White Paper

Mobile IPv6

Mobility support for the Next Generation Internet

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IMPORTANT NOTICE

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Abbreviations

DHCP	Dynamic Host Configuration Protocol
GPRS	General Packet Radio Service
IETF	Internet Engineering Task Force
IP	Internet Protocol
IPng	Internet Protocol next generation
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
OSPF	Open Shortest Path First
RFC	Request for Comment
RIP	Routing Information Protocol
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
WAP	Wireless Application Protocol

1 Introduction

Mobility support for Internet devices is quite important, since mobile computing is getting more widespread. It is expected that the number of mobile computers will increase immense. Furthermore there are already first products of cellular phones offering IP services based on WAP or GPRS, and their number will increase rapidly. Cellular devices of the 3rd generation will be packet switched devices instead of circuit switched, therefore IP services on 3rd generation cellular devices will be an integral part in the future.

Today we have to face several problems that make roaming with mobile Internet devices difficult. Problems start if somebody disconnects his mobile device from the Internet in order to connect it elsewhere. Normally he would not be able to continue communication until he configures the system with a new IP address, the correct netmask and a new default router.

The problem is based in the routing mechanisms which are used in the Internet. IP addresses define a kind of topological relation between the linked computers. Today's versions of Internet protocols assume implicit that any node has always the same point of attachment to the Internet. Additionally the node's IP address identifies the link on which the node resides. If a node moves without changing its IP address, there is no information in its network address about the new point of attachment to the Internet. Existing routing protocols are thus not able to deliver datagrams correctly. In the scenario shown in Figure 1 packets addressed to a node with the subnet prefix B will always be routed to link B. Current Internet routing protocols require the network address to change when a host moves to a new location.

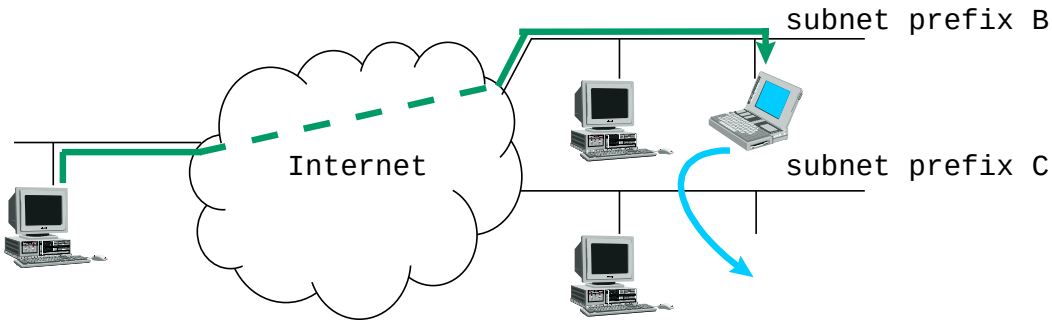


Figure 1 A node moves without changing its IP address
Packets sent to the node on link B are always routed across the Internet to link B. If this node moves to another link, it will not receive packets anymore. Packets addressed to this node are still routed to link B.

To support mobile devices, which dynamically change their access points to the Internet, the Internet Engineering Task Force (IETF) currently standardizes a protocol supporting mobile Internet devices, called Mobile IP. There are two variations of Mobile IP, Mobile IPv4, based on IPv4, and Mobile IPv6 [3], based on IPv6 [1]. This white paper focuses on Mobile IPv6.

Mobile IPv6 allows an IPv6 host to leave its home subnet while transparently maintaining all of its present connections and remaining reachable to the rest of the Internet. This is realized by Mobile IPv6 by identifying each node by its static home address, regardless of its current point of attachment to the Internet. While a mobile node is away from home it sends information about its current location to a home agent on its home link. The home agent intercepts packets addressed to the mobile node and tunnels them to the mobile node's present location.

This mechanism is completely transparent for all layers above IP, e.g. for TCP, UDP and of course for all applications. Therefore DNS entries for a mobile node refer to its home address and don't change if the mobile node changes its Internet access point. In fact Mobile IPv6 influences the routing of packets but it is independent of the routing protocol itself (RIP, OSPF, ...).

