        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.

Status of This Memo

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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].

```
                                   +-------------+
                                   |  +------+   |
                                   |  |DHCP  |   |
   +-----+   +-----+  +------+  +------+ |  |Server|   | +------+
   | MN  |--| BS   |--+Access+---+Access+-+   +------+   +-+Border|
   +-----+   +-----+  | GW   |  |Router| |IP Network(s)| |Router+-Internet
                      +--+---+  +--+---+ |             | +------+
                         |         |     +-------------+
   +-----+   +-----+      |         |      +------+
   | MN  |--| BS   |-----+         |      |AAA   |
   +-----+   +-----+                +--- |Server|
                                         +------+
```
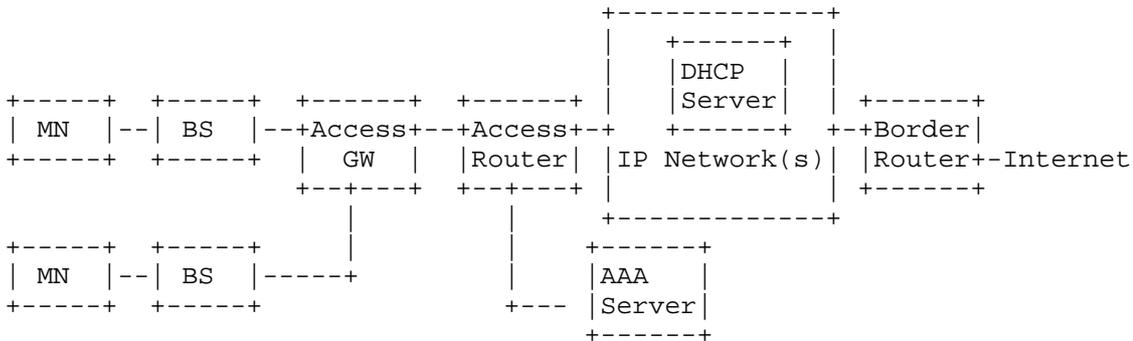
                Figure 1: Key Elements of a Typical Cellular Network

   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:

```
     +-------+                 +---------------------+     +-----------+
     |  MN   |                 |         AR          |     |DHCP Server|
     +-------+                 |DHCP      | Relay     |     +-----------+
     |                         |Client    | Agent     |     |           |
     |                         +---------------------+     |           |
     |1 Initial NW entry |                                 |           |
     |or attach procedure|                                 |           |
     |<----------------->|                                 |           |
     |                   |2 Solicit                        |           |
     |                   |--------->       Relay-forward   |           |
     |                   |                 --------------->|           |
     |                   |                  3 Relay-reply  |           |
     |                   |Advertise        <--------------|            |
     |                   |<--------                        |           |
     |                   |4 Request                        |           |
     |                   |--------->       Relay-forward   |           |
     |                   |                 --------------->|           |
     |                   |                  5 Relay-reply  |           |
     |                   |Reply            <--------------|            |
     |                   |<--------                        |           |
     |6  Attach          |                                 |           |
     | Completed         |                                 |           |
     |<----------------->|                                 |           |
     |7 Router           |                                 |           |
     |  Solicitation     |                                 |           |
     |------------------>|                                 |           |
     | 8 Router          |                                 |           |
     |  Advertisement    |                                 |           |
     |<------------------|                                 |           |
```
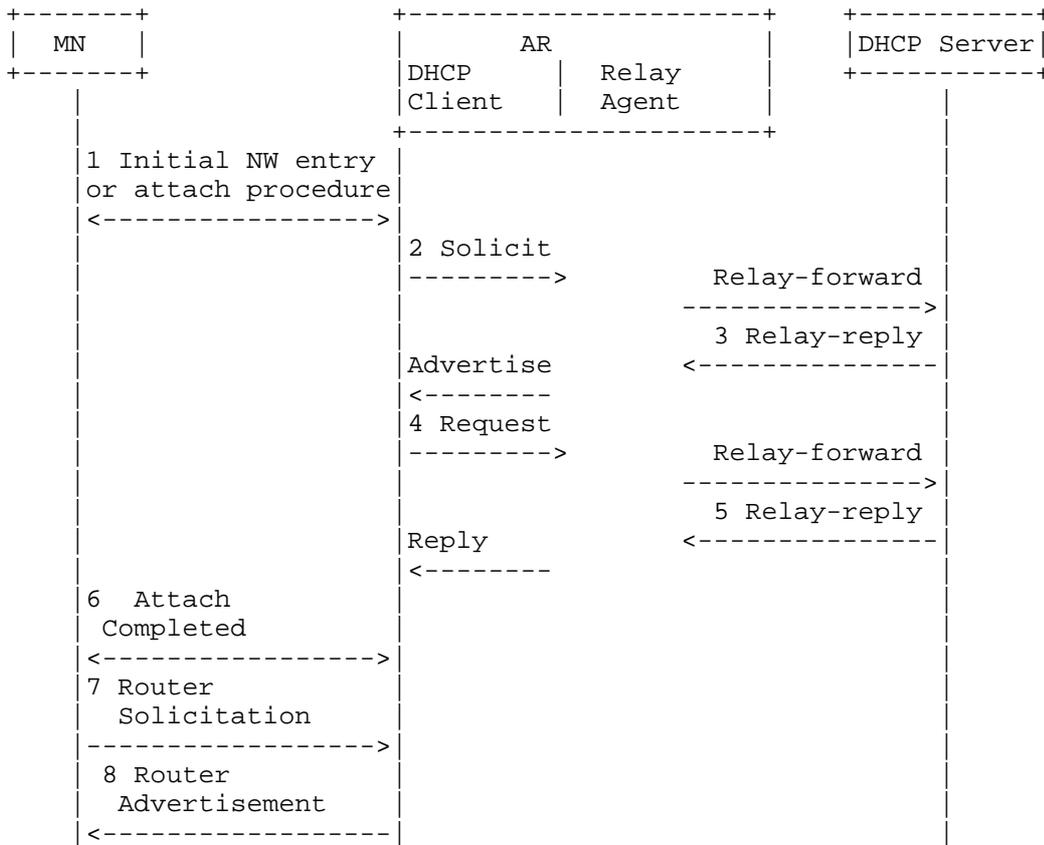
                      Figure 2: Prefix Request

