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### Deployment Considerations for Lightweight 4over6
### draft-sun-softwire-lightweight-4over6-deployment-04

Abstract

   Lightweight 4over6 is a mechanism which moves the translation
   function from tunnel lwAFTR (AFTR) to lwB4s (B4s), and hence reduces
   the mapping scale on the lwAFTR to per-customer level.  This document
   discusses various deployment models of Lightweight 4over6.  It also
   describes the deployment considerations and applicability of the
   Lightweight 4over6 architecture.

Status of this Memo

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## 1.  Introduction

Lightweight 4over6 [I-D.ietf-softwire-lw4over6] is an extension to
DS-Lite which simplifies the AFTR module [RFC6333] with distributed
NAT function among B4 elements.  The lwB4 in Lightweight 4over6 is
provisioned with an IPv6 address, an IPv4 address and a port-set.  It
performs NAPT on end user's packets with the provisioned IPv4 address
and port-set.  IPv4 packets are forwarded between the lwB4 and the
lwAFTR over a Softwire using IPv4-in-IPv6 encapsulation.  The lwAFTR
maintains one mapping entry per subscriber with the IPv6 address,
IPv4 address and port-set.  Therefore, this extension removes the
NAT44 module from the AFTR and replaces the session-based NAT table
to a per-subscriber based mapping table.  This should relax the
requirement to create dynamic session-based log entries.  This
mechanism preserves the dynamic feature of IPv4/IPv6 address binding
as in DS-Lite, so it has no coupling between IPv6 address and IPv4
address/port-set as any full stateless solution ([RFC6052] or
[I-D.ietf-softwire-map]) requires.  This document discusses
deployment models of Lightweight 4over6.  It also describes the
deployment considerations and applicability of the Lightweight 4over6
architecture.

Terminology of this document follows the definitions and
abbreviations of [I-D.ietf-softwire-lw4over6].

## 2.  Deployment Model

   Lightweight 4over6 is suitable for operators who would like to free
   any correlation of the IPv6 address with IPv4 address and port-set
   (or port-range).  In comparison to full stateless solutions like MAP
   [I-D.ietf-softwire-map] and 4rd [I-D.ietf-softwire-4rd], Lightweight
   4over6 frees address planning of IPv6 delegation for CPE from mapping
   rule administration and management in the network.  Thus, IPv6
   addressing is completely flexible to fit other deployment
   requirements, e.g., auto-configuration, service classification, user
   management, QoS support, etc.  The philosophy here is that bits of
   IPv6 address should be left for IPv6 usage first.

   Lightweight 4over6 can be deployed in a residential network (depicted
   in Figure1).  In this scenario, a lwB4 would acquire an IPv4 address
   and a port-set after a successful user authentication process and
   IPv6 provisioning process.  Then, it establishes an IPv4-in-IPv6
   softwire using the IPv6 address to deliver IPv4 services to its
   connected host via the lwAFTR in the network.  The lwB4 can act as a
   CPE, or software located in the host.  The lwAFTR supports
   Lightweight 4over6 which keeps the mapping between lwB4's IPv6
   address and its allocated IPv4 address + port set.  The supporting
   system may keep the binding information as well for logging and user
   management.

```
                        +---------------+
                        |  Supporting   |
                        |   System      |
                        +-------+-------+
                                |
                  +---------------+--------------|
                  |               |              |
 +---------+  +------+---+      +--+--+          |
 |  Host   |  |  lwB4    |      |     |          |
 |         |--|         | ======-| BNG | === +---------+   +-----------+
 +---------+  +---------+      +--|--+       |         |   |   IPv4    |
                                            | lwAFTR  |---| Internet  |
 +---------+  +------+---+      +--+--+      |         |   |           |
 |  Host   |--|  lwB4    | ======|      | ====+---------+   +-----------+
 |         |  |         |      | BNG |            |
 +---------+  +---------+      +--|--+            |
                +               |                |
                  +--------------+--------------+
```
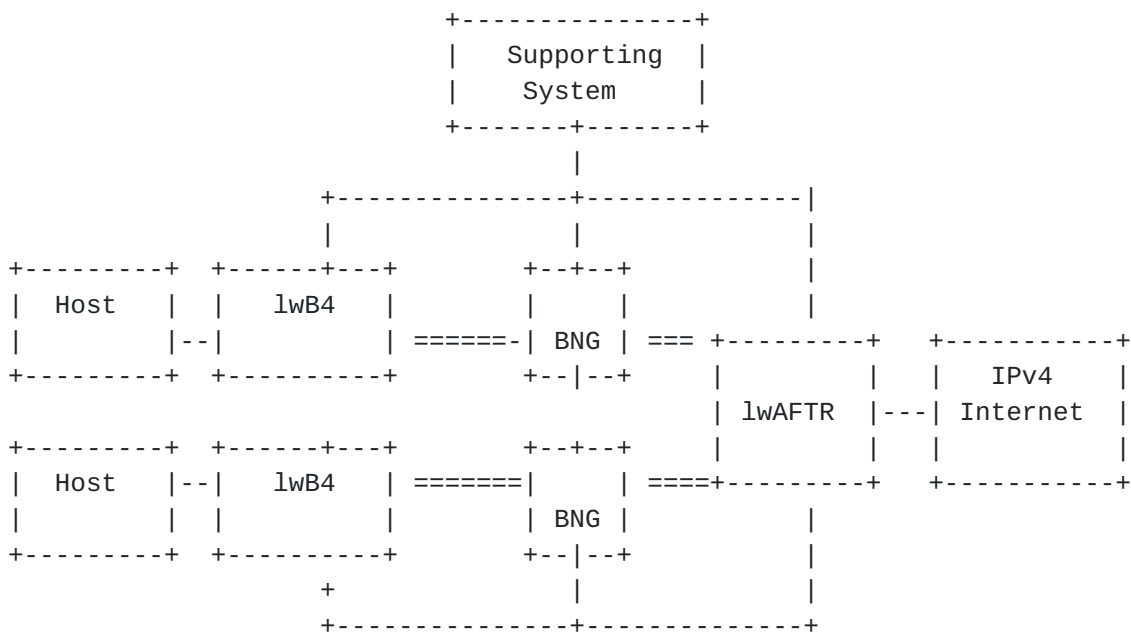
   Figure 1 Deployment Model

