

Independent Submission
Request for Comments: 6653
Category: Informational
ISSN: 2070-1721

B. Sarikaya
F. Xia
Huawei USA
T. Lemon
Nominum
July 2012

DHCPv6 Prefix Delegation in Long-Term Evolution (LTE) Networks

Abstract

As interest in IPv6 deployment in cellular networks increases, several migration issues have been being raised; IPv6 prefix management is the issue addressed in this document. Based on the idea that DHCPv6 servers can manage prefixes, we use DHCPv6 Prefix Delegation to address such prefix management issues as an access router offloading delegation of prefixes and release tasks to a DHCPv6 server. The access router first requests a prefix for an incoming mobile node from the DHCPv6 server. The access router may next do stateless or stateful address allocation to the mobile node, e.g., with a Router Advertisement or using DHCP. We also describe prefix management using Authentication, Authorization, and Accounting (AAA) servers.

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1. Introduction

Figure 1 illustrates the key elements of a typical cellular access network. In a Long-Term Evolution (LTE) network, the Access Router (AR) is the Packet Data Network (PDN) Gateway [3GPP-23401].

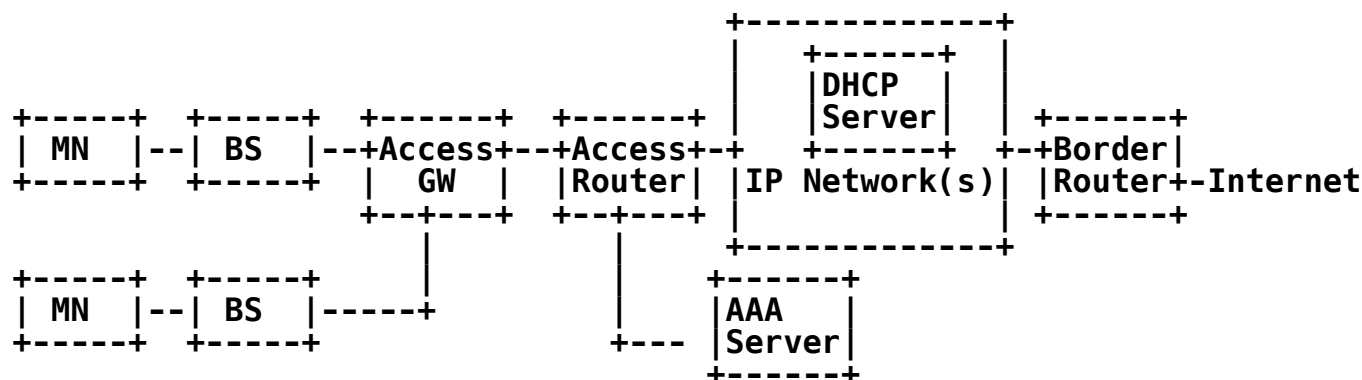


Figure 1: Key Elements of a Typical Cellular Network

The Mobile Node (MN) attaches to a Base Station (BS) through an LTE air interface. A BS manages connectivity of User Equipment (UE) and extends connections to an Access Gateway (GW), e.g., the Serving Gateway (S-GW) in an LTE network. The access GW and the AR are connected via an IP network. The AR is the first-hop router of the MNs and is in charge of address/prefix management.

The AR is connected to an IP network that is owned by the operator; this network is connected to the public Internet via a border router. The network contains servers for subscriber management, including Quality of Service, billing, and accounting, as well as a Dynamic Host Configuration Protocol (DHCP) server [RFC6342].

With IPv6 addressing, because mobile network links are point-to-point (P2P), the per-MN interface prefix model is used [RFC3314] [RFC3316]. In the per-MN interface prefix model, prefix management is an issue.

When an MN attaches to an AR, the AR requests one or more prefixes for the MN. When the MN detaches from the AR, the prefixes should be released. When the MN becomes idle, the AR should keep (i.e., not release) the allocated prefixes.

This document describes how to use DHCPv6 Prefix Delegation (DHCPv6-PD) in mobile networks, such as networks based on standards developed by the 3rd Generation Partnership Project (3GPP) and it could easily be adopted by the Worldwide Interoperability for Microwave Access (WiMAX) Forum as well. In view of migration to

IPv6, the number of MNs connected to the network at a given time may become very high. Traditional techniques such as prefix pools are not scalable. In such cases, DHCPv6-PD becomes the viable approach to take.

