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

   As interest on IPv6 deployment is increasing in cellular networks
   several migration issues are being raised and IPv6 prefix management
   is the one addressed in this document. Based on the idea that DHCPv6
   servers can manage prefixes, we address prefix management issues such
   as the access router offloading delegation and release tasks of the
   prefixes to a DHCPv6 server using DHCPv6 Prefix Delegation. 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 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, access router is
   the packet data network (PDN) gateway [ThreeGPP23401].

```
                                        +-------------+
                                        |  +------+   |
                                        |  |DHCP  |   |
+-----+   +-----+  +------+  +------+    |  |Server|   | +------+
| MN  |---| BS  |---+Access+---+Access+-+   +------+  +-+Border|
+-----+   +-----+  | GW   |  |Router|  |IP Network(s)| |Router+-Internet
                   +--+---+  +--+---+  |             | +------+
                      |         |      +-------------+
+-----+   +-----+     |         |      +------+
| MN  |---| BS  |------+        |      |AAA   |
+-----+   +-----+               +---   |Server|
                                       +------+
```
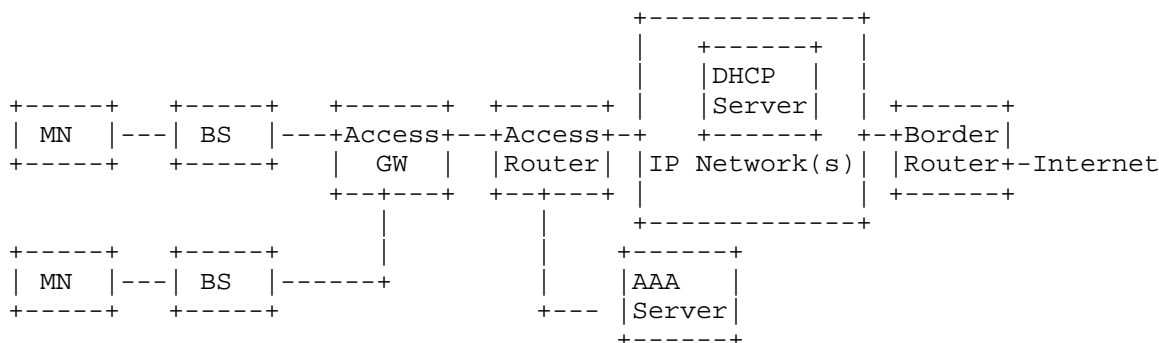
                Figure 1: Key elements of a typical cellular network

   Mobile node (MN) attaches to a base station (BS) through LTE air
   interface. A BS manages connectivity of UEs and extends connections
   to an Access Gateway (GW), e.g. the serving gateway (S-GW) in an LTE
   network. The access gateway and the Access Router (AR) are connected
   with an IP network. The access router is the first hop router of MNs
   and it is in charge of address/prefix management.

   Access router is connected to an IP network which is owned by the
   operator which 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
   Dynamic Host Configuration Protocol (DHCP) server [RFC6342].

   As to IPv6 addressing, because mobile network links are point-to-
   point (p2p) Per-MN interface prefix model is used [RFC3314],
   [RFC3316]. In Per-MN interface prefix model, prefix management is an
   issue.

   When an MN attaches an AR, the AR requests one or more prefixes for
   the MN. When the MN detaches the AR, the prefixes should be
   released. When the MN becomes idle, the AR should hold the prefixes
   allocated.

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

Forum as well. In view of migration to IPv6, the number of mobile
nodes 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
either by the IETF or by 3GPP, except what is described below in
Section 3.3. This document is not a standard or best current
practice. This document is published only as a possibility for
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 Control Protocol

    E-UTRAN Evolved Universal Terrestrial Radio Access Network

    GPRS General Packet Radio Service

    LTE Long Term Evolution

    MN Mobile node

    PDN Packet data network

    PD Prefix Delegation

    p2p Point-to-point

    Serving Gateway S-GW

    WiMAX Worldwide Interoperability for Microwave Access

3. Prefix Delegation Using DHCPv6

   Access router refers to the cellular network entity that has DHCP
   Client. According to [ThreeGPP23401] DHCP Client is located in PDN
   Gateway. So AR is the PDN Gateway in LTE architecture.

