IPv6 over 802.11ah
draft-delcarpio-6lo-wlanah-01

Abstract

   IEEE 802.11 is an established Wireless LAN (WLAN) technology which
   provides radio connectivity to a wide range of devices. The IEEE
   802.11ah amendment defines a WLAN system operating at sub 1 GHz
   license-exempt bands designed to operate with low-rate/low-power
   consumption. This amendment supports large number of stations and
   extends the radio coverage to several hundreds of meters. This
   document describes how IPv6 is transported over 802.11ah using
   6LoWPAN techniques.

Status of This Memo

   This Internet-Draft is submitted in full conformance with the
   provisions of BCP 78 and BCP 79.

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   This Internet-Draft will expire on April 21, 2016.

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1. Introduction

   IEEE 802.11 [IEEE802.11], also known as Wi-Fi, is an established
   Wireless LAN (WLAN) technology operating in unlicensed Industrial,
   Scientific and Medical (ISM) bands. Its IEEE 802.11ah [IEEE802.11ah]
   amendment is tailored for Internet of Things (IoT) use-cases and at
   the moment of writing this draft it is in the final stages of IEEE
   standardization.

   IEEE 802.11ah operates in the Sub-1 GHz spectrum which helps reducing
   the power consumption. It also supports a larger number of stations
   on a single Basic Service Set (BSS) and it provides power-saving
   mechanisms that allow radio stations to sleep in order to save power.

However, the system achieves lower throughput compared to 802.11n/ac amendments.

IEEE 802.11 specifies only the MAC and PHY layers of the radio technology. In other words, 802.11 does not specify a networking layer but it is compatible with commonly used internet protocol such as IPv4 and IPv6. As 802.11ah is a low-rate/low-power technology, the communication protocols used above MAC should also take power-efficiency into consideration. This motivates the introduction of 6LoWPAN techniques [RFC4944] [RFC6282] for efficient transport of IPv6 packets over IEEE 802.11ah radio networks.

This document specifies how to use 6LoWPAN techniques for 802.11ah.

2. Terminology and Language Requirements

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

Terminology from 802.11ah:

Station (STA): defined in 802.11-2012 [IEEE802.11-2012] as a wireless station which is an addressable unit.

Sensor-STA: defined in 802.11ah as a device having low-power consumption requirements. This device might be a battery operated device.

Non-sensor STA: defined in 802.11ah as device which usually does not have low-power consumption requirements.

In this document, any type STA (sensor STA/non-sensor STA) is associated with a 6LoWPAN Node(6LN).

Access Point (AP): entity maintaining the WLAN Basic Service Set (BSS) and it is associated with the 6LoWPAN Border Router (6LBR). It is assumed that APs are connected to the power-line.

The terms 6LoWPAN Router (6LR) and 6LoWPAN Border Router (6LBR) are defined as in [RFC6775] and in this context 6LoWPAN Nodes (6LN) do not refer to a router (Access Point), just to a host (STA).

3. Overview of 802.11ah

The IEEE 802.11 technology uses the unlicensed spectrum in different ISM bands, using CSMA/CA techniques. Specifically 802.11ah is designed to operate in ISM band below Sub-1 Ghz with a basic

bandwidth of 1Mhz/2Mhz (depending of configuration). The system is
formed by an Access Point (AP) which maintains a Basic Service Set
(BSS) and stations (STAs). STAs are connected to the AP in a star
topology.

The 802.11ah is more energy efficient compared to other conventional
802.11 technologies because of it uses mechanisms which allow STAs to
doze periodically and STAs request downlink data when switching to
active mode i.e. Traffic Indication Map (TIM) operation, non-TIM
operation, Target Wakeup Time (TWT)

An exemplary deployment of a 802.11ah BSS may include a large number
of STAs associated to a BSS where STAs are sleeping (dozing) most of
the time and they may monitor periodic beacon-frame transmissions
containing Traffic Indication Maps (TIM). Data packets intended to
STAs cannot be delivered when STAs sleep, thus the TIM indicates
which STAs have downlink data buffered at the AP. After reading the
TIM, STAs request their buffered data by transmitting a Power-Saving
Poll (PS-Poll) frame to the AP. After the downlink data is
delivered, STAs enter into sleep mode again. For uplink data
delivery, STAs might transmit as soon as their data is available.