   There are two deployment models in practice: one is called bottom-up
   and the other is top-down.  In bottom-up model, after port-restricted

IPv4 address is allocated to a given subscriber, the lwAFTR will
report mapping records to the supporting system on creating a binding
for traffic logging if necessary.  Operators may use
[I-D.ietf-behave-syslog-nat-logging] or
[I-D.ietf-behave-ipfix-nat-logging] to report the port set allocated
by lwAFTR.  In this way, the lwAFTR can determine the binding by its
own and there is little impact on existing network architecture.  In
top-down model, the Supporting system should firstly determine the
binding information for each subscriber and then synchronize it with
the lwAFTR.  With this method, one binding record can be easily
synchronized with multiple lwAFTRs and stateless failover can be
achieved.  However, new mechanism (e.g.
[I-D.zhou-dime-4over6-provisioning]) needs to be introduced to notify
each individual binding record between the Supporting system and the
lwAFTR.

Lightweight 4over6 can also be deployed in a campus or enterprise
network, (depicted in Figure2).  In this scenario, a lwB4 acts as a
wireless AP and is connected to a number of hosts.  The lwB4 first
acquire the IPv4 address and port-set information, then it
establishes an IPv4-in-IPv6 softwire using the IPv6 address to
deliver IPv4 services to its connected host via the lwAFTR in the
network.  A network management system could be used to receive
statistic information of the network equipments, such as the binding
table, network load, and connected device.  NETCONF[RFC6241] could be
used for syncronising lwB4's IPv6 address and its allocated IPv4
address + port set with the lwAFTR.  The network management system
may keep the binding information as well for logging and user
management.

```
                        +-------------------+
                        | Network Management|
                        |      System       |
                        +---------+---------+
                                  |
                  +---------------+--------------|
                  |                              |
  +---------+     |                              |
  |  Host   |     |                              |
  |         |--+  +----------+          +---------+   +-----------+
  +---------+ |  |          |          |         |   |  IPv4     |
            + - +   lwB4   | ============= | lwAFTR  |---| Internet  |
  +---------+ |  |          |          |         |   |           |
  |  Host   |--+  +----------+          +---------+   +-----------+
  |         |
  +---------+
```
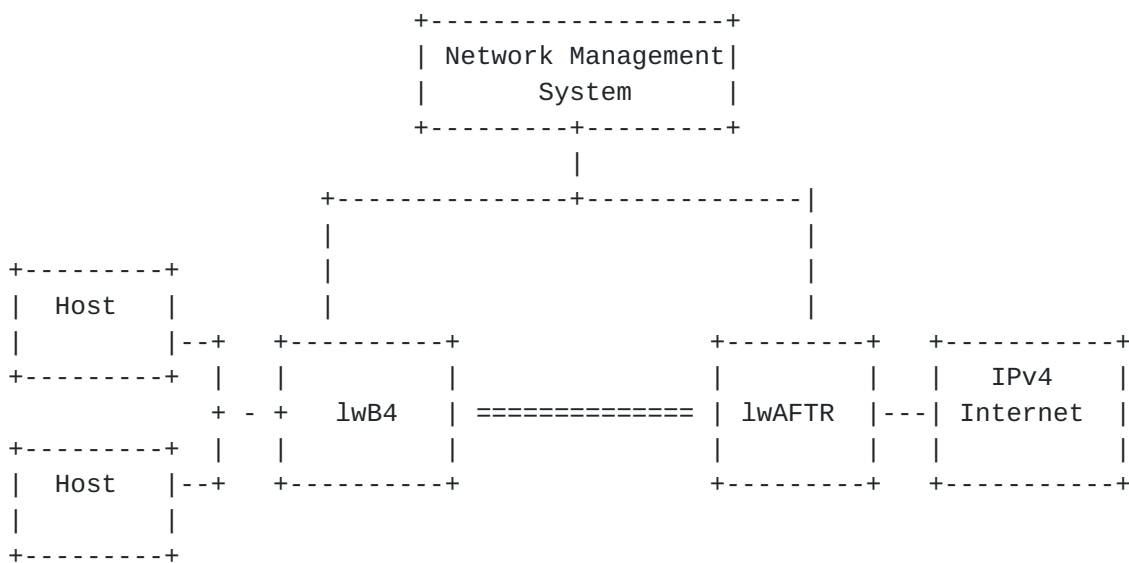
Figure 2 Deployment Model

## 3.  Overall Deployment Considerations

### 3.1.  Addressing and Routing

   In Lightweight 4over6, there is no inter-dependency between IPv4 and
   IPv6 addressing schemes.  IPv4 address pools are configured
   centralized in lwAFTR for IPv6 subscribers.  These IPv4 prefix must
   advertise to IPv4 Internet accordingly.