The solution given by Mobile IPv6 consists of creating a so-called care-of-address whenever a node changes its point of attachment to the web. A care-of-address can be derived from the receipt of router advertisements ("stateless address autoconfiguration" [2]), or be assigned by DHCP server ("stateful address autoconfiguration").

Mobile nodes are always identified by their (static) home address regardless of their current point of attachment to the Internet. While away from home each mobile node has an additional (temporary) address which identifies its current location (Figure 2). Thus, basically messages that arrive at the original home-address are redirected (tunneled) to the care-of-address.

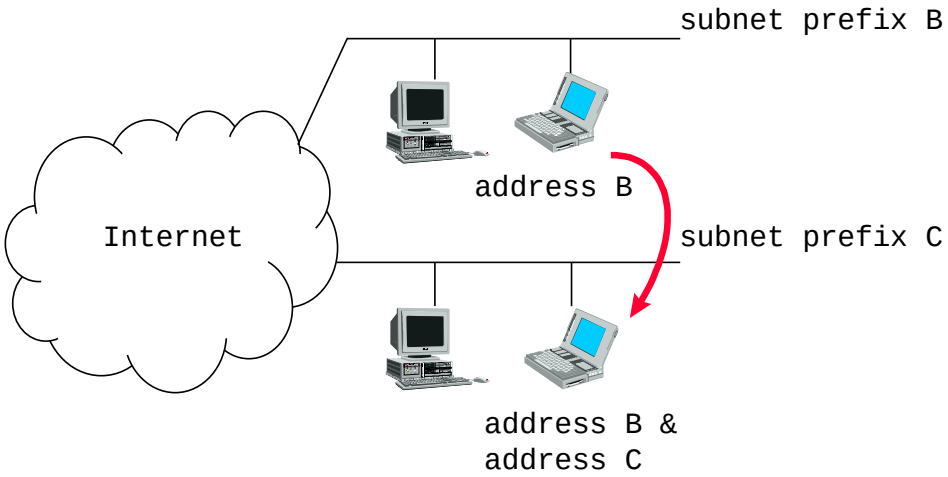


Figure 2 A mobile node moves to another link
A node moves from a link with the prefix B to a link with the prefix C. On link C the node gets an additional address which has the prefix of this link.

2 Terminology

Some special terms defined in Mobile IPv6 [3] are listed in the following:

Binding	The association of the home address of a mobile node with a care-of address for that mobile node, along with the remaining lifetime of that association.
Care-of Address	An IP address associated with a mobile node while visiting a foreign link; the subnet prefix of this IP address is a foreign subnet prefix. Among the multiple care-of addresses that a mobile node may have at a time (e.g., with different subnet prefixes), the one registered with the mobile node's home agent is called its "primary" care-of address.
Correspondent Node	A peer node with which a mobile node is communicating. The correspondent node may be either mobile or stationary.
Foreign Link	Any link other than the mobile node's home link.
Foreign Subnet Prefix	Any IP subnet prefix other than the mobile node's home subnet prefix.
Home Address	An IP address assigned to a mobile node within its home link.
Home Agent	A router on a mobile node's home link with which the mobile node has registered its current care-of address. While the mobile node is away from home, the home agent intercepts packets on the home link destined to the mobile node's home address, encapsulates them, and tunnels them to the mobile node's registered care-of address.
Home Link	The link on which a mobile node's home subnet prefix is defined. Standard IP routing mechanisms will deliver packets destined for a mobile node's home address to its home link.
Home Registration	Registration of the a mobile node with its primary care-of address.
Home Subnet Prefix	The IP subnet prefix corresponding to a mobile node's home address.
Mobile Node	A node that can change its point of attachment from one link to another, while still being reachable via its home address.
Movement	A change in a mobile node's point of attachment to the Internet such that it is no longer connected to the same link as it was previously. If a mobile node is not currently attached to its home link, the mobile node is said to be "away from home".

3 Overview of Mobile IPv6

3.1 Mobile IPv6 Messages

Mobile IPv6 requires the exchange of additional information. All new messages used in Mobile IPv6 are defined as IPv6 Destination Options. These options are used in IPv6 to carry additional information that needs to be examined only by a packet's destination node [1].

The following four new Destination Options are defined in Mobile IPv6 [3]:

Binding Update

The Binding Update option is used by a mobile node to inform its home agent or any other correspondent node about its current care-of address. Any packet including a Binding Update must also include either an AH [4] or ESP [5] header.