3.1. Prefix Request Procedure for Stateless Address Configuration

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

```
        +-------+                +--------------------+   +-----------+
        |  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   |        |
        |                   |Repl            <---------------|        |
        |                   |<--------                                |
        |6  Attach          |                                         |
        | Completed         |                                         |
        |<----------------->|                                         |
        |7 Router           |                                         |
        |   Solicitation    |                                         |
        |------------------>|                                         |
        | 8 Router          |                                         |
        |   Advertisement   |                                         |
        |<------------------|                                         |
```
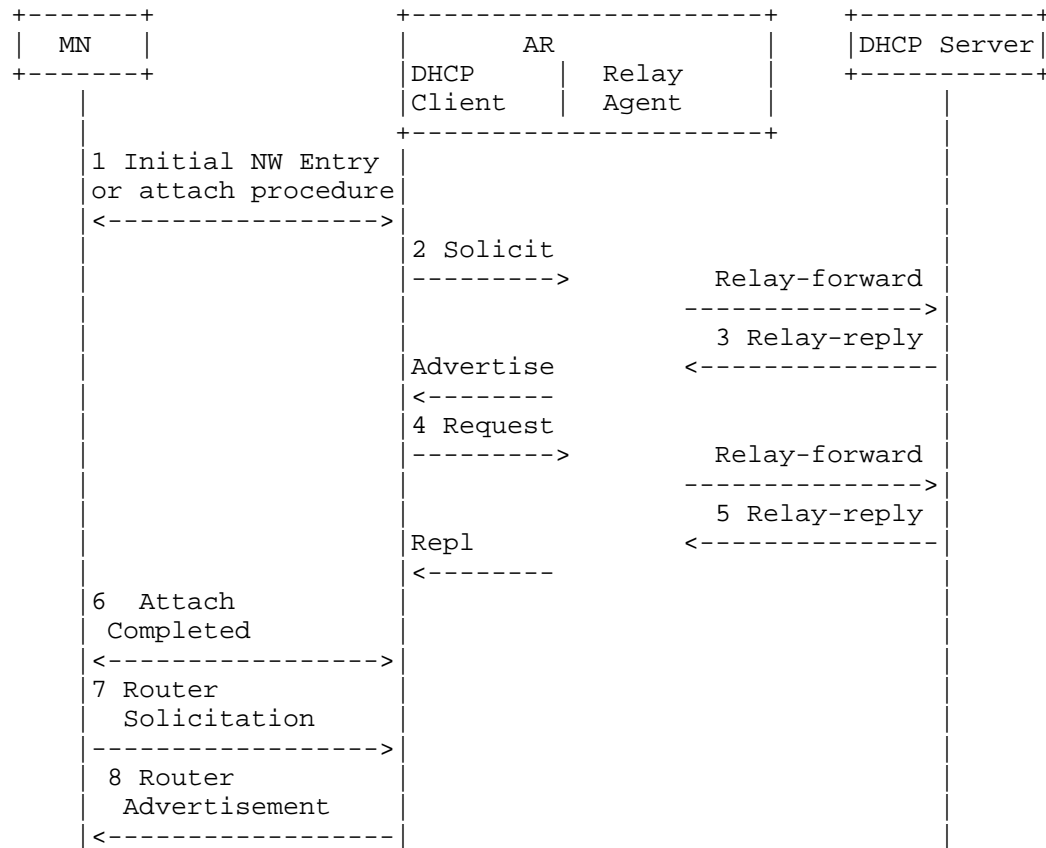
                     Figure 2: Prefix request

1. An MN (UE=User Equipment in 3GPP) performs initial network entry
    and authentication procedures, a.k.a. attach procedure.
2. On successful completion of Step 1, the AR initiates DHCP Solicit
    procedure to request prefixes for the MN. The DHCP Client in 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 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. DHCP Client as
    Requesting Router must set 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 AR sends Relay-Forward message to the DHCP Server
    encapsulating Solicit message.
3. The DHCP server sends an Advertise message to the AR in the same
    way as described in section 17.2.2, "Creation and transmission of
    Advertise messages" of [RFC3315]. Advertise message with IA_PD
    shows that the DHCP server is capable of delegating prefixes.
    This message is received encapsulated in Relay-Reply message by
    the Relay Agent in AR and sent as Advertise message to the DHCP
    Client in AR.
4. The AR (DHCP Client and Relay Agent) uses the same message
    exchanges as described in section 18, "DHCP Client-Initiated
    Configuration Exchange" of [RFC3315] and [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. AR stores the prefix information it received in the Reply
    message.
6. A connection between MN and AR is established and the link
    becomes active. This step completes the PDP Context Activation
    Procedure in 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 message.
8. The AR advertises the prefixes received in IA_PD option to MN
    with router advertisement (RA) once the PDP Context/PDN
    connection is established or in response to Router Solicitation
    message sent from the MN.