The techniques described in this document have not been approved by the IETF or the 3GPP, except for those techniques described below in Section 3.3. This document is not a Standard or Best Current Practice. This document is published only for possible consideration by operators.

This document is useful when address space needs to be managed by DHCPv6-PD. There are obviously other means of managing address space, including having the AR track internally what address space is used by what mobile.

2. Terminology and Acronyms

3GPP - 3rd Generation Partnership Project

AAA - Authentication, Authorization, and Accounting

AR - Access Router

BS - Base Station

DHCP - Dynamic Host Configuration Protocol

E-UTRAN - Evolved Universal Terrestrial Radio Access Network

GPRS - General Packet Radio Service

LTE - Long-Term Evolution

MN - Mobile Node

P2P - Point-to-Point

PD - Prefix Delegation

PDN - Packet Data Network

S-GW - Serving Gateway

WiMAX - Worldwide Interoperability for Microwave Access

3. Prefix Delegation Using DHCPv6

"Access router" refers to the cellular network entity that has a DHCP client. According to [3GPP-23401], the DHCP client is located in the PDN Gateway, and so the AR is the PDN Gateway in the LTE architecture.

3.1. Prefix Request Procedure for Stateless Address Configuration

There are two function modules in the AR: the DHCP client and the DHCP relay. DHCP messages should be relayed if the AR and a DHCP server are not directly connected; otherwise, the DHCP relay function in the AR is not necessary. Figure 2 illustrates a scenario in which the AR and the DHCP server aren't directly connected:

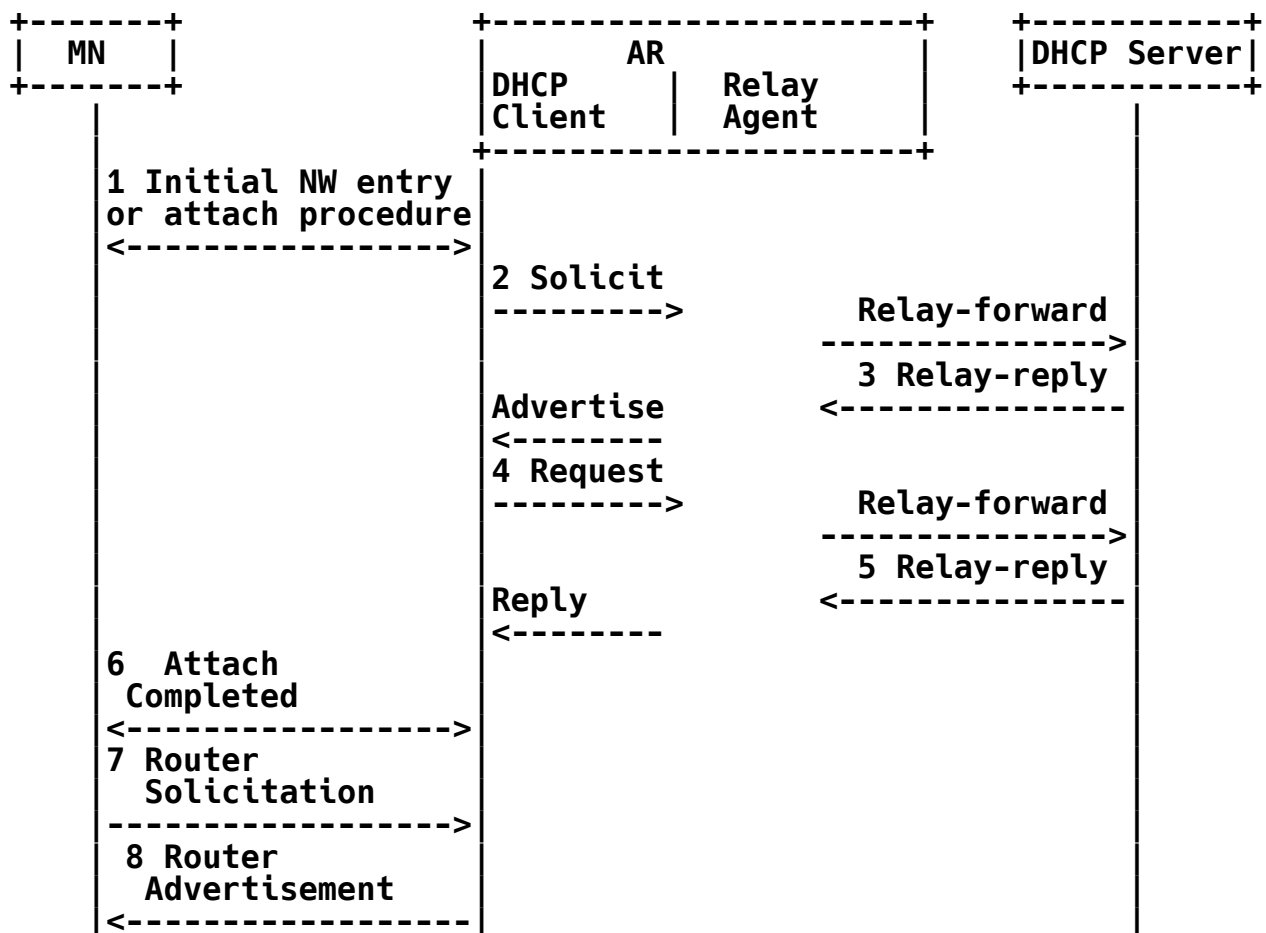


Figure 2: Prefix Request

1. An MN (also referred to as UE, or User Equipment, by the 3GPP) performs initial network entry and authentication procedures, a.k.a. the attach procedure.
2. On successful completion of Step 1, the AR initiates the DHCP Solicit procedure to request prefixes for the MN. The DHCP client in the AR creates and transmits a Solicit message as described in Sections 17.1.1 ("Creation of Solicit Messages") and 17.1.2 ("Transmission of Solicit Messages") of [RFC3315]. The DHCP client in an AR that supports DHCPv6 Prefix Delegation [RFC3633] creates an Identity Association for Prefix Delegation (IA_PD) and assigns it an Identity Association Identifier (IAID). The client must include the IA_PD option in the Solicit message. The DHCP client as Requesting Router (RR) must set the prefix-length field to a value less than, e.g., 48 or equal to 64 to request a /64 prefix. Next, the relay agent in the AR sends to the DHCP server a Relay-forward message in which a Solicit message is encapsulated.
3. The DHCP server sends an Advertise message to the AR in the same way as that described in Section 17.2.2 ("Creation and Transmission of Advertise Messages") of [RFC3315]. An Advertise message with the IA_PD shows that the DHCP server is capable of delegating prefixes. This message is received encapsulated in a Relay-reply message by the relay agent in the AR and is sent as an Advertise message to the DHCP client in the AR.
4. The AR (DHCP client and relay agent) uses the same message exchanges as those described in Section 18 ("DHCP Client-Initiated Configuration Exchange") of [RFC3315] and in [RFC3633] to obtain or update prefixes from the DHCP server. The AR (DHCP client and relay agent) and the DHCP server use the IA_PD Prefix option to exchange information about prefixes in much the same way as IA Address options are used for assigned addresses. This is accomplished by the AR sending a DHCP Request message and the DHCP server sending a DHCP Reply message.
5. The AR stores the prefix information it received in the Reply message.
6. A connection between the MN and AR is established, and the link becomes active. This step completes the Packet Data Protocol (PDP) Context Activation Procedure in Universal Mobile Telecommunications System (UMTS) and PDN connection establishment in LTE networks.

7. The MN may send a Router Solicitation message to solicit the AR to send a Router Advertisement (RA) message.
8. The AR advertises the prefixes received in the IA_PD option to the MN via an RA once the PDP Context/PDN connection is established, or in response to a Router Solicitation message sent from the MN.

The 4-way exchange between the AR as RR and the DHCP server as Delegating Router (DR), as shown in Figure 2, may be reduced to a two-message exchange by using the Rapid Commit option [RFC3315]. The DHCP client in the AR acting as RR includes a Rapid Commit option in the Solicit message. The DR then sends a Reply message containing one or more prefixes.

3.2. Prefix Request Procedure for Stateful Address Configuration

Stateful address configuration requires a different architecture than that shown in Figure 2; in this type of configuration, there are two function modules in the AR: the DHCP server and the DHCP client.