Binding Acknowledgement

The Binding Acknowledgement option is used to acknowledge the receipt of a Binding Update, if an acknowledgement was requested. Any packet including a Binding Acknowledgement must also include either an AH [4] or ESP [5] header.

Binding Request

The Binding Request option is used by any node to request a mobile node to send a Binding Update with the current care-of address.

Home Address

The Home Address option is used in a packet sent by a mobile node to inform the receiver of this packet about the mobile node's home address. If a packet with the Home Address option is authenticated then the Home Address option must also be covered by this authentication.

3.2 Data Structures

The Mobile IPv6 specification describes the protocol in terms of the following three conceptual data structures:

Binding Cache

Every IPv6 node has a Binding Cache which is used to hold the bindings for other nodes. If a node receives a Binding Update, it will add this binding to its Binding Cache. Every time when sending a packet, the Binding Cache is searched for an entry. In case there is an entry the packet is sent to the care-of address of the correspondent node using a routing header.

Binding Update List

Every mobile node has a Binding Update List which is used to store information about each Binding Update sent by this mobile node for which the lifetime has not expired yet. It contains all Binding Updates sent to any (mobile or stationary) correspondent nodes and to its home agent.

Home Agents List

For each home link a node serves as home agent it generates a list, which contains information about all other home agents on this link. The information in this list is learned from unsolicited multicast Router Advertisements, which are sent by all home agents, and which have the home agent bit set if the sender serves as home agent on that link. The information about all other home agents is used by the Dynamic Home Agent Discovery mechanism.

3.3 Mobile IPv6 Operation

The mechanisms of Mobile IPv6 will be explained using the scenario shown in Figure 3

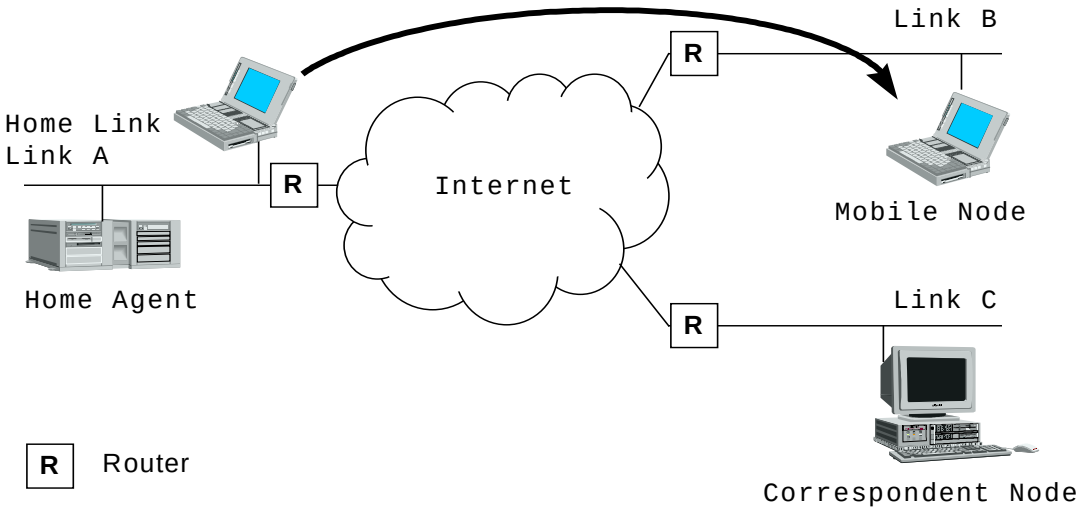


Figure 3 Mobile IPv6 scenario
Link A is the home link of the mobile node which has moved to link B. Another node is connected to link C.

The scenario above shows three links and three systems. On link A resides a router which offers home agent service. This link is also the home link of a mobile node. This mobile node has just moved from link A to link B. Additionally there is correspondent node on link C. This node maybe mobile or stationary.

Home Agent Registration

As soon as a mobile node detects that it has moved from one link to another and it has discovered a new default router, a mobile node performs (stateful or stateless) address autoconfiguration. It uses this new formed address as its care-of address. The prefix of this care-of address is the prefix of the link being visited by the mobile node. All packets addressed to this care-of address will reach the mobile node on the current link.