   For IPv6 addressing and routing, there are no additional addressing
   and routing requirements.  The existing IPv6 address assignment and
   routing announcement should not be affected.  For example, in PPPoE
   scenario, a CPE could obtain a prefix via prefix delegation
   procedure, and the hosts behind CPE would get its own IPv6 addresses
   within the prefix through SLAAC or DHCPv6 statefully.  This IPv6
   address assignment procedure has nothing to do with restricted IPv4
   address allocation.

### 3.2.  Port-set Management

   In Lightweight 4over6, each lwB4 will get its restricted IPv4 address
   and a port-set after successful user authentication process and IPv6
   provisioning process.  This port-set assignment can been achieved by
   DHCPv4-over-DHCPv6 [I-D.ietf-dhc-dhcpv4-over-dhcpv6] and PCP
   [I-D.ietf-pcp-port-set].

   Operator may use DHCPv4 to provision IPv4 address to the lwB4.  In a
   typical deployment, the DHCP server is a centralized DHCP server and
   lwAFTR is the DHCP relay agent to relay the dhcp messages to the
   server over unicast.  Rarely DHCP server will collocate with the
   lwAFTR to provision IPv4 resources to the lwB4.

   Operator may also use PCP Port-set Option to provision IPv4 address
   and port-set to the lwB4.  In a typical deployment, PCP server will
   collocate with lwAFTR, and the subscriber's binding can be determined
   by lwAFTR.  The PCP request should be sent to the lwAFTR's tunnel
   end-point address.  It is not common that PCP server will be
   centralized deployed in which the lwAFTR is the PCP proxy to relay
   PCP requests.

   It is also possible that subscriber's binding is determined in AAA
   server.  In this case, the BNGs will embed with a DHCPv4-over-DHCPv6
   server function which allows them to locally handle any DHCPv4-over-
   DHCPv6 requests initiated by hosts.  The AAA server will pass the
   subscriber's binding to a BNG using the AAA attribute in [I-D.sun-
   softwire-lw4over6-radext] and in turn populates the mapping of the
   lwB4.

   Some operators may offer different service level agreements (SLA) to
   users that some users may require more ports then others.  In this
   deployment scenario, the operator can implement differentiated
   policies in provisioning system specified to a user's lwB4 or a group
   of lwB4s to allocate a certain range of port-set.  The lwAFTR may
   also run multiple instances with different port-set sizes to build
   the mapping table.

### 3.3.  lwAFTR Discovery

   A Lightweight 4over6 lwB4 must discover the lwAFTR's IPv6 address
   before offering any IPv4 services.  This IPv6 address can be learned
   through an out-of-band channel, static configuration, or dynamic
   configuration.  In practice, Lightweight 4over6 lwB4 can use the same
   DHCPv6 option [RFC6334]to discover the FQDN of the lwAFTR.

   When Lightweight 4over6 is deployed in the same place with DS-Lite,
   either different FQDNs can be configured for Lightweight 4over6 and
   DS-Lite separately or different DHCPv6 options can be used for
   Lightweight 4over6 [I-D.sun-softwire-lw4over6-dhcpv6] and DS-Lite.
   More detailed considerations on DS-Lite compatibility will be
   discussed in Section6.

### 3.4.  Impacts on Accouting

   In Lightweight 4over6, the accounting impact due to the tunneling
   protocol is the same with DS-Lite (see section 6.2 of [RFC6908]).
   However, since in Lightweight 4over6, the IPv4 service is only
   available after port-set allocation, if operators will regard IPv4
   service as a on-demand value-added service, e.g.  IPv6 connectivity
   is offered by default, while IPv4 connectivity will be offered untill
   a subscriber requires, etc., IPv4 service accounting should start
   after port-set allocation has completely.

[4](#). lwAFTR Deployment Consideration

   As Lightweight 4over6 is an extension to DS-Lite, both technologies
   share similar deployment considerations.  For example: Interface
   consideration, Lawful Intercept Considerations, Blacklisting a shared
   IPv4 Address, AFTR's Policies, AFTR Impacts on Accounting Process,
   etc., in [[RFC6908](#)] can also be applied here.  This document only
   discusses new considerations specific to Lightweight 4over6.

[4.1](#).  Logging at the lwAFTR

   In Lightweight 4over6, operators only log one entry per subscriber.
   The log should include subscriber's IPv6 address used for the
   softwire, the public IPv4 address and the port-set.  The port set
   algorithm implemented in Lightweight 4over6 lwAFTR should be
   synchronized with the one implemented in logging system.  For
   example, if contiguous port set algorithm is adopted in the lwAFTR,
   the same algorithm should also been applied to the logging system.