After the initial attach is completed, a connection to the AR is established for the MN. The DHCP client function at the AR as RR and the DHCP server as DR follow Steps 2 through 5 of the procedure shown in Figure 2 to get the new prefix for this interface of the MN from the IA_PD option exchange defined in [RFC3633].

The DHCPv6 client at the MN sends the DHCP Request to the AR. The DHCP server function at the AR must use the IA_PD option received in the DHCPv6-PD exchange to assign an address to the MN. The IA_PD option must contain the prefix. The AR sends to the MN a DHCP Reply message containing the IA address option (IAADDR). Figure 3 shows the message sequence.

The MN configures its interface with the address assigned by the DHCP server in the DHCP Reply message.

In Figure 3, the AR may be the home gateway of a fixed network to which the MN gets connected during the MN's handover.

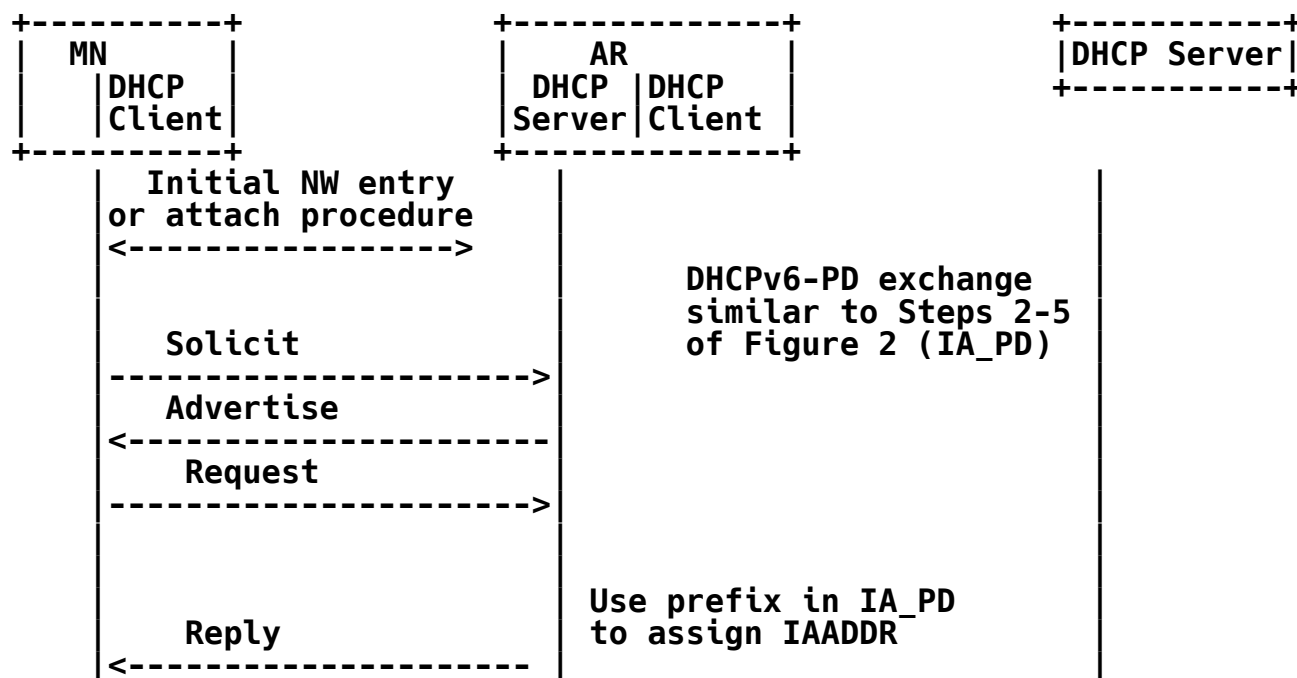


Figure 3: Stateful Address Configuration Following PD

3.3. The MN as Requesting Router in Prefix Delegation

The AR may use a DHCPv6 Prefix Delegation exchange to get a delegated prefix shorter than /64 by setting the prefix-length field to a value less than 64, e.g., 56 to get a /56 prefix. Each newly attaching MN first goes through the steps in Figure 2, in which the AR requests a shorter prefix to establish a default connection with the MN.