The mobile node registers its care-of address with its home agent on the home link. Therefore the mobile node sends a packet to its home agent containing a "Binding Update" destination option (Figure 4). The home agent registers this binding and returns a packet with a "Binding Acknowledgement" destination option to the mobile node.

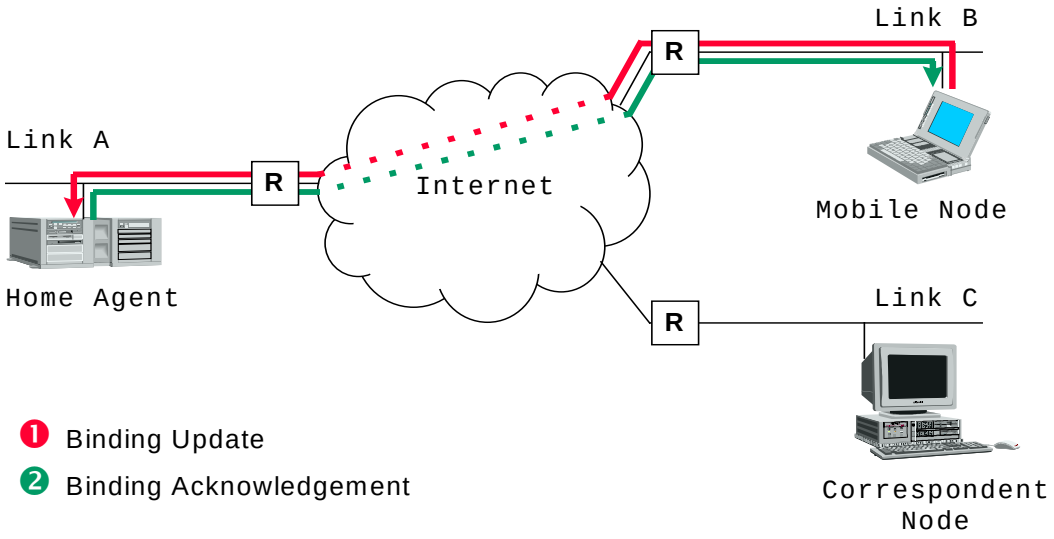


Figure 4 The mobile node registers with its home agent
The mobile node sends a Binding Update to a home agent on its home link. This home agent accepts the Binding Update and returns a Binding Acknowledgement.

Triangle Routing

Now the home agent intercepts any packets addressed to the mobile node's home address. Therefore it uses proxy Neighbor Discovery. Proxy Neighbor Discovery means that the home agent multicasts a Neighbor Advertisement onto the home link on behalf of the mobile node. This advertises the home agent's own link layer address for the mobile node's home address. The home agent replies also to Neighbor Solicitations on behalf of the mobile node. Each intercepted packet is tunneled to the registered care-of address of the mobile node using IPv6 encapsulation.

If the mobile node sends packets to any other node, it sends packets directly to the destination. The mobile node sets the source address of this packet to the

care-of address and includes a "Home Address" destination option. Because the home address is static (in contrast to the care-of address), this allows every correspondent node the transparent use of the care-of address for layers above the Mobile IPv6 support. Higher layers (including applications) do not notice the care-of address, they only notice the home address.

If a mobile node communicates with a correspondent while being away from home, packets are routed from the correspondent node to the home agent, from the home agent to the mobile and from the mobile to the correspondent. This routing anomaly is called Triangle Routing (Figure 5).