   Since the mapping in lwAFTR does not contain destination-specific
   information, operator should be aware that they will not be able to
   have destination-specific log.

[4.2](#).  MTU and Fragmentation Considerations

   As Lightweight 4over6 is also a tunneling protocol, the same
   consideration regarding to the fragmentation and reassembly in DS-
   Lite [[RFC6908](#)] can also be applied.  The only difference is that NAT
   functionality has been removed to lwB4 from lwAFTR in Lightweight
   4over6.  Therefore, on receiving an IPv4 fragmented packet after
   decapsulation in the lwB4, the lwB4 should further re-assemble the
   packets before doing NAT since the transport protocol information is
   only available in the first fragment.

[4.3](#).  Reliability Considerations of lwAFTR

   Operators may deploy multiple lwAFTRs for robustness, reliability,
   and load balancing.  In Lightweight 4over6, subscriber to IPv4 and
   port-set mapping must be pre-provisioned in the lwAFTR before
   providing IPv4 serives.  For redundancy, the backup lwAFTR must
   either have the subscriber mapping already provisioned or notify the
   lwB4 to create a new mapping in the backup lwAFTR.  The first option
   can be considered as Hot Standby mode, which requires state
   syncronization between multiple lwAFTRs.  In Hot Standby mode, the
   bindings are replicated on-the-fly from the Primary lwAFTR to the
   Backup lwAFTR.  When the Primary lwAFTR fails, the Backup lwAFTR will
   take over all the existing established sessions.  In this mode, the
   internal hosts are not required to re-initiate the bindings with the

external hosts.  In Lightweight 4over6, since the number of mapping
states has been greatly reduced compared to DS-Lite, it is reasonable
to adopt Hot Standby mode when there are only two lwAFTRs (one for
Primary lwAFTR and one for Backup lwAFTR).  However, if the number of
lwAFTRs is larger than two, it is not scalable to deploy Hot Standby
mode since each two of the lwAFTRs should to syncronize the binding
states.

The second option is to use Cold Standby mode which does not require
a Backup Standby lwAFTR to synchronize binding states.  In failover,
the lwAFTR has to notify the lwB4 to create a new binding, or fetch
the binding by itself.  [I-D.lee-softwire-lw4over6-failover]
describes these two approaches for simple Cold Standby mode.  For
most deployment scenarios, we believe that Cold Standby mode should
be sufficient enough and is thus recommended.

## 4.4.  Placement of AFTR

The lwAFTR can be deployed in a "centralized model" or a "distributed
model".

In the "centralized model", the lwAFTR could be located at the higher
place, e.g. at the exit of MAN, etc.  Since the lwAFTR has good
scalability and can handle numerous concurrent sessions, we recommend
to adopt the "centralized model" for Lightweight 4over6 as it is
cost-effective and easy to manage.

In the "distributed model", lwAFTR is usually integrated with the
BRAS/SR.  Since newly emerging customers might be distributed in the
whole Metro area, we have to deploy lwAFTR on all BRAS/SRs.  This
will cost a lot in the initial phase of the IPv6 transition period.

## 4.5.  Port set algorithm consideration

If each lwB4 is given a set of ports, port randomization algorithm
can only select port in the given port-set.  This may introduce
security risk because hackers can make a more predictable guess of
what port a subscriber may use.  Therefore, non-continuous port set
algorithms (e.g. as defined in [I-D.ietf-softwire-map]) can be used
to improve security.

## 4.6.  Path Consistency Consideration

In Lightweight 4over6, if the binding state is not syncronized among
multiple lwAFTRs, the lwAFTR in which the subscriber's binding state
is stored should be exactly the one to service the subscriber.
Otherwise, there will be no match in lwAFTR.  This requires the
provionsion packets (either using DHCPv4-over-DHCPv6 or PCP Port-set)

should arrive at the same lwAFTR as the subsquent IP-in-IP traffic.
If multiple lwAFTRs are using the same Tunnel End Point address and
there are intermediate routers between lwB4 and lwAFTR, there might
be a problem when intermediate routers perform ECMP based on L4 hash
for the plain provionsion packets while doing L3 hash for subsequent
IP-in-IP traffic.  In this case, it is recommended that the
privioning packet is sent over IPv6 tunnel so that intermediate
routers can only process ECMP using L3 hash.

5.  lwB4 Deployment Consideration

   For lwB4 consideration, the DNS Deployment Considerations and B4
   Remote Management in [RFC6908] can also be applied here.  In this
   section, we only describe the considerations sepcific to Lightweight
   4over6.

5.1.  NAT traversal issue

   In Lightweight 4over6, since the subscriber's source port will be
   restricted to the port-set allocated from the provisioning system,
   this will have impact on some NAT traversal mechanisms.  For example,
   in UPnP 1.0, the external port number which can be used by remote
   peer is selected by UPnP client in end host.  If the client randomly
   selects a port number which is not in that valid port-set, the UPnP
   process will fail.  This is likely to happen because end-host does
   not know the port-set in lwB4.  More detailed experimental results
   can be found in [I-D.deng-aplusp-experiment-results].  This problem
   will not exist in UPnP 2.0 because the UPnP client in the end-host
   will negotiate the external port number with the server.  Another way
   is to implement a mechanism (e.g.  [I-D.ietf-pcp-port-set], etc.) in
   end host to fetch the port-set from lwB4.  The UPnP client can then
   select the port number within the port-set.