The MN may next request additional prefixes (/64 or shorter) from the AR using DHCPv6 Prefix Delegation, where the MN is the RR and the AR is the DR (see [RFC6459] and Section 5.3.1.2.6 of [3GPP-23401]). In this case, the call flow is similar to that shown in Figure 3. The Solicit message must include the IA_PD option with the prefix-length field set to 64. The MN may request more than one /64 prefix. The AR as DR must delegate these prefixes, excluding the prefix assigned to the default connection.

3.4. Prefix Release Procedure

Prefixes can be released in two ways: via prefix aging, or via the DHCP release procedure. In prefix aging, a prefix should not be used by an MN when the prefix ages, and the DHCP server can delegate it to another MN. A prefix lifetime is delivered from the DHCPv6 server to the MN via the DHCP IA_PD Prefix option [RFC3633] and the RA Prefix Information option [RFC4861]. Figure 4 illustrates how the AR releases prefixes to a DHCP server that isn't directly connected to the AR:

1. A signal that an MN has detached, such as switch-off or handover, triggers the prefix release procedure.
2. The AR initiates a Release message to give the prefixes back to the DHCP server.
3. The server responds with a Reply message. The prefixes can then be reused by other MNs.

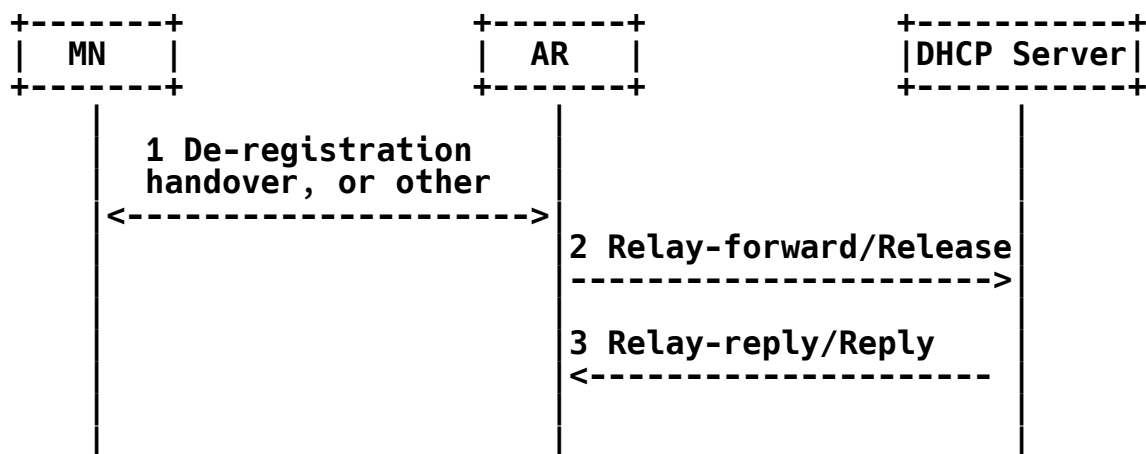


Figure 4: Prefix Release

3.5. Miscellaneous Considerations

3.5.1. How to Generate an IAID

The IAID is 4 bytes in length and should be unique in the scope of an AR. The prefix table should be maintained; this table contains the IAID, the Media Access Control (MAC) address, and the prefix(es) assigned to the MN. In LTE networks, the International Mobile Equipment Identity (IMEI) uniquely identifies the MN's interface and

thus corresponds to the MAC address. The MAC address of the interface should be stored in the prefix table and is used as the key for searching the table.

The IAID should be set to Start_IAID; Start_IAID is an integer of 4 octets. The following algorithm is used to generate the IAID:

1. Set this IAID value in the IA_PD Prefix option. Request a prefix for this MN as described in Section 3.1 or Section 3.2.
2. Store the IAID, MAC address, and received prefix(es) in the next entry of the prefix table.
3. Increment the IAID.

A prefix table entry for an MN that hands over to another AR must be removed. The IAID value is released and can then be reused.

3.5.2. Policy to Delegate Prefixes

In P2P links, if /64 prefixes of all MNs connected to one or more ARs are broadcast dynamically upstream as route information, high routing-protocol traffic (IGP, OSPF, etc.) due to per-MN interface prefixes will result. There are two solutions to this problem. One solution is to use static configuration, which would be preferable in many cases. No routing protocols are needed, because each AR has a known piece of address space. If the DHCP servers also know that address space, then they will assign to a particular AR a prefix from that space.