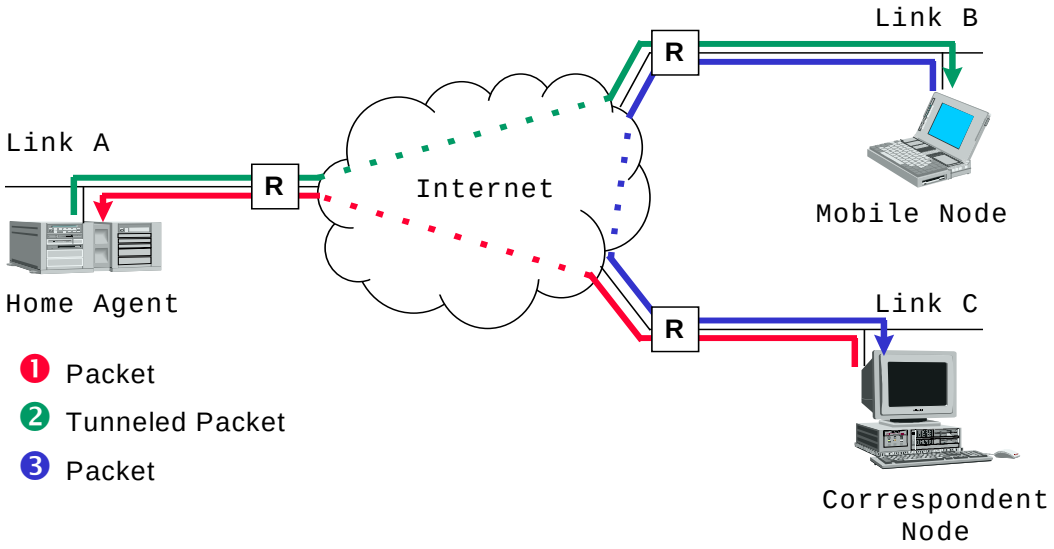


Figure 5 Triangle Routing
The home agent intercepts packets addressed to the mobile node's home address using proxy Neighbor Discovery. It tunnels these intercepted packets to the current care-of address of the mobile node while the mobile node is away from home.

Route Optimization

To avoid triangle routing a mobile node can send Binding Updates to any (mobile or stationary) correspondent node. This allows correspondent IPv6 nodes to cache the current care-of address and send packets directly to a mobile node (Figure 6).

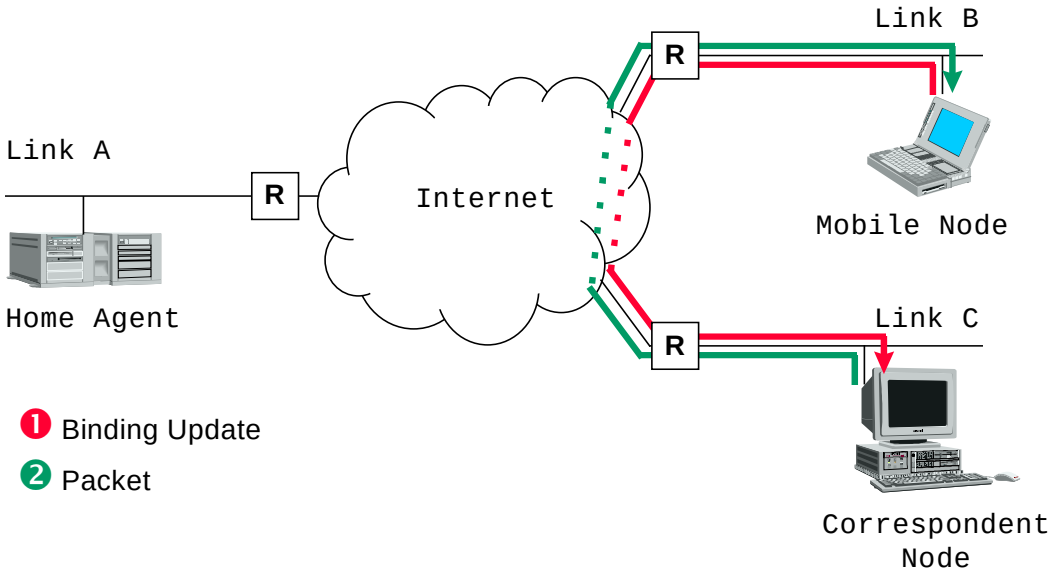


Figure 6 Route Optimization
The mobile node sends a Binding Update to a correspondent Node. The correspondent node is now able to send packets directly to the mobile node.

Any IPv6 node sending a packet first checks its Binding Cache for this destination address. If there is an entry, it will send the packet to the mobile node using a routing header (rather than IPv6 encapsulation). The route specified by this routing header has two hops (Figure 7). The first hop is the care-of address and the second hop is the home address of the mobile node. This results in the packet being directly sent to the care-of address of the mobile node. The mobile node receives this packet and "forwards" it to the next hop specified in the routing header. The next (and final) hop is the home address of the mobile node, therefore this packet will be "looped back" inside the mobile node. Afterwards the packet will be processed in the same way as if the mobile node was at home.