5.2.  Static Port Forwarding Configuration

   Currently, some external initiated applications rely on manual port
   configuration to reserve a port in the CPE.  The restricted port-set
   in lwB4 will also have impacts on manual port forwarding
   configuration.  It is recommended that the port-set allocated from
   the provioning system should be shown explicitly in the lwB4, which
   can be used as a hint for subscribers to add port forwarding mapping.

6.  DS-Lite Compatibility Consideration

    Lightweight 4over6 can be either deployed all alone, or combined with
    DS-Lite [RFC6333].  Since Lightweight 4over6 does not any have extra
    requirement on IPv6 addressing, it can use use the same addressing
    scheme with DS-Lite, together with routing policy, user management
    policy, etc.  Besides, the bottom-up model has quite similar
    requirement and workflow on the supporting system with DS-Lite.
    Therefore, it is suitable for operators to deploy incrementally in
    existing DS-Lite network

6.1.  Case 1: Integrated Network Element with Lightweight 4over6 and DS-
      Lite AFTR Scenario

    In this case, DS-Lite has been deployed in the network.  Later in the
    deployment schedule, the operator decided to implement Lightweight
    4over6 lwAFTR function in the same network element(depicted in
    Figure3).  Therefore, the same network element needs to support both
    transition mechanisms.

    There are two options to distinguish the traffic from two transition
    mechanisms.

    The first one is to distinguish using the client's source IPv4
    address.  The IPv4 address from Lightweight 4over6 is public address
    as NAT has been done in the lwB4, and IPv4 address for DS-lite is
    private address as NAT will be done on AFTR.  When the network
    element receives an encapsulated packet, it would de-capsulate packet
    and apply the transition mechanism based on the IPv4 source address
    in the packet.  This requires the network element to examine every
    packet and may introduce significant extra load to the network
    element.  However, both the B4 element and Lightweight 4over6 lwB4
    can use the same DHCPv6 option [RFC6334] with the same FQDN of the
    AFTR and lwAFTR.

    The second one is to distinguish using the destination's tunnel IPv6
    address.  One network element can run separated instances for
    Lightweight 4over6 and DS-Lite with different tunnel addresses.  Then
    B4 element and Lightweight 4over6 lwB4 can use the same DHCPv6 option
    [RFC6334] with different FQDNs pointing to corresponding tunnel
    addresses.  This requires the supporting system should distinguish
    different types of users when assigning the FQDNs in DHCPv6 process.
    Another option is to use a new DHCPv6 option
    [I-D.sun-softwire-lw4over6-dhcpv6] to discover lwAFTR's FQDN.

```
                 +--------------+-------------|
                 +              |             |
+---------+  +------+---+       +--+--+       |
|  Host   |  | LW 4over6|       |     |       |
|         |--|   lwB4   | ======-| BNG | === +-------------+   +-----------+
+---------+  +----------+       +--|--+      |LW 4over6    |   |   IPv4    |
                                             |lwAFTR/      |---| Internet  |
+---------+  +------+---+       +--+--+       |DS-Lite AFTR |   |           |
|  Host   |--| DS-Lite  | ======|     | ====+-------------+   +-----------+
|         |  |   B4     |       | BNG |              |
+---------+  +----------+       +--|--+              |
                 +              |                    |
                 +--------------+--------------------+
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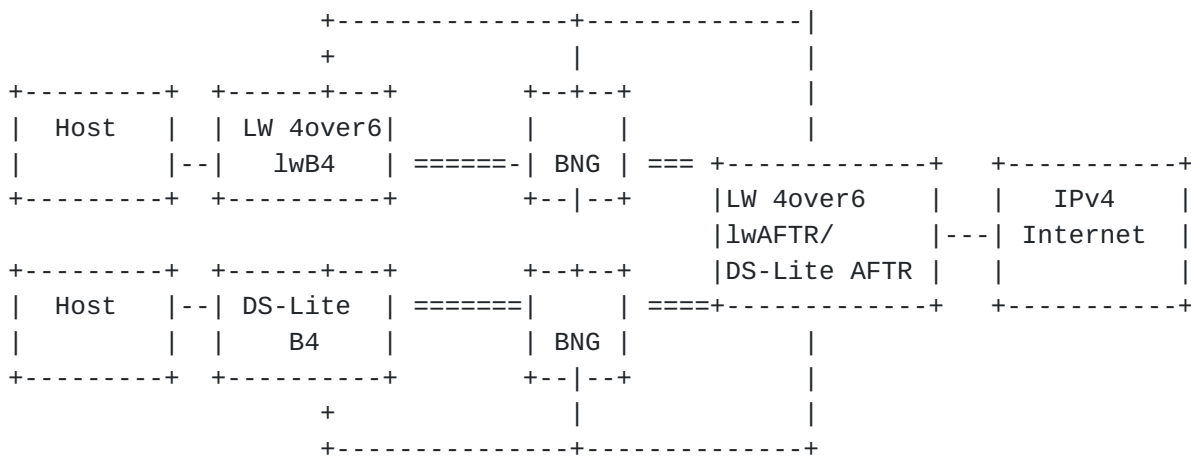
        Figure 3 DS-Lite Coexistence scenario with Integrated AFTR

## 6.2.  Case 2: DS-Lite Coexistent scenario with Separated AFTR

   This is similar to Case 1.  The difference is the lwAFTR and AFTR
   functions won't be co-located in the same network element (depicted
   in Figure4).  This use case decouples the functions to allow more
   flexible deployment.  For example, an operator may deploy AFTR closer
   to the edge and lwAFTR closer to the core.  Moreover, it does not
   require the network element to pre-configure with the CPE's IPv6
   addresses.  An operator can deploy more AFTR and lwAFTR at needed.
   However, this requires the B4 and lwB4 to discover the corresponding
   network element.  In this case, B4 element and Lightweight 4over6
   lwB4 can still use [RFC6334] with different FQDNs pointing to
   corresponding tunnel end-point addresses, and the supporting system
   should distinguish different types of users.