The other solution is to use route aggregation. For example, each AR can be assigned a /48 or /32 prefix (an aggregate prefix, a.k.a. service provider common prefix), while each interface of an MN can be assigned a /64 prefix. The /64 prefix is an extension of the /48 prefix -- for example, an AR's /48 prefix is 2001:db8:0::/48 -- while an interface of the MN is assigned a 2001:db8:0:2::/64 prefix. The border router in Figure 1 may be manually configured to broadcast only an individual AR's /48 or /32 prefix information to the Internet.

4. Prefix Delegation Using RADIUS and Diameter

In the initial network entry procedure shown in Figure 2, the AR as Remote Authentication Dial In User Service (RADIUS) client sends an Access-Request message with MN information to the RADIUS server. If the MN passes the authentication, the RADIUS server may send an Access-Accept message with prefix information to the AR using the Framed-IPv6-Prefix attribute. The AAA server also provides routing

information to be configured for the MN on the AR using the Framed-IPv6-Route attribute. Using such a process, the AR can handle initial prefix assignments to MNs, but managing the lifetime of the prefixes is totally left to the AR. The Framed-IPv6-Prefix is not designed to support delegation of IPv6 prefixes. For this situation, the Delegated-IPv6-Prefix attribute, which is discussed below, can be used.

[RFC4818] defines a RADIUS attribute, Delegated-IPv6-Prefix, which carries an IPv6 prefix to be delegated. This attribute is usable within either RADIUS or Diameter. [RFC4818] recommends that the DR use the AAA server to receive the prefixes to be delegated, by using the Delegated-IPv6-Prefix attribute/Attribute-Value Pair (AVP).

The DHCP server as DR, as shown in Figure 2, may send an Access-Request packet containing the Delegated-IPv6-Prefix attribute to the RADIUS server to request prefixes. In the Access-Request message, the DR may provide a hint that it would prefer a prefix -- for example, a /48 prefix. As the RADIUS server is not required to honor the hint, the server may delegate a longer prefix -- e.g., /56 or /64 -- in an Access-Accept message containing the Delegated-IPv6-Prefix attribute [RFC4818]. The attribute can appear multiple times when the RADIUS server delegates multiple prefixes to the DR. The DR sends the prefixes to the RR using the IA_PD option, and the AR as RR uses them for MNs, as described in Section 3.

When Diameter is used, the DHCP server as DR, as shown in Figure 2, sends an AA-Request message. The AA-Request message may contain a Delegated-IPv6-Prefix AVP. The Diameter server replies with an AA-Answer message. The AA-Answer message may contain a Delegated-IPv6-Prefix AVP. The AVP can appear multiple times when the Diameter server assigns multiple prefixes to an MN. The Delegated-IPv6-Prefix AVP may appear in an AA-Request packet as a hint from the AR to the Diameter server that it would prefer a prefix -- for example, a /48 prefix. The Diameter server may delegate in the AA-Answer message a /64 prefix, which is an extension of the /48 prefix. As in the case of RADIUS, the DR sends the prefixes to the RR using the IA_PD option, and the AR as RR uses them for the MNs as described in Section 3.

5. Security Considerations

This document does not introduce any additional message types and therefore does not introduce any additional threats. The security procedures for DHCPv6 [RFC3633], RADIUS [RFC2865], and Diameter [RFC3588] apply.

6. Acknowledgements

We are grateful to Suresh Krishnan, Hemant Singh, Qiang Zhao, Ole Troan, Qin Wu, Jouni Korhonen, Cameron Byrne, Brian Carpenter, Jari Arkko, and Jason Lin, whose in-depth reviews of this document led to several improvements.

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Authors' Addresses

Behcet Sarikaya
Huawei USA
5340 Legacy Dr.
Plano, TX 75074

EMail: sarikaya@ieee.org

Frank Xia
Huawei USA
1700 Alma Drive, Suite 500
Plano, TX 75075

Phone: +1 972-509-5599
EMail: xiayangsong@huawei.com

Ted Lemon
Nominum
2000 Seaport Blvd.
Redwood City, CA 94063

EMail: mellon@nominum.com