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## Mobile IPv6 Fast Handovers for 3G CDMA Networks

### Status of This Memo

This memo provides information for the Internet community. It does not specify an Internet standard of any kind. Distribution of this memo is unlimited.

### Abstract

Mobile IPv6 is designed to maintain its connectivity while moving from one network to another. It is adopted in 3G CDMA networks as a way to maintain connectivity when the mobile node (MN) moves between access routers. However, this handover procedure requires not only movement detection by the MN, but also the acquisition of a new Care-of Address and Mobile IPv6 registration with the new care-of address before the traffic can be sent or received in the target network. During this period, packets destined for the mobile node may be lost, which may not be acceptable for a real-time application such as Voice over IP (VoIP) or video telephony. This document specifies fast handover methods in the 3G CDMA networks in order to reduce latency and packet loss during handover.

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## 1. Introduction

Mobile IPv6 [2] allows mobile nodes (MNs) to maintain persistent IP connectivity while the MN moves around in the IPv6 network. It is adopted in 3G CDMA networks for handling host-based mobility management [12]. During handover, however, the mobile node (MN) needs to switch the radio link to obtain a new Care-of Address (CoA) and to re-register with the home agent (HA), which may cause a communication disruption. This is not desirable for real-time applications such as VoIP and video telephony. To reduce this disruption time or latency, a fast handover protocol for Mobile IPv6 [3] is proposed. RFC 4260 [7] further describes how this Mobile IPv6 Fast Handover could be implemented on link layers conforming to the IEEE 802.11 suite of specifications. However, 3G CDMA and IEEE 802.11 networks are substantially different in the radio access, the representations of the network nodes or parameters, and the network attachment procedures; for example, the beacon scanning or New Access Router (NAR) discovery based on [Access Point Identifier, Access Router-info (AP-ID, AR-info)] tuples specified in RFC 4260 can not be directly applied to 3G CDMA networks. This document therefore specifies how Mobile IPv6 fast handovers can be applied in the 3G CDMA networks.

## 2. Requirements Notation

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [1].

## 3. Terminology

This document refers to [3] for Mobile IPv6 fast handover terminology. Terms that first appear in this document are defined below:

**Access Network Identifier (ANID):** An identifier that is used by the Packet Data Serving Node (PDSN) to determine whether the MN is being handed off from the access network that was not previously using this PDSN. Anytime the MN crosses into a new region, which is defined by the ANID, it must re-register with that access network. The ANID is further composed of the System ID (SID), Network ID (NID), and Packet Zone ID (PZID) and these values are administered by the operator. The lengths of the SID, NID, and PZID are 2 octets, 2 octets, and 1 octet, respectively. Thus, that of the ANID occupies 5 octets [11].

**Forward Pilot Channel:** A portion of the Forward Channel that carries the pilot. The Forward Channel is a portion of the physical layer channels transmitted from the 3G CDMA access network to the MN. Further, several sets of pilots (e.g., the active set or neighbor set) are defined to determine when and where to handover.

**Home Link Prefix (HLP):** The prefix address assigned to the home link where the MN should send the binding update message. This is also called Home Network Prefix (HNP) and one of the bootstrap parameters for the MN.

**International Mobile Subscriber Identity (IMSI):** The IMSI is a string of decimal digits, up to a maximum of 15 digits, that identifies a unique mobile terminal or mobile subscriber internationally. The IMSI consists of three fields: the Mobile Country Code (MCC), the Mobile Network Code (MNC), and the Mobile Subscriber Identification Number (MSIN). An example of the IMSI is "440701234567890", where "440" is the MCC, "70" is the MNC, and "1234567890" is the MSIN. The IMSI conforms to the ITU-T E.212 numbering standard [6]. In this specification, IMSI is an ASCII string that consists of not more than 15 decimal digits (ASCII values between 30 and 39 hexadecimal), one character per IMSI digit. The above example would therefore be encoded as "34 34 30 37 30 31 32 33 34 35 36 37 38 39 30" in hexadecimal notation.

**Mobile Identity (MN ID):** An identifier of the Mobile Node that is used by the access network. The value (e.g., IMSI) is unique within the operator's network.

**Packet Data Serving Node (PDSN):** An entity that routes MN originated or MN terminated packet data traffic. A PDSN establishes, maintains, and terminates link-layer sessions to MNs. A PDSN is the access router in the visited access provider network.

**Sector Address Identifier (SectorID):** A typical cell divides its coverage area into several sectors. In 3G CDMA systems, each sector uses a different PN (Pseudo Noise) code offset and is associated with SectorID. The SectorID is 128 bits long and can be represented in the IPv6 address format [8].