```
                 +---+--------------+----------------|
                 +                  |                |
+---------+  +------+---+       +------+-----+        |
|  Host   |  | LW 4over6|       |    BNG     |        |
|         |--|   lwB4   | ======-|DS-Lite AFTR| === +------------+
+-----------+                    +------+-----+      |
+---------+  +----------+       +------+-----+    | LW 4over6  |   |
IPv4    |                                          |  lwAFTR    |---|
Internet  |                       +------+-----+    |            |
+---------+  +------+---+       +------+-----+    |            |
|         |          |                                          |            |
|  Host   |--| DS-Lite  | ======|    BNG     | ====+------------+
+-----------+                    |DS-Lite AFTR|                |
|         | |    B4    |          +------+-----+                |
+---------+  +----------+       +------+-----+                |
                 +                  |                          |
```

```
                  +------------------+----------------+
```
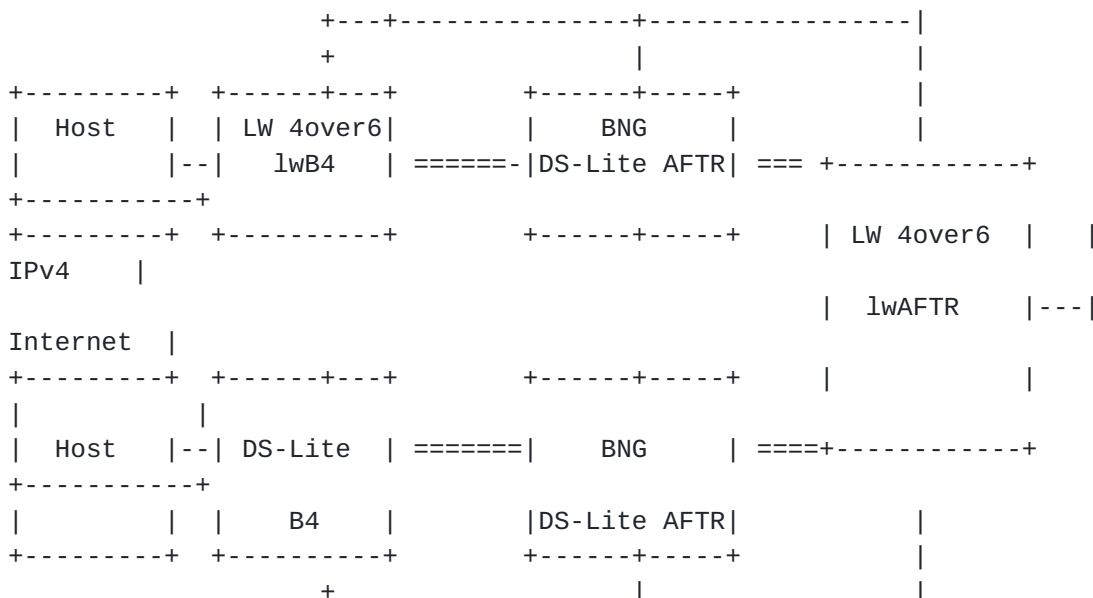
Figure 4 DS-Lite Coexistence scenario with Seperated AFTR

## 7.  Acknowledgement

   TBD

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# 1.  China Telecom Experimental Result

   We have deployed Lightweight 4over6 in our operational network of
   HuNan province, China.  It is designed for broadband access network,
   and different versions of lwB4 have been implemented including a
   linksys box, a software client for windows XP, vista and Windows 7.
   It can be integrated with existing dial-up mechanisms such as PPPoE,
   etc.  The major objectives listed below aimed to verify the
   functionality and performance of Lightweight 4over6:

   o  Verify how to deploy Lightweight 4over6 in a practical network.

   o  Verify the impact of applications with Lightweight 4over6.

   o  Verify the performance of Lightweight 4over6.

## 1.1.  Experimental Environment

   The network topology for this experiment is depicted in Figure 5.

