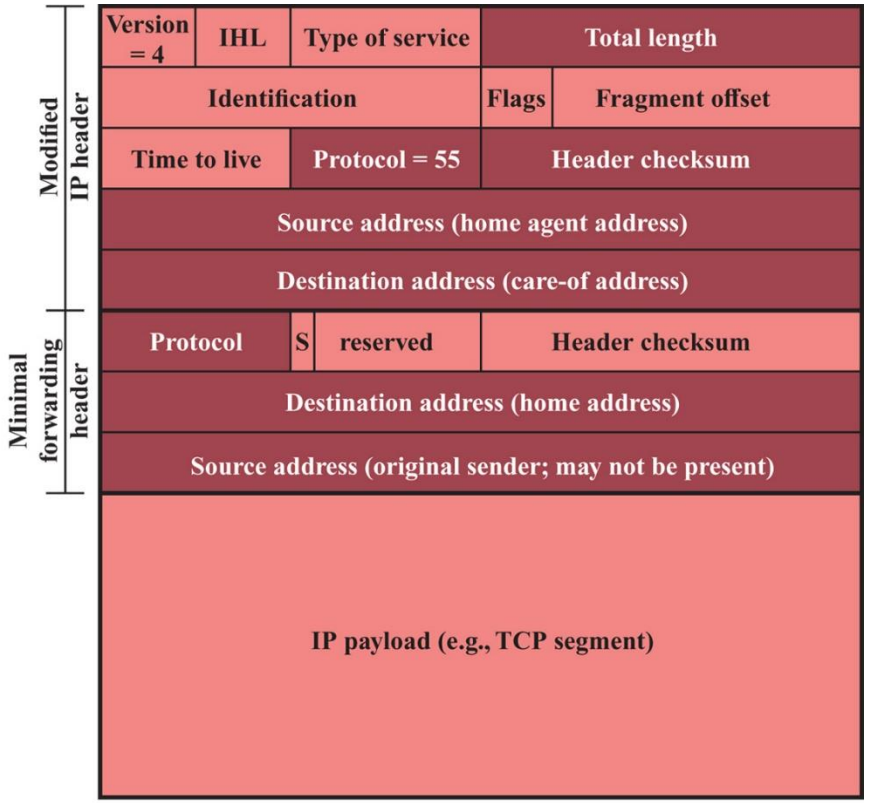
Encapsulation

- Mobile IP supports the following encapsulation schemes:
  - 1. IP-in-IP encapsulation: Required
  - 2. Minimal encapsulation: Optional
  - 3. Generic record encapsulation: Optional
- MIP requires each HA and FA to support tunneling data using IP-in-IP encapsulation.
- Any MN that uses a co-located care-of address is required to support receiving data tunneled using IP-in-IP encapsulation.



Shaded fields are copied from the inner IP header to the outer IP header.

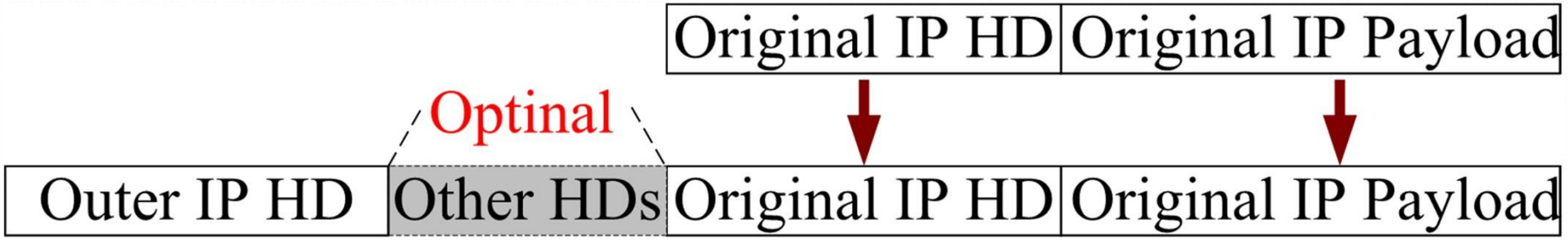
(a) IP-within-IP encapsulation



Shaded fields in the inner IP header are copied from the original IP header.
Shaded fields in the outer IP header are modified from the original IP header.