#### 4. Network Reference Model for Mobile IPv6 over 3G CDMA Networks

Figure 1 shows a simplified reference model of the Mobile IP enabled 3G CDMA networks. The home agent (HA) and Authentication, Authorization, and Accounting (AAA) server of the mobile node (MN) reside in the home IP network, and the MN roams within or between the access provider network(s). Usually, the home IP network is not populated by the MNs, which are instead connected only to the access provider networks. Prior to the Mobile IPv6 registration, the MN establishes a 3G CDMA access technology specific link-layer connection with the access router (AR). When the MN moves from one AR to another, the link-layer connection is re-established, and a Mobile IPv6 handover is performed. Those ARs reside in either the same or different access provider network(s). The figure shows the situation, where the MN moves from the Previous Access Router (PAR) to the New Access Router (NAR) via the radio access network (RAN).

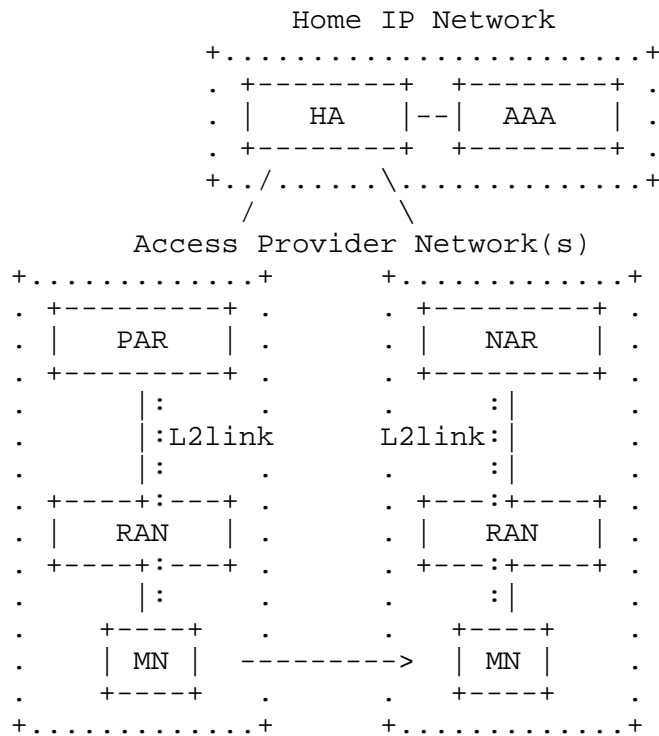


Figure 1: Reference Model for Mobile IP

In 3G CDMA networks, pilot channels transmitted by base stations allow the MN to obtain a rapid and accurate C/I (carrier to interference) estimate. This estimate is based on measuring the strength of the Forward Pilot Channel or the pilot, which is associated with a sector of a base station (BS). The MN searches for the pilots and maintains those with sufficient signal strength in the pilot sets. The MN sends measurement results, which include the offsets of the PN code in use and the C/Is in the pilot sets, to provide the radio access network (RAN) with the estimate of sectors in its neighborhood. There are several triggers for the MN to send those estimates, e.g., when the strength of a pilot in the pilot sets exceeds that of the current pilot, the MN sends the estimates to the access network. As long as the sector to which the MN is going to move belongs to the same access network, the mobility within that access network is handled by the access-specific interfaces [10] and the link-layer connection between the MN and AR can be maintained without a re-establishment. The MN can continually search for pilots without disrupting the data communication and a timely handover is assisted by the network. If, however, the serving access network finds that the sector associated with the highest pilot strength belongs to a different AR, it attempts to close the connection with the MN. The MN then attempts to get a new traffic channel assigned

in the new access network, which is followed by establishing a new connection with the new AR. This could cause a noticeable communication disruption and lead to a serious degradation of the user experience. In order to minimize the service degradation, during the handover between ARs, an IP-level fast handover approach as defined in RFC 5268 needs to be involved. If the air interface information can be used as a trigger for the handover between access routers, fast and smooth handover of Mobile IPv6 can be realized in 3G CDMA networks. The MN can continually search for pilots without disrupting the data communication and a timely handover is assisted by the network.

To assist the handover of the MN to the new AR, various types of information can be considered: the pilot sets, which include the candidates of the target sectors or BSs, the cell information where the MN resides, the serving nodes in the radio access network, and the location of the MN, if available. To identify the access network that the MN moves to or from, the Access Network Identifiers (ANID) or the subnet information can be used [9][10]. In this document, a collection of such information is called "handover assist information". In 3G CDMA networks, the Link-Layer Address of the New Access Point (AP) defined in [3] may not be available. If this is the case, the Handover Assist Information option defined in this document SHOULD be used instead.

## 5. Fast Handover Procedures

There are two modes defined in [3] according to the time of sending the FBU (Fast Binding Update); one is called "predictive mode", where the MN sends the FBU and receives the FBack (Fast Binding Acknowledgment) on the PAR's (Previous Access Router's) link and the other is called "reactive mode", where the MN sends the FBU from the NAR's (New Access Router's) link. In the predictive mode, the time and place the MN hands off must be indicated sufficiently before the time it actually happens. In cellular systems, since handovers are controlled by the network, the predictive mode is well applied. However, if the network is not configured to be able to identify the new AR, to which the MN is moving next, in a timely manner, the reactive mode is better applied.