4-way exchange between AR as requesting router (RR) and DHCP server
as delegating router (DR) in Figure 2 may be reduced into a two
message exchange using the Rapid Commit option [RFC3315]. DHCP
Client in AR acting as RR includes a Rapid Commit option in the

Solicit message. 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
shown in Figure 2. There are two function modules in the AR, DHCP
Server and DHCP Client.

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

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

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

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

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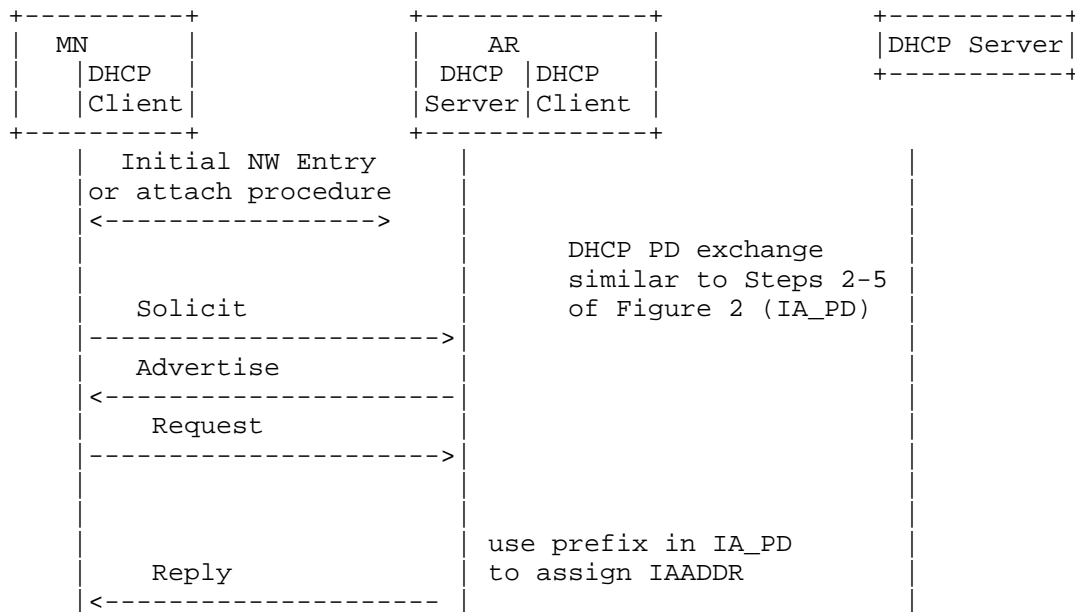
          Figure 3: Stateful Address Configuration Following PD

3.3. MN as Requesting Router in Prefix Delegation

   AR may use DHCPv6 prefix delegation exchange to get a delegated
   prefix shorter than /64 by setting 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 AR requests a
   shorter prefix to establish a default connection with the MN.

   MN may next request additional prefixes (/64 or shorter) from the AR
   using DHCPv6 prefix delegation where MN is the requesting router and
   AR is the delegating router [RFC6459], Section 5.3.1.2.6 in
   [ThreeGPP23401]. In this case the call flow is similar to Figure 3.
   Solicit message must include the IA_PD option with prefix-length
   field set to 64. MN may request more than one /64 prefixes. AR as
   delegating router must delegate these prefixes excluding the prefix
   assigned to the default connection.

3.4. Prefix Release Procedure

   Prefixes can be released in two ways, prefix aging or DHCP release
   procedure. In the former way, 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

through DHCP IA_PD Prefix option [RFC3633] and RA Prefix Information
option [RFC4861]. Figure 4 illustrates how the AR releases prefixes
to a DHCP Server which isn't connected directly:

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

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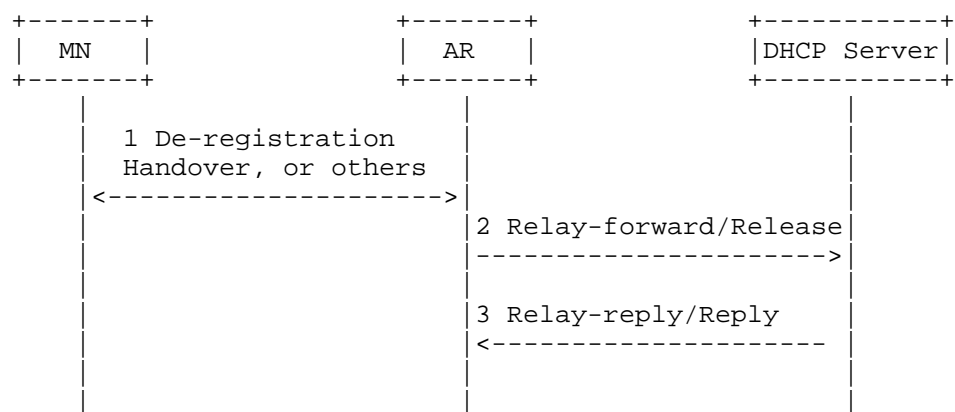
Figure 4: Prefix Release

3.5. Miscellaneous Considerations

3.5.1. How to Generate IAID

IAID is 4 bytes in length and should be unique in an AR scope.
Prefix table should be maintained. Prefix table contains IAID, MAC
address and the prefix(es) assigned to MN. In LTE networks,
International Mobile station Equipment Identity (IMEI) uniquely
identifies MN's interface and thus corresponds to the MAC address.
MAC address of the interface should be stored in the prefix table and
this field is used as the key for searching the table.

IAID should be set to Start_IAID, an integer of 4 octets. The
following IAID generation algorithm is used:

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

   3. Increment IAID.

   Prefix table entry for an MN that hands over to another AR must be
   removed. IAID value is released to be reused.

3.5.2. Policy to Delegate Prefixes

   In point-to-point links, if /64 prefixes of all the MNs connected to
   one or more ARs are broadcast dynamically upstream as the route
   information this causes high routing protocol traffic (IGP, OSPF,
   etc.) due to Per-MN interface prefixes. There are two solutions this
   problem. One 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 know
   this space, too, then they will assign from that space to a
   particular AR.

   The other method is to use route aggregation. For example, each AR
   can be assigned a /48 or /32 prefix (aggregate prefix, aka service
   provider common prefix) while each interface of MN can be assigned a
   /64 prefix. The /64 prefix is an extension of /48 one, for example,
   an AR's /48 prefix is 2001:DB8:0::/48, an interface of MN is assigned
   2001:DB8:0:2::/64 prefix. The border router (BR) in Figure 1 may be
   manually configured to broadcast only individual AR's /48 or /32
   prefix information to Internet.

4. Prefix Delegation Using RADIUS and Diameter

   In the initial network entry procedure Figure 2, AR as Remote
   Authentication Dial In User Service (RADIUS) client sends Access-
   Request message with MN information to RADIUS server. If the MN
   passes the authentication, the RADIUS server may send Access-Accept
   message with prefix information to the AR using Framed-IPv6-Prefix
   attribute. AAA server also provides routing information to be
   configured for MN on the AR using Framed-IPv6-Route attribute. Using
   such a process AR can handle initial prefix assignments to MNs but
   managing lifetime of the prefixes is totally left to the AR. Framed-
   IPv6-Prefix is not designed to support delegation of IPv6 prefixes.
   For this Delegated-IPv6-Prefix attribute can be used which is
   discussed next.

   [RFC4818] defines a RADIUS attribute Delegated-IPv6-Prefix that
   carries an IPv6 prefix to be delegated. This attribute is usable
   within either RADIUS or Diameter. [RFC4818] recommends the
   delegating router to use AAA server to receive the prefixes to be
   delegated using Delegated-IPv6-Prefix attribute/AVP.

DHCP server as the delegating router in Figure 2 may send an Access-Request packet containing Delegated-IPv6-Prefix attribute to the RADIUS server to request prefixes. In the Access-Request message, the delegating router 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 longer prefix, e.g. /56 or /64 in an Access-Accept message containing Delegated-IPv6-Prefix attribute [RFC4818]. The attribute can appear multiple times when RADIUS server delegates multiple prefixes to the delegating router. The delegating router sends the prefixes to the requesting router using IA_PD Option and AR as RR uses them for MN's as described in Section 3.

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

5. Security Considerations

   This draft introduces no additional messages. Comparing to
   [RFC3633], [RFC2865] and [RFC3588] there is no additional threats to
   be introduced. DHCPv6, RADIUS and Diameter security procedures
   apply.

6. IANA Considerations

   None.

7. Acknowledgements

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2011.

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