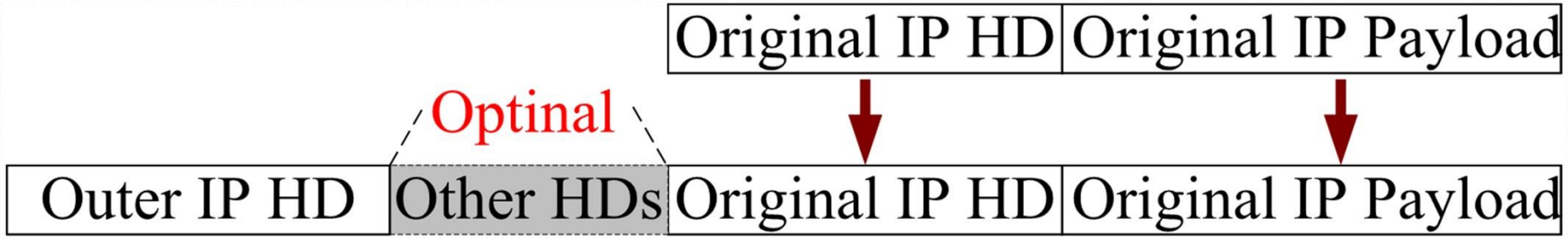
(b) Minimal encapsulation

IP-in-IP Encapsulation (1/3)



- Outer IP header: Source address and destination address identify the end-points of the tunnel.
  - HA (home agent) ⇔ FA (foreign agent)
- Inner IP header: Source address and destination address identify the original sender and recipient, respectively.
  - CN (correspondent node) ⇔ MN (mobile node)

IP-in-IP Encapsulation (2/3)



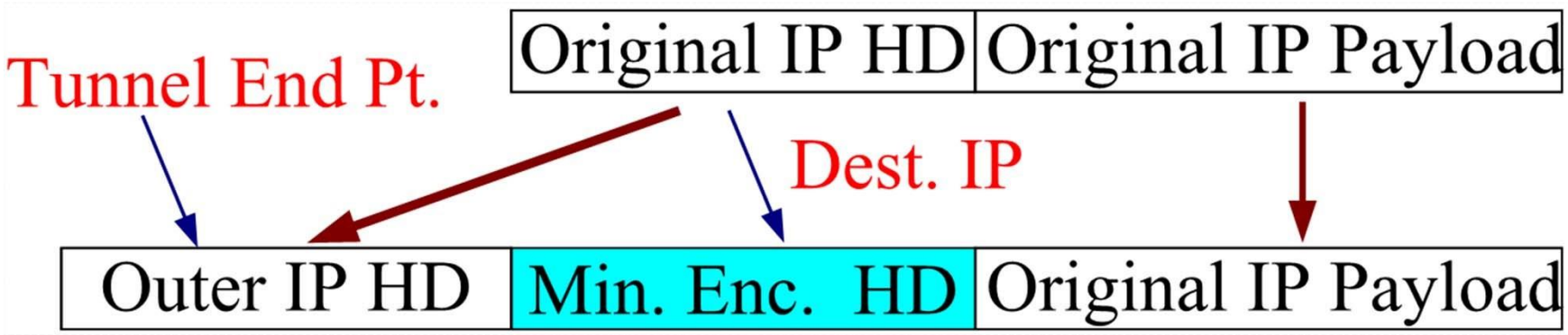
- Inner IP header is not changed by the encapsulator, except to decrement TTL.
- Other protocol headers may be inserted between the outer IP header and inner IP header.
  - Example: IP authentication header may be inserted to protect the original payload during tunneling.

IP-in-IP Encapsulation (3/3)

- Fields in the outer IP header set by the encapsulator:
  1. Version: 4
  2. IHL: Internet header length
     The length of outer IP header (measured in 32-bit words)
  3. TOS: Type of service
     Copied from the inner IP header.
  4. Total length: Length of the entire encapsulated IP data, including the outer header.
  5. Protocol: 4, the protocol number for IP-in-IP
  6. Source address: IP address of the encapsulator; that is, the tunnel entry point
  7. Destination address: IP address of the decapsulator; that is, the tunnel exit point

Minimal Encapsulation (1/4)

- Concept of minimal encapsulation:

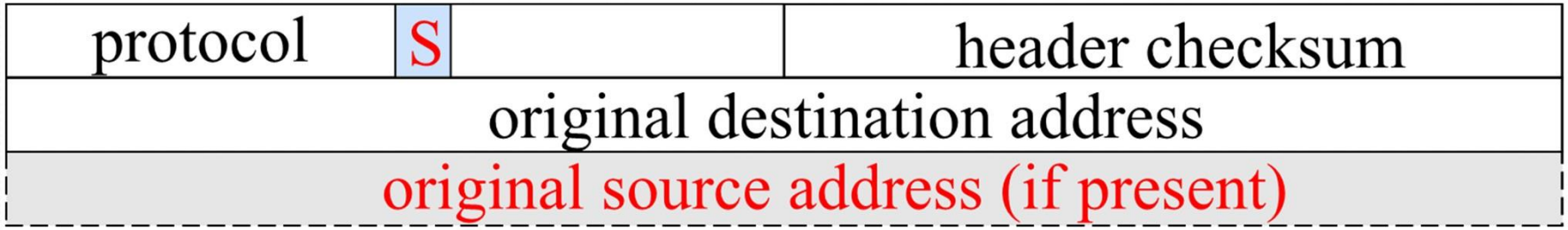


Minimal Encapsulation (2/4)