There might be STAs that do not monitor constantly the TIM and
request downlink data sporadically after waking up.

3.1. Link Layer Topology of 802.11ah

The 802.11ah defines a star topology at L2 link connectivity, where
the STAs are connected to the AP and any communication between STAs
passes through the AP. It also includes L2 relays to extend the
range of the system. As in other 802.11 amendments, the ad-hoc
topology is also suported. Finally, the 802.11 standard does not
define its own networking layer but is compatible with commonly used
protocols e.g. IPv4, IPv6 via the Link Layer Control.

```
                        +---+
                        |STA|
                        +-+-+
           +---+          |
           |STA+------+   |
           +---+      |   |
                    +---+---+    +---+
                    |   AP  +----+STA|
                    ++-----++    +---+
           +----+    |      |
           |STA +-----+      |
           +----+          +-+--+
                           |STA |
                           +----+
```
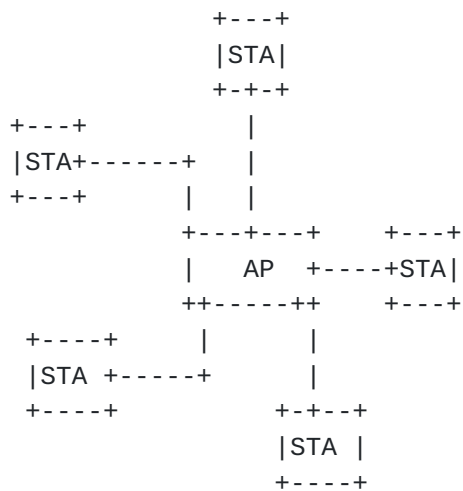
                  Figure 1: Star Link Layer Topology

   It is important to note that the communication link is unidirectional
   at any given point in time and that the medium is shared by CSMA/CA
   techniques which avoid that two or more STAs utilize the medium
   simultaneously.

3.2. Device Addressing and Frame Structure

   The 802.11 physical transmission is composed by a preamble which is
   used to prepare a receiver for frame decoding, basic physical layer
   information, and the physical layer payload which encapsulates the
   MAC Protocol Data Unit (MPDU).

   There can be different classes of MAC frames in 802.11, the MAC data
   frame is the only one carrying higher layer data. Other frames are
   control and management frames which are used to maintain MAC layer
   functions. In general in 802.11 MAC addresses use the EUI-48 bit
   address space.

   A MAC data frame in 802.11 is composed by a MAC header, a MAC payload
   and a Frame Check Sequence (FCS) which are encoded in an MPDU. The
   MAC payload carries Link Layer Control PDUs which encapsulates, for
   example, IP packets. There are two protocol versions for MAC frame
   formats, the Protocol Version 0 (PV0) which is the default format of
   802.11 and it is inherited to 802.11ah and the Protocol Version 1
   (PV1) which has less overhead that PV0 and can be optionally
   supported by 802.11ah non-sensor STA and it is mandatory supported
   for 802.11ah sensor STA.

   In 802.11ah, the maximum size of the MSDU (MAC payload) is given by
   the maximum size of a A-MSDU which is constrained by the maximum size

of the A-MPDU of 7991 bytes. This maximum of the A-MPDU is
independent of Protocol Version.

In addition, segmentation at 802.11 MAC layer level is supported if
required.

3.3. Protocol Version 0

The elements of the MAC data frame with PV0 are defined in
802.11-2012, Section 8.2 [IEEE802.11-2012] and are depicted in the
picture below.

```
+-------+--------+----+----+----+------+----+-----+----+-------+---+
+ Frame +Duration+ A1 + A2 + A3 + Seq. + A4 + QoS + HT + Frame +FCS+
+Control+   /ID  +    +    +    + Ctrl +    + Crl +Crl + Body  +   +
+-------+--------+----+----+----+------+----+-----+----+-------+---+
    2       2      6    6    6     2     6/0   2     4    0-7951  4
```
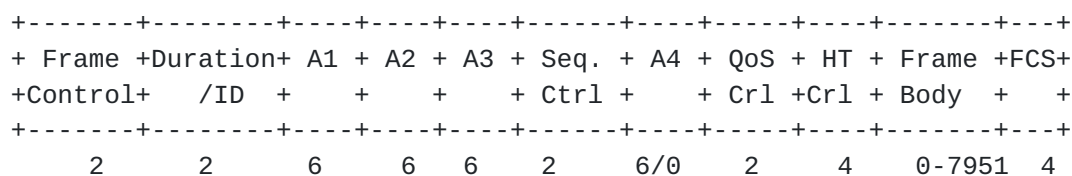
Figure 2: MAC frame PV0

Frame Control: contains information relevant in link layer such as
the Protocol Version, frame type and subtype, Power Management,
Fragmentation Information, among others.