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.

```
  +----------+             +--------------+             +-----------+
  | MN       |             | AR           |             |DHCP Server|
  |   |DHCP  |             | DHCP |DHCP   |             +-----------+
  |   |Client|             |Server|Client |
  +----------+             +--------------+
       |  Initial NW entry       |                             |
       |or attach procedure      |                             |
       |<----------------->      |                             |
       |                         |    DHCPv6-PD exchange        |
       |                         |    similar to Steps 2-5      |
       |     Solicit             |    of Figure 2 (IA_PD)       |
       |------------------------>|                             |
       |     Advertise           |                             |
       |<------------------------|                             |
       |     Request             |                             |
       |------------------------>|                             |
       |                         |                             |
       |                         |                             |
       |                         | Use prefix in IA_PD          |
       |     Reply               | to assign IAADDR             |
       |<------------------------|                             |
```
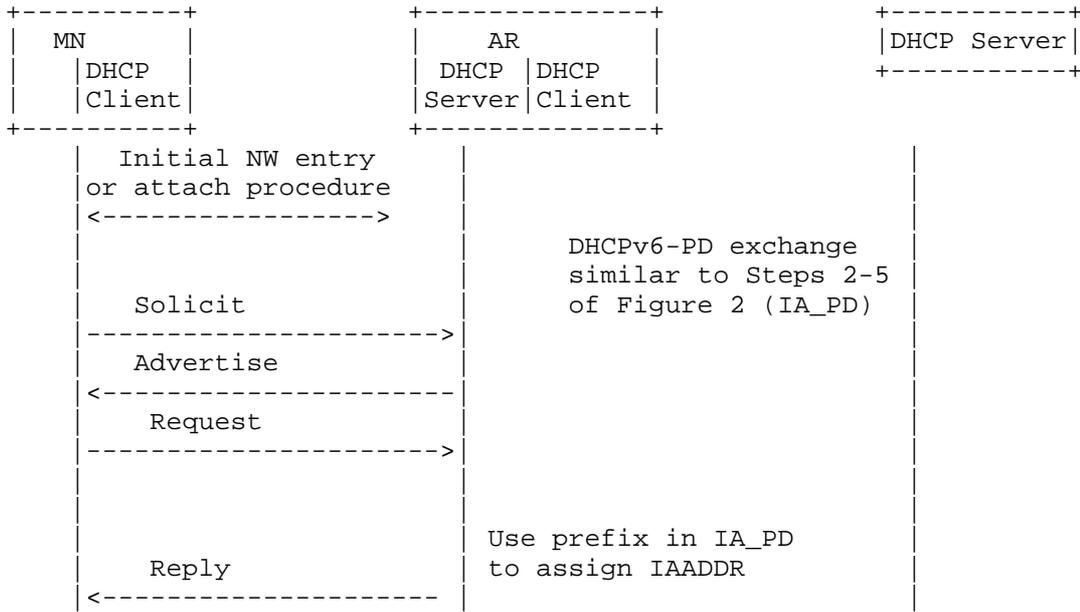
            Figure 3: Stateful Address Configuration Following PD

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.

```
      +-------+                +-------+              +-----------+
      |  MN   |                |  AR   |              |DHCP Server|
      +-------+                +-------+              +-----------+
          |                        |                       |
          |  1 De-registration     |                       |
          |  handover, or other    |                       |
          |<--------------------->|                        |
          |                        |2 Relay-forward/Release |
          |                        |---------------------->|
          |                        |                       |
          |                        |3 Relay-reply/Reply     |
          |                        |<-------------------- |
          |                        |                       |
          |                        |                       |
```
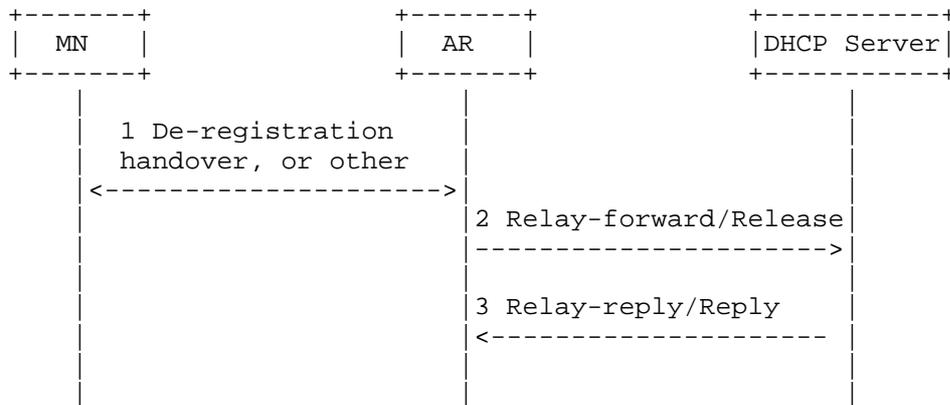
                      Figure 4: Prefix Release

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.

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