- The original IP header is modified by the minimum encapsulation as follows:
  - 1. Protocol: 55, the minimal encapsulation protocol
  - 2. Destination address: IP address of the exit point of the tunnel
  - 3. Source address: IP address of the encapsulator
  - 4. Total length: Incremented by the size of the minimal forwarding header
  - 5. Checksum: Recomputed

Minimal Encapsulation (3/4)

- Header format of the minimal encapsulation:



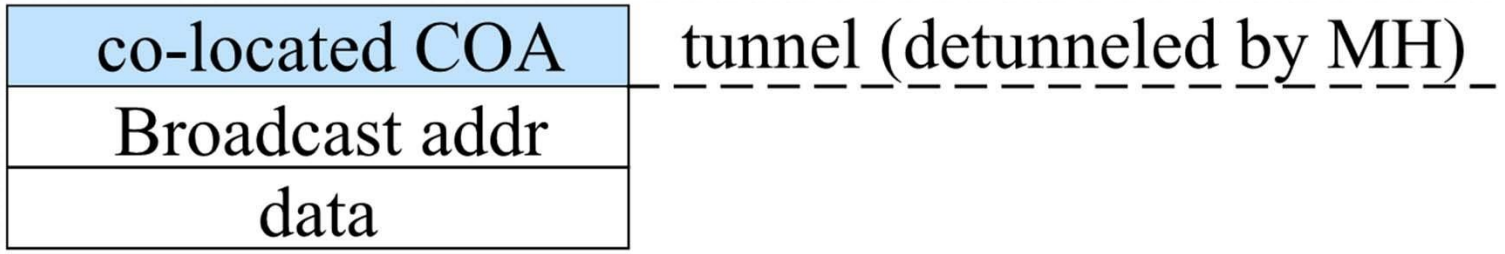
  - 1. Protocol: The protocol in the original IP header
  - 2. Original destination address: destination address in the original IP header
  - 3. Original source address: source address in the original IP header
  - 4. S flag: Original source address present bit
    - S = 0: Original source address is not presented => Size = 8
    - S = 1: Original source address is presented => Size = 12 (original source is not the encapsulator)

Minimal Encapsulation (4/4)

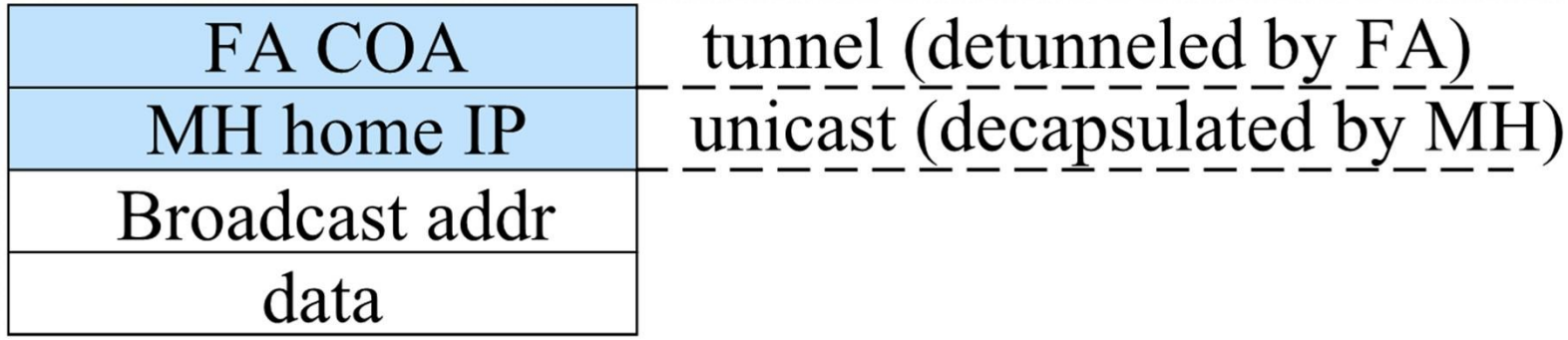
- Decapsulating a datagram with minimal encapsulation:
  - Restore the original IP header
  - Remove the minimal forwarding header
  - Decrement the total length field
  - Recompute the checksum

Broadcast in Mobile IP

- HA forwards broadcast datagrams if MNs have requested.
- Use co-located care-of address: 1-level encapsulation



- Use FA care-of address: 2-level encapsulation



Summary

- To handle the dilemma of IP addressing in supporting mobility, mobile IP is developed.
- Each MN is given a home address and one or multiple care-of address(es).
- Home agent and foreign agent are served as readdressing node and inverse-readdressing node, respectively.
- Location tracking, route optimization, agent discovery, registration, and encapsulation are important functions in mobile IP.
- Mobile IP supports IP-in-IP encapsulation, minimal encapsulation, and generic record encapsulation.