A1, A2, A3: indicate the recipient, the transmitter and the BSSID
which in infraestructure mode is the value of the STA contained in
the AP (AP MAC address in practice). They follow 48-bits MAC address
format.

A4, Sequence control, QoS control, HT control: The meaning of these
field are out of scope of this draft. Please refer to 802.11-2012,
Section 8.2.4 [IEEE802.11-2012] for further information.

Frame Body: is of variable-length field and contains the MAC payload
for example L3 packets.

FCS: The Frame Check Sequence field is a 32-bit field containing a
32-bit CRC which is calculated over all the fields of the MAC header
and the Frame Body field

3.4. Protocol Version 1

The MAC header for the PV1 format is at least formed by a Frame
Control field and the address fields. Other fields are optional.
Please refer to 802.11-2012, Section 8.8.1 [IEEE802.11ah] for further
information.

```
     +---------------+-------+--------+--------------------+
     + Frame Control +  A1   +   A2   + Frame Body +  FCS  +
     +---------------+-------+--------+--------------------+
      Bytes:  2          6/2     2/6       0-7951         4
```
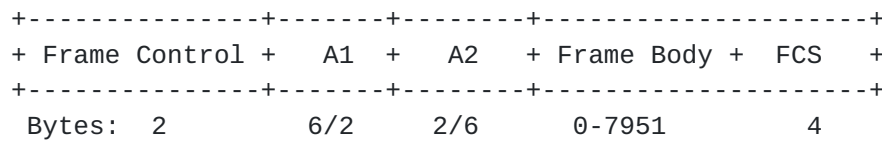
                  Figure 3: MAC frame PV1 of 802.11ah

   Frame control: see above.

   A1, A2: indicates the recipient and the transmitter respectively of
   the frame and it contains the 6-bytes MAC address or the Short ID
   (2-bytes) provided by the AP after association in a given BSS. Short
   ID includes the Association Identifier (AID) field which is used in
   TIM and power-saving mode.

   Frame Body: The minimum length for non-data frames is 0 bytes. The
   maximum length of A-MSDU is constrained by the maximum size of the
   A-MPDU of 7991 bytes.

3.5. Link Layer Control

   The Logical Link Control (LLC) layers works as the interface between
   higher layers, for example IP, and the 802.11 MAC. It supports
   higher layer protocol discrimination via the EtherType value
   utilizing the LLC SNAP or RFC1042.

```
        +----------------------------------------------------+
        | DSAP | SSAP | CTL    | OUI      | Ethertype | SDU |
        | 0xAA | 0xAA | 0x03=UI| 00+00+00 |           |     |
        +----------------------------------------------------+
```

         Figure 4: Format of LPD compatible with current 802.11
                            recommendations

   Examples of EtherTypes are 0x0800 and 0x8DD, which are used to
   identify IPv4 and IPv6, respectively.

```
                +----------------------+
                |     Upper Layer      |
                +----------------------+
                |        802 LLC       |
                +----------------------+
                | MAC Layer (802.11ah) |
                +----------------------+
                | PHY Layer (802.11ah) |
                +----------------------+
```