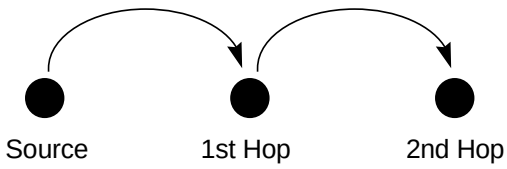


Figure 7 The routing header of a packet sent directly to a mobile node
1st Hop = care-of address of the mobile node
2nd Hop = home address of the mobile node

If the Binding Cache has no entry, this packet will be send normally. Then this packet is routed to the specified network and received by the destination node. In case the destination is a mobile node which is away from home, this packet will be intercepted by the home agent on the home link and tunneled to the mobile node.

Binding Management

A mobile node, which configured a new care-of address as primary care-of address, has to register this new address at its home agent and at the correspondent nodes, which already have been informed about the mobile node's binding. For this purpose the mobile node sends a Binding Update containing its new binding. To make sure, that the intended receiver receives this Binding Update, the mobile node can enforce the receiver to acknowledge the receipt of the Binding Update by responding with a Binding Acknowledgement. To trigger this acknowledgement, the mobile node sets the Acknowledge bit in the Binding Update. Until receipt of the acknowledgement the mobile node continues retransmitting the Binding Update periodically.

In case a mobile node receives a packet from a correspondent node it is able to detect, if the sending correspondent node has already a Binding Cache entry. If the correspondent node has a Binding Cache entry for that mobile node, it addresses the packet directly to the mobile node's care-of address. Otherwise the correspondent node sends that packet to the mobile node's home address which is tunneled by the home agent to the mobile node's care-of address. In this case the mobile node receives a tunneled packet. The mobile node may send a Binding Update to the correspondent node to enable it, to send future packets directly to the mobile node without tunneling by the home agent.

A mobile node MUST set the Acknowledge bit in Binding Updates addressed to a home agent. The mobile node may also set the Acknowledgement bit in Binding Updates sent to a corresponding node. If the Binding Update was not received by the corresponding node, the mobile node would recognize this in receiving still tunneled packets from the home agent.

Before expiration of a Binding Cache entry for a mobile node the correspondent node can initiate a refreshing of the binding by sending a Binding Request towards the mobile node. Receiving this Binding Request the mobile node may reply with a Binding Update.

Movement Detection

While away from home, a mobile node selects one router as its default router and one subnet prefix advertised by that router to use as the subnet prefix in its primary care-of address.

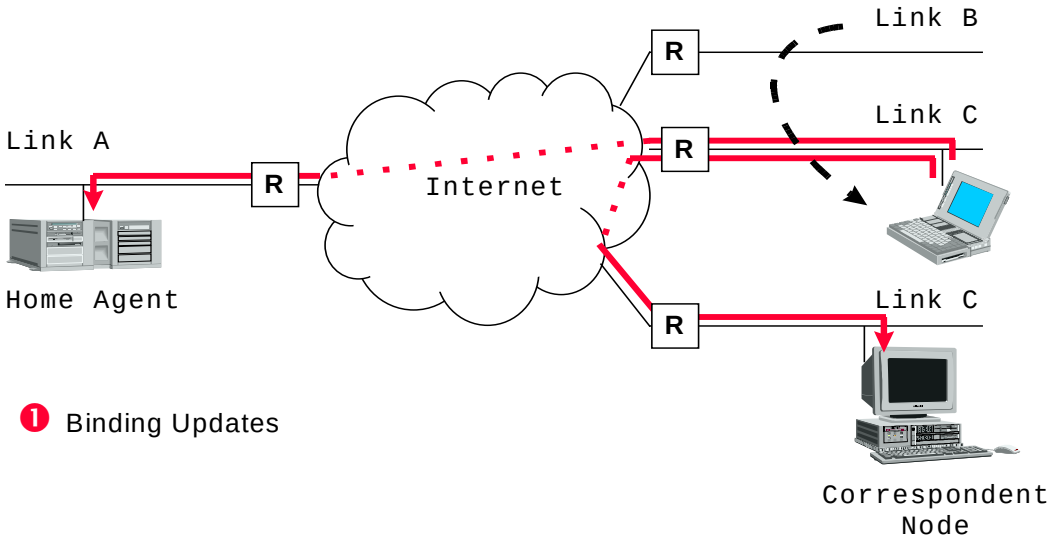


Figure 8 Location updating
The mobile node has moved from one link to another and sends Binding Updates to its home agent and other correspondent nodes

A mobile node can use any combination of mechanisms available to detect when it has moved from one link to another. One possibility is to wait for the periodically sent Router Advertisements. If the mobile node receives no Router Advertisements for a certain time, it will assume that this default router is no longer reachable and decide to switch to another router from which it may currently receive Router Advertisements.