Section 2 of RFC 4907 [20] suggests architectural principles on the link indication and the effectiveness of the optimization. The link indication of this document relies on 3G CDMA networks and the effectiveness of the optimization is attributed to RFC 5268. The above principles are thus considered by the related specifications referenced in this document.

### 5.1. Predictive Fast Handover

Figure 2 shows the predictive mode of MIPv6 fast handover operation. When the MN finds a sector or a BS whose pilot signal is sufficiently strong, it initiates handover according to the following sequence:

- (a) A router solicitation for proxy router advertisement is sent to the PAR. Handover assist information for the target 3G CDMA network is attached to this message.
- (b) Based on the received handover assist information, the NAR is determined and a proxy router advertisement (PrRtAdv) containing the prefix of the NAR is sent back to the MN. The MN also checks that the R flag is not set in the PrRtAdv message, which indicates the network supports the predictive fast handover mode (defined later).
- (c) The MN creates an NCoA (new CoA) and sends the Fast Binding Update (FBU) with the NCoA to the PAR, which in turn sends the Handover Initiate (HI) to the NAR.
- (d) The NAR sends the Handover Acknowledge (HACK) back to the PAR, which in turn sends the FBU acknowledgment (FBack) to the MN.
- (e) The PAR starts forwarding packets toward the NCoA and the NAR captures and buffers them.
- (f) The link-layer connection associated with the PAR is closed and a new traffic channel is assigned in the new access network.
- (g) The MN attaches to the new access network. The attachment procedure is access technology specific and that for 3G CDMA network including the PPP transactions is described later.
- (h) The MN sends the Unsolicited Neighbor Advertisement (UNA).
- (i) The NAR starts delivering packets to the MN.
- (j) The MN sends the Binding Update (BU) to the HA to update the Binding Cache Entry (BCE) with the NCoA, and the HA sends back the Binding Acknowledgment (BA) to the MN.

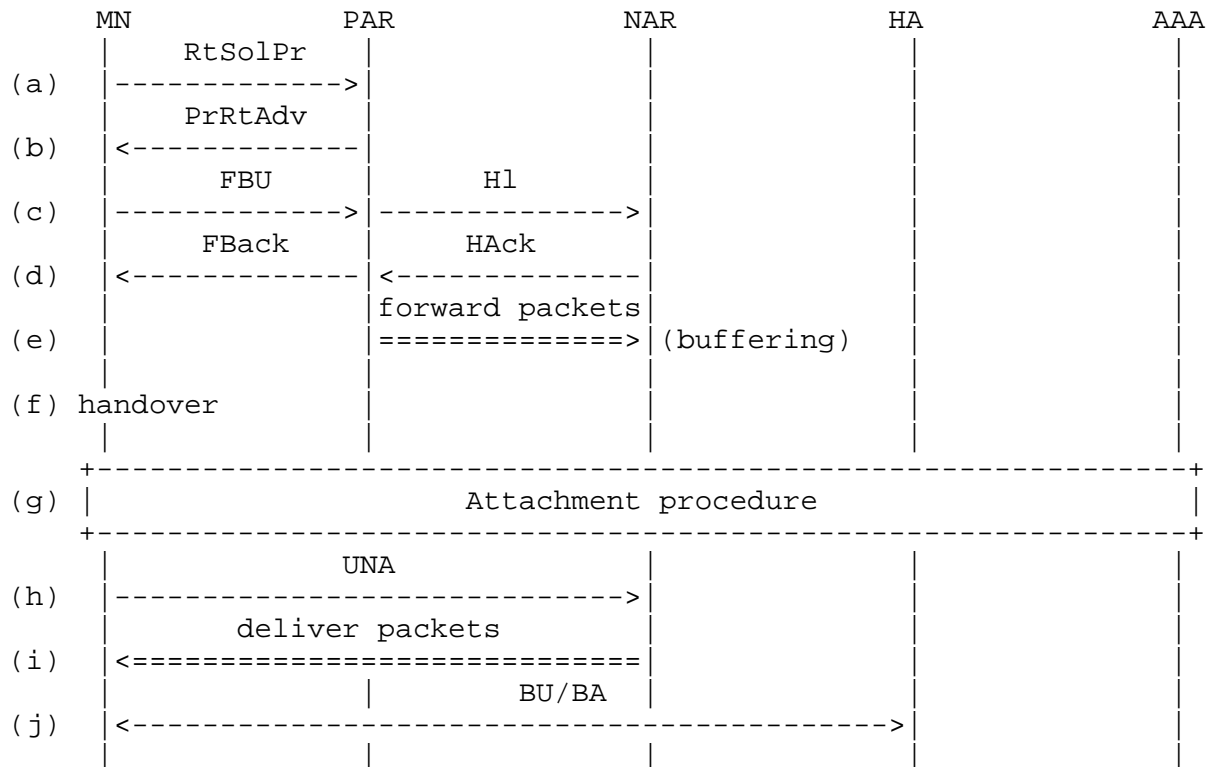


Figure 2: MIPv6 Fast Handover Operation (Predictive Mode)

It is assumed that the NAR can be identified by the PAR leveraging the handover assist information from the MN. To perform the predictive mode, the MN MUST send the FBU before the connection with the current access network is closed. If the MN fails to send the FBU before handover, it SHOULD fall back to the reactive mode. Even if the MN successfully sends the FBU, its reception by the PAR may be delayed for various reasons such as congestion. If the NAR receives the HI triggered by the delayed FBU after the reception of the UNA ((c) comes after (h)), then the NAR SHOULD send the HACK with handover not accepted and behave as the reactive mode.