                   Figure 5: WLAN Protocol Stack

3.6. Ad Hoc Mode and Extended Service Set

   The standard allows to connect devices through ad-hoc mechanisms. In
   this mode the devices are connected using implementation specific
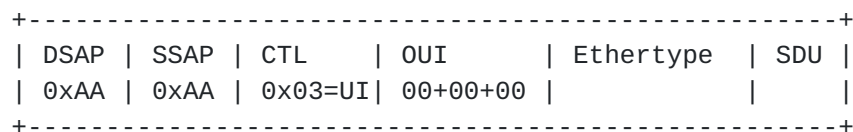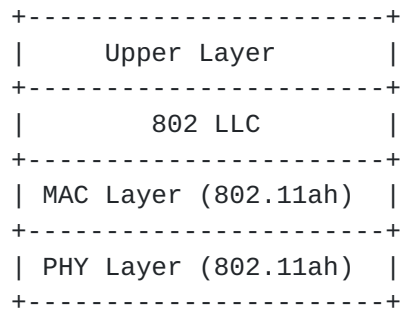   protocols e.g. between two STAs or between two APs and the power-
   saving mechanism of 802.11ah cannot be used (as AP-STA hierarchy is
   required). The following figure describes STAs connected to AP
   through 802.11ah and connections between APs are not based on
   802.11ah, but are implementation specific.

```
   +---+      +---+                +----+       +-----+
   |STA+-----+AP +------------+AP  +------+STA  |
   +---+      +--++                +--+-+        +-----+
                 |                    |
                 |                    |
                 |             +---+-+        +-----+
              +-----------+AP    +------+STA  |
                          +-----+        +-----+
```
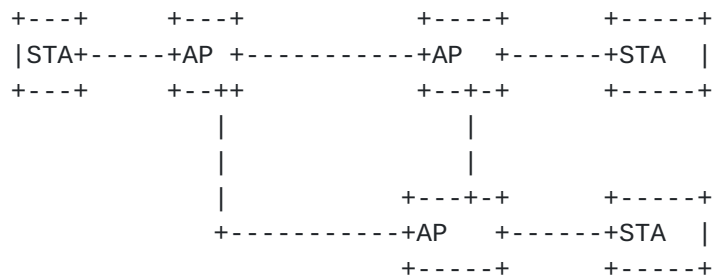
                   Figure 6: WLAN Ad Hoc Mode

   In an Extented Service Set(ESS), the connections between Base Service
   Station (BSS) happen through a distribution system. The distribution
   system (DS) maybe realised by a different technology or it can be
   composed by AP connections.

```
   +------------------+                        +-----------------+
   | +---+     +---+  |                        | +----+    +----+ |
   | |STA+-----+AP +------------ DS -----------+AP  +----+STA | |
   | +---+     +---+  |                        | +----+    +----+ |
   +---------+-------+                         +-----------------+
       BSS   |                                          | BSS
             +--------------->  ESS  <-----------------+
```

                   Figure 7: WLAN Protocol Stack

3.7. Relation with other 802.11 Versions

In principle, the 6Lo stack might be used for other 802.11 versions
such as 802.11b, 802.11n and 802.11ac, due to these standards support
LLC compatibility. LLC 6lo indentifier would be the same for all
mentioned WiFi versions.

4. Uses Cases

[RFC7548] defines use cases for the management of constrained
networks: Environmental Monitoring, Infrastructure Monitoring,
Industrial Applications, Energy Management, Medical Applications,
Building Automation, Home Automation, Transport Applications,
Community Network Applications and Field Operations. These uses
cases are apply as well to 802.11ah.

As a starting point in 802.11ah specification work, the Task Group AH
proposed the following use-case categories
[ReferenceUseCase802.11ah]:

- Sensor and Meters, where large number of sensor deliver data
through 802.11ah connectivity

- Backhaul Sensor and meter data, where 802.11ah STA can be either
directly integrated with a sensor or it will aggregate data from
other tree of wireless sensors and then deliver 802.11ah connectivity

- Extended Range Wi-Fi, where the typical range of the Wi-Fi
connection will extended due to the use of lower frequencies and
other techniques.