As soon as the mobile node detects that it has moved to another link, it sends a Binding Update to its home agent and to correspondent nodes which have an entry in the Binding Update List (Figure 8). In this way the mobile node advertises its new care-of address.

4 Home Agent Discovery Mechanism

Assuming that a mobile node does not know the IP address of its home agent, Mobile IPv6 provides a mechanism that allows a mobile node to dynamically discover the IP address of a home agent on its home link with which it may register its care-of address while being away from home.

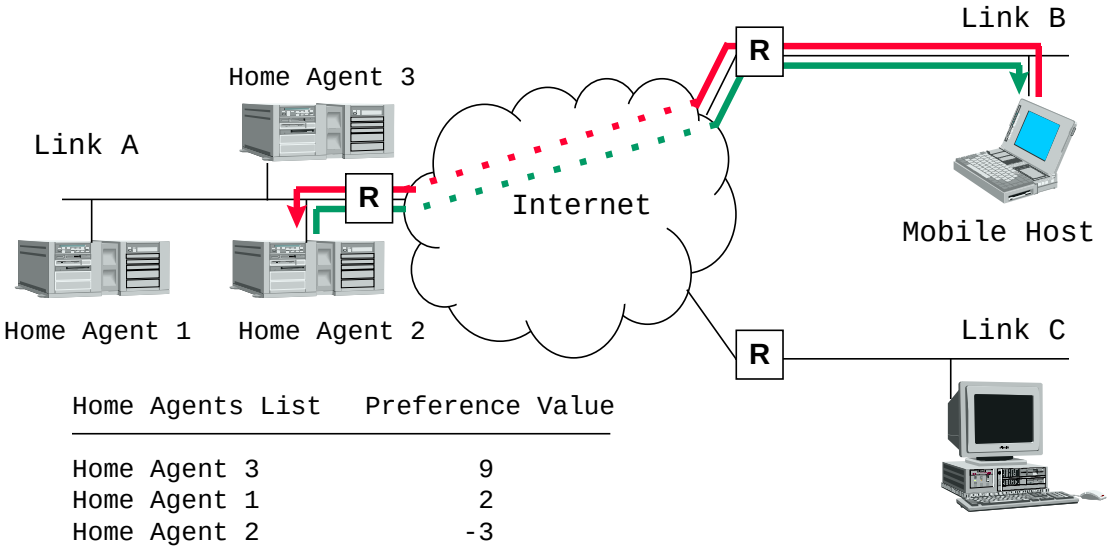
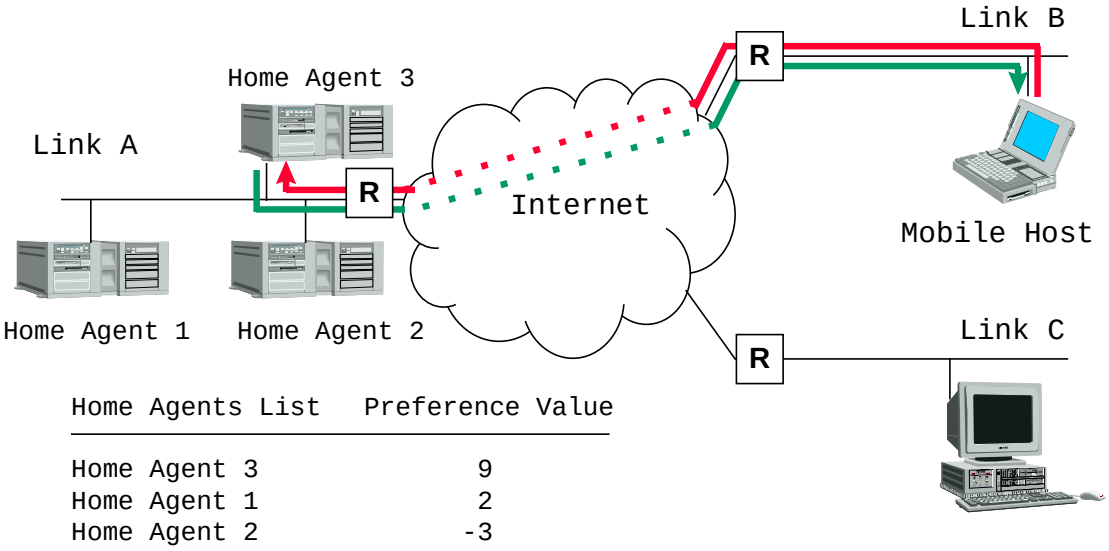