In (a), Router Solicitation for Proxy Advertisement (RtSolPr) is supposed to include the New Access Point and the MN Link-Layer Address (LLA) options (Option Code=1 and 2, respectively) according to [3]. The New AP-LLA option MAY be replaced by the handover assist information option in 3G CDMA networks. As for the MN-LLA option, if the LLA for the MN is not available, 3G specific IDs such as IMSI[11] MAY be used. If this is the case, the MN ID option defined in Section 6.2, which can support other types of IDs and a length that is not necessarily multiples of 8 octets, SHOULD be used instead of the MN-LLA option.



In (b), PrRtAdv MUST include options for the IP address of the NAR, which may be the link-local address, and the prefix for the MN. The PAR SHOULD be able to identify the NAR from the handover assist information provided by the MN.

Figure 3 shows the call flow for the initial attachment in the 3G CDMA network [12]. After the traffic channel is assigned, the MN first establishes a link-layer connection between itself and the access router. As a link-layer protocol, PPP is considered in this figure, and a PPP handshake is depicted as an example. After a link-layer connection is established, the MN registers with the HA by sending a Binding Update message. There are several parameters for using Mobile IPv6 such as the home address (HoA), the Care-of Address (CoA), the home agent address (HA), and the home link prefix (HLP). In [12], obtaining these values is called bootstrapping, and the bootstrapping information can be obtained during the link-layer establishment phase and/or the mobility binding phase [13].

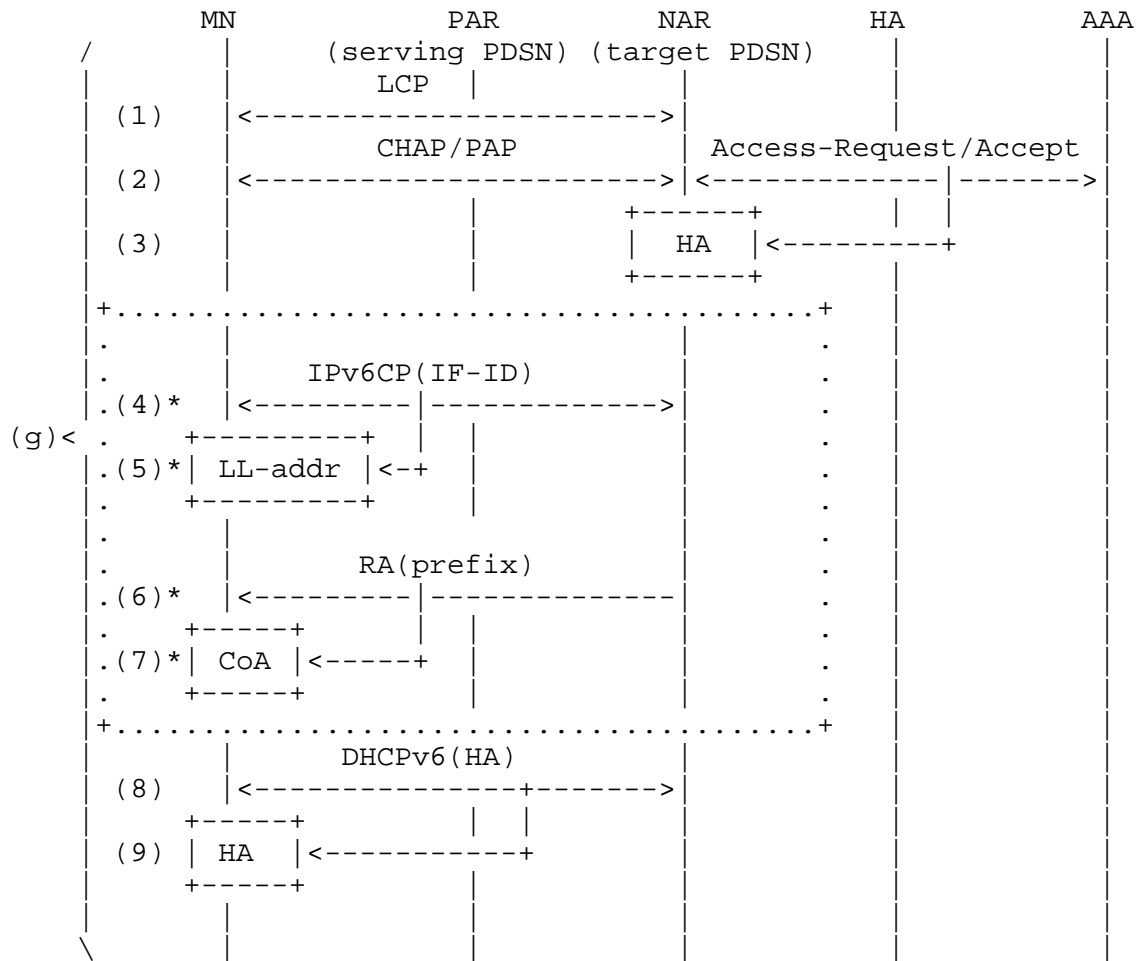


Figure 3: Attachment Procedure in 3G CDMA Network

The procedure for the initial attachment is as follows:

- (g) The link-layer connection establishment and the bootstrapping phase.
- (g-1) The LCP (Link Control Protocol) configure-request/response messages are exchanged.
- (g-2) User authentication (e.g., Challenge Handshake Authentication Protocol (CHAP) or Password Authentication Protocol (PAP)) is conducted.

- (g-3) The static bootstrapping information is conveyed from the AAA and stored in the NAR (target PDSN). The HoA and HLP can be dynamically assigned by the HA in the mobility binding phase. This step can be skipped in the handover case.
- (g-4) Unique interface IDs are negotiated in IPv6 Control Protocol (IPv6CP).
- (g-5) The MN configures its link-local address based on the obtained interface ID.
- (g-6) A router advertisement containing the prefix is received by the MN.
- (g-7) The MN configures its CoA based on the obtained prefix.
- (g-8) DHCPv6 is used to obtain the static bootstrap information (e.g., the HA address). This step is performed in the initial attachment and can be skipped once the MN obtains those parameters.
- (g-9) The MN installs the bootstrap information for further procedures (e.g., the mobility binding).

As is shown in Figure 3, it takes a considerable amount of time to establish a link-layer connection and almost all of the above sequences run every time the MN attaches to a new access network. It is therefore beneficial if packets in transit to the MN are saved not only during the time period when the MN switches to the new radio channel but also during the time period when the MN establishes the link-layer connection.

There are several ways to configure a unique IP address for the MN. If a globally unique prefix is assigned per link as introduced in [12], the MN can use any interface ID except that of the other peer (the AR to which the MN is attached) to create a unique IP address. If this is the case, however, the PAR cannot provide the MN with a correct prefix for the new network in the PrRtAdv since such a prefix is selected by the NAR and provided in the router advertisement. The MN therefore configures a temporary NCoA with the prefix provided by the PAR and the correct NCoA MUST be assigned by the NAR. Therefore, in 3G CDMA network, the PAR MUST send the HI with the S flag set when it receives the FBU from the MN at step (c) in Figure 2.

The UNA is supposed to include the MN-LLA [3], but the point-to-point link-layer connection may be able to uniquely identify the MN. The most required information by the UNA is the NCoA to check if there is a corresponding buffer. Therefore, in (h), the function of the UNA can be realized in several ways:

- o Since the establishment of the link-layer connection in (g) indicates readiness of data communication on the MN side, the NAR immediately checks if there is a buffer that has packets destined for the NCoA, which was configured at steps (c) - (d), and starts delivering, if any (substitution of UNA).
- o The MN sends the UNA as defined in [3]. Instead of the MN-LLA in the LLA option, the MN ID MAY be included in the MN ID option (standard implementation of UNA).

The primary benefit of the predictive fast handover mode is that the packets destined for the MN can be buffered at the NAR, and packet loss due to handover will be much lower than that of the normal MIPv6 operation. Regarding the bootstrapping, the following benefit can be obtained, too:

- o Since the NCoA can be configured via the fast handover procedures, a router advertisement is not required.

Therefore, the procedures (g-4) to (g-7) can be skipped from the standard MIPv6 operation in Figure 3.

## 5.2. Reactive Fast Handover

When the network does not support the predictive fast handover mode, the reactive fast handover is applied. In this document, a new flag is defined in PrRtAdv to inform the MN about the capability of the network (see Section 6.4). To minimize packet loss in this situation, the PAR instead of the NAR can buffer packets for the MN until the MN regains connectivity with the NAR. The NAR obtains the information of the PAR from the MN on the NAR's link and receives packets buffered at the PAR. In this case, the PAR does not need to know the IP address of the NAR or the NCoA and just waits for the NAR to contact the PAR. However, since the PAR needs to know when to buffer packets for the MN, the PAR obtains the timing of buffering from the MN via the FBU or the lower-layer signaling, e.g., an indication of the release of the connection with the MN. Details of the procedure are as follows:

- (a) A router solicitation for proxy router advertisement MAY be sent to the PAR.