5. 6LoWPAN over 802.11ah

IPv4 and IPv6 are compatible with 802.11ah via the LLC. However,
802.11ah technology presents a trade-off between energy consumption
and link bitrate. Consequently, 6LoWPAN techniques are beneficial to
reduce the overhead of transmissions, save energy and improve
throughput. With 6LoWPAN, the nodes, i.e. 6LN, 6LBR, are co-located
on the same devices with 802.11 features. The typical 802.11ah
network uses a star topology where the 6LBR functionally is co-
located with the AP. 6LNs are co-located with STAs and are connected
to the 6LBR through 802.11ah links. As mesh topology at MAC level is
not defined by the 802.11ah standard, 6LBR is the only router present
in the network. Thus, there is no presence of 6LR.

```
                +---------+
                |+-------+|                         +---------+
                ||  6LN  ||  802.11ah               |+-------+|
                |+-------+|                         ||  6LN  ||
                |+-------++-----------+---------|+-------+|
                ||  STA  ||           |         |+-------+|
                |+-------+|           |         ||  STA  ||
                +---------+           |         |+-------+|
                  6LN-STA            |          +---------+
                               +-----+-----+
                               |+----+----+|
                               ||  6LBR   ||
                               |+---------+|
                +---------+    |          |    +---------+
                |+-------+|    |+---------++    ++-------+|
                ||  6LN  ||    ||   AP    ||    ||  6LN  ||
                |+-------+|    |+---------+|    |+-------+|
                |+-------++---+----+------+    |         |
                ||  STA  ||        |  6LBR-AP  |+-------+|
                |+-------+|        |           ||  STA  ||
                +--------+|        |           |+-------+|
                +---------+        +-----------+---------+
```
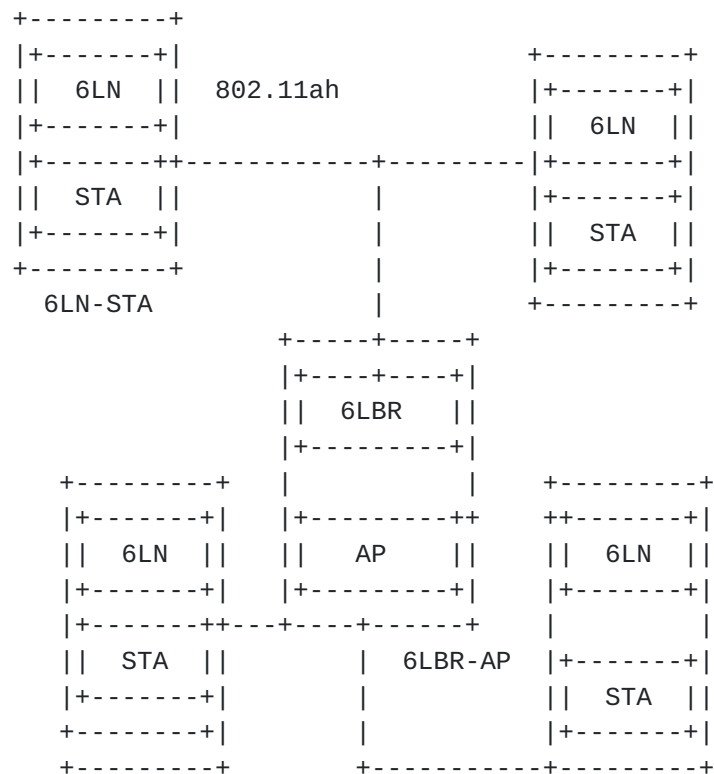
Figure 8: Network Topology

There exists the possibility to have a 802.11ah relay node at L2 to
extend the range of an AP. This however is an L2 feature and it is
experienced as a single hop by the 6LoWPAN network. In case there is
need to connect wirelessly several APs and ad hoc solution needs to
be considered.

Devices in this kind of networks, not necessarily have constrained
resources (memory, CPU, etc), but the radio link capacity is limited.
It might be that APs are connected to mains power and STAs might be
for example battery operated sensors. Therefore 6LoWPAN techniques
might be good to support transmission of IPv6 packets over 802.11ah
battery operated devices. Related to performance gain, a reduction
in air-time is achieved if the stack is compressed. The
communication 6LN-6LN is not supported directly using link-local
addresses, it is done through the 6LBR using the shared prefix used
on the subnet. This specification requires IPv6 header compression
format specified in [RFC6282].

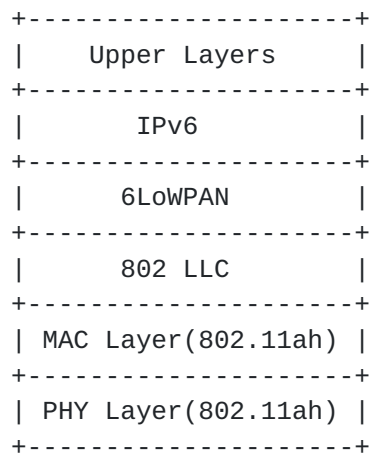The Figure below shows the stack for PHY/MAC and IPv6 including
6LoWPAN

```
          +--------------------+
          |    Upper Layers    |
          +--------------------+
          |        IPv6        |
          +--------------------+
          |      6LoWPAN       |
          +--------------------+
          |      802 LLC       |
          +--------------------+
          | MAC Layer(802.11ah) |
          +--------------------+
          | PHY Layer(802.11ah) |
          +--------------------+
```

Figure 9: Protocol Stack with 6LoWPAN

6. Stateless Address Autoconfiguration

The IPv6 link local address follows Section 5.3 of [RFC4862] based on
the 48-bit MAC device address.