```
                                          +--------+
+-----+  +-------+                        | Syslog |
|Host1+--+lwB4   |----+                   | Server |
+-----+  +-------+    |                    +---+----+     ---------
                     |         /------\        |       //         \\
                     |        //      \\       |      /            \
+-----+  +-------+    +-+--+   |  IPv6  |    +---+----+ |              |
|Host2+--|lwB4   |----+BRAS+--|  Network |---|lwAFTR  +-+ IPv4 Internet +
+-----+  +-------+    +-+--+   \\      //    +--------+ |              |
                     |         \--+---/    (PCP Server) \            /
                     |            |                      \\         //
+-----+  +-------+    |            |                        ---------
|Host3+--+lwB4   +----+            |
+-----+  +-------+                 |                        ---------
                                   |                      //         \\
                                   |                     /            \
                                   |                     |              |
                     +--------------------+ IPv6 Internet +
                                          |              |
                                          \             /
                                           \\          //
                                            ---------
```
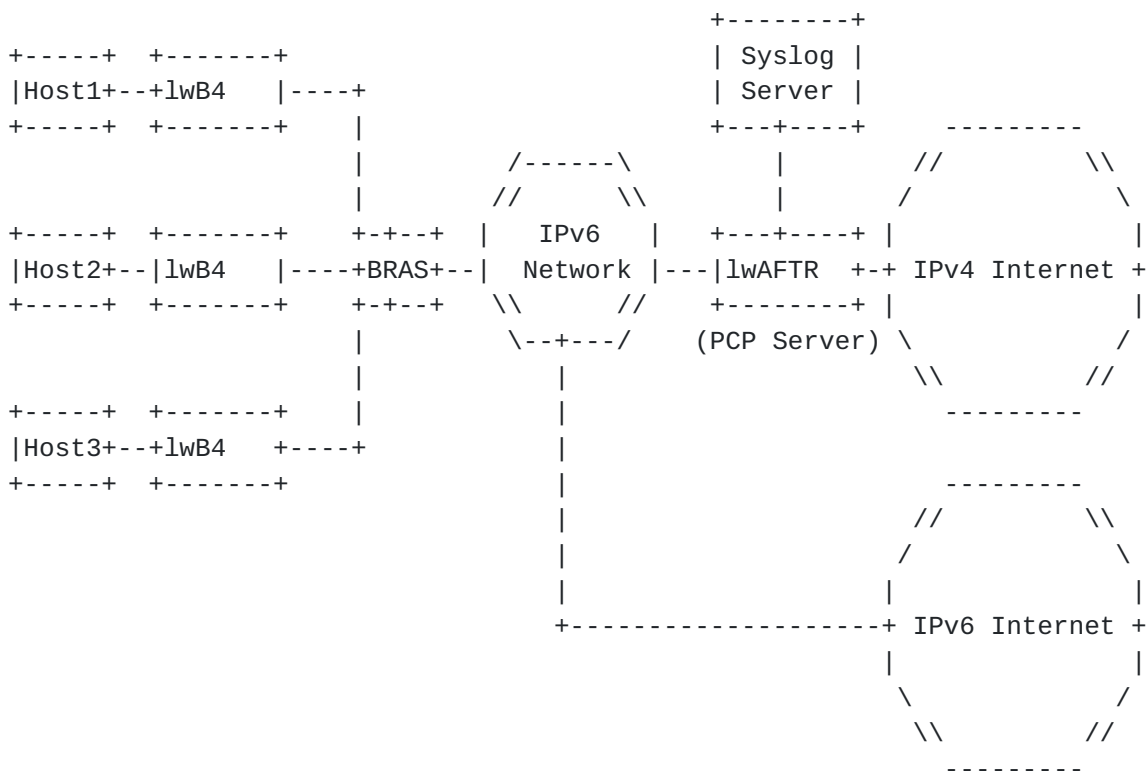
   Figure 5 China Telecom Lightweight 4over6 experiment topology

   In this deployment model, lwAFTR is co-located with a extended PCP
   server to assign restricted IPv4 address and port set for lwB4.  It
   also triggers subscriber-based logging event to a centrilized syslog

server.  IPv6 address pools for subscribers have been distributed to
BRASs for configuration, while the public available IPv4 address
pools are configured by the centralized lwAFTR with a default address
sharing ratio.  It is rather flexible for IPv6 addressing and
routing, and there is little impact on existing IPv6 architecture.

In our experiment, lwB4 will firstly get its IPv6 address and
delegated prefix through PPPoE, and then initiate a PCP-extended
request to get public IPv4 address and its valid port set.  The
lwAFTR will thus create a subscriber-based state accordingly, and
notify syslog server with {IPv6 address, IPv4 address, port set,
timestamp}.

## 1.2.  Experimental Results

In our trial, we mainly focused on application test and performance
test.  The applications have widely include web, email, Instant
Message, ftp, telnet, SSH, video, Video Camera, P2P, online game,
voip and so on.  For performance test, we have measured the
parameters of concurrent session numbers and throughput performance.

The experimental results are listed as follows:

```
+--------------------+--------------------+----------------------+
| Application Type   |    Test Result     |Port Number Occupation |
+--------------------+--------------------+----------------------+
|   Web              |        ok          | normal websites: 10~20|
|                    | IE, Firefox, Chrome| Ajex Flash webs: 30~40|
+--------------------+--------------------+----------------------+
|   Video            |   ok, web based or |        30~40          |
|                    |    client based    |                       |
+--------------------+--------------------+----------------------+
|   Instant Message  |        ok          |                       |
|                    | QQ, MSN, gtalk, skype|      8~20            |
+--------------------+--------------------+----------------------+
|   P2P              |        ok          | lower speed: 20~600   |
|                    |utorrent,emule,xunlei | (per seed)          |
|                    |                    | higher speed: 150~300 |
+--------------------+--------------------+----------------------+
|   FTP              | need ALG for active |        2             |
|                    |   mode, flashxp    |                       |
+--------------------+--------------------+----------------------+
|   SSH, TELNET      |        ok          |1 for SSH, 3 for telnet|
+--------------------+--------------------+----------------------+
|   online game      | ok for QQ, flash game|      20~40           |
+--------------------+--------------------+----------------------+
```

Figure 6 China Telecom 4over6 experimental result

   The performance test for lwAFTR is taken on a normal PC.  Due to
   limitations of the PC hardware, the overall throughput is limited to
   around 800 Mbps.  However, it can still support more than one hundred
   million concurrent sessions.

## 1.3.  Conclusions

   From the experiment, we can have the following conclusions:

   o  Lightweight 4over6 has good scalability.  As it is a lightweight
      solution which only maintains per-subscription state information,
      it can easily support a large amount of concurrent subscribers.

   o  Lightweight 4over6 can be deployed rapidly.  There is no
      modification to existing addressing and routing system in our
      operational network.  And it is simple to achieve traffic logging.

   o  Lightweight 4over6 can support a majority of current IPv4
      applications.

## 2.  Tsinghua University Experimental Result

   Lightweight 4over6 has also been deployed in the campus of Tsinghua
   University, China.  We use DHCPv4 over DHCPv6 [RFC7341] for the
   dynamic provisioning of lwB4's IPv4 address and port set [RFC7618].
   We deployed wireless APs for Lightweight 4over6, covering a large
   portion of the campus, allowing mobile devices to connect to the
   lwB4.  We also deployed lwB4 gateway in some of our buildings so PCs
   could connect directly to the lwB4.  Users could access the IPv4
   Internet through the CNGI IPv6 Network.

### 2.1.  Experimental Environment

   The network topology for this experiment is depicted in Figure 7.

```
+-----+                         -------                    ---------
|Host1+---+                    /       \                   //       \\
+-----+   |                   //        \\                /          \
+-----+   |  +--------+      |  CNGI IPv6 |  +--------+  |            |
|Host2+---+--+lwB4(AP)+--+--|   Network   |--+ lwAFTR +---+ IPv4 Internet +
+-----+   |  +--------+  |   \\          //   +--------+  |            |
+-----+   |              |    \         / (DHCP4o6 Server) \          /
|Host3+---+              |     --+----                     \\        //
+-----+                  |       |                          ---------
                         |       |
+-----+                  |       |                          ---------
|Host4+---+              |       |                         //       \\
+-----+   |   +------+   |       |                        /          \
      +---+lwB4    +--+       |                        |            |
+-----+   |   +------+       +----------------------+ IPv6 Internet +
|Host5+---+                       |                  |            |
+-----+                            \                /
                                    \\             //
                                     ---------
```

   Figure 7 Tsinghua University Lightweight 4over6 experiment topology

   In this deployment model, lwAFTR is co-located with a DHCP4o6 server
   to assign restricted IPv4 address and port set for lwB4. lwAFTR
   listens to all DHCPv4 over DHCPv6 messages generated or received by
   the DHCP4o6 server and updates its binding table through valid
   messages.

   In our experiment, the lwB4 gets its IPv6 address through static
   configuration or dynamic configuration.  It will then send a request
   to the lwAFTR device to get the public IPv4 address and its valid
   port set.  The lwAFTR will add the IPv6 address, IPv4 address, and

port set information of the lwB4 into its binding table.

## 2.2.  Experimental Results

In our experiment, we tested the performence of various applications,
including web, video, p2p, ping, tracert, telnet, SSH, email. online
storage, instant message, online gaming, online payment and so on.
We also tested different terminal devices including PC, laptop
computer, and cell phone.  These include devices using different
operating systems, including Windows 7, MacOS, Android, and IOS.

The experimental results are listed as follows:

| Application Type | Test Applications | Test Subjects | Result |
|---|---|---|---|
| Web | IE, Chrome, Sougou | Browse websites, download files | OK |
| Video | Youku, pptv, qqlive (Web based,client based) | VOD, live video | OK |
| P2P | Bittorrent, xunlei | Download files | OK |
| Ping/tracert | Command line | Ping/tracert URL | OK |
| TELNET/SSH | Putty, secureCRT | Telnet/SSH login | OK |
| Email | 126, QQ, hotmail (Web based,client based) | Send/receive email | OK |
| Cloud storage | Baidu Cloud | Upload/download files | OK |
| Instant messaging | Skype, QQ | Send/receive messages | OK |
| Online gaming | QQ game | Enter game | OK |
| Online payment | JD, Taobao | Complete payment | OK |

Figure 8 Tsinghua University Lightweight 4over6 experimental result

## 2.3.  Conclusions

Lightweight 4over6 supports the majority of current IPv4 applications
and services.  The user experience of using Lightweight 4over6 is no
different from using the native IPv4 network.  It can satisfy the
IPv4 network service demands of IPv6 network users.

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