Figure 9 Dynamic Home Agent Address Discovery (1/2)
The mobile node sends a Binding Update to the Home-Agents anycast address. One home agent on the home link returns a Binding Acknowledgement which rejects the Binding Update but includes the Home Agents List.

The mobile node sends a Binding Update to the "Home Agents' anycast address" [6] for its own home subnet prefix and thus reaches one of the (possible many) routers on its home link currently operating as a home agent. This home agent rejects the mobile node's Binding Update and returns in response a list of all home agents on the home link in the Binding Acknowledgement (Figure 9). This "Home Agents List" is maintained by each home agent on the home link and learned through the periodic sent unsolicited multicast Router Advertisements. The IP addresses of the home agents in this list are placed in order of decreasing preference value of each home agent. The mobile node sends a Binding Update to one of these addresses of this list and waits for the matching Binding Acknowledgement (Figure 10). If it does not receive a Binding Acknowledgement or is rejected, the mobile node may try to register with another home agent of this

list. It should try the IP addresses in the listed order because the first address is the most preferable home agent and the last address is the least preferable home agent.



Home Agents List	Preference Value
Home Agent 3	9
Home Agent 1	2
Home Agent 2	-3

1. Binding Update to Home Agent 3
2. Binding Acknowledgement, registration OK

Figure 10 Dynamic Home Agent Discovery (2/2)
The mobile node has just received the Home Agents List and sends a Binding Update to the most preferable home agent (Home Agent 3).

5 Advantages of Mobile IPv6

Principally the mobility support for Internet devices is possible and standardized for both IP protocol versions, IPv4 and IPv6, but due to the enhanced functionality and later design of IPv6 some features concerning the mobility support have been integrated more efficiently in Mobile IPv6 compared to Mobile IPv4. This chapter shortly lists the main advantages of Mobile IPv6, some additional advantages are listed in [3].

- Mobile IP has to assign global IP addresses to a mobile node on each point it attaches the Internet. On links which serve for mobile nodes a set of IP addresses (at least one) assigned as mobile node care-of addresses has to be reserved. Due to address shortage in IPv4 there may be problems on some links to reserve enough global IPv4 addresses, for IPv6 there are enough addresses available.
- Using anycast addresses of IPv6 enables a node to send a packet to one out of several systems having this anycast address assigned to one of their interfaces. Mobile IPv6 makes efficient use of this mechanism for the Dynamic Home Agent Discovery mechanism by sending a Binding Update to the home agent anycast address and getting response from exactly one of several home agents. IPv4 doesn't provide such an elegant solution.
- Using stateless address autoconfiguration and neighbor discovery mechanisms Mobile IPv6 neither needs DHCP nor foreign agents on foreign links to configure the care-of addresses of mobile nodes.
- Mobile IPv6 can use IPSec for all security requirements, like authentication, data integrity protection, and replay protection.
- To avoid waste of bandwidth due to triangle routing, Mobile IP specifies the mechanisms of Route Optimization. While Route Optimization is an additional functionality for Mobile IPv4, it is an integral part of Mobile IPv6.
- There are several routers in the Internet, which execute "ingress-filtering" for the packets to be forwarded by them, that is they check, if the source address of a packet could be reached over the interface the packet has been received. Mobile IPv6 can coexist with "ingress-filtering" without problems. A mobile node on a foreign link uses its care-of address as source address of its packets, and includes its home address in the Home Address destination option. As the care-of address is a valid address on the foreign link, the packet will pass "ingress-filtering" without any problems.

6 References

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