To get the 64-bit Interface Identifier (IID) RFC 7136 [RFC7136] MUST
be followed. Section 5 of this RFC states:

"For all unicast addresses, except those that start with the binary
value 000, Interface IDs are required to be 64 bits long. If derived
from an IEEE MAC-layer address, they must be constructed in Modified
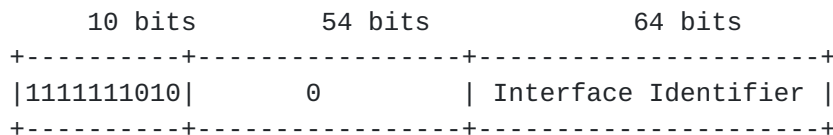EUI-64 format."

```
            10 bits        54 bits              64 bits
         +----------+----------------+---------------------+
         |1111111010|       0        | Interface Identifier |
         +----------+----------------+---------------------+
```

Figure 10: IPv6 link local address

Following Appendix-A of RFC 4291 [RFC4291] the IID is formed
inserting two octets, with hexadecimal values of 0xFF and 0xFE in the
middle of the 48-bit MAC. The IID would be as follow where "a" is a
bit of the 48 MAC address.

```
|0              1|1              3|3              4|4              6|
|0              5|6              1|2              7|8              3|
+---------------+---------------+---------------+---------------+
|aaaaaaaaaaaaaaaa|aaaaaaaa11111111|11111110aaaaaaaa|aaaaaaaaaaaaaaaa|
+---------------+---------------+---------------+---------------+
```
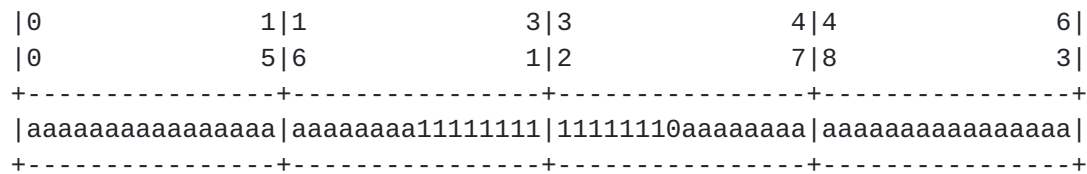
Figure 11: Modified EUI-64 format

For non-link-local addresses a 64-bit IID MAY be formed by utilizing the 48-bit MAC device address. Random IID can be generated for 6LN using alternative methods such as [I-D.ietf-6man-default-iids].

7. Neighbour Discovery in 802.11ah

Neighbour Discovery approach for 6LoWPAN [RFC6775] is applicable to 802.11ah topologies. Related to Host-initiated process, use of Address Registration Option (ARO), through the Neighbour Solicitation (NS) and Neighbour Advertisement (NA). Router Solicitation and Router Advertisement are applicable as well following [RFC6775].

As the topology is star, Multihop Distribution of prefix and 6LoWPAN header compression; and Multihop Duplicated Address Detection (DAD) mechanism are not applicable, since this technology does not cover multihop topology.

8. Header Compression

For header compression, the rules proposed in [RFC6282] are applicable. Section 3.1.1 mentions the base Encoding principle applicable to 802.11ah.

```
0                                           1
0   1   2   3   4   5   6   7   8   9   0   1   2   3   4   5
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
| 0 | 1 | 1 |   TF   |NH | HLIM  |CID|SAC|  SAM  | M |DAC|  DAM  |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
```
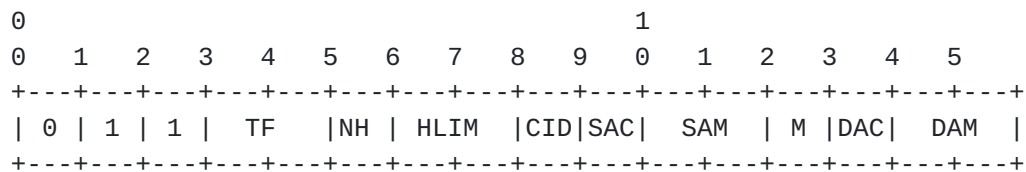
Figure 12: LOWPAN_IPHC base Encoding

TF: Traffic Class; Flow Label; For 802.11ah case would apply this field as defined in [RFC6282].