- (b) The proxy router advertisement MAY be sent to the MN. If the information on the NAR is not available by the PAR, "0::0" MUST be used for the options related to the NAR (e.g., IP address of the NAR).
- (c) The MN sends the FBU or the access network indicates the close of the connection with the MN by the lower-layer signaling. If the MN cannot formulate the NCoA, "0::0", MUST be used for the NCoA in the FBU. If the B flag is set in the FBU, the PAR SHOULD start buffering packets destined for the PCoA.
- (d) The link-layer connection associated with the PAR is closed and a new traffic channel is assigned in the new access network.
- (e) The MN attaches to the new access network. This part is the same as described in Section 5.1 and illustrated in Figure 3.
- (f) The MN sends the UNA to the NAR.
- (g) The MN sends the Fast Binding Update (FBU) to the PAR via the NAR.
- (h) The NAR forwards the FBU from the MN to the PAR.
- (i) The PAR sends the Handover Initiate (HI) to the NAR with the Code set to 1.
- (j) The NAR sends the Handover Acknowledge (HACK) back to the PAR.
- (k) The PAR sends the FBACK to the NAR.
- (l) If the PAR is buffering packets destined for the PCoA, it starts forwarding them as well as newly arriving ones to the NAR.
- (m) The NAR delivers the packets to the MN.
- (n) The MN sends the BU to the HA to update the BCE with the NCoA and the HA sends back the BA to the MN.

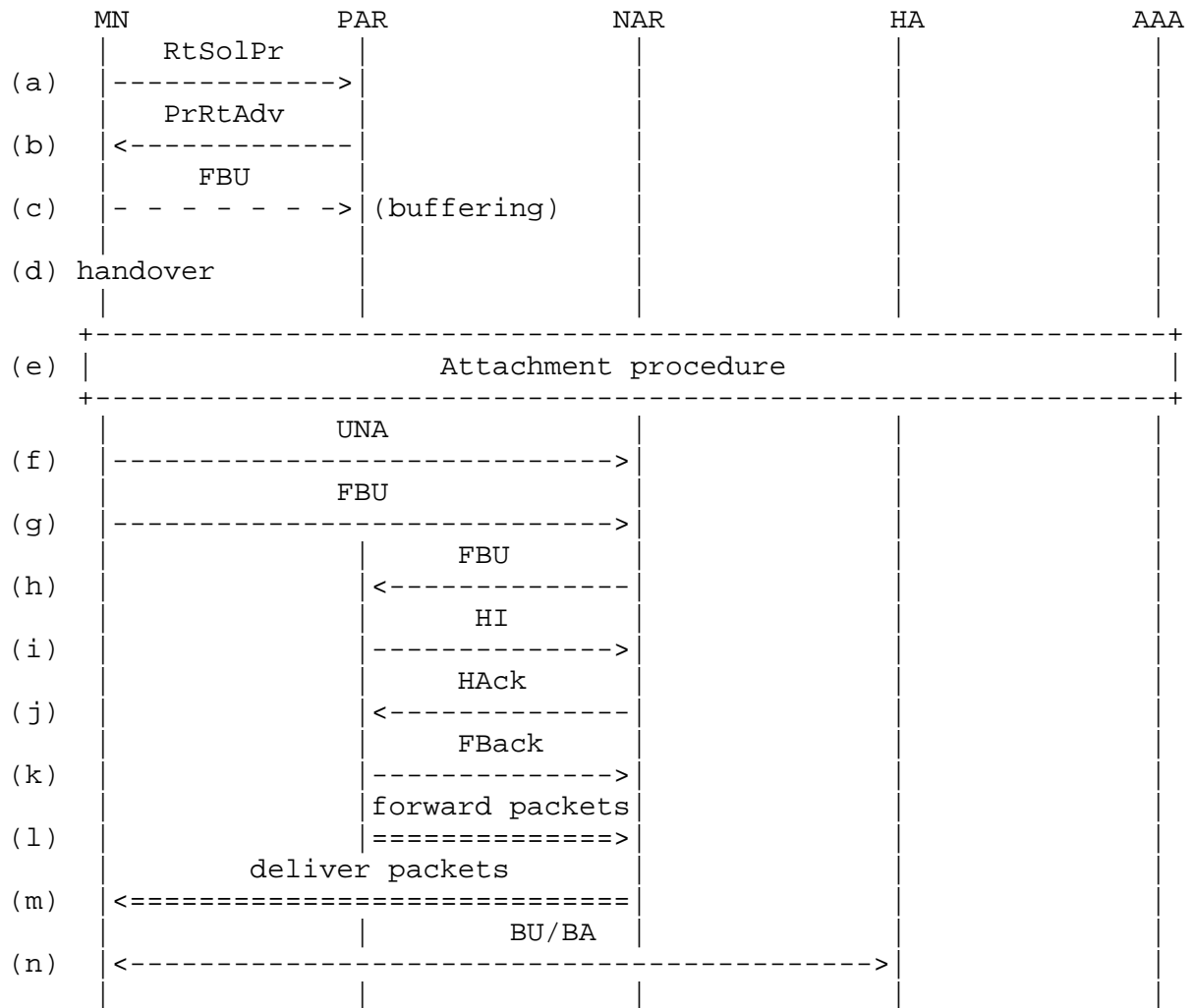


Figure 4: MIPv6 Fast Handover Operation (Reactive Mode)

To indicate the PAR to buffer packets destined for the PCoA, in step (c), a new flag 'B' is defined in the FBU. When the PAR receives the FBU with this flag set, it SHOULD buffer packets for the MN. The PAR MAY also start buffering packets for the MN based on lower layer signal during handover. Since the packets are buffered at the PAR in this scenario, the UNA, which is received and processed by the NAR, can not be used to trigger to forward the buffered packets at the PAR. In Figure 4, the HAck from the NAR is used as the trigger for the forwarding of any buffered packets.