NH: Next Header; as defined in [RFC6282].

HLIM: Hop Limit; as star topology the common value would be HLIM=1.

CID: Context Identifier Extension; as defined in [RFC6282].

SAC: Source Address Compression; as defined in [RFC6282].

SAM: Source Address Mode; In this case, the combinations for 16-bits are not applicable to this technology since 802.11 uses 48-bits for addresses.

M: Multicast Compression; as defined in [RFC6282].

DAC: Destination Address Compression; as defined in [RFC6282].

DAM: Destination Address Mode. In this case, the combinations for
16-bits are not applicable to this technology since 802.11 uses
48-bits for addresses.

9. Fragmentation

802.11ah perform fragmentation at L2, thus the fragmentation at L3
would be not necessary.

10. Multicast at IP Level

802.11ah supports broadcast and multicast at link layer level, both
can be used to carry multicast IP transmission depending on the
system's configuration. TBD: add an example.

11. Internet Connection

For Internet connection, the 6LBR acts as router and forwarding
packets between 6LNs to and from Internet.

```
          +-----+
          | 6LN +--------+
          +-----+        |
                         |        +-----------+
               +----+----+    |           |
               |         |    |  Internet |
       +------+  6LBR    +----+           |
     +--+--+   |         |    |           |
     | 6LN |   +----+----+    +-----------+
     +-----+        |
              +--+--+
              | 6LN |
              +-----+
```
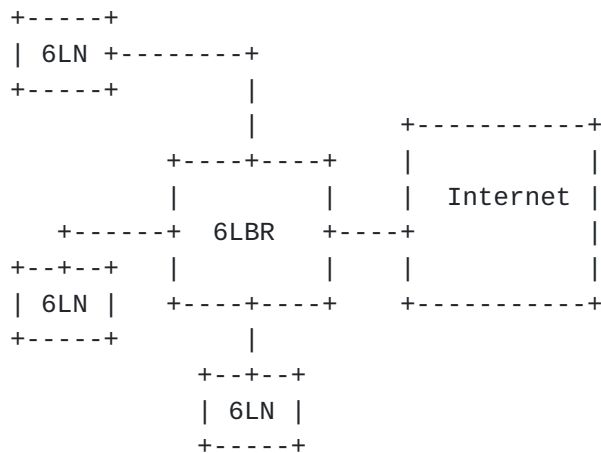
         Figure 13: Internet connection of 6Lo network

12. Management of the Network

TBD: how LightWeight Machine to Machine (LWM2M) or CoAP Management
Interface (COMI) [I-D.vanderstok-core-comi] aspects can be applied to
this technology, considering [RFC7547]

13. IANA Considerations

There are no IANA considerations related to this document.

14. Security Considerations

The security considerations defined in [RFC4944] and its update
[RFC6282] can be assumed valid for the 802.11ah case as well.
Indeed, the transmission of IPv6 over 802.11ah links meets all the
requirements for security as for IEEE 802.15.4. The standard IEEE
802.11ah defines all those aspects related with Link Layer security.
As well as for other existing WiFi solutions, 802.11ah Link Layer
supports security mechanism such as WPA, WPS, 802.1X. To have a
deeper understanding on how the Key Management processes are handled
in 802.11ah, please refer to [TBD]

Implementations defined in [I-D.ietf-6man-default-iids], [RFC3972],
[RFC4941], or [RFC5535], can be considered, for example, as methods
to support non-link local addresses.

For what concerns privacy issues, the draft
[I-D.thaler-6lo-privacy-considerations] introduces a series of
recommendations which can be applied in order to overcome possible
privacy threats in the particular case of technologies designed for
IPv6 over networks of resource-constrained nodes.

15. Acknowledgements

This work is partially funded by the FP7 Marie Curie Initial Training
Network (ITN) METRICS project (grant agreement No. 607728).

The authors are thankful to the members of IEEE Task Group AH for
their valuable comments.

16. References

16.1. Normative References

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