The handover indication from the lower layer of 3G CDMA system is reasonably reliable by the periodical reports from the MN; however, there are several situations where the target link is not available

after the handover (step (d)) and the MN comes back to the PAR, or the MN is not able to move to the target link for some reason after the connection was closed. If this is the case, the attachment procedure is performed on the previous link. The packets buffered at the PAR SHOULD be delivered to the MN after the connection is re-established.

### 5.3. Considerations on the Link Indications

This section discusses if the link indications assumed in this document meet the principles defined in Section 2 of RFC 4907[20], which suggests 11 architectural principles on the link indication and the effectiveness of the optimization. This document relies on the 3G CDMA network regarding the link indication, which is precisely specified by 3GPP2. Therefore, principles (1) to (5), (7), (8), and (11), that is, "Model Validation", "Clear Definition", "Robustness", "Recovery from Invalid Indications", "Congestion Control", "Interoperability", "Race Condition", and "Transport of Link Indications" are considered by those specs. Principle (6) "Effectiveness" mentions the effectiveness of the optimization. This document bases its effectiveness on RFC 5268. Therefore, this principle is dealt by that RFC. Principle (9) "Metric Consistency" mentions inconsistencies between link and routing layer metrics. The spec of this document does not change the routing metrics and multi-homing is not considered. Finally, principle (10) "Layer Compression", mentions an overhead reduction scheme and interoperability. This document does not deal with overhead reduction and therefore this principle does not apply.

## 6. Message Format

### 6.1. Handover Assist Information Option

If the lower layer information of the new point of attachment is not represented as the link-layer address, the following option SHOULD be used. The primary purpose of this option is to convey the handover assist information described in Section 4.

```

0                               1                               2                               3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|   Type   |   Length   | Option-Code |  HAI-Length  |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|                                     HAI-Value...
+---+---+---+---+---+---+---+---+---+---+---+---+---+

```

Type	29
Length	The size of this option in 8 octets including the Type, Length, Option-Code, and HAI-Length (Handover Assist Information-Length) fields.
Option-Code	1: Access Network Identifier (AN ID) 2: Sector ID
HAI-Length	The size of the HAI-Value field in octets.
HAI-Value	The value specified by the Option-Code.

If those that received this message do not support this option, they SHOULD treat this option as opaque and MUST NOT drop it.

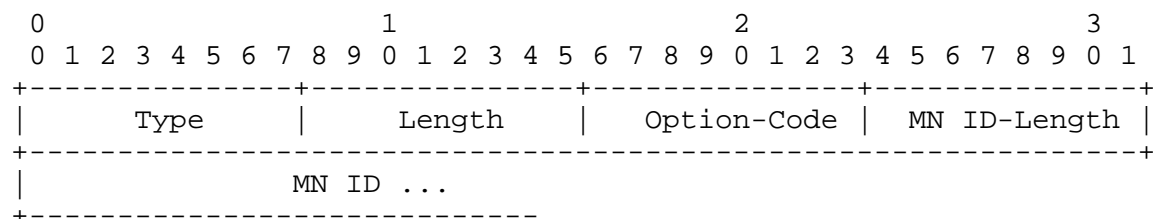
Option-Code indicates the particular type of handover assist information. Currently, two types of information are defined to assist the discovery of the NAR (see Section 3).

Depending on the size of the HAI-Value field, appropriate padding MUST be used to ensure that the entire option size is a multiple of 8 octets. The HAI-Length is used to disambiguate the size of the HAI-Value.

The handover assist information MAY replace the New Access Point Link-Layer Address in 3G CDMA networks.

## 6.2. Mobile Node Identifier Option

This option is used to transfer the Identifier of the MN, which is not its link-layer address.



Type	30
Length	The size of this option is in 8 octets including the Type, Length, and Option-Code.



Option-Code

- ```
1: NAI [4]
2: IMSI (See Section 3)
```

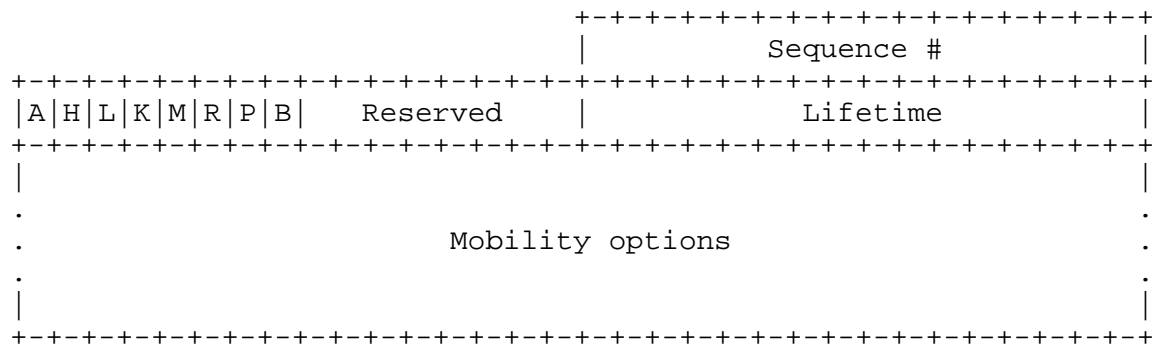
|              |                                    |
|--------------|------------------------------------|
| MN ID-Length | The length of the MN ID in octets. |
|--------------|------------------------------------|

| MN | ID | MN | ID | value |
|----|----|----|----|-------|
|----|----|----|----|-------|

The MN ID MAY replace the MN Link-Layer Address in 3G CDMA networks.

### 6.3. New Flag Extension to FBU Message

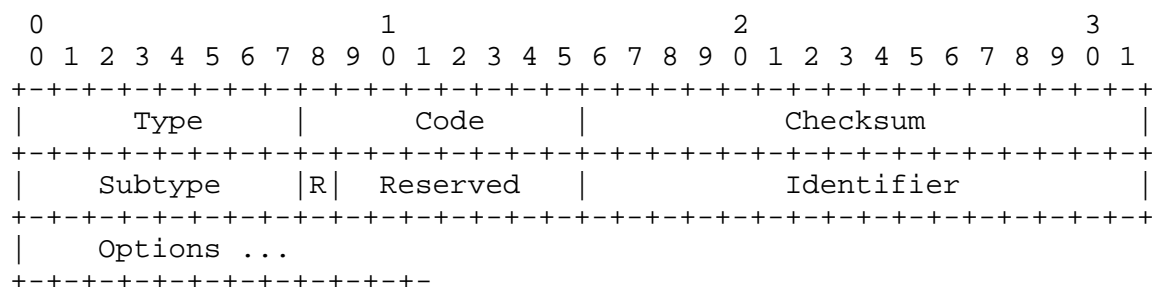
The MN MUST send the FBU to the PAR with the following new (B) flag set in the previous network to indicate the PAR to buffer packets destined for the PCoA. The rest of the Binding Update message format remains the same as defined in [2] and with the additional (M), (R), and (P) flags as specified in [14], [15], and [16], respectively.



B flag: If the 'B' flag is set, the PAR SHOULD start buffering the packets destined for the MN as specified in Section 5.2.

#### 6.4. New Flag Extension to PrRtAdv Message

A new flag 'R' is defined in the PrRtAdv to inform the MN about the fast handover mode that the network supports.



R flag: If the 'R' flag is set, the network supports only the reactive handover mode. Otherwise, the network supports both the predictive and reactive fast handover mode.

## 7. Security Considerations

The security considerations for Mobile IPv6 fast handover are described in [3]. When a 3G CDMA network is considered, it can be assumed that the PAR and the NAR have a trust relationship and the links between them and those between the ARs and the MN are secured. The MN is authenticated every time it attaches to the new link; therefore, the AR can securely identify the MN. Depending on the operator's policy, however, SEcure Neighbor Discovery (SEND) [18] and the shared handover key defined in [17] can also be applied.

## 8. IANA Considerations

This document defines two new IPv6 Neighbor Discovery options that have been assigned from the same space as the IPv6 Neighbor Discovery Options defined in [19].

29: Handover Assist Information Option (Section 6.1)

30: Mobile Node Identifier Option (Section 6.2)

This document creates two new registries for the Option-Code field in the Handover Assist Information Option and that in the Mobile Node Identifier Option. The values for the Option-Code must be within the range 0-255. New values for both registries can be allocated by Standards Action or IESG approval [5].

The Option-Code values that have been assigned by IANA are as follows:

| Option-Code for Handover Assist Information Option |             |             |
|----------------------------------------------------|-------------|-------------|
| Value                                              | Description | Reference   |
| -----                                              |             |             |
| 0                                                  | Reserved    |             |
| 1                                                  | ANID        | Section 6.1 |
| 2                                                  | Sector ID   | Section 6.1 |

| Option-Code | Value | Description | Option Identifier | Reference   |
|-------------|-------|-------------|-------------------|-------------|
| -----       | ----- | -----       | -----             | -----       |
| 0           |       | Reserved    |                   |             |
| 1           |       | NAI         |                   | Section 6.2 |
| 2           |       | IMSI        |                   | Section 6.2 |

## 9. Acknowledgements

The authors would like to thank Kuntal Chowdhury, Ashutosh Dutta, Ved Kafle, and Vijay Devarapalli for providing feedback and support for this work. The authors would also thank Sebastian Thalanany for 3GPP2 expert review.

## 10. References

### 10.1. Normative References

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- [2] Johnson, D., Perkins, C., and J. Arkko, "Mobility Support in IPv6", RFC 3775, June 2004.
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